Alternative Fuels:
Incompletely Addressing the Problems of the Automobile

by

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Abstract

The inordinate reliance of the United States on the automobile for transportation causes a number of problems for the nation. Finite supplies of petroleum imported from volatile parts of the world place the economy at risk from price spikes and eventual depletion. Pollution from motor vehicle exhaust has public health and environmental consequences.

Many politicians, automotive interest groups, and others advocate for the use of alternative fuels to replace fossil fuels. This paper investigates the advantages and disadvantages of the following: Natural Gas, Ethanol, Biodiesel, Hydrogen Fuel Cells, and Hybrid Gasoline Electric Systems.

The paper concludes with a discussion of the problems associated with the automobile that will not be addressed through a movement towards alternative fuels: urban sprawl, transportation equity, environmental degradation, and public health.

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Introduction

The United States is infamous for its high levels of petroleum consumption. The Department of Energy has put forth the following forecasts for the use of Petroleum in the United States from now to 2025. Petroleum imported for domestic use will increase from 53% to between 65-75% with a net imported yearly increase of 2.7%. Petroleum use increases will mainly be in the transportation sector of the economy. Increases in vehicle miles traveled will greatly offset any gains in vehicle efficiency, leading to the increase in consumption. Motor vehicles make up one third of world petroleum consumption worldwide, and half of the petroleum consumption in United States (IEA). The Department of Energy predicts that crude oil production in the lower 48 states will decline after 2008. The IEA predicts that through 2025 petroleum demand will increase by about 2% per year.

However, the longevity of the world's oil reserves is up for debate. According to James MacKenzie at the World Resources Institute, there are 1,800-2,200 Billion Barrels of Oil in the world reserves (based on several different estimations). By 1999 the world had already consumed 857 Billion barrels. Based on current consumption patterns, peaking could occur as early as 2007 or as late as 2019. Peaking could be delayed by holding consumption at current levels, but as DOE numbers show, consumption is set to increase significantly in the next few decades. The DOE also argues that the term "reserves" is relative because it is directly tied to economics. Only what can be accessed economically is termed a reserve. This is dependent on what the future market defines as “economic” and this cannot be predicted entirely. WRI questions the accuracy of reserve predictions by highlighting the following phenomenon, that reserve predictions can be politically motivated. The WRI notes that since 1985 OPEC members have reported huge increases in reserves. Kuwait – 41%, Abu Dhabi and Dubai – 300%, Iran, Iraq, and Venezuela – 200%, and Saudi Arabia – 50%. Also, these reserves are not “declining” even though they have been producing oil in significant amounts for a number of decades. The reliability of these reserve estimates deserves to be questioned. With a high dependence on the oil market, and especially the international oil market, the United States economy is woefully susceptible to any fluctuation in the world market price or supply. Any fluctuation will greatly affect the transportation system of the United States, mainly the automobile.

The automobile has become an integral part of U.S. culture, to the extent that in many areas it is nearly impossible to access many services without an automobile. This has a number of negative impacts upon the people and environment of the United States. This automobile dependence contributes to harmful pollution, environmental destruction, and a burgeoning trade deficit. Motor vehicle exhaust is a source of greenhouse gases, carbon monoxide (45% of which comes from motor vehicle exhaust – Oman pg. 34), nitrous oxides, and various sulfur oxides. These are either dangerous to humans or contribute to photochemical smog and low-level ozone. Automobile exhaust also releases particulates and toxins that are harmful to humans, plants, and wildlife. The greenhouse gas carbon dioxide is another byproduct of motor vehicle exhaust.

According to Environmental Defense, a gallon of gasoline weighs six pounds, but when it is burned it produces 20 pounds of waste products. Therefore, a Jeep Grand Cherokee emits over three times its body weight in CO2 per year (Carbon Emissions Fact Sheet pg. 1).

There are many counties or municipalities considered to be in the EPA's non-attainment classification for 2003 with respect to pollutants. The Los Angeles Basin is listed as Extreme with respect to Ozone levels, 66 counties or municipalities are listed as Serious in 2003, 68 listed as severe-15, and 51 listed as severe-17. (http://www.epa.gov/oar/oaqps/greenbk/anay.html)

Automobiles powered by internal combustion engines are woefully inefficient.

> "The contemporary automobile, after a century of engineering, is embarrassingly inefficient: Of the energy in the fuel it consumes, at least 80 percent is lost, mainly in the engine's heat and exhaust, so that at most only 20 percent is actually used to turn the wheels. Of the resulting force, 95 percent moves the car, while only 5 percent moves the driver, in proportion to their respective weights. Five percent of 20 percent is one percent – not a gratifying result from American cars that burn their own weight in gasoline each year. (Hawken et al, pg. 24).

With such an inefficient machine being virtually ubiquitous in the daily routine of the average inhabitant of the United States, it is hardly surprising that the automobile is the target of reform and improvement. However, that improvement faces many challenges and difficulties, whether they are economic, practical, or political.

According to Carroll Shelby, father of the Cobra and a veritable god in the automotive community,

> "… I'm saying that we're never going to get there in the automobile industry as far as the environment is concerned with the system we have now. …Nobody wants to talk about it because the automobile companies, with their huge political impact in Washington, don't want things like this to happen. They want things to go along just like they are. (Cogan, pg. 7).

What's next for the automobile? Significant change is in the near future, or should be. The potential options have many proponents as well as detractors. This paper will outline the various alternative fuel options, their advantages and disadvantages, and make recommendations accordingly. Alternative fuels covered include Natural Gas, Ethanol, Biodiesel, Hydrogen Fuel Cells, and Gasoline Electric Hybrid Vehicles.

Most importantly, this paper will conclude with a discussion of the broader impacts of the automobile. The automobile has negative impacts that extend beyond the dependence on imported oil and the detriments of pollution. The implications of urban sprawl and extensive highway construction are beginning to be recognized and analyzed. Alternative fuels do not address these drawbacks. The only way to address these issues is through management of urban areas

Natural Gas

Natural gas is made up primarily of Methane (CH_4) but frequently contains trace amounts of ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor. Natural gas is produced from gas wells or tied in with crude oil production. Currently natural gas is distributed across the United States through a large pipeline but can also be transported via truck, barge, or train. Natural gas can be stored and used as compressed natural gas (CNG) or liquefied natural gas (LNG).

There are a number of arguments in favor of the use of natural gas as a motor vehicle fuel. The first set of arguments focuses around the issues of national and economic security. In direct contrast to oil consumption, 87% of the natural gas consumed in the United States is domestically produced. Projections predict that current domestic resources could meet 85% of the foreseeable future demand. Even if the use of NGV's were increased from 60,000 vehicles to 10,000,000 vehicles, natural gas consumption would only increase by 6%. This would not affect the current uses of natural gas.

Natural gas is safer than gasoline in many respects. The ignition temperature for natural gas is 500º F higher than gasoline. Natural gas must be in a concentration of 5% to 15% in order to ignite, making ignition in the open environment unlikely. Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel will pool on the ground, increasing the danger of fire. Natural gas is non-toxic and will not contaminate groundwater if spilled.

The last and most often cited advantages have to do with pollution. The percentages vary depending upon the source, but vehicles burning natural gas emit substantially lesser amounts of pollutants than petroleum powered vehicles. Non-methane hydrocarbons are reduced by approximately 50%, NO_x by 50-87%, CO_2 by 20-30%, CO by 70-95%, and the combustion of natural gas produces almost no particulate matter. Natural gas powered vehicles emit no benzene and 1,3-butadiene which are toxins emitted by diesel powered vehicles. With many of the major urban areas of the United States in non-containment status with respect to air pollution, these are compelling statistics.

Recognizing these advantages and the potential benefits to the environment and the population, the Federal Government has instituted a number of incentives to encourage the use of alternatively fueled vehicles. For individual consumers the most important legislation is the CLEAR ACT. Senators Orrin Hatch (R-UT) and Dave Camp (R-MI) introduced the legislation. The acronym stands for CLean Efficient Automobiles Resulting from Advanced Car Technologies. The legislation includes a tiered income tax credit for individuals or businesses that purchase an alternatively fueled vehicle (AFV) for use. The individual or business can claim a tax credit of 50% of incremental cost and an additional 30% credit if the vehicle meets the strictest emissions standards under the federal Clean Air Act. There is also a tax credit for retailers of alternative fuels for the next 6 years. It ranges from $.30 per gallon of gas equivalent (GGE) in 2003 up to $.50 GGE in 2005-6 and back down to $.30 GGE in 2008. The retailer has the option to pass this credit on to the purchaser or to the supplier if desired. Fueling facilities can claim a $100,000 capital cost tax deduction for up to 10 years and a $30,000 credit for the installation of a public fueling site. Residential units can claim a $1,000 tax credit or 50% of installation costs, whichever is less. There are also funds available to transit agencies through CMAQ funds from the federal government.

Currently there is a wide range of vehicles available to the individual and business consumer. Sedans available include the Honda Civic GX CNG, Ford Crown Victoria, and Chevrolet Cavalier. Pick-up possibilities are the Ford F-150, and GMC/Chevrolet Sierra/Silverado. Full size vans are available from Dodge, Chevrolet, and Ford. Incidentally, the Honda Civic GX is named the cleanest internal combustion engine in the world by the EPA with emissions at 1/10 of SULEV standards. Prices start at $20,510 for the Honda Civic GX.

How do NGV's perform in real world situations? Are the emissions advantages realized? What are the tradeoffs for using a NGV? Unfortunately there has been little study of smaller NGV's as they are not used extensively as of yet. There has been a strong push for natural gas powered buses in the transit sector. This is the area that has seen the most usage and therefore has been evaluated in terms of the effectiveness of NGV's in real world applications.

In the year 2001 transit companies operated fleets with approximately 9% of the vehicles being powered by natural gas. This number was a large increase over the 2% of natural gas powered buses that made up the fleets in 1992. Currently, 25% of all new bus orders are for natural gas powered buses. Natural gas powered buses are more costly than diesel buses. A transit agency can expect to pay 10% to 25% more per bus to acquire a natural gas powered bus. Because of fuel storage issues, natural gas powered buses also have a shorter range than diesel powered buses.

Natural Gas powered transit buses have been in use for a number of years in various transit agencies around the world, with mixed results. The performance and realization of claims has been inconsistent, however, there are a number of factors to consider which can make a natural gas program more successful.

The main argument for the use of natural gas powered vehicles has been the reduction of pollution that will result. In fact, according to a 1999 report from the General Accounting Office, "…the [EPA] receives more complaints from the public about emissions from transit buses than all other environmental issues combined" (GAO pg. 13). Is this emissions advantage borne out with real world testing? The answer: Yes and No. According to a review paper put together for the International Association of Natural Gas Vehicles by Glenn Watt, the following results were found by various transit agencies. Phoenix Transit found CO and hydrocarbon emissions to be about the same or a little lower than a diesel engine. Nitrogen oxides were significantly lower when the engine was under load, but while at idle were significantly higher than a diesel engine. To counter act this Phoenix Transit has fitted all of the natural gas powered buses with catalytic converters. Los Angeles County Metropolitan Transit Authority found that the natural gas powered buses produced between 35% and 55% of the nitrogen oxides of the diesel buses. Particulates produced by CNG powered buses were 14% and 29% of the amount produced by diesel buses. Dallas Area Rapid Transit determined that the LNG powered buses used were 31% cleaner than the diesel buses. Metro Houston found that CNG powered buses produced 8 times as much hydrocarbon pollution, over 2 times the CO pollution, yet 38% of the nitrogen oxide pollution and 25% of the particulate matter of diesel powered buses. It should however be noted that methane likely accounts for 90-95% of the hydrocarbon pollution and is not a factor in low level ozone creation. The conclusion to be reached is that the emissions benefits, while possible, are not guaranteed. There are factors that need to be determined which will help to ensure that CNG and LNG powered buses meet the expectations for pollution benefits before that argument can hold weight against the opposition.

How did CNG and LNG powered buses do comparatively in other respects? Other arguments put forth for natural gas powered vehicles are lower maintenance and operating costs. Is this reflected in the real world? Again, it remains unclear. The potential benefits are there, but issues remain that need to be effectively dealt with. It has been demonstrated that NGV buses need fewer oil changes than diesel buses due to the reductions in particulates in the combustion process. In some cases manufacturers have doubled the recommended interval for oil changes in the natural gas engines (Clean Cities Fact Sheet pg. 4).

Operating costs are where natural gas powered vehicles theoretically have a significant advantage over petroleum-powered vehicles. The basis for this argument is the lower cost per energy unit of natural gas as compared to petroleum. The argument is somewhat more complex than this, however. While it is true that in the vast majority of the country natural gas is cheaper than gasoline or diesel, the analysis plays out differently. Phoenix Transit found that natural gas powered buses achieved 61% of the fuel economy of the diesel buses. With natural gas costing the agency 60% of the cost of diesel fuel, the relative costs evened out. The City of Tucson Mass Transit System found that the CNG buses achieved 60% greater fuel economy than diesel buses. Sunline Transit Agency found that its CNG powered buses managed 88% of the fuel economy of the Sacramento Regional Transit diesel powered buses. Due to pricing in the region however, fuel costs for the diesel buses were 66% greater than the CNG buses. Additionally, maintenance costs for the diesel buses were almost 2 times higher than for CNG buses. Los Angeles County MTA found that their CNG buses achieved 2/3 the fuel economy of the diesel buses. After compression costs were included, CNG costs were 27% higher than diesel. This created a situation where the CNG buses were 40% more costly to operate than diesel buses. Montgomery County Transit found that the fuel costs for the CNG buses were lower than for the diesel buses. New York City MTA found that the operating costs for the natural gas buses were 34% higher than for diesel buses. Again, the potential for savings is there, but each individual situation needs to be analyzed as the economics vary greatly depending on the efficiency of the engine in the bus and the local pricing of fuel.

How reliable are CNG and LNG powered buses when compared to diesel buses? Again, the results vary greatly. Phoenix Transit found no significant difference in reliability for its LNG and diesel powered buses. Los Angeles County MTA found that the NGV buses had chronic problems that resulted in maintenance costs being 97% greater with respect to parts, but 3% cheaper with respect to labor. The time between failures however appeared to be about the same for both bus types. New York City MTA found that the mean time between failures for the NGV buses was half of the time for diesel buses. Dallas Area Rapid Transit found that its diesel-powered buses were 2.5 times more reliable than the natural gas powered buses. Most sources acknowledge that the NGV powered buses are less reliable than their diesel counterparts. However, they also note that NGV buses are relatively young in terms of the technology and it is being rapidly refined and improved and will catch up to the more established diesel technology.

Another consideration for NGV buses is the significant capital costs required to provide the refueling infrastructure. Infrastructure costs for refueling are 5 to 8 times higher than for diesel vehicles (Watt pg. 7). However, Eudy found that the issue of fueling infrastructure was extremely important for program success. Adequate fueling infrastructure must be obtained and more successful fleets operate the fueling facility themselves. The high capital costs can be offset with a number of strategies including a public-private partnership as one example. The importance of adequate fueling infrastructure is apparent in the experiences of India with respect to commercial NGV's. Following a mandate from the Supreme Court to convert all commercial vehicles to CNG, citizens found the infrastructure to be less than effective in coping with the demands.

This caused a great deal of frustration and criticism of the government, but did not change the positive perception of CNG as a beneficial and cleaner fuel (Bhatnagar pg. 1-2). Other issues with fueling infrastructure include impurities that occur naturally and unnaturally in CNG pipeline situations. Pipelines often contain water vapor, oil, particulates, hydrogen sulfide, and oxygen. Gas companies also practice “shaving” where air is input into the gas pipeline during peak demand to maintain pressure. All of these cause problems for CNG powered vehicles. However, these problems can be overcome by installing a fueling infrastructure that uses LNG that is then evaporated to CNG for use in the vehicles. LNG is 98% methane and does not contain the same impurities as pipeline CNG and is not subject to shaving. Additionally, LNG infrastructure is often cheaper than CNG infrastructure, partially due to the fact that the problems of pipeline CNG do not need to be addressed. (Beale, pgs. 1-6)

In the NREL Technical Report on Natural Gas in Transit Fleets, Leslie Eudy found that there were additional attributes that made some transit fleets more successful than others in integrating NGV buses into the fleet makeup. One of the most important is that there is an economy of scale associated with NGV buses. Eudy found that smaller fleets were much more likely to be dissatisfied with the overall NGV bus experience. This is reiterated in the IANGV report which states that in order to be successful, at least 1/3 of the buses in a fleet should operate on natural gas with a minimum number of 50 buses being the target (Watt, pg. 6). More broadly, an economy of scale also applies to the prices of the buses themselves and the parts needed to maintain them. The

GAO report notes that "…the relatively low number of CNG bus orders contributes to the higher prices of CNG buses… if production of these buses was to increase significantly, then the production costs per bus would likely decrease" (GAO pg. 10).

Another key component for success cited in the Eudy report is the need for adequate training of all stakeholders involved in the programs success. All maintenance staff and managers need to be educated on the functions and differences of natural gas buses. The greater understanding leads to more effective integration and greater overall satisfaction with the performance of the vehicles.

Eudy also found that promoting the use of NGV buses to the public had a positive impact on the success of the program. The success centered on the perceptions of the public that the transit companies were doing something productive to counteract the problems of air pollution.

The IANGV states that natural gas is currently the only commercially available alternative to diesel for the transit industry. Low sulfur diesel fuel is not commercially available and is expensive. Fuel cell technology is not yet affordable and is still being perfected. Hybrid technology, while increasing efficiency, may not always address pollution problems as effectively as natural gas. Biodiesel has limited availability and is currently not cost effective. However, before natural gas can be considered commercially available for the general consumer population the issues associated with distribution infrastructure need to be addressed adequately.

Ethanol

MTBE is currently used as an oxygenate to aid in the efficient combustion of gasoline in internal combustion engines. MTBE raises the octane level of gasoline, reducing the fuel's propensity to "knock". MTBE has been credited with reducing ground level ozone levels in many non-attainment areas, but it has drawbacks. MTBE has been found to contaminate surface and ground level water supplies. It is also a highly recalcitrant compound, meaning it resists degradation in the natural environment (Da Silva pg. 864). This means that it is highly mobile and can be found in many areas, whether or not MTBE was used in gasoline in the area. Currently, 18 states are considering a phase-out of MTBE and the federal government is considering mandating the use of a renewable in place of MTBE as an oxygenate for gasoline. The only viable oxygenate sold on the U.S. market at this time is ethanol. (USDA pg.1)

Ethanol is also the only liquid fuel alternative currently available. Other technologies are under consideration, but none with the exception of natural gas is feasible at this time. Fuel cells are still under development and are not economically viable. Electric cars have range drawbacks, and according to Lester Lave,

> "If the current U.S. fleet of 200 million vehicles were run on current lead acid, nickel cadmium, or nickel metal hydride batteries, the amount of these metals discharged into the environment would increase by a factor of 20 to 1,000, raising vast public health concerns (pg. 74).

Ethanol, or grain alcohol, is produced in the U.S. primarily from corn, and in Brazil from sugar cane. According to a recent study by the USDA, current production of ethanol nets a 34% energy gain as the conservative estimate, making it energy efficient. The upper estimate was a 53% gain in energy. Additionally, the liquid fuel form produced is a more desirable form of fuel than either solid or gaseous (USDA pg. 12). It offers excellent performance as a fuel for internal combustion engines and has low hydrocarbon and toxin emissions (EPA pg. 2). It minimizes the release of CO_2 into the atmosphere because it releases the CO_2 trapped during the growth cycle, making the net CO_2 released zero. This, however, does not include fossil fuels burned to facilitate the production of ethanol. Ethanol can also be produced from biomass. While a less efficient process, the raw materials available are significantly greater. Softwoods, which can be used to make ethanol, currently make up 50% of the earth's biomass (Galbe pg. 619). Biomass can be burned to power the process as well instead of natural gas or coal. A byproduct of the process would be lignin, which could also be used as a fuel to power the production or sold on the market (Lave pg. 75).

In the United States currently, passenger cars and trucks produce 20% of total CO_2 emissions. In order to make a significant impact on fuel consumption, the price of gasoline would need to be raised 9X to produce a driving mix averaging 50 mpg (Lave pg. 74). This is economically and politically unfeasible, which presents ethanol as a more attractive alternative to reducing emissions. Ethanol is credited with reducing tailpipe emissions of CO by 30%, volatile organic compounds by 12%, and toxics by 30% when compared to gasoline (Whybiotech pg. 2).

Brazil currently uses ethanol extensively in auto fleets. Ethanol is available in two forms, as pure ethanol and as 24% gasohol that is mixed with 76% gasoline. The price of ethanol is stable in Brazil and is now 40% lower than gasoline. This makes it an attractive alternative even though it is necessary to buy more alcohol than gasoline due to increased combustion (Khalip pg. 4). This increase in combustion is somewhat offset by an increase in efficiency of 15% over gasoline, but not completely (Galbe, pg. 619). A mixture of 4% ethanol with diesel fuel increases torque output significantly in compression ignition engines. Horsepower is increased slightly as well while fuel consumption declines (Bilgin pg. 437).

Ethanol is not without drawbacks, however. These drawbacks range from mild inconveniences to severe concerns. There are economic concerns related to the use of ethanol. In the United States it currently costs more to produce ethanol than gasoline, leading to a higher price at the pump. Also, vehicles running on ethanol burn more fuel in comparison to gasoline powered vehicles. These vehicles often require larger capacity fuel tanks that raise the costs per vehicle. Alcohol fueled cars also need unique fuel pumps and injection systems that also add costs to the vehicle (Khalip pg. 2). Incentives can offset these increases, however. Also, an economy of scale would likely cause the prices to drop with increased production of the vehicles, bringing capital costs closer to those of gasoline vehicles.

Another issue is the lack of infrastructure available to support a market for ethanol. Little currently exists and the majority would have to be built to make any large-scale conversion to ethanol feasible (U.S. GPO pg. 6). There is also inadequate tanker supply required to transport ethanol, and it is unlikely that enough could be constructed to adequately support a rapid phase in of ethanol (Romanow pg. 19). Phase-out of MTBE could also bring about gasoline shortages, as there is not sufficient supply. This could cause gasoline to rise as high as $3.00 a gallon (Romanow pg. 19).

There are health concerns associated with ethanol. Ethanol is listed as a carcinogen with respect to humans. While there is speculation about whether the risks associated with using ethanol as a motor vehicle fuel would be significant, there is no established threshold for exposure in humans (U.S. GPO pg. 7).

Combustion of ethanol leads to pollution concerns. Combustion increases outputs of aldehydes, which can increase ground level ozone, and peroxyacyl nitrates or PAN. PAN is highly toxic to plants and an eye irritant. Breakdown of PAN is very slow in cold weather and it can be transportbed by wind. It is not a currently regulated pollutant, but its effects should be investigated thoroughly before any large-scale movement towards ethanol is initiated (Demmler pg.). Combustion of ethanol, while reducing emissions of BTEX compounds (benzene, toluene, ethylbenzene, and xylene), increases emissions of formaldehyde and acetaldehyde (Leong p. 3499). Acetaldehyde is linked to eye irritation, respiratory complaints, and nervous disorders (Leong pg. 3495). Both compounds are also factors in low-level smog formation (Leong pg. 3501). A properly designed catalytic converter can reduce these emittants, however (Leong pg. 3502).

Ethanol has also been shown to have negative impacts on the degradation of other pollutants in the natural environment. Ethanol appears to have a "preference" or biodegrade more readily than pollutants such as BTEX compounds that are found in gasoline. The ethanol degradation removes the oxygen and electron receptor necessary to degrade the BTEX compounds. Benzene especially is of concern because it is toxic and a carcinogen. This preferential degradation was found to increase benzene plume lengths by 27% (Deeb pgs. 868-872).

There are also significant pollution concerns regarding the production of ethanol. In October of 2002, the Department of Justice, the Environmental Protection Agency, and the state of Minnesota reached civil settlements with 12 ethanol plants for Clean Air Act violations (Oil and Gas, pg. 22). The EPA also found that ethanol plants are emitting between 5 and 430 times the amount of pollutants that they are permitted (Hodge pg. 21). The plants were also found to be emitting formaldehyde and acetic acid, both carcinogens (Hodge pg. 25).

The ethanol industry also raises anti-trust questions. If a mandate does go into effect, the demand for ethanol would skyrocket. The ethanol industry is highly concentrated with the largest firm holding a 41% market share and the top four firms enjoying a market share of 58%. However, if marketing agreements and production capacity are factored in, four companies control 95% of the supply. This will effectively create an oligarchy in the ethanol industry (Hodge pg. 26). Additionally, one manufacturer holds the patents for ethanol in gasoline meeting the California requirements. This presents a problematic potential in the market forces governing the sale and production of ethanol.

If the making of ethanol from biomass is improved in efficiency in order to be economically viable, according to Lave,

> "To provide sufficient ethanol to replace all of the 130 billion gallons of gasoline used in the light-duty fleet, we estimate that it would be necessary to process the biomass growing on 300 million to 500 million acres, which is in the neighborhood of one-fourth of the 1.8 billion acre land area of the lower 48 states (pg. 75).

While it is argued that man has impacted the majority of land in the U.S. already, and that this land usage would not impact wilderness areas, parks, or development areas, this still seems like an inordinate amount of land usage to fuel the automobile. Statistics like this really highlight the fact that the amount of automobile usage in the United States needs to be reduced considerably. With respect to production of ethanol from corn, it is argued that biotechnology will increase corn yields significantly (whybiotech.com pg. 2). However, some farmers are resisting integration of biotech corn and the safety of biotech corn in the environment has not been proven.

Biodiesel

According to the Department of Energy, "Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases" (www.afdc.doe.gov). Biodiesel has properties similar to petroleum-based diesel fuel that give it a number of advantages over other alternative fuels.

Biodiesel is made by reacting vegetable oils or animal fats with an alcohol, often methanol, to produce fatty acid methyl esters. A co-product of this process is glycerol.

Biodiesel can be blended with fossil diesel at any ratio. The most frequently used ratio is B20 or 20% biodiesel. B100 or 100% biodiesel is referred to as "neat" biodiesel. Blends as high as B20 can be used in almost all diesel equipment and transportation/distribution systems. Biodiesel is safe and biodegradable. In fact, in June of 2000 biodiesel became the only alternative fuel to complete tiers I & II of the health effects pertaining to the Clean Air Act. Biodiesel presents no threat to human health. There is no danger from ingestion of biodiesel. It is also less combustible than diesel with a flash point 73 degrees Celsius higher than petroleum-based diesel. "… biodiesel fuels have a better burnability with respect to petroleum diesel" (Cardone, et al, pg. 4660).

Emissions are overall greatly reduced with the use of biodiesel. Neat biodiesel reduces Carbon Dioxide emissions (a greenhouse gas), by 75%. B20 brings about a reduction of 15%, consistent with the ratio of the fuel. Significant reductions are also seen in hydrocarbons, carbon monoxide, and smoke opacity. Sulfur related emissions are virtually eliminated.

One drawback of using biodiesel is that nitrogen oxide emissions can increase significantly. However, this can potentially be addressed through the use of fuel additives, or as Cardone, et al found,

> "…the increase in NO_x emissions seems to be fundamentally determined by the operating mode of the injection pump, which causes a premature needle lift compared to the nominal conditions occurring when the engine is fueled with diesel fuel.
>
> This behavior results in an equally premature release of heat which, as we have seen above, generates higher temperatures inside the cylinder during the combustion process. Therefore, it is reasonable to assume that if we modify the injection system to restore the nominal advance conditions, the phenomenon will be eliminated or drastically reduced and return the NO_x emissions to comparable values, regardless of fuel used" (pg. 4660).

Other disadvantages to biodiesel include a 10% reduction in power and fuel economy. While engine efficiency remains comparable regardless of fuel used, the higher heating value of biodiesel is responsible for the increased consumption. Biodiesel will also soften and break down some types of rubber compounds, including natural and butyl rubbers. The shelf life of biodiesel is also shorter than petroleum based diesel.

Another disadvantage of biodiesel is availability. While B20 can be used in many distribution systems, anything higher requires special consideration. Currently, there are only 75 stations in the United States where biodiesel can be purchased. Of these 75, not all are open to the public.

Currently biodiesel fuel is not cost effective as is it significantly more expensive to produce than regular petroleum based diesel or ultra low sulfur diesel. However, with government incentives, biodiesel production could reach as high as 1.9 billion gallons, or approximately 8% of the diesel market. One of the major advocates for biodiesel is the soybean industry. They are motivated largely by a combination of excess production capacity, product surplus, and declining prices (www.afdc.doe.gov).

Is biodiesel energy efficient from a production standpoint? Studies conducted using sunflowers in Greece indicate that the answer is yes. According to Kallivrovssis, the ratio of energy outputs to energy inputs is 4.5 to 1. Perhaps with intelligent investment, biodiesel could become a more cost effective alternative fuel.

Hydrogen Fuel Cells

Hydrogen is almost the perfect fuel. It has the highest energy content by weight of any fuel. It has almost no emissions when burned and when used in a fuel cell the only by-product is water. Hydrogen is very abundant and is found readily in many compounds on earth. It is also the only viable fuel identified for the future when current stores of fossil fuels run out (www.eere.energy.gov). If an efficient method of renewable or "green" production can be developed, it offers what is a nearly perfect source of energy and fuel for the future of the world. A fuel cell is a device that produces an electric current between a cathode and an anode. The fuel cell most often targeted for vehicle applications uses hydrogen and oxygen to produce an electric current. It is similar to a battery in terms of use only it creates the electricity as it is needed instead of storing the energy for later use.

Fuel cells work by utilizing hydrogen gas (H_2), which must be supplied, and oxygen gas (O_2) from the air. The hydrogen gas goes through the anode (-) side and the oxygen through the cathode (+) side. The anode side contains a platinum catalyst that breaks the hydrogen atoms into H^+ ions and e- electrons. In between the cathode and anode is a PEM or proton exchange membrane. This membrane allows only the H^+ ions to travel though from the anode to the cathode. The electrons must travel through an external wire. This creates the electric current that can be utilized to drive accessories and the propulsion motor. At the cathode the hydrogen and oxygen combine to form water, which is the only byproduct of the fuel cell process. Individual fuel cells generally do not produce large amounts of power. In order to create an amount of current that is useful, they must be combined into stacks, similar to batteries being grouped to provide a greater power source. When grouped in this manner, the voltage and current reach levels that are useable in the real world. The surface area of the PEM also affects the output level of the fuel cell. (www.fueleconomy.gov – How They Work).

Hydrogen gas does not occur naturally, despite hydrogen being the most abundant element in the universe. Therefore, the hydrogen gas must be created in order to have fuel for the fuel cell. All the hydrogen is contained in other compounds. Examples of these compounds are water and our various hydrocarbon fossil fuels. Hydrogen can be obtained through the electrolysis of water or the reforming of hydrocarbon fuels.

Electrolysis of water is the utilization of an electric current through water to split the water molecule into hydrogen and oxygen gas. This process of hydrogen gas creation does not produce any pollution. However, the creation of the electric current can. If the current is produced by a power plant that runs off of fossil fuels, then the same issues regarding release of greenhouse gasses and toxic emissions still apply. Electric currents produced from renewable sources like solar or wind would help to alleviate this problem. One thing to keep in mind is that power plants are more efficient in producing electricity from fossil fuels per unit energy than other methods, so this may still prove to be more efficient than vehicles powered by internal combustion engines (Griscom pg. 3).

One theory for obtaining hydrogen gas is to use the electricity from nuclear power plants in the evenings when demand is low to produce the hydrogen. “The cost of producing hydrogen during the night by electrolyzing water with power from nuclear plants would be trivial” (Oman, pg. 34). Thus a low-cost source of hydrogen gas would be available to support the hydrogen energy shift.

Currently, the most popular and least expensive way to produce hydrogen is via steam methane reformation. This costs about 1/10 of the costs that would be associated with creating hydrogen gas via solar energy (Griscom pg. 3). Until the green methods such as solar energy are economically viable, it will be necessary to trade off some emissions in return for the cleaner technology. With continued research, hopefully solar technologies will be able to catch up and build economies of scale, becoming more competitive.

Vehicles can either be designed to carry pure hydrogen gas on board, or be fitted with reformers to convert hydrogen rich fuels, such as ethanol, natural gas, or gasoline to hydrogen gas. This adds some complexity to the design of the vehicle. A source fuel such as methanol is stored in a similar manner to how fuel is currently stored in a vehicle, in a non-pressurized tank. The fuel is processed by the reformer and broken down into hydrogen gas, carbon dioxide, and water. The hydrogen can then be utilized by the fuel cell to make electricity. The carbon dioxide can either be released into the atmosphere or sequestered.

One advantage of operating a fuel cell powered vehicle is greatly reduced emissions. Pure hydrogen fueled FCV’s will emit only water during operation.

This removes the point source emission of pollutants out of the immediate area. The only emissions would be related to the production and transportation of the hydrogen gas. If scientists are able to determine an economically viable, renewable, and clean way to produce hydrogen gas, there is the potential for a continual and non-polluting source of energy. Steam reformation and other methods of creating hydrogen gas do produce greenhouse gasses and other pollutants, but these are in smaller amounts than by a traditional petroleum powered vehicle. Additionally, fuel cell powered vehicles are generally at least 40% efficient, making them twice as efficient as petroleum powered vehicles. This means they require one half the energy and fuel to do the same amount of work. Research on fuel cells will render future versions more efficient and improve this advantage.

FCV's would also address the problem of noise associated with internal combustion engines. Internal combustion engines are extremely noisy and often large efforts to control the noise and its effects on the public are undertaken. Fuel cells have no moving parts and electric motors are significantly quieter than internal combustion engines.

Another vast improvement made possible by fuel cell cars would be the health of the populous. According to one study, moving to a hydrogen-based economy could save billions of dollars. According to Contadini, $85 Billion can be saved in human health damage costs and $3 Trillion in monetary private costs over the course of 50 years (pg. 1349). This is no minor sum indeed.

Some disadvantages associated with fuel cell powered vehicles are related to properties of hydrogen. Hydrogen is a gas, and a highly diffuse one at that. At room temperature it takes up a huge amount of space per unit of energy. In order to be useful as a fuel, it must be compressed or potentially liquefied. These processes use a great deal of energy, reducing the overall energy value of the hydrogen. In fact, liquefying hydrogen requires cooling it to near absolute zero. This requires the use of tanks to store the hydrogen at very high pressures or low temperatures. These tanks are sophisticated, expensive, and heavy. They complicate considerably the storage of the fuel on the vehicle and the infrastructure required for transportation and refueling. FCV's that utilize conventional fuels with onboard reformers by-pass this problem with the trade-off being some emission of pollutants and greenhouse gasses.

Research is also focusing on certain materials that have the ability to absorb large amounts of hydrogen gas. Since the compressing and liquefying of hydrogen is so expensive and requires such large amounts of energy, other alternatives must be developed. "Metal alloys can be persuaded to absorb up to 1,000 times their own volume of hydrogen, but they are heavy and become brittle…" (www.hydrogen.org.au pg. 1). The newest research focuses on carbon nanotubes that can absorb large amounts of hydrogen. Right now, however, the process is still very expensive. If breakthroughs can be made, this could address the problems of storage and render hydrogen more practical as a fuel for automobiles.

Additionally, use of pure hydrogen fuel requires the development and construction of an entirely new fueling station infrastructure. This will be expensive in terms of both money and time to develop and install. One study estimated that a fueling station with an onsite reformer for the conversion of natural gas would require a land area of 210 square meters (Oman pg. 36). This is significantly larger than a current service station and the capital cost and environmental impacts must be considered.

The new customers will have to be educated to use this new technology. The use of conventional fuels to derive hydrogen in the vehicles allows for the use of the current infrastructure with small modifications, which would be significantly cheaper. However, the technology will still be different and new and will require education of the public to ensure acceptance and success. If this is not done effectively, fear and misunderstanding could ground the operation before it starts. One misconception that would need to be cleared up is that hydrogen is less safe than petroleum. This is influenced by the perception that the Hindenberg exploded because it was filled with hydrogen when in fact it was due to the fabric that was used (www.science.org.au pg. 4).

The performance of fuel cells is directly related to the temperature at which they are operating. While PEM fuel cells are among the most efficient at lower temperatures (60 – 90 degrees Celsius) they can be difficult to operate in cold situations. Considering the fact that one of the by-products of the fuel cell is water, operation in climates that have prolonged exposure to weather conditions below freezing could be problematic.

Currently, fuel cell powered vehicles are extremely expensive. As with all products, increased production will bring about greater economies of scale. This will be directly accompanied by a reduction in price. However, the costs are likely to still be significantly higher than those of conventional internal combustion powered vehicles.

Recent research has also revealed one potentially disastrous side effect of a hydrogen economy that had not been previously considered. Scientists, using a model, have predicted that any escaping hydrogen gas would rise to the top of the stratosphere where it would bond with tiny particles in the air. When this occurs, the new molecules would freeze. This surface would act as a catalytic site for the destruction of the ozone layer (www.npr.org). This conclusion is controversial due to some of the assumptions made in the model, but is certainly a concern that warrants further consideration before a full foray into the hydrogen economy is undertaken.

The green production of hydrogen gas is still not economically viable. This leaves the production of hydrogen gas to be based on the use of fossil fuels. While FCV's are more efficient than internal combustion engines, they are still dependent on fossil fuels in this circumstance. This may prolong the inevitable, it certainly does not solve the problem. The stores of fossil fuels will continue to be used up and will eventually be depleted. If no green methods of producing hydrogen efficiently have been developed, the world will once again be in a situation of dire proportions.

There are two major initiatives in place to encourage the development of fuel cell vehicles. One is the FreedomCAR and Fuel Initiative from the Federal Government. President George W. Bush announced this proposal in the State of the Union Address on January 28, 2003. This initiative pledges $1.2 Billion in research funding to help facilitate the development of fuel cell vehicles. It is based around a public-private partnership and builds on the FreedomCAR initiative launched a year earlier. The goals are to help develop a clean technology of transportation and to reduce the United States dependence upon foreign oil.

The second is the State of California initiative named the California Fuel Cell Partnership (CaFCP). This initiative is a partnership of various organizations to evaluate fuel cell vehicles under real world circumstances in order to help move them towards mass production and consumption. The initiative consists of auto companies, government agencies, fuel providers, and companies that produce fuel cells (www.fueleconomy.gov).

The FreedomCAR and Fuel Initiative came under criticism from many groups for two main reasons. First of all, according to an MIT study released shortly after the inaugural address, more gains can be made for significantly less money by improving and revising technologies already in existence. Increases in fuel economy and reductions in emissions can have a greater impact on the environment and oil dependence than a movement towards hydrogen cars. They do not recommend abandoning research on fuel cells at all, just that the money may be more effectively spent elsewhere, on further development of hybrid cars, for example. The fact still remains that hydrogen is the only identified fuel source for the future once fossil fuels run out.

The other major criticism leveled at the Bush administration for the initiative is that funds were diverted from renewables research into hydrogen fuel cells. One of the most attractive aspects of the fuel cell is the ability to have a completely green source of energy of the hydrogen which powers the fuel cell could be created in a renewable manner. This would create an almost pollution-free source of energy. Otherwise, the fuel cell is still dependent upon fossil fuels to be effective. Without the renewable sources being developed in tandem, the benefits of the fuel cell are considerable lessened. (Griscom pg. 2).

Gasoline-Electric Hybrid Vehicles

In the State of the Union Address on January 28, 2003, President George W. Bush announced the FreedomCAR and Fuel Initiative. The initiative proposed $1.2 billion in funds for research into Fuel Cell driven cars powered by Hydrogen. One of the major goals is to reduce the national dependence upon foreign oil.

In February, shortly after President Bush's announcement, the Massachusetts Institute of Technology released a report stating that hybrid cars would provide a much greater advantage over fuel cells in the short term, and perhaps the long term (MIT LFEE 2003-001 RP). Additionally, the technology currently exists in a mass produced form and has been marketed successfully. With a push towards the hybrid car, many of our energy dependence and pollution issues can be addressed in the short term until hydrogen cars become viable, and if that fails, be the preferred technology.

Gasoline-electric hybrid vehicles come in two basic varieties, commonly referred to as "mild" or "light" hybrids and "full" hybrids. According to Ricardo Consulting Engineers, Ltd of the United Kingdom, " A 'mild' hybrid is defined as being when the electric motor is also able to provide up to 10 per cent of the maximum engine power in the form of additional torque. A 'full' hybrid is defined as being one in which the electric motor typically provides around 40 per cent of the maximum engine power as additional torque" (www.ricardo.com).

One full hybrid system on the market is the Toyota Prius. The Toyota uses a 50 kW electric motor combined with a 76 hp gasoline internal combustion engine. The Prius can be powered entirely by either motivational system, or by both combined, if necessary. The combined interaction of the electric and internal combustion engines allows the Prius to be highly fuel efficient with EPA ratings of 60/50 city/highway MPG. The 2004 Prius qualifies as a SULEV (super ultra low emissions vehicle) and a PZEV (partial zero emissions vehicle).

There are a few disadvantages to buying a hybrid car. One is that they are more technologically sophisticated, and therefore, more expensive to produce. Because of this, hybrid cars carry a price premium over vehicles powered by a traditional internal combustion engine. The United States Government currently offers a one-time Clean-Fuel Vehicle Federal Tax Credit for the purchase of a hybrid car to help offset some of the price premium, but this incentive is currently being reduced by $500 yearly towards a phase out in 2007 (www.irs.gov).

This issue is politically significant because the Federal Government has made a large public investment. Many would argue this investment was made in a way that does not directly serve the goals it is stated for. Technology exists today, including the hybrids, which would immediately and directly reduce the consumption of imported oil and output of pollution. The MIT study directly states that the goals of the administration would be better served by investing in hybrid technology, in the short term and also possibly in the long term.

Some environmentalists charge that the administration is using this issue to buy credibility and time on the issue by instituting a policy that sounds good, but makes no real demands on automakers to increase fuel efficiency and provides support to the energy companies that support the Republican party (Mieszkowski, pg. 2-3). The most likely sources of hydrogen gas are petroleum and natural gas, powerful energy lobbies that support the President. Additionally, some of the funds for the initiative came from cutting programs related to sustainable energy sources. This seems contradictory considering the stated goals of the campaign. There is bi-partisan support for increasing the fuel-efficiency standards of cars and light trucks (Tapper, pg. 5). Legislation of this nature would provide an immediate boost to hybrid technology and speed its incorporation into the market.

Conclusions

Each of the alternatives presented has advantages and disadvantages. However, it is also important to note that most of the alternatives only address a few of the problems associated with the automobile, namely pollution and foreign oil dependence. With 189 counties or municipalities listed as serious to severe in terms of pollution, addressing these issues with alternative fuels will no doubt have the potential for positive outcomes. Quality of life in many urban areas will be greatly improved. There are other issues to consider, for instance the social, environmental, and public health ramifications of an auto-dependant society.

Fixing the pollution and oil dependence of the automobile leaves one glaring fault un-addressed. The automobile is the enabler in the national habit of sprawling development. This development pattern has a multitude of negative aspects associated with it. Urban sprawl contributes to social isolation by income, age, and ethnicity. As urban areas expand, the poor are pushed further and further away from the areas where they can obtain employment, leading to long commuting times and detraction of time away from other activities. This can degrade the quality of life for families at lower income levels. In a report issued in July of 2003, the Surface Transportation Policy Project found that,

> "For lower-income families, the expense of transportation poses a tremendous burden and inhibits wealth creation. The poorest 20 percent of American households, those earning less than $13,908 (after taxes) per year, spend 40.2 percent of their take home pay on transportation… the working poor who were able to take public transportation, bicycle, carpool, or walk to work spent far less, leaving more left over for housing, health care, food, and education (American Dream Report, pg. 3).

A report released in April of this year by the Surface Transportation Policy Project on aging Americans and mobility found that seniors with access to public transportation fared much better than older Americans in areas without public transportation options. More than half of older non-drivers utilized public transit in more dense areas while only 5% utilized public transportation in less dense areas (Bailey, pg. 2). As baby boomers approach old age, greater transportation options need to be made available, or else many of these individuals will live in situations of increasing isolation and difficulty in accomplishing daily tasks to fulfill needs.

Urban sprawl also causes the destruction of natural habitat through the proliferation of roads and small lot single-family homes. This development pattern eats up land at a much higher rate than more compact types of development. Migration patterns of wildlife are disrupted. Within the field of Conservation Biology, roads act as barriers or filters to animals and plants. "One significant type of barrier in many landscapes is roads. Habitat fragmentation is usually accompanied, and augmented, by road building. …roads fragment populations into smaller demographic units that are more vulnerable to extinction" (Meffe et al, pg. 286).

Farmland is parsed and used for housing instead of growing food or tending livestock. Not only does this diminish the overall food productivity in the region, it requires food to be transported from greater and greater distances to feed the residents of the expanding urban area, contributing to greater fuel consumption.

While these alternatives may address some of the public health concerns associated with pollution, they do not address the mortality rates associated with automobiles. According to Ian Roberts, “Every day about 3,000 people die and 30,000 people are seriously injured on the world’s roads in traffic crashes” (pg. 3). He also notes that most victims are pedestrians, cyclists, and bus passengers. “By 2020 road crashes will have moved from ninth to third place in the world ranking of the burden of disease and injury” (Roberts, pg. 3).

An additional detrimental health effect of sprawling development is the link to a sedentary lifestyle and adulthood obesity. Smart Growth America released a report in September 2003 detailing the link between obesity, high blood pressure, and sprawl. The report found a positive correlation between a higher level of sprawling development and the diseases of obesity and hypertension.

In order to address these greater issues, growth-related policies need to be implemented ensuring the protection of the environment, maximizing efficient land use, and the promotion of mass transit as a viable means of transportation. According to the International Energy Agency, the impact of one bus on the road frees up 8.4 bus-equivalents of road space by users of other modes switching to the bus (Bus Systems for the Future, pg. 46). STPP estimates that it would require $14.8 Billion to maintain the current public transportation system and $43.9 Billion would be required annually to upgrade it significantly. While this sounds like a great deal of money, according to Greenpeace, the United States Government subsidizes the oil and gas industry to the tune of $11.9 Billion if defense of Persian Gulf oil fields were not taken into consideration. Including defense of the Persian Gulf oil fields, this amount ballooned to $35.2 Billion. The watchdog organization Friends of the Earth compiled an estimate of new subsidies included in the H.R. 6 Energy Policy Act of 2003. Their estimate amounted to "$45.7 Billion in new or expanded tax breaks and subsidies and other benefits for oil and gas" (Pica 11/08/03). It appears that with a restructuring of priorities from polluting fossil fuels to public transit, a large portion of the bill could be accounted for.

However, this does not mean that alternative fuels should not be pursued as an important advance. The gains realized by AFV's will be much faster in coming than the politically more contentious limits of urban expansion and promotion of public transit. Additionally, public transit cannot effectively manage the current urban form. While future development can be directed and built to rely on transit, the current urban form is here to stay in the areas that are already built out. This will not change rapidly. The automobile will always be the preferred method of transportation in these areas. Promoting AFV's for these areas will greatly reduce the deleterious effects currently wrought by petroleum-powered vehicles on the quality of life of citizens and the health of the environment.

If this future vision is to come about, it will require a dramatic shift in thinking in the United States. The single-family home needs to be discarded as the ideal. It will require creating situations where people can realize that a shift in thinking and in lifestyle is possible, and in fact advantageous. In the United States it needs to be recognized that the sustainability issues faced are interrelated, and will require action on multiple fronts. Simply perfecting the fuel cell will not solve all the problems. It must be accomplished in tandem with many other goals and initiatives working toward a more sustainable existence.

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