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Executive Summary

One of the many measures proposed to reduce U.S. greenhouse gas (GHG) emissions is a Low Carbon Fuel Standard (LCFS). An LCFS would apply to sellers of motor fuels, who would be required to meet a per unit GHG emission standard in the fuels they sell, with that standard gradually reduced over time. While proposals for an LCFS differ from one another, the essence is to establish measures of life cycle GHGs per unit of energy in fuel, and set the standard to reduce these GHGs below those of petroleum-based fuels.[1]

We analyze various effects of an LCFS imposed upon sellers within the U.S. motor fuel market. For purposes of this analysis, we follow others in assuming that ethanol would be initially utilized to meet the standard. More is known about its emissions and costs than most other alternatives so that economic analysis can be more readily applied to its adoption. Also, for now it is probably the lowest cost alternative fuel that might meet an LCFS standard. We address whether an LCFS would reduce GHGs, what its costs would be, who would bear those costs, and the effects on U.S. energy security. Our analysis examines these effects in the context of a world petroleum market in which actions taken in the U.S. are not necessarily followed elsewhere. The analysis is applied also to an individual U.S. state imposing an LCFS.

We reach the following conclusions:

- Without relatively inexpensive low carbon fuels, attainment of an LCFS is likely to be prohibitively costly.
- With present technology, the costs of a national LCFS are likely to be very high. Estimates in the open literature indicate that the annual costs of reaching a 90% LCFS via use of ethanol would range between \$80 billion and \$760 billion—that is, between \$695 and \$6520 per year per U.S. household. We independently assessed these annual costs for a hypothetical LCFS effective in 2020 and derived a similar, although slightly smaller magnitude of \$65.5 billion—equivalent to \$570 per household annually.
- The cost per ton of carbon removed by an LCFS is an order of magnitude greater than the estimated costs imposed by GHGs, and also an order of magnitude greater than the costs per ton of other measures that would reduce these gases. This suggests that an LCFS is a highly inefficient means to reduce GHG emissions.
- An LCFS imposed within the U.S. cannot be analyzed in isolation. There will be offsetting effects elsewhere, reducing whatever decrease in GHGs might be achieved in this country. Because of these offsetting effects, the cost per ton of GHG reduced likely will be several times that found when considering the U.S. alone. This is another reason why an LCFS is highly cost ineffective.

- An LCFS redistributes income from fuel consumers and gasoline sellers to the producers of the low carbon fuel. If that fuel is ethanol, an LCFS would increase federal and state subsidies and hence redistribute income from taxpayers as well. Presently, ethanol receives about $7 billion in federal and state subsidies annually. With an LCFS, the annual figure could increase by between $1 billion and $16 billion.
- Economic analysis implies that an LCFS is an inefficient means to curb greenhouse gases because it implicitly subsidizes consumption of a fuel such as ethanol that results in increased emissions. An efficient device would tax GHG emissions from all sources. For example, a carbon tax applied to the carbon content of fuels would discourage high carbon fuels relative to low carbon ones without subsidizing incremental use of the latter.
- It is unclear what practically available fuels have lifecycle GHGs below those of gasoline produced from crude oil. Considerable controversy surrounds fuels such as ethanol, where land use and nitrous oxide considerations raise the possibility that lifecycle emissions exceed those of gasoline.
- U.S. energy security would not be much enhanced by an LCFS. Use of imported oil would fall, but others elsewhere would consume more, leaving the world oil market little changed. Imports of the low carbon fuel likely would rise, potentially raising a new form of energy insecurity. How much insecurity would depend on the nature of the low carbon import and the extent to which its supply is concentrated in a small number of countries.
- A state or regional LCFS would be even less effective than a national version. For a state like California, with a somewhat isolated fuel market, the costs likely would be high and little GHG reduction would be accomplished. For one like Minnesota, with ready access to ethanol, an LCFS would largely result in reshuffling, with reduced gasoline consumption and increased ethanol consumption within the state being offset elsewhere. Fuel consumers in the state would pay higher prices, however. For example, legislation currently being considered by Minnesota would, even under favorable assumptions, cost Minnesotans at least $570 million annually in 2020—an annual average of about $260 per household.
- We find little justification for an LCFS as a means to reduce U.S. or state GHGs. Uncertainty over fuel lifecycle GHGs, the costs of such an approach and clear indication that there are far better means to reduce GHGs suggest it is a poor policy choice. Both the U.S. government and state governments such as California and Minnesota should look to other policies to reduce GHGs within their respective jurisdictions.

Introduction

Though debate continues over the extent to which anthropogenic sources are responsible for climate change, many U.S. policy makers have concluded that measures to compel reductions in greenhouse gas (GHG) emissions are needed. They cite findings of the UN Intergovernmental Panel on Climate Change (IPCC) and of individual scientists which suggest that carbon dioxide (CO_2) and other GHG emissions are at least partly responsible for much of the 20th century and early 21st century global warming,[2] and argue that voluntary emission reductions are insufficient to prevent significant impacts upon the world's climate. This report does not address the scientific premise of an LCFS. However, it assumes that whatever measures are taken to mitigate GHG emissions should be cost effective relative to other potential policy measures.

A wide variety of policies have been considered. These range from government encouragement for voluntary reductions in GHG emissions to a proposed cap and trade system designed to set limits on the nation's carbon emissions and to reduce these limits over time. Other measures include federal support for the development of low-carbon forms of energy and for energy efficiency technology development, and compulsory measures such as increased fuel efficiency standards for vehicles, buildings and appliances.

Among the various measures proposed for consideration is a Low Carbon Fuel Standard. The underlying idea is to set a fuel standard for GHG emissions that sellers must meet, and then reduce the standard over time. While proposals for an LCFS differ from one another, the essence is to establish measures of life cycle GHGs per unit of energy in fuel, and set the standard to reduce these GHGs below those of petroleum-based fuels. An Administrator, perhaps the Environmental Protection Agency (EPA), would develop a measurement methodology.[3] Fuel sellers would gain credits by marketing fuels below the standard, and would require sufficient credits to assure that the average GHGs for their total fuel sales met the standard. Most LCFS proposals would allow trading, whereby those selling fuels averaging life cycle GHGs below the standard could sell credits to those whose fuels averaged above.

In this study we analyze various effects of an LCFS imposed upon sellers within the U.S. motor fuel market. For purposes of this analysis, we follow others in assuming that ethanol (since it is the cheapest alternative and the only one with proven technology) would be utilized to meet an LCFS. We address whether the standard would reduce GHGs, what its costs would be, and who would bear those costs. Our analysis examines these effects in the context of a world petroleum market in which actions taken in the U.S. are not necessarily followed elsewhere. The analysis is applied also to an individual U.S. state imposing an LCFS.

We then discuss whether there actually are fuels that would allow fuel sellers to meet an LCFS. Early estimates indicated that ethanol had fewer GHG emissions, when measured on a life cycle basis, than gasoline. By blending ethanol with gasoline fuel sellers would be able to meet the standard. However, recent research concerning lifecycle GHGs from biofuels raises questions whether this is so. Uncertainty exists with respect to lifecycle GHGs from other fuel sources as well. We discuss hydrogen, electricity and other possible fuel sources in this context.

A final section summarizes the conclusions of our analysis.

Context of a U.S. LCFS

Ongoing U.S. Efforts to Reduce GHGs

An LCFS is one of many proposed approaches to curbing U.S. GHGs. These can be broadly classified into voluntary measures, technology development, cap and trade, carbon taxes, and government command and control.

The U.S. approach to date largely has consisted of voluntary measures and government expenditures on low carbon technology development. Several federal agencies have organized public/private partnerships in which private organizations commit to reducing their GHGs to some target over a period of time in exchange for public recognition. The U.S. Department of Energy (DOE), EPA and the Department of Agriculture all have active programs in this regard.[4]

DOE spends over $3 billion per year on energy research and development, some of which is devoted to development and deployment of energy efficient equipment and renewable fuels such as solar and wind energy and to hydrogen for use in fuel cells. A good portion is devoted to research on nuclear energy, another low greenhouse gas emitting technology. A number of analysts have argued that very substantial investment in low carbon technology development is necessary if the U.S. is to dramatically curb its GHGs without imposing very high economic cost.

The U.S. Senate debated but did not enact a GHG cap and trade bill in 2008.[5] Such an approach would cap the annual rate of U.S. emissions and then reduce that cap over time. Emitters of carbon dioxide or its equivalent from other GHGs would be required to submit allowances for every ton of carbon emitted.[6] Holders of allowances could trade among themselves, so that those able to reduce GHGs at low cost could sell allowances to those able to reduce only at high cost. Each year's allowances would be auctioned by the government or distributed freely to emitting entities, or some combination of the two.

Congress may well reconsider cap and trade legislation within the next few years. In the meantime, states in the Northeast have formed a Regional Greenhouse Gas Initiative which has begun to be implemented. Several states and two Canadian provinces on the West Coast are forming a second regional cap and trade organization, and a collection of Midwestern states is moving towards yet a third such initiative. It appears, therefore, that a cap and trade system or set of systems likely will be in place whether or not an LCFS is enacted.

Many economists and some in the media have proposed that the U.S. enact a carbon tax as the least costly and most efficient means to curb GHGs. The tax would raise the cost of carbon based fuels relative to other energy sources and so induce consumers and investors to conserve the one and develop the other. However, there has been little political interest in such an approach, as most politicians fear voter backlash should they enact such a tax.

Beyond encouragement for voluntary measures and R&D, the most utilized federal approach to achieving GHG reductions has been command and control. In 2007 legislation was enacted to compel a significant increase in vehicle fuel efficiency and a very large substitution of ethanol and other biofuels for gasoline and diesel.[7] Other federal legislation has mandated building and appliance efficiency standards. These policies were enacted for a variety of reasons, but they were rationalized in part by their ability to reduce GHGs.

U.S. GHG emissions have been growing at a slow rate in recent years and actually declined by 1.5% in 2006 (the latest data available).[8] They are expected to grow at an annual rate of 1.1% between now and 2030.[9] In contrast, emissions outside the U.S. have been growing at a more rapid rate and are expected to increase at rates 2 and 3 times those of the U.S.

Table 1. U.S. and World Energy Related CO_2 Emissions (million metric tons of carbon dioxide)

Region	1990	2003	2004	2030	Annual % Change 2004-2030
U.S.	4,989	5,800	5,923	7,950	1.1
OECD	11,399	13,225	13,457	16,654	0.8
Non-OECD Asia	3,627	6,479	7,411	16,536	3.1
Total Non-OECD	9,847	12,283	13,465	26,226	2.6
Total World	21,246	25,508	26,922	42,880	1.8

Source: EIA, "Emissions of Greenhouse Gases in the United States," Table 3, November 2007.

U.S. and World Petroleum Market

Examination of an LCFS in the United States requires some market context. Broadly, the world consumes about 86 million barrels per day (mmb/d) of crude oil, each barrel containing 42 gallons. U.S. daily consumption is approximately 20 mmb/d, of which road-based motor fuels constitute about 60%. Gasoline consumption alone is about 9 mmb/d and diesel consumption about 3 mmb/d. Transport fuel consumption also includes jet fuel, which is about 1 mmb/d.

About 65% of the oil consumed in the U.S. is imported, either as crude oil or refined product. A large portion of these imports come to the U.S. from Western Hemisphere nations such as Canada, Mexico and Venezuela.

Overall in the world market, OPEC countries export around 25 million b/d, and there are other large exporters such as Russia, Angola and Norway. Because oil is so widely traded, the market is international in scope and actions taken in a single nation must be viewed in a broader context.

The Energy Information Administration (EIA) of the U.S. Department of Energy provides annual forecasts of U.S. petroleum consumption, basing its estimates on expected prices and economic growth, continuing increases in efficiency technology, and existing law and regulation. EIA's 2008 forecast estimates that U.S. transportation fuel demand will grow by a little under 1% per year between 2008 and 2030, much of it in the heavy duty truck and aircraft markets. If this forecast is borne out, the U.S. fuels market in 2030 will be about 20% larger than at present.

Over the same period, total petroleum liquids consumption in the transportation sector is projected to grow by much higher rates in developing countries—2.9% per year in India, 5.3% in China and 3.1% in all non-OECD countries. Because of these rates of growth, world consumption of liquid transportation fuels is expected to increase 1.6% annually over the period.[10] If that happens, world demand for transportation fuels will increase by roughly 50% by 2030.

Proposals for a Low Carbon Fuel Standard

National Standard

As explained earlier, the essence of an LCFS is to establish an average per unit fuel carbon standard which fuel sellers must meet, giving credits to those selling fuels whose GHG emissions fall below the average, and allowing trade of credits so that those selling fuels with GHG emissions above the average can purchase from those selling fuels below. Thus, for example, if the standard is set below the GHG emissions of gasoline, a gasoline refiner-seller still could participate in the market by purchasing credits from someone selling fuels whose GHG emissions average below it.

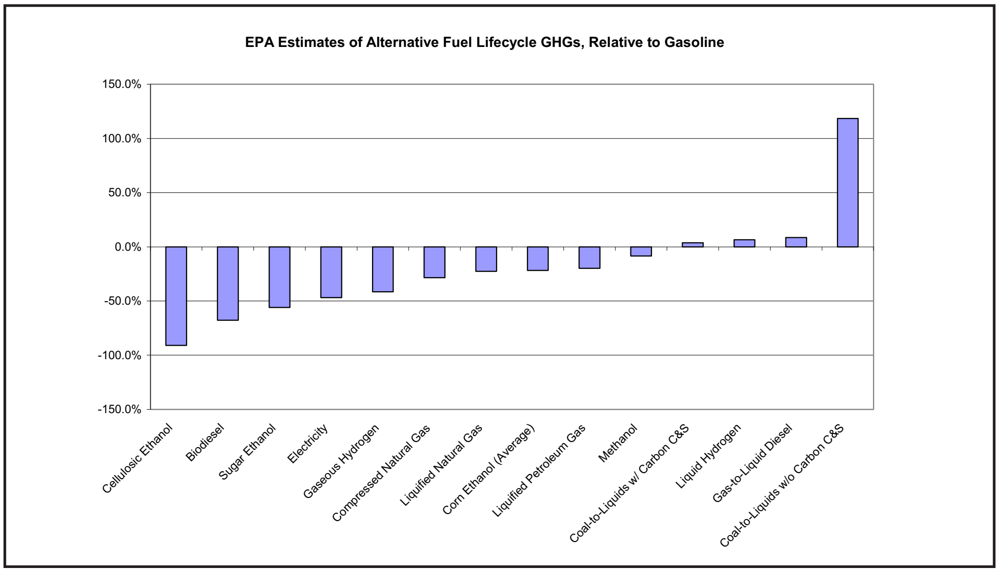
An LCFS might take a number of different forms. Often the definition stipulates an average life cycle GHG per unit of energy for petroleum-derived fuels as of some particular time, and then specifies a reduction, such as 10%, that must be achieved by some later time. For example, Senate bill 1324, introduced in 2007 and co-sponsored by Senators Harry Reid (D-NV), Tom Harkin (D-IA) and Barack Obama (D-IL), required that motor fuels sold in the U.S. market achieve a 5% reduction in carbon content relative to a 2005-2007 baseline by 2015, and a 10% reduction by 2020.[11]

However, other types of baselines have been suggested. These include the amount of carbon per transportation mile (for a standardized vehicle), individual firm historical energy sales, or a rolling average of historical energy sales for each firm.[12]

Some congressional proposals for an LCFS contain a second constraint, namely that fuel suppliers must supply some minimum quantity of ultra-low carbon fuels. S. 1324 defined two categories of ultra-low carbon fuels, "category 1" and "category 2." Category 1 ultra-low carbon fuels are those with lifecycle GHGs at least 50% below those of conventional fuels, while category 2 ultra-low carbon fuels are those with lifecycle GHGs at least 75% below conventional. The bill specifies that fuel suppliers must supply 0.5 billion gallon equivalents of category 1 ultra-low carbon fuel and 0.25 billion gallon equivalents of category 2 ultra-low carbon fuel by 2012, with the amounts rising to 13 billion and 8 billion gallons by 2025.

For practical implementation, an LCFS requires a specific methodology to measure life cycle GHG emissions. The Argonne National Laboratory has produced the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model, which provides estimates of "well-to-wheel" GHGs for any fuel. GREET has been used by EPA to analyze GHG reductions from the use of alternative fuels, and would be one model that could be used with an LCFS. In 2007 EPA used the GREET model to provide estimates of lifecycle GHGs from a number of motor fuels. Figure 1 below shows those estimates, expressed relative to GHG emissions from gasoline made from crude oil. As can be seen in Figure 1, a variety of fuels appear able to reduce lifecycle GHGs relative to gasoline. Some even could be used to meet the "ultra-low" categories in recent congressional legislation.

Figure 1



Source: EPA, Emission Facts, "Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use," April 2007.

However, given the status of the nation's vehicle fleet and fueling infrastructure, several of these fuels are unlikely to much contribute to an LCFS for some time. Further, given present technology, many of these fuels would be extremely costly to supply in the quantities needed to meet such a standard. At least initially, refiners almost certainly would turn to ethanol as their fuel of choice, and given existing fuel mandates, would use corn ethanol and then cellulosic ethanol as it became available in quantity. That is why we have chosen to use ethanol as the low carbon option in our analysis of an LCFS.

We acknowledge, however, that recent modeling work has raised serious questions concerning lifecycle GHGs from ethanol and other biofuels. Searchinger *et al.* (hereinafter Searchinger) examined land use changes associated with the production of ethanol and other biofuels, and concluded that lifecycle GHG emissions from these fuels are considerably higher than estimated by GREET.[13] Others have pointed to nitrous oxide emissions from the production of biofuels as offsetting carbon reductions from use of these fuels.[14] By their estimates, ethanol may even result in more GHGs than gasoline. This topic is more fully addressed below.

State LCFS proposals

California has enacted AB32, legislation that mandates reductions in the state's greenhouse gas emissions to 1990 levels by 2020 and to 80% below those levels by 2050. As part of this initiative, California plans to impose an LCFS. In March 2008, the California Air Resources Board (CARB) issued a Proposed Concept Outline (PCO) which laid out the general principles under which it would impose an LCFS. In October, 2008, the state issued a draft regulation for stakeholder comment.[15] The regulation provides information concerning how various fuels will be rated, but cautions that no final decisions have yet been made.

The basic objective of the draft regulation is to reduce the average carbon content of fuel sold in California by around 10% by 2020, relative to its presumed content in 2010, with the reduction gradually phasing in between 2011 and 2020.[16] The reductions apply to motor fuel used by autos, trucks and trains (gasoline and diesel), but not to that used by aircraft or ships. In the earlier PCO, there was an additional requirement for sale of an "ultra-low" carbon fuel, but this requirement appears to have been dropped in the draft regulation.

CARB's regulatory document indicates that the GREET model will be used to measure life cycle GHGs from fuels. Credits can be earned from the sale of fuels below the standard, and these can be traded among fuel sellers in the California market. CARB has asked for comments on its proposed methodology.

California is not the only state considering an LCFS. In early 2009, eleven states in the Northeast and Mid-Atlantic region announced plans to create a regional LCFS. In the Midwest, the Minnesota legislature has been holding hearings on a bill to establish an LCFS in that state.[17] We analyze the impacts of an LCFS in a state such as California or one such as Minnesota below.

Economics of an LCFS

Meeting an LCFS

The arithmetic of meeting a fuel standard is straightforward. For fuel sellers to do so, there must be a fuel whose lifecycle GHGs are at or below the standard. Sales of the low carbon fuel, when averaged with those of the high carbon, enable fuel sellers to meet the standard. The closer the GHG emissions of the low carbon fuel are to the standard, the more of that fuel must be supplied of the total amount of fuel in the marketplace.

Corn Ethanol Dominates Gasoline Supply to Meet a 10% LCFS

LCFS proposals advanced in California, Minnesota, and nationally typically require a 10% reduction in the carbon content of the gasoline supply by 2020. If an LCFS is set at 90% of the GHG emissions of fuel made from crude oil and accepting EPA's estimate that corn ethanol has lifecycle GHGs about 80% those of gasoline, then for fuel sellers to meet the 90% standard in 2020 using that fuel, it would have to constitute about 50% of the market in that year.

For example, suppose an LCFS is set at 90% of the GHG emissions of fuel made from crude oil. EPA’s 2007 estimates shown in Figure 1 suggest corn ethanol has lifecycle GHGs about 80% those of gasoline. If corn ethanol were the most cost effective alternative, then for fuel sellers to meet the 90% standard in 2020 using that fuel, it would have to constitute about 50% of the market in that year.

Analogy to CAFE standards

An LCFS is analogous in some ways to the U.S. Corporate Average Fuel Economy (CAFE) program, which set minimum average MPG standards that auto sellers were compelled to meet. This program has been analyzed by a number of economists. Using standard economic analysis, Kwoka showed that an auto seller could comply with the standard by changing the relative prices of its low mileage (large) and high mileage (small) cars in order to increase the sales of the latter at the expense of the former.[18] In effect, the seller would “tax” sales of low mileage autos and subsidize those with high mileage. Further, according to the analysis, there is no a priori reason to assume that total auto sales would remain constant. If the demand elasticity for the high mileage, smaller cars were greater than the demand elasticity for the larger cars, total sales could increase. Kwoka did not make an empirical estimate of the effects of CAFE on total vehicle sales, but it is plausible that consumers buying the smaller, cheaper cars were more sensitive to price than those buying the larger, more expensive alternatives. If so, directionally CAFE may have helped to boost vehicle sales.

Kwoka focused on vehicle pricing, but automakers also could respond by using technology to increase the fuel efficiency of automobile engines, by making vehicles lighter in order to improve their gas mileage, or by inducing buyers to switch from larger autos to light trucks and Sport Utility Vehicles, for which lower CAFE standards applied. In fact, by 2006 sales of light trucks and SUVs constituted over 50% of U.S. light duty vehicle sales. This was one reason why, between 1991 and 2006, the last year for which aggregate data is available, the average miles per gallon (mpg) of the U.S. vehicle fleet hardly changed.[19]

Economists also have examined the effect of higher fuel economy on consumption, and on the consequences of making cars lighter in order to increase their mpg. Portney *et al* cited previous analyses which indicates that, because increased mpg reduced the per mile cost of driving, there is a "rebound effect," in which drivers are induced to drive more miles. They estimated this effect at between 10 and 20% of any reduction that CAFE otherwise would have achieved.[20]

Crandall and Graham found that CAFE led to a decrease in the average weight of U.S. autos, and that this in turn led to an increase in deaths and injuries from auto accidents.[21] They concluded that this is a social cost of the CAFE program. Portney *et al.*, in assessing whether CAFE should be further increased, concluded that "it's quite possible that tightening CAFE could do more harm than good."[22]

Application to an LCFS

Kwoka's analysis of CAFE standards suggests an approach to analyzing fuel seller behavior under an LCFS. To simplify, suppose there are but two fuels, one a high carbon source and the other a low carbon. Assume that the high carbon fuel is superior with respect to per unit energy content and price, so that it is the only fuel demanded if there is no LCFS. However, the LCFS forces fuel suppliers to offer some combination of the low and high carbon fuels to meet the standard. How will they do so?

The incentives are similar to those of the CAFE standard. Fuel sellers can meet the standard by decreasing sales of the high carbon fuel, increasing sales of the low carbon fuel, or some combination of the two. By increasing the price of the high carbon fuel and reducing that of the low carbon, they can discourage consumption of the one while encouraging consumption of the other. If the elasticity of demand is low for the high carbon fuel whereas it is high for the low carbon fuel, overall fuel sales could actually increase. Depending on the relative increase in sales of the low carbon fuel and decrease in the high carbon, GHG emissions could increase or decrease overall.[23]

The low carbon fuel might be expensive to produce, however. Though its price to consumers is reduced by the cross subsidy from the high carbon fuel, its forced introduction into the market could raise the overall cost of fuels. In that case, even with more use of the low carbon fuel, the overall demand for fuel would be less than before. GHG emissions would drop. But the drop would be principally due to the higher price for fuels, not the introduction of a low carbon fuel.

Other Economists' Analyses

The economics of an LCFS have been analyzed by Holland, Knittel and Hughes (hereinafter HKH).[24] Their analysis is the first that looks carefully at how such a standard might work, what it would cost, and who would bear the costs. Also, they look at different forms of an LCFS and which of them would be the least costly to implement.

HKH assume that ethanol can be used to meet the standard, with GHG emissions 75% those of gasoline. Using this assumption, they simulate outcomes of a U.S. LCFS under varying demand and supply elasticities of petroleum and ethanol and conclude that while it is theoretically possible that total fuel sales could increase under such a standard, the likelihood is that they would decrease. This implies a decrease in GHG emissions. However, they conclude that an LCFS is an inefficient means to curb greenhouse gases because it subsidizes consumption of a fuel (ethanol) that results in increased emissions. A device such as a carbon tax would curb carbon-related GHGs from all sources, not only some while subsidizing others. The subsidy to some sources of carbon emissions is an important weakness of an LCFS.

HKH estimate the costs of an LCFS under a variety of assumptions concerning the elasticity of demand for motor fuels, elasticities of supply for ethanol and gasoline, and the carbon emissions rate of ethanol relative to gasoline. They show the potential increase in fuel price, the cost to consumers and producers (expressed as a loss in consumer and producer surplus), the annual loss in tax revenue, the impact on emissions and the cost per ton of carbon. We summarize their findings for a 90% LCFS in Table 2 below.

Cases 1-4 demonstrate the importance of supply elasticity values in determining fuel price increases and overall costs to producers and consumers. Generally, a low ethanol supply elasticity (cases 1 and 4) causes steep price increases to fuel consumers and large overall economic losses. These cases achieve the largest emission reductions, however, because there is relatively little increase in ethanol consumption. A high ethanol supply elasticity (cases 2 and 3) reduces the costs considerably though the cost of reducing carbon still is several hundreds of dollars per ton.

Cases 5 and 6 have an intermediate ethanol supply elasticity but vary the ethanol emissions rate relative to gasoline. In Case 5, that emissions rate is reduced to 65%, reducing costs to approximately those of Case 2 (which had a higher ethanol supply elasticity) while in Case 6 it is increased to 85%, which results in much more ethanol having to enter the mix, with much higher costs. This illustrates the point that estimates of lifecycle GHG emissions will have a major impact on the consequences of an LCFS.

Table 2.
Estimated Economic & Emission Consequences of a National LCFS

	Fuel Price Increase ($ (per gallon)	Annual Cost to Consumers & Producers ($ billions)	Annual Tax Revenue Loss ($ billions)*	Emission Reduction	Annual Cost per ton of Carbon Reduced
Case 1	$12.67	$760	$7	25%	$2,272
Case 2	$0.60	$80	$5	20%	$307
Case 3	$0.13	$110	$1	12%	$723
Case 4	$9.37	$493	$16	45%	$836
Case 5	$0.67	$91	$3	17%	$417
Case 6	$3.31	$319	$10	31%	$772

Case 1: Fuel demand elasticity = .1; gasoline supply elasticity = .5; ethanol supply elasticity = 1.0; ethanol emission rate = 75%

Case 2: Fuel demand elasticity = .5; gasoline supply elasticity = 2.0; ethanol supply elasticity = 4.0; ethanol emission rate = 75%

Case 3: Fuel demand elasticity = .3; gasoline supply elasticity = .5; ethanol supply elasticity = 4.0; ethanol emission rate = 75%

Case 4: Fuel demand elasticity = .3; gasoline supply elasticity = 2.0; ethanol supply elasticity = 1.0; ethanol emission rate = 75%

Case 5: Fuel demand elasticity = .3; gasoline supply elasticity = 1.0; ethanol supply elasticity = 2.5; ethanol emission rate = 65%

Case 6: Fuel demand elasticity = .3; gasoline supply elasticity = 1.0; ethanol supply elasticity = 2.5; ethanol emission rate = 85%

**At the time these estimates were made, the federal excise tax subsidy for ethanol was $.51/gallon. It since has been reduced to $.45/gallon. We have adjusted the numbers in the tax revenue loss column accordingly.*

Tax revenue losses from ethanol subsidies vary between $1 billion and $16 billion, per year, among the cases. These losses are in addition to present state and federal subsidies to ethanol, which totaled about $7 billion in 2006.

Perhaps the most striking finding of the HKH analysis is the cost per ton of GHG reduction. The simulation results show a range from around $300 per ton of carbon to over $2200 per ton. In contrast, Tol, after examining estimates of GHG damage costs in twenty eight different studies, concluded that the mean estimate is $16 per ton of carbon with a 95% probability that the cost does not exceed $62 per ton.[25]

We take a simpler, more direct approach to see if we arrive at a similar conclusion. We assume, along with HKH, that the low carbon fuel of choice is corn-based ethanol. The reason is there is no currently available practical alternative. For example, though attention has been focused on cellulosic ethanol, there are currently no operational production plants and it is unlikely that even the modest 100 million gallon goal for 2010 will be reached.[26] Advances in the technology of producing cellulosic ethanol could, of course, alter the outlook, but these hoped for advances have not been forthcoming in the last several years and some are now concluding that "cellulosic ethanol is something that is always five years away."[27] In addition, recent research has raised question whether the life cycle GHG emissions of cellulosic ethanol actually are below those of gasoline.

Nevertheless, for present purposes, we follow HKH in assuming that ethanol has 75% the GHG emission rate of gasoline. Given this assumption, we calculate that in order to achieve a 10% reduction in the carbon content of transportation fuel by 2020, the U.S. would need to substitute ethanol for 40% of projected gasoline consumption, bringing total ethanol consumption in 2020 to 61.2 billion gallons from DOE's presently projected 21.6 billion gallons.[28] Given that the present mandate limits domestic ethanol production from corn to 15 billion gallons, the rest would have to come from major advances in cellulosic ethanol technology or from imports.

Such a huge increase in U.S. ethanol consumption would put very substantial upward pressure on ethanol prices (and on food prices) and provide a very large incentive for renewable fuel innovation. Perhaps such innovation would result in a reduction in the cost of cellulosic ethanol. Present law requires that 15 billion gallons of biofuels derived from sources other than corn be sold in 2020. For convenience, we assume its cost in 2020 is no more than that of ethanol from corn. Further, we assume that the rest of the 61.2 gallons would be obtained on world markets.[29]

Since DOE has projected that almost all gasoline will be sold in the form of E10 by 2020, the increase in ethanol consumption most likely would be accommodated by a substantial expansion in the use of E85. Assuming this to be the case, we estimate that the 10% reduction in fuel GHG emissions mandated by the LCFS would have the following costs:

- The price of ethanol would increase by 46%—from $2.01 per gallon to $2.93 per gallon due to the rise in U.S. ethanol demand.
- The price of gasoline (both conventional gasoline and gasoline blended with 10% ethanol) would increase by $0.61 per gallon from DOE's projected $2.35 per gallon to reflect the higher price of ethanol used in E85 and E10, and to compensate E85 users for their lower MPG at the new, higher price of ethanol.[30]
- The total cost to consumers of this program would be roughly $65.5 billion per year in 2020—an annual average cost of $570 per household.[31] These estimated costs would be even larger were increased food costs included.
- The net savings in GHG emissions, given our assumption of corn ethanol's 25% GHG savings relative to gasoline, would be 142 million metric tons per year—equal to 7% of transportation emissions and 2.2% of total projected U.S. GHG emissions in 2020.

- The per ton cost of the 142 million metric ton reduction is $457. This number is within the range found by HKH.

While the preceding are likely the major costs of an LCFS, there are other potential costs that are not included in the above analysis. These include increased shipping costs, the additive effect of agricultural commodity price volatility on petroleum price volatility, additional service station trips resulting from reduced miles per gallon and increased food costs resulting from the higher ethanol use. Because we have assumed that an LCFS would treat different types of crude oil uniformly (this topic is covered at greater length later on in this paper) we have also not included the potential costs of discriminating against unconventional crude oil because of its higher GHG emissions—most notably Canadian oil sands crude or Venezuelan extra heavy oil.

A U.S. LCFS in an International Context

GHG emissions, regardless of their point of origin, have identical climate change impacts. Because of this, analysts have identified the problem of "reshuffling," whereby emission reductions achieved by a program in one country are undone by effects of the program elsewhere.[32] When this happens, the locus of emissions is merely shifted—reshuffled—from one country to another. Overall emissions may be largely or wholly unaffected or even increased. The HKH analysis provides considerable insight into how an LCFS would work within the U.S. market, but leaves open what would happen elsewhere. We next examine this question.

Reshuffling International Markets for Petroleum Under an LCFS

One example of how reshuffling might work involves Canadian oil sands. A U.S. LCFS effectively would tax this source of crude oil, since product derived from it involves higher lifecycle GHGs than from conventional crude oil. But such a tax, because it would lower the price received by Canadian producers, would make it more attractive for them to ship oil sands crude to the Far East, particularly China. This sort of reshuffling could cause GHG emissions to increase because of the increases in fuel used to transport the Canadian oil, a possibly less efficient refining process, and the greater U.S. imports from other sources that would be required to replace the oil sands oil.

As viewed by world markets, the decrease in U.S. demand for the high carbon fuel (gasoline) reduces demand for that fuel whereas the increase in U.S. demand for the low carbon fuel (ethanol) increases demand for it. Prices fall outside the U.S. in the gasoline market, but rise for ethanol.

The fall in price for gasoline encourages demand in other countries. Further, if the elasticity of supply of the fuel is low, then the reduction in U.S. demand has relatively little effect on overall world consumption. The U.S. demand decrease is largely offset by increased consumption elsewhere, and though U.S. GHG emissions from consumption of gasoline decrease, they increase in other countries. The net effect is a small decrease overall.

At the same time, the increased world price for ethanol reduces consumption of that fuel elsewhere. The amount depends on worldwide supply elasticity for this fuel. For example, if the elasticity of worldwide supply for ethanol is high, the increase in U.S. demand will have relatively little price impact abroad, and hence a relatively small impact on consumption. Overall, there could be a net increase in consumption of ethanol, less consumption abroad, but more in the U.S. If so, GHG emissions would rise with the increased quantity of this fuel demanded and supplied. Also, in this case the decrease in the price of gasoline abroad might more than offset the rise in price of ethanol, so that fuel prices in aggregate outside the U.S. would decrease.

Overall, GHG emissions fall in the gasoline market and rise in the ethanol market. The net effect depends on supply elasticities for the two fuels. The lower the supply elasticity of gasoline and the higher that of ethanol, the more likely that worldwide GHG emissions increase, even if there is a decrease within the U.S. But even if the overall result is a net worldwide decrease, it is smaller than in the U.S. alone. This implies that the per ton cost of reducing GHGs is higher than estimated by HKH, possibly much higher. In short, U.S. consumers and taxpayers are asked to bear a burden that would have very little payoff, in part because of offsetting actions abroad.

The world-wide impact of an LCFS is difficult to assess quantitatively. Nevertheless, a very rough estimate can be made. If the reduction in U.S. gasoline demand is 2.15 million b/d, midrange estimates of price and demand elasticities suggest that this would lead to an additional 1.4 million b/d of gasoline consumption elsewhere. The net reduction in gasoline consumption then is only 0.7 million b/d. This assumes that a price drop from reduced U.S. consumption induces others to consume more.[33] Conceivably, producers could reduce supply to fully offset the U.S. demand reduction, but we assume they reduce prices and that demand elsewhere consequently increases.

At present, the U.S. consumes at least half the ethanol produced worldwide. An increase in U.S. ethanol demand of 40 billion gallons (over what would otherwise be produced in 2020 from domestic sources) likely would swamp the world ethanol market. If consumption outside the U.S. otherwise would have grown to, say, 27 billion gallons per year by 2020, the increase in U.S. demand might well reduce it to near zero. Thus, U.S. actions are offset by a 1.4 million b/d increase in petroleum consumption plus 27 billion gallons of reduced ethanol consumption elsewhere. About two thirds of the gains in terms of emission reductions are lost, but about two thirds of the increase in U.S. ethanol use (over what was mandated anyway) is offset. Then the emissions reduction impact of the LCFS calculated only for the U.S. would be reduced by about two thirds, so that the cost per ton would triple. Given our earlier estimate of $457 per ton without regard to offsetting actions elsewhere, this would imply a per ton estimated cost of $1373.

This analysis assumes an internationally traded low carbon fuel such as ethanol. If instead the low carbon fuel is limited to the U.S. market, then the impacts are somewhat different. There is still a net reduction in worldwide consumption of the high carbon fuel, gasoline, but the increase in low carbon fuel consumption in the U.S. is not offset by reductions elsewhere. Thus, there is a net decrease in gasoline fuel consumption coupled with a gross increase in that of the low carbon fuel. Worldwide GHG emissions are more likely to rise than in the case of a traded low carbon fuel such as ethanol because there are no offsetting reductions in low carbon fuel consumption elsewhere.

The analysis can be applied to ultra-low carbon fuels as well. These are likely to be costlier than low carbon fuels and because of this, less likely to be internationally traded. Minimum requirements for these fuels would add to U.S. motorist costs and costs per ton of GHG reduction. By raising the cost of fuel even further, they would reduce fuel consumption in the U.S. more, but the cost of GHG reductions would be even greater relative to the damage cost of such emissions and to other means that might be used to reduce U.S. GHGs.

Energy Security Considerations

One purpose of a low carbon fuel standard is to reduce U.S. dependence on petroleum products. If low carbon fuels were produced domestically, this could increase U.S. energy security. However, as we have shown, decreased petroleum consumption from an LCFS in the U.S. almost certainly would be replaced by increased petroleum consumption elsewhere, so that, worldwide, little change in consumption would take place. This would leave petroleum producers in about the same position as if no U.S. LCFS had been promulgated.

Further, the U.S. might well be forced to import some of the low carbon fuel to meet its goals, as it almost certainly would if ethanol were chosen. This would create new import dependencies, so that the net effect of an LCFS on U.S. energy security likely would be minimal and could even be negative if few countries produced the low carbon fuel in question.

Costs of Other Approaches to CO_2 Reduction

Yet another way of assessing the costs of U.S. GHG reduction via an LCFS is to compare these with the costs of alternative GHG emission reduction alternatives. A number of analysts have taken this approach.[34] One of the more recent and comprehensive is McKinsey and Company, which analyzed the costs of 250 different options for reducing GHG emissions over a 25 year period.[35] Their conclusions were based on a "bottoms up" analysis, in which engineering data concerning means of reducing GHGs was used. The study provided many specific examples of potential GHG reduction opportunities. They found that "the United States could reduce greenhouse gas emissions in 2030 by 3.0 to 4.5 gigatons of CO_2e using tested approaches and high-potential emerging technologies."[36] Further, most of the reductions could be made at a cost of less than $50 per ton with a substantial number actually having negative costs (energy savings outweighing costs), as shown in Table 3 below.

Table 3. Innovative Greenhouse Gas Emission Abatement Alternatives with Costs Less than $50 per ton CO_2e

Cost to Abate One Ton of CO_2e	**Alternative Approaches**
Savings of at least $30 per ton	• Enhance energy efficiency of commercial and residential electronic devices • Improve efficiency of residential lighting • Install more LED and CFL lighting in commercial buildings • Increase fuel economy of light trucks using existing technologies • Install new shell improvements in commercial and residential buildings • Increase use of Combined Heat and Power (CHP) cogeneration technology in commercial buildings
Costs between -$29 and +$30 per ton	• Increase use of Combined Heat and Power (CHP) cogeneration technologies in industrial plants • Promote research, development, and use of cellulosic biofuels • Continue efficiency improvements in existing power plants • Expand use of conservation tillage farming techniques • Build new nuclear power plants • Increase afforestation of pastureland • Promote reforestation • Plant more winter cover crops • Build enough onshore wind energy capacity to reach "medium" penetration levels
Costs between $30 and $50 per ton	• Increase afforestation of crop land • Build enough onshore wind energy capacity to reach "high" penetration levels • Increase HVAC equipment efficiency in buildings • Install Carbon Capture and Storage (CCS) systems in coal power plants • Equip new industrial plants with CCS technology

The McKinsey work identifies a large number of options for reducing GHG emissions that can be done at a small fraction of the estimated cost per ton of an LCFS. For example, the options in the top third of the table, which include improved efficiency in buildings and appliances, increased fuel efficiency in vehicles[37] and improved efficiency in industry operations, may even yield net savings. The three "clusters" of activities have the potential to decrease GHG emissions by between 1,670 and 2,300 megatons—reducing annual U.S. GHG emissions by between 18% and 24%. And if the cost estimates are accurate, the reductions can be done for $50/ton or less.

The McKinsey analysis is open to challenge. If GHG reductions that pay for themselves are available, why aren't they being utilized? Often bottoms up analyses fail to take account of information costs that make energy conservation options more costly than they first appear. Still, even if McKinsey's numbers are on the low side, they suggest there are a large number of options to reduce GHGs at costs of $50 per ton or below. This number is an order of magnitude below the $457 per ton cost of GHG emission reductions from an LCFS which we estimated, and even more below the $1371 per ton we estimated after offsetting actions elsewhere in the world are considered.

Analysis of a State-Based LCFS[38]

California

The California market differs from that of many other states because it is both large (almost 10% of the U.S. total) and somewhat isolated from the rest of the country. Further, California regulations require a special blend of gasoline that is made in very limited quantities outside of California and is costly to transport. Nevertheless, because the petroleum market is worldwide in scope, any reduction in the consumption of petroleum products caused by a California LCFS would have offsetting effects elsewhere. The net reduction in petroleum consumption would consist of California's reduction less the increase in petroleum product consumption elsewhere.

California's relative isolation might have an impact on the alternative fuels used to comply with the standard, however. California produces relatively little ethanol, and it is costly to ship large quantities from one area of the country to another. For that reason, fuel sellers in the California market might utilize relatively high priced electricity, hydrogen or other alternatives. If, because of their high costs, these alternatives to gasoline were not utilized as motor fuels in other states, then the increased use in California would not be offset by decreased use elsewhere. Thus, the gross life cycle GHG emission increase from use of those alternative fuels in California would also be the net increase. In that case, aggregate U.S. (or worldwide) GHG emissions likely would not much decrease from a California LCFS, but the cost to California consumers could be very high.

Minnesota

Minnesota is actively considering newly introduced LCFS legislation (Senate File 13). The bill seeks to reduce Minnesota transportation related GHG emissions by 10% from 2005 levels by 2020, beginning in 2011. The bill would incorporate life cycle GHG emissions estimates for alternative fuels from the GREET model, with all gasoline produced from crude oil assumed to have the same GHG emissions. Thus, the bill would not assign a higher GHG emissions level to gasoline refined from oil sands or other unconventionally produced crude oil. However, many of those testifying (including a representative of the Canadian Government) believe that, if the Minnesota bill is enacted, political pressure to discriminate against petroleum products produced from oil sands crude (a rising source of crude oil to the state) will be overwhelming.[39]

Minnesota is a relatively small part of the total U.S. gasoline market. With a population less than 2% of the U.S. total, the state made up somewhat less than 2% of total U.S. gasoline consumption in 2007.[40] It has two refineries, is close to major refining centers, and is well integrated with the rest of the country's petroleum distribution system by pipeline, water, rail and truck.

Nevertheless, the cost to Minnesota consumers could be considerable, for the same reasons that a national LCFS is likely to be very costly. There is no alternative fuel, available at low cost, that has dramatically lower life cycle GHG emissions than gasoline. As long as the only feasible alternative fuel is corn-based ethanol, the amounts that would be required to achieve even a 10% reduction in GHG emissions are very substantial, as would be the consumer cost.

Minnesota also comprises a relatively small part of the ethanol market. If every single gallon of gasoline sold in Minnesota contained 10% ethanol, the state would comprise 3% of the national market.

As a result, a state-mandated LCFS that doubled or even tripled the use of ethanol in Minnesota likely would have limited effect on markets elsewhere. Minnesota faces supply curves for both gasoline and ethanol which are very elastic. Decreases in petroleum consumption in Minnesota, because it is such a small part of the national and international market, would not have much of an effect on petroleum prices, nor would increases in ethanol consumption much affect the price of that fuel. There would be a reshuffling of fuels among states, more gasoline flowing elsewhere and more ethanol to Minnesota, with little overall impact on GHG emissions.

Nevertheless, the cost to Minnesota consumers could be considerable, for the same reasons that a national LCFS is likely to be very costly. There is no alternative fuel, available at low cost, that has dramatically lower life cycle GHG emissions than gasoline. As long as the only feasible alternative fuel is corn-based ethanol, the amounts that would be required to achieve even a 10% reduction in GHG emissions are very substantial, as would be the consumer cost. To understand this more fully, Senate File 13 provides an instructive example.

In 2005 Minnesota consumed 7.2 million gallons per day (mg/d) of gasoline, including roughly 0.6 mg/d of ethanol. Applying EIA's projected fuel market growth rates for the country, this will increase to 7.3 mg/d in 2020, including about 0.7 mg/d of ethanol.[41] Because ethanol GHG emissions are assumed to be about 75% those of gasoline, complying with a mandate to reduce transportation GHG emissions by 10% from 2005 levels will require an <u>increase</u> of 2.6 mg/d of ethanol, bringing Minnesota's total ethanol consumption in 2020 to around 3.2 mg/d. How could fuel sellers comply with such a mandate?

Minnesota ethanol consumption is close to saturation in the sense that almost all of its gasoline is now blended with at least 10% ethanol. There is thus little room for expansion without forcing a higher gasoline/ethanol blend or by increasing the E85 market.[42] But capacity to produce ethanol exceeds the requirement. For that reason, the state has requested a waiver from EPA that would allow up to a 20% blend to be used in conventional gasoline engines. EPA has considered this waiver request for some time and the auto industry has registered strong concerns about the use of anything greater than E10 in conventional vehicles, fearing possible damage to their engines. Although engine testing is currently underway, for now it seems unlikely that such testing will lead to regulatory approval for the use of E20 in conventional vehicles. However, were the Minnesota waiver to be granted, fuel sellers then could legally use about 1.5 mg/d of the 3.2 mg/d of ethanol in conventional gasoline. How would they sell the remaining 1.7 mg/d? With few other alternatives, they would be compelled to expand the E85 market.[43]

Because there is roughly a 30% fuel penalty in flex fuel vehicles using E85, gasoline distributors would be forced to subsidize E85 sales while increasing prices for conventional gasoline.[44] The subsidy is needed to compensate consumers for the lower energy content of E85.

The size of the subsidy borne by the buyers of conventional gasoline (including subsidies to buyers of E20) will be a function of the price of both ethanol and gasoline as well as the carbon target of the LCFS. However, assuming (as has been true in most years) that the price of ethanol approximates that of gasoline and the latter price is $2.50 per gallon, the subsidy would be in the neighborhood of 30% or around $.75 per gallon to bring E85, on an energy content basis, into line with that of gasoline. Applying this subsidy to the necessary E85 sales would result in an annual transfer from gasoline consumers to E85 consumers of about $570 million—an average of roughly $260 per Minnesota household.

Implementation of an LCFS in Minnesota also would require that substantially more stations be equipped to sell E85. Although Minnesota already has more than 100 stations that are so equipped,[45] this number would have to be increased substantially, at a cost per station of between $30,000 and $240,000,[46] depending on whether additional tankage is required.[47] Making the simplifying assumption that each pump would deliver 50,000 gal per month, the additional E85 consumption would require roughly 500 additional E85 pumps and related equipment. Assuming one half of these also required new tankage while the cost of the remaining half was covered by the federal tax credit, the total cost to Minnesota consumers would be over $50 million.

What do Minnesota gasoline and ethanol consumers obtain as a result of this program? Very little. GHG emissions would be essentially unaffected as the total consumption of both ethanol and gasoline is reshuffled between Minnesota and the rest of the U.S. Minnesota E85 consumers are only compensated for the loss in fuel efficiency and thus experience no gain, while consumers of conventional gasoline (including gasoline blended with 10% or 20% ethanol) are faced with higher prices. Thus, in Minnesota as with a national LCFS, consumers would pay higher costs while the environment would be largely unaffected. Who then benefits from an LCFS?

Winners and Losers under an LCFS

The principal winners under an LCFS are those who are subsidized—namely suppliers of the low carbon fuel, and raw material suppliers and processors of that fuel. For ethanol, that would mean farmers who supply corn or other inputs, processors, such as Archer Daniels Midland, which make the fuel, and distributors. These groups may be expected to be strong champions of an LCFS, as will be the supply chains of other fuels judged to be low in carbon content.

Among the principal losers are consumers who will have to pay higher costs and suppliers of high carbon fuels, namely suppliers of gasoline, diesel, and any other petroleum fuels covered under the standard. Consumers would pay more per gallon and, if ethanol were the principal low carbon fuel, they would obtain less energy content per gallon of fuel purchased. This implies more fill-ups per mile driven as mileage per gallon would fall. Also, because demand elasticity for petroleum is low, prices might have to rise considerably to achieve a sufficient reduction in gasoline consumption to meet the standard.

To the extent ethanol is used to meet an LCFS, consumers of food products also would be adversely affected. The diversion of land away from food production and towards fuel production will drive up the price of foodstuffs. According to media sources, an unpublished World Bank study indicates that rising biofuel demand accounts for 75% of the rise in food prices over the past year.[48]

Taxpayers also would be adversely affected. Table 2 above reported on these costs, which are a result of ethanol's per gallon federal subsidy and various state subsidies.[49]

If electricity from renewable sources were also considered a low carbon fuel, then subsidies to providers of power from these sources also would rise. U.S. petroleum producers receive subsidies as well, but since domestic supply is only a fraction of U.S. consumption, these subsidies likely would not be much affected.

> *Among the principal losers are consumers who will have to pay higher costs and suppliers of high carbon fuels, namely suppliers of gasoline, diesel, and any other petroleum fuels covered under the standard. Consumers would pay more per gallon and, if ethanol were the principal low carbon fuel, they would obtain less energy content per gallon of fuel purchased. This implies more fill-ups per mile driven as mileage per gallon would fall. Also, because demand elasticity for petroleum is low, prices might have to rise considerably to achieve a sufficient reduction in gasoline consumption to meet the standard.*

Suppliers of petroleum products include refining companies, marketers, and importers of products. Rates of return and thus the value of investments that had been made in gasoline production, transportation and storage facilities would be reduced, and there would be less investment in these types of assets. Refiners in particular would experience lower returns as their market was reduced in size and they were forced to subsidize the sale of competing products. In the event of a state LCFS, refiners or other fuel sellers with small market shares might opt to leave that market entirely.

HKH examined the income transfer between petroleum fuel sellers and sellers of ethanol for a 90% national LCFS. For each of the six cases above outlined, they provide an estimate of the net change in income for sellers of ethanol and of petroleum fuels.[50] These numbers are shown in Table 4 below. They vary greatly by the parameters of the six cases, but could be as much as several hundreds of billions of dollars per year for the ethanol sellers.

Table 4.
Income Transfer between Ethanol and Petroleum sellers from an LCFS

	Gain to Ethanol Sellers (billions of dollars)	**Loss to Petroleum Sellers** (billions of dollars)
Case 1	$690	$129
Case 2	$23	$32
Case 3	$26	$119
Case 4	$374	$39
Case 5	$2	$15
Case 6	$405	$380

The impact on the environment (other than GHGs) is unclear. Though strictly regulated, gasoline and diesel emit hydrocarbons and other pollutants. Thus, a reduction in consumption of these fuels would have air quality benefits. However, ethanol combustion emits aldehydes, a toxic set of chemicals, so that increased use of this fuel would have offsetting adverse effects.

Outside the U.S., consumers of petroleum products would be made better off by lower prices induced by the reduction in U.S. demand. On the other hand, consumers of internationally traded low carbon fuels such as ethanol would be adversely affected by the price rise for that fuel.

U.S. energy security would not be much enhanced by an LCFS. Use of imported oil would fall, but others elsewhere would consume more, leaving the world oil market little changed. Imports of the low carbon fuel likely would rise, potentially raising a new form of energy insecurity. How much insecurity would depend on the nature of the low carbon import and the extent to which its supply is concentrated in a small number of countries.

Finally, what of those who genuinely wish for GHG reductions? Because the net impact of an LCFS on worldwide GHGs is uncertain, we cannot be sure. But our inclination is that these emissions probably would not much fall under an LCFS, the net reduction in petroleum consumption being small and offset by increased consumption of other motor fuels. It is even possible that net GHG emissions could rise. But even if there is a small reduction, the impact in the U.S. being only partially offset by increases elsewhere, the cost per ton of carbon would be very high—probably many times the costs imposed by GHGs and also many times higher than alternative means to reduce them. If so, those advocating GHG reductions are worse off because the resources devoted to meeting an LCFS could have achieved greater GHG reductions if spent elsewhere, on policies capable of achieving greater GHG reductions at lower costs.

What Fuels Could Meet an LCFS?

We turn next to whether there actually are fuels that could meet a low carbon fuel standard. A number of alternative fuels are reviewed. We will focus particularly on estimates of the lifecycle GHG emissions of ethanol. As will be seen, estimation of lifecycle GHGs is far from a settled science, and the mix of fuels that could qualify under an LCFS might be quite different from what is now expected. In addition, before focusing on fuels that might be substituted for gasoline, we review what is known about lifecycle GHGs from the processing of crude oil itself.

Crude Oil

The combustion of petroleum products accounts for more than 75% of the GHG emissions associated with most crude oils.[51] Because of that, the combustion process has appropriately received most of the focus concerning reduced emissions. However, an LCFS might also take into account differences in GHG emissions from different crude types. For example, the amount of energy required to perform the necessary seismic and exploratory drilling work in frontier areas (areas without previous oil production) is greater than in areas with well understood underground structures and a history of production. Similarly, oil that is produced via directional drilling, perhaps from smaller reservoirs, will require more energy to produce than that from larger reservoirs that can be tapped using conventional drilling processes. Oil that is produced using enhanced recovery techniques will require more energy than oil produced under natural pressure. And while transportation-related emissions are a relatively small component of lifecycle petroleum emissions, oil collected in small quantities or transported over long distances will use more energy than oil from large fields located close to major refining centers.

The GHGs produced in the refining process (while only around 6% of total petroleum related emissions)[52] are also affected by the type of crude oil used and the slate of products produced. A refinery with limited downstream conversion processes, producing relatively small proportions of light products from a light sweet (low sulfur) crude oil, for example, will use less energy per barrel of output than a refinery with substantial downstream conversion capacity using a heavy, sour crude oil.

If an LCFS were to take account of such differences, it would require a thorough understanding of the GHG emissions resulting from the exploration, production, transportation and refining of each type of crude oil, the efficiency of each refining process and the slate of products produced. In reality there has been little attention devoted to this. Rather, what analysis has been done has largely focused on the higher amounts of energy needed to recover and refine Canadian oil sands. For *in situ* mining of such oil, EPA has estimated that it takes almost ten times the energy as for conventional crude oil.[53]

Table 5. Energy Use in Crude Oil Production

Type of Oil Production	Energy Use*
Conventional Crude Oil Production	20,408
Oil Sands Surface Mining	54,852
Oil Sands In Situ Production	186,239
Oil Sands Bitumin Upgrading	14,198

*BTU/mmBTU of fuel throughput

For this reason, reformulated gasoline produced from conventional crude oil is currently estimated to require roughly 190,000 Btu/mm of fuel while the same gasoline produced from *in situ* produced oil sands is estimated to require almost double the amount of energy. However, on a full life cycle basis, gasoline or diesel from oil sands crude generate only about 17% more GHGs than if produced from conventional crude oil.

However, with advances in technology, the energy used in oil sands production and hence the GHG intensity, has been declining. The province of Alberta estimates the decline at 32% between 1990 and 2006.[54] Further, Alberta legislation effective in 2007 required an immediate 12% reduction in emission intensity while national Canadian legislation to take effect in 2010 requires an 18% reduction in energy intensity and 2% per year thereafter.[55]

Although there has been some effort to measure the difference between GHG emissions from oil sands and conventional oil production, there appears to be little effort being made to evaluate differences amongst conventional crude oil types. Yet these differences could be as great as or greater than those between oil sands and the average among conventional crudes. This would be particularly true, for example, if the range of conventionally produced crude oil included Mexican heavy, Venezuelan extra heavy, or California heavy, all of which require considerable energy to lift and to transport.

An LCFS might set default values for upstream GHG emissions analogous to those set by Great Britain's Renewable Transport Fuel Obligation Program for petroleum products. This would provide petroleum fuel suppliers with an incentive to justify a lower and more accurate measure. But the larger problem would be the futility of the exercise. The world oil market offers abundant opportunities for reshuffling of crude oils in response to a single country tax on any given source, with the result that higher carbon crudes would simply be shipped elsewhere. Indeed, in recent testimony Gary Marr, the Canadian Minister-Counselor, discussed proposals to build the necessary infrastructure to ship oil sands crude to other markets, if this crude could not be exported to the U.S.[56] If that happened, then rather than reducing GHGs an LCFS likely would increase them because of the incremental transport of crude oil that would occur. This is one reason why we assume herein that an LCFS would not differentiate among different types of crude oils but instead would assume an average upstream GHG emission for all petroleum-based fuels.

Ethanol

In anhydrous form (containing less than 1% water), ethanol has been used for many years in spark ignition engines.[57] Although it has a 34% lower energy content per gallon than gasoline, it has an octane rating of 116 and thus serves to increase the octane rating of a gasoline-ethanol mixture. Blended at a rate of 10% or less, in the past it was one means of enhancing the efficiency of the burning process, reducing emissions of carbon monoxide. However, modern engines achieve the same benefit by other means. Adding ethanol to gasoline also allows refiners to reduce certain toxic substances in gasoline (primarily benzene), but its combustion also results in the production of aldehydes, a different type of toxic substance.

Due to its corrosive effect on pipeline components and its tendency to absorb water, ethanol presently cannot be shipped by pipeline and cannot be blended with gasoline until the point at which it is shipped to the retailer (splash blended). Given the need to use relatively expensive truck and rail transportation, it is generally uneconomic to blend it with gasoline at points far from its manufacture even though it received a 62 cent per gallon subsidy, now reduced to 45 cents.

Although ethanol can be blended at rates higher than 10%—up to a maximum of 85%—such blending requires the use of flex fuel vehicles that have been specially designed to handle the corrosive effects. However, because the price of ethanol has tended to track the price of gasoline (net of the ethanol subsidy), the roughly 30% MPG loss experienced by consumers when using an E85 blend has limited its acceptability in the marketplace.[58] It may be possible to optimize the design of an E85 engine to take advantage of the higher octane in ethanol and thus reduce this penalty by around 5%.[59] However, to date U.S. auto companies (perhaps recognizing that most E85 vehicles use regular gasoline) have not optimized E85 vehicles for ethanol consumption.[60]

Though roughly 40% of the ethanol used in the world is made from sugar cane, virtually all the ethanol produced in the U.S. is produced from starch obtained from corn kernels and other agricultural products. This is an inherently more expensive process since it involves more capital and energy to first convert the starch to a sugar.[61]

There also has been a great deal of attention devoted to cellulosic ethanol, which can be made from feedstocks that are far cheaper than corn. These include switchgrass, corn stover and agricultural waste product. Until recently it was thought that the use of cellulosic ethanol would lead to large reductions and possibly even elimination of GHG emissions from ethanol use in internal combustion engines.[62] However, it has proven extremely difficult to identify a process that can efficiently and economically break apart the cellulosic materials that make up the cell walls of the plant, a step which is necessary before the starch can be converted to sugar and then to alcohol. Thus, though there are several pilot plants operating and substantial research interest in enhancing the economics of producing cellulosic ethanol, no commercial scale plant capable of producing cellulosic ethanol competitive with gasoline has yet been constructed. Further, as discussed below, the GHG benefits of some types of cellulosic ethanol are being rethought.

In 2004, the IEA estimated the costs of ethanol in the U.S. and Europe, both under current technology and under optimistic (and yet to be realized) assumptions.[63] At the time, IEA projected that several large plants would be constructed and optimized by now and that cellulosic ethanol would be roughly competitive with conventional gasoline (including the per gallon ethanol subsidy) by 2010. However, to date there are no large commercial plants operating and IEA's assumptions about the rapid advance of cellulosic technology appear overly optimistic.

Biodiesel

Biodiesel consists of fatty acid methyl esters and can be made from a wide variety of vegetable and animal oils, including waste oils. It is thought by some to have the potential to displace as much as 5% of the distillate fuel market[64] and thus, with lower GHG emissions than conventional diesel, could be a means for complying with an LCFS. But though biodiesel has a higher cetane rating than conventional diesel, problems of purity, stability, gelling temperature and concerns about its effects on engine components have limited its acceptance in the marketplace. Thus, its use to meet an LCFS raises questions concerning motorist acceptance and the amount of subsidy necessary to overcome reluctance to use it.

Fisher Tropsch fuels

Fisher Tropsch fuels are produced by first producing a synthetic gas from a solid fuel such as biomass or coal, or from natural gas, and then reforming the synthesis gas to produce diesel. The process has been well known for decades and produces a product with attractive qualities—low sulfur, high cetane, low corrosivity and insoluble in water. However, costs for Fisher Tropsch fuels are quite high, a good deal of energy is used, and the process is thus unlikely to be a principal means for complying with a LCFS.

Biobutanol

Butanol is an alcohol that can be used as a substitute for or additive to gasoline in a manner very similar to ethanol. It can be produced from the fermentation of plant material, in which case it is referred to as biobutanol. Biobutanol has several important advantages over ethanol. It has low vapor pressure and an energy content close to that of gasoline. It can be blended at refineries and shipped though existing pipelines (since it does not absorb water), and it can be produced from a variety of agricultural feedstocks.[65] However, although several companies are doing research and a pilot plant is being constructed, the amount of energy needed to produce biobutanol for use as a fuel presently renders it uneconomic relative to other alternatives.

Biofuels from Algae

Biofuels made from algae are yet another possible low carbon alternative. The process involves growing algae in water and then extracting lipids from which high quality fuels can be manufactured. Algae grows rapidly and yields more fuel per acre than do plant sources such as corn, jatropha, soybeans, and other sources. Sunlight is required, as is some form of fertilizer. CO_2 captured in power generation plants can be used to enhance the growth rate of the algae. Also, land areas that are unsuitable for farming such as deserts or coasts are suitable for algae farming. This has the advantage that algae farming need not compete for land with food farming. Technologies for growing algae and for transforming it into fuel are fairly well known, and a number of companies including Chevron and Shell are investing in the process.

However, biofuels from algae have a number of obstacles to overcome. The process is capital and land intensive, requiring vast acreage to produce fuel in quantity and containerization to prevent evaporation. Desert climates are cold at night, slowing the rate of growth in this environment. Some have proposed growing algae in saltwater ponds located in coastal areas, but storms and hungry fish pose problems for this approach. Also, fertilizers represent a major capital expense and consume a fraction of the energy produced. If captured CO_2 is used, the algae ponds must be near a generating plant or a pipeline must be built to transport it. Because fuels from algae are of high quality and could be used in today's engines, there is considerable interest in trying to make this a viable approach. For now, it is largely experimental, working in a laboratory and pilot plant setting, but likely several years from large scale production.

Electricity

Although battery storage capacity and the weight of batteries have limited the acceptance of electric powered vehicles to specialized uses, this could change if research into improved battery technology bears fruit. If that happens, electricity could theoretically be an alternative fuel for LCFS compliance. However, the extent to which electrical power reduces GHG emissions will largely depend on the emissions from the generation and transmission of the power needed to charge the batteries. For example, the use of plug-in hybrids or fully electric automobiles could result in increased emissions if the power used for battery charging came primarily from one of the nation's coal fired plants, which comprise about half of U.S. generating capacity. Less than 2.5% of electricity is generated from renewables other than hydroelectric, while roughly 20% of capacity is powered by natural gas. If future battery powered autos were simply "plugged in" at any time of day and received electricity that had been generated using the U.S. average fuel mix, CO_2 emissions could actually increase. Ascertaining which source of electricity was used to power a particular plug-in hybrid raises difficult questions. Further, it is unclear whether the supplier of electricity or the supplier of the vehicle, with its batteries, would be credited.

Hydrogen

Most hydrogen used in the U.S. is produced in the refining of petroleum, and its manufacture results in similar GHG emissions. While it can be substituted for petroleum in internal combustion engines, problems of safety, cost and storage capacity have made it an unacceptable alternative in the marketplace to date. While hydrogen could also be produced from biomass or from nuclear, wind or solar generated electricity, widespread use of hydrogen in internal combustion engines is unlikely because of its high cost and because such use would require either the construction of specialized pipelines or the commercialization of on-board reformers—a technology that has proven extremely difficult to develop.

Hydrogen also can be used as a fuel in fuel cell vehicles, which have both high efficiency and no tail pipe emissions. Before this can occur on a widespread basis, however, not only must the cost of producing and transporting hydrogen from a low emission source be overcome, but the cost of producing a fuel cell vehicle itself would have to dramatically decrease. The National Academy of Sciences is reasonably optimistic about the potential for hydrogen, concluding that "With the possible future technology advances, hydrogen generated by central station nuclear energy, distributed natural gas steam reforming and distributed electrolysis using wind-turbine generated electricity could have costs within about $1.00 per kilogram of gasoline costs on a gasoline-efficiency-adjusted basis."[66]

However, costs of hydrogen from current biomass technologies are several times greater than the cost of gasoline. In addition, the generally lower costs associated with central station hydrogen production, either with current or future technology, require that at least 5-10% of vehicles run on hydrogen—a level that DOE does not expect until at least 2025.[67] Thus, although there has been a great deal of government and private research into the use of fuel cells for transport, it does not appear that a solution to these problems is on the immediate horizon and we do not consider hydrogen a near-term option for complying with a LCFS.

Summary of Available Alternatives

Although there are other options that might be considered for compliance with an LCFS, the above discussion covers those considered most cost competitive with conventional gasoline or which may become viable with relatively modest advances in technology. We have not, however, made assumptions about when those technologies might become available nor what their costs might be. Past efforts to do so have been uniformly disappointing and misleading. We thus conclude, based on current technology, that corn-based ethanol is the most competitive with gasoline throughout much of the U.S. and thus is the most likely alternative fuel to be used for compliance with an LCFS. The amount will be a function of both ethanol's price and the GHG emissions savings which the regulator associates with its use.

Well to Wheel Emissions Analysis of Fuels

In Figure 1, EPA's estimates of lifecycle GHGs from a number of alternative fuels were shown. Such lifecycle (also known as well-to-wheels) estimates cover the production, transportation, processing and use of each fuel. Properly done, such an analysis takes into account all of the direct and indirect impacts of the fuel on GHG emissions. But lifecycle GHG analysis is fraught with difficulty. Often the final stage of the analysis, the emissions released when the fuel is burned or consumed, is the most straightforward, involving a relatively noncontroversial calculation of the CO_2 released from the engine. The more difficult part of the analysis, particularly with respect to biofuels, is the analysis of carbon released from planting, harvesting, fertilizing, transportation and distillation, and from the conversion of land from other uses or from forest to crop land. As seen below in the case of ethanol, different assumptions and approaches can yield substantially different estimates of GHGs emissions.[68]

The accuracy and completeness of well-to-wheels analysis is a critical element of an LCFS since the number assigned each fuel, relative to gasoline, determines the size of the implicit tax or subsidy to which it is subject. In addition, the outcome of the life cycle analysis is a major determinant of which fuel technologies would receive new investment and which not. Thus, lifecycle GHG emission analysis would have critical impact on how an LCFS is implemented.

The fact is, however, that well-to-wheels analyses of GHG impacts are subject to great uncertainty. We illustrate these uncertainties for biofuels such as ethanol, but they exist for other potential alternative fuels as well.

With regards to biofuels, a great deal of recent attention has been placed on changes in agricultural practices, the issue of land use and the notion that changes in such use could reduce or offset apparent reductions in GHG emissions from the use of biofuels. Recent studies of ethanol show a range of net energy balance (the energy content of the fuel minus that of all fuels consumed prior to its use in the engine) from a negative 60,000 Btu per gallon to a positive 40,000 Btu per gallon.[69] The GREET model itself can yield a net energy balance for ethanol between a positive 20,000 Btu per gallon and a negative 30,000 Btu per gallon, depending on what assumptions are made about joint products and land use changes.[70] At present, therefore, well-to-wheels decisions by a regulator are likely to be based on lifecycle estimates for which there are major disagreements among analysts.

The controversy over land use changes has occurred because of a Congressional mandate to U.S. fuel sellers to greatly increase the amount of ethanol in their fuel mix. Table 6 below shows the amounts produced and sold over the past few years. The Energy Security and Independence Act of 2007 mandates further increases in ethanol sales, to reach a maximum of 15 billion gallons from corn by 2016.

Table 6. Recent Growth in Ethanol Market

Year	Ethanol Production*	Ethanol Production Capacity*	Corn Price Per bushel
2002	2.13	2.347	$2.34
2003	2.8	2.706	$2.52
2004	3.4	3.1	$1.93
2005	3.904	3.643	$2.00
2006	4.855	4.336	$3.33
2007	6.5	5.493	$4.64
2008	9	7.229	$5.55

*Billion gal/year

Source: Renewable Fuels Association, 2008, “Industry Statistics” available at http;//www.ethanolrfa.org/industry/statistics. Note that capacity is as of January of each year so that capacity growth during the year can result in production in that year exceeding capacity. Corn price is from the U.S. Dept of Agriculture, Economic Research Service. 2008 production is RFS mandate. The 2008 average price is estimated by the authors.

Such very large increases in corn production have had indirect effects on both U.S. and foreign agricultural markets, namely diversion of land previously dedicated to other crops and new plantings on land previously unused. Lifecycle GHG analyses of corn ethanol therefore have begun to take account of these changes in land use patterns, calculating GHG effects from conversion of forests and grasslands to farming for both corn and other commodities whose prices have increased. This newly planted acreage releases carbon that had been sequestered in grasses or forests and halts ongoing CO_2 sequestration that was taking place on this acreage as the plants on it grew each year.

Recent work has shown that these effects may be sizeable, with 43% of U.S. land that was used for grain in 2004 projected to be dedicated to corn ethanol in 2016.[71] Searchinger *et al* calculated that the roughly 13 billion gallon per year increase in fuel ethanol (presumably from the 2002 level of 2 billion gallons) by 2016 would lead to an additional 10.8 million hectares (ha) of additional land being brought into cultivation, including 2.8 million ha in Brazil, 2.3 million in China and India and 2.2 million in the U.S.[72] By their calculations, the effect of including these land use changes on lifecycle GHGs from biofuels is dramatic, as the following table shows:

Table 7. Impact of Land Use Change on GHG Emissions

Source of Fuel	**Carbon Absorption From Atmosphere**	**Effect of Land Use Change**	**Total GHG Emis-sions**	**Net Change vs Gasoline**
	Grams of GHGs CO_2 equivalents per MJ of energy in each fuel			
Gasoline	0	---------	92	--------
Corn Ethanol (GREET)	-62	---------	74	-20%
Corn Ethanol with Land Use Change	-62	104	177	93%
Biomass Ethanol (GREET)	-62	------	27	-70%
Biomass Ethanol with Land Use Change	-62	111	138	50%

Source: Searchinger et al (2008).

The conventional assessment of ethanol made by the GREET model is shown in the second line. GREET's projection of a 20% reduction in GHG emissions from the use of corn-based ethanol was largely accepted until recently. But incorporating the effects of direct and indirect land use changes on GHG emissions reverses GREET's conclusion. According to Searchinger's estimates, the use of corn-based ethanol does not decrease GHG emissions, but instead almost doubles them relative to gasoline. Even the use of cellulosic ethanol from biomass, found by GREET to result in significantly reduced GHG emissions relative to gasoline, is estimated by Searchinger to generate a 50% increase because of land use changes.

Searchinger's analysis and findings have been questioned. For one thing, the research may not have taken full account of expected increases in corn farm productivity or of the amount of agricultural waste products available in the U.S. Also, critics argue that historical land use changes may not indicate future changes.[73]

However, other studies too have questioned whether corn ethanol decreases lifecycle GHG emissions. Crutzen *et al* consider increased nitrous oxide (N_2O) emissions from corn ethanol, concluding that "when the extra N_2O emissions from biofuel production is calculated in 'CO_2 equivalent' global warming terms … the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn … can contribute as much or more to global warming by N_2O emissions than cooling by fossil fuel savings."[74]

Using a different approach than Crutzen, Delucchi estimated N_2O emissions from corn, suggesting that the inclusion of N_2O emissions may negate the CO_2 savings from ethanol use as a transportation fuel.[75] Clearly, if life cycle GHG emissions from biofuels are greater than those of petroleum based fuels, an LCFS relying on these sources cannot achieve its goals at any price.

Other considerations have been raised with regard to the use of biofuels. Kreider and Curtiss argue that "Land based biofuels require massive and unavailable land requirements…corn ethanol and soy-based biodiesel demands for water are very large; there is no more water in the U.S. thereby disqualifying these fuels on this basis alone …carbon emissions in the life cycle sense are about 50% larger for ethanol than for traditional fossil fuels; such fuels are not the answer to global warming, they make it worse."[76] Estimates of CO_2 emissions for corn ethanol, cellulosic ethanol and soybean diesel from the Kreider and Curtiss study are shown in Table 8.

Table 8. Fuel Source Energy Ratio and CO_2 Emissions

Fuel Source	Energy Ratio*	CO_2 Emissions**
Conventional gasoline	0.05	60
Conventional diesel	0.09	60
Corn-based ethanol	0.98	95
Cellulosic ethanol	0.92	90
Soybean diesel	0.76	50-60

*Btu input per Btu of fuel **lb per mm Btu of fuel

Note: Kreider and Curtis assumed that a significant expansion in the use of soy biodiesel would "force farmers into bettering their practices," and thus find a higher energy ratio than would apply to today's production. In addition, the authors have requested an explanation from Kreider and Curtis regarding the reasons for the relatively low energy ratio they have assumed for gasoline and diesel.

The Kreider and Curtiss findings regarding CO_2 emissions from corn-based and cellulosic ethanol are consistent with other studies we have cited. At minimum, there is growing question whether corn ethanol and cellulosic ethanol hold the GHG reduction potential once thought.

Other Considerations Regarding Lifecycle GHG Emissions From Fuels

Many other alternatives to fossil fuels could be considered as candidates under an LCFS but we would need to make heroic assumptions regarding GHG emissions at each stage of their life cycle, not to mention their future technological status and economics. Hydrogen, for example, could be an alternative to gasoline if technological advances revealed a way to bring it to market economically or to use it cost effectively in fuel cell powered vehicles. Likewise, advances in battery technology could make plug-in electric vehicles economically viable, while large increases in solar, wind and nuclear power could result in low lifecycle GHG electricity capability. However, the lifecycle GHG emissions of hydrogen, fuel cells and plug-in hybrid technologies are only partly understood, and it is unclear how much emissions improvement over gasoline these would achieve.

We might also assume that an LCFS would be "technology forcing," so that technical advances will result in low lifecycle GHG emission fuels being brought to the market in response to the regulatory requirement. We believe this is a risky assumption, particularly in that such technology forcing can result in much wasted investment and unnecessary costs to the public, as for example occurred with California's early attempts to force electric vehicles into the market. Also, while speculating about future technology changes in response to regulatory requirements is an interesting exercise, it is unlikely to lead to insights into the most efficient methods of reducing GHG emissions.

Conclusions

We have examined an LCFS from a number of perspectives and reach the following conclusions:

- Without relatively inexpensive low carbon fuels, attainment of an LCFS is likely to be prohibitively costly.
- With present technology, the costs of a national LCFS are likely to be very high. Estimates in the open literature indicate that the costs of reaching a 90% LCFS via use of ethanol would range between $80 billion and $760 billion annually—that is, between $695 and $6520 per year per U.S. household. We independently assessed these costs and derived a similar, although slightly smaller magnitude of $65.5 billion—equivalent to $570 per household annually.
- The cost per ton of carbon removed by an LCFS is an order of magnitude greater than the estimated costs imposed by GHGs, and also an order of magnitude greater than the cost per ton of other measures that would reduce these gases. This suggests that an LCFS is a highly inefficient means to reduce GHG emissions.

- An LCFS imposed within the U.S. cannot be analyzed in isolation. There will be offsetting effects elsewhere in the world, reducing whatever decrease in GHGs might be achieved in this country. Because of these offsetting effects, the cost per ton of GHG reduced likely will be several times that found when considering the U.S. alone. This is another reason why an LCFS is highly cost ineffective.
- An LCFS redistributes income from fuel consumers and gasoline sellers to the producers of the low carbon fuel. If that fuel is ethanol, an LCFS would increase federal and state subsidies and hence redistribute income from taxpayers as well. Presently, ethanol receives about $7 billion in federal and state subsidies annually. With an LCFS, the annual figure could increase by between $1 billion and $16 billion.
- Economic analysis suggests that an LCFS is an inefficient means to curb greenhouse gases because it implicitly subsidizes consumption of a fuel such as ethanol that results in increased emissions. An efficient device would tax GHG emissions from all sources. For example, a carbon tax applied to the carbon content of fuels would discourage high carbon fuels relative to low carbon without subsidizing incremental use of the latter.
- It is unclear what practically available fuels have lifecycle GHGs below those of gasoline produced from crude oil. Considerable controversy surrounds fuels such as ethanol, where land use and nitrous oxide considerations raise the possibility that lifecycle emissions exceed those of gasoline.
- U.S. energy security would not be much enhanced by an LCFS. Use of imported oil would fall, but others elsewhere would consume more, leaving the world oil market little changed. Imports of the low carbon fuel likely would rise, potentially raising a new form of energy insecurity. How much insecurity would depend on the nature of the low carbon import and the extent to which its supply is concentrated in a small number of countries.
- A state or regional LCFS would be even less effective than a national version. For a state like California, with a somewhat isolated fuel market, the costs likely would be high and little GHG reduction would be accomplished. For one like Minnesota, with ready access to ethanol, an LCFS would largely result in reshuffling, with reduced gasoline consumption and increased ethanol consumption within the state being offset elsewhere. Consumers in the state would pay higher prices for fuel, however. For example, legislation currently being considered by Minnesota would, even under favorable assumptions, cost Minnesotans at least $570 million annually in 2020—an annual average of about $260 per household.
- We find little justification for an LCFS as a means to reduce U.S. or state GHGs. Uncertainty over fuel lifecycle GHGs, the costs of such an approach and clear indication that there are far better means to reduce GHGs suggest it is a poor policy choice. Both the U.S. government and state governments such as California and Minnesota should look to other policies to reduce GHGs within their respective jurisdictions.

Endnotes

1. Lifecycle GHG emissions generally refer to emissions from the production, processing, transportation, storage and use of a fuel.
2. IPCC Fourth Assessment Report, released in 2007 with three Working Group sections and a Synthesis Report, summarized in a Summary for Policymakers.
3. EPA has used the Lifecycle Emissions Model (LEM) of the Institute of Transportation Studies at the University of California at Irvine, and the Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) model of the Argonne National Laboratory to estimate lifecycle GHGs in transportation. The approach and some results are discussed in "Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003," EPA Office of Transportation and Air Quality, (March 2006).
4. See Michael E. Canes, *A Cap and Trade System v. Alternative Policies to Curb U.S. Greenhouse Gases*, (Washington, D.C.: The George C. Marshall Institute, 2006).
5. S.2191, co-sponsored by Senators Joe Lieberman (I-CT) and John Warner (R-VA).
6. The other GHGs are methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons, and hydrofluorocarbons.
7. Energy Independence and Security Act of 2007. Under this Act, the quantity of ethanol from corn is mandated to increase to 15 billion gallons by 2017, and biofuels from all sources to increase to 36 billion gallons by 2022.
8. Total U.S. GHGs for 2007 have not yet been reported. However, according to DOE, GHG emissions from energy use rose by 1.6% in that year.
9. Energy Information Administration, *Emissions of Greenhouse Gases Report*, (November 2007).
10. Energy Information Administration, *International Energy Outlook, 2008*, (June 2008).
11. There is comparable legislation on the House side. HR 6186 of 2008 specifies a 5% reduction by 2023 relative to an unspecified baseline, and a 10% reduction by 2028.
12. The economics of each of these baselines and others are analyzed in Stephen P. Holland, Christopher R. Knittel and Jonathan E. Hughes, "Greenhouse Gas Reductions under Low Carbon Fuel Standards?" National Bureau of Economics Working Paper 13266, (July 2007).
13. Timothy Searchinger *et al*, "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," *Science*, (February 29, 2008).
14. P.J. Crutzen, A.R. Mosier, K.A. Smith, and W. Winiwarter, "N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels," *Atmospheric Chemistry and Physics*, (January 2008).
15. California Air Resource Board, *The California Low Carbon Fuel Standard Regulation*, (October 2008).
16. For gasoline the proposed reduction would be 10.5%, for diesel 10.0%.
17. Minnesota Senate Energy, Utilities, Technology and Communications Committee, January 22 and February 3, 2009.

18. John E. Kwoka, “The Limits of Market Oriented Regulatory Techniques: The Case of Automotive Fuel Economy,” *Quarterly Journal of Economics*, (November 1983).

19. According to EIA, the average fuel economy of the U.S. fleet in 1991 was 16.9 MPG. In 2006 it was 17.2.

20. Paul R. Portney, Ian W.H. Parry, Howard K. Gruenspecht and Winston Harrington, “The Economics of Fuel Economy Standards,” *Journal of Economic Perspectives*, Vol. 17, No. 4 (Autumn, 2003).

21. Robert W. Crandall and John D. Graham, “The Effect of Fuel Economy Standards on Automobile Safety,” *Journal of Law and Economics*, (April 1989).

22. Portney *et al* (2003): 216.

23. Other changes could occur. Fuel sellers might find ways to reduce the lifecycle carbon content of the high carbon fuel, e.g., by changing its chemical makeup. But the full ramifications of such an approach are not clear. As happened with automobiles becoming lighter to meet the CAFE standard, such a fuel might have other, less desirable consequences.

24. Holland *et al* (2007): footnote 11.

25. Richard S.J. Tol, “The Marginal Cost of Carbon Dioxide Emissions: an Assessment of the Uncertainties”, *Energy Policy*, (2005).

26. “Ethanol, Just Recently a Savior, Is Struggling”, *New York Times*, (February 12, 2009): A1.

27. Ibid, p. 14, quotation attributed to Aaron Brady, of Cambridge Energy Research Associates.

28. Energy Information Administration, *Annual Energy Outlook 2008*, (June 2008): 136. We assume that fuel providers would be credited with the ethanol already required under the Renewable Fuel Standard. Thus, ethanol consumption increases from 14% to 40% of total motor fuel (gasoline and ethanol) consumption in 2020. The required increase in ethanol production would be 2.58 million b/d, while the decrease in gasoline consumption would be 2.15 million b/d—assuming that all of this increment was used in the form of E85 and that auto companies redesigned E85 engines to optimize the use of E85. Because of this optimization, we assume only a 20% fuel penalty for the additional ethanol. As a result of the loss in efficiency, total motor fuel consumption increases slightly from 9.91 (gasoline and ethanol) to 10.33 million b/d. Our analysis does not take account of the changes in demand for the combined fuels that would result from the LCFS.

29. In fact, such a huge increase in ethanol use would have major impacts on worldwide land use patterns and food prices. This raises questions whether increases of this magnitude, barring major technological breakthrough, are politically viable.

30. This assumes that E85 consumers are only subsidized for the loss in mpg relative to gasoline and for the difference between the gasoline and higher ethanol price. This subsidy would be $1.16 per gallon of E85.

31. Based on U.S. Census Bureau 2020 projected population of 341.4 million people in the U.S.

32. See James Bushnell, Carla Peterman and Catharine Wolfram, “California’s Greenhouse Gas Policies: Local Solutions to a Global Problem?” (University of California Energy Institute, Center for the Study of Energy Markets, Working Paper 166, April 2007).

33. Given the rapid increases in vehicle ownership in China, India and other developing economies, it seems likely that there would be a ready market for motor fuels released through reduced U.S. consumption.

34. For example, in 2005 the Electric Power Research Institute released a Climate Brief which summarized the costs per ton of 11 different programs to reduce GHGs, entitled "The Costs of Key Electric Sector Greenhouse Gas Reduction Actions." The 11 actions varied in cost between $0/ton and $100/ton.

35. J. Creyts, A. Derkach, S. Nyquist, K. Ostrowski and Jack Stephenson, "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost," (McKinsey and Company, December, 2007).

36. Creyts (2007): ix.

37. McKinsey includes in the category of increased vehicle efficiency, increased use of hybrid and plug in hybrid technology and commercialization of cellulosic ethanol.

38. In this section we discuss California and Minnesota efforts to establish an LCFS. They are not the only states considering such a standard, however. Eleven Northeast and Mid-Atlantic states led by Massachusetts have endorsed formation of a regional LCFS. The 11 states have signed a letter of intent to jointly design and implement such a standard, with a Memorandum of Understanding to be forwarded to their governors by the end of 2009 or shortly thereafter.

39. One means of doing so would be for a refiner to petition the state for a lower carbon emission rating for the imported light crude oil it buys, to the disadvantage of heavier but less expensive crudes used by other refiners in the state. Any such attempt likely would be very costly for Minnesota consumers. Judging from imported crude oil costs to refineries based elsewhere in the U.S. and considering the increased transportation costs to deliver such imports to Minnesota, a conservative estimate of the additional costs would be $4 per barrel. Given product volumes consumed in the state, this would imply costs of $1.7 billion per year.

40. EIA Petroleum Monthly, which can be found at www.eia.doe.gov/dnav/pet.

41. Ibid, projections from EIA, *Annual Energy Outlook* (2008), available at the same source.

42. EPA does not allow ethanol blends higher than 10% to be used in any vehicles other than flex fuel vehicles.

43. Ethanol producers also could seek to reduce the greenhouse gas emissions associated with its production, say by using biomass to power the production process or by converting their plants to produce cellulosic ethanol. In both cases, however, the required amount of ethanol to meet the standard would fall, aggravating rather than alleviating the excess production capacity problem.

44. Faced with a similar problem, this, of course, is exactly what some auto manufactures did when required to increase the miles per gallon of their autos.

45. Renewable Fuels Association, http://www.ethanolrfa.org/resource/e85/.

46. Richard Truett, "Ethanol Gains Momentum but Needs More Pumps," *Automotive News,* (February 20, 2006).

47. These costs could be offset by a federal tax credit of up to $30,000 currently (through 2009) available for installing E85 facilities.

48. Elizabeth Chiles Shelburne, “The Great Disruption,” *Atlantic Monthly*, (September 2008). Also cited in the *Guardian* newspaper*,* July 4, 2008.

49. The per gallon subsidy was $.51/gallon at the time of the study. It since has been reduced to $.45/gallon.

50. This net change in income is a combination of the change in producers’ surplus in each market and the income transfer from petroleum to ethanol.

51. T.J. McCann and Associates, “Typical Heavy Crude and Bitumin Derivative Greenhouse Gas Life Cycles in 2007,” (November 16, 2001).

52. McCann (2001): 10.

53. EPA, unpublished estimates, (September 2007).

54. Province of Alberta, presentation provided to the authors entitled “Oil Sands and California’s LCFS,” undated.

55. Canadian Association of Petroleum Producers, “Carbon Standards: What is the right choice for Canada and the U.S.” presentation given at the Woodrow Wilson Cross Border Energy Forum, (October 2, 2008).

56. Minnesota Energy, Utilities, Technology and Communications Committee hearing, January 22, 2009.

57. Ethanol has not generally been used in compression ignition engines because of engine manufacturer concerns about volatility (reduced flash point) of the resulting mixture of diesel and ethanol.

58. The fuel economy penalty for E85 vehicles listed in U.S. Environmental Protection Agency, *Model Year 2007 Fuel Economy Guide,* ranges from 19% to 35%.

59. B. West *et al*, “Benchmarking the Ethanol Optimized Saab 9-5 Biopower,” (Presentation to the Society of Automotive Engineers, Government/Industry Meeting, May 14-16, 2007).

60. In actual testing, Consumer Reports. (Consumer Reports, *The Ethanol Myth,* October, 2006) reported a 28.6% fuel penalty with an E85 vehicle.

61. Alexander Farrell and Daniel Sperling, “A Low Carbon Fuel Standard for California,” Part 1, Technical Analysis, (August 1, 2007): 59.

62. Michael Wang, “Overview of GREET Model Development at Argonne,” (Presentation at GREET User Workshop, Sacramento, CA., March 18, 2008). Wang suggests that the use of fast growing trees to produce cellulosic ethanol would result in almost a 120% reduction in GHG emissions compared to gasoline.

63. International Energy Agency, “Biofuels for Transport” (2004).

64. National Renewable Energy Laboratory, http://www.nrel.gov/vehiclesandfuels/npbf/renewable_diesel.html.

65. DuPont/BP, Biobutanol Fact Sheet,” (June 2006).

66. Committee on Alternatives and Strategies for Future Hydrogen Production and Use, *The Hydrogen Economy*, (Washington, D.C.: National Academy of Sciences, 2004): 62.

67. Farrell, *et al* (2007): 71.

68. Farrell *et al* (2007) point to the treatment of market mediated effects such as joint products, land use changes, climate impact of emissions and the inherent variability and limited quality of the data as major sources of uncertainty and disagreement in life cycle analysis

69. Michael Wang, "The GREET Model," (Presentation at the Advanced Stationary Reciprocating Engines Conference, September 19, 2007).

70. Wang (2007), slide 13. In their March 14, 2008 letter to *Science*, Michael Wang and Zia Haq agree that the land use changes from ethanol used in GREET need to be updated since they are based on changes modeled by USDA in 1999 for ethanol production of 4 billion gallons in 2010.

71. Searchinger *et al* (2008).

72. Searchinger *et al* (2008).

73. M. Wang, and Z. Haq, "Letter to *Science*," *Science* (March 14, 2008).

74. Crutzen (2008).

75. M.A. Delucchi, "Lifecycle Analysis of Biofuels" (Draft Manuscript, May, 2006), http://www.its.ucdavis.edu/publications/2006/UCD-ITS-RR-06-08.pdf.

76. Jan Kreider, and Peter S. Curtiss, "Comprehensive Evaluation of Impacts from Potential Future Automotive Fuel Replacements," (American Society of Mechanical Engineers, Energy Sustainability 2007 Conference, Long Beach CA, June 27-30, 2007).

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