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OF MOTOR FUELS**

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BIOFUELS, PETROLEUM REFINING, AND THE SHIPPING OF MOTOR FUELS[†]

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Abstract

A number of Asian and European countries, the U.S. federal government, and numerous individual U.S. states and localities have proposed or mandated use of biofuels—such as ethanol made from corn or biodiesel made from soybeans or other crops—partly in an effort to reduce greenhouse gas emissions and reduce consumption of petroleum products. These mandates call for biofuels to be blended in varying proportions with traditional gasoline or diesel and, in some cases, allow or require different biofuel standards. To maintain engine performance and emissions requirements, varying biofuel blends and standards will require changes to gasoline and diesel blendstocks that biofuels are mixed with. The manufacture of these different blendstocks will require modifications to the refining infrastructure. In addition, changes to blendstocks will further balkanize the mix of liquid fuels and put additional strain on an already stressed pipeline and storage infrastructure as smaller batches of incompatible fuels are shipped to an increasing number of locations. Further, because biofuels will typically be produced near the bio-feedstocks—which are currently not typically served by pipeline systems—trucking, rail, and barge infrastructure may expand until and unless new pipelines are built. Finally, the different blendstocks required for different regions will reduce the fungibility of petroleum liquid fuels, thereby reducing trade and increasing price volatility, similar to the effects in the United States of a proliferation of gasoline blends in response to Clean Air Act air quality standards. These and other unintended effects and additional capital expenditures raise serious questions about the efficacy of rapid expansion of biofuel use and also call for policy makers to consider negotiating biofuel production and blending standards to reduce the eventual number of incompatible liquid fuels.

[†]The views expressed in this paper are solely those of the authors and are not to be attributed to the authors' employers.

1. INTRODUCTION

The use of biofuels as liquid fuels for powering internal combustion engines is not a new idea. In fact, Rudolf Diesel, the inventor of the diesel engine in the 1880s, designed his first engine to run on biodiesel and envisioned the diesel engine as much an instrument of agriculture policy as a means of human transportation. Similarly, Henry Ford, with an eye to providing affordable automobile transportation for the American middle class designed his first automobile to run on ethanol. Biofuels were used in the United States and elsewhere extensively in the early decades of the 20th century but were eventually displaced by cheaper and more energy dense fossil fuel-based gasoline and diesel. Interest in biofuels surged again in the late 1970s and early 1980s in response to high oil prices but waned by the mid 1980s as oil prices plummeted and remained relatively low for almost 25 years. However, a coincidence of several factors has caused a recent resurgence in interest and a growing

production of ethanol and biodiesel. These factors include increasing fossil fuel prices, a growing consensus that human carbon emissions should be reduced, and pro-agricultural interests successfully lobbying governments for incentives for biofuel production and research and development.

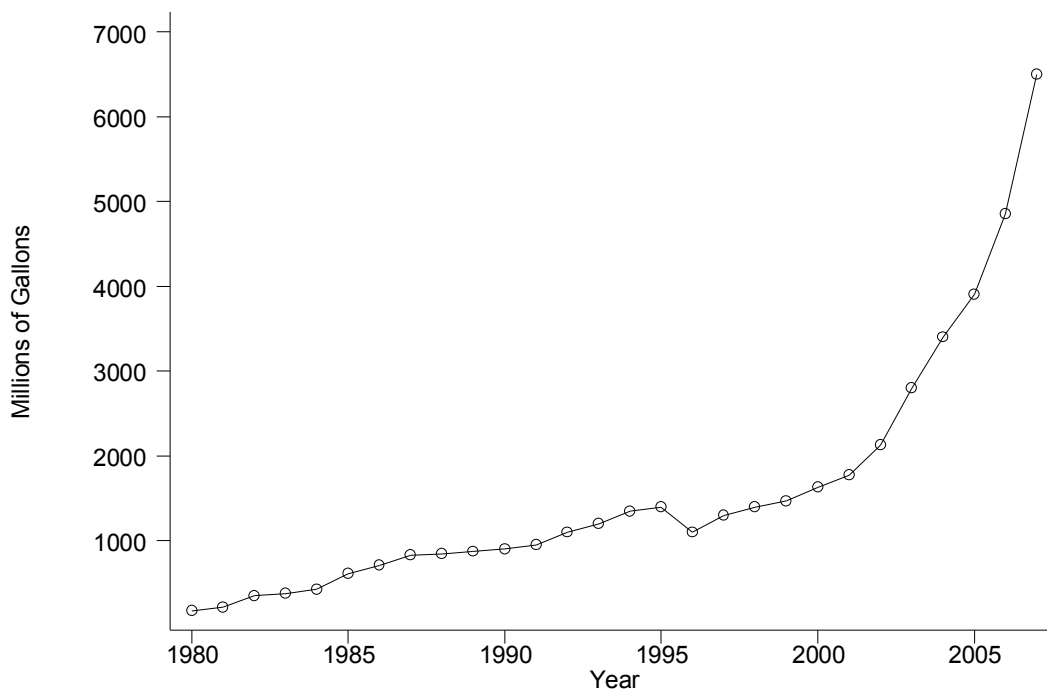
Table 1: Ethanol Production in Various Countries, Millions of Gallons

Country	2004	2005	2006
Brazil	3,989	4,227	4,491
U.S.	3,535	4,264	4,855
China	964	1,004	1,017
India	462	449	502
France	219	240	251
Russia	198	198	171
South Africa	110	103	102
U.K.	106	92	74
Saudi Arabia	79	32	52
Spain	79	93	122
Thailand	74	79	93
Germany	71	114	202
Ukraine	66	65	71
Canada	61	61	153
Poland	53	58	66
Indonesia	44	45	45
Argentina	42	44	45
Italy	40	40	43
Australia	33	33	39
Japan	31	30	30
Pakistan	26	24	24
Sweden	26	29	30
Philippines	22	22	22
South Korea	22	17	16
Guatemala	17	17	21
Cuba	16	12	12
Ecuador	12	14	12
Mexico	9	12	13
Nicaragua	8	7	8
Mauritius	6	3	2
Zimbabwe	6	5	7
Kenya	3	4	5
Swaziland	3	3	5

Source: Renewable Fuels Association.

The recent growth in biofuel production has been impressive although biofuels still make up a small percentage of the world's liquid transportation fuels. The United States and Brazil produce the bulk of global ethanol; 6.5 and 5 billion gallons in 2007, a 33 percent and 11 percent increase over the previous year, respectively. European countries have been the leaders in producing biodiesel, in total, producing 4.9 million tonnes in 2007, up by more

than 50 percent from the previous year. As of 2007, global ethanol production made up only a small percentage of liquid transportation fuels by volume and less by energy content because of the lower energy density of ethanol compared to gasoline derived from crude oil. Similarly, global biodiesel production is only a small fraction of total global distillate production by volume but has been growing rapidly—global biodiesel production grew at an annual rate of 40 percent from 2002—2006 (Ren21, 2008). Europe has been the largest producer of biodiesel in recent years—85 percent of global production in 2005—but many other countries are expanding their acreage devoted to biodiesel feedstocks and some potentially large consumers—including China and India—are experimenting with biofuels. Less developed countries may be less invested in fossil liquid fuels infrastructure than are the United States and Europe. In addition, some biodiesel feedstocks, which generate high fuel yields per acre grow primarily in tropical climates, so the future may well bring significant shifts in centers of biofuel production and use, as well as the proportion of total liquid transportation fuels made from bio-feedstock. In addition, many other countries, including the United States, as well as most individual states have either mandated use of biofuels or provided tax or other incentives to encourage production and use of these fuels. To date, there has been little coordination among these governments with respect to setting uniform standards for producing or blending of ethanol and biodiesel with gasoline or diesel produced from crude oil.



Data Source: Renewable Fuels Association.

Figure 1: U.S. Production of Ethanol

As a result of this lack of coordination there is a wide range of ethanol blending standards that have been either mandated or proposed and there as well as a number of different biodiesel standards. For example, according to the Pew Center on Global Climate Change,

37 U.S. states provide tax exemptions, credits, and/or grants to encourage the production and use of ethanol and or biodiesel. Nine of these states have also imposed renewable fuel standards that mandate varying degrees of use of biofuels. Specifically, the mandated blends of ethanol vary between 2 percent to 85 percent ethanol with different dates associated with state implementation goals. Table 2 shows biofuels standards in some individual U.S. states.

Table 2: Biofuel Standards Mandated by Individual U.S. States

State	Fuel Standard
Hawaii	85% of gasoline to contain 10% ethanol by April 2006
Iowa	25% of motor fuel from renewables (E10, E85, biodiesel by 2020)
Louisiana	All gasoline to contain 2% ethanol; 2% of all diesel to be biodiesel
Minnesota	All gasoline to contain 20% ethanol by 2013; 2% of all diesel to be biodiesel
Missouri	All gasoline except premium grade gasoline to contain 10% ethanol by 2008
Montana	All gasoline except 91 octane to contain 10% ethanol
Washington	All gasoline to contain 2% ethanol by 2008; 2% of all diesel to be biodiesel by 2008

Source: PEW Center on Global Climate Change. <http://www.pewclimate.org/node/5859>

A similar proliferation of biofuel blends and standards is beginning to emerge in Europe, in which countries with suitable lands and agriculture sectors to produce biodiesel are tending to mandate greater proportions of blending of biodiesel than other countries not so endowed. An additional issue exists with biodiesel in that, unlike ethanol—which is generally fungible regardless of how it is produced or from which bio-feedstock—different biodiesel production processes and feedstocks lead to biodiesels having different performance and other properties. Table 3 shows biofuels standards in various other countries.

Table 3: Biofuel Standards Mandated by Individual Countries

Country	Fuel Standard
Brazil	5% ethanol in gasoline and 2% biodiesel by 2008; 25% ethanol in gasoline by 2013
Canada	10% ethanol in gasoline by 2010; 5% ethanol in Ontario gasoline by 2007
China	10% ethanol in five provinces
Colombia	10 % ethanol in gasoline in cities with population > 500,000
India	5% ethanol in gasoline
Philippines	5% ethanol in gasoline, 2% biodiesel by 2007
Thailand	10% ethanol in gasoline by 2010

Source: PEW Center on Global Climate Change. <http://www.pewclimate.org>

Many unintended but significant problems must be addressed if biofuels are to become an increasingly important part of the liquid fuel mix. Among these are the competing uses of land and water, the effects of placing more land under commercial use on biodiversity and traditional or indigenous populations, concerns about the net carbon impacts of some biofuel production processes, and the effects on engine performance and fuel efficiency. Each one of these issues is currently receiving a great deal of interest from researchers and policy makers. This paper explores yet another issue related to biofuel expansion, namely, the effect of differing biofuel production and blending standards on the existing liquid fuels supply infrastructure.

2. PETROLEUM REFINING AND BIOFUELS

When ethanol is blended with gasoline, it affects both the energy content, as well as the octane and emissions characteristics of the resulting fuel. Specifically, ethanol is less energy dense than petroleum based gasoline. As a result, cars using gasoline blended with ethanol generally will suffer a reduction in their rated fuel economy. In addition, ethanol is an octane booster. When ethanol is added to gasoline, refiners must remove some lighter-end gasoline components that also boost octane in order to meet vehicle octane specifications. Finally, ethanol has a very high Reid Vapor Pressure, meaning it evaporates at very low temperatures. This means that gasoline blended with ethanol has greater evaporative emissions of volatile organic compounds. This requires further changes to the gasoline blendstocks to mitigate these emissions.

The adjustments to gasoline blendstocks required to maintain automobile performance and emissions requirements for the resulting fuels have two main effects on the refining sector and thus on the gasoline market. First, adding ethanol reduces total gasoline refining capacity because some of the lighter components that are produced during refining must be taken out of the gasoline to accommodate the high octane and evaporative qualities of ethanol. These lighter products may be used elsewhere, for example, as feedstocks for petrochemical products. Alternatively, some can be sold to other refining regions that do not have high blends of ethanol and can therefore accommodate more of the light-end products of the refining process. Finally, some high end products of the refining stream can be stored during the summer and reintroduced into the gasoline stream in the winter when colder temperatures reduce evaporative emissions. Either way, the end result is an increase in the average cost of producing gasoline, either because light-end components are not going to their highest valued use, or because they must be shipped to refiners that can use them in gasoline or stored, thereby incurring transportation expenses and costs of managing transactions between refiners.

The second effect is on the market structure of the refining industry. With different states and countries mandating different blending levels of ethanol with petroleum-based gasoline, the refineries that serve those states and regions will be making gasoline blendstocks that are not readily compatible with one another. A similar “Balkanization” of the refining market occurred with the proliferation of boutique gasoline blends that followed Clean Air Act requirements that areas out of compliance with air quality standards take steps to improve their air quality. A number of states, cities, or areas that were out of compliance with air quality standards adopted to use cleaner burning gasoline blends as part of their plans to

improve air quality. This required refiners who served these areas to invest in billions of dollars of new capital equipment to make these fuels. The result was a less fungible gasoline market in which a relatively few refiners regularly serve areas with special gasoline blends compared to areas using conventional gasoline. In the case of the proliferation of gasoline blends, those cities and areas adopting these blends generally ended up paying higher prices and having more volatile prices than areas using conventional gasoline. While it is too early to try to measure the effects of further Balkanization of the refining sector that will occur without coordination on ethanol blending standards, it is reasonable that some of the additional costs will be passed on into gasoline prices. It is also likely that, to the extent that differing blending standards lead to smaller numbers of refiners serving specific states or regions, that this could increase the response time to address refinery outages among any group of refiners serving a specific market. This would have the effect of increasing the amplitude and length of price spikes associated with such outages.

The case of biodiesel is more complicated than ethanol because the properties of biodiesel produced from different feedstocks and different processes can differ considerably in terms of their energy content, impacts on engine performance and wear, their usability at low temperatures, and other characteristics (DOE, 2006; National Biodiesel Board, 2008). Currently there are at least three biodiesel standards in the United States and Canada and one in Europe (National Biodiesel Board, 2008b; DieselNet, 2008). In addition to biodiesel standards differing and leading to a potential lack of global fungibility, similar refining issues exist with blending biodiesel and the petroleum-based diesel as with gasoline. For example, different biodiesels have varying lubricity characteristics, which require different components in petroleum-based diesel blends to provide proper engine performance (Knothe and Steidley, 2005). In addition, the same issues with respect to market structure could also exist and perhaps be even more significant because of the inherent lack of fungibility of biodiesel.

3. SHIPPING MOTOR FUELS: BIOFUELS AND THE SUPPLY CHAIN

Ethanol produced from agricultural feedstocks will generally be produced in smaller refineries near the sources of the feedstocks because moving the finished ethanol is much cheaper than moving the much larger volumes of feedstocks required for its production. This means that much of the ethanol produced will not be near existing demand or existing suitable pipeline infrastructure. In addition, currently, most petroleum product pipelines cannot ship high concentrations of ethanol because of the corrosive nature of ethanol that destroys certain seals and other parts in the pipelines as well as ethanol's capacity to absorb water. Nonetheless, it is likely that ethanol will eventually be shipped by pipeline because that is by far the cheapest mode of liquid fuel transport for most regions. In order to achieve this, collecting pipelines will have to be built to connect the smaller refineries scattered around agricultural areas to larger trunk lines used to serve major fuel demand areas. This, along with the adjustments to existing pipelines that will be required to handle ethanol will amount to billions of dollars of investments in supply infrastructure and will require a long time to get permits and negotiate placement of the pipelines. In addition, ethanol will likely be blended with gasoline before it goes into major existing pipelines to reduce the corrosive and water absorption effects on these older and less suitable lines. Finally, if different regions require different blends, this will reduce shipping and storage capacity, similar to what happened with the proliferation of boutique gasoline blends in response to the Clean Air Act. Specifically, just as different gasoline blends must be kept segregated during shipping and storage, so will different ethanol blends. This will require that large tanks that were built

to handle a more fungible liquid fuel supply will be handling smaller batches of more types of fuel and this reduces total storage capacity. Similarly, batches going through the pipelines may also be smaller as a result of more different fuel types having to be segregated. This will reduce the capacity of the existing pipeline infrastructure because sending smaller batches through the system requires greater precision in placing and removing these fuels from the pipelines and this is generally achieved at the cost of a slowing of the rate of flow through the pipelines.

Biodiesel can already be shipped by pipeline, generally without any modifications to the infrastructure. However, biodiesel made from different feedstocks has different properties in terms of the fuels “cloud point,” which refers to the temperature at which the biodiesel begins to gel. The variation in cloud point could have impacts on the ability to ship biodiesels in pipelines in different climates. With these exceptions, the other problems associated with incorporating different blends of ethanol apply. Specifically, the biodiesel refineries will generally not be located on or near existing pipeline infrastructure so new feeder pipelines will have to be built or more expensive truck and rail transport will have to be used. Similarly, to the extent that different biofeedstocks are used and that this creates biodiesels with varying qualities, these fuels may have to be segregated during transport and storage, further adding constraints to the existing infrastructure.

Whatever the magnitude of air quality improvements attributable to biofuels, it should be clear that these benefits come at a cost. Specifically, as the number and volume of special fuel blends has increased, the ability of the supply infrastructure to keep up with growing demand has become increasingly stressed. In nearly all jurisdictions, the pipeline and storage terminal system was designed and built for a more fungible fuel slate so that the number of separate pipelines and tanks is fewer and the size larger than is optimal for transporting and storing multiple blends of motor fuels. This has slowed the speed at which pipelines operate and has rendered potential storage capacity unusable when small batches of special fuel blends are stored in large tanks designed for a fungible product. Further, the production of special biofuel blends has required refiners to make additional investments in refining processes, which raises the average costs of refining motor fuels. Finally, the fact that many valuable components of the refining stream cannot be used in many special blends, Means that the variable costs of producing these blends has also risen.

While there has been no definitive study of the precise price effects of the proliferation of special gasoline blends, there is a consensus among industry experts and government agency analysts that prices are higher and/or more volatile as a result of the increased use of special blends. Studies by the U.S. Environmental Protection Agency (EPA, 2001), the Department of Energy’s Energy Information Administration (EIA, 2002), the U.S. Government Accountancy Office (GAO, 2005; GAO, 2007), and a number of private and academic sector analyses (*c.f.* Ludwigson et al., 2005; Muehlegger, 2005; Hirshfeld and Kolb, 1997; NACS, 2003; Walls and Rusco, 2007) have concluded that areas that isolate themselves from a large and fungible gasoline market by adopting a rare or more costly to produce gasoline blend pay for this isolation through higher gasoline prices and greater price volatility. This is especially true in the event of local supply disruptions, because it takes longer to bring in replacement supplies. It is likely that the increased use of biofuels with idiosyncratic standards leading to a further balkanization of the liquid fuel slate will exacerbate the price effects already associated with special fuel use.

4. CONCLUDING REMARKS

Higher production costs and the more balkanized market structure lead to unambiguously higher prices for transportation motor fuels. There may well be benefits to the expansion of biofuel use in terms of diversifying liquid transportation fuel supplies, adding production capacity to a supply-constrained market with growing demand, and potentially reducing carbon emissions (assuming the biofuels that are produced actually do reduce emissions). Although biofuels may help reduce emissions and improve air quality, the introduction of these fuels could further divide the motor fuels market into islands of smaller and more local markets for blends of motor fuels that are typically not interchangeable. This transformation of the motor fuels market may further complicate the supply infrastructure, increase production and delivery costs, and reduce the availability of motor fuels in some cases. The impacts of the proliferation of special biofuels blends will likely be most evident when there is a disruption in the supply chain, such as when a refinery or pipeline is shut down. In these instances, localities using a blend different from that used in nearby areas must seek replacement supplies from farther away, leading to delays that likely cause higher and longer price spikes until these supplies arrive. In light of the opposing effects of environmental benefits and negative market implications, an ideal policy for any locality considering use of a special biofuels blend would entail an analysis of the likely effects of this fuel on both the environment and on the level and volatility of fuel prices. Finally, from a more global policy perspective, other effects of increasing production and use of biofuels must also be considered, including the effects on land and water use, species diversity, food prices, and other related issues.

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