

Methanol: A Versatile Fuel for Immediate Use

Methanol can be made from gas, coal, or wood.
It is stored and used in existing equipment.

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In the short period of a decade we have developed a healthy concern about our pollution of the environment and an awareness that we will soon face a shortage of convenient forms of energy. Hydrogen has been suggested (1, 2) as a universal, nonpolluting fuel, since it can be produced from water and burns cleanly to water. Although we may some day see a "hydrogen economy," we have yet to find ways of making hydrogen cheaply, of storing and transporting it, of adapting it to the automobile, and of using it safely.

In several recent, comprehensive studies of potential fuels, hydrogen has been compared with other synthetic fuels such as methanol, ethanol, hydrazine, and methane (3-5). In these studies methanol has been described as being superior to hydrogen in many ways, and as providing an especially attractive alternative fuel to gasoline. In this article we discuss the advantages of using methanol as a fuel and suggest ways in which it could be introduced immediately into our fuel economy.

Methanol, CH_3OH , can be thought of as two molecules of hydrogen gas made liquid by one molecule of carbon monoxide. It thus shares many of the virtues of pure hydrogen. Last year in the United States, 3.2×10^9 kilograms (10^9 gallons or 1 percent of present gasoline production) of methanol were manufactured and sold at an average price of \$0.06 per kilogram (\$0.183

per gallon) (6). It can be made from almost any other fuel—from natural gas, petroleum, coal, oil shale, wood, farm and municipal wastes—so that a methanol economy would be flexible and could draw from many energy sources as conditions change. Methanol is easily stored in conventional fuel tanks and can be shipped in tank cars, tank trucks, and tankers; it can be transported in oil and chemical pipelines. Of most importance is the fact that up to 15 percent of methanol can be added to commercial gasoline in cars now in use without it being necessary to modify the engines. This methanol-gasoline mixture results in improved economy, lower exhaust temperature, lower emissions, and improved performance, compared to the use of gasoline alone. Methanol can also be burned cleanly for most of our other fuel needs, and it is especially suited for use in fuel cells for generating electricity. The sources, distribution, and uses of methanol are shown diagrammatically in Fig. 1.

Properties of Methanol and Related Fuels

Methanol, which is also called methyl alcohol, wood alcohol, or methylated spirits (7), is a colorless, odorless, water-soluble liquid. It freezes at -97.8°C , boils at 64.6°C , and has a density of 0.80. It is miscible with water

in all proportions, and spillages are rapidly dispersed. Methanol burns with a clean blue flame and is familiar to most people as the alcohol used for heating food at the table or as the alcohol in Sterno. Mixtures with between 6.7 percent and 36 percent of air are flammable. The autoignition temperature of methanol is 467°C , which is high compared with 222°C for gasoline (5). This may account for the high octane number, 106, of methanol; a typical gasoline has an octane number of 90 to 100 (8).

The energy content of a number of fuels is shown in Table 1. Hydrogen produces the most energy on a weight basis; hence its use in rockets where volume and cost are secondary considerations. Petroleum products such as gasoline have the highest energy of the fuels listed on a volume basis and are second highest on a weight basis; hence gasoline will long be preferred for airplanes where lowest weight is at a premium. However, of all the liquid fuels, methanol produces the second highest amount of energy on a volume basis.

Although methanol is not the cheapest fuel (see Table 2), its properties make it competitive with the other fuels. Ethanol, which has many of the desirable fuel properties of methanol and could be used in most of the applications discussed herein, costs, in this country, about three times more than methanol. In less industrialized countries, however, ethanol may be an attractive fuel because it can be produced from agricultural products by fermentation.

In the manufacture of methanol, the output of the plant can be increased by 50 percent if small amounts of other alcohols can be tolerated in the product (9, 10). Such a mixture is called "methyl-fuel," and it contains more energy than pure methanol because of the presence of ethanol, propanol, and isobutanol. It can be produced in larger quantities at a lower price than pure methanol, and, in general, has superior properties as a fuel. In this article, we consider methanol and methyl-fuel to be synonymous.

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Historical Uses of Alcohol for Fuel

During the last 50 years in the United States, methanol and other alcohols have not competed successfully with the abundant supplies of petroleum. Before this time, however, alcohols were used extensively as fuels. Alcohol, for example, became a popular fuel for lighting in about 1830, when it replaced malodorous fish and whale oils. In about 1880, kerosene replaced alcohol as a lighting fuel because of its sooty flame which gave more light; a clean flame produces no light without special additives. During the middle of the last century, France was partially on a methanol fuel economy. Wood was distilled in the provinces to give alcohol, which was burned in Paris for heating, lighting, and cooking. This was more economical than transporting wood to Paris and then disposing of the ashes.

During World Wars I and II, when gasoline shortages occurred in Germany and France, vehicles of all sorts, including tanks and planes, used wood burners in the rear or in trailers. Wood chips were distilled to make alcohol vapors that included carbon monoxide and hydrogen; these vapors would (barely) drive the vehicle. In 1938, 9000 wood-burning cars were used in Europe. "Power alcohol" (ethanol) was also used by France and Germany to supplement gasoline supplies and stimulate alcohol production for anticipated use in munitions production (11).

In about 1920, manufacturers in the United States began to produce metha-

Table 1. The energy content of some fuels, shown on the basis of weight and volume.

Fuel	Formula	Heat of combustion (low)*	
		Kjoule/ g	Kjoule/ cm ³
<i>Liquids</i>			
Hydrogen	H ₂	124.7†	8.7
Methanol	CH ₃ OH	20.1	15.9
Gasoline	C ₈ H ₁₈	44.3	30.9
<i>Solids</i>			
Hydrides	VH ₃ ‡	4.7	28.4
Coal	C _{.28} H _{.42}	32.2	41.8
Wood	C _{.32} H _{.46} O _{.22}	17.5	14.2
<i>Gases</i>			
Hydrogen	H ₂	124.7	0.0010
Methane	CH ₄	61.1	0.0044

* Combustion to CO₂ and H₂O (gas). † Conversion factors are: 0.948 kjoule = 1 Btu; 2.10 kjoule/g = 10³ Btu/lb; 0.27 kjoule/cm³ = 10³ Btu/gallon; 33.4 × 10³ kjoule/cm³ = 10⁶ Btu/ft³.
‡ Vanadium hydride is given as an example.

nol for use as a solvent, for plastic manufacture, and for fuel injection in piston aircraft. In 1972, 3.2 × 10⁹ kg (10⁹ gallons) of methanol were produced (6, 7), equal to about 1 percent of the amount of gasoline produced.

Methanol in the Internal Combustion Engine

It has been claimed that hydrogen is an ideal fuel for the internal combustion engine (12). It certainly causes little pollution, but is difficult to store, high in price, and difficult to burn efficiently in the engine without it knocking and backfiring (13). These problems arise because of the very wide flamma-

bility limits and the very high flame velocity of hydrogen. Perhaps an engine can be invented which takes advantage of these unusual properties.

Methanol used as an additive or substitute for gasoline could immediately help to solve both energy and pollution problems. We will first discuss its use in place of gasoline and then present new results to show that 5 to 15 percent of methanol added to gasoline could produce disproportionate improvements in the fuel economy, pollution levels, and performance of cars now in use.

A number of studies (14, 15) of methanol and ethanol have been conducted in the last 50 years to test their suitability as substitutes for gasoline in the internal combustion engine. Existing engines can be converted to use pure methanol by decreasing the ratio of air to fuel consumed from about 14 for gasoline to 6 for methanol, by recycling more heat from the exhaust to the carburetor, and by providing for cold starts. The conversion is estimated to cost about \$100 per vehicle (16). A municipal vehicle converted in this way has been operating satisfactorily in Santa Clara, California, for the past year. Compared with gasoline, the use of methanol in a standard test engine (without catalytic treatment of exhausts) yielded one-twentieth of the amount of unburned fuel, one-tenth of the amount of carbon dioxide, and about the same amount of oxides of nitrogen NO_x as gasoline (3, 17). Table 3 shows that a 1972 Gremlin fueled with methanol almost met the 1976 federal standards for emissions and had five times lower emissions than a similar car operated with gasoline (3, 4, 18). In these studies the reduced emissions were attributed to methanol being able to burn without misfire at an air-to-fuel ratio 25 percent higher than gasoline; exhaust temperatures with methanol were 100°C cooler; more spark retard was possible with methanol because of its higher flame speed (18). It was suggested that greater performance and economy could be expected in an engine designed specifically for methanol, and that such design should encompass higher compression ratios and a fuel injection system. In another study, on a one-cylinder research engine, it was found that 10 to 20 percent leaner mixtures could be tolerated with methanol than with gasoline. The amounts of unburned hydrocarbons, CO, and NO_x produced were lower with methanol than with gasoline,

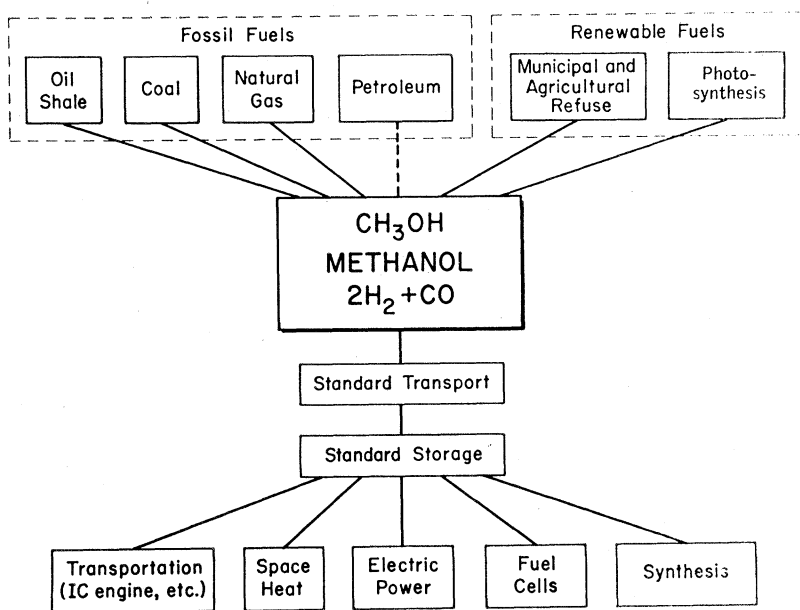


Fig. 1. Sources, transport, and possible applications of methanol.

while the amounts of aldehydes produced were higher (19).

From these results it seems clear that if gasoline becomes scarce or too expensive, we can design cars that will operate on pure methanol and cause less pollution. Specific fuel consumption will certainly be higher on a weight or volume basis (see Table 1), necessitating a larger fuel tank; but specific energy consumption (energy per kilometer) will certainly be lower because higher compression ratios and simpler pollution controls can be used.

The principal drawback to the immediate use of pure methanol as a gasoline substitute is that not enough is available. We have recently tested the possibility of adding 5 to 30 percent of methanol to gasoline (20). A number of unmodified private cars (year models 1966 to 1972) were tested and operated over a fixed course with varying concentrations of methanol. It was found that (i) fuel economy increased by 5 to 13 percent; (ii) CO emissions decreased by 14 to 72 percent; (iii) exhaust temperatures decreased by 1 to 9 percent; and (iv) acceleration increased up to 7 percent. The results obtained on a 1969 Toyota (1900 cm³ engine, 85 brake horsepower, 8:1 compression ratio) are shown in Fig. 2. This car has now been driven about 8000 kilometers fueled alternately with gasoline and with mixtures of gasoline and 10 to 30 percent methanol. There have been no mechanical problems. A most striking feature observed with two unmodified cars was the elimination of knock and "Diesel operation" (continued operation after the ignition is

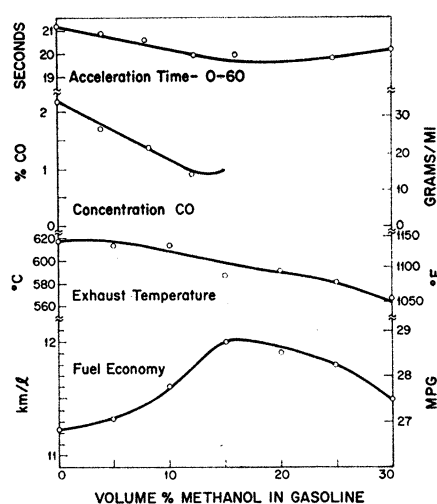


Fig. 2. Performance of a 1969 Toyota Corona with methanol-gasoline mixtures. MPG, miles per gallon.

turned off) when gasoline containing 5 percent methanol was used.

An octane rating of 106 for pure methanol hardly seems sufficient to explain these improvements. The methanol is said to have a "blending octane value" (BOV) of 130 (9, 10) defined by

$$\text{BOV} = [O_b - O_g(1 - x)]/x$$

where O_b and O_g are the octane numbers of the blend and the gasoline (8), and x is the volume fraction of methanol in the gasoline. From this, 10 percent of methanol added to gasoline with an octane rating of 90 would be expected to yield a fuel with an octane rating of 94, equivalent to the addition of 0.13 gram of tetraethyl lead per liter of gasoline (9). Ethanol has a BOV of 110 to 160, depending on the octane of the gasoline (15).

To account for the disproportionate effects of methanol on the octane value and other properties of gasoline, we propose the following mechanism (20). When methanol is synthesized from CO and 2H₂ at 50 to 300 atmospheres and 200°C, -90.8 kilojoules of heat must be removed (see Eq. 1). In the compression stroke of the internal combustion engine, methanol can dissociate at very low temperatures and reabsorb this energy, cooling the charge and quenching premature combustion. For example, at 10 atmospheres methanol is 18, 85, and 99.7 percent dissociated at 100°, 200°, and 300°C, respectively [calculated from data in (7)]. The CO and H₂ formed on dissociation increase the flame velocity of the charge, giving more complete and efficient combustion.

Other Aspects of Methanol Utilization

Although methanol is suggested here principally as a fuel for automobiles, it could also be used advantageously in most other fuel applications if it becomes sufficiently plentiful. It is a safe, clean fuel for home heating and can also be burned in power plants to generate electricity without polluting the atmosphere. In a recent set of pilot-plant and full-scale power boiler demonstrations, methyl-fuel was tested against No. 5 fuel oil and natural gas (9). In the tests with methyl-fuel it was observed that (i) no particulates were released from the stack; (ii) the amount of NO_x in flue gases was less than the amount emitted from natural gas and much less than that emitted from the oil; (iii) the CO concentration was less than that from oil and gas; (iv) no sulfur compounds were emitted; (v) the amounts of aldehydes, acids, and unburned hydrocarbons produced were negligible; and (vi) soot deposits in the furnace from previous oil firing were burned off with methyl-fuel, thereby allowing higher heat-transfer rates and higher efficiency.

Methanol is one of the few known fuels suited to power generation by fuel cells (21). In principle, the fuel cell can convert chemical energy to electricity with much higher efficiencies than heat engines such as turbines. Although methanol is not as simple to use in a fuel cell as hydrogen, it can be stored and shipped more easily. Recently a fuel cell has been developed that gives more than 30,000 hours of continuous operation on methanol and air. It uses tungsten carbide and charcoal as electrodes and sulfuric acid as electrolyte (22).

The costs of storage and shipment of methanol and other fuels are shown in Table 4. The storage of methanol mixed with gasoline may present cer-

Table 2. Production cost of the energy contained in some fuels. The costs are for large plant capacities, assuming that 15 percent of the plant cost is spent annually on profit, interest, depreciation, and maintenance [data from (3, p. 12)].

Fuel	Source	Cost (\$/10 ⁶ kJoule)
Gasoline	Crude oil*	1.00
Methanol	Natural gas†	1.49
	Coal‡	1.40
	Lignite§	1.18
Methane gas	Wellhead	0.14-0.37
	LNG imported	0.76-0.95
	Coal	0.76-0.95
Hydrogen gas	Natural gas	0.92
	Coal	1.25
Liquid hydrogen		2.37

* Gasoline produced at \$0.118 per gallon. † Natural gas at \$0.040 per 10³ ft³. ‡ Coal at \$7 per ton or \$0.25 per 10⁶ kJoule. § Lignite at \$2 per ton or \$0.14 per 10⁶ kJoule. || LNG, liquefied natural gas.

Table 3. Emissions from a 1972 Gremlin (i) that uses gasoline and (ii) that was modified for use with methanol fuel and equipped with a catalytic converter (18). Projected (as of 1973) federal standards (for 1975 to 1976) are included for comparison.

Fuel	Emissions (g/mile)		
	Unburned hydrocarbons	CO	NO _x
Gasoline	2.20	32.5	3.2
Methanol	0.32	3.9	0.35
Federal standards	0.41	3.4	0.40

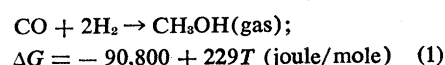
tain problems because of the solubility of methanol and water in gasoline. Only about 0.01 percent of water is soluble in pure gasoline, and therefore excess water from condensation sometimes accumulates in storage tanks and causes corrosion. Gasoline containing 10 percent methanol will dissolve ten times as much water and so can keep the tanks dry; in fact proprietary gas-tank drying agents generally contain methanol. However, water in larger quantities will remove almost ten times its own weight from gasoline containing 10 percent methanol, so that unless a storage tank is first dried out, problems may arise when a mixture of gasoline and methanol is first put in it (15).

Although methanol is miscible with gasoline at room temperature, less than 10 percent is soluble in some gasolines at 0°C. However, the volatile constituents added to gasoline in cold weather to aid ignition increase this solubility. Also, the higher alcohols in methyl-fuel increase the solubility of methanol. For instance, 2.4 percent of isobutanol in one gasoline increased the solubility of methanol from 3 to 10 percent at 0°C (15).

Methanol, although not highly toxic, can be lethal if ingested. It would therefore be prudent to avoid the names methyl alcohol and wood alcohol in any labeling of methanol containers. Methanol vapors are also poisonous, but no more so than those of many other common substances. For example, the maximum allowable exposure to methanol vapor is 200 parts per million (ppm), while the value for ethyl alcohol is 1000 ppm; for benzene, 10 to 25 ppm; octane, 400 ppm (octane and benzene are typical constituents of gasoline); trichloroethylene, 100 ppm; and carbon tetrachloride, 10 ppm (23).

Methanol Manufacture

Methanol can be made from many sources, as shown in Fig. 1. Until about 1925 it was made (along with acetic acid and tars) by the destructive distillation of wood. Since that time, most methanol has been synthesized from CO and H₂ (7) according to Eq. 1:



where ΔG is the free energy change and T is the temperature.

In the original high-pressure process, pressures of 300 atmospheres at 200°C

Table 4. Costs of storage and transportation of methanol, gasoline, and liquid and gaseous hydrogen (3).

Fuel	Cost (\$/10 ⁶ kjoule)	
	Storage	Transport over 100 km
Methanol	3-21	0.027
Gasoline	2-15	0.018
Liquid hydrogen	300-1000	1.55
Gaseous hydrogen	350	0.035

were used in the presence of a zinc-chromium oxide catalyst, and yields of over 60 percent were obtained. In 1968 the Imperial Chemical Industries (ICI) developed a low-pressure process using 50 atmospheres at 250°C and a highly selective, copper-based catalyst. This process produces much purer methanol. A number of processes in which intermediate pressures are used have since been developed (6, 9).

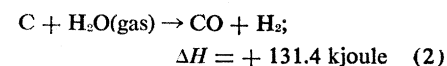
The CO and H₂ (synthesis gas) for manufacturing methanol can be obtained by partial oxidation of any carbonaceous fuel with oxygen or water. At present it is obtained almost exclusively from methane by partial oxidation with water. This source of methanol will not long be useful in this country, because there is not now enough natural gas available for our domestic heating needs. However, in the Near East the energy value of the methane flared off at the oil wells would be sufficient to supply much of our energy needs. Plans are now under way to construct methanol plants so that this gas can be converted to methanol at the wellhead and shipped in conventional tankers to this country (24).

In a recent study (25) it was estimated that methanol could be produced on the Persian Gulf and landed on the East Coast of the United States at a cost of \$1 per 10⁶ kjoule (\$0.061 per gallon; \$1.05 per 10⁶ British thermal units). The construction of refrigerated tankers for methane is also being considered. Liquefied gas in refrigerated tankers would cost \$1.46 per 10⁶ kjoule. These estimates, which include the cost of construction of new plants or refrigerated tankers, would vary according to the distance of transportation.

Methane gas is also produced biologically by the decomposition of natural wastes, such as pig and chicken manure and sewage. It has been claimed that such methane can be used for powering automobiles, where it has an operational cost equivalent to a cost of \$0.03 per gallon for gasoline (26).

It is also claimed that enough fuel could be made from this source to meet all present fuel needs in the United States, and that the use of such a process would reduce by half the problem of sewage and animal-waste disposal (27). In experiments with cars and trucks converted to use methane, the U.S. General Services Administration has reported clean, reliable operation (28). However, the type of cylinder required to contain compressed gaseous methane severely limits the amount of fuel that can be carried; a six-cylinder sedan has a range of 80 km (50 miles), each cylinder measuring 6.7 m³ and weighing 100 kg (29). Conversion of the organic wastes to methanol rather than methane would make this fuel source much more practical.

For the next few decades, coal is the most attractive candidate for methanol production. Coal has long been used for the production of synthesis gas, according to the endothermic reaction (with ΔH being the heat change):



Although synthesis gas contains CO, which is poisonous, it is used for industrial power and for heating homes in many European cities without further conversion. It represents a clean, gasified coal (30). Much work is in progress to develop methods to obtain methane and hydrogen from coal for use as pipeline gas. The same technology can be applied to the manufacture of methanol from synthesis gas. It is estimated that the cost of making methanol from coal would be \$1.40 per 10⁶ kjoule (\$0.085 per gallon) for a plant making 20,000 metric tons per day (3). If lignite is used as the starting material instead of coal, the resulting ash may contain 0.40 percent uranium, equivalent to commercial uranium ore, as well as other valuable minerals such as molybdenum, vanadium, arsenic, germanium, selenium, cobalt, and zirconium (3). Efforts are being made to develop practical methods of gasifying coal in the ground, eliminating the need for strip mining and consequent landscape destruction.

Some day we will run out of fossil fuels. By coupling the manufacture of methanol with the disposal of wastes, we could supplement our fuel supply and thereby prolong the existence of fossil fuels, and simultaneously clean up the landscape. A recent patent (31)

describes an "oxygen refuse converter that can dispose of our refuse and at the same time generate useful energy. In a shaft furnace shown in Fig. 3, unseparated trash or sewage sludge is fed into a hopper at the top. Low-cost oxygen (0.2 kg of O_2 per kilogram of refuse) is fed into this furnace near the bottom, creating a 1500°C zone that melts the metals and glasses found in refuse. These melts, drawn off as slag and metal, have 2 percent of the original refuse volume, while all other products are gaseous or water soluble. Carbon, burning in the high-temperature zone, produces CO, which rises through the furnace. The hot CO creates an intermediate-temperature zone where carbohydrates and plastics are broken down to a gas containing, typically, 47 percent CO, 28 percent H_2 , 17 percent CO_2 , and 5 percent CH_4 by volume. Finally, in the uppermost section the incoming refuse is dried as the gas mixture cools to about 100°C .

This gas mixture stores 8.0 kJoule per gram of refuse ($7 \times 10^6 \text{ Btu}$ per ton), or 76 percent of the original refuse energy. Because oxygen rather than air is used in burning, the output gas is high in heat content, low in volume, and relatively easy to scrub to remove fly ash and chlorine.

The United States produces about $1.8 \times 10^{11} \text{ kg}$ of solid refuse each year. The energy in the gas from this refuse is $1.4 \times 10^{15} \text{ kJoule}$, or 2 percent of the $7.4 \times 10^{16} \text{ kJoule}$ ($7.0 \times 10^{16} \text{ Btu}$) consumed each year (32). If this gas were converted to methanol, it could supply about 8 percent of the fuel for our transportation needs. Although initially developed for refuse, converters of this type could also be used to convert farm waste and the waste from lumbering into more useful forms of energy such as methanol.

Forests, which are one means of capturing solar energy, formed the principal energy source for this country until about 1875. Commercial forests now cover about 23 percent of the land area of the United States, or $2.1 \times 10^{12} \text{ m}^2$. These forests intercept from the sun about $5.8 \times 10^6 \text{ kJoule/m}^2$ per year, or a total of $1.2 \times 10^{19} \text{ kJoule}$ per year (33). If the conversion of solar energy with an efficiency approaching 1 percent could be achieved by improved forest management (34), the annual energy harvest might be $1.2 \times 10^{17} \text{ kJoule}$ per year, more than our present energy needs of $7.4 \times 10^{16} \text{ kJoule}$ per year. The advantage of utiliz-

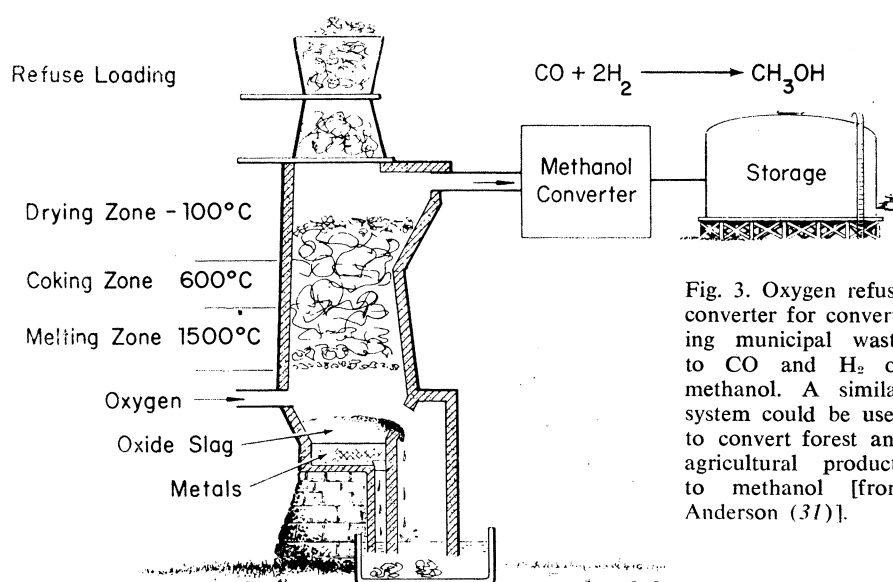


Fig. 3. Oxygen refuse converter for converting municipal waste to CO and H_2 or methanol. A similar system could be used to convert forest and agricultural products to methanol [from Anderson (31)].

ing forests for the production of methanol is that whole trees can be used, not merely those fractions that make good lumber or pulp. It has been calculated that between 5 and 20 percent of our commercial forests operated as "energy plantations," could supply all of our electrical power (35).

Recommendations

The management of energy resources is the management of the lifeblood of our economy, and whatever future energy sources evolve should be those that best blend environmental and technical solutions with economic reality. Therefore we look forward in the next few years to vigorous, public, and possibly polemic debate on the virtues of various fuels.

Recently it has been recommended that "the various energy planning agencies should now begin to outline the mode of implementing hydrogen energy delivery systems in the energy economy" (2). On the contrary, we see methanol as a more benign solution to our fuel problems. The use of methanol would produce the least dislocation of our economy and industry, and would solve environmental as well as energy problems. Since it is compatible with gasoline and existing automobiles, it can be introduced gradually as a fuel as production increases. We will not then have to scrap refineries, automotive facilities, or our cars.

The course of these debates should be influenced by the results of research on all of the various fuels that might

be used to supply our energy needs. We suggest that there are three main areas for research into the large-scale production of methanol. First, since a plant must operate under different and less exacting constraints in producing methyl-fuel than in producing the present industrial grade of alcohol, the existing methods of methanol production should be reexamined and optimized for the production of methyl-fuel. Second, while methanol is now being produced primarily from natural gas, likely to be augmented by production from coal (31), other processes should be developed for utilizing all major sources of carbonaceous materials for methanol synthesis. Third, methanol is now produced primarily by partially oxidizing other fuels to CO and H_2 and by rebuilding these to methanol with some loss of the potential energy value of the original fuel. We should look for methods of direct conversion that do not entail this energy loss.

Finally, we recommend that the various energy planning and regulatory agencies for fuels should strongly consider altering existing regulations to accommodate the introduction of new fuels. For instance, the blending of methanol with gasoline could be encouraged by considering it an environmentally beneficial additive, rather than as a fuel to be taxed. This would certainly make methanol-blend gasolines cheaper than gasoline and encourage production all over the world. We think also that it would be in the national interest to reexamine the tariff now imposed on imported methanol if it is to be used for fuel.

Summary

We believe that methanol is the most versatile synthetic fuel available and its use could stretch or eventually substitute for, the disappearing reserves of low-cost petroleum resources. Methanol could be used now as a means for marketing economically the natural gas that is otherwise going to waste in remote locations. If methanol were used as an additive to gasoline at a rate of 5 to 15 percent, for use in internal combustion engines, there would be an immediate reduction in atmospheric pollution, there would be less need for lead in fuel, and automobile performance would be improved.

With increasing production of fuel-grade methanol from coal and other sources, we foresee the increasing use of methanol for electrical power plants, for heating, and for other fuel applications. We hope that a practical methanol fuel cell will be commercially available by the time that methanol becomes plentiful for fuel purposes.

Methanol offers a particularly attractive form of solar-energy conservation, since agricultural and forest waste products can be used as the starting material. Indeed, at 1 percent conversion efficiency the forest lands could supply the entire present energy requirements of the United States.

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