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Ethanol versus Gasoline : The Contestation and Closure of a Socio-technical System in the USA

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ABSTRACT A variety of forces aligned at the turn of the last century to make ethyl alcohol – what is today known as ethanol – inefficient and uneconomical as a fuel alternative. Rather than a case of inevitable technological unfolding, the transition from King Coal to Big Oil was a sociologically contingent event. As a controversy study, this paper seeks to avoid the reductionist tendencies of past historical analyses of fuel. The author also seeks to redress a fundamental gap within the STS literature on the subject of automobile/fuel socio-technical systems, where the story of ethyl alcohol remains conspicuously absent. Among studies that examine how/why the automobile became locked in, little is said about ethyl alcohol, even though, as this paper details, it remained part of the fuel landscape well into the 20th century. The paper begins with an overview of the landscape developments of fuel during the later decades of the 19th century. Attention then turns to examining the various factors that went into shaping the automobile/fuel socio-technical system within the US during the first half of the 20th century.

Keywords biofuel, ethanol, petroleum, problem redefinition, socio-technical system

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The story behind ethanol is a lengthy one. Recent bans on methyl tertiary butyl ether (MTBE), the rising cost of oil, and post 9/11 sentiments in the US that emphasize energy independence from the Middle East are just some of the forces propelling the ethanol juggernaut forward. And a juggernaut it has become: the Energy Information Administration estimates that demand for ethanol will grow by 5.2% annually, reaching 14.6 billion gallons by 2030 (Winters, 2007); the utilization of corn for ethanol production increased from 70 million bushels in 1980 to 1.6 billion bushels in 2005 (Corn Marketing Program of Michigan, 2007); and, as of April 2007, the ethanol production industry within the US consisted of 115 plants operating in 19 states with 79 additional plants under construction (Clean Fuels Development Coalition, 2007). Yet few are aware of the fuel debate – between ethanol and gasoline – that raged a century ago.

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Unlike so many Whiggish accounts of fuel (see for example, Robert, 1983; Yergin, 1991; Shah, 2004), I do not assume that the transition from King Coal to Big Oil was predetermined or inevitable. While the shift from coal to oil as the fuel par excellence occurred, this transition was the effect of an amalgamation of forces that aligned in such a way as to *make* ethyl alcohol (what is today called ethanol) inefficient and uneconomical as a fuel alternative (this distinguishes the following analysis from other works that offer largely descriptive accounts of alcohol fuel's past [see for example, Giebelhaus, 1980a; Berton et al., 1982; Wright, 1993; Kovarik, 1998]). In short, as a controversy study, this paper seeks to avoid the reductionist tendencies of previous analyses. No one factor can be linked to alcohol fuel's ultimate demise as a legitimate alternative to gasoline.

This paper also seeks to redress a fundamental gap within the STS literature on the subject of automobile socio-technical systems. Within this literature (for example, Hard, 1994; Kline & Pinch, 1996), the story of ethyl alcohol remains conspicuously absent. For example, scholars have skillfully examined the early contestation between, say, gasoline, diesel, and steam engines (for example, Hard & Jamison, 1997). In describing how gasoline automobiles eventually became 'locked in' – while, for example, steam autos were slowly 'locked out' – these studies come to the conclusion that 'automotive engineering began to stabilize around the gasoline engine … in 1907 … [and] from then on, it became possible to write the early history of automobility as a gasoline success story' (Hard & Jamison, 1997: 149). As described in the pages that follow, this historical account is not entirely accurate. The gasoline automobile socio-technical system still had to contend with ethyl alcohol.

To set the stage, the paper begins with an overview of the 'landscape developments' (Geels, 2005) of fuel during the latter decades of the 19th century. I then discuss the competing socio-technical systems that remained in play during the earlier decades of the 20th century. It is important to realize that 'fuel' is a rather peculiar technology. Nothing is inherently fuel. Fuel is simply a term for a carrier of energy. Importantly, therefore, a socio-technological system must be in place that requires a particular carrier of energy if said carrier is to be called 'fuel'. In what follows, I detail how gasoline and ethyl alcohol as fuels were effects of, and in turned affected, these broader socio-technical systems.

Landscape Developments from the Mid 19th to Early 20th Century

Alcohol was a popular fuel for lighting during the first half of the 19th century. It was cheap, clean burning, and, perhaps most important of all (from a consumer's standpoint), it was derived from renewable resources; namely, farm commodities. In 1860, 13,157,894 gallons of alcohol were burned in the US for lighting (Herrick, 1907). The Revenue Act of 1862, however, would alter alcohol fuel's trajectory for decades to come. This Act was passed to help generate revenue to pay for the Civil War. One of the many items contained within this act (it also created the Internal Revenue Service) was a 'sin tax' on all alcohol. The alcohol tax began at 20 cents per gallon in 1862 and rose to $2.08 per gallon by 1864 (Herrick, 1907). While there was a temporary alcohol tax imposed between 1814 and 1817 to help fund the War of 1812, and an earlier short-lived 'Whiskey Tax', alcohol had largely been untaxed before the Revenue Act of 1862 (Nelson, 1995).

The tax, however, made no distinction between alcohol for drink and what is known as 'denatured' or 'industrial' alcohol (alcohol that has been made unfit for consumption). Consequently, all forms of ethyl alcohol were taxed. (Methyl alcohol [alcohol from wood] was not taxed because it cannot be ingested nor is it flammable [thus excluding it as a type of fuel].)[1] When the tax was first enacted, Congress did want to exclude industrial alcohol from taxation and to tax only its consumption as a beverage, yet 'no way could be devised, as at the time denaturing was not an established fact as it is now' (Herrick, 1907: 7). The tax therefore remained in place for the rest of the century. Before the tax, alcohol sold for approximately 50 cents a gallon, which was about one-half the price of lard oil and one-third the price of whale oil (both major fuel sources at the time) (Berton et al., 1982). After 1864, alcohol rose to more than $2.50 a gallon.

Yet, while industrial alcohol continued to be taxed in the US, other countries began passing legislation to encourage its use. Germany, for example, passed a 'denaturing law' in 1887, which exempted industrial alcohol from taxation. Similar laws were passed in England, the Netherlands, and France – indeed, throughout much of Europe – before the turn of the century (Long, 1906). This legislation did much to stimulate industrial alcohol production in those countries. By the turn of the century, between 5% and 6% of all German potatoes were going into the production of alcohol (*Science News Letter*, 1928). In 1901, the total production of alcohol in Germany exceeded 112 million gallons (Baskerville, 1906). By 1903, the use of alcohol to power internal combustion engines in Germany exceeded the one million gallon mark, with the government calling for production of alcohol fuel to move past three million gallons (with the help of government support [for example, agricultural subsidies]) (*Science News Letter*, 1928). Similarly, while Britain possessed tremendous coal reserves (by World War I Britain produced approximately 25% of the world's coal [Jones, 1978]), it could not claim any domestic oil fields of significance. Thus, while the US was burning kerosene (an oil product) in the late 1800s, in part because of its large oil reserves and the aforementioned tax on alcohol, Germany and England turned to alcohol.

There was another factor at play, which goes beyond the fact that the US possessed large domestic oil fields while other countries did not. The unique quality of early crude extracted from oil wells in the US before the turn of the century is often forgotten. The first commercial well was brought online in 1859 by E.L. Drake in Pennsylvania. Soon oil wells throughout western Pennsylvania were established, just at the time that the 1862 alcohol tax was brought into effect. Between 1860 and 1862, oil production in Pennsylvania increased from 2000 barrels to 3 million (Hordeski, 2007). This oil had an important material characteristic: these early fields yielded upon refining a very high percentage of lighter petroleum products, such as kerosene. In the early 1870s, refiners were recovering about 75% kerosene from the crude oil (Jones, 1978).

This point is significant because at the time there was only a market for this 'lighter' crude. Fuel oil and diesel, which are derived from the 'heavier' elements of crude, were not yet in wide use (liquid fuels at this time were still used primarily for lighting, making the more combustible kerosene of greater value than less refined fuel oil and diesel). In short, it was a bit of ecological luck that the first oil fields to be discovered in the US happened to yield a type of crude that could be most easily marketed by oil companies. These early oil fields thus proved immensely profitable. Although the company was not formally established until 1870, the origins of Standard Oil can arguably be traced back to 1865, when Rockefeller began to buy up and consolidate the oil industry in the US. By 1879, Standard Oil controlled 90% of all the oil refined in the US (Yergin, 1991). Had these early oil fields yielded heavier and therefore less marketable crude, Standard Oil would likely not have experienced the same rate of investment returns, which would have at least slowed its movement toward consolidation. Consequently, when oil fields began to yield heavier crudes by the 1880s, the oil industry (read: Standard Oil) had sufficient capital to produce a market for these previously useless residuals.

Even after improvements to refining technology in the early 1890s, crude coming from newly discovered oil fields in Ohio, Indiana, Texas, and California were yielding less than 50% light products (for example, kerosene and gasoline). Early on, the heavier petroleum materials were discarded as waste, for example, burned in open pits (Jones, 1978). As fields began yielding higher ratios of heavier crude, however, oil companies started to devise ways to transform this by-product into a product. Standard Oil formed a special department whose sole purpose was to promote these heavier fuels. One strategy involved giving away – or selling well below cost – thousands of barrels of heavy fuel oil. The most effective strategy, however, involved producing, selling, and sometimes providing free-of-cost oil-burning appliances to demonstrate the practicality of this fuel (Jones, 1978).

The level of consolidation in the industry as a result of Standard Oil Trust focused a tremendous amount of resources on resolving the 'problem' of oil fuel. Had the industry still been in its infancy or had it been composed of many competing firms it is difficult to see how the same level of resources – and coordination of research and development – could have been directed at turning oil fuel into a desirable commodity in just a couple of years. Yet, in only 5 years, Standard Oil did just that. While fuel oil represented only 8.6% of refined petroleum product output in the US in 1904, that proportion had grown to 40.5% by 1909 (Schurr & Netschert, 1960).

Fuel oil's main competition was coal, not alcohol; and oil at this time was beginning to replace coal as fuel for boats (for example, Britain's Royal Navy began this conversion process in the second decade of the 20th century [Jones, 1978]), trains, and industrial furnaces (North, 1911). Nevertheless, the development of uses for the heavier elements of crude is important to the story of alcohol. By the turn of the century, it was estimated that gasoline constituted only 2% of raw crude (Baskerville, 1906). By finding a market for the remaining 98% of its product, the oil industry was able to increase its influence over the entire fuel market. Granted, the distribution and storage needs differed across petroleum-based fuels. Yet revenues generated across oil fuel types could be pooled for buying more refineries, railroads, pipelines, and oil fields. This is exactly what Standard Oil did, and it brought the industry tremendous gains in efficiency and profitability (Bringhurst, 1979).

Eventually, the alcohol industry received the break it needed. In 1906, a bill to repeal the tax on industrial alcohol was passed. The bill had wide public support (although, in the words of Senator Champ Clark, 'the Rockefellers' were firmly against the tax repeal [Kovarik, 1998]). President Theodore Roosevelt supported the bill, as did the Temperance Party (hoping to find some virtuous use for an otherwise evil product), the president of the Automobile Club of America, and most auto manufacturers (Kovarik, 2003). Following the repeal, the price of industrial alcohol dropped to roughly 30 to 35 cents a gallon, where it remained in the ensuing years (McCarthy, 2001). Nevertheless, the price of gasoline remained well below that of alcohol (when the tax on industrial alcohol was repealed gasoline reportedly cost approximately 15 cents a gallon [Baskerville, 1906]).

The reasons behind this cost differential between alcohol and gasoline were numerous (for example, at that time fuel alcohol in Cuba was selling for approximately 10 cents a gallon [Herrick, 1907], while in Germany the price per gallon was 13 cents [McCarthy, 2001]). One often-missed reason centers on the requirement of denaturing alcohol, which involves making the fuel undrinkable and thus exempt from the alcohol 'sin tax'. While no firm numbers exist on the subject, it is fair to say that the cost of alcohol fuel would have been considerably less had the denaturing requirement not existed. At the time, denaturing was accomplished by mixing 90% ethyl alcohol (alcohol made from grain, potatoes, beets, corn, and so on) with 10% of methyl alcohol (wood alcohol) (Wright, 1907). Whereas the price of industrial alcohol hovered in the 30 to 35 cent range, methyl alcohol could cost well over a dollar a gallon (Baskerville, 1906). Thus, the denaturing requirement created an additional expense that ultimately made alcohol fuel more costly than it would otherwise have been. As a chemist at the time noted: 'It is somewhat unfortunate that wood alcohol remains still the chief material used in the denaturing process, since when used in so large a proportion as 10 per cent, it is a considerable expense … ' (Gradenwitz, 1907: 393).

This was just a couple of decades before Prohibition in the US – a period when the Temperance Movement was most influential. The idea of using potable (drinkable) alcohol for fuel – and lifting the sin tax on this very sinful liquid – would have had little support among the public and politicians. It is worth noting, however, that to support its potato industry Czechoslovakia in the 1930s mandated by law that all of its automobiles run on a 20% alcohol blend using non-denatured – which is to say drinkable – alcohol (*Science News Letter*, 1933). Langdon Winner (1999) has written famously about how artifacts have politics. Alcohol fuel at the turn of last century most certainly had politics, which is to say that it quite literally *embodied* certain values. In the context of the denaturing requirement, those values spoke to issues of public safety, the social good, and the overall sinfulness of potable alcohol. As in all politics, these values had consequences; in this case, alcohol that was of the more expensive industrial variety.

Fixing Engine Design Around Gasoline

Many early internal combustion engines ran on alcohol. The first such engine, built by Samuel Morey of Oxford, NH, US, in 1826, ran on ethyl alcohol and turpentine (Cummins, 2002). Having been exempt from taxation in many European countries well before it was exempted in the US, alcohol fuel had become popular in certain parts of the world by the turn of the century. In 1902, a major exhibit was held in Paris where alcohol fuel was celebrated. Spectators could observe a range of machines powered by this renewable fuel – from automobiles to stoves, lamps, farm machinery, and boats (Kovarik, 1998). In Germany, the military was employing a fuel blend containing 80% alcohol and 20% benzol (Hamlin, 1915). Similarly, by 1906 approximately 10% of all engines built by Deutz Gas Engine Works of Germany were designed to run on denatured alcohol (Kovarik, 1998). And in Greece the use of alcohol fuel had become so great that the government was forced to impose an alcohol fuel tax to compensate for the loss of revenues from petroleum taxes (Berton et al., 1982).

To read newspapers, magazines, and scientific reports at the time one would have thought that alcohol – not gasoline – was on the brink of becoming the fuel par excellence for the newly birthed century. In a 1925 lecture to the Chemists Clubs of New York, for example, M.C. Whitaker offered the following remarks:

> 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 fuels is now safely established by actual experience*. (Whitaker, 1925, quoted in Hixon, 1933: 1) (my emphasis)

Proponents of alcohol were also fond of noting numerous other less immediate characteristics that further positively distinguished their fuel from gasoline. These characteristics, while perhaps less visible to engineers and others in the automobile industry, were said to be important and needed to be included in any overall evaluation. In the words of one such proponent:

> Mixtures of alcohol vapor and air stand a higher compression without premature explosion than gasoline and air. Insurance companies do not take the risk, or an extra hazard is charged, when gasoline is stored near a barn. Burning gasoline radiated sufficient heat to set fire to things at a distance from it. Alcohol does not. Gasoline is insoluble in and floats upon water.

> When afire, the conflagration is spread by throwing water on it. Alcohol dissolves in water in all proportions. When afire, it is readily quenched by water, as it does not burn when diluted. (Baskerville, 1906: 214)

Others pointed to the environmental benefits (although never stated as such) of alcohol fuel, specifically in regard its clean-burning properties. Such arguments, for example, can be found in the pages of the turn of the century magazine *The Horseless Age* (the first automotive magazine in the US):

> 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 exhaust from an alcohol engine is never clouded with a black or grayish smoke, as is the exhaust of a gasoline or kerosene engine when the combustion of the fuel is incomplete, and it is seldom, if ever, clouded with a bluish smoke when a cylinder oil of too low a fire test is used or an excessive amount supplied, as is so often the case with gasoline engine. The odors of denatured alcohol and the exhaust gases from an alcohol engine are also not likely to be as obnoxious as the odor of gasoline and its products of combustion. (Clough, 1909: 607)

It is also important to note that insurance companies, city ordinances, and company laws at the time placed restrictions on the use of gasoline in particular areas due to the risks associated with this liquid. Alcohol, on the other hand, was often exempt from such restrictions. Recognizing that ‘price’ is in part an effect of costs that are (and are not) externalized, alcohol proponents made the case of how users must include *all* costs when evaluating the two fuels:

> The restrictions that are placed on the use of denatured alcohol are, however, never greater than those placed on the use of gasoline. In some places they are such that the use of an alcohol engine is permitted where the use of a gasoline engine is prohibited. For instance, alcohol motor trucks and automobiles are admitted to many of the streamer piers in New York that are not open to gasoline machines. When the restrictions placed upon the use of denatured alcohol are less than those placed on the use of gasoline or where safety and cleanliness are important requisites, the advantages to be gained by the use of alcohol engines in place of gasoline engines may be such as to overbalance a considerable increase in fuel expense, especially if the cost of a fuel is but a small portion of the total expense involved, as is often the case. (Clough, 1909: 607)

Having reviewed a wide range of peer-reviewed and popular press reports on the subject from this era, I can find no clear indication as to which was considered the clearly superior fuel: gasoline, alcohol, or a blend of both. If anything, the bulk of evidence points to alcohol as having greatest support among scientists and automobile engineers. Other than being cheaper than alcohol at the pump – although hidden costs (like increased insurance premiums) make the issue of ‘price’ more complex – gasoline did not appear the obvious victor. This is not to suggest that alcohol was problem-free as a fuel for the automobile socio-technical regime in place at the time. Engines fueled with alcohol had problems starting at colder temperatures. Yet this was easily remedied by adding ether to the fuel (Kovarik, 1998). The most significant problem resided in what is known as 'phase separation', which refers to the separation of alcohol and gasoline in the presence of water (though this was only 'problematic' because the socio-technical system included gasoline). In order to create alcohol blends the fuel must be essentially free of water, producing what was called 'anhydrous ethyl alcohol' or 'absolute alcohol' (Pines, 1931). Yet this problem too was quickly and cost-effectively resolved through a process of distillation: 'The dehydration of alcohol by continuous distillation [when the alcohol is initially manufactured], and at a reasonable cost, has therefore removed a serious defect in the alcohol-blended fuel, and today it occupies the position of being at once available and profitable to use ... ' (Doran, 1924: 641). This did not stop gasoline proponents, however, from exploiting phase separation for their own ends.

Well after being resolved through processes of distillation, phase separation continued to be employed by the oil industry as justification for abandoning alcohol (Giebelhaus, 1979). This argument was bolstered by Standard Oil's brief foray into selling an alcohol blend in a test market (although this had more than anything else to do with the company having access to cheap surplus alcohol from the World War I munitions industry [Berton et al., 1982]). For a few months in 1923 Standard Oil attempted to market an alcohol blend in the Baltimore area (Robert, 1983). The company quickly abandoned this experiment, however, noting mechanical problems that were attributed to alcohol's instability in the presence of water (Giebelhaus, 1980b; Robert, 1983). It was only later revealed that the problem stemmed from Standard Oil not properly cleaning out its fuel storage tanks (water was left in them). In other words, this attribute – being 'problematic' – was a function of alcohol's 'fit' within a socio-technical system designed around gasoline.

What about engine design? Contrary to previous accounts, which are conspicuously silent on the subject of alcohol fuel (for example, Hard & Jamison, 1997), automotive engineering did *not* stabilize around the gasoline engine during the first decade of the 20th century because of its superiority (as defined by the 'needs' of the system). Numerous studies were conducted from 1900 well into the 1930s to determine the efficiency and effectiveness of engines powered by alcohol, gasoline, and alcohol/gasoline blends (Giebelhaus, 1979). In 1906, for example, the US Department of Agriculture conducted a series of experiments with alcohol fuel in various internal combustion engines. All engines were operated using 94% grain alcohol. The conclusions reached were quite positive for alcohol:

> When an engine is run on alcohol its operation is more noiseless than when run on gasoline, its maximum power is usually materially higher than it is on gasoline, and there is no danger of any injurious hammering with alcohol such as may occur with gasoline (Sorel, 1907: 16).

Another notable study was conducted jointly by the US Geological Service and the US Navy. Between 1907 and 1908 approximately 2,000 tests were performed on alcohol and gasoline engines. It was concluded that higher compression ratios – which improve an engine's efficiency – could be reached with alcohol. Thus, while gasoline carries about one-third more energy than an equal amount of alcohol (120,000 BTUs per gallon compared with about 80,000 BTU per gallon [Hartline, 1979]), the higher engine compression ratios allowed by the latter made the two fuels highly comparable (Tunison, 1920). As the report argued: '[I]n regard to general cleanliness, such as absence of smoke and disagreeable odors, alcohol has many advantages over gasoline or kerosene as fuel' (cited in Kovarik, 2003: 6).

The oil industry responded by pointing to other tests that arrived at just the opposite conclusion. Perhaps the most potent was a study performed by the American Automobile Association (AAA) in 1933. Five stock cars, powered by different fuels, were operated on a circular racetrack. The findings of the experiments pointed to alcohol as the inferior fuel. The cars powered with alcohol had poorer mileage and less power. These results were then broadcast in newspapers across the country (Berton et al., 1982). Alcohol proponents, however, quickly rebuffed the tests. Dr Leo Christensen, Professor of Chemistry at Iowa State University, noted how several members of the test committee had refused to sign off on the tests, arguing that they were performed in 'extreme heat and with unusually volatile gasoline' (quoted in Berton et al., 1982: 20). Though not mentioned in reports at the time, the AAA study brings up an important automobile/fuel socio-technological reality of the 1930s: engines were designed with low compression ratios.

Knocking occurs when combustion of the air/fuel mixture occurs unevenly in the cylinder. The existence of multiple combustion fronts produces a shock wave within the cylinder, resulting in what is commonly known as 'engine knock' (Taylor, 1985). One of the major problems with early gasoline (pre tetraethyl lead) was that it produced this engine knock. Because of its low octane, engineers could not develop a high compression ratio engine to run on conventional gasoline, which would have eliminated any knocking in the engine. A resolution to this problem, which had become apparent in the early years of the 20th century, was blending alcohol with gasoline. Studies consistently revealed that alcohol boosted octane sufficiently to eliminate engine knock (by creating more complete combustion in the cylinder) and therefore produced an overall cleaner-running engine (see for example, Sorel, 1907; Tunison, 1920).

While automobile engineers experimented early on with different engine configurations, such as steam, diesel, and alcohol (Hard & Jamison, 1997; Berton et al., 1982), these designs began to stabilize around gasoline during the first decade of the 20th century. This design closure, however, was less an effect of gasoline being universally recognized as superior to alcohol. Rather, just the opposite was the case. Engines were being built with low compression ratios so as to accommodate the low octane gasoline of the day. In turn, these engines could easily be converted to burn pure ethyl alcohol by merely adjusting the air/fuel mixture within the carburetor. Indeed, even without adjustments these engines could operate on alcohol blends, though their efficiency and power would be greatly compromised (Sorel, 1907). For example, the

Hart-Part Company of Charles City, Iowa, began equipping some of their tractors with alcohol burning carburetors in 1908 (Wik, 1962). That same year Ford began production of his famous Model T, which was designed to run on alcohol, gasoline, or an alcohol blend (Pahl, 2005). Olds Gas Power Company, a competing auto manufacturer, soon followed suit, offering components for their cars' carburetor that would allow them to run on either alcohol or gasoline (Berton et al., 1982). And in 1917, Henry Ford began promoting his new Fordson Tractor, which was designed to run on either alcohol or gasoline (Wik, 1962).

Not long after Ford began mass-producing the famous Model T, alcohol enthusiasts had hopes that engines would become increasingly designed around this fuel: 'It also seems reasonable to expect a greater general improvement in alcohol engines than in gasoline engines' (Clough, 1909: 607). In truth, just the opposite happened. In order to handle either fuel, early automobiles (and tractors, motorized boats, and so on) had to be designed to handle the poorer of the two: namely, gasoline. This ultimately worked against alcohol fuel. Having been designed for gasoline, lower compression engines, as one would expect, did not perform as well when run on alcohol.

Farm Chemurgic Movement: An Unsuccessful Attempt at Problem Definition

The beginning of the Farm Chemurgic Movement has been traced to two papers published in October 1926 (Beeman, 1994; Wright, 1995). One was written by William 'Billy' Hale (at the time of publication Hale was Director of Organic Chemical Research at the Dow Chemical Company). Appearing in Henry Ford's newspaper *The Dearborn Independent*, Hale's piece (titled 'Farming Must Become a Chemical Industry: Development of Co-products will Solve the Present Agricultural Crisis') made the case for how industry could be effectively built around domestic agricultural commodities. The other paper was written by Wheeler McMillen, who at the time was Chair of the Chemistry and Chemical Technology Division of the National Research Council. Published in *Farm and Fireside*, this paper (titled 'Do We Need This Foundation') similarly called for a synergistic relationship between agriculture and industry. Given the authors' prominence, both pieces were widely read (Wright, 1993).

The term 'chemurgy' combines the Egyptian root for chemistry and the Greek root for work (Wright, 1993). First coined in 1934 by 'Billy' Hale (1934), the term was intended to evoke a comparison with metallurgy (in that both were concerned with extracting properties from nature and converting them for industrial ends) (Effland, 1995). To put it simply: the goal of the Farm Chemurgic Movement was to find industrial applications for the growing surplus of farm products following World War I. As H.E. Barnard, a Farm Chemurgic Council member, explained in the *Journal of Farm Economics* in 1938:

> While our chemists and experiment stations have been showing the farmer how to produce more and more they have given less attention to the

> importance of developing uses for his [or her] crops outside the satisfaction of the appetites of men [sic] and animals. … By using the power produced by gasoline instead of by corn and hay burning horses, we have deprived the farmer of a market for the crops from many million acres. (Barnard, 1938: 119)

This raises the question: Why did the Chemurgic Movement only begin to take shape in the 1920s? One reason was World War I. During this time, Europe's grain production was severely disrupted. Because of this, the Allies turned to the US for grain, sending grain prices skyward (Santos, 2006). Moreover, once the US entered the war the government began guaranteeing farmers a minimum price of at least $2 a bushel for wheat in an attempt to encourage production. Consequently, in 1918 and 1919 farm income exceeded nonfarm income by 50% (Shideler, 1976). There would have been little incentive among farmers during this time to invest in the Farm Chemurgic Movement. Similarly, there would have been little incentive for industry to look toward agriculture for its raw materials. Grain prices were simply too high to make such a venture economically feasible.

Following the Armistice in November 1918 farm prices began to drop with the fall harvest. Europe was soon using its land to raise crops again, creating a downward pressure on prices. Farmers during this period were also beginning to mechanize. The replacement of human and animal power with technology allowed farmers to cultivate far larger tracts of land than ever before (it has been estimated that farmers placed into production an additional 20 million acres during this period) (Shideler, 1976). Together, these events served to flood an already glutted grain market. Out of this emerged the 'farm crisis' that came on the heels of the World War I (Hall, 1973). While commodity prices would soon rebound, concerns over overproduction persisted throughout the 1920s (Shideler, 1976). Improvements in seed varieties, mechanization trends, and advances in artificial fertilizers all contributed to a level of agricultural output that had never before been witnessed. Yet it was not until the Great Depression that conditions became acute enough to cause actors in industry and agriculture to look toward chemurgy for potential solutions to their problems.

Grain prices were at near record lows in the early 1930s. In 1933, for example, corn prices slumped to as little as 10 cents a bushel (Giebelhaus, 1980a). In this market environment, agricultural commodities were suddenly commercially attractive to those in industry (industry had long been attracted to chemurgic ideas, but high market prices kept them from acting on these sentiments). Similarly, those associated with agriculture saw in chemurgy a way to develop new markets for their commodities, which, it was hoped, would result in an upswing in commodity prices.[2] In light of these incentives, industry and agriculture begun to form behind what would eventually be termed the Farm Chemurgic Movement. And within this movement, alcohol was priority number one.

A number of works have already examined the organizational history of the Farm Chemurgic Movement, from its inception in the 1920s to its decline in the 1940s (for example, Giebelhaus, 1980a; Wright, 1993, 1995; Effland, 1995; Finlay, 2004). For the sake of brevity, I will not revisit this history. Instead, the following discussion centers upon something yet to be addressed in the alcohol fuel literature; namely, the struggle between alcohol and oil proponents over just what 'the problem' was that these fuels were to resolve. Both fuels had their attributes. The rub, however, lay in determining which of these attributes best fit with the 'needs' of society. And to the victor of 'problem redefinition' (Bijker, 1995: 278) – alcohol or gasoline – went the spoils. For, as Hughes (1987: 53) explains, 'technological systems [emerge to] solve problems or fulfill goals'.

Problem: Anti-Knock, Engine Noise, and So On

Perhaps alcohol proponents' most vociferous claim, up until that point, lay in alcohol's anti-knock properties. Yet this would soon be taken away from them when, in December 1921, Thomas Midgley (an engineer for General Motors) discovered the anti-knock properties of tetraethyl lead when blended with gasoline (Robert, 1983). With the invention of leaded gasoline higher compression engine ratios could now be designed, which made them cleaner burning and more efficient than their pre-leaded counterparts. Of course, lead was known, even at this time, to be a very pernicious poison. (As one paper at the time reports: 'refiners' and jobbers' licenses were necessary for the maintenance of the quality of the treated gasoline [leaded gasoline] and for the protection of the public in its use of a product containing a *dangerous poison*' [Harbeson, 1940: 191, emphasis added].) Yet leaded gasoline possessed one important property that alcohol did not: it could be patented.

In 1923, General Motors calculated that lead would allow them to capture 20% of the gasoline market, resulting in revenues in excess of $36 million a year in the first years of commercial applications. They calculated that within 10 years profits would reach $360 million a year and by the 1950s profits would be in the billions (Kovarik, 2005: 385). The ease of producing alcohol, on the other hand, precluded any possibility of corporations quickly securing a monopoly over this anti-knock additive. In August 1924, General Motors and Standard Oil of New Jersey (which had recently patented their own lead manufacturing technique) pooled their patents and created the Ethyl Gasoline Corporation (Robert, 1983). The discovery of lead's anti-knock properties removed a multitude of reasons once used by alcohol proponents to problematize the gasoline engine: engine knock, engine inefficiency, engine noise, and so on.

Problem: National Energy Dependence

Alcohol proponents also played upon the nationalistic sentiments of the time by attempting to link oil dependency upon other countries with questions of sovereignty and national defense. As one alcohol proponent explained during the second annual national meeting of chemurgists (formally called the Second Annual Dearborn Conference of Agriculture, Industry, and Science): 'They say we have foreign oil. Well, how are we going to get it in case of war?

It is in Venezuela, it is out east, in Persia, and it is in Russia. Do you think that is much defense for your children?' (Garvan, 1936: 11).

In the end, this frame also proved problematic. Unlike most other Western countries (for example, Germany, England, and so on), the US was still years away from becoming a net importer of oil (that did not occur until 1947 [Terzian, 1991]). Yet we only know this with the benefit of hindsight. In 1920, for example, the US only imported 12% of its petroleum, though estimates at the time predicted this would rise to nearly 25% by 1925 (White, 1920). Granted, the US did make major oil field discoveries in the early 1930s. Something, however, occurred in the 1920s to help insulate oil from the 'problem' of national energy dependence. With a shift from government-funded petroleum reserve estimates to estimates funded by the oil industry, oil reserve projections changed from showing this resource as finite to one that was almost limitless. Dennis (1985) links these competing estimates to competing interests. Specifically, the oil industry sought to downplay the possibility of the US ever becoming a net importer of petroleum. In conditions of domestic scarcity, 'only government intervention could assure the US a continuous supply of imported oil', which was something the oil industry wished to avoid at all costs (Dennis, 1985: 245). Conversely, the government *wanted* greater control over this industry. Thus, whereas the government's estimates helped, among other things, to 'force the oil companies to realize that they needed geologists to find the increasingly scarce resource' and to legitimize federal oversight in oil extraction, refinement, and distribution (Dennis, 1985: 254), the oil industry's estimates sought to 'forestall direct government regulation of the oil industry' (Dennis, 1985: 242; see also Bowden, 1982, 1985). Estimates pointing to inevitable increases in oil imports would justify 'increased government regulation as a means of halting rampant waste in both the production and consumption of oil' (Dennis, 1985: 245). For a number of reasons (for example, the institutional connections, lobbying power, and media saturation), the petroleum industry's estimates were given greater weight by policy makers and the public, which greatly undermined the effectiveness of the national energy dependence frame utilized by alcohol proponents.

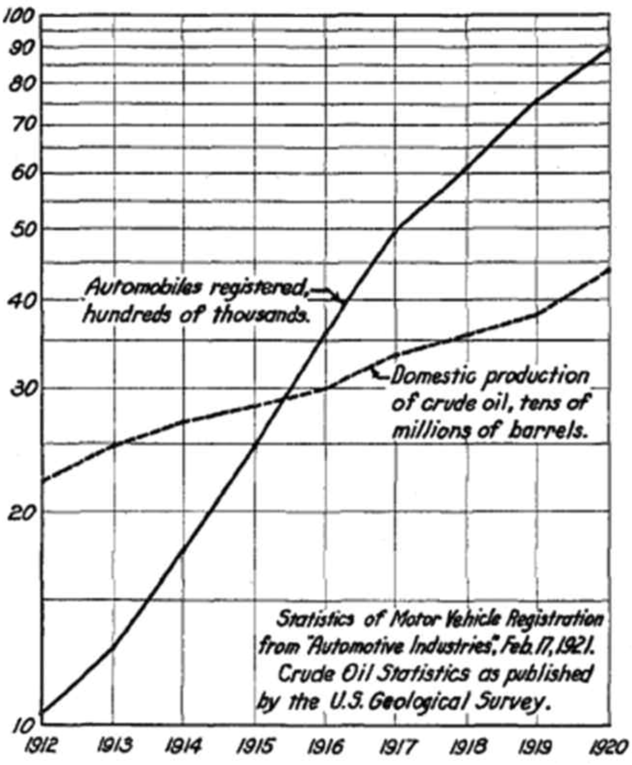
Problem: Dependency on a Non-Renewable and Finite Resource

Another popular problem pushed by chemurgists – and alcohol proponents more generally – pointed to oil being a non-renewable and (as it was believed at the time) soon-to-be-depleted fuel. In the words of one concerned scientist at the time:

> In 1914 the world's output of crude oil amounted to 57 million tons and the highest yield of petrol from the whole quantity is placed by Professor Lewes at 1,700,000,000 gallons, of which amount the United States, alone, last year used 1,200,000,000 gallons and Great Britain over 200,000,000. (Hamlin, 1915: 631)

The finite nature of oil reserves had been a persistent problem in the minds of many in the US ever since crude was discovered in Pennsylvania in the

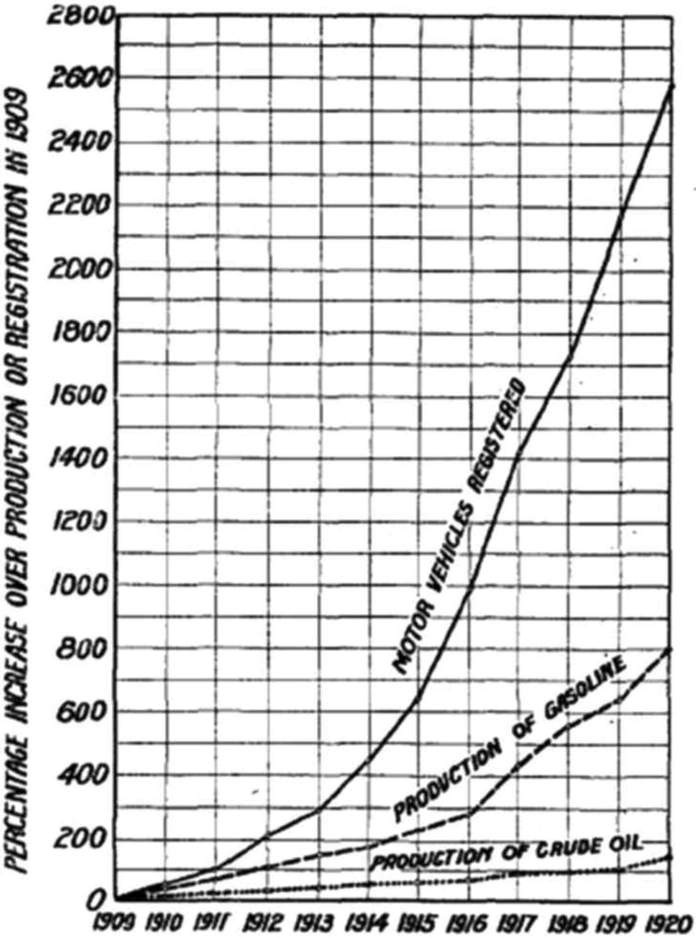
FIGURE 1
Relation between automobiles registered and production of crude oil (source: Boyd, 1921)



mid 1800s. In 1919, for example, government geologists estimated US petroleum reserves at 6.74 billion barrels: enough oil for approximately 17 years if consumption remained constant (White, 1920). By 1920, oil had reached a record price of $3.50 a barrel (Dennis, 1985). In 1921, just months before General Motors came upon lead's anti-knock properties, a top engineer for General Motors by the name of T.A. Boyd was decrying the country's dependency on this soon-to-be-exhausted fuel. From the perspective of automobile manufactures, future car sales would be greatly hampered if the energy to power these machines was to run out. Making his case in the *Journal of Industrial and Engineering Chemistry* (in a paper titled 'Motor Fuel from Vegetation'), Boyd (1921) presents two figures. These figures (Figs 1 and 2) – gave a bleak outlook if alternatives to oil were not quickly invested in.

Yet, the material and symbolic landscapes changed in important ways that helped neutralize the frame pointing to the finite nature of oil. Perhaps the most significant material change came by way of a massive oil field discovery in 1930: the East Texas field. The East Texas field eclipsed all other fields that

FIGURE 2
Percentage increases in motor vehicles registered, production of crude oil, and production of gasoline, compared with 1909 (source: Boyd, 1921)



had been discovered to date (it had been estimated as being 10 to 12 times as large as Oklahoma City [Libecap, 1989]). By 1933, the East Texas oil field was producing one million barrels a day (Libecap, 1989): enough crude to satisfy the entire country's daily oil consumption (Constant, 1989). The symbolic change, on the other hand, was reflected in the aforementioned shift in oil estimates. With the aid of hindsight, we can now say that both government- and industry-funded estimates were incorrect – that is, the government's estimates were too conservative while the petroleum industry's estimates proved overly optimistic. What matters, however, is that *at the time* a significant amount of validity was given to the estimates provided by the petroleum industry. At the very moment the Farm Chemurgy Movement was at its zenith – the 1930s have been termed the 'heyday of chemurgy' (Finlay, 2004: 37) – the discourse pointing to the problem of oil's non-renewable and finite nature began falling on deaf ears.

Science and Technocratic Optimism

Throughout the early decades of the 20th century, proponents of alcohol and gasoline battled for scientific credibility. Some of the scientific demonstrations have already been mentioned, such as the 1906 experiments conducted by the Department of Agriculture, and the series of tests by the US Geological Service and the US Navy that occurred between 1907 and 1908 (when some 2,000 tests were performed on alcohol and gasoline engines). Having read many popular and scientific accounts of gasoline and alcohol from between 1900 and the early 1920s, I have yet to come across a study that speaks to gasoline's clear superiority over alcohol (as defined by issues of engine knock, power, engine efficiency, and so on). Even General Motors' top engineer, Thomas Midgley, as late as mid 1921 – just months before discovering lead's anti-knock properties – was praising alcohol fuel blends. At that time, he drove an automobile powered by a 30% alcohol fuel blend from Dayton, Ohio, to the Society of Automotive Engineers Annual Meetings in Indianapolis, Indiana. At the meeting Midgley proclaimed: 'Alcohol has tremendous advantages and minor disadvantages, [the former include] clean burning and freedom from any carbon deposit … [and] tremendously high compression under which alcohol will operate without knocking' (quoted in Kovarik, 1998: 14).

I can find little scientific controversy dating before the emergence of leaded gasoline over which fuel offered a smoother running engine, greater power, and gains in engine efficiency. Those titles all went to alcohol. Gasoline proponents also marshaled their own scientific evidence when pleading their case to the public and to politicians. Their focus, however, often centered on phase separation – the fact that alcohol blends separate in the presence of water. And gasoline proponents managed to advertise this 'fact' across the countryside in those areas in the Midwest that had access to service stations selling alcohol blends. As described in an early book on chemurgy:

> Among the neatest tricks to discourage the use of the blend were the repeatedly reported demonstrations with which traveling 'experts' *proved* that alcohol and gasoline do not mix. The self-styled 'experts' conducted this little trick by driving into fill stations and showing proprietors and bystanders that Agrol fluid [alcohol fuel] and gasoline separate into layers. It worked beautifully because the 'experts' used small glass tubes which they carefully washed beforehand. Since a drop of water in a small vial is large enough to cause separation in the small amount of blended fuel in the tube, the demonstration was very effective …. (Borth, 1943: 170, emphasis in original)

Not surprisingly, chemurgists abhorred such forms of non-scientific trickery (Giebelhaus, 1979). Chemurgists literally embodied the technological and scientific optimism of the day. Chemurgists believed that in technology lay solutions 'to virtually every problem, including social problems'

(*Popular Mechanics*, 1934: 507; see also *Popular Mechanics*, 1933). As the founder of the Chemurgic Movement once explained:

> [It is] necessary that science be given control. She must take the helm to steer our course. Poor humans that we are there is no order in our make-up save as science bids us follow. Politically we lead each other, then we are led and finally lost. Religiously we display deep emotion and fervor but cannot remember the golden rule. Science is the only mistress we will obey. (Hale, 1934: 192)

And from this faith in science followed a belief that 'man never need fear poverty if he sufficiently understands and utilizes the wealth of the vegetable kingdom' (McMillen, 1946: 8). Thus, in spite of such titles as 'The Chemist as a Conservationist' (Bailey, 1911), a 1911 article in *Science*, chemurgists were less environmentalists than they were technological optimists.

Yet this unflappable faith in science and technology worked against them in at least two ways. First, being guided by technocratic scientists for purposes of industry, chemurgists' goals often placed them at odds with farmers and the agricultural community more generally. As one historian explains: 'the technocratic vision of chemurgy actually attempted to divorce the concept of *culture* from agriculture, replacing the terminology of the vaunted "family farm" with concepts such as "agricenters" – large units to be staffed by managers, scientists, and laborers' (Beeman, 1994: 26). This detachment from the history, culture, and institutional tradition of agriculture was at work when in 1935 the Chemurgic Council began talk of building a large alcohol plant that would use Jerusalem artichokes as its source material, and smaller ones designed for other starchy commodities such as sugarcane, potatoes, and corn. With financial backing from the Chemical Foundation, the Council announced at the second annual Dearborn Conference in May of 1936 that the plant would be located in Atchison, Kansas, and would produce 10,000 gallons of alcohol and 30 tons of protein feed a day from Jerusalem artichokes, sweet potatoes, sorghum, corn, potatoes, and grain (Chemical Foundation & Farm Chemurgic Council, 1936; Giebelhaus, 1980a).[3]

While possessing a more exploitable carbohydrate source than corn, given the technology at the time (Thaysen et al., 1929), commodities such as Jerusalem artichokes and sweet potatoes were not traditional Midwestern commodities. This illustrates the policies that can emerge when the guiding principle of an organization is that 'science is the only mistress we will obey' (Hale, 1934: 192). This technocratic vision and disregard for the cultural and institutional realities of agriculture eventually turned many away from the promises of chemurgy. For example, Secretary of Agriculture Henry Wallace, although an earlier supporter of this movement, eventually distanced himself from chemurgy. In his own words: '[E]nthusiasts tend to burn out the brake bands of their imagination on the subject of farm chemurgy. "Imagineering" has an important place but let us be hard-headed and not count chickens before the eggs are laid' (quoted in Beeman, 1994: 41).

Technocratic-scientific exuberance also made chemurgists ill-suited for the type of non-scientific mudslinging that often occurs when well entrenched, powerful interests are threatened. While chemurgists too played upon fears (for example, the county had become too dependent upon others for its oil, oil reserves will soon run out, and so on), petroleum advocates appeared to have the upper hand when it came to utilizing fear tactics to sway sentiments in their favor. Playing upon the pernicious nature of alcohol was a particularly popular tactic (remember that Prohibition lasted from 1920 to 1933). For instance, in a widely distributed paper written in 1933, a member of the Universal Oil Products Company argued the following: 'To force the use of alcohol in motor fuel would be to make every filling station and gasoline pump a potential speakeasy' (Egloff, 1933, quoted in Giebelhaus, 1979: 41). During that same year, the host on a radio program sponsored by Standard Oil spoke of how alcohol fuel would 'make alcoholics out of America's 22,000,000 motor cars' (quoted in Giebelhaus, 1979: 42). Similarly, a Standard Oil circular distributed in the early 1930s suggested the ease with which industrial alcohol could be converted to potable alcohol by using the term 'drinkable moonshine' when speaking of the fuel (Christensen et al., 1934: 159).

Other tactics involved making claims that the fuel was derived from materials *imported* from other countries (which would have rebuffed chemurgists' claims that their fuel created energy independence from other nations). One particularly damaging rumor was circulated that imported blackstrap molasses – and not Louisiana molasses as advertised – was being used by the country's largest alcohol fuel plant (Bernton et al., 1982). As Leo Christensen described during a US Senate subcommittee in 1939 (quoted in Bernton et al., 1982: 26):

> Disaster struck the Agrol plant in the form of a false and I think malicious rumor which spread all over the territory which it was serving, to the effect that the alcohol it was making was made from blackstrap molasses, and the impression was that it was imported. … Sales dropped very, very rapidly, and all of the capital of the Atchison Agrol Company was used up in overcoming the damage which resulted from that rumor.

Alcohol and gasoline proponents both employed, in different forms, science and expertise to win over support. Yet chemurgists arguably embraced technocratic optimism to a fault. Their view of fuel was truly 'objective', which is to say they failed to take into consideration the context of the situation. For example, purely scientific principles led them to study (and eventually call for the utilization of) commodities such as Jerusalem artichokes and sweet potatoes. Yet these vegetables fell outside the commodity profiles of most Midwestern farms at the time. This technocratic optimism also underlies why alcohol proponents were often reacting to mudslinging tactics rather than slinging mud themselves. For chemurgists, the debate ultimately should have been decided based upon the application scientific principles, which, in turn, could be used to determine the cleanest, safest, and overall 'best' fuel.

It is rare in the US that technocratic optimism lands on the losing side of a struggle for the popular imagination, particularly in an era that gave birth to slogans such as 'Better Things for Better Living … Through Chemistry' (adopted by DuPont in 1935). Unlike, say, early steam cars, which came to represent 'old fashionedness' (Hard & Jamison, 1997: 148), early biofuels rested upon 'the miracles of modern chemistry' (as an article in *Popular Mechanics* [1933: 488] titled 'Miracles from Tests Tubes' proclaims). For a time, particularly during the 1930s, chemurgy represented the forefront of chemistry in the US (Beeman, 1994). Yet this status was not to last. Soon chemists would turn their attention to the other chemical properties of petroleum. 'By the late 1930s', as one historical account of plastics in the US explains, 'the push to exploit basic chemical raw materials derived from coal, natural gas, or petroleum' had reached a fevered pitch (Meikle, 1995: 82). And as chemists turned towards petroleum they turned away from the agro-materials of chemurgy:

> Acrylic plastic was not seriously employed until the Second War provided a need for strong, lightweight, optically perfect thermoplastic sheets that could be formed into aerodynamic shapes for airplane cockpit covers and gunners' enclosures, but it first appeared on the market during the 1930s. … The acrylics also provided another example of the fundamental shift in raw materials from *cellulose* and coal tar to petroleum and natural gas. (Meikle, 1995: 84, emphasis added)

The plastics revolution during (and after) World War II arguably made chemurgy appear, like the steam car decades earlier, old fashioned. To look only at the 1930s, one might draw the conclusion that the 'state of the art' – namely, chemurgy – lost the discursive struggle over popular imagination. Yet, I believe it more accurate to say that public perceptions of what constituted 'state of the art' shifted as landscape conditions changed (for example, design demands of World War II, advances in synthetic organic chemistry [Steen, 2001], and so on). Those on the side of what was perceived to represent 'cutting edge' science still, in the end, prevailed.

Constructing a 'Sustainable' Oil Market

Before government regulation in 1933, decisions on oil extraction were made by companies that leased land from property owners. Typically, oil firms did not own oil fields. Rather, they leased access to fields through a surface point lease. This, however, created common property conditions. Given that a competing firm could access the same field by leasing an adjoining property, oil companies had an incentive to maximize their output. Oil companies therefore frequently raced against each other to drain the same reservoir (Dennis, 1985). Consequently, issues of conservation rarely played into production decisions. Limiting one's output simply meant that another company would capture a greater share of a field's oil (Libecap, 1989).

Crude oil output and prices were highly volatile. When new fields were discovered, oil prices plummeted as production was maximized across the industry. Not long after, prices would climb as known oil fields were pumped dry. This proved both a blessing and a curse for alcohol. On the one hand, it helped create periods of opportunity for alcohol, such as during those 'lean' years of oil discovery when crude prices inched upward. Yet it also proved quite debilitating, such as during periods when large fields were being brought into production. For reasons just mentioned, such discoveries were typically followed by a spike in oil output and a drop in its market price (after the East Texas field was discovered gasoline prices fell in some parts of the country to as low as two and one-eighth cents a gallon [Harbeson, 1940]). In the end, the market never remained optimal for the alcohol industry long enough for it to establish an infrastructure and organizational configuration similar to that previously established by the oil industry. Unfortunately for alcohol, a steady discovery of fields in Kansas, Oklahoma, and Texas throughout the 1920s and 1930s meant that those 'lean' years of discovery for the oil industry were few and far between (though California was also a large oil-producing state at this time, its isolation kept it from supplying the national market until after World War II [Libecap, 1989]).

Table 1 presents both the nominal and real prices (constant 2005 US dollars) of oil per barrel from 1860 to 1945 (prices in bold indicate a nominal price below 1 dollar a barrel). The table is insightful on a number of fronts: it adds further context to what has already been discussed. For example, the table illustrates that the price of oil remained high throughout the 1860s and 1870s, spiking right as the Revenue Act of 1862 was passed (which mandated the $2.08 'sin tax' on all alcohol). It is quite possible that alcohol fuel would have been competitive with petroleum fuels during these years had denatured alcohol been exempt from taxation. Indeed, the oil industry spent much of the latter decades of the 19th century overcoming extraction, shipping, and refining difficulties (Williamson & Daum, 1959). Yet, by the turn of the century it developed efficiencies and scales of economy unmatched by its competitors in other countries (Williamson & Daum, 1959). Conversely, had there been an equivalent to Standard Oil Trust in the alcohol industry – some centralized organizational force to establish early economies of scale and concentrate lobbying efforts – ethyl alcohol might have been better positioned to capitalize on oil's early production cycles. Note, for example, how inexpensive oil was in 1906 (and in the ensuing years), which marks when industrial alcohol was finally freed from the tax. By the 1930s, oil prices began to stabilize, just when the alcohol movement was finding its organizational feet in the form of the chemurgic movement. This price stabilization was an effect of an interstate oil cartel that formally took shape in 1935.

As fields age they become more expensive to operate. The reservoirs in Kansas and Oklahoma in the late 1920s and early 1930s cost considerably more to run than newly discovered fields in Texas (for reasons related to their geology). And with the discovery of the massive East Texas field in 1930 some of these higher cost wells became vulnerable to the price effects of a market now flooded with cheap crude. The oil industry became concerned that 'old' wells would have to be closed in response to declining prices, and believed that greater coordination across firms was needed to ensure its long-term economic sustainability (Libecap, 1989). This coordination took the form of an interstate oil cartel, which formed with the signing of the Interstate Oil Compact in 1935. As Libecap (1989: 840) explains:

TABLE 1
Nominal and real prices (constant 2005 US dollars) of oil per barrel, 1860 to 1945

Year	Nominal price ($)	Real price ($)	Year	Nominal price ($)	Real price ($)
1860	**0.49**	**10.81**	1903	**0.86**	**18.96**
1861	1.05	20.84	1904	**0.62**	**13.67**
1862	3.15	50.69	1905	**0.73**	**15.10**
1863	8.06	102.10	1906	**0.72**	**15.00**
1864	6.59	85.30	1907	**0.70**	**14.81**
1865	3.74	50.61	1908	**0.61**	**12.97**
1866	2.41	34.16	1909	**0.61**	**12.97**
1867	3.63	54.03	1910	**0.74**	**15.19**
1868	3.64	54.18	1911	**0.95**	**19.09**
1869	3.86	60.48	1912	**0.81**	**16.04**
1870	4.34	71.78	1913	**0.64**	**12.55**
1871	3.64	60.48	1914	1.10	20.05
1872	1.83	32.05	1915	1.56	24.20
1873	1.17	21.11	1916	1.98	26.19
1874	1.35	24.36	1917	2.01	23.06
1875	2.56	47.63	1918	3.07	30.44
1876	2.42	45.03	1919	1.73	19.26
1877	1.19	24.43	1920	1.61	19.11
1878	**0.86**	**18.29**	1921	1.34	15.62
1879	**0.95**	**19.50**	1922	1.43	16.60
1880	**0.86**	**17.66**	1923	1.68	19.03
1881	**0.78**	**16.01**	1924	1.88	21.11
1882	1.00	21.26	1925	1.30	14.89
1883	**0.84**	**18.52**	1926	1.17	13.55
1884	**0.88**	**19.41**	1927	1.27	14.72
1885	**0.71**	**15.66**	1928	**1.19**	**14.16**
1886	**0.67**	**14.77**	1929	**0.65**	**8.50**
1887	**0.88**	**19.41**	1930	**0.87**	**12.68**
1888	**0.94**	**20.73**	1931	**0.67**	**10.30**
1889	**0.87**	**19.19**	1932	1.00	14.86
1890	**0.67**	**14.77**	1933	**0.97**	**14.05**
1891	**0.56**	**12.35**	1934	1.09	15.63
1892	**0.64**	**13.61**	1935	1.18	16.32
1893	**0.84**	**17.86**	1936	1.13	15.94
1894	1.36	28.92	1937	1.02	14.58
1895	1.18	25.09	1938	1.02	14.47
1896	**0.79**	**16.80**	1939	1.14	15.40
1897	**0.91**	**19.35**	1940	1.19	14.50
1898	1.29	27.43	1941	1.20	13.78
1899	1.19	25.30	1942	1.21	13.68
1900	**0.96**	**20.41**	1943	1.05	11.60
1901	**0.80**	**17.01**	1944	1.12	11.41
1902	**0.94**	**20.73**	1945	1.90	16.91

Data compiled from *Forbes* (<www.forbes.com/static_html/oil/2004/oil.shtml>).
Prices in bold indicate a nominal price below $1 a barrel.

> The elements [of this cartel] include state prorationing rules to set monthly production totals and to allocate them among regulated wells; Bureau of Mines market-demand estimates for determining state production levels; the Connally Hot Oil Act for federal enforcement of state production rules in interstate commerce; and the Interstate Oil Compact to coordinate state production policies.

The Connally Hot Oil Act helped mark the end of the oil production cycles that had existed in the oil industry since its inception. The formation of the interstate oil cartel helped remove the aforementioned market fluctuations that created spaces of opportunity for alcohol. And with this, we have yet another factor that contributed to the eventual 'closing' of the debate between gasoline and alcohol.

Conclusion

A survey conducted in 1933 involving 1,327 users of alcohol blends (from the Midwest where alcohol fuel had been made available to several test communities) revealed a demand for the fuel, even if that meant respondents had to pay a premium at the pump. The survey was summarized in a 1933 issue of *Science News Letter*:

> [A survey asking alcohol fuel consumers to give] their impression of alcoholized gasoline on the scores of starting, acceleration, smoothness of operation, anti-knock, power and general motor performance, shows that over 1,100 of them considered the new fuel better than 'straight' non-premium gasoline on starting, and that on all the other points over 1,200 agreed that the new fuel was superior. Most of the dissenting votes merely reported 'no difference noticed'; hardly anyone considered the unblended gasoline better. … [Respondents would] be willing to pay a premium of two or three cents a gallon for alcoholized gasoline, provided the alcohol is produced from surplus grain, the report stated. (Whelpton, 1933: 301)

When the Atchison (KS, US) alcohol plant was in operation gas stations reported selling alcohol blends for between 1 and 2 cents more than conventional gasoline (*Science News Letter*, 1936). Yet even at this slightly higher price, sales of alcohol blends were said to have been brisk (Berton et al., 1982). In light of this, it is imperative that we not reduce alcohol's past to a matter of 'supply and demand'. The evidence suggests, rather, that at least among those familiar with alcohol blends, demand existed for this fuel.

As a controversy study, this paper avoids the reductionist tendencies of past historical examinations of fuel. With that said, I make no claims to offer an exhaustive analysis of the controversy. For example, space constraints do not allow for a thorough discussion on the political economy of this controversy. Given that such an analysis has been undertaken elsewhere (for example, Giebelhaus, 1979, 1980a; Wright, 1993), a decision was made to focus on less explored aspects of alcohol fuel's past.[4] I also hope to redress through this paper a gap within the STS literature on the subject of automobile socio-technical systems, where the story of ethyl alcohol remains conspicuously absent. Among those studies that seek to understand how and why the automobile became locked in, little is said about ethyl alcohol (see for example, Kline & Pinch, 1996), even though, as detailed above, it remained very much part of the fuel landscape well into the 20th century. Given alcohol's 'fit' with the then-emerging socio-technical regime, this omission can be forgiven.

The steam car rested upon a different organizational, social, and infrastructural arraignment than that required by the gasoline automobile. In other words, the former 'fit' poorly within the latter's socio-technical world. Moreover,

> [the steam car] demanded a behavior that did not square well with user patterns that were developing in the early 1900s, i.e., high speeds, long-distance trips, immediate starting. And last but not least, these automobiles were carried by institutions that both acted in an elitist way and were regarded as archaic – at a time when the mass-produced gasoline-driven automobile began to be the car of the masses. (Hard & Jamison, 1997: 149)

Conversely, alcohol cars fit well with this emerging socio-technical regime. Alcohol could, for example, operate within standard internal combustion engines, be transported using the same tanker trucks as oil, and sold at gas stations without any significant modifications to existing equipment. And as for its fit with emerging driving behaviors, alcohol, unlike steam, actually *exceeded* (pre-leaded) gasoline on a number of accounts (for example, power, clean burning, engine efficiency, engine noise). It is therefore understandable why previous sociological accounts of the early automobile socio-technical system missed alcohol. While still involving a 'battle of the systems' (Hughes, 1993), the alcohol versus gasoline controversy lasted as long as it did because these competing systems were far more similar than those underlying, say, steam, fuel oil, and wood cars.

Finally, it must also be noted that this paper makes no claim about 'global closure' around petroleum (Hard, 1994). It would be naive to think that the same factors adduced in this paper apply equally to, say, 'closure' in Europe. Granted, some events were common to countries on either side of the Pacific – such as World Wars I and II, falling grain prices following World War I, and, later, the Marshal Plan (which supplied vast qualities of oil to a war-torn Europe [see for example, Painter, 1984]). Nevertheless, European countries lacked, for example, an East Texas oil field, Standard Oil Trust, and a 50-year long industrial alcohol 'sin tax'. As in the US, then, 'closure' in European countries around gasoline was a multi-variable event. Yet those variables cannot be universalized across cases absent a multi-case analysis.

Notes

1 Ethyl alcohol must not be confused with wood alcohol, which is not made by fermenting at all, but by destructively distilling (heating) the wood in iron retorts or

ovens and then condensing the vapors. … It is volatile, inflammable, and is a solvent for many resins, gums, etc. … Commercial wood alcohol has a very marked and repugnant odor and taste. The fumes or vapors from it occasion violent headaches, a depressed nervous condition, and often blindness, when prolonged exposure to such vapors has occurred. Taken internally it nearly always causes blindness or death, and the internal use of wood alcohol is now considered fatal. (Herrick, 1907: 2–3)

2. Twenty per cent of the population in the 1930s still lived on farms (compared with less than 2% today), suggesting that a 'farm crisis' had direct meaning for a larger segment of the population during this era than would be the case today.
3. After coming online, the plant did refine a larger portion of corn than originally planned. Nevertheless, the plant only remained in operation a few years. A number of problems have been cited for the plant's failure. For example, the plant had locked in contract prices with farmers just before market prices declined (which forced the plant to pay an inflated price for its inputs) (Giebelhaus, 1980a). Plant operators also experienced difficultly obtaining the necessary permits from the Federal Alcohol Tax Unit. The plant's technical director estimated that the cost of compliance with all government regulations eventually reached $100,000 (Giebelhaus, 1979).
4. As others have detailed, automobile clubs, representatives from oil producing states, and elements of the federal government (for example, Bureau of Standards) had been beneficiaries of major contributions from the American Petroleum Institute throughout the late 1920s and early 1930s (Giebelhaus, 1980a; Wright, 1993). It has also been reported that Standard Oil spent in excess of $100,000 to defeat pro-alcohol legislation in Iowa, Nebraska, and South Dakota in 1933 (Giebelhaus, 1979). In a paper presented at the 1939 Farm Chemurgic Council meeting in Omaha, NE, Standard Oil was criticized for threatening to close down their district office in Sioux City, IA, if the city's Chamber of Commerce continued in their support of alcohol blend legislation (Standard Oil, in response, claimed it had long intended to close this office) (Giebelhaus, 1979: 50). The same paper also claimed that 'somebody' called many of the city's business owners reminding them of how many of their customers were employed by major oil companies (Giebelhaus, 1979: 50). Arguably the most blatant display of oil's organizational influence, however, occurred when Ethyl Gasoline Corporation (owned by General Motors and Standard Oil of New Jersey) denied licenses to wholesale fuel dealers who sold alcohol blends. This maneuver forced fuel dealers to sell only leaded gasoline or face elimination from the market (see for example, *Yale Law Journal*, 1939; Harbeson, 1940). This continued until 1937, when the Department of Justice stepped in to stop this practice, an act that was eventually supported by the Supreme Court in 1940 (Kovarik, 1998).

References

Bailey, E.H.S. (1911) 'The Chemist as a Conservationist', *Science* 34(883): 748–50.

Barnard, H.E. (1938) 'Prospects for Industrial Uses for Farm Products', *Journal of Farm Economics* 20(1): 119–33.

Baskerville, Charles (1906) 'Free Alcohol in the Arts and as Fuel', in Albert Shaw (ed.), *The American Monthly Review of Reviews* (New York: The Review of Reviews Company): 211–14.

Beeman, Randal (1994) 'Chemivisions: The Forgotten Promise of the Chemurgy Movement', *Agricultural History* 68(4): 23–45.

Berton, Hal, William Kovarik & Scott Sklar (1982) *The Forbidden Fuel: Power Alcohol in the Twentieth Century* (New York: Boyd Griffin).

Bijker, Wiebe (1995) *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Cambridge, MA: MIT Press).

Borth, Christy (1943) *Pioneer of Plenty: Modern Chemists and their Work* (New York: The New Home Library).

Bowden, Gary (1982) 'Estimating US Crude Oil Resources: Organizational Interests, Political Economy, and Historical Change', *Pacific Sociological Review* 25(4): 419–48.

Bowden, Gary (1985) 'The Social Construction of Validity in Estimates of US Crude Oil Reserves', *Social Studies of Science* 15: 207–40.
Boyd, T.A. (1921) 'Motor Fuel from Vegetation', *Journal of Industrial and Engineering Chemistry* 13(9): 836.
Bringhurst, Bruce (1979) *Antitrust and the Oil Monopoly: The Standard Oil Cases, 1890–1911* (Westport, CN: Greenwood Press).
Chemical Foundation & Farm Chemurgic Council (1936) *Proceedings of the Second Dearborn Conference of Agriculture, Industry, and Science* (Dearborn, MI: Farm Chemurgic Council, Inc. and New York: Chemical Foundation).
Christensen, L., R. Hixon & E. Fullmer (1934) *Power Alcohol and Farm Relief* (New York: The Chemical Foundation).
Clean Fuels Development Coalition (2007) *The Ethanol Fact Book* (Washington, DC: Clean Fuels Development Coalition), available at: <www.ethanol.org/pdf/contentmgmt/2007_Ethanol_Fact_Book.pdf>, (accessed 12 December 2007).
Clough, Albert. (1909) 'Comparison of Gasoline and Alcohol Motor Tests', *The Horseless Age* 24(21): 607.
Corn Marketing Program of Michigan (2007) 'Ethanol – American's Renewable Fuel, 2007 Update', *CORN – Check Off Report and Newsletter* (DeWitt, MI, January), available at <www.micorn.org/downloads/EthanolNewsltr2007.PDF> (accessed 21 December 2007).
Constant, Edward (1989) 'Cause or Consequence: Science, Technology, and Regulatory Change in the Oil Business in Texas, 1930–1975', *Technology and Culture* 30(2): 426–55.
Cummins, Lyle (2002) *Internal Fire: The Internal Combustion Engine, 1673–1900* (New York: Carnot Press).
Dennis, Michael (1985) 'Drilling for Dollars: The Making of US Petroleum Reserve Estimates, 1921–25', *Social Studies of Science* 15(2): 241–65.
Doran, J.M. (1924) 'Some Recent Developments in Industrial Alcohol', *Industrial and Engineering Chemistry* 20(2): 641–44.
Effland, Anne (1995) 'New Riches from the Soil: The Chemurgic Ideas of Wheller McMillen', *Agricultural History* 69(2): 288–97.
Egloff, Gustav (1933) 'Alcohol–Gasoline Motor Fuels', Pew Papers, Box 52: pp. 1–6.
Finlay, Mark (2004) 'Old Efforts at New Uses: A Brief History of Chemurgy and the American Search for Biobased Material', *Journal of Industrial Ecology* 7(3/4): 33–46.
Garvan, Francis (1936) 'Introduction', in F. Garvan (ed.), *Proceedings of the Second Annual Dearborn Conference of Agriculture, Industry, and Science* (New York: The Chemical Foundation): 2–8.
Geels, Frank (2005) 'Co-evolution of Technology and Society: The Transition in Water Supply and Personal Hygiene in the Netherlands (1850–1930) – A Case Study in Multi-level Perspective', *Technology in Society* 27: 363–97.
Giebelhaus, August (1979) 'Resistance to Long-term Energy Transition: The Case of Power Alcohol in the 1930s', in Lewis Perelman, August Giebelhaus & Michael Yokell (eds), *Energy Transitions: Long-term Perspectives* (Boulder, CO: Westview Press): 35–63.
Giebelhaus, August (1980a) 'Farming for Fuel: The Alcohol Motor Fuel Movement of the 1930s', *Agricultural History* 54(1): 173–84.
Giebelhaus, August (1980b) *Business and Government in the Oil Industry: A Case Study of Sun Oil, 1876–1945* (Greenwich, CN: JAI Press).
Gradenwitz, Alfred (1907) 'The Denatured Alcohol Situation', *Scientific American Supplement* S1(1688): 393.
Hale, William (1934) *The Farm Chemurgic: Forward the Star of Destiny Lights Our Way* (Boston, MA: Stratford).
Hall, Tom (1973) 'Wilson and the Food Crisis: Agricultural Price Controls During World War I', *Agricultural History* 47(1): 24–46.
Hamlin, M. (1915) 'Liquid Fuel for Internal Combustion Engines', *Journal of Industrial and Engineering Chemistry* 7(7): 631–32.
Harbeson, Robert (1940) 'The Present Status of the Sherman Act', *Michigan Law Review* 39(2): 189–212.

Hard, Mikael (1994) 'Technology as Practice: Local and Global Closure Processes in Diesel-engine Design', *Social Studies of Science* 24(3): 549–85.
Hard Mikael & Andrew Jamison (1997) 'Alternative Cars: The Contrasting Stories of Steam and Diesel Automotive Engines', *Technology in Society* 19(2): 145–60.
Hartline, Frederick (1979) 'Lowering the Cost of Alcohol', *Science* 206 (4414): 41–42.
Herrick, Rufus (1907) *Denatured or Industrial Alcohol* (New York: John Wiley and Sons).
Hixon, R.M. (1933) *Use of Alcohol in Motor Fuels: Progress Report No. 6* (Ames, IA: Iowa State College (1 May).
Hordeski, Michael (2007) *Alternative Fuels: The Future of Hydrogen* (Lilburn, GA: The Fairmont Press).
Hughes, Thomas (1987) 'The Evolution of Large Technological Systems', in W. Bijker, T. Hughes & T. Pinch (eds), *The Social Constructions of Technological Systems* (Cambridge, MA: MIT Press): 51–82.
Hughes, Thomas (1993) *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: The Johns Hopkins University Press).
Jones, Gareth (1978) 'The Oil Fuel Market in Britain 1900–14 – A Lost Cause Revisited', *Business History* 20(2): 131–52.
Kline, Ronald & Trevor Pinch (1996) 'Users as Agents of Technological Change: The Social Construction of the Automobile in the Rural United States', *Technology and Culture* 37(4): 763–95.
Kovarik, Bill (1998) 'Henry Ford, Charles F. Kettering and the Fuel of the Future', *Automotive History Review* 32: 7–27.
Kovarik, Bill (2003) 'Ethyl: The 1920s Environmental Conflict over Leaded Gasoline and Alternative Fuels', Paper to the American Society for Environmental History, Annual Conference (26–30 March), Providence, RI, available at <www.runet.edu/~wkovarik/papers/ethylconflict.html> (accessed 7 December 2007).
Kovarik, Bill (2005) 'Ethyl-leaded Gasoline: How a Classic Occupational Disease Became an International Public Health Disaster', *International Journal of Environmental Health* 11(4): 384–397.
Libecap, Gary (1989) 'The Political Economy of Crude Oil Cartelization in the United States, 1933–1972', *Journal of Economic History* 49(4): 833–55.
Long, J.H. (1906) 'The Question of Tax-free Alcohol', *Science* 23(580): 234–35.
McCarthy, Tom (2001) 'The Coming Wonder? Foresight and Early Concerns about the Automobile', *Environmental History* 6(1): 46–74.
McMillen, Wheeler (1946) *New Riches from the Soil: The Progress of Chemurgy* (New York: D. Van Nostrand).
Meikle, Jeffrey (1995) *American Plastic: A Cultural History* (New Brunswick, NJ: Rutgers University Press).
Nelson, Derek (1995) *Moonshiners Bootleggers and Rumrunners* (Osceola, WI: Motorbooks International).
North, Sydney (1911) *Oil Fuel: Its Supply, Composition and Application* (London: Griffin).
Pahl, Greg (2005) *Biodiesel: Growing a New Energy Economy* (White River Junction, VT: Chelsea Green Publishing).
Painter, David (1984) 'Oil and the Marshall Plan', *Business History Review* 58(3): 359–83.
Pines, Clifton (1931) 'The Story of Alcohol', *American Journal of Police Science* 2(6): 500–08.
Popular Mechanics (1933) 'Miracles from Test Tubes', *Popular Mechanics* 60 (October): 488–92.
Popular Mechanics (1934) 'The Miracles of Chemurgy', *Popular Mechanics* 61(April): 506–09.
Robert, Joseph (1983) *Ethyl: A History of the Corporation and the People Who Made It* (Charlottesville, VA: University Press of Virginia).
Santos, Joseph (2006) 'Going Against the Grain: Why did Wheat Marketing in the United States and Canada Evolve so Differently?' unpublished manuscript, Department of Economics, South Dakota State University, available at <www.thebhc.org/publications/BEHonline/2006/santos.pdf> (accessed 7 December 2007).
Schurr, Sam & Bruce Netschert (1960) *Energy in the American Economy 1850–1975* (Baltimore, MD: The Johns Hopkins University Press).

Science News Letter (1928) 'Alcohol and Bitumen Sands for Power', *Science News Letter* 14(391): 209–10.
Science News Letter (1933) 'Alcohol–Gasoline Mixture Suggested as Motor Fuel', *Science News Letter* 23(620): 116.
Science News Letter (1936) 'Power-alcohol Plant Now in Commercial Production', *Science News Letter* 30(809): 237.
Shah, Sonia (2004) *Crude: The Story of Oil* (New York: Seven Stories Press).
Shideler, James (1976) *Farm Crisis, 1919–1923* (New York: Greenwood Press).
Sorel, Ernest (1907) *Carbureting and Combustion in Alcohol Engines* (New York: John Wiley and Sons).
Steen, Kathryn (2001) 'Patents, Patriotism, and "Skilled in the Art": USA v. The Chemical Foundation, Inc., 1923–26', *Isis* 92(1): 91–122.
Taylor, Charles (1985) *Internal Combustion Engine in Theory and Practice*, vol. 2, revised edition (Cambridge, MA: MIT Press).
Terzian, Pierre (1991) 'The Gulf Crisis: The Oil Factor – An Interview with Pierre Terzian', *Journal of Palestine Studies* 20(2): 100–05.
Thaysen, Aage, William Bakes & Brian Green (1929) 'On the Nature of the Carbohydrates Found in the Jerusalem Artichoke', *Biochemical Journal* 23(3): 444–55.
Tunison, B. (1920) 'The Future of Industrial Alcohol', *Journal of Industrial and Engineering Chemistry* 12(4): 370–76.
Whelpton, P.K. (1933) 'Alcoholized Gasoline Approved in Tests', *Science News Letter* 23: 631: 301–02.
Whitaker, M.C. (1925) 'Alcohol for Power', Lecture given to Chemists Club, New York (30 September).
White, David (1920) 'The Petroleum Resources of the World', *Academy of Political and Social Science Annals* 89: 111–34.
Williamson, H. & A. Daum (1959) *The American Petroleum Industry: The Age of Illumination, 1859–1899* (Evanston, IL: Northwestern University Press).
Wik, Reynold (1962) 'Henry Ford's Science and Technology for Rural America', *Technology and Culture* 3(3): 247–58.
Winner, Langdon (1999) 'Do Artifacts have Politics?' in Donald MacKenzie & Judy Wajcman (eds), *The Social Shaping of Technology*, second edition (Philadelphia, PA: Open University Press): 28–41.
Winters, Paul (2007) 'Industrial Biotechnology Is Revolutionizing the Production of Ethanol Transportation Fuel', Biotechnology Industry Organization, Washington, DC, available at <www.bio.org/ind/biofuel/CellulosicEthanolIssueBrief.pdf>, (accessed 21 December 2007).
Wright, David (1993) 'Alcohol Wrecks a Marriage: The Farm Chemurgic Movement and the USDA in the Alcohol Fuels Campaign in the Spring of 1933', *Agricultural History* 67(1): 36–66.
Wright, David (1995) 'Agricultural Editors Wheeler McMillen and Clifford V. Gregory and the Farm Chemurgic Movement', *Agricultural History* 69(2): 272–87.
Wright, F.B. (1907) *A Practical Handbook on the Distillation of Alcohol from Farm Products*, second edition (New York: Camelot Press).
Yale Law Journal (1939) 'A Possible Extension of the Scope of the Patent Monopoly', *Yale Law Journal* 48(6): 1089–95.
Yergin, Daniel (1991) *The Prize: The Epic Quest for Oil Money and Power* (New York: Simon and Schuster).

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