The Gasohol Handbook

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Preface

During the past several years, I have been associated with the national movement to develop, demonstrate, and document the real potential of alcohol fuels for transportation applications.

My association with the Solar Energy Research Institute, Department of Energy, National Alcohol Fuel Commission, and Department of Agriculture has encouraged me to produce in a comprehensive volume the technical, economic, production, environmental, and utilization information for gasohol.

In recent years, fermentation ethanol produced from agricultural feedstocks, in particular grains such as corn, has been demonstrated to be one of our most promising near-term options for producing synthetic fuels. For all practical purposes, gasohol, which is a blend of 10 percent anhydrous agricultural-derived fermentation ethanol and 90 percent unleaded gasoline, is an opportunity to reduce our dependence on foreign oil in the near-term.

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Fairfax Station, Virginia

Acknowledgments

The information in *The Gasohol Handbook* has been obtained from a wide variety of authorities who are specialists in their respective fields.

I wish to thank Mr. Paul Notari and his staff at the Solar Energy Research Institute for the provision of data, reports, photographs, and illustrations, which are used extensively in this volume.

Also, I thank the contributors whose cooperation in providing source material was indispensable in preparing this handbook. In particular, those consultants and individuals who participated in the preparation of *Fuel from Farms—A Guide to Small Scale Ethanol Production, A Guide to Commercial Scale Ethanol Production and Financing,* and *Small-Scale Fuel Alcohol Production,* all of which this book is based upon.

We acknowledge the significant contributions to this effort by Dr. Harlan Watson, Subcommittee on Energy, Nuclear Proliferation and Federal Services; Mr. Steven J. Winston, Energy Incorporated; Mr. Milton David, Development Planning and Research Associates; Mr. Samuel Eakin, Energy Research Group; Dr. Jean-Francois Henry, TRW Energy Engineering; Mrs. Ann Heywood, RPA Inc.; Mr. Don Fink, U.S. Department of Agriculture; Mr. Ted D. Tarr, Vulcan Cincinnati; and Dr. Raphael Katzen, Raphael Katzen Associates International Inc.

A book of this magnitude is dependent upon excellent staff, and I have been fortunate. Judith A. Anderson has effectively served as coordinator and technical editor of this effort. Mr. B.A. "Dusty" Rhodes and Allen Higgs and their staff at Guild, Inc. have done an excellent job in preparing the graphics. Special thanks are extended to Anne Potter for the composition and typing of the manuscript.

Credits for the photographs and illustrations are indicated where appropriate throughout this book. The Department of Energy and the Solar Energy Research Institute are credited with public domain illustrations from *Fuel from Farms—A Guide to Small Scale Ethanol Production* and *A Guide to Commercial Scale Ethanol Production and Financing.* We thank the U.S. Department of Agriculture for the preparation of *Small-Scale Fuel Alcohol Production* which we have utilized where possible.

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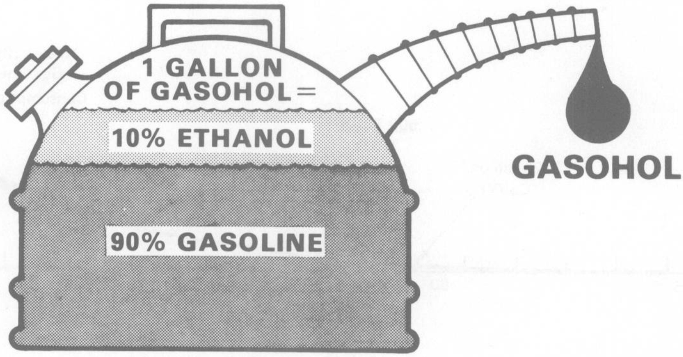
Chapter 1

Introduction to Gasohol

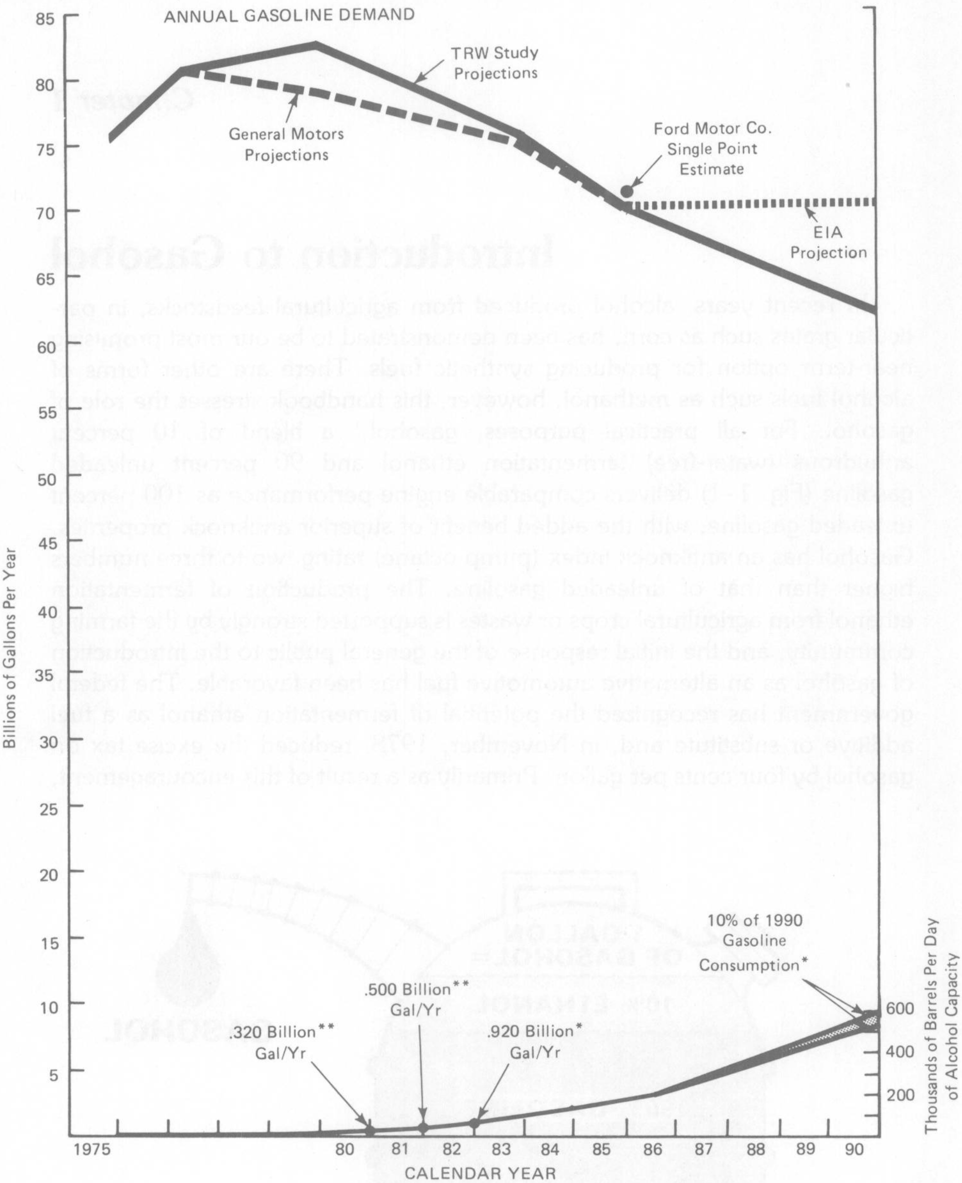
In recent years, alcohol produced from agricultural feedstocks, in particular grains such as corn, has been demonstrated to be our most promising near-term option for producing synthetic fuels. There are other forms of alcohol fuels such as methanol; however, this handbook stresses the role of gasohol. For all practical purposes, gasohol,[1] a blend of 10 percent anhydrous (water-free) fermentation ethanol and 90 percent unleaded gasoline (Fig. 1-1) delivers comparable engine performance as 100 percent unleaded gasoline, with the added benefit of superior antiknock properties. Gasohol has an antiknock index (pump octane) rating two to three numbers higher than that of unleaded gasoline. The production of fermentation ethanol from agricultural crops or wastes is supported strongly by the farming community, and the initial response of the general public to the introduction of gasohol as an alternative automotive fuel has been favorable. The federal government has recognized the potential of fermentation ethanol as a fuel additive or substitute and, in November, 1978, reduced the excise tax on gasohol by four cents per gallon. Primarily as a result of this encouragement,



Courtesy NAFI

Figure 1-1. Gasohol is a mixture of gasoline and ethanol.

[1]The name "gasohol" is a trademark of the Nebraska Agricultural Products Industrial Utilization Committee (APIUC).



*Public Law 96-294 Goals
**President's Goals from Jan '80 Address

Courtesy NAFI

Figure 1-2. U.S. goals for alcohol-fuel production from biomass.

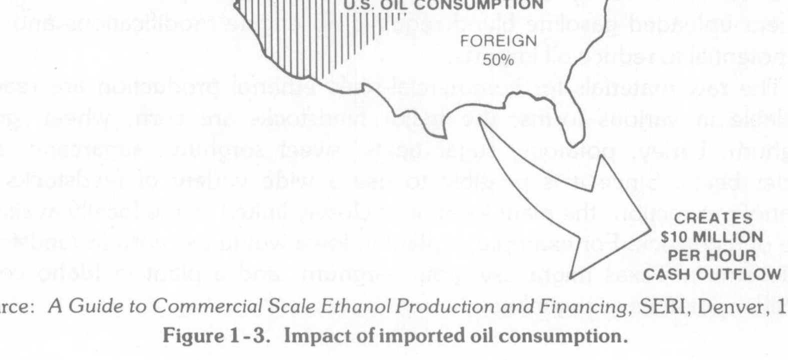
fermentation ethanol capacity increased from a few million gallons to about 80 million gallons annually by the end of 1979.

Goals for increased production of fermentation ethanol for blending with gasoline were established by President Carter; legislation that encourages the production of fermentation ethanol for fuel use has been adopted. Figure 1-2 shows the projected contribution of gasohol to the automotive gasoline market and indicates the magnitude of the President's objectives for ethanol-fuel production. Meeting the 1982 goal will increase the potential fermentation ethanol-fuel market about 10 times over the end of 1979s production.

Perspective

United States dependence on imported oil is illustrated in Fig. 1-3. The United States can no longer afford such a degree of dependence on oil reserves outside its control to meet its energy needs. Such dependence is hazardous to the U.S. economy and security. Therefore, during the past several years, there has been increased emphasis on domestic alternatives and pressure to develop synthetic fuels such as fermentation ethanol from biomass resources.

Statistics show a drop in crude oil imports over the past four years, perhaps implying that the United States is responding to the President's calls to conserve energy. However, increased development of U.S. reserves (particularly in Alaska), increases in the price of gasoline, and public response to gasohol play a role in bringing about this decrease.



Source: *A Guide to Commercial Scale Ethanol Production and Financing*, SERI, Denver, 1980.

Figure 1-3. Impact of imported oil consumption.

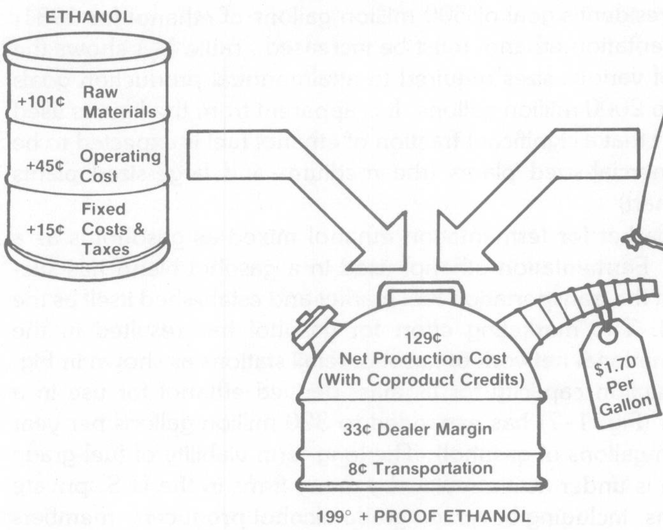
Although little gasohol was marketed in the mid-1970s, by the end of 1979 about 80 million gallons of fermentation ethanol, which could be blended with unleaded gasoline, were produced and sold across the United States.

In the current political and economic climates, fermentation ethanol used as gasohol has become increasingly attractive. The Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) have supported increased production of fermentation ethanol in small-scale facilities. DOE has also expanded its role by encouraging fermentation ethanol production in commercial-scale facilities. Small-scale is currently defined as under 15 million gallons of fermentation ethanol per year; this category includes the farmer producing 10 to 25 gallons per day strictly for his or her own use. Commercial-scale plants may range in size from 15 million to 100 million gallons annually. Figure 1-4 shows a breakdown of average fermentation ethanol production costs for the larger scale plants.

In recent years, the increase in gasoline price and the desire for energy independence have made alcohol attractive as a transportation fuel, even though this is not a new idea. Henry Ford was an early supporter of using "home-grown" fuels, and his Model-T could be adjusted to burn pure alcohol or gasoline. During World War II, many countries relied on alcohol as a fuel source. Since 1975, Brazil has had a huge program in operation to produce a national change from the use of petroleum to the use of alcohol fuels. Brazil is now using 20 percent alcohol blends on a regular basis, and large fleets of government- or industry-owned cars run on 100 percent alcohol. Figure 1-5 shows the trends in ethanol production in Brazil. It is apparent that, since the announcement of the Brazilian National Alcohol Program in November, 1975, the total production of ethanol, as well as anhydrous ethanol for blending, has increased dramatically. This experience shows that a dedicated effort to reduce oil imports by developing national renewable resources can produce significant results in a short period of time.

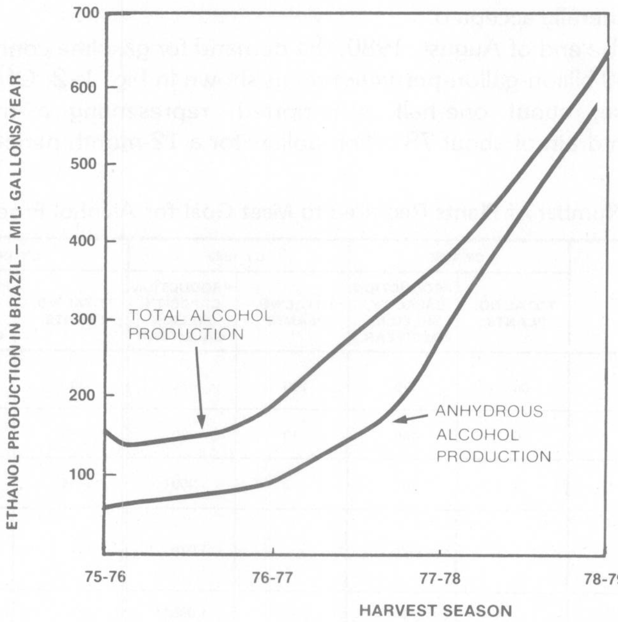
If the need arises, the United States could develop an intensive ethanol program similar to Brazil's program. A significant reduction in gasoline use could be achieved by changing to gasohol. The 10 percent alcohol/90 percent unleaded gasoline blend requires no engine modifications and has the potential to reduce oil imports.

The raw materials for commercial-scale ethanol production are readily available in various forms; the major feedstocks are corn, wheat, grain sorghum, barley, potatoes, sugar beets, sweet sorghum, sugarcane, and fodder beets. Since it is possible to use a wide variety of feedstocks for ethanol production, the plant location is closely linked to the locally available type of feedstock. For example, a plant in Iowa would use corn as feedstock, while one in Texas might use grain sorghum, and a plant in Idaho could consider potatoes or sugar beets.



Source: U.S. DOE 1st Annual Report to Congress (Revised).

Figure 1-4. Breakout of production costs for fermentation ethanol.



Source: *A Guide to Commercial Scale Ethanol Production and Financing*, SERI, Denver, 1980.

Figure 1-5. Ethanol production in Brazil.

To meet the President's goal of 500 million gallons of ethanol for 1981, production of fermentation ethanol must be increased. Table 1-1 shows the number of plants of various sizes required to attain annual production goals ranging from 200 to 2000 million gallons. It is apparent from the figures used to develop the chart that a significant fraction of ethanol fuel is expected to be produced in commercial-sized plants (the medium- and large-sized plants mentioned in the chart).

The primary market for fermentation ethanol mixed as gasohol is as a transportation fuel. Fermentation ethanol used in a gasohol blend has successfully penetrated the transportation fuel market and established itself as the first usable synfuel. The marketing effort for gasohol has resulted in the establishment of a national network of gasohol retail stations as shown in Fig. 1-6. Annual production capacity for biomass-derived ethanol for use in a gasohol-type blend (Fig. 1-7) has expanded to 320 million gallons per year (equal to 3.2 billion gallons of gasohol). The long-term viability of fuel-grade ethanol production is under active review by many firms in the U.S. private sector. Several firms, including beverage-grade alcohol producers, members of the food processing industry, and some major oil companies such as Texaco, have made long-term commitments to fuel-grade ethanol production. The contribution of biomass-derived alcohol as a means of satisfying near-term demand for automotive fuel, and therefore reducing petroleum demand, is generally accepted.

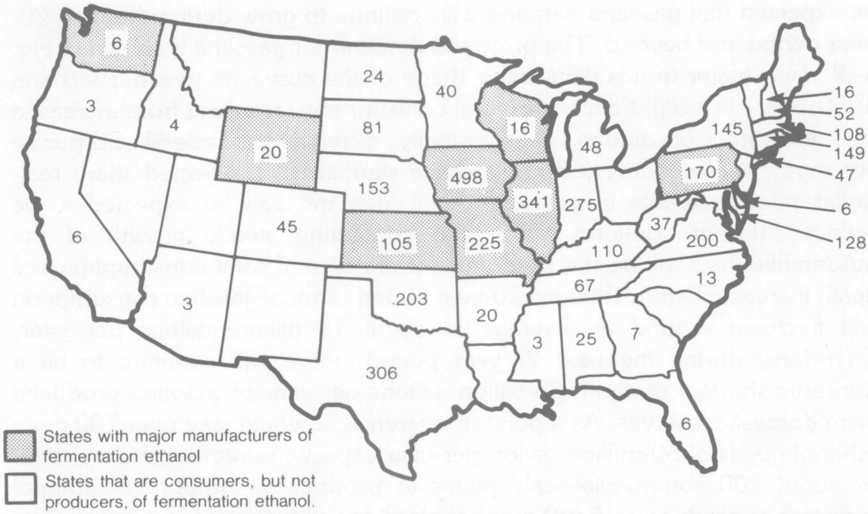
Through the end of August, 1980, the demand for gasoline continued at a staggering 80 billion-gallon-per-year rate as shown in Fig. 1-2. Of the total petroleum use, about one-half is imported, representing a minimum projected cash drain of about 78 billion dollars for a 12-month period. It can

Table 1-1. Number of Plants Required to Meet Goal for Alcohol Production

PLANT SIZE	CY 1980		CY 1982		CY 1985	
	TOTAL NO. PLANTS	PRODUCTION CAPACITY, MILLION GALS/YEAR	TOTAL NO. PLANTS	PRODUCTION CAPACITY, MILLION GALS/YEAR	TOTAL NO. PLANTS	PRODUCTION CAPACITY, MILLION GALS/YEAR
10,000 – 15 Million Gallons/Year	96	175	200	375	300	600
> 15 – 50 Million Gallons/Year	6	150	13	450	23	900
> 50 Million Gallons/Year	1	100	2	200	5	500
Cumulative Total Installed Capacity (Projected in Million Gallons Per Year)		425		1,025		2,000
National Goals Million Gallons/Year		300*		1,000**		2,000*

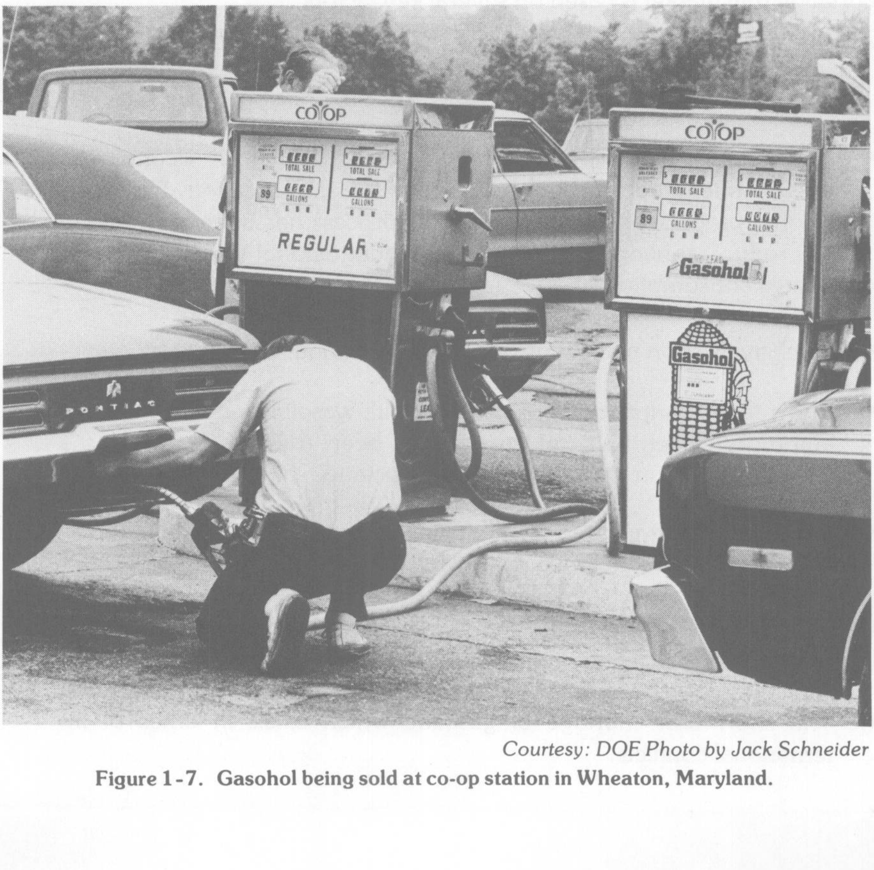
*President's Goals Announced 11 January 1980.
**P.L. 96-294.

Source: *A Guide to Commercial Scale Ethanol Production and Financing,* SERI, Denver, 1980.



Source: *A Guide to Commercial Scale Ethanol Production and Financing*, SERI, Denver, 1980.

Figure 1-6. National network of retail gasohol stations.



Courtesy: DOE Photo by Jack Schneider

Figure 1-7. Gasohol being sold at co-op station in Wheaton, Maryland.

be expected that gasoline demand will continue to grow during the next 20-year period and beyond. The projected demand for gasoline is shown in Fig. 1-2. Two major trends dictate the shape of the curve. Between 1980 and 1990, there is a slight decline in total consumption, resulting from increased fuel economy of automobiles originally dictated by Federal Corporate Average Fuel Economy (CAFE) mileage standards. If expected sharp real-dollar price increases in gasoline occur, demand can be expected to be reduced further. Beyond 1990, the continuing steady growth of the automobile fleet will be the predominant effect, and total consumption will again increase. During the next 20-year period, annual gasoline consumption will fluctuate around an average of about 70 billion gallons per year. Therefore, during the next 20-year period, there will continue to be a domestic shortfall of about 35 billion gallons per year of gasoline produced from domestic reserves. As a point of reference, it would take over 700 grain ethanol plants of 50-million-gallon-per-year capacity to replace this shortfall, or about 200 commercial-scale plants to produce an amount of ethanol sufficient to produce a 10/90 gasohol blend for all fuel sales. A very sizable, stable market exists for transportation synfuels such as gasohol.

The initial success of fermentation ethanol in penetrating the transportation fuel market is based on several key factors:

- The existence of industries related to fuel-grade ethanol (e.g., potable alcohol producers) and grain processors (e.g., corn starch producers) which have an existing business base.

- The technical feasibility of commercial-scale fuel-grade alcohol processes. Fuel-grade alcohol technology is a modification of potable alcohol processes wherein the overall process has been reoptimized to produce anhydrous ethanol with higher alcohol yields and lower energy consumption.

- A relatively short plant construction time of about 2 years.

- The ready compatibility of ethanol with gasoline and the current automobile fleet. Ethanol has already been used in the past as a blending agent for gasoline to improve octane.

- The competitive price of fermentation ethanol relative to petroleum-derived ethanol sold as a chemical feedstock.

- A combination of political support, government subsidy, and consumer acceptance and preference.

- The short-term shortage of gasoline which exists in times of international conflicts.

The History of Alcohol Fuels[2,3]

The use of alcohol in motor vehicles is not a new technology; an exhaustive international bibliography prepared on the subject has entries which date before 1920. Alcohol fuels have been used in both wartime and peacetime in our country, and are currently attracting renewed attention as petroleum prices increase and supplies remain uncertain.

Because it was clean and odorless, alcohol fuel replaced whale oil in lamps in the mid-1800s. By the end of the century, alcohol was being considered as a prime automobile fuel. The first modern internal combustion engine, the Otto cycle of 1876, ran on alcohol as well as gasoline.

Henry Ford was an early champion of alcohol fuels. He thought that the agricultural feedstocks used in alcohol production would help make farmers energy producers. In the 1880s, he designed one of his earliest automobiles—the quadri-cycle—to burn alcohol. His subsequent Model T was built with an adjustable carburetor that could easily be modified to use pure alcohol in the engine. Despite the intense price competition from gasoline, alcohol fuels were used to power American cars well into the 1920s and 1930s.

Falling farm crop prices after the 1929 stock market crash kept interest in alcohol alive because alcohol production for industry offered an alternative market for farm crops. Hiram Walker, in 1934, sold a gasoline-alcohol mixture called Alcoline. By 1938, the Atchison Agrol plant in Kansas was producing 18 million gallons of ethanol for distribution to about 2000 independent service stations in the Midwest. Dealers sold the ethanol/gasoline mixture under the trade name Agrol. The Agrol venture ultimately proved unprofitable and was abandoned at the time the United States was emerging from the Depression.

In December, 1938, the U.S. Department of Agriculture issued a noteworthy document identified as Miscellaneous Publication No. 327, titled *Motor Fuels From Farm Products*. The publication contained information on a variety of crops, including cereal grains, sugarcane, beets, tubers, and fruits. The data presented for the various materials included crop yields, fermentable starch (sugar) content (average and high), and probable commercial yields of 199-proof fermentation ethanol.[4]

Even wider use was being made of alcohol fuels in other countries. Worldwide, over 40 nations were blending alcohol (usually ethanol) into their fuel base. In Czechoslovakia, Hungary, France, Germany, Sweden, Italy,

[2]Material reproduced and edited from "A History of Alcohol Fuels" in the January 1980 issue of DOE's *The Energy Consumer*.

[3]National Alcohol Fuels Commission, *Farm and Cooperative Alcohol Plant Study*, Raphael Katzen Associates International, 1980.

[4]National Alcohol Fuels Commission, *ibid*.

Poland, Austria, Brazil, and Chile, the use of 10-25 percent alcohol blends was mandatory. Prior to World War II, more than 4 million European automobiles ran on alcohol fuels. In Australia, International Harvester proudly advertised motor trucks powered with engines especially designed to burn alcohol. Simultaneously, Chrysler was shipping to New Zealand Detroit-made cars that had a modified manifold and different carburetor jets to permit the use of pure alcohol.

The onset of World War II prompted an even greater interest in alcohol-fuel sources. Throughout much of Europe, alcohol provided a primary fuel source to power motor vehicles. Hitler converted Germany's aircraft and much of the other war machinery to alcohol fuels after his East European refineries were destroyed. In the United States, though, it was the need for synthetic rubber that brought about a surge in the domestic industrial alcohol market. With the aid of two refugee scientists, a major synthetic rubber industry was created and three new grain alcohol plants were constructed to support the effort.

Furthermore, a Government decree ordered the nation's whiskey distilleries to modify their plants to produce industrial alcohol for the war effort. Torpedoes and submarines were fueled by both grain and wood alcohol. Alcohol was also used as an additive to jet fighter fuels to prevent carburetors from icing. And in China, the U.S. Army purchased alcohol for use in its jeeps, generators, and Land Rovers. In total, during the war years, the U.S. alcohol industry managed a sixfold increase in production. By 1944, the United States was producing almost 600 million gallons of alcohol, not primarily for fuel, but rather as a solvent and as a chemical intermediate.

Federal officials quickly lost interest in alcohol-fuel production: Many of the wartime distilleries were dismantled, while others were converted back to beverage alcohol plants. By 1949, less than 10 percent of U.S. industrial alcohol was made from grain; the rest was distilled with a new and cheaper process using natural gas.

After World War II, interest in the use of agricultural crops to produce liquid fuels decreased. Fuels from petroleum and natural gas, and synthetic ethanol from these sources, became available in large quantities at low cost and eliminated economic incentives for the production of liquid fuels from crops. The United State's use of petroleum products grew without any apparent limit. Simultaneously, the farming community enjoyed bountiful harvests, leading to accumulation of large grain reserves for which there was no ready market.

Throughout the 1950s and 1960s, few automotive uses were made of alcohol other than for racing cars—alcohol has powered race cars run at the Indianapolis 500.

Then, in the early 1970s, rising gasoline prices coupled with the continuing search for new markets for agricultural products sparked a renewed interest in ethanol production for fuel. In 1971, American farmers, in an effort to create markets for these accumulating grain reserves, put forth the idea that excess grains (corn and wheat) might be used in the production of liquid-fuel supplements. The movement was initiated in Nebraska, but economics associated with the production of liquid fuels from agricultural products were still unfavorable. This version of the "ethyl alcohol from agricultural crops" scenario became known as the "Gasohol" movement. In Nebraska in 1973, legislation went into effect to reduce that state's gasoline tax by 3 cents per gallon for fuels that contained a minimum of 10 percent agricultural ethanol of at least 190 proof. In 1975, Nebraska's new Agricultural Products Industrial Utilization Committee was established to coordinate alcohol-fuel commercialization in the state; it conducted a two-week marketing experiment, selling over 90,000 gallons of gasohol. The committee also initiated a 3-year, 2-million-mile test program to compare the performance and properties of unleaded gasoline and gasohol.

The "OPEC Oil Crisis" of 1973 made the American people aware of the extent of their dependence on foreign oil imports. The decision by the OPEC countries to escalate the price of oil placed a growing burden on the American economy, and the United States began to look for means of relieving our foreign energy dependence. Farm groups revived their interest in the possibility of using excess crop production to produce fuel-grade alcohol.

Other states, among them Virginia, Maine, and Indiana, began studies or demonstration projects to assess the feasibility of using alcohol in automobiles. In the U.S. Congress, Senators Carl Curtis and Robert Dole successfully cosponsored an amendment to a 1977 farm bill that directed the USDA to develop four pilot alcohol-production plants.

The USDA reluctantly accepted the mandate, arguing that alcohol-fuel production was not economically viable. The DOE took a similarly dim view of alcohol fuels, claiming that they were not price-competitive with gasoline and that it required more energy to produce ethanol than it could yield. President Carter's 102-page National Energy Plan in 1977 did not mention ethanol fuels.

Taking a more optimistic view, the Department of Commerce decided in 1977 to experiment with alcohol fuels. A grant was awarded to construct an alcohol-production plant that could salvage diseased crops produced that year. This project was the first of a rapidly growing number of experimental alcohol-fuel projects. The number of service stations selling the 10 percent alcohol/90 percent unleaded gasoline blends now called "gasohol" multiplied rapidly.

In October, 1978, the Congress approved the National Energy Act, which included a provision exempting gasoline containing at least 10 percent alcohol produced from agricultural products or wastes from the 4 cent per gallon federal gasoline excise tax. By early 1979, over 1000 service stations