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ALCOHOL FUELS—THE QUESTION OF THEIR INTRODUCTION: A COMPARISON WITH CONVENTIONAL VEHICULAR FUELS AND HYDROGEN

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Abstract—Alcohol fuels are gaining increased attention. A move to alcohol fuels would reduce vehicular emissions of hydrocarbon and greenhouse gases and could lessen the dependence on the fossil energy sources. Yet, it also threatens the quality of life. A brief account of the pros and cons of alcohol fuels is given and a critical comparison is made with alternative sources of energy, in particular that of hydrogen. A number of factors account for the rapid emergence of hydrogen as a high priority fuel, gaining new prominence.

1. INTRODUCTION

The search for petroleum alternatives is not new. Ever since the turn of the century, when petroleum became the dominant transportation fuel, authoritative sources have warned on and off of an impending oil shortage. Not until recently have a few countries managed to replace substantial quantities of petroleum with other alternative transportation fuels. For instance, *Canada* and *South Africa* have built large production plants to produce gasoline and diesel fuel from tar sands and coal; *Brazil* has taken up ethanol for most of its gasoline; while *New Zealand* has replaced almost half of it, with natural gas-based fuels. Besides these four countries however, the transportation sector worldwide remains still totally dependent on petroleum fuels. These fuels, however, as automobile emissions, namely *carbon oxides (carbon monoxide and carbon dioxide), nitrogen oxides (nitrous oxide, nitric oxide and nitrogen dioxide), hydrocarbons (volatile organic compounds), sulphur oxides (sulphur dioxide and sulphur trioxide)*, etc., contaminate water, land and global atmosphere. They are a threat to the quality of life, as they contribute to the global warming as greenhouse gases (Table 1) and poison the biosphere as acid rain caused by air pollution. Authoritative scientific assessment predicts the earth's average temperature will increase about 0.3°C by the year 2100 and over the same period, the mean sea will rise about 30–100 cm. The virtual absence of non-petroleum fuels in the transportation sector suggests that the barriers to alternative energy are greater here than in other sectors.

Table 1. The contribution of greenhouse gases towards global warming*

Pollutants	Amount (%)
Carbon dioxide	55
Methane	15
Chlorofluorocarbons	24
Nitrous oxide	6

*Adapted from P. S. Zurer, Economic considerations enter fray over global climate change policies. *Chem. Engng News* (1 April 1990).

2. CONCEPTS FOR REVIEW

Much has been written of late on the alternative automotive fuels to gasoline. The major emphasis is being placed on the economics and combustion characteristics rather than the end products and their effect on air quality and public health. Global warming is caused by increasing atmospheric concentrations of carbon dioxide and other greenhouse gases, many of which are emitted by the production and use (combustion) of conventional fuels (Table 2). The major gases of concern are carbon dioxide, methane, chlorofluorocarbons and nitrous oxide. It is unlikely that carbon dioxide emissions could be reduced, to a reliable extent, commercially by adding control systems to vehicles. The most feasible strategy for reducing carbon dioxide emissions from transportation is therefore by less consumption of fossil fuels, namely coal, oil and natural gas or using non-fossil clean energy sources, such as

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Table 2. Comparison of air pollutant emissions from energy conversion processes with controls*

Product	Feedstock	Particulates	Sulphur oxides	Hydrocarbons	Nitrogen oxides	Carbon monoxide	Carbon dioxide
		(grams/million Btu output†)					
Syncrude	Oil shale, bituminous coal	10–35	3–60	0.3–15	4–210	3–16	50,000–55,000
Ethanol	Corn, crop residues	45–370	37–1500	5–140	100–830	10–170	—
Methanol	Subbituminous and lignite coal, coal, wood	0–30	0–200	100–500	10–276	13.7	65,000–125,000
Synthetic natural gas	Bituminous and lignite coal	5.7–11	28–108	no limit†	63–82	no limit†	no limit†
Petroleum	Crude oil	2–25	10–40	10–20	7–12	2–360	§
Electricity	Various coals	2–20	8–400	very low	32–43	2–500	—

*Adapted from D. Sperling and M. A. DeLuchi, Transportation energy futures. *A. Rev. Energy* **14**, 375 (1989).
†1 Btu ≈ 1054 J.
‡"no limit" means no emission limits were established.
§Petroleum produces only half the amount of carbon dioxide as that of coal and oil shale based fuels.

hydrogen or electricity, as they can directly be obtained from hydro or solar power.

We have had enough oil spills, gas leaks and of late the painful calamity of fires in oil wells. There is no doubt that these polluting, risky energies are continuing to grow rapidly. The consequences of all these panic events represent a major threat and, of course, give us the chance to solve our real problems of survival on this planet. Improvement measures for conventional, polluting energies should be seriously looked at, with a plan for remedial action on:

- how improvements can be made to reduce their detrimental environment effects within the shortest possible time;
- how to improve existing conventional polluting (fossil fuels) and clean (hydro, tidal, wave, wind and geothermal power) energy systems to reduce environmental effects and risks;
- how to break effectively the current trend of exponen- on a world scale;
- how to apply clean energy in traffic;
- how to break effectively the current trend of exponential pollution growth in order to prevent climate collapse and environmental suicide.

While a climate agreement will be very difficult to attain, the international scientific community appears to be rapidly moving towards the goal. This will be a joint challenge, which necessitates the cooperation of all conventional and advanced energy representatives.

3. CONVENTIONAL FUELS

The quest for cleaner automotive fuel has become particularly urgent. Until about the mid-1980s the preferred fossil fuel alternatives were the so-called petroleum-like liquids or synthetic fuels (syn-fuels) made from coal and oil shale that imitated gasoline and diesel fuels. Since synthetic gasolines are costly and offer no environmental advantages, they emit more air pollution than any other alternatives, their emergence is unlikely in the foreseeable future and hence they are no longer considered seriously. In addition to the environmental issues, they have other series shortcomings, such as the non-renewability of the resources, pollution related health hazards and the uneven distribution of the resources around the world. The other alternative fossil resources and fuels include compressed natural gas, liquefied natural gas, synthetic natural gas and biomass fuels. However, on the practical side, they too have drawbacks. For example:

- compressed natural gas must be kept under a pressure and so requires a set of heavy tanks—a serious liability in terms of vehicle performance and fuel efficiency;
- liquefied natural gas faces fundamental limits on supply;
- synthetic natural gas impacts on the environment are much more severe;
- biomass is limited on supply, costly and dirty to produce, increases soil erosion and adds much to the air and water pollution. Moreover, they are incompatible

with current vehicle operation and fuels distribution systems.

Currently, a large number of compressed natural gas vehicles are operating in Canada, Italy, New Zealand and Soviet Union. The use of compressed or liquefied natural gas would lead to small reductions in emissions of greenhouse gases from the fuel production and use cycle compared with gasoline and diesel fuel. However, if coal were used as the feedstock instead of natural gas itself, emissions of greenhouse gases would increase considerably.

4. ALCOHOL FUELS

The pressing fossil fuel related problems of urban air pollution, regional acid precipitation and global warming have focussed the attention towards the oxygenates (ethanol – grain alcohol and methanol – wood alcohol) which are current emerging as a short/medium-term energy option. Regardless of the reasons, the alcohols are interesting because they are capable of being used as engine fuels. They can be produced from a variety of feedstocks—for example, natural gas, garbage, wood and even sludge for methanol, grain/corn and sugar-cane for ethanol. The more complete combustion and higher octane rating of alcohols – compared with gasoline—offer more horse power and a relatively cleaner atmosphere. They also require just a minimal change in the existing network for distributing motor fuel. The present interest in alcohols, as fuels, result from a hope that they may reduce the undesirable exhaust emissions and due to their complete burning prevent the influence on the ozone formation. Alcohol fuels have low vapor pressure (half that of gasoline) indicating that it evaporates at a much slower rate. The low water tolerance of alcohol – gasoline blends necessitates the use of anhydrous alcohols, making them more expensive than gasoline. Great care must be exercised to avoid water contamination when alcohol blends are used.

If alcohols for transportation is such an excellent idea, why isn't the transition occurring? Alcohol as a motor fuel is a controversial issue. Considerable heated and partisan discussions are still taking place about the usefulness of alcohol as motor fuel. The 'anti-alcohol' group brings out unfavorable features such as phase separation, necessity for blending agents, starting troubles, vapor lock tendency, overheating, increased cylinder wear, in addition to their environmental, ecological and human health problems. The 'pro-alcohol' group generally stress on the high octane rating, safe storage and good thermal efficiency. There are reports which will likely show that methanol may become a serious contender as motor fuel and that a number of other alcohols and ethers will also enter the picture. At the same time, there are hints that alcohols may not prove to be the panacea for cleaner vehicles and cleaner urban air that is hoped for.

4.1. *Food versus fuel*

Already, in Brazil, a single-minded dependence on sugar-cane as a feed stock for the nation's rapidly expanding ethanol industry, has diverted the prime agricultural lands and the sparse economic resources to the production of energy crops, rather than stable food crops. Critics of the Brazilian alcohol fuels program sharply question the wisdom of such a policy, at a time of growing hunger among the nation's poor, who can scarcely afford the luxury of owning an automobile, much less of buying a liter of ethanol fuel. The initial reliance of the ethanol industry on its primary feedstock has sparked similar concern that a 'food versus fuel' conflict might eventually occur.

4.2. *Accidental intake*

A hydrocarbon fuel spill separates on top, and the resulting contaminated water tastes so bad that the consumer knows something is amiss but in the case of the low-odor and colorless alcohols, it passes away unnoticed producing great danger to human life. Of course a petrol spill is silent too.

4.3. *Alcohol abuse*

Despite precautions, the long, sad history of alcohol abuse leads on inevitably to conclude that some unfortunate soul—no matter how clearly these are labelled as toxic—will try to drink them instead of drive with them. The painful results of such experimentation should succeed in deterring all but the most desperate of alcoholics from a second drink.

4.4. *Reluctance of acceptance*

Industrialists are not willing for the transition of gasolines to alcohols as the technology and production becomes costlier and cumbersome. Nevertheless, the oil and auto industries are talking about making reformulated gasolines to compete with methanol. No specifics have been revealed as yet, and many observers are skeptical that refiners can change traditional gasoline without running up the cost.

5. THE CASE FOR METHANOL

Not long ago, in an era of high oil prices, methanol was envisaged as a potential alternative motor fuel, but practical problems of distribution and storage as well as a need for engine alterations, albeit minor ones, dimmed the prospects. Around 1984 or so, when conventional wisdom shifted to methanol, it become one of the suggested contenders for use, as either neat or in blends. Methanol is not the only possible alternative fuel to gasoline but at the moment it appears to be a promising substitute—at least to some of the developed countries. Ethanol is also used as a gasoline supplement, but is currently about twice as expensive as methanol, whose low cost is one of its most attractive features. If oxygenates achieve recognition as vehicle fuels, the biggest contributor will probably be methanol, production of which is mostly from synthetic gas derived from methane. Several studies have shown that methanol, because of its low atmospheric chemical reactivity, could be effective in reducing the formation of photochemical

smog and ozone. Methanol has fewer benefits compared to its major drawbacks, some of which are listed below:

- it burns with a colorless flame;
- imbibed, it can cause blindness or even death;
- when burnt it produces formaldehyde, a potential human cancer causing agent;
- in addition to being a carcinogen and powerful irritant for hypersensitive people, formaldehyde forms ozone at a rapid rate—five times faster than gasoline;
- it is also highly corrosive, which means that fuel tanks have to be made of stainless steel, or something equivalent rather than the conventional aluminium-based tanks;
- on an equivalent basis, it is more *toxic* to humans than gasoline;
- unlike oil-derived gasoline, methanol penetrates the skin and is metabolized quickly;
- methanol is soluble in water, and the tank spills could penetrate deeply into the water table (oil-based fuels tend to float);
- per unit volume of methanol produces about 40% less energy than the same amount of gasoline;
- pure methanol cars do not start well in cold weather.

6. QUESTIONS FOR DISCUSSION

Few aspects of climate change are well suited for strong policy actions, but the consensus is that there are probably no acceptable near-term solutions to climate change. The following additional questions are posed on the use of methanol:

- Have we given enough attention to the fact that methanol is a violent poison through either skin absorption, inhalation or ingestion? Death from ingestion of less than 30 ml has been reported; lesser quantities can cause permanent blindness—both horrible fates.
- Before we get moving down this road too far, have we given full thought of the consequences of unleashing this lethal compound for wide-scale use at the consumer level?
- Our existing methanol industry has shown that the product can be manufactured, stored, transported and used in a safe and exemplary manner. But this, by and large, is under the trained professional supervision of scientists and engineers. And what happens on a day-to-day basis in the local unsupervised arena in case of leak?
- We build elaborate and redundant safeguards into our processes that the best scientific minds can devise. Yet look at us. Accidents do happen, much to our chagrin and sorrow.
- From my observations, most of what is reported today on alternative fuels dwells on economics, combustion values, systems corrosion, resulting emissions, etc. Are we focussing enough on public health, ecology and human error in the event of misuse, a spill or a leak from an underground storage tank?
- What are the consequences of methanol getting into our upland lakes and rivers and aquifers feeding our potable water supply? Here's a water-white, low-odour fully miscible liquid, so it will be very difficult for the average citizen to detect before it is too late.
- If methanol were to rely heavily on wood as a feedstock, it could put heavy pressure on forests and other stands of vegetation and could create conflicts in land use.

7. CLEAN ENERGY OPTIONS

The key to dealing effectively with our 'energy problem' is the identification of and transition to an alternative transportation fuel which can be produced from domestic resources. Here comes the most difficult part. What would be the best alternative energy source? So many questions and factors must be considered in any forecast.

- How, when and where should we initiate a transition to alternative transportation fuel?
- Which fuel should we choose and how fast should we introduce it?
- Will economic forces motivate a shift back to natural gas?
- Will environmental forces compel an even more drastic shift, to hydrogen or electric vehicles?

For all these queries there is no obvious answer and no consensus. The fundamental importance of energy has often been analysed. Motor fuels are of particular significance not only because transportation is important to our life style and our overall economy but also for the essential purposes. A noteworthy point is that, of the major users of fuels, it is only the transportation sector that is not flexible. Coal, natural gas, or nuclear energy cannot substitute petroleum as motor fuel.

While synthetic fuels would damage the environment more than gasoline and diesel fuels, hydrogen and electricity would be virtually pollution-free. As an illustration of the facts, look at Table 3. Notice that hydrogen and electricity vehicles hardly emit any pollutant. They are linked here because both are part of a potentially sustainable and very clean energy path and both could use the same clean sources of energy. Battery-powered electric vehicles can use electricity made with solar energy, and hydrogen-powered vehicles could use the same to split water to make hydrogen. Electric vehicles, of course, emit no pollutants at all—except for those emitted by the electric power plants that recharge the vehicles' batteries. By the end of this century, electric vehicles may also be making a dent in urban transportation. Electric vehicles, however, are now limited by battery technology as these batteries are heavy and need to be recharged frequently—a time-consuming process too. In this context, fuel hydrogen has emerged as an increasingly attractive option to meet the challenge of our energy needs, and environmental and ecological prospects.

7.1. *Hydrogen*

The prospect of a clean, widely available transportation fuel has motivated much of the research on hydrogen fuels.

Table 3. Percentage reduction in emissions from alternative-fuel vehicles, relative to alcohol and gasoline vehicles*,†

Fuel	Hydrocarbons	Carbon monoxide	Sulphur oxides	Nitrous oxide	Ozone
Methanol‡	−50	−40	−100	0	−50
CNG/LNG‖	−60	−95	−100¶	+25	−60
Electricity**	−100	−100	−100	−100	−100
Hydrogen**	−95††	−99††	−100	−60††	−95††

*Adapted from D. Sperling and M. A. DeLuchi, Transportation energy futures. *A. Rev. Energy* **14**, 375 (1989).

†These are rough estimates only—assuming advanced technology, single-fuel cars, and engine operation with excess air.

‡Ethanol-powered vehicles will have similar emissions.

§However, recent findings strongly argue that alcohol vehicles would emit more nitrogen oxides than gasoline vehicles.

‖CNG—compressed natural gas; LNG—liquefied natural gas.

¶Assumes that natural gas do not contain sulphur, which may not always be true.

**From non-fossil sources.

††Due to the combustion of lubricating oil.

‡‡Significant reduction could be achieved by improved combustion characteristics.

It is an exceptionally clean-burning fuel—cleaner than today's fossil fuels and such proposed fossil fuel-based synfuels as methanol made from coal or natural gas (see Tables 2 and 3). No carbon dioxide is emitted in the production or use of fuel. Indeed, photovoltaic hydrogen is one of the few long-term energy supply options that could meet world's energy needs without contributing to the greenhouse effect. Hydrogen is the most attractive transportation fuel in two ways:

- It is the least polluting fuel (Table 3), the main combustion product being water, and it can be used in an internal combustion engine without much difficulty.
- It is potentially available wherever there is water and a clean source of power.

Hydrogen vehicles would not produce significant amounts of greenhouse gases. That is, it emits no carbon monoxide, reactive organic gases, or particulates (the troublesome urban air pollutants), no sulfur dioxide (a precursor of acid rain), and no carbon dioxide (the principal greenhouse gas). In fact, the only pollutant of concern would be nitrogen oxides, which are formed, as in all internal combustion engines, from nitrogen taken from the air during combustion. This can be controlled to very low levels. The prospect of hydrogen fuel produced with solar energy is exciting. Produced via electrolysis from photovoltaic electricity using thin-film silicon solar cells, the hydrogen would not be resource-constrained, because it is based on the exploitation of renewable resources (water and sunlight) and on abundant materials (silicon from ordinary sand in the case of amorphous silicon thin-film cells). Implementation of hydrogen now as an an alternative fuel would considerably extend the world's oil supply, which is far more valuable as a potential chemical source than as an energy source, and will become increasingly so. While hydrogen fuel is not a near-term option, with strong research and development effort, better technological progress, and continuing reductions in the cost of solar electricity, the hydrogen vehicles would be cost-competitive on a social cost basis (taking into consideration air pollution, energy security, global warming, etc.) within a few decades.

8. CONCLUSION

In summary, the delayed introduction of new fuels and the resulting dependence on petroleum could be costly in the medium term and untenable in the long term. It would be a mistake for the transportation industry to go on the same route, in switching alternatives, once again to oil. It should also be recognized that the fuels such as methanol and compressed natural gas are not problem free long-term solutions, though they may give false optimism as preferred fuels at the present time. However, the long-term and possibly permanent transportation fuels would probably be a mix of electricity and hydrogen. They provide the potential for a superior, substantial and sustainable future. Already few countries have initiated a move with the objective of introducing solar hydrogen as an energy vector and increasing clean, renewable energy production in order to curb pollution. Let us also march into future with this hope in our minds. If we make a mistake on the alternative fuels question and its socio/scientific/health considerations, it could be the end of true scientific inquiry as we know it. Does the scientific and industrial community really need another *Exxon Valdez* or *Bhopal tragedy?* Please let us take due pause and make doubly sure all factors are imputed into the equation before we come down on the solution.

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