Henry Ford, Charles Kettering and the "Fuel of the Future"

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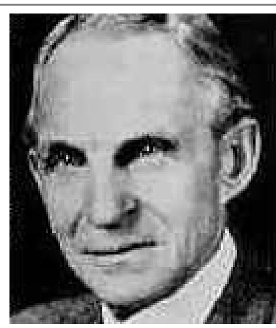
This photo, taken in April 1933, shows a Lincoln Nebraska gas station of the Earl Coryell Co. selling "Corn Alcohol Gasoline." The test marketing of ethanol blends was comon in the Midwest at this time, but it did not succeed due to the market dominance of the major oil companies. Coryell was subsequently among complainants to the Justice Dept. in the US v. Ethyl antitrust lawsuit of 1936, which Ethyl lost in a Supreme Court decision in 1940. (Nebraska Historical Society)

Abstract



The fuel of the future, according to both Henry Ford and Charles F. Kettering, was ethyl alcohol made from farm products and cellulosic materials. Ford, of course, is well known as an automotive inventor; Kettering was the head of research at General Motors and a highly respected inventor in his own right.

Henry Ford's outspoken support for alcohol fuel culminated with the the Dearborn, Mich. "Chemurgy" conferences in the 1930s. Little is known about Kettering's interest in ethyl alcohol fuel and how it fit into G.M.'s long term strategy. Moreover, aside from the Chemurgy conferences and a brief period of commercial alcohol-gasoline sales in the Midwest during the 1930s, very little is known about the technological, economic and political context of alcohol fuels use. This paper examines that context, including the competition between lamp fuels in the 19th century; the scientific studies about alcohol as a fuel in the early 20th century; the development of "ethyl" leaded gasoline as a bridge to the "fuel of the future" in the 1920s; the worldwide use of alcohol - gasoline blends in the 1920s and 30s; and the eventual emergence of the farm "Chemurgy" movement and its

support for alcohol fuel in the 1930s.

Introduction When Henry Ford told a New York Times reporter that ethyl alcohol was "the fuel of the future" in 1925, he was expressing an opinion that was widely shared in the automotive industry. "The fuel of the future is going to come from fruit like that sumach out by the road, or from apples, weeds, awdust -- almost anything," he said. "There is fuel in every bit of vegetable matter that can be fermented. There's enough alcohol in one year's yield of an acre of potatoes to drive the machinery necessary to cultivate the fields for a hundred years."[1]

Ford's optimistic appraisal of cellulose and crop based ethyl alcohol fuel can be read in several ways. First, it can be seen as an oblique jab at a competitor. General Motors (and Charles Kettering) had come to considerable grief that summer of 1925 over another octane boosting fuel called tetraethyl lead, and government officials had been quietly in touch with Ford engineers about alternatives to leaded gasoline additives.

More importantly to Ford, in 1925 the American farms that Ford loved were facing an economic crisis that would later intensify with the depression.[2] Although the causes of the crisis were complex, one possible solution was seen in creating new markets for farm products. With Ford's financial and political backing, the idea of opening up industrial markets for farmers would be translated into a broad movement for scientific research in agriculture that would be labelled "Farm Chemurgy."

Historiographic notes

The history of ethyl alcohol fuel has been partially explored by Giebelhaus,[3] Bernton[4] and this author,[5] but the historical focus of all three works tended to be on the U.S. Farm Chemurgy Movement in the 1930s. The context of Ford's support has not been well understood. And the ideas of Charles F. Kettering, in particular, have been grossly misrepresented.

American farmers embraced the vision of new markets for farm products, especially alcohol fuel, three times in the 20th century: around 1906, again in the 1930s with Ford's blesssing, and most recently, during the oil crisis of the 1970s. By the mid-1980s over one hundred corn alcohol production plants had been built and over a billion gallons of ethyl alcohol were sold per year in the fuel market. In the late 1980s and 1990s, with an apparently permanent world oil glut and rock bottom fuel prices, most of the alcohol plants shut down. Some observers joked that ethyl alcohol was the fuel of the future -- and always would be. "Gasohol" had become passe.

Why, then, delve so deeply into this history?

Even if infinite amounts of petroleum were available, the history of alternative energy sources is worthy of study from many points of view, not the least of which is the pragmatic need to understand alternatives to oil supply from politically unstable regions of the world. Francis Garvan noted the problem in a speech promoting alcohol fuel at the Dearborn, Mich. "Chemurgy" Conference on Agriculture, Industry and Science in 1936.

> "They say we have foreign oil," he said. "It is ... in Persia, and it is in Russia. Do you think that is much defense for your children?"[6]

Another pragmatic reason to consider the history of alternative fuels involves the risk of continued reliance on oil relative to global climate change -- a problem more recently appreciated.

Aside from pragmatic justifications, historians of technology have long noted a general preoccupation with "success stories" to an extent that might be called "whiggish." Research into some of the "roads not taken" would provide history with better focus and broader perspective, according to historian John Staudenmier.7 The direction a technology takes is too often seen as a result of pre-determined or inevitable conditions that arise from instrinsic properties of a technology, rather than from industry preference or policy choice.

Background

Ethyl alcohol has long been used as an automotive fuel in two ways: First, it replaces gasoline outright in a somewhat modified internal combustion engine; and secondly, it is an effective "octane booster" when mixed with gasoline in blends of 10 to 30 percent and requires no engine modification. These blends achieve the same octane boosting (or anti-knock) effects as petroleum-derived aromatics like benzine or metallic additives like tetraethyl lead.

Many people are familiar with "Gasohol," a popular fuel blend in the American Midwest in the late 1970s, which was a blend of ten percent ethyl alcohol and gasoline. (Fuel pumps are now simply labelled "with 10 percent ethanol."). Most people are not familiar with the other fuel blends using alcohol. "Gasonol" (with an "n") was a blend of 20 percent sugar cane alcohol with gasoline and kerosene used in the Philippeans in the 1930s. Koolmotor, Benzalcool, Moltaco, Lattybentyl, Natelite, Alcool and Agrol are some of the other obscure but interesting blends of fuels once found in Britain, Italy, Hungary, Sweden, South Africa, Brazil and the U.S. (respectively) in the 1920s and 1930s.

Economic issues have generally worked against the use of alcohol in favor of petroleum, but it is simplistic to view the problem simply in terms of relative consumer expense. Prices for ethyl alcohol blends and high octane gasoline are in the same relative range, and alcohol has been cheaper at times in various countries, depending on international politics and national tariff and incentive program

In the cultural and political context, alternative fuels -- especially ethyl alcohol -- have held a symbolic and politically strategic significance among advocates and opponents alike that goes far beyond the simple substitution of one product for another. Opponents have seen ethyl alcohol fuel as a scheme for robbing taxpayers to enrich farmers, as turning food for the poor into fuel for the rich, as compounding soil erosion problems, and as a marginally useful enhancement or replacement fuel for a transportation system that is poorly designed in the first place.

Advocates have seen in alcohol fuels the potential for revolutionizing agricultural economics, for dispelling city smog, and for curbing the power of the petroleum industry over the economy. In addition, the idea that agriculture and biological resources could be primary sources of energy, the idea that humankind could live on solar "income" rather than fossil fuel "capital," has held a fascination for several generations of automotive and agricultural engineers. Proponents could see in ethyl alcohol the potential to help strike balance between city and farm and the prospect of civilizing and humanizing industrial machinery.

For example, this hope is graphically depicted in the symbolism used at the 1902 Paris alcohol fuel exposition. On the cover of the exposition's proceedings, a muse with an overflowing bouquet of roses looks down over the steering wheel with a confident smile. She is a portrait of wisdom and beauty, firmly in control of a gentle machine which seems appropriately located in some lush flower garden.8

Rhetoric of the technological sublime, as it has been called, frequently attends the birth of any new technology, and of course there is nothing surprising about the high hopes of French automobile enthusiasts for alcohol fuel in 1902. While the spirit of the marriage was not always as artfully depicted, many of the great scientific minds of the 20th century expressed their support and interest specifically in alcohol as a high quality fuel and the general idea of opening vast new industrial markets for farm products. These included Henry Ford, Alexander Graham Bell, Thomas Edison and Charles F. Kettering.

Bell called alcohol "a wonderfully clean-burning fuel ... that can be produced from farm crops, agricultural wastes, and even garbage."9 Henry Ford, who idealized country life despite his contribution to the urbanization of America, hoped that alcohol could help power a rural renaissance. Thomas Edison backed the idea of industrial uses for farm products, and respected Ford's vision of the fuel of the future.10 Charles Kettering and proteges Thomas Midgely and T.A. Boyd noted that the "most direct route which we now know for converting energy from its source, the sun, into a material suitable for use as a fuel is through vegetation to alcohol..."11 Kettering's interest is particularly important because, as we will see, he was enthusiastic about alcohol fuel even after the discovery of tetraethyl lead. In fact, Kettering originally planned that the octane boosting power of leaded gasoline would pave the way for the fuel of the future -- ethyl alcohol from cellulosic biomass.

The broad ranging competition between gasoline and alcohol fuels around the turn of the century is not today as well known today as a similar competition between steam and electric automobiles with gasoline powered automobiles.12 Nevertheless, the competition from alcohol fuel was a well recognized fact at the time. Hundreds of magazine articles, reports, books and technical papers were written about alcohol fuel from the 1900 - 1926 period before and during the "Ethyl" leaded gasoline controversy, and hundreds more were published in the 1926-1960 period.13

Ethyl Alcohol Fuel before the Discovery of Petroleum

The history of energy is loaded with inaccuracies and myths. One myth is that Edwin Drake's first oil well, drilled in Pennsylvania in 1859, arrived in the nick of time to replace a rapidly dwindling supply of whale oil. Actually, as we will see, a variety of lamp fuels were common in the U.S. and Europe through the 19th and early 20th centuries. These fuels offered the most logical starting point in the search for portable liquid fuels which inventors would use in the internal combustion engine.

Lamp fuels included all kinds of vegetable oils (castor, rapeseed, peanut); animal oils (especially whale oil and tallow from beef or pork,); refined turpentine from pine trees; and alcohols, especially wood alcohol (methanol or methyl alcohol) and grain alcohol (ethanol or ethyl alcohol). The most popular fuel in the U.S. before petroleum was a blend of alcohol and turpentine called "camphene" or simply "burning fluid."

The"whale oil myth," appears in many places, most recently in the history of the oil industry, The Prize, which hailed kerosene as "the new light which pushed back the night and extended the working day." It was a "marvel to eyes that had strained to see by means of a lighted rag,"14 A recent Smithsonian exhibit provided a similar perspective: "It was the discovery of petroleum in 1859 that kindled the revolution in artificial lighting," the exhibit said. "Kerosene ...was cheap and relatively clean. Lamp companies had sprung up immediately and by the 1870s virtually everyone could enjoy indoor lighting." 15 This traditional error is found in many other accounts of the history of energy. According to a 1960 history, "petroleum arrived on the scene in answer to a world-wide quest for a new source of artificial light."16 In an Ethyl Corp. magazine of 1943, for example, we find the following:

"During the first half of the 19th century, scientists eagerly sought to develop better lighting fuels ... At that time, rural America for the most part depended on whale oil and sperm oil lamps to light its homes, and upon beeswax and tallow candles. Supplies, however, were limited and were becoming insufficient to meet a constantly growing demand."17

These accounts seem to be inspired examples of rhetoric of the technological sublime. They are also fiction. In fact, kerosene came into an already well-established liquid fuel system with full scale production, distribution and end-use technology well in place. In other words, kerosene replaced other fuels; it did not emerge to light up a previously dark world.

In the 30 or 40 years before petroleum was discovered in Pennsylvania, the leading fuel was "camphene" (sometimes simply called "burning fluid"). It was a blend of high-proof ethyl alcohol with 20 to 50 percent turpentine to color the flame and a few drops of camphor oil to mask the turpentine smell. Alcohol for camphene was an important mainstay for distilleries, and many sold between one third and 80 percent of their product on the fuel market.18 The first U.S. patent for alcohol as a lamp fuel was awarded in 1834 to S. Casey, of Lebanon, Maine but it is clear that alcohol was routinely used a fuel beforehand.19 Samuel Morey used the readily available alcohol in the first American prototype internal combustion engine at the surprisingly early date of 1826.20 We should note that Morey's work was lost in the enthusaism for the steam engine and a lack of funding. No other internal combustion engine would be developed until Nicholas Otto began his experiments 35 years later.

By the late 1830s, alcohol blends had replaced increasingly expensive whale oil in most parts of the country. It "easily took the lead as the illuminant" because it was "a decided improvement on other oils then in use," (especially lard oils) according to a lamp manufacturer's "History of Light."21 By 1860, thousands of distilleries churned out at least 90 million gallons of alcohol per year for lighting.22 In the 1850s, camphene (at $.50 per gallon) was cheaper than whale oil ($1.30 to $2.50 per gallon) and lard oil (90 cents per gallon). It was about the same price as coal oil, which was the product first marketed as "kerosene"23 (literally "sun fuel").

Kerosene from petroleum was a good fuel when it arrived in the 1860s: it was usually not too volatile, it burned brightly and it was fairly cheap. A gradual shift from camphene to kerosene might have occurred, but instead, a $2.08 per gallon tax on alcohol was imposed in stages between 1862 and 1864 as part of the Internal Revenue Act to pay for the Civil War. The tax was meant to apply to beverage alcohol, but without any specific exemption, it was also applied to fuel and industrial uses for alcohol. "The imposition of the internal-revenue tax on distilled spirits ... increased the cost of this 'burning fluid' beyond the possibility of using it in competition with kerosene..," said Rufus F. Herrick, an engineer with the Edison Electric Testing Laboratory who wrote one of the first books on the use of alcohol fuel.24

While a gradual shift from burning fluid (or spirit lamps) to kerosine did occur in Europe during the last half of the 19th century, the American alcohol tax meant that kerosene became the primary fuel virtually overnight, and the distilleries making lamp fuel lost their markets. The tax "had the effect of upsetting [the distilleries] and in some cases destroying them," said IRS commissioner David A. Wells in 1872. "The manufacture of burning fluid for lighting suddenly ceased; happily, it was replaced by petroleum, which was about to be discovered."25 Similarly, C.J. Zintheo, of the US Department of Agriculture, said that 90 million gallons of alcohol per year were used for lighting, cooking, and industry before the tax was imposed.26 Meanwhile, use of oil shot up from almost nothing in 1860 to over 200 million gallons in 1870.27 "The effect was disastrous to great industries, which, if [they were to be] saved from ruin, had to be rapidly revolutionized," according to Irish engineer Robert N. Tweedy.28

The distress in the alcohol industry may be reflected in the number of patents for various combinations of burning fluids. Between 1861 and 1867, the patent office issued 32 different patents for burning fluids, alcohol or camphene blends; only five had been awarded in the previous 33 years. After 1867, no patents for "burning fluids" are listed.29 The dramatic increase in numbers of patents, as alcohol became prohibitively expensive, may reflect desperate attempts to find new combinations of inflammable liquids to replace the product of the rapidly dying alcohol fuel industry .

Thus, the growth of the petroleum industry in the 1860s was greatly aided by the heavy federal tax on its primary competitor .The myth that petroleum was at first a dramatic deliverance from the darkness, and then the only important fuel for the horseless carriage, indicates the extent to which oil industry historians have been influenced by the rhetoric of the technological sublime. In fact, early automotive inventors resorted to both petroleum and alcohol spirit lamp fuels as readily available energy sources.

Fodder for the Horseless Carriage

The idea of replacing the external combustion steam engine with an internal combustion liquid fuel engine seized the world's imagination in the late 19th century, but the origins of internal combustion engines can be traced back to early experiments with gunpowder in the late 1600s. Historian Lyle Cummins has noted that at least a dozen inventors tried to develop some form of internal combustion engine by the early 19th century.30

The first authentic internal combustion engine in America, developed by Samuel Morey around 1826, ran on ethyl alcohol and turpentine. It powered an experimental wagon and a small boat at eight miles per hour up the Connecticut river. Morey, like many other inventors, was never able to attract financing for his idea and only the prototype was built.31

Another early developer of the internal combustion engine was German inventor Nicholas August Otto. In 1860, Otto used ethyl alcohol as a fuel in an early engine because it was widely available for spirit lamps throughout Europe. He devised a carburetor which, like Morey's, heated the alcohol to help it vaporize as the engine was being started. But a January 1861 patent application with the Kingdom of Prussia was turned down, probably because heated alcohol carburetion was already being widely used in spirit lamps.32 It is interesting to note that Otto's initial financing came from Eugen Langen, who owned a a sugar refining company that probably had links to the alcohol markets of Europe. Of course, the Otto & Langen company went on to success in the 1870s by producing stationary gas engines (usually powered by coal gas) and the later "Otto-cycle" engine was fueled primarily with gasoline but was still adaptable to alcohol or benzene from coal.

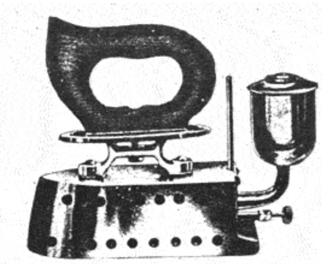
Numerous other engine prototypes were developed using alcohol or turpentine, including US inventor George Brayton's engine developed in the 1870s. However, at the dawn of the automotive age, kerosene was widely available and gasoline, although volatile and dangerous for lamps, was cheap and very much in surplus.

Promoting Alcohol Fuel in Europe 1890 - 1914

During the 1890 - 1914 time period, German, French and British scientists and government officials were worried about the longevity of oil reserves and the unpredictable nature of oil supplies from Russia and America. "The oil trust battles between Rockefeller, the Rothschilds, the Nobels and Marcus Samuel's Shell kept prices in a state of flux, and engines often had to be adaptable to the fuel that was available," said Cummins.33 Manufacturing companies in Germany, England and France sold engines equipped to handle a variety of fuels. In tropical nations where oil supplies were quite irregular, and in closed environments such as mines and factories, alcohol engines were often preferred.

With few domestic oil reserves, France and Germany especially were eager to encourage widespread development of a fuel that could be readily distilled from domestic farm products. Research at the Experimental Mechanical Laboratory of Paris and at the Deutsche Landwirtschaftliche Gesellschaft in Berlin in the 1890s helped pave the way for expanded use of alcohol fuel.34 By 1896, horseless carriages were showing up on roads in Europe and the United States, and internal combustion engines were also beginning to replace steam engines in light machinery and farm equipment. The question of whether gasoline or alcohol was the better fuel often provoked spirited debate, and numerous races between cars with different fuels were held in Europe.

One of these races took place in 1899 with four alcohol fueled vehicles racing from Paris to Chantilly. Only one made the entire distance.35 Two years later, 50 vehicles ranging from light quadracycles to heavy trucks made the 167 mile trek from Paris to Roubaix. The rallys were sponsored by the Automobile Club of Paris and fuels varying from pure alcohol to 50 percent alcohol and 50 percent gasoline were measured for each vehicle before and after the 1902 rally. Most drivers apparently preferred the 50-50 blend.36


Pyro "self heating" alcohol fueled iron, 1906. USDA NARL, Beltsville, Md.

Exhibits of automobiles held every year contained large proportions of alcohol fueled cars, and the growing enthusiasm was reflected in the 1902 Paris exhibit (mentioned above in the introduction). The exhibit was devoted to alcohol powered automobiles, farm machinery and a wide variety of lamps, stoves, heaters, laundry irons, hair curlers, coffee roasters and every conceivable household appliance and agricultural engine powered by alcohol. Many of these were not experimental items but represented a well established industry. By one estimate, some 95,000 alcohol fueled stoves and 37,000 spirit lamps were made in Germany in 1902.37 The exhibit published a set of papers and speeches,.38 and was reported in many newspapers and technical journals of the day. Eight other exhibitions and congresses on alcohol fuels took place -- in Germany, France, Italy and Spain between 1901 and 1904.39 Meanwhile, French fuel alcohol production rose from 2.7 million gallons in 1900 to 5.7 million gallons in 1903 and 8.3 million in 1905.40 Enthusiasm over the marriage of agriculture and industry in alcohol fuel was not the only motivation for French interest. A very practical problem was the decline in French sugar beet exports and rising surplus of many crops. Another concern was the increase in oil imports from the U.S. and the lack of domestic oil reserves.41

Germans were also concerned about a domestic fuel supply that would also provide farmers with new markets for crops. In 1899, the German government organized the Centrale fur Spiritus Verwerthung (office of alcohol sales) which maintained alcohol prices at an equilibrium with petroleum at around the equivalent of 27 cents per gallon through subsidies to alcohol producers and a tariff on imported oil.42 Other incentives included scientific prizes, including a medallion from the emperor offered for the best alcohol engines. As a result, alcohol production rose from 10 million gallons to about 26 million gallons between 1887 and 1904.43 "To Kaiser William II, it seems, we are indebted for the great, new industry," said a New York Times magazine writer in 1906. "Not that he discovered the fuel, but that he forced its use on Germany. The Kaiser was enraged at the Oil Trust of his country, and offered prizes to his subjects and cash assistance ... to adapt [alcohol] to use in the industries."44

According to a representative of the Otto Gas Engine Works of Philadelphia, by 1906 ten percent of the engines being produced by the firm's parent company in Germany were designed to run on pure ethyl alcohol, while one third of the heavy locomotives produced at the Deutz Gas engine works of Germany ran on pure ethyl alcohol.45 Alcohol engines were advertised as safer than steam engines (as they did not give off sparks from smokestacks) and far cleaner than kerosine or gasoline engines. In a survey conducted around 1903, some 87 percent of German farmers considered alcohol engines to be equal or superior to steam engines in performance.46 Conflicting reports on the number of German distilleries at least give some idea of the scale of the enterprise. By one 1906 account, some 72,000 distilleries operated, of which 57,000 were small farm "Materialbrennereien" stills producing a total of 27 million gallons.47 Another account, from 1914, put the number at 6,000 distilleries producing 66 million gallons of alcohol per year.48

These alcohol stills may have had the effect of prolonging World War I. According to Irish engineer Robert Tweedy, when oil shortages seemed likely to paralyze Germany's transportation system in 1915, thousands of engines were quickly modified. "Every motor car in the empire was adapted to run on alcohol. It is possible that Germany would have been beaten already [by 1917] if production of alcohol had not formed an important part of the agricultural economy."49

U.S. Congress Lifts Alcohol Tax in 1906

American farmers watched the growing use of alcohol fuel in Europe with great interest. Their markets were glutted with grain surpluses created when vast new tracts of virgin prairie were plowed under to produce bumper crops. To absorb these surpluses, many looked to the market for liquid fuels created by the widespread acceptance of the automobile. It seemed logical to replace their declining market for horses by growing fuel for the horseless carriage.

Several attempts had already been made to remove the $2.08 federal tax placed on alcohol during the Civil War.. In 1894 the Wilson tariff bill allowed a rebate of taxes on alcohol for industrial uses, but the Treasury Dept. refused to issue regulations. Manufacturers tried to claim the rebate but lost in court. In 1896 a joint committee studied the issue, and minutes show opposition from wood alcohol (methyl) producers.

In 1906, the farm lobby found an ally in President Theodore Roosevelt, a bitter foe of the oil industry. Although embroiled in other disputes at the time, Roosevelt sent a message of support for the repeal of the alcohol tax to the House of Representatives, saying it provided a possible check to the depradations of the oil trust.50 In April, 1906, a bill to repeal the alcohol sales tax sailed through the House on a 224 to 7 vote with widespread support from farm-belt representatives. Additional support came from the Temperance Party, which saw in alcohol fuel a beneficial use for a pernicious commodity.

When the Senate Finance Committee attempted to table the "Free Alcohol" bill, the president of the Automobile Club of America said that he was considerably surprised and disappointed at the Senate committee, although he did not think Standard Oil would oppose the bill. "Gasoline is growing scarcer, and therefore dearer, all the time... Automobiles cannot use gasoline for all time, of that I am sure, and alcohol seems to be the best substitute that has yet appeared."51 U.S. Senator Champ Clark of Missouri, however, placed "the Rockefellers" squarely in the opposing camp as attempting to retain the tax on a potential competitor.52

By mid-May, 1906, the Senate committee relented and the New York Times reported the bill was likely to be approved. "It is only the heavy tax imposed by the United States that has prevented the use of a large number of vegetable products for the manufacture of exceedingly cheap and available alcohol," a Times editorial said. These sources included potatoes in the West, sugar beets in Michigan, and cheap imported molasses in the east. A report from the U.S. ambassador to Cuba noted alcohol made there cost 10 cents per gallon, and with improved methods in the U.S. it could cost even less when made from imported molasses. "The chief opponents, at least the open opponents, have been the manufacturers of wood alcohol," the Times said.53

Auto manufacturers supported the bill wholeheartedly. A representative of the Detroit Board of Commerce, James S. Capen, told the Senate Finance Committee that alcohol was "preferable" to gasoline because it was safer, "absolutely clean and sanitary," and because "artificial shortages" could not raise the price in the future. The biggest problem for auto makers, Capen said, was not so much cost as the question of long term supply.54

The Senate passed the bill May 24, 1906, and the New York Times again noted the low cost of alcohol (14 cents from corn, nine and a half cents from molasses) as compared to the high price of kerosene and gasoline (18 and 22 cents, respectively). "The new fuel and illuminant will utilize completely an important class of agricultural crops and byproducts thus benefiting in a double sense the farms and villages throughout the country," an editorial said.55 Roosevelt signed the bill June 8, 1906.

Additional bills specifically exempting farm stills from government controls passed shortly afterwards, and triumphant farm belt senators, like North Dakota's Hansbrough, proclaimed that "every farmer could have a still" to supply heat, light and power at low prices. "Advocates look forward with hope to a big change in the farmers life," the New York Times reported. "If the law accomplishes what is hoped it will... make a revolution on the farm."

Experts noted that while alcohol would probably not drive out gasoline entirely, "it will find its field as every other fuel energy has." More typical was the statement of a National Grange master who predicted an immediate market for 100 million gallons of alcohol. Along with a large additional market for farm crops, alcohol would serve as a "balance wheel to maintain an equilibrium" in commodity prices.56

The lofty farm rhetoric obscured a difficult economic picture, but the bill kindled interest in alcohol fuels among farmers who wanted new markets and automakers who wanted to continue to have a market if oil were to run out. Pure alcohol fuel went on sale in Peoria, Illinois at 32 cents per gallon in January, 1907 as the tax took effect, and prices elsewhere hovered around 25 to 30 cents. At the same time, gasoline prices at 18 to 22 cents per gallon were beginning to drop as new Texas oil fields came on line and found markets on the East Coast. These new fields were brought in by independent oil companies, especially Gulf and the Texas Co. (Texaco). Suddenly, the future for alcohol fuel seemed more remote than anticipated.

"Of all the chimerical projects ever foisted upon Congress, the free denatured alcohol scheme has proved the greatest disappointment," said a news column in the New York Times in 1907. With only ten alcohol plants built under the new law, "gasoline, kerosene and electricity are still being used." One disappointed farm machinery manufacturer said the problem was a lack of frugality among Americans; the manufacturer said German farm stills often used "cull" crops that had been partly damaged or spoiled. Meanwhile, an Internal Revenue commissioner noted that Germany protected farm alcohol with tariffs on petroleum imports, and said that fuel prices there were the equivalent of 15 to 27 cents per gallon.57 USDA set up a demonstration small scale alcohol still in the Bureau of Chemistry with "the aim of creating a body of experts who would return to their districts filled up with enthusiasm and knowledge which would be served out to farmers." In 1908, fourteen experts were trained; in 1909 only four could be trained, and the project was abandoned. The U.S. commissioner of revenue noted in 1910 that no alcohol had been used for fuel, and in 1911 he reported that a new industrial alcohol industry was unlikely.

Attempts to revive the moribund hopes of the alcohol industry proved futile. In 1914 the Free Alcohol bill was amended again to decrease the regulatory burden, but one observer said that the small distillery "is only a myth in this country." In 1915, Congressional hearings on more demonstrations and proposals for an Industrial Alcohol Commission within the Department of Agriculture were held, but the proposals were turned down. "The theater is open, the stage is set, but the play does not begin. There are no actors..." said Tweedy.58

Alcohol from grain and potatoes, at about 25 to 30 cents per gallon, was far too expensive to compete with petroleum, but alcohol from Cuban molasses, at 10 cents per gallon, was thought to be competitive. Some observers suspected a conspiracy in the fact that Standard Oil of New Jersey had financial ties to the Caribbean alcohol market. The influence of an oil company over the alcohol industry was "a combination which many will regard as sinister," said Tweedy.59 In 1942, Senate committees began looking into the extent to which the oil industry had controlled other industries, including the alcohol industry and the rubber industry. Attorney General Thurmond Arnold testified that anti-trust investigations had taken place into the oil industry's influence in the alcohol industry in the 1913-1920 period, in the early 1920s, and between 1927 and 1936. "Renewed complaints in 1939 were brought to the anti-trust division but because of funds no action was taken," Arnold said.60 Then the investigation of 1941 which exposed a "marriage" between Standard Oil Co. and the German chemical company I.G. Farben also brought new evidence concerning complex price and marketing agreements between du Pont Corp., a major investor in and producer of leaded gasoline, U.S. Industrial Alcohol Co. and their subsidiary, Cuba Distilling Co. The investigation was eventually dropped, like dozens of others in many different kinds of industries, due to the need to enlist industry support in the war effort. However, the top directors of many oil companies agreed to resign and oil industry stocks in molasses companies were sold off as part of a compromise worked out with Arnold.

Scientific Investigations of Alcohol Fuels 1890 - 1920

Scientific journals contain hundreds of references to alcohol fuel at the dawn of the automotive era. Research during the earliest decades tended to focus on pure alcohol as a replacement for petroleum. The focus shifted to the anti-knock ("octane" boosting) properties of alcohol blends in gasoline during the 1915 to 1936 period because of an increasing need for anti-knock gasoline and because of improvements in anhydrous alcohol production techniques.61

Studies of alcohol as an internal combustion engine fuel began in the U.S. with the Edison Electric Testing Laboratory and Columbia University in 1906. Elihu Thomson reported that despite a smaller heat or B.T.U. value, "a gallon of alcohol will develop substantially the same power in an internal combustion engine as a gallon of gasoline. This is owing to the superior efficiency of operation..."62 Other researchers confirmed the same phenomena around the same time.

USDA tests in 1906 also demonstrated the efficiency of alcohol in engines and described how gasoline engines could be modified for higher power with pure alcohol fuel or for equivalent fuel consumption, depending on the need.63 The U.S. Geological Service and the U.S. Navy performed 2000 tests on alcohol and gasoline engines in 1907 and 1908 in

Norfolk, Va. and St. Louis, Mo. They found that much higher engine compression ratios could be achieved with alcohol than with gasoline. When the compression ratios were adjusted for each fuel, fuel economy was virtually equal despite the greater B.T.U. value of gasoline. "In regard to general cleanliness, such as absence of smoke and disagreeable odors, alcohol has many advantages over gasoline or kerosene as a fuel," the report said. "The exhaust from an alcohol engine is never clouded with a black or grayish smoke."64 USGS continued the comparative tests and later noted that alcohol was "a more ideal fuel than gasoline" with better efficiency despite the high cost.65

The French War Office tested gasoline, benzene and an alcohol-benzene blend in road tests in 1909, and the results showed that benzene gave higher mileage than gasoline or the alcohol blend in existing French trucks.66 The British Fuel Research Board also tested alcohol and benzene mixtures around the turn of the century and just before World War I, finding that alcohol blends had better thermal efficiency than gasoline but that engines developed less brake horsepower at low rpm.67 On the other hand, a British researcher named Watson found that thermal efficiencies for alcohol, benzene and gasoline were very nearly equal.68

These experiments are representative of work underway before and during World War I. The conclusions were so definitive that Scientific American concluded in 1918: "It is now definitely established that alcohol can be blended with gasoline to produce a suitable motor fuel ..."69 By 1920, the consensus, Scientific American said, was "a universal assumption that [ethyl] alcohol in some form will be a constituent of the motor fuel of the future." Alcohol met all possible technical objections, and although it was more expensive than gasoline, it was not prohibitively expensive in blends with gasoline. "Every chemist knows [alcohol and gasoline] will mix, and every engineer knows [they] will drive an internal combustion engine."70

During and after the war, the British Fuel Research Board actively researched military and civilian fuels. W.R. Ormandy in 1918 said that alcohol and coal based fuels could replace oil in the post-war period, and Ormandy noted that only five percent of the American grain crop would meet requirements for a blended fuel.71 The board's committee on "power alcohol" noted the absence of technical problems a year later, although it concluded that "alcohol cannot compete with gasoline at present prices."72 Harold B. Dixon, working for the board and other governmental departments, reported in 1920 that higher possible engine compression compensated for alcohol's low caloric value. A mixture of alcohol with 20 percent benzene or gasoline "runs very smoothly, and without knocking."73 Also, B.R. Tunnison reported in 1920 the anti-knock effects of alcohol blends in gasoline and said mileage was improved.74

Another significant set of British experiments was performed by the London General Omnibus Co. in 1919 comparing gasoline with blends of ethyl alcohol and benzene. Mileage was about the same, with gasoline slightly ahead. "In all other respects the [alcohol] fuel compared favorably with petrol [gasoline], and exhibited the characteristics of other alcohol mixtures in respect of flexibility, absence of knocking and cleanliness."75 The absence of knocking is significant, since London omnibus studies were widely reported and well known two years before leaded gasoline was discovered and six years before oil industry representatives told government officials that alternatives to leaded gasoline did not exist.76 The bus experiment also showed that a large scale switch from petroleum was technically feasible. "We are fast squandering the oil that has been stored in the fuel beds, and it seems so far as our present knowledge takes us that it is to the fuels experimented with that we must turn for our salvation," said the omnibus company engineer in a technical journal.77

Despite the value of demonstrating the flexibility of technology, road tests proved to be an unreliable index of mileage and thermal efficiency. A German road test of benzene alcohol blends found that the 50 /50 alcohol benzene mixture had 30 percent better mileage than gasoline.78 Because of the unreliability of such road tests, Thomas Midgely in the U.S. and H.R. Ricardo in Britain developed reference engines, indicators, and measuring apparatus for showing the exact extent of knocking. Midgely's system led to the development of iso-octane as a reference fuel, and eventually, the "octane" system of measuring anti-knock. Ricardo's work focused in part on testing fuels at various compression ratios up to the point where they would begin knocking, or what he termed the "highest useful compression ratio." Ethyl alcohol had a 7.5 value, with commercial gasolines then available at 4.5 to 6. Ricardo also developed the Toluene Index, which like "octane" measured anti-knock with a reference fuel. Ricardo concluded that the low burning rate of alcohol lessens the tendency to knock, and that, using toluene as the reference point at 100 anti-knock, alcohol had a 130 rating. 79

Several difficulties with alcohol fuels were known: cold starting was one, and E.C. Freeland and W.G. Harry noted in a chemical society paper that blends of small amounts of ether in alcohol could solve the problem.80 Another problem was "phase separation," noted above. But the tendency of alcohol and gasoline to separate at lower temperatures in the presence of water could be easily overcome with "binders," and was noted by Thomas Midgley, among others. These were small amounts of additives such as higher-carbon alcohols (such as propyl or butyl alcohol), ethers and / or benzene. Operating practice was also important tin dealing with alcohol fuels. Fuel distributors and chemists used anhydrous (low water content) alcohol and avoided storing alcohol-gasoline blends in tanks with water "bottoms." Swedish researcher E. Hubendick said that the danger of separation "can be ignored in my estimation" because even if it did occur, it would never stop the motor in the way that a small amount of water in the gas tank would.81

In short, technical research into ethyl alcohol as a fuel ranged from neutral to extremely positive, with very few negative findings. By 1925, an American researcher speaking at the same New York Chemists Club told an audience:

> "Composite fuels made simply by blending anhydrous alcohol with gasoline have been given most comprehensive service tests extending over a period of eight years. Hundreds of thousands of miles have been covered in standard motor car, tractor, motor boat and aeroplane engines with highly satisfactory results... Alcohol blends easily excel gasoline on every point important to the motorist. The superiority of alcohol gasoline fuels is now safely established by actual experience... [Thus] the future of alcohol motor fuels is largely an economic problem. 82

Yet in the 1930s, oil industry opponents of alcohol blends in the US claimed that technical problems prohibited their use. "Alcohol is much inferior, gallon for gallon, to gasoline as a motor fuel," claimed the American Petroleum Industries Committee. While admitting there was some anti-knock advantage, the committee said the blends would be "unstable in the presence of small amounts of accidental moisture."83 The American Petroleum Institute's Conger Reynolds, in a 1939 barb aimed at Henry Ford and the Farm Chemurgy conferences of the 1930s, said:

> "With all due deference for the dream chemists, armchair farmers and platform orators who have touted alcohol-gasoline as the greatest of all fuels, oil industry technologists know and automotive engineers know that it is not as satisfactory a fuel as straight gasoline of normal quality."84

The context of Reynolds speech to fellow oil men was that of fending off (by his count) 19 federal bills and 31 state bills on alcohol gasoline tax incentives and blending programs between 1933 and 1939. To be forced to use alcohol gasoline would mean giving consumers an inferior fuel at an exorbitant cost, Reynolds said. At the time, the API had virtually no technical data to back up claims of inferiority. The vast bulk of scientific research pointed very much in favor of alcohol blended fuels. That soon changed as industry-sponsored tests found phase separation, cold starting and other problems. Ten years later, British researcher S.J.W. Pleeth would observe:

> "The bias aroused by the use of alcohol as a motor fuel has produced [research] results that are incompatible with each other ... Countries with considerable oil deposits -- such as the US -- or which control oil deposits of other lands -- such as Holland -- tend to produce reports antithetical to the use of fuels alternative to petrol; countries with little or no indigenous oil tend to produce favorable reports. The contrast ... is most marked. One can scarcely avoid the conclusion that the results arrived at are those best suited to the political or economic aims of the country concerned or the industry sponsoring the research. We deplore this partisan use of science, while admitting its existence, even in the present writer."85

U.S. Automakers, Alcohol Fuels and Ethyl Leaded Gasoline

Before World War I, U.S. automakers were aware of the potential for alcohol fuel, but given the short-term economic picture, stayed with gasoline and low compression engines. Most popular cars, such as the Ford Model T, had low compression engines, an adjustable carburetor and a spark advance that made it possible to switch from gasoline to alcohol to kerosene as needed. Despite Ford's later support for alcohol fuel in the 1920s and 1930s, the only fuel the company actually handled was "Fordsol," benzine from Ford factory coking operations and regular gasoline. Some early auto manufacturers, such as the Olds Gas Power Company, offered a simple mixer attachment for alcohol and found that "under actual operating conditions... the fuel consumption per horsepower is about the same, pound for pound, whether using alcohol or gasoline." The Hart-Parr Company, a tractor manufacturer based in Charles City, Iowa, commented in 1907: "We have watched with great interest, and added our efforts to help bring about the free use of alcohol for power purposes... Our engine is so constructed that alcohol can be used with very little change ..." 86

Minneapolis Steel and Machinery Co. began making alcohol engines for tractors in 1909, and with increasing demand for alcohol powered farm equipment after World War I, began intensive studies on a more efficient alcohol engine. "In our opinion alcohol is an ideal fuel," said researcher A.W. Scarratt, because it vaporized at a practically constant temperature and it formed no carbon deposits. "We believe the entire automobile industry should get behind this idea and bring it to pass as quickly as possible so as to provide another source of fuel supply and to bring down the operating costs of all equipment depending now on hydrocarbon fuels."87

After World War I, the focus of fuel research shifted into two directions. One research direction led to the discovery of a metallic additive called tetra ethyl lead. The story of how General Motors researchers Thomas Midgley and Charles F. Kettering discovered it has often been told.88 However, the second research direction into the "fuel of the future" is not well known.

Kettering and Midgley's initial research into fuel involved work on DELCO generators and airplane engines in World War I. In a report on the war research, Midgley wrote: "Engineers have heretofore believed knocking to be the unavoidable result of too high a compression, and while the fact that [ethyl] alcohol did not knock at extremely high compressions was well known, it was [erroneously] attributed to its extremely high ignition point .."89 The point was generally understood by scientists and military technology experts. For example, a naval committee concluded in 1920 that alcohol gasoline blends "withstand high compression without producing knock."90

Kettering, who had become General Motors vice president of research and the president of the Society of Automotive Engineers, noted two directions in fuel research in a 1919 speech to the society. There was, he said, a "high percentage" direction, with blends of up to 20 percent or more of benzine or alcohol; the other was a "low percentage" additive, such as iodine, which was too expensive to be practical but pointed to the possibility of other additives.91 The low percentage research effort would lead to the discovery of leaded gasoline in 1921.

Around 1920 and 1921, Kettering came to believe that alcohol fuel from renewable resources would be the answer to the compression problem and the possibility of an oil shortage. Along with his British counterpart, H.R. Ricardo, Kettering settled on alcohol as the key to unshackling the internal combustion engine from non-renewable fossil fuels," said historian Stuart Leslie. "Ethanol (ethyl alcohol) never knocked, it could be produced by distiling waste vegetable material, and it was almost pollution-free. Ricardo compared alcohol fuel to living within a man's means, implying that fossil fuels were a foolish squandering of capital." 92

At Kettering's urging, General Motors began to consider just what would be involved in a total switch from petroleum to alcohol fuel. One G.M. researcher reported that some 46 percent of all foodstuffs would have to be converted to alcohol to replace gasoline on a BTU for BTU basis.93 In another G.M. study, T.A. Boyd surveyed the steep rise in number of new cars and the increasing difficulty of providing new fuel supplies. The solution, Boyd said, would be to use other fuels, and benzene and alcohol "appear to be very promising allies" to petroleum.94 Alcohol was the "most direct route ... for converting energy from its source, the sun, into a material that is suitable for a fuel..." Boyd said.

Despite advantages of cleanliness and high antiknock rating, there were supply problems. In 1921, about 100 million gallons of industrial alcohol supply was available. Overall, enough corn, sugar cane and other crops were available to produce almost twice the 8.3 billion gallon per year demand for gasoline. But the possibility of using such a large amount of food acreage for fuel "seems very unlikely," he said.95 In a speech around 1921, Kettering noted that "industrial alcohol can be obtained from vegetable products ... [but] the present total production of industrial alcohol amounts to less than four percent of the fuel demands, and were it to take the place of gasoline, over half of the total farm area of the United States would be needed to grow the vegetable matter from which to produce this alcohol."96

Kettering, Midgley and Boyd apparently framed the question in terms of totally replacing gasoline, although a related goal of the research was to create antiknock additives. It stands to reason that if a 20 percent blend of alcohol were to be used in all fuel, then (using Boyd's figure) only about nine percent of grain and sugar crops would be needed. Since grain was in surplus after the war, American farmers probably would have welcomed a new market for their crop, and the kinds of supply problems in the G.M. and du Pont studies would probably not have materialized. Also, with Prohibition, distillers would have welcomed a new use for their services. Another problem with Kettering's analysis demonstrates a lack of understanding of agriculture and the distilling industry. Grain is not "used" for fuel; it is fed to cattle after it is distilled with no loss in food value. This is as true of brewers' grains from beer distilleries as it is of fuel facilities.

Thus, supply of an additive would not have been the problem that G.M. engineers apparently assumed that it would have been. However, since the original studies on fuel alcohol are missing from the archives, and it is difficult to fathom the reason for their narrow frame of reference.97 One reasonable explanation is that Kettering, Boyd and Midgley were preoccupied with the long-term replacement of petroleum. In 1920 and 1921 they were not technically or politically opposed to ethyl alcohol as a straight fuel or in blends with gasoline. Kettering spoke out against taxes on alcohol as an impediment to fuel research and helped overcome other obstacles.98 In 1920, K.W. Zimmerschied of G.M.'s New York headquarters wrote Kettering to note that foreign use of alcohol fuel "is getting more serious every day in connection with export cars, and anything we can do toward building our carburetors so they can be easily adapted to alcohol will be appreciated by all." Kettering assured him that the adaptation "is a thing which is very readily taken care of," and said that G.M. could rapidly change the floats in carburetors from lacquered cork to metal.99 Midgley also filed a patent application for a blend of alcohol and cracked (olefin) gasoline on February 28, 1920, clearly intending it to be an antiknock fuel.100

The problem of the long-term resource base for the fuel of the future continued to worry Kettering and Midgley. At one point they became interested in work on cellulose conversion to fermentable sugar being performed by Prof. Harold Hibbert at Yale University. Hibbert was a visionary, and pointed out that the 1920 U.S.G.S. oil reserve report had serious implications for his work. "Does the average citizen understand what this means?" he asked. "In from 10 to 20 years this country will be dependent entirely upon outside sources for a supply of liquid fuels... paying out vast sums yearly in order to obtain supplies of crude oil from Mexico, Russia and Persia." But chemists might be able to solve the problem, Hibbert said, by converting abundant cellulose waste from farm crops, timber operations and seaweed into ethyl alcohol.101 In the summer of 1920, Boyd and his family moved to New Haven so that he could study with Hibbert. Boyd found Hibbert impressive but the volume of literature about cellulose hydrolysis and synthesis was overwhelming. When Midgley came east in late July, he was more interested in meeting Standard Oil Co. officials than with Hibbert, and Boyd left without a clear sense of where the cellulose research could go.102

Boyd did insist that a source of alcohol "in addition to foodstuffs" must be found, and that the source would undoubtedly be cellulose: "It is readily available, it is easily produced and its supply is renewable." Using it and returning farm crop residues to the soil would not harm soil fertility. But the problem of developing a commercial process for cellulose conversion to alcohol was serious, he had learned in his stay with Hibbert. A ton of wood yielded only 20 gallons of alcohol in the least expensive "weak acid" process, whereas a commercially profitable "weak acid" process would need a yield of at least 50 gallons, and possibly 60 to 65. Such yields had been achieved with the "strong acid" process, but that technology was complex and more expensive. Still, success might be found if the "strong acid" yield could be obtained in a weak acid process, and as a result, "the danger of a serious shortage of motor fuel would disappear," Boyd said. "The great necessity for and the possibilities of such a process justify a large amount of further research."

To promote the idea of alcohol blended fuels among automotive and chemical engineers, Midgley drove a high compression ratio car (7:1) from Dayton to an October, 1921 Society of Automotive Engineers (SAE) meeting in Indianapolis using a 30 percent alcohol blend in gasoline. This was only two months before tetraethyl lead was discovered. "Alcohol has tremendous advantages and minor disadvantages," Midgley told fellow SAE members in a discussion. Advantages included "clean burning and freedom from any carbon deposit... [and] tremendously high compression under which alcohol will operate without knocking... Because of the possible high compression, the available horsepower is much greater with alcohol than with gasoline..." Minor disadvantages included low volatility, difficulty starting, and difficulty in blending with gasoline "unless a binder is used."103 Another unnamed engineer (probably from G.M., possibly Boyd) noted that a seven and a half percent increase in power was found with the alcohol-gasoline blend "...without producing any 'pink' [knock] in the engine. We have recommended the addition of 10 percent of benzol [benzene] to our customers who have export trade that uses this type of fuel to facilitate the mixing of the alcohol and gasoline."104 In a formal part of the presentation, Midgley mentioned the cellulose project. "From our cellulose waste products on the farm such as straw, corn-stalks, corn cobs and all similar sorts of material we throw away, we can get, by present known methods, enough alcohol to run our automotive equipment in the United States," he said. The catch was that it would cost $2 per gallon. However, other alternatives looked even more problematic -- oil shale wouldn't work, and coal would only bring in about 20 percent of the total fuel need.105

Midgley and Kettering's interest in ethyl alcohol fuel did not fade once tetraethyl lead was discovered as an antiknock in December, 1921. In fact, not only was ethyl alcohol a source of continued interest as an antiknock agent, but more significantly, it was still considered to be the fuel that would eventually replace petroleum. A May, 1922 memo from Midgley to Kettering was a response to a report on alcohol production from the Mexican "century" plant, a desert plant that contains fermentable sugars. Midgley said he was "not impressed" with the process as a way to make motor fuel:

Unquestionably alcohol is the fuel of the future and is playing its part in tropical countries situated similar [sic] to Mexico. Alcohol can be produced in those countries for approximately 7 - 1/2 cents per gallon from many other sources than the century plant, and the quantities which are suggested as possibilities in this report are insignificantly small compared to motor fuel requirements. However, as a distillery for beverage purposes, these gentlemen may have a money making proposition.106

Even as chemists tinkered with various processes to produce tetraethyl lead in a nearby lab, Midgley and Boyd continued working on alcohol for fuel. In a June 1922 Society of Automotive Engineers paper, they said:

> That the addition of benzene and other aromatic hydrocarbons to paraffin base gasoline greatly reduces the tendency of these fuels to detonate [knock] ... has been known for some time. Also, it is well known that alcohol ... improves the combustion characteristics of the fuel ...*The scarcity and high cost of gasoline in countries where sugar is produced and the abundance of raw materials for making alcohol there has resulted in a rather extensive use of alcohol for motor fuel.* As the reserves of petroleum in this country become more and more depleted, the use of benzene and particularly of alcohol in commercial motor fuels will probably become greatly extended." 107 (Italics indicate section omitted from printed version).

In September, 1922, Midgley and Boyd wrote that "vegetation offers a source of tremendous quantities of liquid fuel." Cellulose from vegetation would be the primary resource because not enough agricultural grains and other foods were available for conversion into fuel. "Some means must be provided to bridge the threatened gap between petroleum and the commercial production of large quantities of liquid fuels from other sources. The best way to accomplish this is to increase the efficiency with which the energy of gasoline is used and thereby obtain more automotive miles per gallon of fuel."108 At the time the paper was written, in late spring or early summer 1922, tetraethyl lead was still a secret within the company, but it was about to be announced to fellow scientists and test marketed. The reference to a means to "bridge the threatened gap" and increase in the efficiency of gasoline clearly implies the use of tetraethyl lead or some other additive to pave the way to new fuel sources.

This inference is consistent with an important statement in an unpublished 1936 legal history of Ethyl Gasoline for the du Pont corporation:

> It is also of interest to recall that an important special motive for this [tetraethyl lead] research was General Motors' desire to fortify itself against the exhaustion or prohibitive cost of the gasoline supply, which was then believed to be impending in about twenty-five years; the thought being that the high compression motors which should be that time have been brought into general use if knocking could be overcome could more advantageously be switched to [ethyl] alcohol. 109

Thus, during the time Kettering and Midgley researched anti-knock fuels (1916 to 1925), and especially after tetraethyl lead was discovered in December of 1921, there were two "ethyls" on the horizon for General Motors: Ethyl leaded gasoline, which would serve as a transitional efficiency booster for gasoline, and ethyl alcohol, the "fuel of the future" that would keep America's cars on the roads no matter what happened to domestic or world oil supply. Thus, Kettering's strategy in the post World War I years was to prepare cars for high-octane alternative fuels.

Clearly, G.M. switched gears sometime in 1923 or 1924. When controversy broke out about the public health impacts of leaded gasoline in 1924, Midgley and Kettering told the media, fellow scientists and the government that no alternatives existed. "So far as science knows at the present time," Midgley told a meeting of scientists, "tetraethyl lead is the only material available which can bring about these [antiknock] results, which are of vital importance to the continued economic use by the general public of all automotive equipment, and unless a grave and inescapable hazard exists in the manufacture of tetraethyl lead, its abandonment cannot be justified."110 And at a Public Health Service conference on leaded gasoline in 1925, Kettering said: "We could produce certain [antiknock] results and with the higher gravity gasolines, the aromatic series of compounds, alcohols, etc... [to] get the high compression without the knock, but in the great volume of fuel of the paraffin series [petroleum] we could not do that."111 Even though experts like Alice Hamilton of Harvard University insisted that alternatives to leaded gasoline were available,112 the Public Health Service allowed leaded gasoline to remain on the market in 1926. (Leaded gasoline was banned in 1986 in the US for the same public health concerns that had been expressed 60 years earlier).

Interestingly, Kettering and Midgley came up with another fuel called "Synthol" in the summer of 1925, at a time when the fate of leaded gasoline was in doubt. Synthol was made from alcohol, benzene and a metallic additive -- either tetraethyl lead or iron carbonyl. Used in combination with a new high compression engine much smaller than ordinary engines, Synthol would "revolutionize transportation."113 When Ethyl leaded gasoline was permitted to return to the market in 1926, Kettering and Midgley dropped the Synthol idea.

By the mid-1930s, the alliance between General Motors, DuPont Corp. and Standard Oil to produce Ethyl leaded gasoline succeeded beyond all expectations: 90 percent of all gasoline contained lead. Public health crusaders who found this troubling still spoke out in political forums, but competitors were not allowed to criticize leaded gasoline in the commercial marketplace. In a restraining order forbidding such criticism, the Federal Trade Commission said Ethyl gasoline "is entirely safe to the health of [motorists] and to the public in general when used as a motor fuel, and is not a narcotic in its effect, a poisonous dope, or dangerous to the life or health of a customer, purchaser, user or the general public."114

Direct comparison between leaded gasoline and alcohol blends proved so controversial in the 1920s and 1930s that government studies were kept quiet or not published. For instance, a Commerce Department report dated May 15, 1925 detailed dozens of instances of alcohol fuel use worldwide.115 The report was printed only five days before the Surgeon General's hearing on Ethyl leaded gasoline. Yet it was never mentioned in the news media of the time, or in extensive bibliographies on alcohol fuel by Iowa State University researchers compiled in the 1930s. Another instance of a "buried" government report was that of USDA and Navy engine tests, conducted at the engineering experiment station in Annapolis. Researchers found that Ethyl leaded gasoline and 20 percent ethyl alcohol blends in gasoline were almost exactly equivalent in terms of brake horsepower and useful compression ratios. The 1933 report was never published.116

International Use of Alcohol Fuels, 1920s and 30s

By the mid-1920s ethyl alcohol was routinely blended with gasoline in every industrialized nation except the United States. Ten to twenty five percent alcohol blends with gasoline were common in Scandinavian countries, where alcohol was made from paper mill wastes; in France, Germany and throughout continental Europe, where alcohol was made from surplus grapes, potatoes and other crops; and in Australia, Brazil, Cuba, Hawaii, the Philippians, South Africa, and other tropical regions, where it was made from sugar cane and molasses. In some countries, especially France, gasoline retailers were required to blend in large volumes of alcohol with all gasoline sold. Germany, Brazil and others also followed the "mandatory blending" model. In other countries, such as Sweden, Ireland and Britain, alcohol blends received tax advantages.117

In France, insecure supplies of oil during World War I led to a research program at the Pasteur Institute on sources of alcohol, including marine biomass sources like kelp.118 Continued research by a national fuels committee appointed in 1921 led to a recommendations of a national fuel consisting of 40 to 50 percent alcohol, and on Feb. 28, 1923, "Article 6" required gasoline importers to buy at alcohol from a state monopoly at a volume of at least 10 percent of their gasoline imports. "Article 7" provided a five-Franc per hectoliter tax on gasoline to help subsidize the alcohol monopoly. The blend, often reaching as much as 50 percent in some fuels, was not well accepted by consumers who were using engines which were specifically adapted to gasoline. At a minimum, carburetor settings needed to be changed to allow a greater fuel volume when the percentage of alcohol in the gasoline rose above 20 to 30 percent, and bitter complaints flowed in from motor clubs and garages.119 Amendments to the law in 1926 and 1931 helped create a more workable blend, and alcohol fuel use rose from 7.8 million gallons per year in 1925 to 20 million gallons in 1932.

Although the French government was initially one of the most enthusiastic toward alcohol, by 1932 so many other nations had surpassed the French effort that one proponent explained the "slowness" in reviving alcohol fuels use. It "is due in part to the poor results obtained when such fuels were first introduced and also to the casting of discredit upon such fuels by its adversaries who profit in the fuel business," said Charles Schweitzer, a research chemist in the Melle complex.120 Schweitzer also noted that alcohol was far preferable to leaded gasoline from a public health standpoint.121

National initiatives were also under way in Britain, Italy and Germany, and tax incentives were passed in all three nations to encourage the use of alcohol or alcohol blended fuels.

In England, a Departmental Committee on Industrial Alcohol reported in 1905 that alcohol from potatoes would be more expensive than gasoline, even though farmers wanted an alcohol industry built to absorb crop surpluses. In 1915 "agitation" for an alcohol industry was noted.122 A Fuel Research Board experimented with alcohol production between 1917 and 1924, and reported that while economics of traditional crops were marginal, novel crops like Jerusalem artichokes might be useful. "The most economical source [of alcohol] may be found ultimately in some of the luxuriant tropical growths within the Empire," an article in SAE Journal said. Even so, it continued attention to power alcohol was important. "Looking at the fuel question very broadly, the dominant fact is that almost all the fuel supplies at present used are what lawyers call wasting securities... As mineral fuels grow dearer, the advantage of fuels of vegetable origin must become accentuated."123 By the 1930s, two major blends of up to 30 percent alcohol -- Cleveland Discoll (part owned by Standard Oil of New Jersey) and Cities Service -- were widely used. Discoll continued to be used until the 1970s.

German firms such as I.G. Farben had by the early 1920s come up with a process for making synthetic methanol from coal, a development which was widely reported in the popular and technical press. Observing the synthesis of methanol and other fuels, the editor of Industrial and Engineering Chemistry said: "We do not predict that these will necessarily be the fuels to supplement our diminishing petroleum reserves ... But who shall say? The field is new and the opportunities are correspondingly great."124 The German ethyl alcohol monopoly of the pre-World War I (the Centrale fur Spiritus Verwerthung) had apparently fallen apart in the post-war chaos, but in September, 1926 a commercial fuel called "Monopolin" was introduced and "favorably received due to its anti-knock qualities." 125 The fuel, which included I.G. Farben's octane-boosting iron carbonyl additive, was endorsed by a famous race car driver of the era, Herbert Ernst, and alcohol use in fuel climbed from a quarter million gallons in 1923 to 46 million gallons in 1932. In 1930 gasoline importers were required to buy from 2.5 to 6 percent alcohol relative to their gasoline import volumes, but around 1933, I.G. Farben and several oil companies acquired 51 percent of Monopolin.126 Production of alcohol did not diminish, abut climbed by 1937 to about 52 million gallons per year as part of Hitler's war preparations.127

In Italy, the first Congress of Industrial Chemistry which took place in April 1924 focused strongly on fuel problems, with a large percentage of the papers concerned with alcohol fuels. 128 A strong scientific endorsement of the idea of using surplus crops in the national fuel mix led to a national decree on mandatory use of alcohol fuels in 1925. Several oil companies initially refused to blend alcohol with gasoline, but government pressures prevailed. By the late 1920s blends included Benzalcool (20% ethanol and 10% benzine) and Robur (30% ethanol, 22% methanol, 40% gasoline and other additives). Other nations, such as Hungary, Poland, and Brazil would follow the French and Italian examples with mandatory alcohol and gasoline blends in national fuels in the 1920s and 30s, while the tax incentive approach was adopted by many other European nations such as Switzerland, Sweden, Germany and Czechoslovakia.

The total use of alcohol as a substitute fuel in Europe may have never exceeded five percent, according to the American Petroleum Institute. Synthetic gasoline and benzene created by I.G. Farben from coal substituted for seven percent and 6.5 percent respectively of European petroleum by 1937. Synthetic gasoline was cheaper (at 17 to 19 cents per gallon) than alcohol at around 25 cents per gallon, API said. 129

In tropical nations where sugarcane was abundant and petroleum sources distant, blends and straight alcohol fuels were common. A tractor operator for American Sugar Co. in Cuba in the 1921-24 period recalled using cheap molasses derived alcohol by the barrel at a time when gasoline was expensive to import. The practice was to start the tractors with gasoline (which cost 40 to 50 cents per gallon) and then run them on alcohol (at 5 cents per gallon) for the rest of the day. When the tractors were to be idled over a weekend or between harvests, a little gasoline was injected into the cylinders to minimize corrosion.130 In 1931 the Brazilian government followed the French example and required alcohol mixtures in five percent of imported oil; blending continued sporadically through the 1950s. When the oil price shocks hit Brazil in the 1970s, the relatively recent technological expertise with alcohol fuel blends was a factor in that nation's adoption of an extensive alcohol fuels program.131

Alcohol use in fuel dropped by 25 percent in 1937 as Europe shifted gears and prepared for war. Crop failures in 1938 and 1939 eliminated surpluses and, temporarily, the need for an alcohol fuels program for farmers. With the outbreak of World War II, virtually all industrial alcohol production shifted to ammunition, and crop surpluses disappeared for a decade.

U.S. Commercial Alcohol Fuels Programs

Alcohol blended fuel was adopted in isolated instances in America during the 1920s and early 1930s. One World War I era American blend was "Alcogas." Little is known about it, although a photo of a service station at an unknown location survives 132 and references to Alcogas are found in the technical literature.133 Another 1920s blend was made from potatoes. The alcohol was distilled in Spokane and the blended fuel, called "Vegaline," was widely sold in Idaho and Washington state. "There was no apparent difference in the operation of the vehicle whether it was fueled by the Standard Oil pump or the Vegaline pump," said Ralph Curtis, a Washington resident. Curtis' great-grandfather was an enthusiastic investor in Vegaline. "He would tell us that by adding this alcohol to gasoline that the farmers of our area would benefit. His theory was that production of the alcohol would not be limited to cull potatoes but [could include] other unmarketable fruits and vegetables." The Vegaline plant was caught up in the great depression of 1929 and closed its doors.134

An apparently formative experience for the oil industry was Standard Oil's attempt to market a 10 percent alcohol blend in Baltimore for a few months in 1923. At the time, industrial alcohol from molasses was selling for less than 20 cents per gallon, while retail gasoline prices had reached an all-time high of 28 cents per gallon. But "difficulties" stopped the experiment, according to a cryptic 1933 internal memo of the American Petroleum Institute's "Special Technical Committee" on alcohol fuels. The memo did not refer to Standard itself, but said that a major company had experienced the difficulties. A 1939 publication would later identify Standard as the company in question. All that is known about the difficulties is that they were "largely were of a marketing and car operating nature and resulted from the instability of the alcohol-gasoline in the presence of water."135 Standard apparently did not clean out its fuel storage tanks and viewed the resulting "problem" as a difficulty inherent in using the fuel rather than in the fuel handling system. Standard did not document the experiment or publicize its results. No reference to it is found in the Baltimore Sun during this period. However, the American Petroleum Institute used this single incident as a technical justification for opposition to alcohol blended fuels in the 1930s.

Alcogas, Vegaline and other sporadic attempts to market an alcohol blended fuel never caught on in the 1920s, due to primarily to economic disadvantages but also to Prohibition and opposition by the oil industry. By the 1930s, with the country caught in the depths of the Great Depression, new ideas were welcome. Corn prices had dropped from 45 cents per bushel to 10 cents, it was only natural that people in Midwestern business and science would begin thinking about new uses for farm products, and indeed, alcohol fuel turned out to be the most controversial of these proposals. The battle between U.S. farmers and the oil industry in the 1930s over alcohol fuel has been reviewed by Giebelhaus136 and Bernton137 but aspects of this tumultuous debate has yet to be fully explored.

Many scientists, businessmen and farmers believed that to make their own fuel would help put people back to work and ease the severe problems of the Depression. Nearly three dozen bills to subsidize alcohol fuel were taken up in eight states in the 1930s. Most of the subsidy proposals involved forgiveness of state sales taxes. Not surprisingly, the incentives had the most support in the central farm states such as Iowa, Nebraska, Illinois and South Dakota. Legislation did pass in Nebraska and South Dakota, but the tax break passed by the Iowa legislature was struck down by the state supreme court. The Nebraska legislature also petitioned the US Congress for a law making 10 percent ethyl alcohol blending mandatory throughout the US. This proposal, along with a national tax incentive and other pro-alcohol bills, were defeated in Congress in the 1930s.

The thinking behind these proposals had little to do with energy substitution. Rather, it was "a form of farm relief and not energy relief," said Ralph Hixon, who along with Leo Christensen and others in Iowa State University's chemistry department, had been testing blends of alcohol and gasoline. "We found that it was one of the very best fuels, it gave a performance greater than Ethyl," Hixon said. The Ames chemists worked with local gasoline retailers to put a 10 percent alcohol blend with gasoline on sale in Ames service stations in 1932. The alcohol-gasoline pump at the Square Deal stations operated until the late 1930s, and the blend sold for 17 cents. It was "in competition with Ethyl," which also sold for 17 cents at the same stations.138 Some 200,000 gallons of Agricultural Blended Motor Fuel were eventually sold in an Iowa campaign in the early 1930s.139

Similar efforts, not as well backed up with research and documentation, broke out all over the Midwest. In Lincoln, Nebraska, the University of Nebraska and the Earle Coryell gasoline company marketed several hundred thousand gallons of "Corn Alcohol Gasoline Blend." In Peoria, Illinois, the Illinois Agricultural Association teamed up with Keystone Steel & Wire Co. and Hiram Walker distillery to produce half a million gallons of "HiBall" and "Alcolene" blended fuels.140 In Yankton, South Dakota, Gurney Oil Co. marketed 200,000 gallons of blended fuel.141

After legislative setbacks in 1933, the movement for alcohol fuels then came to be seen as part of a broader campaign for industrial uses for farm crops to help fight the Depression. It was called "farm chemurgy," and it was, in part, a populist Republican alternative to Democratic President Franklin Delano Roosevelt's agricultural policies. Henry Ford backed the idea by sponsoring a conference at Dearborn, Mich. in 1935. The conference created the National Farm Chemurgic Council, and annual conferences followed.142

Another key supporter of the farm chemurgy concept was the Chemical Foundation, quasi-federal agency which administered German patent royalties as part of reparations for World War I. The Chemical Foundation, with Ford's blessing, decided in 1936 to finance an experimental alcohol manufacturing and blending program in the Midwest. The chemurgy movement, with alcohol fuel as a controversial centerpiece, had far outstripping original legislative proposals and had grown into an unprecedented mixture of agronomy, chemistry and Prarie Populism. Many felt that the time had come to compete directly with the oil industry. By 1937 motorists from Indiana to South Dakota were urged to use Agrol, an ethyl alcohol blend with gasoline. Two types were available -- Agrol 5, with five to seven percent alcohol, and

Agrol 10, with twelve and a half to 17 and a half percent alcohol. "Try a tankfull -- you'll be thankful," the Agrol brochures said. The blend was sold to high initial enthusiasm at 2,000 service stations. However, Agrol plant managers complained of sabotage and bitter infighting by the oil industry,143 and market prices were also a major influence. Although Agrol sold for the same price as its "main competitor," leaded gasoline, it cost wholesalers and retailers an extra penny to handle it and cut into their profit "spread," Business Week said. "Novelty appeal plus ballyhoo provided sufficient increase in gallonage to offset the difference in spread. Now jobbers and dealers, having done their share, are again plugging the old house brands with four and a half cent spreads. Agrol is in the last pump -- for those who want it."

By 1939, the Atchison Agrol plant closed its doors, not in bankruptcy, but without viable markets to continue. The experiment had failed, but it was not the end of the story. As war broke out two years later, California assembly considered a motion to create an auxiliary fuel from surplus fruits and vegetables. President Franklin Roosevelt wrote the speaker of the assembly and said:

> "While it is true that a number of foreign countries process agricultural materials for the production of alcohol as a motor fuel, it is equally true that the motor fuel economy of countries possessing no petroleum resources is very different from such economy in the United States. It has never been established in this country that the conversion of agricultural products into motor fuel is economically feasible or necessary for national defense. On the other hand, it has been recognized for a long time that a real need exists in this country for the development of all the information possible on this very contentious subject..." 144

Roosevelt's intense political feud with the Republican forces who backed chemurgy, and especially with Sen. Guy Gillette over the Supreme Court issue in the late 1930s, would have led him to oppose virtually anything that the Midwestern Republicans advanced, but Roosevelt's judgement was premature. Several months later, as war industry plans were accelerated, the need for alcohol became apparent. Within two years, chemists and agricultural engineers from Midwestern universities who had tried their alcohol production ideas at the Agrol plant would be mass producing enormous quantities of ethyl alcohol for synthetic "Buna-S" rubber and for aviation fuel. From a pre-war peak production of 100 million gallons of alcohol per year, well over 600 million gallons of new capacity was created. The alcohol based system which in 1942 seemed capable of providing only one-third of the raw materials for the total synthetic rubber demand ended up supplying three quarters and making a significant impact on the war effort.145 The Agrol experience had clearly helped pave the way for this war effort, in terms of providing trained personnel, novel techniques and a history of mistakes to avoid. The resilience and flexibility of agricultural systems was well demonstrated, the chemists believed, because petroleum based synthetic rubber technologies owned by Standard and the German chemical company I.G. Farben had faltered at the critical moment. Without the previous experience in alcohol fuels production in the 1930s, the war effort might have been considerably delayed.146

The Agrol experiences and the mass production of alcohol for war industries were also recalled in the 1970s, when the conventional wisdom recognized only coal and nuclear power as alternatives to embargoed Middle Eastern oil.147 In contrast, it was clear at the end of World War II that eventually US oil reserves would be depleted. According to the US Tariff Commission in 1944: 148

"When a certain point in costs has been reached, several methods of meeting the situation will be available: These include: increased importation of petroleum; more complete recovery of domestic petroleum from the ground by various so-called secondary methods; conversion of natural gas into gasoline; extraction of oil from shale; synthesis of oil from coal; domestic production of alcohol from vegetable materials; and foreign production of such alcohol."

Oil Industry Opposition to Ethyl Alcohol Fuel

The onset of interest in alcohol fuel in 1933 caught the oil industry off guard, but once alarmed, it reacted swiftly. The American Petroleum Institute urged formation of state level "emergency committees" in the spring of 1933 to oppose proposals for tax incentives. In a set of memos sent under a red cover marked "IMPORTANT," API introduced a "coordinated program to be connected throughout the industry" to combat alcohol gasoline blending. The memo explained the threat: compulsory blend of alcohol and gasoline, as was used in France, Italy and Germany in the 1920s and early 30s, "will harm the petroleum industry and the automobile industry as well as state and national treasuries by reducing [oil] consumption," the memo said. The only ones to benefit would be distillers, railroads (which would transport the alcohol) and bootleggers "to whom would be opened brand new fields of fraud." 149

API's campaign was waged across many states, especially the Midwest, in the spring of 1933, and at the federal level for most of the 1930s.150 Technical experts in the oil industry claimed that alcohol fuel blends "are definitely inferior to gasoline alone from every angle of motor performance."151 Editorials by Lowell Thomas and other radio announcers paid for by oil industry sponsors claimed that alcohol fuel would make "speakeasys" out of gasoline stations because bootleggers could easily separate out the gasoline and sell the alcohol. Thomas said: "The automobile manufacturer resents it [alcohol] because it interferes with the horsepower of the motorists car, requires extensive carburetor changes and presents other difficulties..." (In fact, this might be true of pure alcohol but not alcohol blends with gasoline). Thomas' radio address was recorded in a cable sent from Sun Oil Co.'s J.Howard Pew to H.D. Collier, president of Standard Oil Co. of California, on April 26, 1933. "Confirming telephone conversation reference alcohol blend our radio announcement was as follows quote..." When an apparently large number of critical telegrams poured in, Sun took pains to distance Thomas from "our radio announcement," even writing a "suggested reply to Congressman Dirksen" in which Thomas was to say "This is news and not propaganda, which I myself nor my sponsors would for a moment tolerate over the air." The suggested reply was unsigned but written on stationary clearly showing the Sunoco watermark.152 It was not clear whether Thomas actually sent the suggested reply.

Other tactics involved private investigations of politicians and businessmen who supported alcohol blends. Sun Oil Co. investigated the private lives of the directors of Keystone Steel and Wire Co. and others.153 Then-Congressman Everett Dirksen, who supported Keystone, wrote constituents that he was being investigated by unknown people. "Here you have the proof of how the insidious oil lobby works in order to defeat any measure or any individual who opposes their interests," Dirksen said.154

Officials from Standard Oil of Indiana and the Ethyl Corp. exchanged worried letters about the outbreak of interest in alcohol blends in the winter of 1933. Standard's chief lawyer wrote Ethyl president Earle Webb: "Much publicity has gone through the state to the effect that alcohol mixed with gasoline makes a motor fuel high in anti-knock rating and the move has been to require gasoline to contain a high percentage of alcohol (manufactured locally, of course) or pay a high state tax. Manifestly this would materially interfere with the use of Ethyl in Iowa... Let me know what you are doing or intend to do, and to what extent we can cooperate."155 Webb wrote back: "I entirely agree that proposed legislation of this character is apt to have a serious termination and that almost anything may happen where there is so much discontent. We would very much appreciate being kept informed as to developments."156 By April, 1933, Standard was apparently worried about anti-trust laws, and wired Ethyl: "Believe absolutely necessary Ethyl Gasoline Corp. avoid any public opposition or any such direct action."157

Also in the 1930s, as Ethyl's marketing power grew, the company began to enforce what it considered to be "business ethics" on the market. Ethyl refused to grant dealer contracts to certain gasoline wholesalers, and often provided no formal explanation for their actions. The exclusion of "unethical" businessmen was especially aimed at those who cut prices, but it was a means of excluding from the entire fuel market any wholesaler who adopted practices which the oil industry disliked. Since wholesalers had to carry a wide range of products to survive, and since advertising had created enormous consumer demand for Ethyl, to be denied an Ethyl contract was in effect to be forced out of business. Most wholesalers could not or would not tell the Federal Bureau of Investigation why Ethyl would consider them unethical, but at least one wholesaler, the Earl Coryell company of Lincoln, Nebraska, blended ethyl alcohol about the same time that it could not get an Ethyl license.158 Pressure to stick with Ethyl leaded gasoline exclusively rather than try alcohol fuel blends would have been quite strong with this enforcement mechanism at the oil industry's disposal, but it is difficult to estimate how many gasoline dealers wanted to use alcohol instead of lead. In 1940 the U.S. Supreme Court upheld an anti-trust verdict against Ethyl, 159 but by then, the Midwestern alcohol fuel movement had disintegrated.

Clearly, the tactics used by the oil industry involved more than simple marketplace competition and public relations in response to the prospect of legislative controls. Yet economic issues and assumptions are at the heart of the dispute and deserve careful consideration.

Economics of Alcohol Fuel

Alcohol fuel has never been economically attractive as a straight gallon for gallon substitute for gasoline. When alcohol fuel returned to the American market in 1907 at a retail price of 32 cents per gallon, it was competing with gasoline at 18 to 22 cents per gallon. This roughly one-third advantage has been the rule for most of the 20th century in the U.S. In 1933, grain alcohol cost 25 cents per gallon wholesale as opposed to gasoline at 10 to 13 cents per gallon wholesale. Despite attempts to make alcohol from cheaper materials (such as wood waste and cellulose), the cost differential has been the most serious obstacle to the widespread use of alcohol fuel and, according to some historians, the primary focus of most oil industry resistance to its use.160

Modern researchers have noted that the value of alcohol as a fuel depends on whether it is considered a gasoline substitute or an octane enhancer. "If refiners turn to using alcohols as octane enhancers as lead phasedown occurs, there may be sufficient demand to warrant the capital outlay required for production facilities, in which case the market value of alcohol fuels would become much greater," according to the Canadian Energy Research Institute.161

Although T.A. Boyd and Thomas Midgley of Ethyl found ethyl alcohol to be a good anti-knock additive in 1922, it was not until 1933 that studies at Iowa State University publicly quantified the quality and economic comparisons between ethyl alcohol and Ethyl lead. Hixon and others concluded that it took 15 percent alcohol to create the octane boost of 3 grams of lead, as seen in the table below. Since Ethyl lead sold at a 3 cent premium over regular gasoline, the question was whether ethyl alcohol blends, with the same anti-knock / octane advantage, should not be sold at the same premium price. Proponents of alcohol blended fuels insisted that this -- and not the "extender" use of alcohol -- was the proper basis of comparison.

Table I
How Agriculture Compared
Ethyl leaded gasoline and ethyl alcohol

Fuel	Octane number	Increase	Wholesale Price *
Base fuel	56	--	10
Base fuel plus 3 grams lead	68	12	13
Base fuel plus 10 % ethyl alcohol	65	9	11.5 **
Base fuel plus 20 % ethyl alcohol	80	24	13 **

* Wholesale price; assumes 25 cents per gallon for ethyl alcohol and 10 cents per gallon for gasoline purchased from jobber in Midwest.

** Note substitution of base fuel with 10 percent ethyl alcohol means 9 cents worth of gasoline added to 2.5 cents worth of alcohol. Substitution of 20 percent ethyl alcohol is 8 cents gasoline + 5 cents alcohol = 13.

Also note: Iowa State included a half-cent per gallon blending charge for the two alcohol blended fuels. Data from: Iowa State College, The Use of Alcohol In Motor Fuels, Progress Report Number III, Divs. of Industrial Science, Engineering, Agriculture; Jan. 20, 1933. Also: Rayburn D. Tousley, "The Economics of Industrial Alcohol," Washington State Univ., 1945.

The oil industry did not use the same economic yardsticks in comparing the costs of alcohol fuel blends, although they did incorporate the same half cent per gallon blending charge used by the Iowa State researchers. According to one pamphlet, alcohol cost five to ten times more than gasoline, depending on the price of corn, and had technical problems. "Seeing that alcohol fuels cannot compete with gasoline on a price or quality basis ... huge sums of money [are] now being spent on a nationwide propaganda campaign to convince the American people that alcohol gasoline would bring permanent prosperity to farmers." The "Alky-Gas" scheme "robs Peter to pay Paul," that is, it takes money from motorists to pay for farm relief. It would be cheaper just to pay farmers to burn their corn.162

Table II

How the Oil Industry Saw Alcohol Fuel Economics

Fuel	Cost
Total cost gasoline one gallon	13.5 cents
Compared with	
Base gasoline 9/10 gal	12.1 cents
Ethyl alcohol 1/10 gal (at 39.3 cents/gallon)	3.9 cents
Total cost 10 % alcohol-gasoline blend	16 cents

Notes: All prices before taxes. Source "Who would Pay for Corn Alcohol?" Iowa Petroleum Commission pamphlet, 1935, American Petroleum Institute library, Washington, D.C.

Perhaps the most extreme example of the oil industry's argument is illustrated by a letter from Joseph Pew of Sun Oil Co. to an alcohol fuels proponent. Pew said that alcohol had 60 percent the BTU value of gasoline, and it would only be worth 60 percent of the value of gasoline. To a refinery, gasoline was worth only 6 cents per gallon. Thus, alcohol would have to cost only 3.6 cents per gallon to compete with gasoline, and even then there would still be the expense of having it transported to the refinery. "I figure it isn't worth more than a cent" per gallon, Pew said.163

The differences in these economic assumptions demonstrate that the debate over alcohol fuel that broke out in the Midwest in the 1930s depended greatly on the viewpoint of the company or individual. In essence, political conditions shaped the marketplace and the new competition faced a difficult economic playing field heavily tilted toward established industries.

Conclusion

Alcohol fuels as anti-knock blending agents were well known long before tetraethyl lead was discovered in 1921, and their technical qualities had been well characterized by scientists in the US and in Europe by 1925. The experience in other nations with alcohol blended fuels was usually (although not universally) quite positive. Practical techniques were well known to overcome most problems with alcohol as a pure fuel or in blends with gasoline. Fuel blends were economically successful in countries where oil was more expensive or where independence in fuel supply was seen as a political or strategic problem.

Alcohol fuels advocacy among American farmers was present in the 1906 - 1908 period and again in the 1930s. Scientists and engineers in the U.S. and Europe ranged from neutral to enthusiastic about the clean burning, high compression characteristics of alcohol fuel, yet the U.S. oil industry claimed it was technically inferior. Charles Kettering and his General Motors researchers were particularly interested in alcohol from cellulose in the 1919 - 1925 time frame, and saw Ethyl leaded gasoline as paving the way for the "fuel of the future" by providing a temporary octane boost and allowing engine compression ratios to increase. In 1924, however, G.M. allied itself with Standard Oil, creating the Ethyl Corp. Shortly afterwards, G.M. researchers contradicted years of their own research and hundreds of other studies by claiming that only tetra ethyl lead could produce anti-knock results.

If there is an historical lesson to learn from the "fuel of the future," it is that technology is often political. In this case, fuel technology developed in a direction that was a matter of policy choice and not predetermined by any clear advantage of one technology over another. For different reasons, Henry Ford and Charles Kettering both saw the fuel of the future as a blend of ethyl alcohol and gasoline leading to pure alcohol from cellulose. A dedicated agrarian, Ford thought new markets for fuel feedstocks would help create a rural renaissance. On the other hand, Kettering, as a scientist, was worried about the long term problem of the automotive industry's need for oil, a resource with rapidly declining domestic reserves. Clearly, the shortage of domestic oil that was feared in the 1920s has occurred in the late

20th century, although it has hardly been noticed because of the abundance of foreign oil. Whether the oil substitute envisioned by the scientists and agrarians of the first half of the century would be appropriate in the latter half remains an open question.

"Many years may be necessary before the actual development of such a [fuel] substitute," Kettering concluded. There was always the possibility, according to Kettering's friend Charles Stewart Mott, "that if a time ever came when the sources of [fossil] heat and energy were ever used up ... that there would always be available the capturing of... energy from the sun... through agricultural products ..."164

Footnotes

1 "Ford Predicts Fuel from Vegetation," New York Times, Sept. 20, 1925, p. 24.

2 Reynold Millard Wik, "Henry Ford's Science and Technology for Rural America," Technology and Culture, Summer 1963; also see "Ford Predicts Fuel from Vegetation," New York Times, Sept. 20, 1925, p. 24

3 Augustus W. Giebelhaus, "Resistance to Long-Term Energy Transition: The Case of Power Alcohol in the 1930s," paper to the American Association for the Advancement of Science, Jan. 4, 1979.

4 Hal Bernton, Bill Kovarik, Scott Sklar, The Forbidden Fuel: Power Alcohol in the 20th Century (New York: Griffin, 1982).

5 Bill Kovarik, Fuel Alcohol: Energy and Environment in a Hungry World, (London: International Institute for Environment and Development, 1982). Also, "Charles F. Kettering and the Development of Tetraethyl Lead in the Context of Technological Alternatives," Society of Automotive Engineers, Fuels & Lubricants Division, Historical Colloquium, Baltimore, Md. Oct. 17, 1994.

6 Francis P. Garvan, "Scientific Method of Thought in Our National Problems," Proceedings of the Second Dearborn Conference on Agriculture, Industry and Science (New York: The Chemical Foundation, 1936), p.86.

7 John Staudenmier, Technology's Storytellers (Oxford: Oxford University Press, 1988), p. 175.

8 Congress des Applications de L'Alcool Denature, 16 au 23 Dec., 1902, Automobile-Club de France, National Agricultural Library collection, Beltsville, Md. Ironically, it was in this same Paris exhibition hall in 1900 that American writer Henry Adams found dark inspiration for his book "the Virgin and the Dynamo," in which he described the end of religious faith.and the dawn of powerful yet somehow profane technology. Adams dark vision might have been lightened had he attended the 1902 Paris exposition. Not only was the scale of machinery far less imposing, being made up of small horseless carriage engines and household items like alcohol-powered irons and stoves, but the symbolism of the exposition had a far different flavor.

9 National Geographic, Vol. 31, Feb. 1917, p. 131.

10 Christy Borth, Chemists and Their Work (New York: Bobbs-Merrill, 1938).

11 Thomas Midgely, "Our Liquid Fuel Reserves," Soceity of Automotive Engineers, Oct. 13, 1921; CF Kettering, "The Fuel Problem," draft address, unprocessed papers, Thomas Midgely drawer, GMI Alumni Foundation Collection of Industrial History, Flint, Mich (cited as GMI).

12 George Basalla, The Evolution of Technology, (Cambridge University Press, 1988) p. 197.

13 Some 152 popular and scholarly articles under the heading "Alcohol as a Fuel" can be found the the Readers Guide to Periodical Literature between 1900 and 1921; about 20 references to papers and books written before 1925 are found in the Library of Congress database catalog; a 1933 Chemical Foundation report lists 52 references before 1925 on alcohol fuels; a 1944 Senate report lists 24 USDA publications on alcohol fuels before 1920; and several technical books from the period document hundreds of references from the 1900 - 1925 period.

14 Daniel Yergin, The Prize, (NY: Simon & Schuster, 1991), p. 14, also p. 51.

15 Henry R. Luce exhibit on American Journalism, Smithsonian Museum of American History, Washington DC. 1970 - 1990.

16 Sam H. Schurr and Bruce C. Netschert, Energy in the American Economy 1850 - 1975; An Economic Study of its History and Prospects (Baltimore, Resources for the Future, Johns Hopkins Press: 1960).

17 Anon., "Gasoline to Burn," Ethyl News, March, 1943, p. 20.

18 Robert N. Tweedy, Industrial Alcohol (Dublin, Ireland: Plunkett House, 1917).

19 Index of patents issued from 1790 to 1873, Inclusive, (Washington, D.C.: US Patent Office). Listed as "patent for alcohol for burning fluid, carbureted," March 17, 1834.

20 Lyle Cummins, Internal Fire (Warrenton, Pa.: Society of Automotive Engineers, 1989), p. 81. Also, Horst Hardenberg, Samuel Morey and his Atmospheric Engine (Warrendale, Pa.: Society of Automotive Engineers, Feb. 1992), SP922; also Katharine Goodwin and Charles E. Duryea, Captain Samuel Morey: The Edison of His Day (White River Junction, Vermont: The Vermonter Press, 1931); also Gabriel Farell Jr., Capt. Samuel Morey who built a Steamboat Fourteen Years Before Fulton, (Manchester, NH: Standard Book Co., 1915). Ray Zirblis, "Was Samuel Morey Robbed?" Vermont Life, Autumn, 1994, p. 53.

21 History of Light, pamphlet by the Welsbach Gas Co., Philadelphia Penn, 1909; on file in the Smithsonian collection of Advertising, Museum of American History, Washington, D.C.

22 Free Alcohol Law, Senate Finance Committee Hearings on HR 24816, Feb. 1907, Doc. No. 362, page 320. The authority cited is the Civil War era Special Commissioner of the Internal Revenue Service, David A. Wells, and the apparent reference is to the New York regional market. It is possible that ovar a hundred million gallons per year of camphene were sold by the late 1850s. The city of Cincinattie alone reportedly used 10 million gallons in 1860. Note that kerosine sales in 1870 reached 200 million gallons.

23 Harold F. Williamson & Arnold R. Daum, The American Petroleum Industry, 1859-1899, The Age of Illumination (Evanston Ill NW U Press, 1959).

24 Rufus Frost Herrick, Denatured or Industrial Alcohol, (New York: John Wiley & Sons, 1907), p. 16.

25 Free alcohol hearings, U.S. Senate 1907, p. 320. Also, Free Alcohol Hearings, House Ways & Means Committee, 59th Congress, Feb.-Mar. 1906. It is interesting that Wells' contemporary account places the discovery of petroleum after the cessation of alcohol fuel use. Note also that most turpentine came from the U.S. South at this time.

26 John K. Brachvogel, Industrial Alcohol: Its Manufacture and Use, (New York: Munn & Co., 1907) p. 13.

27 "How Long the Oil Will Last," Scientific American, May 3, 1919, p. 459.

28 Robert N. Tweedy, Industrial Alcohol .

29 Author's search of records at the U.S. Patent Office, Crystal City, Virginia.

30 Lyle Cummins, Internal Fire (Warrendale, Pa.: Society of Automotive Engineers, 1989).

31 Ibid., p. 81. See above for additional references.

32 Ibid., p. 135. The patent was not granted "because of cited prior art." Apparently the idea was a commonplace. American burning fluid lamp manufacturers described the carburetion process in brochures in the 1850s.

33 Ibid., p. 281.

34 Brachvogel, Industrial Alcohol, p. 353; also G.W. Monier-Williams, Power Alcohol:Its Production and Utilization (London: Oxford Technical Publications, 1922, p. 275.

35 "Alcohol Automobiles at the Paris Alcohol Exhibition," Scientific American, Dec. 28, 1901. Note that gasoline powered automotive races had begun five years earlier with the Paris-Rouen race of 1894.

36 "Alcohol as a fuel for motor carriages," Scientific American, June 1, 1901, p. 344.

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39 C.E. Lucke, Columbia University, and S.M. Woodward, USDA, "The Use of Alcohol and Gasoline in Farm Engines," USDA Farmers Bulletin No. 277, (Washington: GPO, 1907).

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41 "Paris Exhibition of Alcohol Consuming Devices," Scientific American, Nov. 16, 1901

42 Rufus Frost Herrick, Denatured or Industrial Alcohol, (New York: John Wiley & Sons, 1907), p. 307.

43 Brachvogel, Industrial Alcohol, p. 13.

44 "Launching of a Great Industry: The Making of Cheap Alcohol," New York Times, Nov. 25, 1906, Section III p. 3.

45 Statement of Leonard B. Goebbels, Otto Gas Engine Works, Senate Finance Committee hearings on HR 24816, Feb. 1907.

46 Brachvogel, Industrial Alcohol.

47 "Free Alcohol Distilleries," New York Times, Sept. 13, 1906. The source of the statistic is U.S. Consul General Thackara in Berlin.

48 Col. Sir Frederic Nathan, "Alcohol for Power Purposes," The Transactions of the World Power Congress, London, Sept. 24 - Oct. 6, 1928.

49 Robert Tweedy, Industrial Alcohol.

50 Tweedy, Industrial Alcohol. Tweedy did not directly quote Roosevelt but the phrasing is suggestive of Roosevelt's tone.

51 "Auto Club Aroused over Alcohol Bill," New York Times, April 26, 1906.

52 Free Alcohol Hearings, House Ways & Means Committee, p. 113.

53 "Tax Free Alcohol," New York Times, May 22, 1906.

54 Capen testimony to Senate Finance Committee.

55"The New Cheap Illuminant," New York Times, May 25, 1906.

56 "Future of Alcohol in the Industries," New York Times Aug. 5, 1906.

57 "Farmers Neglect Making of Alcohol,"New York Times, Dec. 23, 1907; note that the USDA's 1907 report said alcohol prices were 15 cents per gallon in Germany, while benzene was 16 cents per gallon and gasoline 32 cents per gallon).

58 Tweedy, Industrial Alcohol.

59 Ibid.

60 "Utilization of Farm Crops," Hearings of a Subcommittee of the Committee on Agriculture and Forestry, United States Senate, S. Res. 224, (1942), Part I, p. 286.

61 Gasoline and alcohol do not readily mix unless the alcohol is nearly free of water ("anhydrous" or 99.4% pure), or unless a blending agent or "binder" is used, such as benzene or a higher alcohol (butanol, propanol, etc.). Otherwise, alcohol tends to separate from gasoline at lower temperatures, a problem known as "phase separation." Ordinary distillation only achieves 95 percent purity because of a final chemical bond between the remaining water and alcohol known as the azeotrope. The final azeotropic processing tends to be somewhat complex and expensive.

62 "Future of Alcohol in the Industries," New York Times Aug. 5, 1906. Note that in publications as recent as 1990, fuel tanks of double the volume are supposed to be needed for pure alcohol vehicles because of this smaller BTU value.

63 C.E. Lucke, Columbia University, and S.M. Woodward, USDA, "The Use of Alcohol and Gasoline in Farm Engines," USDA Farmers Bulletin No. 277, (Washington: GPO, 1907).

64 Robert M. Strong, "Commercial Deductions from Comparisons of Gasoline and Alcohol Tests on Internal Combustion Engines," Dept. of the Interior, U.S. Geological Survey, Bulletin 392, (Washington: GPO, 1909).

65 R.M. Strong and Lauson Stone, "Comparative Fuel Values of Gasoline and Denatured Alcohol in Internal Combustion Engines," Bureau of Mines Bulletin No. 43, (Washington: GPO, 1918). Strangely, some 75 to 80 years later, many technical editors still believed that a crticial problem with alcohol fuel was that lower BTU necessitated double-sized fuel tanks.

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68 W. Watson, Proc. Inst. Automobile Engineers, 1913-14, p. 73, cited in Monier-Williams.

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71 W.R. Ormandy, "The Motor Fuel Problem," Journal of the Institute of Petroleum Technologists, Vol. 5, 1919, p. 33-66.

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85 S.J.W. Pleeth, Alcohol: A Fuel for Internal Combustion Engines (London: Chapman & Hall, 1949) .

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88 Joseph C. Robert, Ethyl: A History of the Corporation and the People Who Made It (Charlottesville, Va.: University Press of Virginia, 1983); Also Stuart Leslie, Boss Kettering (New York: Columbia University Press, 1983);T.A. Boyd, Professional Amateur (New York: E.P. Dutton, 1957); Rosamond Young, Boss Ket (New York: Longmans, Green & Co., 1961); Graham Edgar, "Tetraethyl Lead," paper to the American Chemical Society, New York, Sept. 3-7, 1951, reproduced by the Ethyl Corp.; T.A. Boyd, "Pathfinding in Fuels and Engines," Society of Automotive Engineers Transactions, (April 1950), pp. 182-183; and Stanton P. Nickerson, "Tetraethyl Lead: A Product of American Research," Journal of Chemical Education 31, (November 1954), p. 567.

89 "A Report of Fuel Research by the Research Division of the Dayton Metal Products Co. and the U.S. Bureau of Mines," July 27,1918, Midgley unprocessed files, GMI.

90 "Alcogas as Aviation Fuel Compared with Export Grade Gasoline," SAE Journal, June 1920, p.397.

91 Charles F. Kettering, "Studying the Knocks,: How a Closer Knowledge of What Goes on In the Cylinder Might Solve the Problems of Fuel Supply," Scientific American, Oct. 11, 1919, p. 364.

92 Leslie, Boss Kettering , p. 155. Ethyl alcohol was "income" rather than "capital" because it could be produced from renewable resources.

93 Boyd, Early History p. 54.

94 Large-scale production of benzene was questionable. Even if all the coal mined in the U.S. in 1920 were used to supply benzene, only about 900 million gallons, or one-fifth of the U.S. gasoline supply would be replaced, he said.

95 T.A. Boyd, "Motor Fuel From Vegetation," Journal of Industrial and Chemical Engineering 13, No. 9 (Sept. 1921), pp. 836 - 841.

96 C.F. Kettering, "The Fuel Problem," undated, probably 1921, Kettering collection unprocessed, GMI.

97 This is probably a good point to note that a good many original documents are missing from public General Motors archives. These include: "The Lead Diary," a collection of several thousand original documents from which T.A. Boyd and Charles Kettering refreshed their memories as their memoirs were written in the 1940s; Test diaries and day-to-day

records of experiments conducted during 1920 - 22 period when tetraethyl lead was discovered by G.M. researchers in Dayton, Ohio.; Minutes of the Board of Directors of the Ethyl Corp 1924 to 1940; Minutes of the "Medical Committee" of du Pont, G.M. and Standard, 1924 to 1925. Reports of the Standard Oil Co.of New Jersey experiment with alcohol fuel blends in Baltimore, Md. in 1923 and (possibly) correspondence with G.M. researchers about the experiment; Reports on the use of the century plant in Mexico to produce alcohol at 7 cents per gallon, cited in 1922 memo from Midgley to Kettering; and records or memos relating to "Synthol" experiments, Dayton G.M. labs, summer 1925.

98 Leslie, Boss Kettering, p. 156.

99 Zimmerschied to Kettering, Feb. 27, 1920; Kettering to Zimmerschied, March 3, 1920, Kettering collection, GMI. Note that carburetors had been built with lacquered cork floats before this time, which was not a problem with gasoline. However, alcohol was a solvent for the lacquer. Therefore, GM switched to metal carburetor floats to accommodate the new international fuel blends.

100 Application Serial No. 362,139, Patent No. 1578201, issued Mar. 23, 1926. The patent covers blending alcohol and unsaturated hydrocarbons, particularly olefins formed during the cracking process.

101 Harold Hibbert, "The Role of the Chemist in Relation to the Future Supply of Liquid Fuel," Journal of Industrial and Chemical Engineering 13, No. 9 (Sept. 1921) p. 841.

102 Boyd to Midgley, July 8, 1920, Midgley unprocessed files, GMI.

103 This is an important point in technical discussions. Many who object to alcohol fuel, ostensibly on technical grounds, will omit any mention of the possibility of a "binder," which is a small amount of a higher alcohol or other compound that prevents "phase separation" of gasoline from alcohol in the presence of water. The American Petroleum Institute's discussions concerning the technical problems of alcohol blends in the early 1930s, for example, did not mention such binders. .

104 "The Discussion" transcript of SAE meeting discussion, Indianapolis, Oct. 1921. Midgley unprocessed files, GMI.

105 Thomas Midgley, "Discussion of papers at semi-annual meeting," SAE Journal, Oct. 1921, p. 269.

106 Midgley to Kettering, May 23, 1922, Factory Correspondence, Midgley unprocessed files, GMI.

107 Thomas A. Midgley and T.A. Boyd, "Detonation Characteristics of Some Blended Motor Fuels," SAE Journal, June 1922, page 451. Note: italics indicate a section used at the oral presentation at a June 1922 SAE meeting but not published in the SAE paper; oral presentation from Midgley unprocessed files, GMI.

108 Thomas Midgley and Thomas Boyd, "The Application of Chemistry to the Conservation of Motor Fuels," Industrial and Engineering Chemistry, Sept. 1922, p. 850.

109 N. P. Wescott, Origins and Early History of the Tetraethyl Lead Business, June 9, 1936, Du Pont Corp. Report No. D-1013, Longwood ms group 10, Series A, 418-426, GM Anti-Trust Suit, Hagley Museum & Library, Wilmington, Del., p. 4.

110 "Radium Derivative $5,000,000 an ounce / Ethyl Gasoline Defended," New York Times, April 7, 1925, p. 23; Also, Thomas Midgley, Jr., "Tetraethyl Lead Poison Hazards," Industrial and Engineering Chemistry, Vol. 17, No. 8 August, 1925, p. 827.

111 U.S. Public Health Service, Proceedings of a Conference to Determine Whether or Not There is a Public Health Question in the Manufacture, Distribution or use of Tetraethyl Lead Gasoline, PHS Bulletin No. 158, (Washington, D.C.: U.S. Treasury Dept., August 1925), p. 6. (Hereafter cited as PHS Conference). Of course, Kettering originally planned to get alcohols fom outside the paraffin series through grain and cellulose.

112 "U.S. Board Asks Scientists to Find New 'Doped Gas,'" New York World, May 22, 1925, p. 1.

113 "Work on New Type of Auto and Fuel," New York Times, Aug. 7, 1925; also "New Auto, Fuel to Save Costs are

Announced," United Press, Aug. 6, 1925.

114 Federal Trade Commission Docket No. 2825, Cushing Refining & Gasoline Co., June 19, 1936, Dept. of Justice files, 60-57-107, National Archives, Washington, D.C.

115 Homer S. Fox, "Alcohol Motor Fuels," Supplementary Report to World Trade in Gasoline, Minerals Division, Bureau of Domestic & Foreign Commerce, Trade Promotion Series Monograph No. 20 (Washington, D.C.: Dept. of Commerce, May 15, 1925). The report provided detailed statistics on trade volume, duties, tax incentives and laws surrounding the use of alcohol blended fuels, including ethanol and methanol, in France, Germany, England, Italy and 15 other countries were it was routinely used.

116 R.B. Gray, "On the Use of Alcohol-Gasoline Mixtures as Motor Fuels," unpublished, USDA, April 1933, National Agricultural Library, Beltsville, Md.

117 World Trade in Gasoline, Bureau of Domestic & Foreign Commerce, US Dept. of Commerce monograph, Trade Promotion Series No. 20, May 15, 1925.

118 "Seaweed as a Source of Alcohol," Scientific American, Nov. 9, 1918, p. 371. A simple acid hydrolysis technique yielded only about 10 gallons per ton.

119 "What French Motorists Say about Alcohol-Gasoline Motor Fuel Blends," Washington, D.C.: American Motorists Association, Dec. 15, 1933. The association reprinted letters to the magazine of the French National Federation of Automobile, Bicycle, Aeronautical and Related Trades. In a decidedly non-random poll, the majority of 40 letter writers disapproved of the inconveniences of alcohol blends, primarily citing problems with cork floats in carburetors and hesitation and stalling with high volume alcohol blends used in unadapted engines. Note that GM changed cork floats to metal floats in the early 1920s to deal with this problem.

120 Charles Schweitzer, "L'Etat Actuel De La Question De L'Alcool Carburant," Chimie & Industrie Vol. 28, No. 1, 1932; Translated and abstracted by E.I. Fulmer, R.M. Hixon, L.M. Christensen, W.F. Coover in "The Use of Alcohol in Motor Fuels: Progress Report Number I, A Survey of the Use of Alcohol as Motor Fuel in Various Foreign Countries," May 1, 1933, unpublished manuscript, Iowa State University archives.

121 "Anti-detonants: leur emploi dans les carburants et leur danger," Ind. Chimique, 1931, No. 208, p. 332, cited in Fulmer, "The Use of Alcohol in Motor Fuels."

122 New York Times, Nov. 28, 1915.

123 "Power Alcohol from Tubers and Roots, SAE Journal, May, 1925, p. 546. Also, Nathan, "Alcohol for Power Purposes."

124 Industrial and Engineering Chemistry, April 1925, p 334 .

125 E.I. Fulmer, "The Use of Alcohol in Motor Fuels."

126 Ibid.

127 Gustav Egloff, Motor Fuel Economy of Europe (Washington, D.C.: American Petroleum Institute, Dec. 1940).

128 "Italian Congress of Industrial Chemistry," Industrial & Engineering Chemistry, July 10,1924, p. 6.

129 Egloff, Motor Fuel Economy of Europe.

130 Personal communication, Fred R. Robinson to columnist Jack Anderson, April 24, 1978. See footnote No. 91. Cuba continued using alcohol fuels throughout the 20th century, especially after the communist revolution of 1960, in order to stretch petroleum supplies from the former Soviet Union.

131 Bernton, The Forbidden Fuel, p. 140, p. 226.

132 Personal communication, Maurine Lorenzetti, editor, Oxy-Fuel News, Information Resources Inc., Washington DC, March, 1991.

133 "Alcogas as Aviation Fuel Compared with Export Gasoline," SAE Journal, June 1920, p. 397.

134 Personal communication, Col. Ralph Curtis, April 17, 1979. Curtis' letter to columnist Jack Anderson was prompted by Anderson staffer Hal Bernton's articles about gasohol.

135 "Analysis of Technical Aspects of Alcohol Gasoline Blends," Prepared by American Petroleum Institute Special Technical Committee, No. 216 in an unspecified series, undated, with memo dated April 10, 1933. Series 4, Box 52, Pew collection, Hagley Library, Wilmington, Del.

136 Augustus W. Giebelhaus, "Resistance to Long-Term Energy Transition: The Case of Power Alcohol in the 1930s," American Association for the Advancement of Science, Jan. 4, 1979.

137 Hal Bernton, Bill Kovarik, Scott Sklar, The Forbidden Fuel: Power Alcohol in the 20th Century (New York: Griffin, 1982).

138 Joyce Manchester, "Gasohol born in Ames, sold at service station," Ames Daily Tribune, March 11, 1978.

139 Donald Despain, The One and Only Solution to the Farm Problem (New York: Vantage Press, 1956), p. 113. Critics of alcohol fuel might describe this book as one of the world's longest crank letters because Despain is so obviously emotional about his subject. Factual information should be seen in this light as potentially biased.

140 Everett M. Dirksen, "The Congressional Front," March, 1933, Dirksen Congressional Center archives, Peoria, Ill. Also, "Why the Proposal to Blend Alcohol with Gasoline for Automotive Fuel is Simple and Practical..." Keystone Steel & Wire CO, Peoria, Ill.

141 Donald Despain, The One and Only Solution to the Farm Problem (New York: Vantage Press, 1956), p. 113.

142 See, for example, Proceedings of the Third Dearborn Conference, Farm Chemurgic Journal, National Farm Chemurgic Council, Dearborn, Mich., various volumes. Numerous references to the Farm Chemurgy movement are found in the literature.

143 Statement of L.M. Christensen, "Use of Alcohol from Farm Products in Motor Fuel," Committee on Finance, U.S. Senate Hearings on SB 522, May 1939 (Washington: GPO, 1939); Also see "Alky-Gas Flops in Sioux City, Business Week, July 30, 1938, p. 20; "Farm Crop Alcohol Blended into Auto Fuel," Popular Mechanics, Oct. 1937; "Alky-Gas Gets Going," Business Week, Dec. 25, 1937; "Blackstrap Alky-Gas," Business Week, Sept. 9, 1939.

144 "Power Alcohol: Not yet feasible or necessary in U.S.," Scientific American, April, 1942.

145 U.S. Tariff Commission, Industrial Alcohol, War Changes in Industry Series, Report No. 2, (Washington, GPO: Jan. 1944).

146 It certainly would have been delayed had not chemists familiar with details of the synthetic rubber process been smuggled by British spy groups out of Poland and Russia to the US just as war broke out. The British were well aware that Standard Oil of N.J. had a deal with Farben to block synthetic rubber, and considered Standard a "hostile and dangerous element of the enemy" according to William Stephenson's A Man Called Intrepid (New York: Ballentine, 1976), p. 284.

147 For example, see Al Frisbie, "The Old Alcohol Plant: Is there a Lesson There?" World-Herald Magazine, May 28, 1978, Omaha, Nebraska. Similar articles by other enterprising reporters turned up information about American energy history which had been completely overlooked.

148 US Tariff Commission, Industrial Alcohol.

149 Harry Benge Crozier, Director of Public Relations to members of the public relations advisory committee, American

Petroleum Institute, April 24, 1933, Series 4 Box 52, J. Howard Pew papers, Hagley Museum and Library, Wilmington, Del.

150 Hundreds of memos on the organization of the anti-alcohol campaign originating from API's various committees, including the industries, public relations and refinery committees, are found in Series 4 Box 52, J. Howard Pew papers, Hagley Museum and Library, Wilmington, Del. Memos prepared by the "Special Technical Committee" and the "Special Economics Committee" show an intense level of activity. Every major American oil company and most minor ones were involved in the campaign against alcohol fuel through these committees, either directly or indirectly. It is interesting to note that the position papers presented by these committees contained not a whiff of dissenting data, nor were any of the conclusions footnoted or referenced in any way whatsoever.

151 Gustav Egloff, "Alcohol Gasoline Motor Fuels," National Petroleum Association paper, April 21, 1933, Series 4 Box 52, J. Howard Pew papers, Hagley Museum and Library, Wilmington, Del.

152 These docuemtns are found in Series 4 Box 52, J. Howard Pew papers, Hagley Museum and Library, Wilmington, Del.

153 "I have told you what we could find out about the Keystone officials ..." E.W. Teagle, Chicago office of Sun, to J.N. Pew, April 27, 1933. Series 4 Box 52, J. Howard Pew papers, Hagley Museum and Library, Wilmington, Del.

154 Everett M. Dirksen, "The Congressional Front," May 5, 1933, Dirksen Congressional Center archives, Peoria, Ill.

155 L.L.Stephens to Webb, Jan. 24, 1933, transcribed by FBI agents, US Dept. of Justice Central Files, RG 60-57-107, Box 386-387, National Archives, Washington, D.C. Parentheses as transcribed.

156 Webb to Stephens, Feb. 9, 1933. US Dept. of Justice Central Files, RG 60-57-107, Box 386-387, National Archives, Washington, D.C.

157 William B. Plummer to Graham Edgar, Ethyl, April 12, 1933, US Dept. of Justice Central Files, RG 60-57-107, Box 386-387, National Archives, Washington, D.C. It should be noted that while the FBI found this telegram, other documentary sources about Ethyl's activities at this time that should have been reviewed are missing from GMI, Justice Dept. archives and other areas.

158 FBI Interview with L.L. Coryell, Jr., Jan. 18, 1935, US Dept. of Justice Central Files, RG 60-57-107, Box 386-387, National Archives, Washington, D.C.

159 Ethyl Gasoline Corp. et al, v United States, 309 US 436, March 25, 1940.

160 For example, Giebelhaus reaches this conclusion.

161 Michelle Heath, Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels, Canadian Energy Research Institute, Study no. 29, Jan. 1989.

162 "The ABCs of Alky-Gas," Iowa Petroleum Public Relations Committee, 1936, library, American Petroleum Instutute, Washington, D.C.

163 Joseph Pew to H. Smith Richardson, Dec. 23, 1938, Hagley Museum & Library, Wilmington, Del.

164 C.S. Mott, Kettering Oral History Project, Interviewed by T.A. Boyd, October 19, 1960, GMI, Flynt, Mich.