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ALCOHOL FROM AGRICULTURAL SOURCES AS A POTENTIAL MOTOR FUEL[1]

By G. E. Hilbert
Chief, Bureau of Agricultural and Industrial Chemistry
Agricultural Research Administration
United States Department of Agriculture

During the past 10 years there has been a striking change in our agricultural and petroleum economies. In the 1930's we were faced with large surpluses of agricultural commodities. These surpluses hanging over the market depressed prices to the point where frequently it was scarcely profitable for the farmer to grow his crops. The only large-scale outlet for huge surpluses of starchy crops then known was their conversion to alcohol for use as motor fuel. This was advocated not only by farm organizations but also by experts in the fields of economics and technology. But at the same time the petroleum industry was beset by overproduction of oil and gasoline, large fields of petroleum having been discovered. The petroleum refining industry vigorously opposed the recommendation of the agricultural groups concerning the desirability of conversion of starchy crops to synthetic liquid fuels, because of the debatable economic aspects then existing. As you may remember, the ensuing national debate frequently was tinged with overstatement. However, one significant objection of petroleum producers was on the proposed legal aspects of *enforced* use of relatively expensive alcohol in blended fuels, when gasoline was much cheaper.

During World War II, surpluses of both grains and petroleum products were erased so effectively that acute shortages developed. Now, because of recent bountiful harvests and the great development in mechanized farming, we soon may be faced again with undesirable surpluses of cereals. Likewise, we are not at present suffering from shortages of petroleum products. It is difficult, however, to forecast when, if ever, serious surpluses of petroleum products again will be with us, since consumption of such products has increased greatly in the past decade.

About 10 years ago, the consumption of crude petroleum in the United States was 1.3 billion barrels annually, or 3 million barrels a day. Our national capacity to produce petroleum, however, was at the rate of 4 million barrels a day. At present, the consumption of petroleum is more than 2 billion barrels annually, which represents an increase of more than 50 percent in 10 years. Crude petroleum consumption is now somewhat more than 5 million barrels a day, about equivalent to current production. During the past year, for the first time in the history of this country, we imported more petroleum than we exported, but this seemingly reflects current refining capacity, primarily.

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[1] Based on a speech delivered at the Farm Supply and Service Conference, 1949 annual meeting of the National Council of Farmer Cooperatives, Memphis, Tenn., January 4, 1949.

Consumption of petroleum products in all probability will continue to increase. The Bureau of Mines recently predicted an increase in consumption of petroleum products of 1.5 to 2 million barrels a day during the next 5 years. This would mean a total consumption of 6.5 to 7 million barrels a day, eventually.

This tremendous increase is due to the gearing of our industrial, farm, and pleasure machines to liquid fuels. Several factors are responsible for the increased demand for petroleum products: increased mechanization on the farm, greater use of fuel oil for heating homes; expanding "Dieselization" of our railroads and industry; greater use of gasoline in automobiles, trucks, busses, and airplanes; and the widening use of petroleum products in the chemical industry. Another factor of considerable importance is the vast quantity of fuel oil and gasoline now used by our military establishment, a quantity much larger than before the war. The demand for petroleum products is due to the greater facility with which liquid fuels can be used, in contrast to solid fuels. It is conceivable that this increase in the use of liquid fuels will be stopped only by the limitations of our capacity to produce them.

The quantity of petroleum used in this country is difficult to visualize or comprehend. One fact which illustrates the dramatic role which oil can play in our economy may be cited. Of the total weight of men and materials—including food supplies, weapons, and equipment—shipped abroad during World War II, more than 70 percent was accounted for by petroleum.

How can the increased demand for petroleum be met? There are four possibilities:

1. *Discovery of new oil deposits.*—This possibility may have only limited promise. In recent years discovery rates have been insufficient for replacement of withdrawals.

2. *Importation of petroleum.*—This involves transportation and political problems. For example: Oil fields owned by American capital in Rumania and Mexico have been expropriated. At present, Venezuela retains one barrel of oil for every two barrels produced by American companies. In Arabia oil fields being worked by American companies possibly could not be operated if we were engaged in another World War. However, on a peace time basis, these foreign supplies may be adequate to meet the domestic situation.

3. *Coal and oil shale.*—It is technically feasible to produce petroleum from mineral sources at reasonable costs, but such costs will be higher than the costs of petroleum at the present time. The use of coal as a raw material for the production of petroleum undoubtedly would create social, labor, and construction-material problems. The cost of plants to produce just one-fifth of our requirement for liquid fuels from coal would amount to many billion dollars. To produce sufficient coal for this purpose would entail an increase in our present production of about 50 percent. Considering the difficulty we have experienced in maintaining our current production of coal during the past several years, the job we would face in this direction is tremendous. Similarly, production of liquid fuels from oil shale involves creating a vast industry. A likely source of fuels can be visualized in the Fischer-Tropsch reaction of synthesis from carbon monoxide and hydrogen, derivable from natural gas or other sources. One plant of this type is now under construction. However, again there is the probability that costs will be very great.

4. *Agricultural sources*.—Agriculture can help to meet our national liquid fuel requirements. Agricultural crops are annually replaceable. In contrast, petroleum, natural gas, coal, and oil shale are irreplaceable. They are natural resources in the form of captured sunlight laid down over millions of years, but they may be consumed by our civilization in less than a thousand years. Although in crop production we are mining our soil, to a certain extent at least, by far the major portion of the minerals extracted by vegetation eventually is returned to the soil, except the small fraction lost by erosion or abandoned in non-arable areas. This represents a loss in soil fertility, it is true, and over the years this cumulative loss becomes sizable and real and can only partly be offset by intelligent farming practices. In producing farm crops we are using up a natural resource just as we are in the mining of petroleum, iron, and copper—but with this important difference—the rate of loss of minerals in the soil is comparatively very small, and restoration is comparatively easy.

Only two types of crops offer significant possibilities for the production of liquid fuels. One is the starchy crops, particularly grains, the other is cellulosic agricultural residues such as bagasse, corncobs, hulls, flax shives, and so forth. It is well known that grain or starchy root crops can be converted easily to ethyl alcohol, which is an excellent liquid fuel. The quantity of grain that would be required to meet our national requirements for liquid fuels is such a high figure that it is presently impossible of attainment. If gasoline were replaced, gallon for gallon, with ethyl alcohol, more than 12 to 16 billion bushels of corn annually, or equivalent quantities of other grains, would be required for its production. Compare this theoretical figure of 12 to 16 billion bushels with the 3 billion bushels of corn or the approximate 5 billion bushels of all grains which we have been producing annually during the past several years. It is obvious that grains can play a relatively minor role in supplementing our liquid fuel requirements. Nevertheless, this role may be an important one in balancing our economy.

The Bureau of Agricultural and Industrial Chemistry is convinced that the production of motor fuels offers the only presently known large-scale industrial outlet for surplus grains. The fact that more than 12 billion bushels of grain would be needed to satisfy our gasoline requirements of today clearly shows the ease with which any quantity of surplus grain that might be produced in the future could be consumed as motor fuel.

Let us now consider the cost of producing ethyl alcohol from grain. Under present procedures, the manufacturing cost from dollar corn is in the range of 40 to 50 cents a gallon. From 75-cent corn, the cost is about 35 to 40 cents a gallon. Costs will vary among plants, depending on operational efficiency and byproduct recovery, and some additional sales expense must be added to these figures. I have used the example of dollar corn, regardless of corn's present price, because if a corn surplus appears the price might well fall to that figure or even less.

In contrast to the possible price of 40 to 50 cents a gallon for alcohol made from dollar corn, gasoline right now sells for around 25 to 30 cents a gallon. About one-third of this price, however, is in the form of direct taxes and certain distribution expenses. For alcohol to sell at the same price as gasoline, corn would have to be priced at very low levels, (probably under 50 cents per bushel) which is certainly at an uneconomic level for the farmer. If alcohol is to compete with gasoline, therefore, it must possess some outstanding fuel characteristic which will make it sell at a premium price, or else its cost of production must be lowered drastically.

The development of methods for lowering the cost of producing alcohol from grain is a major objective of this Bureau's Northern Regional Research Laboratory, located in Peoria, Illinois. We have been working on such methods for several years. A decrease in the cost of alcohol production might be effected in three possible ways: first, by lowering the cost of processing; second, by increasing the yield of alcohol; and third, by raising the value of fermentation byproducts, for example, by refermentation to increase their nutritive value as stock feed, or by using them for the production of vitamins or other biologically valuable compounds.

We have made considerable progress on lowering the cost of processing. During the past few years, we have developed a submerged culture method of producing a particular type of mold which can be used as a complete replacement for malt. Replacement of malt by this mold can lower the cost of producing alcohol several cents per gallon. Other methods of decreasing the cost of production are also being investigated, and they show promise.

The Northern Regional Laboratory has given a great deal of attention to the fuel characteristics of alcohol in an effort to determine whether alcohol has any outstanding properties as a motor fuel, and to evaluate the economic position of alcohol in any method of use as fuel. My discussion of this work will be divided into two parts: first, research on alcohol-gasoline blends, and second, the automatic injection of alcohol-water mixtures into engines, at or near full load.

As a motor fuel, alcohol surpasses isooctane on the Research motor octane scale with a rating of 100 + 1.4 milliliters of tetraethyl lead per gallon. In other words, alcohol is equivalent to isooctane containing 1.4 milliliters of tetraethyl lead. The so-called Motor Method octane number of gasoline is 92; however, it is the Research number which gives closer correlation between the "rating" of the engine on the road and that in the laboratory, particularly for higher compression engines. One very important fact must be kept in mind—on the basis of percentage of potential power output, the higher octane numbers are much more valuable than the ones in the lower range. In general, no engine, of course, yields more power with use of a gasoline with an octane rating higher than is necessary to obtain knock-free operation. Addition of alcohol simply makes a premium grade or high-octane motor fuel out of lower octane gasoline. For illustration, a certain type of regular 74-octane gasoline plus 25 percent of ethanol will have a Motor rating of 86 and a Research rating of 97, much higher than the octane rating of any present premium grade.

Moreover, a blend of regular gasoline and alcohol in the ratio of 9:1--that is, a 10 percent alcohol blend--gives excellent performance in an engine. It is equal to a good grade, premium gasoline. The use of such blends requires no change in engine design or adjustment. Many of the technological criticisms previously leveled against alcohol as a motor fuel cannot be supported and in any case can be avoided by employing proper procedures.

During the past 20 years Sweden has used a 25 percent blend very successfully. The use of alcohol-gasoline blends in automobiles in that country has thus provided a large-scale practical demonstration of the feasibility of using this type of fuel. With reasonable precautions no separation because of water absorption is encountered and performance is considered equal to or better than that of gasoline. Many other countries have utilized alcohol blends.

The benefit obtained in ordinary blending of alcohol with gasoline in present day engines is not great enough, however, for alcohol to command a premium price over gasoline. To be competitive when used in a blend, alcohol would have to sell at essentially the same price as gasoline. Under such circumstances the production of alcohol from grains would have to be subsidized, unless the petroleum industry voluntarily decided to use alcohol and pass the cost along to the consumer.

A much more promising method of using alcohol as a fuel is by injection into the engine manifold. Actually, the term "injection" is a misnomer. The process might be designated more properly as supplementary carburation. This was an important development for military aircraft operations during the War. Alcohol injection was valuable for giving planes an extra burst of speed, for example, in approaching or getting away from an enemy fighter plane. Use of an alcohol-water mixture also enables aircraft engines to produce the extra power required for take-off, without injury to the engine.

Since the war, attention has been devoted to the application of alcohol injection to motor-driven vehicles. In this case, however, it is not to increase power but to improve octane rating. Investigations on alcohol-water injection have been conducted for several years at the Northern Laboratory, and we are rather impressed by its potentialities. With alcohol injection, an engine supplied with a low-octane gasoline (with even an octane number as low as 55) will perform as satisfactorily as when fed a good grade, regular gasoline. Although alcohol, used either as a blend or by injection, improves markedly the anti-knock rating of low-octane gasoline, there is one important difference in the two methods. Alcohol in a gasoline blend is, of course, fed continuously to the engine, even when the car is traveling on level ground at an even speed, although high-octane (regular or premium) fuel is not necessary under these conditions. On the other hand, an alcohol-water mixture is automatically injected *only* when it is needed—that is, during rapid acceleration, in starting, passing, or climbing a hill. Under ordinary driving conditions, a relatively low-octane gasoline usually suffices for knock-free driving. In a sense, the use of alcohol by injection increases the octane rating of gasoline by about 20 units. Road tests conducted at the Northern Regional Research Laboratory show that the amount of fuel used for efficient operation of an automobile is in the ratio of about 95 parts low-octane gasoline to 5 parts alcohol. These road tests were conducted over hilly and flat country and involved some city driving. Stated another way, only 1 gallon of alcohol-water mixture is used for every 50 to 65 gallons of gasoline consumed.

The equipment needed to inject alcohol into an automobile or truck engine is relatively simple. It is essentially an accessory carburetor, located near the ordinary carburetor immediately above the engine and connected with a small alcohol tank under the hood of the car. The capacity of the alcohol tank is about 1 gallon. It is necessary to fill the alcohol tank only about every 750 miles of driving, depending somewhat on the make of car and kind of operation.

The alcohol injection device used at the Northern Laboratory was invented by Laboratory engineers and a patent on it has been filed. This device is still undergoing development and improvement. Other devices now privately manufactured (such as one called the Vita-Meter) also permit efficient injection of alcohol into the engine. The estimated cost of a commercial alcohol injection device, the gallon alcohol tank, and other accessories now is about $30. However, with mass production, this cost probably can be reduced. It takes only a few hours to attach this equipment to an automobile or truck. Wider use should also bring about reduction in the cost of the mixture.

A factor of major significance in connection with alcohol injection and use of lower octane gasolines in motor-driven vehicles is that relatively more low-octane than high-octane gasoline can be produced from a given quantity of petroleum. Quality gasoline can be obtained only at the sacrifice of quantity. It is generally estimated that there is a loss in yield of 1 percent when the octane number is increased by one unit, in refining gasoline. For example, loss of perhaps 20 percent in yield may be sustained when gasoline having an octane number of 58 is refined to high-test gasoline with an octane number of 78. However, this loss becomes more notable in the production of aircraft grade high-test (± 130 octane number) gasoline. Different refineries have a varying experience in this respect. Present trends toward the cracking of high-boiling fuel oils, for which there is a diminishing market, complicates the situation.

Injection of alcohol-water mixtures offers a means of reducing the general use of high-octane gasoline under conditions where it is not needed. This is important because one aspect of the problem in the conservation of our petroleum resources is their most efficient utilization.

One other factor favoring the use of alcohol injection is the apparent trend in the automotive industry to build high-compression engines. Several automobile manufacturers have already announced their intention of producing high-compression engines within the next two years. These engines will permit greater fuel economy in motor vehicles and give higher mileage per gallon of gasoline. However, they will require super-octane gasoline for knock-free operation. There is some doubt as to the ability of petroleum refiners to furnish sufficient quantities of super-octane gasoline for this purpose. Alcohol-water injection, used in conjunction with present-day gasoline, is one of the several ways of meeting this need for super-octane gasoline.

Although alcohol injection is very promising, much research and development work needs to be done on it. By extensive road tests we expect to find whether there are any special lubrication problems in operating an automobile using alcohol injection, and we should also learn whether the wear on the engine is greater than normal. The purpose of our road tests is to study the application of alcohol injection under all types of practical operating conditions and, if possible, to determine the premium that alcohol could command over gasoline through increased efficiency in motor operation.

To determine the price at which alcohol would be competitive with gasoline under these conditions will not be easy. Factors favoring the efficient use of low-octane gasoline in combination with alcohol injection are possible greater yield of fuel from petroleum and savings in the cost of gasoline production, and lower expenditures for investment in new and expensive refining equipment. The total effect of these various factors will be difficult to evaluate from a cost standpoint, but through cooperation with the petroleum industry it should be possible. At this early stage, a reasonable guess is that ethyl alcohol for injection purposes may be able to command a relative price as high as 40 or possibly even 50 cents per gallon. Such a value would permit the production of alcohol from surplus grains at higher price levels and, of course, would provide a solution to the perplexing grain surplus problem.

To summarize, agriculture can be expected to play only a relatively small role in meeting our future requirements for liquid fuels. It is evident that through conversion to ethyl alcohol any grain surplus that might develop in the future could easily be absorbed in the market for motor fuels. This market is so tremendous that a surplus might disappear, figuratively speaking, practically overnight. I am not prepared to evaluate the possibility of accomplishing this without Government subsidization, but I am hopeful that this can be accomplished. Alcohol from dollar corn may well be competitive with gasoline at some future time, if the alcohol is used by direct injection in automobiles, busses, and trucks. Factors favoring the application of this development are the declining rate of discovery of petroleum deposits, the increasing demand for petroleum products, the rising price of gasoline, and the trend in the automotive industry to higher compression engines. It can be said, therefore, that conversion of surplus grains to alcohol, although of minor significance in satisfying our over-all needs for liquid fuels, can nevertheless be of great importance both in stabilizing our agricultural and national economy and in utilizing our natural resources to best advantage.

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