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Rio natural gas, the alternative fuel of the future

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Abstract

Automobile exhaust is a major contributor of harmful air pollutants. Exhaust emissions include water (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxides (NO_X), sulfur oxides (SO_X), hydrocarbons (HC), and particulate matter (PM), and of these the four major air pollutants are CO, HC, NO_X, and PM. Particulate matter is predominantly emitted from diesel fuel burning vehicles. In order to aid in reduction of air pollution, and reduce dependence on foreign oil imports, federal legislation has been enacted. The two prominent acts are the National Energy Security Act in 1992, which mandates use of alternative fuels, and the Clean Air Act Amendments in 1990, which require compliance to ambient air quality standards. The alternative fuels that will be discussed in this paper are methanol, ethanol, electricity, hydrogen, reformulated gasoline, liquefied petroleum gas (LPG)/propane, and natural gas. The research data shows that natural gas is considered the best choice as an alternative fuel. Some of the advantages of natural gas are it requires no refining, minor processing, burns cleaner, provides more heat per unit weight than any other fossil fuel, and is less expensive than its primary competitor gasoline. Furthermore, the infrastructure to supply and provide services to the fleet vehicles is established and its conversion technology has been proven. Natural gas is a fuel that is being phased into government and private company fleets, and eventually can be the fuel of choice for the public.

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Table of Contents

Table of Figures and Tables

Introduction

The use of natural gas in automobiles has environmental advantages over other alternative fuels. Due to its efficient combustion properties, it produces less harmful air pollutants, resulting in cleaner air quality and in turn promoting a healthier environment. Should the automobile industry promote fuel conversion of vehicles from gasoline to natural gas? This thesis suggests that they should. The primary reason is the reduction of harmful air pollutants to the environment (Bell, 1995). Various tests have demonstrated superior efficiency of natural gas over gasoline and other alternative fuels (Battelle, 1997). By switching to natural gas instead of using inefficient gasoline as a primary fuel source, air pollution from automobiles can be significantly reduced. The purpose of this paper is to examine the pollutants from automobiles, and one of the ways to cut the level of these harmful air pollutants such as sulfur dioxides, nitrogen dioxides, hydrocarbons, carbon monoxide, and carbon dioxide. The focus will be on how to lower pollutants by using more of the alternative fuel, natural gas.

What Is Natural Gas and How Is It Formed?

Natural gas originates, just as all fossil fuels, from organic matter that is trapped in sediments and is found in conjunction with both oil and coal deposits. Unlike petroleum, which forms almost exclusively from the organic matter of marine sediments, natural gas forms in both marine and terrestrial rocks (Craig, Vaughan, & Skinner, 1996). Figure 1 is a diagram that illustrates the formation of fossil fuels from organic matter beneath the earth's surface.

Figure 1
(Craig et al., 1996)
Diagram of Fossil Fuel Formation

Natural gas is produced in all three of the major phases of fossil fuel production diagenesis, catagenesis and metagenesis. Anaerobic bacteria are responsible for biogenic gas production in diagenesis and increased temperature and pressure is responsible for thermogenic gas production at lower depths. About 80 percent of the world's natural gas reserves are believed to be of thermogenic origin and 20 percent of biogenic origin (Craig et al., 1996). Prior to the 1940s, vast quantities of natural gas were allowed to escape or were burned off because there was no market for them. After World War II, the rebuilding of Europe and the growth of American suburbs created large markets for natural gas. Natural gas became attractive as a fuel because it required no refining, a little processing, burned cleanly, and provided more heat per unit weight than any other fossil fuel (Craig et al., 1996). Generally, more than 99 percent of natural gas is methane, but minor amounts of ethane, propane, butane, carbon dioxide, hydrogen sulfide, helium, hydrogen, nitrogen, and ammonia may be present. Figure 2 is an illustration of the composition of natural gas.

Figure 2
(Craig et al., 1996)
Illustration of Various Components of Natural Gas

Why Should Natural Gas be the Choice Among Alternative Fuels?

The use of natural gas as a vehicle fuel has several advantages over other conventional alternative fuels as well as gasoline. The results of tests conducted on natural gas vehicles (NGVs) compared to other alternative fuel vehicles are summarized below:

- natural gas is the cheapest of any alternative fuel
- its availability is greater than other alternative fuels
- conversion of gasoline engines to natural gas has proven its technology
- NGVs emit the lowest carbon monoxide emissions (Bell et al., 1995).

(Electric and solar vehicles were not included among the alternative fuels evaluated in this test.)

The primary reason why gasoline engines should be converted to NGVs is that gasoline engines produce larger quantities of harmful air pollutants than NGVs and the other alternative fuels. The current air pollution problem is caused, in part, by the large number of vehicles that use gasoline. Smog and acid rain are partly due to nitrogen oxides emissions from gasoline fueled vehicles. It is estimated that gasoline fueled vehicles contribute to 50 percent of acid rain and 60-70 percent of smog (*Oil and Gas Journal*, 1997).

The gasoline fueled, internal combustion engines do not burn fuel efficiently. One reason is that gasoline is in a liquid state and for the fuel to burn more efficiently, the liquid gasoline has to be completely atomized. The mechanics of a carburetor in a gasoline engine do not allow this to be accomplished efficiently. In the short time that gasoline has to combust, the fuel is only partially burned and the unburned portion of the fuel comes out as pollutants, such as nitric oxide (NO), carbon dioxide (CO_2), carbon monoxide (CO), and sulfur dioxide (SO_2) (Gates, 1994).

In contrast, NGVs do not contribute to pollution nearly as much as gasoline vehicles because they burn fuel more efficiently. The fuel is already in a gaseous state and doe not need to be atomized, resulting in combustion that is more efficient and less unburned fuel is released as pollutants. The ability of natural gas to burn more completely helps alleviate both pollution and smog problems (Tussing & Tippee, 1995).

Tests conducted by the California Air Resource Board (CARB) showed a significant reduction in the pollution that NGVs produced in comparison to alternative fuel vehicles as shown in Table 1.

Table 1
Evaporative Emissions from Vehicle Combustion

Motor Fuel	**Reactive Organic Gases**	**Carbon Monoxide (CO)**	**Nitrogen Oxides (NO)**	**Carbon Dioxide Equivalents**
Gasoline	.444	3.4	0.400	384
Reformulated Gasoline	.252	3.4	0.400	384
Liquid Propane	.250	3.4	0.400	342
Natural Gas	.021	0.4	0.040	318

Methanol 85	.444	3.4	0.400	385

Table 1. Evaporative Emissions from Vehicle Combustion, Grams per Vehicle –Mile.
Source: Gas Research Institute, 1994, (GRI-93/0472; 58)

From the results shown it is obvious that natural gas produces less pollution in comparison to other alternative fuels. Table 1 shows that natural gas produces 3.00 grams less of CO, .360 grams less of NO, and 66 grams less of CO2 per vehicle-mile compared to gasoline.

Harmful Pollutants Produced by Gasoline Fuel

The problem of air pollution and attempts to solve it are not new. King Edward II (1284-1327) banned the burning of coal while Parliament was in session to attempt to reduce the problem of smoke (Vesilind, Peirce, & Weiner, 1990). Since that time, an increased number of sources for air pollution have been identified and the detrimental effect to the health of segments of the population have been studied. The Environmental Protection Agency (EPA) has established a list of six major criteria air pollutants and they are:

- carbon monoxide
- nitrogen oxides
- sulfur dioxide
- particulates and particulate matter
- ozone
- lead (Krieger, 1996).

In order to protect public health and regulate emissions from mobile and stationary sources, major federal legislation includes the Air Quality Act of 1967, the Clean Air Act Amendments of 1970, the Clean Air Act Amendments of 1977, and most recently the Clean Air Act Amendments of 1990. Ambient air quality standards are national in scope and air quality goals are set by each state with state implementation plans (SIPs) (Kreiger, 1995). One way for states to be able to maintain compliance with standards would be to encourage the use of natural gas as a fuel alternative to gasoline, especially for fleet use.

The automobile exhaust compounds that will be discussed are nitrogen oxides (NO_x), hydrocarbons (HC)/reactive organic gases, sulfur oxides (SO_x), carbon monoxide (CO), and carbon dioxide (CO_2). Continuous increase in emission of these harmful pollutants into the atmosphere is detrimental to human health and the environment. Characteristics and potential hazards of each pollutant of gasoline combustion engines will be described next.

Nitrogen oxides released into the atmosphere are one of the components of photochemical smog, a phenomenon very familiar to urban dwellers. In the United States, about half of the nitrogen oxides are produced by stationary sources and about half by automobiles (Vesilind et al., 1990). Nitric oxide (NO) forms in the cylinders of gasoline combustion engines by the direct combination of nitrogen and oxygen (Brown, LeMay, & Bursten, 1991). Through a series of chemical reactions with atmospheric oxygen, driven by sunlight, the nitrogen oxides ultimately combine to form ozone as well as other photochemical oxidants. In the upper atmosphere, ozone is an essential component that screens ultraviolet (UV) radiation. While in the lower atmosphere, it is reactive and toxic and breathing air that contains ozone can be hazardous to asthma sufferers, exercisers, and the elderly (Brown et al., 1991). Nitrogen oxides also react with water in the atmosphere forming nitric acid, which contributes to acid rain.

Hydrocarbons are not listed as one of the major criteria pollutants, but will be discussed since hydrogen and carbon are the principal components of gasoline. Hydrocarbons are a major factor in the formation of photochemical smog. In the presence of sunlight, hydrocarbons react with atomic oxygen to produce aldehydes, acids, oxides of nitrogen and sulfur, and a series of other irritant and noxious compounds (Environment, Health and Safety Newsletter, 1997). Hydrocarbons are also responsible for lower atmospheric ozone when it reacts with nitrogen oxides in the presence of sunlight (American Lung Association, 1998).

Coal fired power plants and industrial processes are major contributors of sulfur oxides into the air, but automobile exhaust does contribute some. Sulfur oxide compounds, chiefly sulfur dioxide (SO_2), are among the most harmful of the common pollutant gases produced by the combustion of fossil fuels (Brown et al., 1991). Sulfur dioxide is a colorless gas that has a pungent odor in high concentrations, and when released into the atmosphere is transformed into sulfur trioxide and later into sulfuric acid (Sulfur Dioxide – Emissions and Pollutions, 1996). The sulfuric acid produced is largely responsible for acid rain. Due to sulfur dioxide's high solubility, it acts upon the mucous membranes of the eyes and upper respiratory system (Sulfur Dioxide – Emissions and Pollutions, 1996). Sulfur dioxide constrict the bronchi and experiments with rabbits and other animals have shown that cilia, which protect the respiratory system by sweeping out particles, decrease their beat in the presence of sulfur dioxide (Vesilind et al., 1990).

Carbon monoxide is a product of the incomplete combustion of carbon containing compounds. Most of the carbon monoxide in the ambient air comes from automobile exhaust and in terms of total mass, is the most abundant of all the pollutant gases (Brown et al., 1991). Carbon monoxide is a relatively unreactive molecule, but poses a threat to human health because hemoglobin, the iron containing protein responsible for oxygen transport in blood, has a greater affinity for carbon monoxide than it does for oxygen (Vesilind et al., 1990).

Carbon dioxide and water vapor are components of the atmosphere with major importance in maintaining the earth's surface temperature (Brown et al., 1991). The earth's heat energy budget is maintained by carbon dioxide, water vapor, and other trace gases that absorb re-radiated heat energy from the earth to help limit wild fluctuations of atmospheric temperatures (Gabler, Sager, & Wise, 1997). All oxidation of carbon compounds produces carbon dioxide, but recent large increases of carbon dioxide in the atmosphere are attributed to the increased combustion of fossil fuels (Vesilind et al., 1990). Carbon dioxide is not presently listed as a pollutant, but predictions from models seem to agree that a doubling of carbon dioxide in the atmosphere would result in a rise of global mean temperature from 1.5º to 5.5º C (Gabler et al., 1997).

The results of the tests listed in Table 1 show that natural gas compared to several other alternative fuels produces the least amount of several of the harmful pollutant gases (hydrocarbons, carbon monoxide, nitrogen oxides, and carbon dioxide). Natural gas produces about 21 times fewer hydrocarbons/reactive organic gases, almost 9 times less of carbon monoxide, 10 times less of nitrogen oxides, and 66 grams less of carbon dioxide per vehicle mile than gasoline engines.

Characteristics of Alternative Fuels

Each of the alternative fuels has advantages and disadvantages in comparison to gasoline and with each other. Alternative fuels are considered as vehicular fuels other than gasoline and diesel fuel. The alternative fuels that will be discussed are methanol, ethanol, electricity, hydrogen, reformulated gasoline, liquefied petroleum gas (LPG)/propane, and natural gas.

Methanol can be produced from natural gas, coal, biomass, and urban refuse. Currently, most of the methanol produced in the United States comes from natural gas. Natural gas and coal are nonrenewable resources and methanol produced from these sources is not compatible with a long-term energy strategy. A drawback in the production of methanol from natural gas is that a considerable amount of energy is lost (Maxwell & Jones, 1995). In addition, methanol production from coal generates a greater amount of carbon dioxide than the refining of gasoline (Maxwell & Jones, 1995). A reason to continue development of methanol from biomass and urban refuse could be part of a good long-term energy strategy. The United States is facing problems with finding adequate landfill space and producing methanol from urban refuse could help reduce the volume of waste disposed of in landfills. In addition, when methanol is produced from biomass and urban waste, significant energy is produced and little to no fossil energy is used (Maxwell & Jones, 1995).

The primary emission problem of methanol is the generation of aldehydes, especially formaldehyde. Aldehydes are mucous membrane irritants and cause pulmonary, skin, eye, and central nervous system effects and the Occupational Health and Safety Administration (OSHA), and the Environmental Protection Agency (EPA) have set air standards for aldehydes (Hee & Shen, 1997). In addition to the adverse health effects to the human population, methanol requires the installation of alcohol resistant compounds for seals, gaskets, hoses, and regulator diaphragms on equipment that it comes into contact with during use. It also does not transform readily from a liquid to vapor at temperatures below 20º F making it difficult to start engines in cold weather and twice as much methanol is required to drive a vehicle an equivalent distance as gasoline (Maxwell & Jones, 1995). These disadvantages do not make methanol the best choice as an alternative fuel.

Ethanol is an alcohol with chemical and physical properties that are similar to methanol. Most of the ethanol produced in the United States comes from the fermentation of grain, primarily corn and this process requires more energy than is obtained when ethanol is burned as fuel (Maxwell & Jones, 1995). As with methanol, aldehydes are a by-product of combustion and ethanol does not readily change from liquid to vapor at temperatures below 20º F. Although not as corrosive as methanol, certain resistant materials are required for use with ethanol (Maxwell & Jones, 1995). In addition, ethanol is very hygroscopic (readily takes up and retains moisture) and in the presence of water, it separates from hydrocarbons, which is a problem when it is used in fuel blends, such as gasohol (Maxwell & Jones, 1995). These disadvantages make ethanol a low contender as a good alternative fuel.

Electric vehicles produce the lowest emissions of any other fuel, even when considering emissions from electric power generating plants necessary for recharging (Maxwell & Jones, 1995). The technology of electric vehicles has been available since the late 19^{th} century. The first commercially produced electric vehicles were manufactured in France in 1894 and the first electric vehicle built in the United States was in Iowa in 1891 (Ingersoll, 1996). The electric vehicle was popular until the development of the self-starter, for gasoline engines, in 1911 and the closed car in 1919, which lead to the disappearance of electric vehicles by the 1930s (Ingersoll, 1996). Some of the disadvantages of the electric vehicle were the same in the early part of this century as they currently are:

- more expensive to produce than gasoline vehicles
- range was only 50 to 80 miles
- charging facilities were virtually nonexistent outside large cities
- storage batteries deteriorated rapidly
- hill climbing ability was poor because of excessive weight of batteries (Ingersoll, 1996).

California's requirement that 2% of the vehicles sold in the state beginning in 1998 have zero emissions has spurred automobile manufacturers to improve and refine batteries for electric vehicles. Types of batteries currently being considered are lead acid, nickel-cadmium, nickel-metal hydride, sodium sulfur, zinc-air, and lithium polymer. Of all the types of batteries being considered, the lead acid battery is today the only viable option in terms of technological maturity, performance, and cost as it was at the turn of this century (Ingersoll, 1996). A recent report concluded that electric vehicle prices would remain about 50% higher than similar internal combustion engines into the next century (Maxwell & Jones, 1995).

Hydrogen is the fuel that undergoes nuclear fusion, which produces the energy emitted by the sun, and it is the most abundant element in the universe compromising about 80% of it. The major source of hydrogen on earth is water, which constitutes 2.4% of the mass of the earth or about 3.1×10^{21} pounds in total (Ingersoll, 1996). The history of hydrogen as a motive fuel can be traced back to 1820, when Reverend

William Cecil presented a treatise “On the Applications of Hydrogen Gas to Produce Moving Power in Machinery” at Cambridge University in England (Ingersoll, 1996). Several thousand hydrogen fueled internal combustion engines were operating in Germany and England in the 1930s. However, hydrogen did not regain serious consideration as a vehicular fuel until 1970, when J. O’ M. Bockris introduced the term “hydrogen economy” during a discussion on alternative fuels at the General Motors Technical Center in Warren, Michigan (Ingersoll, 1996). Hydrogen is the best choice for alternative fuels when considering energy content and emissions; it is the least complex molecule (H_2) of all the alternative fuels and when oxidized forms water (Maxwell & Jones, 1995). The only major criteria pollutant produced in a hydrogen engine is nitrogen oxides that form from the nitrogen present in the ambient air as it does with other fuels. The major problem with hydrogen is its suitability for on-board vehicle storage. Hydrogen is highly flammable and burns with an invisible flame so it would require being seeded with another gas for safety (Maxwell & Jones, 1995). In addition, if hydrogen were stored as a liquid it would require a tank that occupies three times the volumetric storage space of a tank holding an equivalent amount of gasoline (Maxwell & Jones, 1995).

The most promising use for hydrogen as a vehicular fuel is with the development of a hydrogen fuel cell. However, it will require a major technological breakthrough in materials science, and if past experience of technological change is any indication of future technological changes this will most likely occur after the year 2020 (Ingersoll, 1996). A remark often heard regarding hydrogen fuel is “Hydrogen is the transportation fuel of the future, and probably always will be” (Maxwell & Jones, 1995).

Reformulated gasoline was mandated by the Clean Air Act Amendments of 1990 to reduce hydrocarbons and toxic emissions of carbon monoxide and ozone in non-attainment areas. Vehicles in these non-attainment areas consume almost 25% of the nation's gasoline and reformulation will be required as follows:

- vapor pressure will be reduced to reduce volatile organic compounds (VOCs) in the exhaust
- benzene will be reduced to reduce toxic emissions
- oxygenates will be added to reduce VOCs, control toxins, and reduce No_x
- toxic emissions will be controlled by decreasing benzene and controlling aromatics by adding oxygenates (Maxwell & Jones, 1995).

This will be as great a challenge to the refining industry as the removal of lead was in the 1970s, and there is a projected increase of from $0.02 to $0.17 per gallon (Maxwell & Jones, 1995). Reformulated gasoline will be an integral part in the effort for cleaner air since other alternative fuels are not expected to totally replace gasoline in the near future.

Liquefied petroleum gas (LPG) / propane is a mixture of petroleum and natural gases that exist in a liquid state at ambient temperatures and under moderate pressure (less than 200 psi). Propane is the principal component of liquefied petroleum gas therefore it is often identified as propane (Maxwell & Jones, 1995). A majority of LPG vehicles are converted gasoline engines. Most of these vehicles are located in the southwest and western states where most of the refueling sites are located, many at truck stops. Texas produces about 34% of the nation's LPG supply and accounts for over one-third of the total LPG sales in the United States (Maxwell & Jones, 1995). The major advantages of LPG over gasoline are:

- reduction of carbon dioxide (CO_2) greenhouse gas
- reduced reactivity of the hydrocarbon (HC) emissions as they consist of 50% or more propane, which is less reactive than gasoline HC emissions
- the sealed, pressurized fuel system that could control evaporative and running loss emissions very effectively
- improved emissions at cold temperatures (Ingersoll, 1996).

LPG is heavier than air and is more likely to cause a fire as a result of an accident, unlike compressed natural gas (CNG), which dissipates rapidly into the air. However, both LPG and CNG are considered safer than gasoline when used as a vehicle fuel (Maxwell & Jones, 1995).

Natural gas burns cleaner than gasoline and the other alternative fuels as illustrated in Table 1. Natural gas reserves are relatively abundant in the United States and worldwide and the cost has historically remained lower than gasoline as illustrated in Table 2 on the following page (Maxwell & Jones, 1995). In the United States, 23 states have large natural gas deposits and there are large deposits of natural gas in Canada, Mexico, the Middle East, Indonesia, and the former Soviet Union (Natural Gas Vehicles, 1995). Using projected estimates of the amount of natural gas that will be needed to fulfill increased use for transportation there is an adequate supply in the United States for a minimum of 60 to 80 years (Ingersoll, 1996). However, historical experience of projections for the use of crude oil show that the actual supply of natural gas will stretch out considerably as recoverable resources and vehicle efficiency improve (Ingersoll, 1996).

The air/fuel mixture, known as the compression ratio, is a measure of an engine's efficiency. Diesel engines are more efficient than gasoline engines because their compression ratios are between 14/1 to as high as 25/1 compared to gasoline engines' ratios between 8/1 to 12/1 (Brain, 1998). Optimized CNG engines are more efficient than gasoline engines and approach the efficiency of diesel engines with a compression ratio as high as 15/1 (Maxwell & Jones, 1995).

Table 2

Historic Price Comparisons of Natural Gas & Gasoline (Maxwell & Jones, 1995).

The advantages of natural gas are, as mentioned earlier, it required no refining, minor processing, burned cleanly, provided more heat per unit weight than any other fossil fuel, and is cheaper than gasoline.

Discussion

Air pollution from automobiles is not only environmentally harmful to society, but also has a costly effect on the economy. Automobile air pollution costs society millions of dollars each year by externalities. Some of these externalities are increased health costs and damage to property, lakes, and plants by acid rain. Total elimination of pollution is impossible because the laws of thermodynamics state that there is no such thing as a non-polluting product. Hence, to achieve zero pollution we would have to have zero economic activity, which is not logical (Pearce & Turner, 1990). However, a socially optimum level of pollution can be achieved through government intervention, with regulations and standards, and using technology that can help reduce pollution by activities that cause pollution.

One method to help reduce harmful pollution caused by automobiles is to increase the use of natural gas as an automotive fuel. Among recent federal environmental legislation is the National Energy Security Act in 1992, which is aimed at reducing United States dependence on foreign crude oil imports and provides mandates for alternative fueled vehicles (Maxwell & Jones, 1995). This act requires government and private fleet operators to phase in alternative fuels over time. Only three alternative vehicular fuels have the potential to reduce emissions to levels mandated by recent federal standards: natural gas, electricity, and hydrogen (Ingersoll, 1996). As noted earlier, the technologies for use of electricity and hydrogen are not sufficient for current replacement of gasoline and diesel fuels, but natural gas technology is. Technology is linked closely to economics and natural gas is not only technologically useable, but is less expensive than gasoline, as noted in Table 2. In fact, natural gas is already replacing gasoline in government and private fleets.

The alternative fuel strategy for Clark County, Nevada has a program framework for the transition of county fleet vehicles to operate on CNG in the Las Vegas Valley, a non-attainment area (Clark County Alternative Fuel Strategy, 1993). The report says natural gas was chosen as the best alternative fuel because:

- lowest price of any alternative fuel
- infrastructure network established and in the ground
- best availability of any alternative fuel
- proven conversion technology
- emerging private sector markets
- offers the lowest carbon monoxide emissions (Clark County Alternative Fuel Strategy, 1993).

Natural gas is the alternative fuel that can help improve air quality and not impinge economic activity dramatically. If it is phased in by government and private fleets, eventually the infrastructure for refueling will become more accessible to the general public as well.

Conclusion

Natural gas is the best alternative automobile fuel currently available to replace gasoline and diesel fuel. Current world natural gas reserves are estimated to be able to meet increased demand, the price is less than gasoline, and the improvement of air quality will help to meet current required standards. The United States should lead the way in promoting incentives for the conversion of gasoline and diesel powered engines to natural gas and for the development of new vehicles to be dedicated natural gas vehicles. Promoting this domestically and encouraging developing nations to follow suit will help in creating cleaner air quality and a healthier environment until technological advances are developed for even cleaner fuels, such as solar, electric, and hydrogen.

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