1992

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1992. *Transactions of the Nebraska Academy of Sciences*, XIX: 1–6

THE IMPACTS OF ENVIRONMENTAL LEGISLATION AND VEHICLE EMISSIONS ON THE FUTURE OF ALTERNATIVE FUELS IN THE TRANSPORTATION INDUSTRY

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ABSTRACT

This paper addresses the impacts of environmental legislation and vehicle emissions on the future of alternative fuels such as methanol, compressed natural gas, propane, electricity, hydrogen, and reformulated gasoline in the transportation industry, and it discusses the advantages and disadvantages of each type of fuel in terms of fuel efficiency, fuel cost, environmental impacts, and vehicle performance.

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New environmental legislation and the willingness to cut dependence on foreign oil are driving science and industry to develop alternative fuel vehicles for the future. Alternative fuels are non-fossil fuels that can replace gasoline and diesel fuels in vehicles and include methanol, ethanol, hydrogen, natural gas, propane, and electricity. Each has some advantages over gasoline, mainly because they burn cleaner and thus are less harmful to the environment. Unfortunately, each of these alternatives also has drawbacks in either cost, performance, lack of existing technology, or safety. In this paper the impacts of environmental legislation and vehicle emissions on the future of alternative fuels are addressed, and the advantages and disadvantages of each type of fuel are discussed.

ENVIRONMENTAL LEGISLATION

Although reducing dependence on foreign oil is a goal set by government since the first oil crunch of the 1970s, the real force behind alternative fuel programs is the 1990 Clean Air Act and other environmental legislation. The 1990 Clean Air Act mandates that gasoline be reformulated and sold in the nine cities with the worst ozone levels by 1995. It also requires that by 1998 large fleet operators begin using clean fuels such as compressed natural gas. California, which has the world's strictest emission standards, is requiring all auto makers which do business within the state to offer electric vehicles for sale by 1998 (Cook, 1991). With one tenth of national new car sales taking place in California, car makers are hard at work to develop practical electric vehicles. As the states and the federal government keep lowering exhaust standards, which will likely be the case, the more industry will turn to alternative fuels to keep within vehicle emission standards.

MOTOR VEHICLE EMISSIONS

Motor vehicles are a leading cause of air pollution in United States. Major vehicle emissions include carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), and volatile organic compounds or VOCs. About 66% of carbon monoxide along with 43% of the nitrogen oxides and one third of the hydrocarbons produced nationally originate from motor vehicles (Cannon, 1989). All of these emissions contribute to health and environmental problems. Carbon monoxide displaces oxygen in the blood stream and in large doses can affect health and even cause death. Carbon dioxide has been implicated as a gas which plays a major role in global warming, commonly referred to as the greenhouse effect (Bleviss and Walzer, 1990). Nitrogen oxides and VOCs in the presence of sunlight form ground level ozone (O_3), a lung irritant.

On a planetary scale, carbon dioxide is thought to contribute to the controversial greenhouse effect, which is created by gases in the atmosphere which trap thermal radiation given off by the earth and thus heat the atmosphere. This is a natural effect which makes the planet habitable by humans. The earth's natural gases which create this effect are composed of water vapor, clouds, and carbon dioxide. Without this natural effect, the earth may be perhaps 60 degrees Fahrenheit cooler than present (U. S. Congress, Office of Technology Assesment, 1990). With vehicles emitting large quantities of carbon dioxide, scientists are concerned with the possibility that the effect is being intensified and that global temperatures are rising.

On a regional scale, vehicle emissions produce ozone, a lung irritant. Ground level ozone, commonly referred to as smog, should not be confused with the Earth's upper ozone layer which has been publicized as being depleted for years. Ozone is produced from VOCs and nitrogen oxides when they react in the presence of sunlight. This explains why ozone levels are the worst in the summer months and also why ozone levels are typically higher in warmer climates. Currently, Los Angeles (which has become almost synonymous with smog) is the nation's biggest violator of the Environmental Protection Agency's public health standard for smog. Eighty to one hundred other American cities also do not conform to the Environmental Protection Agency's standards. The standard is violated whenever an air sample has an average ozone content over 0.12 parts per million in a given hour (Cannon, 1989).

The key to reducing ozone is to reduce its reactants. VOCs are produced from engine exhaust as well as industrial chemical and solvent evaporation. Nitrogen oxides are products of fossil fuel combustion. Traditionally, VOCs have been targeted for reduction because the technology was thought to be cheaper and easier. Now ozone component reduction is implemented on a city-by-city basis. Typically, the limiting component of ozone is targeted for reduction in cities with ozone problems. For example, if all of the VOCs in a city's air sample were reacting with only some of the nitrogen oxides, then the VOCs are the limiting components of ozone production and should be targeted for reduction. A reduction in nitrogen oxides in this scenario will have no impact on ozone levels until the nitrogen oxides become the limiting components of ozone production.

The alternative fuels such as methanol, ethanol, compressed natural gas, propane, electricity, hydrogen, and reformulated gasoline are believed to be less pollutant than gasoline and diesel fuels. However, each fuel has its advantages and disadvantages in terms of efficiency, cost, vehicle performance, and environmental impacts. These advantages and disadvantages are discussed in the following sections of the paper.

ALTERNATIVE FUELS

Methanol

Methanol can be easily produced from abundant coal and natural gas reserves in United States. The combustion of methanol releases far fewer pollutants than gasoline, although there seems to be some pollutants released during methanol production. Critics of methanol argue that the conversion from natural gas to methanol releases as much carbon dioxide as gasoline does during combustion, and that the coal to methanol conversion process releases twice as much carbon dioxide (Cannon, 1989). The beneficial emission reductions for methanol will come in the form of reactive hydrocarbons and carbon monoxide.

The technology for methanol-powered vehicles is available and advanced. The first widely-used methanol fuel will most likely be a mixture of 85% methanol and 15% gasoline, a fuel referred to as M85. Pure methanol has cold starting problems which is why 15% gasoline is added to the fuel to make it more volatile and to ease starting. M85 has an octane rating of 100 compared to 87–92 for gasoline. The higher octane rating means it will be able to burn more smoothly at higher engine compression ratios than that of gasoline engines and won't cause "pinging" or "knocking." The higher engine compression ratio allows a more fuel efficient engine design which can optimize the energy value of the fuel. This fact is evident in Indianapolis 500 race cars which have been running on pure methanol for years because of its high octane rating of 110. Methanol also has a faster flame speed than does gasoline. This will speed burning in the cylinders and will make the engine more efficient. Also, with a high heat of evaporation, methanol will let the engine dissipate heat faster. Due to high heat dissipation, a conventional water cooling radiator can be replaced by an air cooling radiator to save weight and increase mileage.

M85 has only about half of the energy content of gasoline at 65,000 Btu compared to 116,000 Btu for gasoline (Ross, 1990). With only half the energy content, a methanol powered car needs twice the volume of methanol to cover the same distance as gasoline. Since the densities of the two fuels are comparable, the extra fuel weight and volume requirements for methanol vehicles will relate to greater drag and decreased passenger room compared to gasoline vehicles.

Car makers are well along on producing methanol vehicles. Chevrolet will offer a methanol-powered Lumina in the 1992 model year, while Ford is still developing methanol versions of its Escort, Taurus, and Crown Victoria. Chrysler and foreign manufacturers are also in advanced stages of methanol vehicle development (Moffat, 1991). The first methanol cars will run on a variety of mixes of gasoline and methanol, from pure gasoline to M85. This will allow the initial supply of methanol to be less than demand, which will ease capital investment in a distribution network. These flexible fuel cars will use a computer which adjusts fuel injection and spark timing to optimize engine performance. The flexible fuel system will keep the cars from being hampered by limited range due to a scarce fuel supply. However, as soon as there is a sufficient distribution network in place, new cars would be dedicated to operate on M85 only, to keep gasoline combustion to a minimum. During the initial transition to methanol vehicles, the price of methanol fuel may present a problem.

The California Energy Commission has forecasted that M85 would cost $1.44 for the energy equivalent of a gallon of gasoline in 1993–1994, the time that methanol cars will be in production (Ross, 1990). That estimate is 23 cents higher than the forecasted price of premium gasoline, though the difference in prices will be only pennies by the year 2000 when methanol is in bulk production. During this initial variable fuel phase, the price of methanol will almost certainly need to be subsidized so consumers won't consistently fill up with cheaper gasoline. That will most likely leave the government to pick up the tab. This subsidy is not as bad as it looks, considering ethanol has been subsidized at 60 to 80 cents per gallon for years (Fumento, 1990).

A final argument for methanol is increased vehicle performance for production cars. During performance tests by Ford, its Crown Victoria accelerated from 0 to 60 mph in 11 seconds, a half second improvement over gasoline models. Similarly, their Escort picked up one second off its time in the same test (Moffat, 1991). While in the U.S., it has not been demonstrated that people will pay more for lower vehicle emissions, they do pay more for performance, and on this note, methanol is ahead of the other alternative fuels.

Ethanol

Ethanol is a fuel produced from the fermentation of farm crops, typically corn and sugar cane. The environmental advantage results from the fact that the farm crop consumes as much carbon dioxide during photosynthetic growth as the ethanol releases during combustion. Corn supply is limited in the United States and probably could not provide for large-scale ethanol production. Because of its relative costs and advantages of other alternative fuels, ethanol will not likely become a widely used fuel in the future.

Since ethanol is in a familiar liquid fuel form, it requires little change in the distribution and retail network. Like methanol, ethanol has a high octane rating and can be manipulated to achieve higher engine efficiency. Also, an ethanol transition vehicle that can run on multiple blends of gasoline and ethanol is available to ease the fuel conversion process.

Ethanol has been used widely over the last ten years in the U.S., where it is made from corn and is used as a 10% fuel additive to gasoline to make "gasohol." Brazil has also used ethanol made from sugarcane quite extensively and uses it in vehicles in pure form (E100). Pure ethanol, like M100, has cold starting problems and would need some gasoline added to ease starting in the colder climates of the United States. For ethanol to be used in the U.S. as a true alternative fuel however, it would need to be used in near pure form and that is not likely due to its high cost.

Currently, ethanol is being subsidized by the government at 60 cents per gallon. This subsidy in gasohol relates to 6 cents per gallon because of the 10% ethanol content. The subsidy is needed for ethanol to compete with gasoline. Ethanol costs about $1.40 per gallon and has only 70% of the energy of gasoline (Fumento, 1990). Hidden costs are also associated with ethanol. Ethanol producers take advantage of government corn subsidies which cost consumers indirectly and taxpayers directly. Ethanol production from corn also creates competition between corn for fuel and corn for food, which drives up food prices. After considering these secondary costs, ethanol becomes one of the most expensive alternative fuels currently available.

In the future, ethanol may be produced from wood if technology can make costs acceptable. The result of ethanol derived from wood will provide significant greenhouse benefit and will eliminate the food vs. fuel problem and its associated costs.

Compressed natural gas

Approximately 30,000 vehicles in the U.S. and 700,000 vehicles worldwide are powered by compressed natural gas (CNG). Italy alone has 300,000 CNG vehicles and has been using it as an alternative fuel in vehicles since the 1930s.

According to the American Gas Association, 8 to10 million CNG vehicles can be powered by less than 6 percent of current U.S. natural gas consumption (Cook, 1991). This would not be the case if natural gas is converted to methanol and then burned in vehicles. Using natural gas directly in vehicles is much more energy efficient than converting it into methanol. Making methanol from natural gas results in a 40% loss of energy during the conversion process.

Other natural-gas benefits include a cheaper price at the pump and low vehicle maintenance costs. The volume of natural gas that is equivalent to the fuel value of a gallon of gasoline costs a mere 70 cents. Natural gas is also a much cleaner fuel than gasoline which lets crankcase oil last 50,000 miles and requires spark plugs to rarely need replacing (Cook, 1991).

Problems with natural gas stem from its low energy-to-volume relationship. The gas must be pressurized to 3000 psi in bulky cylinders, and still it will have only a fourth of the energy as the same amount of gasoline. This requires a natural gas tank four times the size of existing gasoline tanks, and would take up the entire trunk of a small vehicle.

Obtaining a natural gas vehicle does not require the purchase of a new car. CNG vehicles can be converted from gasoline engines with add-on kits ranging from 2 to 3 thousand dollars (Cook, 1991). A gasoline engine conversion can run on either natural gas or gasoline, but unlike the alcohol transition vehicles, they cannot run on a mixture of their two fuels. Production vehicles may or may not have the dual fuel systems. GMC started selling 1000 Sierra pickups in the spring of 1991 in Texas, Colorado, and California under cost-sharing agreements with local gas utilities. These pickups are dedicated to only natural gas and can't operate on gasoline. The Sierra has three aluminum gas tanks wrapped in fiberglass that run along the underside of the truck's frame. With each tank over five feet long, the pickup carries enough CNG to travel 150–200 miles.

CNG's biggest problem lies with its refueling procedure. The tanks must either be filled by slow or high rate pumps, and both have their drawbacks. The slow rate compressors take up to several hours to fill the tank, which restricts CNG use to either company fleet use, or requires consumers to install CNG compressors in their homes. Residential overnight compressing units cost $2,000 and up currently and will take out the consumer savings of using the cheaper natural gas. Commercial fleet slow rate compressors are a little more practical for companies where many vehicles can be refueled by one large compressor.

High-rate compressors may pose a bigger problem. These compressors can be used in a filling station atmosphere with the filling time taking approximately twice the time it takes to fill up with gasoline. Their problems lie with their associated high costs. The Department of Energy forecasts that a station which serves 300 vehicles per day would cost an estimated $320,000 without land and upgraded gas pipeline costs (Cook, 1991). With this high cost, high-rate filling stations would need to be subsidized by natural gas companies and consumers, and would likely take CNG's economical benefit away.

A final argument for CNG is the existing pipeline network through which natural gas is distributed through nationwide. Other fuels such as methanol and ethanol will need to be transported by truck, like gasoline. Because of the lower fuel value of methanol, twice as many trips will be taken during distribution than those presently using gasoline. The case will be similar to ethanol and these extra trips will increase fuel transportation costs and safety problems which can be avoided using natural gas.

Liquified petroleum or propane gas (LPG)

Nearly 4 million vehicles worldwide are fueled by LPG, performing various duties (Cannon, 1989). Propane is a colorless gas at atmospheric conditions that is easily stored under pressure as a liquid. It is originally odorless but is given its unpleasant smell during production for safety reasons. Approximately 270 gallons of propane vapor can be compressed into one gallon of liquid in a pressurized container.

About 70% of the world's propane supply is a byproduct of natural gas production while the remainder is made from crude oil refinement. Although a petroleum product, its emissions from combustion contain none of the olefins or aromatics that produce smog.

Unfortunately propane, like CNG, also has the disadvantage of needing heavy fuel tanks. Propane also has about 85% the energy value of gasoline but is much cheaper and has a lower fuel cost per mile (Fumento, 1990). One handicap propane has is running in very cold climates. Propane vaporizes at -44 degrees Fahrenheit, and if the ambient temperature falls below this, the propane won't vaporize and can't be burned.

Benefits of propane include a high octane rating of 104 which can be exploited to raise engine efficiency, and the cleanliness of the fuel which lets crankcase oil last 5–10 times longer than gasoline engines. Lower maintenance costs and reduced engine wear and tear are direct benefits of propane's clean characteristics. It has been reported that engines last 2 to 3 times longer running on propane as compared to gasoline. Propane is so clean burning that it has been used for years to power indoor forklifts in plants because of its low emissions. Even with propane powered forklifts indoors, production plants and warehouses can meet Occupational Safety and Health Administration air quality requirements.

A final note on propane is the connection between propane and oil production. If used widely, propane would need to be produced from oil reserves and would then not be considered a true alternative fuel. Also, propane's price would be directly connected to oil prices and would fluctuate with them.

Electricity

Electric cars may be the "air pollution solution," due to the fact that there are no emissions from these vehicles. Car makers have been working on electric cars for years and are getting close to marketing them. General Motors has developed a two-seat compact coupe, appropriately named the Impact, which may be sold by the mid 1990s. The coupe can reportedly accelerate like many gasoline-powered sport cars and has a top end of over 100 mph (Fumento, 1990).

Although electric cars produce no air pollution, some of the generating plants which may supply power to these vehicles do. A substantial increase in electric vehicles would increase power demand from coal- and oil-burning power plants and may offset any environmental benefits of the electric cars. The major drawbacks to electric cars are the cost and bulk of batteries and their limited range. GM's Impact has a range of about 124 miles and a recharge time of 2 hours, which limits it to urban driving conditions (Fumento, 1990). The Impact's batteries are only good for about 20,000 miles and will cost about $1500 upon replacement (Cook, 1991). This incremental cost will offset the pennies-per-mile cost of running the car and will make it twice as expensive per mile as gasoline engines (Fumento, 1990). There is also the problem of heating and air conditioning the vehicle. These processes rapidly drain batteries and decrease driving range. Countering this will require auto makers to heavily insulate electric vehicles to keep space conditioning power requirements to a minimum.

The electric car is well suited to city driving because it uses no power when stopped like idling gasoline engines. Also during braking, the motor can be reversed to charge the batteries, a process called regenerative braking. An added feature is the much quieter operation of electric vehicles, a feature any golf cart driver will attest. Also, lack of range in electric vehicles may not need the attention it receives since most Americans drive only 15 to 35 miles daily (Cook, 1991).

GM hopes to increase battery life to 40,000 miles before marketing the Impact to lower operating costs. Research is being conducted on sodium and sulfur batteries as well as other chemical batteries to increase range of electric vehicles. These vehicles may be able to increase range to 300 miles, or twice that of the traditional lead batteries (New York Times, 1991). Other possible ways to increase the range of electric vehicles include installing a small gasoline or propane generator for recharging while driving, or by adding solar panels on the exterior. Unfortunately, solar technology is still very expensive and not suited to all types of climates or hours of the day.

Despite any present problems, the future of electric vehicles is quite bright. If the advent of superconductivity ever comes about, electric vehicles will most certainly become the only vehicles on the road.

Hydrogen

Hydrogen-powered vehicles are the technology of the future. Still in the early stages of development, hydrogen vehicles are plagued with problems including safety and cost. Their lure is the prospect of zero vehicle emissions. Hydrogen combustion produces mainly steam and only trace amounts of nitrogen oxides. Any major emissions related to hydrogen vehicles will come from the production of hydrogen and not its combustion.

Hydrogen gas can be produced in a number of methods, with the most economical at present being coal gasification. Coal, combined with steam under high pressure and temperature, separates into carbon dioxide and hydrogen. Unfortunately, using coal as a hydrogen feed stock has negative impacts environmentally due to high CO_2 production and negative environmental impacts inherent to coal mining. Hydrogen gas can also be produced by electrolysis, passing electric current between two plates immersed in water which splits the water molecules into hydrogen and oxygen. This method could prove very beneficial to the environment. However, electrolysis is very energy intensive, and if powered by fossil fuel power plants, the environmental benefits of hydrogen power would be defeated. Ideally, hydroelectric or renewable wind and solar power plants would be used for powering this process as well as nuclear power.

These hydrogen-production methods are not without their high fuel costs. The 1985 estimated costs of hydrogen's equivalent to a gallon of gasoline ranges from $1.50 to $5.00 per gallon for hydrogen produced from coal gasification and from $3.50 to $14.00 per gallon for hydrogen produced from electrolysis (U.S. Congress, Office of Technology Assessment, 1990).

Although hydrogen is in early stages of development, car manufacturers have working hydrogen prototypes. Mercedes Benz and BMW both have working models of gasoline engine vehicles that run on hydrogen, but are not without their faults (Templeman and Miller, 1991). The main problems in hydrogen development stem from gas tank construction. Compressed gaseous hydrogen tanks are not considered safe because they could create an explosion if in a crash situation. Therefore, hydrogen tanks must be built to withstand crash situations, making them more difficult and expensive to build.

Mercedes is using a tank built for gaseous hydrogen which bonds with powdered metals inside. The tank is pressurized to 725 psi. Low fuel volume is the tank's biggest fault. BMW is developing a tank which stores hydrogen in liquid form at -253 degrees Celsius and costs a staggering $26,000 (Templeman and Miller, 1991). This cost will need to be reduced at least 90% if BMW mass produces the car. Because of the low temperature of liquid hydrogen the BMW tank needs to be heavily insulated to keep hydrogen loss to a minimum. Even with heavy insulation the tank has storage problems. Hydrogen will begin to boil off after a car sits for a few days as heat seeps through the insulation, resulting in the need to vent hydrogen because of high pressure. The loss of fuel from BMW's tank can reach 2% of its volume daily compared to gasoline tanks which lose up to 1% of their volume per month (Templeman and Miller, 1991).

Hydrogen will also prove difficult for consumers at the fuel pumps. The Mercedes' hydride tanks currently take about ten minutes to fill while BMW's compressed hydrogen tanks take about an hour for safety reasons. Because liquid hydrogen is stored at -253 degrees Celsius, even a drop on a station attendant or consumer causes serious injury. BMW plans to solve this problem with robotic refueling systems which would only add to the price of hydrogen. Hydrogen still has a long road ahead of it in terms of design and development. Although research and development are currently being performed, a safe and cost-effective hydrogen vehicle is still 20 years away.

Reformulated gasoline

Reformulated gasoline is gasoline which has been chemically engineered to give off fewer pollutants during combustion. Although reformulated gasoline will not be a true alternative fuel, it is an option which will produce significantly lower emissions almost immediately. All of the alternative fuels discussed so far will take years or even decades to make a significant reduction in pollutants due to initially low vehicle numbers. Reformulated gasoline can be used in older vehicles with no modifications to the vehicle or supply network. Although reformulated gasoline is not considered to be able to compete environmentally with other alternative fuels, it is an excellent transitional fuel to lower vehicle emissions in the near future until enough alternative fueled vehicles are on the road.

Older vehicles are currently responsible for an exceptionally large percentage of total vehicle emissions. If current levels of ground-level ozone (smog) are to be reduced, then these biggest polluters need to be targeted. Reformulated gasoline has the potential to lower emissions of these older vehicles and will most likely be used first in urban areas where ozone levels are the worst. Federal law now mandates that the seven smoggiest American cities sell only reformulated gas by 1995.

Several oil companies are hard at work developing reformulated gasoline. In August of 1989, Arco introduced a reformulated gasoline named EC-1 (short for Emission Control 1) to be marketed in southern California. EC-1 will cost Arco an additional two cents per gallon to manufacture (U.S. Congress, Office of Technology Assessment, 1990). This gasoline lowers emissions by limiting olefins and aromatics, along with benzene and sulfur content in the gas, thus lowering emissions released during combustion.

CONCLUSION

Alternative vehicle fuels will become increasingly popular in the years to come. In the immediate future, reformulated gasoline, along with methanol and compressed natural gas, will get a head start over the other fuels. Reformulated gasoline will only be a temporary fuel, and the non-fossil fuels would replace it after several years. Most likely, ethanol and propane will never become broadly popular because of their high cost and limited production capacity, respectively.

Because of tightening environmental standards, electric and hydrogen cars will eventually give all fuels a run for their money and will most likely become the standard. However, it remains to be seen if hydrogen vehicles will ever become cost effective enough to compete with the other alternative fuels.

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