Biofuel Potential in Oregon: Background and Evaluation of Options

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Report Summary

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This study examines the economics of three biofuel options for Oregon: corn-based ethanol, canola-based biodiesel, and cellulosic wood-based ethanol. In each case we address three questions: 1) Is the biofuel commercially viable?; 2) Does it represent a cost-effective way to further our national goal of energy independence?; and 3) Does it represent a cost-effective way to pursue the environmental goal of reducing greenhouse gas emissions?

A key observation in our analysis is that the commercial viability of a biofuel is not, by itself, sufficient to conclude that the biofuel addresses the energy independency or environmental goals at an acceptable cost. The "net energy" of a biofuel may be significantly less than than the energy in a gallon of the fuel because of the energy required to produce the fuel. The cost per unit of net energy, therefore, may be much higher than price per gallon would suggest.

Our analysis draws on existing studies, private sector information, and our own analysis. We evaluate commercial scale production of these fuels, and our assumptions reflect the costs and technologies currently available for the appropriate scales of operation. In the case of corn-based ethanol, we assume that corn feedstock is imported from the Midwest rather than coming from Oregon (because little corn grain is, or is likely to be, produced in Oregon). In the other two cases we assume that feedstock would be available in sufficient quantities in Oregon, or from both Oregon and Washington. We also examine some of the consequent issues that arise for these options. For example, in the case of canola, the limited ability to increase feedstock production at reasonable cost, potential conflicts for increased production due to pollen drift and pest issues, and the limited capacity of regional markets to absorb coproduct production.

To address the energy independence question we must estimate the "net energy" contribution of each of these biofuels where "net energy" is the energy contained in the biofuel minus the energy required for its production, processing and transportation. This consideration is crucial because if the net energy contribution were zero or negative (meaning equal or greater energy is needed to produce the fuel than is contained in the fuel), then production of the biofuel will not contribute to energy independence.

Our analysis estimates the net energy contribution of corn ethanol to be just 20% of the energy contained in the fuel (or about 18,600 Btus/gallon). For canola biodiesel the share is 69% (or 123,000 Btus/gallon), or about 6.5 times the net energy per gallon of corn-ethanol. The importance of this difference is that if these two biofuels had the same production cost per gallon, corn-ethanol would actually cost 6.5 times as much per unit of net energy. Cellulosic wood-based ethanol is estimated to have a net energy contribution of 84% (or about 76,300 Btus/gallon).

When net energy and cost aspects are combined, our estimates suggest that the three biofuels considered are significantly more costly than gasoline and petroleum diesel (including

direct and indirect subsidies). Per unit of net energy, corn ethanol is estimated to cost 750 percent more than gasoline; canola biodiesel is estimated to cost 125 percent more than petroleum diesel; and the cost of cellulosic wood-based ethanol is nearly 200 percent higher than gasoline.

On the question of reductions in greenhouse gas emissions, we combine information for each biofuel on their greenhouse gas emissions, net energy, and cost of production. The biofuels were then compared on this basis to the current alternatives of gasoline and diesel. The biofuel costs include existing subsidies and, in the case of cellulosic wood-based ethanol, the additional subsidies that would be necessary to make the fuel commercially competitive. For each biofuel we find that if it were promoted as an alternative to gasoline or diesel it would reduce greenhouse gas emissions, but at a significant cost.

The cost of reducing CO_2-equivalent emissions by promoting biofuels is compared to various economic studies that have evaluated the costs of other types of climate change policies. These policies include regulatory controls on CO_2 emissions, carbon sequestration actions of various types, and market-based approaches such as carbon taxes or 'cap-and-trade' schemes. Those studies suggest a midrange estimate of $50 per ton. Compared to this benchmark, the cost of reducing CO_2 emissions with corn-ethanol is found to be more than 200 times higher, or $10,700 per ton of CO_2-equivalent emissions. For biodiesel, the cost is estimated to be 11 times as high as the $50 estimate, or $580/ton. And in the case of cellulosic wood-based ethanol, the cost is 7 times as high, at $350/ton. Hence, other policies aimed at reducing greenhouse gas emissions appear to be significantly more cost-effective than a shift to these three biofuels.

These cost estimates, however, do not take account of the intangible costs associated with dependence on foreign oil or climate change. Therefore, the policy question can be framed with the following two questions: Are the higher costs of biofuels justified given energy independence and environmental goals? Are there other ways to achieve those same goals but in a more cost-effective way than with biofuels? For comparison, promoting energy independence with an increase in the average fuel economy standards (CAFE standards) is estimated to cost 20 to 40 percent more than gasoline, compared to 750 percent for corn ethanol and 125 percent for canola biodiesel.

To address the question of commercial viability, we have taken account of existing market conditions, existing costs of production, technologies and government incentives. Government incentives include subsidies as well as regulatory requirements including ethanol targets for gasoline and the banning of the MTBE additive. Our results indicate that corn-based ethanol and canola-based biodiesel appear to be commercially viable under current conditions. In both cases we find that revenues cover, or nearly cover, the costs of production. In the case of wood-based cellulosic ethanol, however, costs appear to be at least 25% above revenues, suggesting that current conditions do not provide adequate incentives for commercial production.

For each of these biofuels, its byproducts or "coproducts" play an important role in the analysis. Corn-ethanol and canola biodiesel generate significant quantities of animal feed. Canola biodiesel also produces glycerin; and wood-based ethanol generates lignin and other coproducts. In each case these coproducts represent significant measures of revenue, energy, or both. Indeed, in the case of dry-milled corn-ethanol, most of the positive "net energy" is accounted for by the distiller dry grains and solubles (DDGS) used for animal feed. The analysis summarized above assumes that these coproducts are used efficiently and are valued at current market rates. If these coproducts are not able to be used efficiently, or if their markets prices decline as a result of increased supply, then the economic calculations summarized above may be too optimistic.

The potential impact of these three biofuel options on energy independence, given the scales of operation being evaluated here, would be small. For a 50 million gallon corn ethanol plant, a 50 million gallon wood-based ethanol plant, and a 2 million gallon canola biodiesel plant, the combined contributions of their net energy generation to Oregon's annual petroleum energy consumption would be slightly more than one percent. Together they would reduce U.S. greenhouse gas emissions by 1/8th of one percent. In contrast to these small energy and environmental contributions, the resource requirements and coproduct quantities are large in some cases. To satisfy one percent of Oregon's current petroleum energy consumption with canola biodiesel would require over 400,000 acres, or 100 times the current canola acreage in Oregon. This amount of canola would generate 600 million pounds of canola meal, enough to feed five times the number of cows currently raised in Oregon. For comparison, the degree of energy independence resulting from a one mile-per-gallon increase in average motor vehicle fuel economy in Oregon would be equivalent to 3 - 4 corn ethanol plants like the one evaluated here, or 13 biodiesel plants like the one evaluated here.

I. Introduction

Interest in biofuel production has grown recently in Oregon in response to the mandate in the 2005 U.S. Energy Policy Act to increase the production and use of biofuels such as ethanol and biodiesel. This mandate calls for up to 7.5 billion gallons of “renewable fuels” to be used by 2012, representing about 3-4% of national gasoline consumption (in terms of energy content). There is particular interest in Oregon’s agricultural communities where production of biofuel and their feedstocks could have significant economic implications.

At the state level, Oregon has established its own goals for renewable energy including increased use of ethanol and biodiesel in transportation. Oregon’s Renewable Energy Action Plan includes goals for 2 percent of diesel consumption from biodiesel and 15 million gallons produced from Oregon sources. Similarly, the Plan calls for gasoline sold in Oregon to be 2 percent ethanol on average, and 100 million gallons of ethanol to be produced in the state annually. Higher percentages of biofuels are planned for state government fleets (Oregon DOE, 2006).

The reasons for promoting a shift nationally and locally toward biofuels and other renewable energy sources and away from exhaustible, fossil fuel-based energy is due to: a) concerns about energy independence given our current reliance on uncertain future supplies of fossil fuels and, b) concern about the environmental effects of fossil fuel energy sources including air pollution and emissions of greenhouse gases (GHGs) linked to climate change. For example, Governor Kulongoski’s Advisory Group on Global Warming includes promotion of biofuel use and production as one of their recommended actions estimated to contribute 1 million metric tons of greenhouse gas emissions reductions by 2025 (Oregon DOE, 2004).

In this context, a number of questions have been asked about the potential for increased commercial biofuels production in Oregon. The main questions can be summarized as follows:

1. Can biofuels be produced in Oregon at a cost that is competitive with conventional fuels? What level of public support is currently provided, or would be needed, to provide adequate incentives to both producers and consumers?

2. Do biofuels contribute to energy independence? In particular, is the energy content in the biofuel greater than the energy required to produce it? If so, what is the cost per unit of net energy compared to the net energy cost for conventional fuels or for other means of fostering energy independence?

3. Do biofuels contribute to environmental protection? If so, how costly would it be to achieve the environmental benefits in this way, as compared to other means of attaining the same environmental objectives? In particular, how do biofuel emissions of greenhouse gases compare to those of fossil fuels?

In addition to these central questions, there are a number of related issues that deserve consideration such as the capacity for fuel or feedstock production that can realistically be achieved in Oregon, and the potential market impacts (positive and negative) of an increase in biofuel production, since these changes could have direct or indirect effects on other agricultural markets including coproducts and animal feed.

This report presents a summary of information and analysis. We draw on a range of national and regional studies and private sector information, and we evaluate the questions listed above for Oregon. The report also includes "sensitivity analysis," whereby we consider how sensitive our results are to variations in assumptions about prices, technology, and other factors that would affect the quantitative economic values. Our "central estimates," however, are based on the best available information for the scale and type of biofuel operations being evaluated.

In addressing the question about commercial competitiveness, we take account of existing government payments and subsidies in order to assess the costs of biofuel production both with, and without, public support. Here we are interested in recognizing the need for adequate private incentives to producers and consumers if biofuels are to be voluntarily produced by suppliers and purchased by consumers. We refer to this analysis as reflecting "private costs" and "private benefits," or revenues. In cases where private incentives do not appear, by themselves, to provide sufficient incentives for commercial biofuel development – but where there may be other public justifications for promoting biofuels (such as energy independence or environmental objectives), we focus on the question of how large or small public support would need to be in order to provide producers and consumers with sufficient incentives. For these questions, which are posed from a public perspective, we include both private costs and public costs (e.g., taxpayer funded subsidies) and refer to these as "social costs" and "social benefits."[2]

There is a range of different types of biofuels, multiple feedstocks, and different technologies for processing. In most cases there are also byproducts or "coproducts" that have value in other markets and need to be accounted for (e.g., animal feed, fuel for power generation). The presence of coproducts will be important in terms of commercial viability of the biofuel, and in many cases they also represent important quantities of energy.

For the current analysis we have chosen to focus on three types of biofuels based on a preliminary evaluation of agronomic and economic considerations in an Oregon context. Several types of biofuels were not evaluated in detail because they appeared to hold little promise in Oregon. For example, switchgrass, a warm-season grass, doesn't grow well in Oregon; neither do soybeans. We settled on three biofuels: 1) corn-based ethanol production, 2) canola-based biodiesel, and 3) lignocellulosic, wood-based ethanol (e.g., from wood, straw, or other cellulosic materials):

- Corn-ethanol: our analysis is based on feedstock being imported from the Midwestern U.S. because insufficient quantities are grown in Oregon to adequately supply a commercial scale ethanol plant. Indeed, all of the corn grain currently grown in Oregon represents less than ¼ of the feedstock needed for one commercially viable

[2] For our current purposes, we will not attempt to include in our measures of "social cost", the environment, or other externalities sometimes considered under the label of "social cost."

minimum sized corn-ethanol plant producing 50 million gallons per year. We implicitly assume an ethanol plant would be located near a rail terminal to minimize costs of feedstock imports and coproduct exports.

- Canola biodiesel: even though current canola production in Oregon is only enough to supply 10% of what would be needed for a 2 million gallon plant, there appears to be more potential for increasing canola acreage in Oregon and Washington. Significant acreage would be available for canola production in the dryland areas of the Columbia Basin if planting issues can be overcome and pricing is favorable. Dry soils in the fall limit planting at this time. We assume that canola processing would occur in a central location relative to canola planting areas and that it could be transported to a processing plant at relatively low cost.

- Cellulosic wood-based ethanol: our analysis is based on the assumption that material from sources such as forest thinning (related to fire suppression), clearing of invasive juniper, or waste from wood-processing operations would be available. No specific location is intended to be the basis of our estimations.

There are many alternative types of biofuel, biofuel technologies, and scales and configurations of production and use that we do not evaluate. To evaluate alternatives such as on-farm production and use, alternative feedstocks, or localized small-scale oil pressing and distribution would require a separate analysis. We also cannot know how future changes in prices or technologies might alter the results of our analysis. We point to some of those factors in the concluding section.

The analysis below is quantitative and includes estimates of costs, revenues, conversion rates, etc. It is important to recognize, however, that in some cases these estimates are subject to considerable uncertainty for two reasons. First, future prices, costs, availabilities, and technological progress cannot be known with certainty. Second, we have very limited information on actual costs from operating commercial production facilities for processing biofuels. In the case of corn ethanol, we acquired detailed financial data from a sample of firms. In the case of biodiesel, even though there are 53 commercial biodiesel plants in the U.S. producing an estimated 91 million gallons, these are all soybean-based and detailed financial results are unavailable for any of these firms. Therefore we rely on estimates from government and academic researchers. Finally, in the case of wood-based cellulosic ethanol, there exist no commercial operations in North America,[3] which further limits the confidence one can have in the accuracy of the research studies that have evaluated these processes. Our expectations based on the evidence from private sector financial data for corn ethanol suggest that government and academic studies may tend to underestimate the actual costs of production.

In section II we evaluate the commercial viability of each of these three biofuels. This is followed in section III with an evaluation of the net energy generated by each, and the social cost

[3] One experimental plant in Ottawa, Canada has operated for only occasional short periods.

of that net energy gain. Section IV looks at the estimated reductions in greenhouse gas emissions for each fuel, and the costs of those reductions compared to fossil fuel alternatives. Section V reports on our sensitivity analysis and section VI offers concluding discussion and observations.

II. Commercial Viability

In this section we summarize our estimates for the cost, price, and technical parameters used to arrive at measures of the commercial viability of each of the three biofuels. We include in our estimates government support in the form of subsidies which contribute to the social cost of making the biofuels acceptable to consumers.

II.A. Corn based ethanol

Corn-based ethanol production has grown rapidly over the past 15 years, increasing to 4 billion gallons in 2005 (Eidman 2006). About 75% of this production is 'dry mills' (producing ethanol, dried distillers grains and solubles (DDGS), and CO_2). Production is expected to reach 5 billion gallons in 2006; the vast majority of which is concentrated in the Midwestern states ($3/4^{ths}$ of current U.S. production occurs in Iowa, Illinois, Minnesota, Nebraska, and South Dakota).

The existing national studies from government and university researchers provide a range of estimates of the technical and economic factors relevant to the commercial viability of corn-based ethanol (see Gallagher 2006). There is also private sector information from firms producing corn-based ethanol. Our analysis is based on the assumption that the feedstock would be imported from the US Midwest, since all of Oregon's corn production (for grain) would amount to less than $1/4^{th}$ of the feedstock needed for one commercial scale ethanol plant (50 million gallons/year).

Based on information from a combination of sources including the most recent studies and analyses, and using private sector results from public documents, we have compiled a set of economic and technical factors as the basis for formulating "midpoint estimates" and ranges of the costs, revenues and net energy gains, as well as the effects of biofuels on greenhouse gas emissions.[4] Our analysis is based on estimates for a standard scale (50 million gallon) corn-ethanol plant to be located in Oregon, with feedstock shipped by rail from Minneapolis to Portland. These estimates should be interpreted as midpoint values in a range of estimated real world outcomes. We subsequently conduct sensitivity analysis to consider how the results of our analysis would be affected by the use of different estimates.

Our analysis of corn ethanol includes feedstock production costs based on average prices for the past three years ($2.35/bushel), transportation from the U.S. Midwest (Minneapolis) to

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[4] CO_2 is the main greenhouse gas, although other gases such as methane also contribute to the atmospheric accumulations of gases that cause climate change. As is done elsewhere in the scientific and policy literature, we will base our analysis on a measure of 'grams of CO_2 equivalent" gases, where the emissions of the relevant gases have been added together in a weighted fashion reflecting their relative contributions to "radiative forcing" (climate change).

Portland ($0.80/bushel). Processing and conversion costs excluding feedstock costs ($1.36/gallon) are based on private-sector results (see Appendix A) which include some overhead and capital costs that are unlikely to have been fully reflected in the (lower) research studies estimates (approximately $1.25/gallon).[5] A conversion rate of 2.75 gallons per bushel was used based on average private sector results. Blending subsidies of $0.51 per gallon of ethanol are not included at the producer level because these are generally paid to blenders (gasoline/ethanol mixtures) rather than producers of ethanol. These subsidies, however, are included in the overall consideration of the social costs of current programs. Revenue from the sales of coproducts ($0.26 of DDGS/gallon of ethanol).

Our estimates of the private costs and revenues for a corn ethanol plant located in Oregon suggest that revenues would come very close to covering costs (Figure 1). Compared to the costs and revenues for production in the U.S. Midwest, these estimates include slightly higher costs and slightly lower revenues due to the added cost of transporting corn to Oregon from Minneapolis (29 cents/gallon) and a lower market price for ethanol from the major Midwest market if shipped to Oregon (7 cents/gallon).

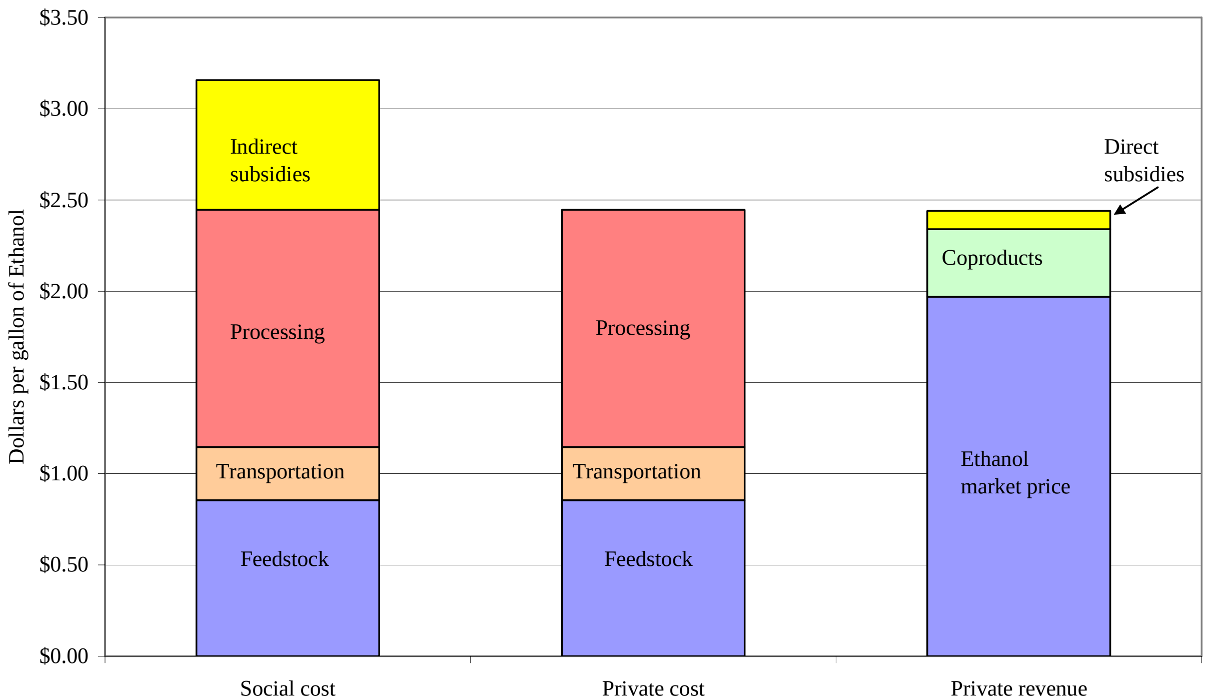
Overall private cost and revenue are essentially equal based on our estimates, suggesting that corn ethanol plants located in Oregon may be commercially viable for producers. There remains, however, the issue of consumer preferences and their willingness to buy gasoline blended with ethanol. As is evident in figure 1, there are significant subsidies offered at the post-production stage to blenders for biofuel ethanol (See appendix B for details). Subsidies can be expected to induce market adjustments that have a ripple effect on prices paid by consumers, distributors and suppliers. The overall effect of these price adjustments – along with regulatory requirements – will alter the incentives for consumers to buy ethanol-blended gasoline. There are a variety of federal and state policies throughout the country, and the banning of MTBE in many states as an additive to gasoline, which have resulted in increased use of ethanol (Eidman 2006). Under the Renewable Fuels Standards of the Energy Policy Act of 2005, the U.S. fuel industry will be required to produce a minimum of 7.5 billion gallons of renewable fuel by 2012 (Eidman 2006). All these policies help ensure an active market for corn ethanol, and prices can be expected to adjust to bring revenues into alignment with costs over time (as they appear to have done, approximately, in the Midwest). These same forces would come into play if Oregon faced similar incentives to serve state-wide markets.

An important consideration for some biofuels is the potentially large increased production of coproducts, their use and their impact on markets. For example, for one 50 million gallon corn ethanol plant in Oregon, an additional 165,000 tons of DDGS will be available. A excess of DDGS could result in this coproduct being disposed of as waste rather than sold as animal feed. Although DDGS has been widely used for dairy, beef, pork, and poultry, it requires some time and experience before livestock producers embrace its usage (Tiffany and Eidman 2003). Oregon already imports animal feed, including some DDGS. If production rose to where it exceeded in-state needs, exporting DDGS may be a possibility given the convenient proximity

[5] Recent private sector financial results were compiled from public disclosures related to stock offerings for ethanol firms. These financial results indicate a cost of production/conversion (excluding the feedstock cost) of $1.36 per gallon of ethanol. This cost figure includes overhead (sg&a) of $0.12 per gallon and operating cost of capital of $0.25 per gallon.

to the port of Portland. Indeed, around 700,000 metric tons of DDGS have been exported annually in recent years, mostly to European countries. Beginning in 2004, however, exports to Malaysia, Thailand and Taiwan were begun, raising hopes for international market development from the West Coast. The future potential for accessible and attractive Pacific export market opportunities, however, remains highly uncertain and will depend on ocean freight rates and the supply of DDGS from other competing sources.[6]

Figure 1. Costs and Revenue Estimates for Corn Ethanol Production in Oregon
(feedstock delivered from the U.S. midwest)



II.B. Canola-based biodiesel

Canola oil is used for a small portion of the biodiesel produced in the U.S. In 2005, 1.5% of U.S. soybean harvest was converted into 67 million gallons of biodiesel, which nevertheless amount to less than 0.1% of U.S. diesel consumption (Hill et al. 2006). There were 53 commercial biodiesel plants in the U.S. in early 2006 with a production capacity of 354 million gallons. Demand for biodiesel has remained relatively low because, until recently, the fuel’s cost has been well above the price of petroleum diesel (Eidman 2006). Similar to ethanol, however,

[6] As we will see below, however, exports of coproducts may help promote commercial viability, but coproduct exports represent energy exports, and this will reduce the net energy contribution of the biofuel nationally.

elements of recent federal legislation will continue to enhance demand. These incentives, which include a federal tax credit and the Renewable Fuels Standards as well as new diesel fuel standards requiring refiners to greatly reduce sulfur levels in diesel, could create new market demand for biodiesel as a lubricity additive (Eidman 2006).

From 2000-2004, soybean oil made up 57% of total U.S. feedstock supply for biodiesel, with yellow grease and "other grease" contributing 8%, and animal sources accounting for 17% (Eidman 2006). Most data and studies of biodiesel focus almost exclusively on soybeans, with only rare mention of canola. In addition, estimates of the effect of significant increases in biodiesel production in the U.S. (e.g., from 90 million gallons to 124 million gallons), suggest that soybean prices would rise as a result. One estimate suggests that implementation of the Renewable Fuels Standards would raise soybean prices by 17% (Eidman 2006).

With this national context in mind, canola-based biodiesel is viewed by some observers as a potential biodiesel feedstock that could be grown in Oregon. However, current canola production amounts to less than 10% of what would be needed to supply a single, 2 million gallon commercial plant. Smaller commercial processing plants (e.g., 0.5 million gallons) are possible, but average costs per gallon are likely to be higher for smaller scale operations. Moreover, increasing canola production from 3,000 acres to 30,000 acres is challenging due primarily to the low return per acre compared to alternative crops available to farmers. One agronomic obstacle for establishing dryland canola crops in the fall is the limited available moisture. And any increases in acreage would need to overcome the competition for land from other crops such as dryland winter wheat and many alternative crops in irrigated areas. It is therefore unclear that at current prices canola would appeal to enough farmers to achieve adequate acreage increases.

A small number of biodiesel analyses have been conducted that address questions of the economics, net energy generation and environmental effects (including changes in CO_2 emissions). No private sector information was attainable in a form similar to the case of corn ethanol which permitted us to document key parameters. For biodiesel, however, nearly all of these studies have based their analysis on soybean feedstock rather than canola. Information on some of the differences between canola and soybeans are available and are taken into account as described here, and in more detail in the Appendix C. In particular, canola production per acre is higher than for soybeans and oil yield of canola is about double that of soybeans. Canola also has the disadvantage of requiring nitrogen fertilizer, unlike nitrogen-fixing soybeans.

As with corn ethanol, we first assess the cost of feedstock production and the technical conversion rates to canola oil. Given a conversion of 27 pounds of canola per gallon of oil, and a price of $9/hundredweight for canola, our estimated cost of production is $3.21 per gallon. Processing costs are estimated to be $0.68 per gallon. These conversion rates are based on studies for commercial scale biodiesel plants processing at least 2 million gallons per year, and utilizing canola, rapeseed, and soybean feedstocks.[7] Federal and state subsidies amount to $1.10 per gallon of biodiesel. Coproducts are important components of the economics of biodiesel. For

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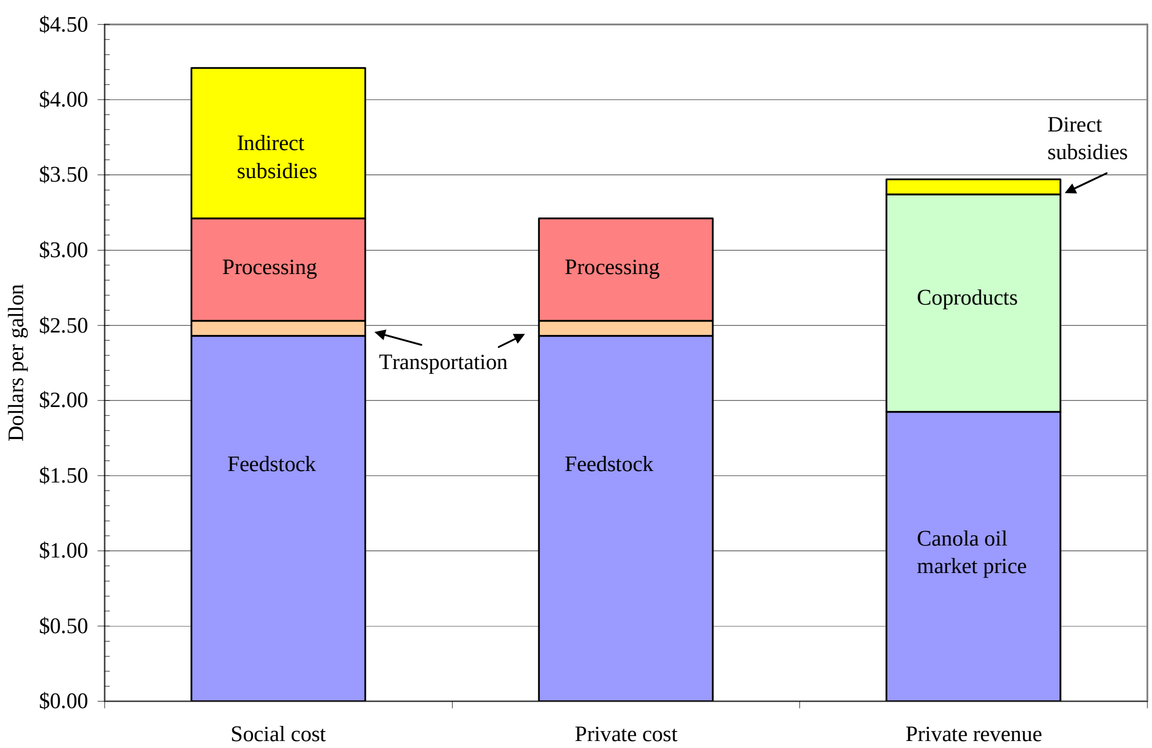
[7] The studies relied upon are described in Fortenbery (2004), Hass (2006), Noordam and Withers (1996), and NYSERDA (2004). Overhead costs for sales, general and administrative (SG&A) are added.

each gallon of canola oil, 17.5 pounds of canola meal is produced that, depending on market prices, may be worth nearly as much as the oil. Glycerin is another coproduct adding an estimated 23 cents of revenue per gallon of canola oil. As in the case of corn ethanol, a significant increase in the availability of these coproducts could put downward pressure on their market prices. If the regional market were to become flooded, the disposal of canola meal as waste would alter the economics of canola production significantly and make the net energy generation for this type of biodiesel negative (see net energy discussion below).

Costs of production for canola will vary greatly within Oregon due to differences in climate, soil and whether the crop is irrigated. Average yields for the state are around 2,000 lb/acre, although yields as high as 4,000 lb/acre are possible under irrigation in some areas. As a result of these differences, the ability of individual farmers to find canola-based biodiesel to be economically attractive for local or on-farm use may vary considerably.

Given these parameters, our estimates of costs and revenues suggest that canola oil production may be commercially successful given current market conditions and with existing government subsidies. These government supports include an indirect "blender's credit" of $1.00/gallon. This credit is not included in the revenues to producers because it is generally paid to separate firms that purchase soybean or canola oil and blend it for biodiesel for retail sales. These figures suggest that canola biodiesel may be economically viable for growers. The blender's credits may be necessary to generate adequate demand from blenders to be willing to buy canola oil and produce biodiesel.

Figure 2. Costs and Revenue Estimates for Canola-based Biodiesel Production in Oregon



II.C. Cellulosic wood-based ethanol

We evaluate cellulosic ethanol based on woody feedstocks such as waste from forest thinning or from the wood products industry in Oregon. Only a few studies are available that have evaluated cellulosic ethanol but these studies use a range of feedstocks including switch grass, corn stover, wheat straw, wood waste, and plantation poplar or other fast-growing trees. We are not aware of any commercial operation for wood-based cellulosic ethanol in the U.S. or Canada (see Gallagher, 2006).

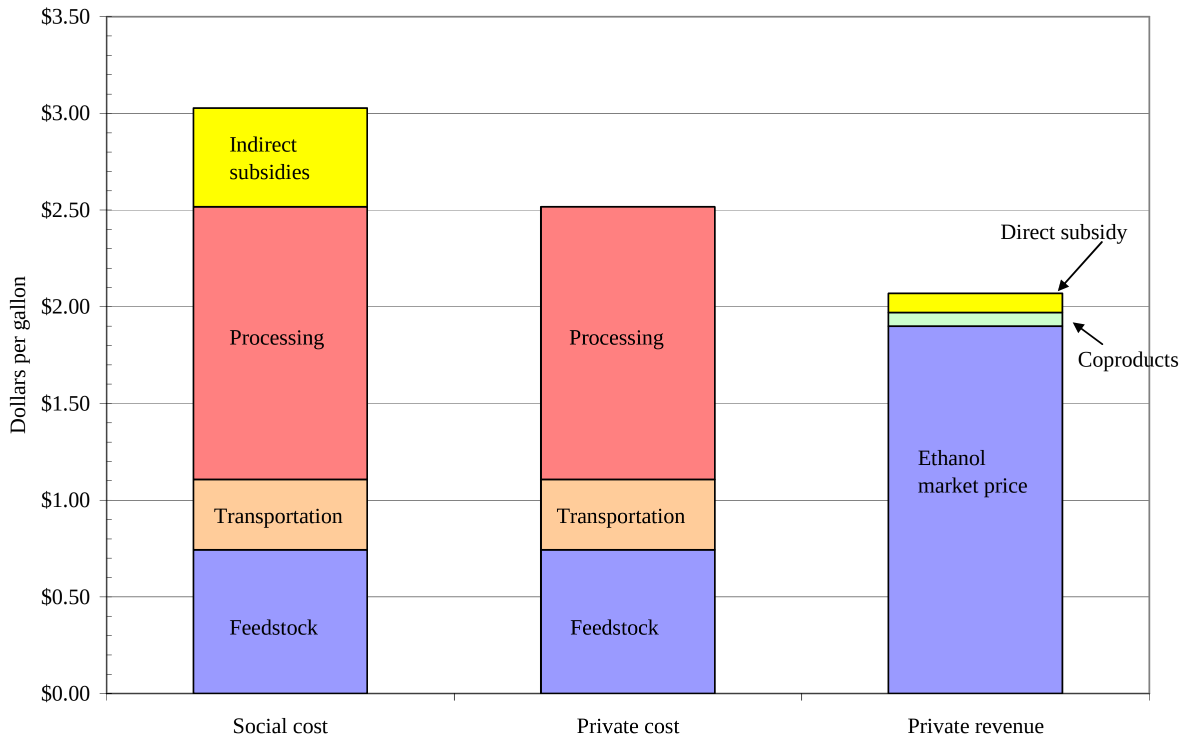
For the case of forest thinning, feedstock production costs may be lower than for plantation-grown feedstocks, but cutting and collection of wood biomass can be costly. Based on two studies of wood collection costs for ponderosa pine (Aden, Wooley and Yancey 2000) and juniper (Swan 1997), we estimate the average collection cost for feedstock of $52/ton in 2005 dollars, mainly labor costs. Transportation and handling is also expensive to bring feedstocks from expansive forested areas to the processing location. We estimate these costs to average $25.50/ton. Processing is estimated to cost $99/ton or $1.42 per gallon of ethanol. Currently available subsidies amount to $0.61 per gallon for the federal blender's credit and the small producer credit. Coproducts in the form of lignin can generate savings if they are sold, or if they generate electricity that is then sold. Alternatively they may use this coproduct to generate heat and power on site. We do not include costs of fertilizer for feedstock production, but for plantation production of wood feedstock fertilizer would be an added cost.

Based on the estimates available, Figure 3 suggests that wood-based ethanol falls short of being commercially viable even with existing subsidies. As expected, processing represents a larger share of the costs when converting cellulosic feedstocks into ethanol. These costs can be expected to vary considerably due to differences in the cost of feedstock collection and transportation.[8] If feedstocks are commercially grown trees, different cost and other estimates must be taken account of. For the case described in Figure 3, revenues fall about 20% short of costs. In addition, no administrative costs or overhead are included in these cost estimates.

As noted elsewhere, these estimates are inexact and will vary by location and market conditions. This is especially true in the case of cellulosic ethanol because the technical and cost parameters are not based on private sector data or actual commercial enterprises. Because there are currently no cellulosic ethanol plants operating commercially in the U.S. or Canada, these estimates are necessarily less reliable than the estimates for corn ethanol and biodiesel where such operations can be observed directly. In addition, our expectations based on the 'bottom-up' estimation methods (adding up the costs of feedstock, equipment, labor, etc.), as well as our evidence from private sector financial data for corn ethanol, lead us to believe that the existing estimates for wood ethanol underestimate the actual costs of production.

[8] Processing costs will vary due to the range of technologies and processes that can be used.

Figure 3. Costs and Revenue Estimates for Cellulosic (Wood) Ethanol Production in Oregon



III. Net Energy Generation and Its Costs

Production of biofuels involves the use of energy. Currently, this energy comes largely from fossil fuel sources. For biofuels to represent a net gain in energy independence, the energy contained in the fuel must exceed the energy used in its production. We therefore examine the ‘net energy’ generated by biofuels as well as their cost per unit of net energy. This latter assessment is crucial for evaluating the cost-effectiveness of promoting biofuels compared to alternative ways of promoting energy independence, and as a benchmark against which to assess society’s willingness to pay costs of this magnitude to promote energy independence.

III.A. Fuel-specific net energy estimates

Much analysis and public debate surrounding ethanol and other biofuels has focused on whether the ‘net energy’ generated by producing them is positive or negative. The conclusion that the net energy balance for corn ethanol is negative comes primarily from two studies, one by Patzek (2004) and the other by Pimentel and Patzek (2005). Several careful reviews of these and other studies discredits those negative findings which suffer from errors of omission and other shortcomings in the analyses (Farrell et al., 2006). The graphical comparisons of a range of estimates summarized in Farrell et al. (2006) are reproduced in the Appendix D.

While most studies estimate a positive net energy gain in the case of corn ethanol, the amount of energy used in its production is relatively high due primarily to the use of energy in corn production (including fossil fuel-based fertilizers) and energy requirements for processing and conversion. Although a gallon of ethanol contains 91,742 Btus of energy, 73,118 Btus are used in its production making the net energy generated just 20.3% of the energy contained in the fuel. Another way that net energy is sometimes presented is in terms of the gain in energy in excess of the energy used in production. By this measure, referred to as net energy balance NEB), the proportion would be 25% ((91,742-73,118)/73,118). In the case of corn ethanol, however, the fact that it has a positive net energy gain is attributable almost entirely to the “energy credit” it gets for the content of the DDGS coproduct which is used in livestock feed. Indeed, without this coproduct credit, the net energy for corn ethanol would be less than 4,000 Btus/gallon. This result implies that if the DDGS were exported, it may (depending on prices) contribute to the commercial viability of ethanol production, but it may also mean that the net energy contribution domestically is extremely small.

A central observation in our analysis is that a positive net energy contribution of a particular biofuel is necessary, but not sufficient, to conclude that it represents a desirable way to promote energy independence. If the net energy contribution is small, and the cost of that contribution is high, a given biofuel feedstock or production technology may be excessively costly per unit of net energy.

Since the net energy gain by itself does not provide information about the cost of generating additional energy, we need to weigh the net energy generated with biofuels to their cost. By combining these two considerations – cost and net energy – a measure of the cost of promoting energy independence via biofuel production can be compared to the costs of promoting energy independence in other ways (e.g., with other sources of energy, or with energy conservation, the substitution of capital for energy, or with incentives for stimulating technological change).

The resulting measures of the cost per unit of net energy generation may look very different for biofuels than they do for gasoline or petroleum-based diesel. The reason is that the energy content varies by fuel, and the portion of that energy content that represents a ‘net’ energy gain can vary dramatically. For example, gasoline and diesel fuel have net energy gains of 76% and 85%, respectively. For corn ethanol, by contrast, only 20% of the energy contained in the fuel can be considered net energy. For canola biodiesel the figure is 69%, and for wood ethanol we estimate 84% of the energy is additional, or net, of the energy used to produce it. In each of these cases the energy contained in the coproducts is ‘counted’ either as an energy coproduct, or as a source of energy cogeneration used as fuel for all or part of the energy required for processing.

For each biofuel, and for the relevant fossil fuel based alternative, we want to compare the social costs for the net energy they generate. The social costs for this purpose include all the actual costs for production of the feedstock, transportation and processing, but also the subsidies that exist currently as incentives for the producers of the feedstock (farm support programs), for producers of the biofuels (direct subsidies), and for blenders, distributors and consumers (indirect subsidies) that have been introduced as a way to stimulate market demand.

Given these differences in net energy balance, the cost per unit of net energy for corn ethanol is 8 ½ times as high as for gasoline (see figure 4).[9] This is due to both the lower energy content of ethanol compared to gasoline and the higher amount of energy used in producing corn ethanol compared to gasoline. As a result of these differences, the cost of net energy from corn ethanol is $170 per million Btus compared to $20 per million Btus of net energy from gasoline.

In the case of canola biodiesel, the net energy gain is relatively high compared to corn ethanol, 123,000 (178600-55600). Not only is the energy contained in a gallon of biodiesel about twice that of a gallon of ethanol, but about 69% of that is net energy: only about 55,600 Btus are used to produce a gallon of canola biodiesel. The comparison of the social cost of canola biodiesel to the net energy generated give rise to an estimated cost per unit of net energy of $35 per million Btus or 125% higher than for petroleum diesel (Figure 5).

Once again, however, the coproduct credits play an important role in the net energy gain for canola biodiesel. Without the coproduct credits for canola meal, which contain about half as much energy as the fuel itself, the net energy gain from canola biodiesel would be less than 25,000 Btus/gallon, or about one-fifth as large as when the coproducts are fully credited. So, for example, if the canola meal is exported so that it does not contribute to domestic net energy availability, we would want to look at the cost per unit of net energy for biodiesel excluding the coproduct offset. This would give us a cost per unit of net energy of about $170 per million Btus, or ten times the cost of petroleum diesel.

And, finally, in the example of wood-based cellulosic ethanol, the net energy produced represents a much greater share of the energy contained in the biofuel, due to the low level of energy used in production (and because it is assumed that some of the energy used in processing is derived from the biofuel itself). As a result, the cost per unit of net energy from wood-based ethanol is more favorable than for corn ethanol as reflected in Figure 6. Despite this much higher net energy share, this biofuel would require more subsidies to make production commercially viable (see section II). If additional subsidies were offered, the cost per million Btus of net energy would be nearly three times as high as for gasoline.

III.B. Interpreting the "cost per unit of net energy"

How should we interpret these estimates of the cost of biofuels in terms of their net energy contributions? On what basis would we judge their cost to be too high to warrant public support? One way to put this information in perspective is to consider the equivalence between a policy that subsidize a desirable good versus a policy that taxes an alternative undesirable good (e.g., a tax on a highly-polluting energy source will have an equivalent effect as a subsidy on clean energy source). By presenting the magnitudes of both options, the information provides two different kinds of benchmarks against which to judge the policy's justification or its public support.

The rationale for either approach is derived from economic principles about publicly-justified interventions in the marketplace. When markets fail to take account of some public goal

[9] Gasoline and petroleum diesel prices are based on average, pre-tax prices for the past three years.

or negative externality (e.g., the benefit of energy independence, the damage from pollution), the most general and efficient approach would be a tax on the offending goods or activities (imported oil, highly polluting commodities) up to the point where the tax is equal to the damage done. (The revenues from that tax could be used to substitute for preexisting revenue-raising taxes, fund other efforts to clean the environment or promote energy independence such as research and development). For example, if emissions of SO_2 are estimated to cause \$50 of damage per ton, then the "optimal tax" on SO_2 emissions would be \$50 and this would be the appropriate incentive to discourage SO_2 emissions to an "efficient" level.

In the current context, however, we are interested in the substitution of biofuel net energy for fossil fuel net energy. Employing the tax/subsidy comparison on a "per gallon" basis will be misleading as a way to compare the cost of public intervention to shift from one source of net energy to another. On a per gallon basis, the current subsidies for corn ethanol, biodiesel, and cellulosic ethanol are equivalent to gas or diesel taxes per gallon of \$0.81, \$1.10 and \$0.61, respectively. These dollar amounts, however, do not represent the level of substitution in terms of net energy, because of the differences in net energy per gallon among these fuels.

For comparison purposes, we can consider the differences in estimated cost per net energy Btu, and ask whether an approach using a tax at a comparable level would be viewed as justified given the policy objective (and also assuming that it was implemented in a revenue-neutral way, meaning that other taxes would be lowered so that the net effect on government revenues was zero). In the case of corn ethanol, the current cost including subsidies per Btu is 850% higher than the cost per Btu for gasoline. If consumers were buying "net energy" directly, a 750% tax on gasoline's net energy would be needed to make the net energy from biofuels equally attractive to consumers. In the case of canola biodiesel, the figure would be a 125% tax on net energy from petroleum diesel. For wood-based cellulosic ethanol, the equivalent tax on gasoline's net energy would need to be 190%.[10]

Quantitative measures of net energy and the cost per unit of net energy combine two crucial considerations: 'energy accounting' and 'economic accounting.' These two measures, however, do not include other considerations such as the environmental effects of different energy sources (one of which is addressed in the next section). Also, it is important to recognize the versatility or "convenience" of different types of energy such as the ability to store the energy and the crucial need for a "mobile source" of energy that can be used to power motor vehicles. To the extent that the net energy generated by biofuels uses an immobile source of energy in its production, but generates a mobile type of biofuel that can power motor vehicles, then the net energy calculation may undervalue the contribution of that biofuel because the measure overlooks the mobility or convenience factor. On the other hand, to the extent that a significant proportion of the energy generated comes in the form of animal feed, this reduces the attractiveness of that net energy given the importance in the U.S. of coming up with alternative mobile sources of energy to power vehicles.

[10] The price of gasoline is affected by many factors including taxes, subsidies, and market manipulation by OPEC. Federal, State and local taxes on gasoline amount to about \$0.45 per gallon. Total subsidies for oil in the US were estimated in fiscal year 1999 to be \$567 million. At the same time, the federal gasoline tax of 18.4 cents per gallon amounts to over \$20 billion, far offsetting all federal subsidies (EIA 2000).

Figure 4. Cost per unit of Net Energy

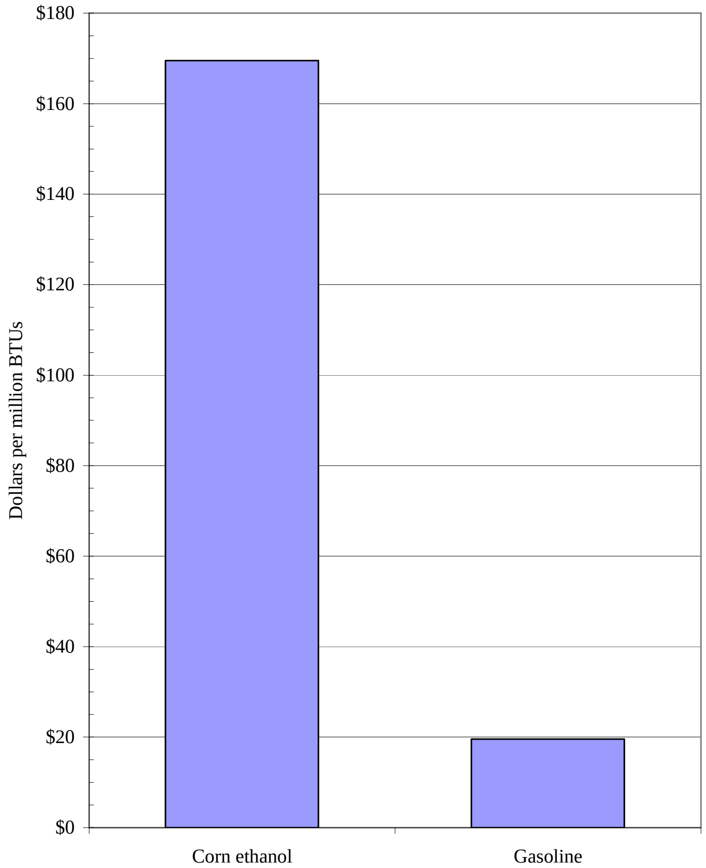


Figure 5. Cost per Unit of Net Energy

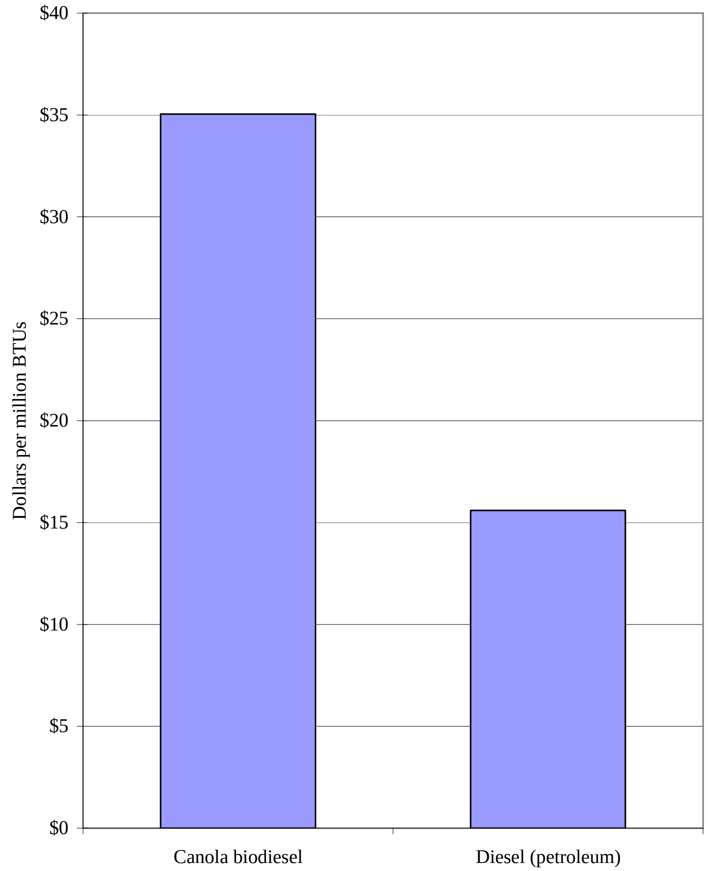
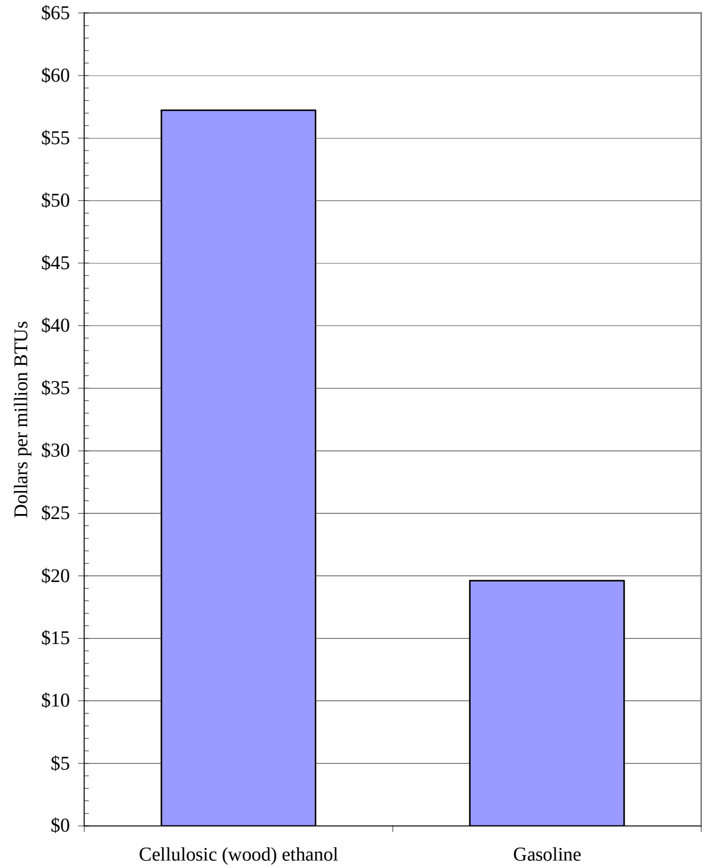


Figure 6. Cost per Unit of Net Energy



IV. Reductions in Greenhouse Gas Emissions & Their Cost

The second motivation for promoting biofuels we consider is its effects on the environment. Fossil fuels can have negative environmental effects related to extraction, transporting, refining and consuming. Among the leading areas of concern is the accumulation of greenhouse gases in the atmosphere due, in large part, to the emissions of CO_2 and other greenhouse gases resulting from the combustion of fossil fuel energy. To the extent that corn ethanol has lower greenhouse gas emissions than fossil fuels per unit of net energy, the substitution of corn ethanol for gasoline would have an environmental benefit.

Biofuels, however, can also have negative environmental effects based on current production technologies. In the case of corn, soybeans, or canola, these are due primarily to the use of farm chemicals including nitrogen, phosphorous, and pesticides (Hill et al. 2006). Hill et al. consider three environmental effects, fertilizers, pesticides and greenhouse gas emissions. They find that in the cases of fertilizer and pesticide use, corn grain ethanol is much more polluting than is soybean biodiesel (Hill et al., 2006, p. 11208). In the current analysis we consider only greenhouse gas emissions (GHGs) and the cost of reductions in those emissions.

Until recently it was common to refer to some biofuels as a "zero net GHG emissions" source of energy. This was because the carbon contained in the feedstock, having been recently drawn out of the atmosphere as the plant grows, represented the maximum amount of CO_2 that could be released. This would only be true, however, if no fossil fuel sources of energy were used in the production, transportation, and processing of the biofuel. In the case of corn ethanol, a relatively high level of fossil fuels are currently used in its production, and due to the relatively low net energy balance, the reduction in GHG emissions per unit of net energy is small. Indeed, per unit of net energy, GHG emissions for corn ethanol are estimated to be only 12.4% lower than in the case of gasoline. The combination of the relatively high cost of producing net energy with corn ethanol and the small net reduction in GHG emissions implies a cost of reducing GHG emissions by substituting corn ethanol for gasoline of $10,700 per ton, which is more than 200 times more expensive than midrange estimates of about $50 per ton for other ways of reducing greenhouse gas emissions (see Figure 7).[11]

The substitution of canola biodiesel for petroleum diesel is estimated to reduce GHG emissions by 40.5% per million Btus. Given the relative social cost of biodiesel to petroleum diesel, the cost of this GHG reduction is estimated at $596 per ton of CO_2 equivalent emissions, or eleven times higher than the midrange estimate for other climate change mitigation policies (Figure 8). Finally, wood-based ethanol has a very low level of greenhouse gas emissions due to the fact that large amounts of the CO_2 emissions released when the fuel is processed and burned are mitigated when the feedstock is grown (CO_2 is absorbed from the atmosphere). As a result, when substituting for gasoline, wood ethanol will result in a 96% reduction in GHG emissions. Even with this high degree of mitigation, however, the costs of wood ethanol production imply that as a means for reducing GHG emissions, the necessary level of subsidization would make this biofuel seven times as costly as other climate change policy options (Figure 9).

[11] Cost estimates for regulatory policies, market-based incentives, and carbon sequestration rise from $0 up to $50/ton for emissions reductions of up to 250 million tons per year; for reductions of 500 million tons per year cost estimates rise to $100 per ton (Lubowski, Plantinga and Stavins 2006).

Figure 7. Cost of Reducing Greenhouse Gas Emissions

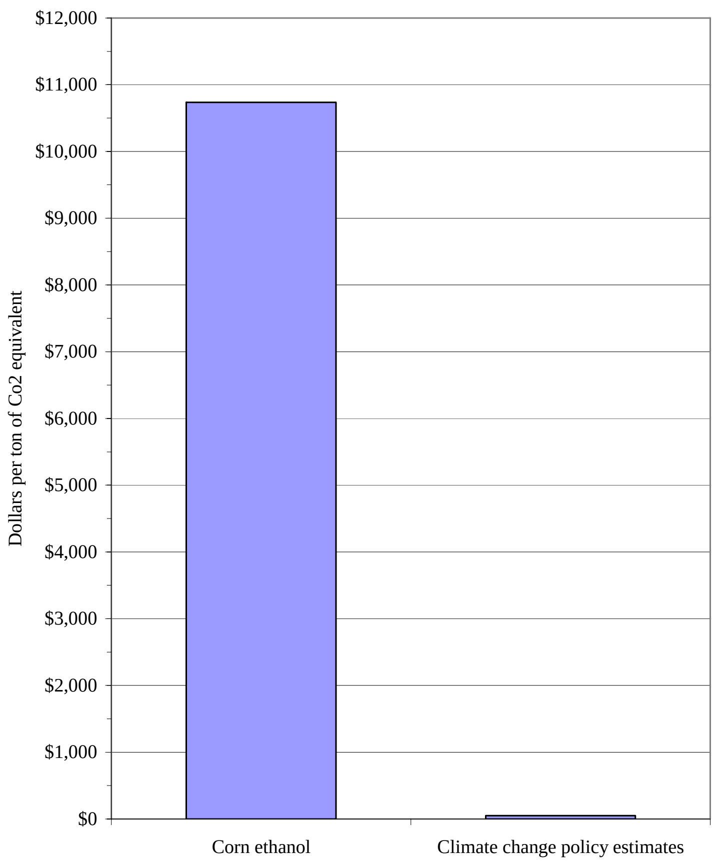


Figure 8. Cost of Reducing Greenhouse Gas Emissions

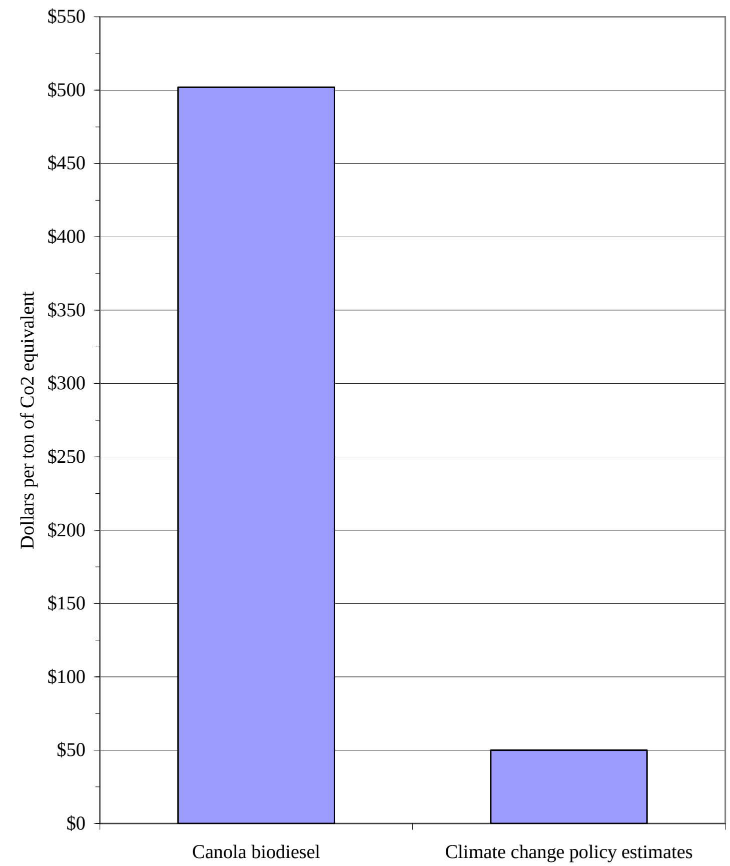
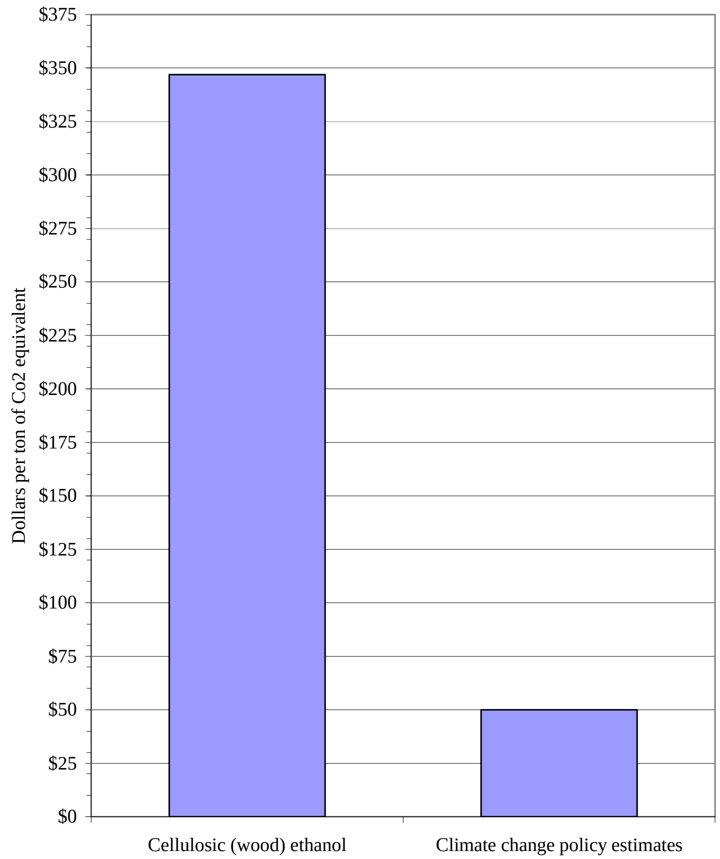


Figure 9. Cost of Reducing Greenhouse Gas Emissions



V. Sensitivity analysis

In this section we consider how sensitive our results are to some of the underlying assumptions. In particular, we ask whether changes in expectations about future market prices for feedstocks, ethanol, canola oil, or coproducts will alter our results significantly. Some of the relative magnitudes of these effects can be inferred from the breakdown of costs and revenues in Figures 1-3. For example, a 25% increase or decrease in the coproduct price will have a negligible effect on revenue per gallon for cellulosic wood-based ethanol (Figure 3), a small but significant effect for corn ethanol (Figure 1), and a large effect for canola biodiesel (Figure 2).

Similarly, we see that processing costs are a much larger share of total cost for the two ethanol biofuels than for canola biodiesel. Hence, any proportional error in these estimates, or any possible cost-reducing efficiency improvements in their processing, will likely to be more consequential for bio-ethanol fuels than for canola biodiesel. By contrast, the cost of feedstock dominates production costs in the case of canola biodiesel.

Most of our price assumptions and sensitivity analysis are built around market price information for the past three years. For our base case prices we use national or regional market price information for ethanol, canola oil, DDGS, and canola meal. In characterizing the changes in revenue associated with variations in the prices, we consider a high and low price based on the extremes observed over the past three years. The effects of these prices on revenue per gallon are reported in Appendix E in dollars and also in percent changes from the base line or central case. For example, given the somewhat larger fluctuations in ethanol prices, our sensitivity analysis indicates a revenue range of +22% to -19% for corn ethanol and +30% to -20% for cellulosic wood-based ethanol. And despite the large share of the cost of biodiesel due to the canola feedstock, the overall cost of production varies by only plus or minus 18% when Oregon canola prices are assumed to vary between $0.07 and $0.11 per pound. Recent fluctuations in DDGS prices are shown to influence corn ethanol revenues per gallon by plus or minus 15%; the range is +21% to -12% in the case of canola meal.

Although some very useful inferences from these results are possible, it is prudent to recognize that there are self-correcting mechanisms at work in the marketplace. The incentives and regulations that may result in high demand for biofuels can be expected to generate “derived demand” (and the necessary price signals) for feedstocks in order to satisfy that demand.

The potential effect of technological change on the profits, net energy contribution, or GHG emissions is highly uncertain. One important factor affecting the extent to which these biofuels contribute to the goals of energy independence and reductions in GHG emissions is the amount of energy used in their production, and in particular the dominance of fossil fuel energy. Hypothetically, if a 10% reduction in the energy requirements for production of these biofuels were possible, due, for example, to either technological progress or the substitution of renewable energy for fossil fuel energy, the net energy contributions would rise and the cost of both net energy and GHG emissions reductions would decline.

In the case of corn ethanol, the cost of net energy would decline by 28%, but still be six times greater than for gasoline. The cost of GHG emissions reductions would decline by 32%, but still be 146 times higher than the estimates for other climate change policies. For canola biodiesel, a 10% reduction in the energy required to produce the biofuel would result in only a 4.4% reduction in the cost of net energy (still 2.15 times greater than for gasoline), and a 8% decrease in the cost of GHG emission reductions (still more than 9 times more costly than other climate change policies). And finally, for cellulosic, wood-based ethanol, a 10% reduction in the energy used in production would result in a 2% decrease in the cost of net energy, and a 3% decrease in the cost of GHG emission reductions.

VI. Discussion

VI.A. Summary of results

Our assessment of biofuel potential in Oregon leads to several observations. In terms of the two motivations cited for promoting biofuels, energy independence and reductions in greenhouse gas emissions, our evaluations suggest a note of caution. We find that corn ethanol results in a positive net energy gain, and it reduces greenhouse gas emissions relative to gasoline, but these changes are small per gallon of biofuel, so that the cost of these gains are many times higher than the range of cost estimates for alternative ways to achieve these same social goals. On a net energy basis, the cost of promoting corn ethanol represents an 750% subsidy compared to the cost of net energy from conventional fuels.

In the case of canola biodiesel, the gains in energy independence and greenhouse gas emissions are positive and somewhat more promising than for corn ethanol. When differences in cost are reflected in terms of net energy gain and greenhouse gas emissions per unit of net energy, however, the cost of promoting those objectives with canola biodiesel are still significant. The cost per unit of net energy is estimated to be 2.25 times that of petroleum diesel. And the cost per unit of greenhouse gas emissions reduction is about 10 times as high as the cost estimates for other climate change policies.

In the case of cellulosic wood ethanol which is not currently commercially viable (as summarized below), if producers were given additional subsidies on the order of $0.53 per gallon, this obstacle could be overcome based on our estimates. These added incentives, however, would raise the costs of the net energy gains and greenhouse gas emission reductions. Indeed, with these added incentives, the cost of net energy generation with wood ethanol would be 3 times as costly as for gasoline, and the cost of reducing GHG emissions with wood ethanol would be 7 times as costly as for other policy approaches to climate change. For comparison, promoting wood-based ethanol with these levels of government subsidies and other incentives on a per-unit of net energy basis would be equivalent to a 190 per cent subsidy on this source of net energy.

These shortcomings for achieving energy independence and environmental goals notwithstanding, both corn ethanol and canola biodiesel appear to have commercial potential for production in Oregon. Existing costs and revenues appear to be at or near the breakeven point – at recent prices – in both these cases. This situation is influenced by the presence of direct and indirect government support as well as regulations that have contributed to the demand for biofuels (and hence market prices sufficient to give rise to adequate producer incentives). In the case of wood-based cellulosic ethanol, our evaluation suggests that current government support, while significant, is not sufficient to cover production costs. In the case of corn ethanol, we have evaluated only the option of importing the feedstock from the U.S. Midwest.

VI.B. Scale of impacts

The potential impact of these three biofuel options on energy independence, given the scales of operation being evaluated here, would be quite small. The net energy generated from a single 50-million gallon corn ethanol plant would contribute less than 1/10th of one percent of Oregon's annual energy use. For a similarly-sized cellulosic wood-based ethanol plant, the contribution would be about 3/4^{ths} of one percent of annual energy use. And a two-million gallon canola biodiesel plant would contribute less than 0.03% of Oregon's annual energy needs.

The contributions of these options toward reductions in greenhouse gas emissions would be similarly small. Twelve of the cellulosic wood-based ethanol plants evaluated here would be required to reduce U.S. greenhouse gas emissions by one percent. For corn ethanol, 86 similar plants would be required to achieve a one-percent reduction; and in the case of canola biodiesel, 30 plants would be required.

In contrast to the small relative magnitude of the energy and greenhouse gas effects for these biofuel operations, their potential impact on land use and coproducts markets in Oregon would be large. Indeed, to satisfy one percent of Oregon's energy needs with canola biodiesel would require planting canola on 25% of all Oregon cropland, and this would generate 2,300 tons of canola meal. Given our assumption that the feedstock for corn ethanol would be imported from the U.S. Midwest, there would be no effect of a 50 million gallon ethanol plant on cropland in Oregon. However, the generation of an additional 165,000 tons of DDGS would be highly significant, and although this could be beneficial to livestock producers in Oregon due to the downward pressures on market prices for feed, it would likely have an adverse effect on local producers of competing animal feeds.

For both goals of energy independence and reductions in greenhouse gas emissions, these biofuel options can be put into perspective by comparing them, for example, to a one mile-per-gallon increase in the average motor vehicle fuel economy (CAFE standards). To achieve the same net energy benefits as a one mile-per-gallon increase in average fuel economy, Oregon would need 3-4 corn ethanol plants, or about 13 biodiesel plants, like the ones evaluated here. Raising the CAFE fuel economy standard is estimated to introduce a cost of $4-8 per million BTU of energy savings (Parry, Fischer and Harrington, 2004).

VI.C. Issues in need of further investigation

An evaluation of this kind is a complex endeavor requiring a detailed examination of scientific, engineering, agronomic, and economic information. The current analysis has been exploratory in nature and is necessarily incomplete (e.g., in evaluating only three biofuel options). This is largely due to the fact that a comprehensive investigation would have been beyond the scope, resources and timeline for the current effort.

A number of issues can be identified, however, that deserve additional investigation and analysis. A more detailed examination of the likely impact of increased coproduct production is warranted given the very large impact this could have both on the economics of biofuels and the net energy contribution (for example, if a flooded animal feed market led to disposal of DDGS or canola meal as waste). The potential for shipping these coproducts to international markets also deserves careful examination.

In the case of wood-based cellulosic ethanol, a more focused study of location and logistical issues is needed. Unless it is possible to find a location for such a plant that is near ample quantities of wood feedstock without exhausting those supplies within a few years, the costs of transporting feedstocks to the plant could rise significantly over time. At the same time, however, an analysis of wood-based ethanol production that took explicit account of the indirect social benefits from forest thinning and clearing (fire suppression), could improve the balance between benefits and costs for this biofuel option.

In addition, there may be complementarities among biofuel types if the value of the coproducts for animal feed may depend on the ability to mix animal feed components (e.g., mixing both DDGS and canola meal with other available ingredients). The proximity of livestock operations to these plants may improve their economic outlook.

Other biofuel options may deserve detailed examination such as using wheat straw or grass straw as a feedstock for cellulosic ethanol. Detailed analysis will be required to assess the net energy and GHG implications of other alternatives. There is also interest in smaller-scale, farm-level biofuel operations that would require a separate analysis.

VI.D. Future prospects

The present analysis is based on current and recent information about technologies, productivities, prices and costs. Any of these factors can change in the future, and prices for fuels and feedstocks can fluctuate widely due to market forces. Changes in some of these factors could make biofuel production in Oregon more attractive and competitive; other changes could also shift the balance in the opposite direction.

Changes that may affect the economics of biofuel production in Oregon favorably include technological improvements that increase the yield or reduce the costs of feedstock production or processing. Private and public research has contributed to technological improvements in the recent past. Indeed, the efficiency of biofuel conversion has improved significantly in recent years.

Some potential changes in the future can cut both ways, however. For example, higher corn or canola prices may offer the kinds of incentives necessary for Oregon to achieve the levels of production needed for these commercial scale plants, but higher feedstock prices will also raise the cost of biofuel production. This change would adversely affect the cost and competitiveness of the biofuels. Improvements in crop yield via biotech and increased fertilizer utilization could increase production and possibly lower feedstock costs, however increased fertilizer utilization will reduce the net energy contribution of the biofuels, which increases the cost of net energy for these alternative technologies. And finally, higher petroleum prices will make biofuels more competitive compared to gasoline and petroleum diesel, but this will also make it more costly to export coproducts to international markets.

One change that could prove problematic with increased biofuel production in Oregon is the effect of coproduct availability on markets for those coproducts. The 50 million gallon corn ethanol plant evaluated here will generate 165,000 tons of DDGS, or about 50 percent more than is needed to feed Oregon's 65,000 cows each year (some of which are actually grass fed). In the case of biodiesel, canola meal from a 2 million gallon plant would be 20,000 tons, or about one-third of what is needed to feed Oregon's cows. Of course, canola meal can also be used to feed other livestock and poultry. In both cases, export opportunities may help avert downward pressure on the prices of these coproducts, but there is uncertainty about the extent of these opportunities. The coproduct issue is critical because a surplus of coproducts on Oregon or national markets could have large deleterious effects on the profitability of biofuel production; and the disposal of these coproducts as waste could cause their net energy contributions to be negative – making biofuel production undesirable from an environmental as well as from an energy independence perspective. For both corn ethanol and canola biodiesel, exporting coproducts would undercut the contribution of these biofuels to national energy independence by reducing the net energy gain that is consumed domestically.

Two additional caveats deserve highlighting: the rapid changes in technology development and entrepreneurship surrounding biofuels, and the development of small-scale, local and on-farm biofuel endeavors. The present analysis is limited to large scale commercial production of biofuels, and the costs considered are specific to those sized operations. And while there is evidence that "scale-economies" make the cost per gallon lower for large-scale plants compared to smaller ones, local or on-farm operations may offer other kinds of advantages that compensate for the scale effects. In any case, the jury is still out on the economics for small-scale biofuel operations; and the current study did not evaluate those options. These issues, as well as other rapid changes that are occurring currently in the design of biofuel systems, will raise new questions about future alternatives for meeting energy and environmental objectives.

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Appendix A: Ethanol production cost summary

The ethanol production budget summarizes fiscal year 2005 audited financial results from four private-sector ethanol producers located in the Midwest region. Firms ranged in annual ethanol production capacity from 50 to 230 million gallons. Capacity expansion costs are capitalized separately and do not appear in the ongoing operating expenses section. All budget items are per gallon of ethanol produced. More than 80% of total revenue comes from ethanol sales, averaging $1.58 per gallon in 2005. The sales are generally forward contracted. Other revenue items include coproducts (distiller's dry grains and solids, or DDGS) at $0.24 and related products and services at $0.13.

Private sector ethanol production cost summary
(based on U.S. Midwest location)

Revenues	$/gallon
Ethanol sales	1.58
Coproducts	0.24
Related products and services	0.13
Total Revenue	1.96
Expenses	
Corn	0.67
Natural gas (1)	0.26
Freight	0.18
Government support payments	(0.04)
Other production costs	0.64
Sales, general, and administrative	0.11
Return on invested capital (2)	0.12
Total Cost	1.93
Profit (loss) before taxes	0.03

(1) Natural gas based on data for three of four firms
(2) Invested capital based on data for three of four firms
Source: documentation from SEC filings.

Corn represents the largest single production cost, at $0.67 per gallon of ethanol ($1.84 per bushel). These data also indicate an average conversion rate of one bushel of corn into 2.75 gallons of ethanol, with firms ranging between 2.70 to 2.81. Natural gas averaged $0.26 per gallon of ethanol, or $8.76 per million Btu. Return on invested capital of $0.12 represents an assumed 10% rate of return on assets required to produce a gallon of ethanol. Total book value of assets at the beginning of the production period average $1.24 and range from $1.19 to $1.42. Government support payments off-set production expenses by $0.04 and consist of a variety of state and federal programs, including the “small producer credit” of $0.10 per gallon on the first 15 million gallons. Firms produce almost no blended ethanol and thus do not receive the “blender’s credit,” a $0.51 per gallon federal subsidy.

Before tax profit of $0.03 per gallon suggest that a 10% return is achievable, given commodity prices and government support levels in 2005. These cost estimates are close, but somewhat higher, than those reported in Gallagher (2006). New ethanol plants, however, and those expected to come on line in 2007, are reported to reflect significantly higher capital costs (P. Gallagher, personal communication December 14, 2006).

Observations	
Gallons of ethanol per bushel of corn	2.75
Corn cost per bushel	1.84
Natural gas cost per MMBTU	8.76
Total assets required	1.24
Assumptions	
Rate of return on capital	0.10

Appendix B: Data and computations for each biofuel

Table B1. Assessment of costs for corn-based ethanol in Oregon (feedstock from US midwest)

		Social cost	Credits & subsidies	Private cost (after credits, subsidies)
	Private and Social Cost Accounting			
1	Costs			
1	Cost of feedstock production ($/bushel)	2.63	0.28	2.35
2	Transportation and handling ($/bushel)	0.80		0.80
3	Processing and conversion ($/bushel)	3.58		3.58
4	Total ($/bushel)	7.01	0.28	6.73
5	Post production subsidies ($/gal.)	0.51	0.51	
6	Total ($ per gallon of fuel)	3.06	0.61	2.45
7				
8	Revenues			
9	Market price ($/gallon)			1.97
10	Coproducts value (per gallon)			0.37
11	Other government payments			0.10
12	Total			2.44
13				
14	Energy Accounting			
15	Energy use in:	(BTU/gallon)		
16	Feedstock production	22,844		
17	Transportation and handling	3,853		
18	Processing and conversion	46,421		
19	Distribution and marketing			
20	Total	73,118		
21	Energy contained in biofuel	91,742		
22	Net energy produced per gallon	18,624		
23	As share of energy in biofuel	20.3%		
24				
25	Greenhouse gas accounting			
26	GHG emissions in:	(gCO2eq./ million BTU)		
27	Feedstock production			
28	Transportation and handling			
29	Processing and conversion			
30	Distribution and marketing			
31	Total	89,563		
32	GHG emissions from equivalent gasoline	102,235		
33	Net GHG change with biofuel substitution	-12,671		
34	As share of fossil fuel alternative	-12.4%		
35				
36	Social cost of net energy ($/mm BTU)	$169.53		
37	Compared to cost of gasoline (market price)	$19.61		
38				
39	Social cost of reduced GHG emissions			
40	($ per ton of CO_2 equivalent)	$10,734		
41	Compared to Kyoto policy estimates:	$50		

Notes for Table B1. Assessment of corn-based ethanol in Oregon (feedstock from US midwest)

Line no.	Notes
1	Corn grain cost based on national average for 2003-2005. Subsidy based on estimated direct payments.
2	Rate for rail costs Minniapolis to Portland.
3	Based on financial results from four ethanol plants
5	Federal blenders credit of 51 cents for ethanol production
9	Average midwest ethanol price for past three years (1.90), cif Portland adds 7 cents.
10	Value of DDGS is 24 cents; private sector results include an average of 13 cents for other products and
11	Federal subsidy of 10 cents for small producers of ethanol
16-22	Source: Hill et al., 2006
31	Source: Hill et al., 2006
32	Energy contained in gasoline taken to be 120,000 BTU/gallon. Net energy for gasoline is 76.5%.
36	Lines 5 plus 11, divided by 22
37	Average price for past three years, $1.80/gallon for 91,800 BTU/gallon net energy.
40	Lines 36 minus 37, divided by (negative of) 33, and converted to new units.
41	See Lubowski, Plantinga and Stavins (2006)

Table B2. Biofuel Assessment for canola-based biodiesel

		Social cost	Credits & subsidies	Private cost (after credits, subsidies)
	Private and Social Cost Accounting			
	Costs			
1	Cost of feedstock production ($/cwt)	9.00		9.00
2	Transportation and handling ($/cwt)	0.37		0.37
3	Processing and conversion ($/cwt)	2.52		2.52
4	Total ($/cwt)	11.89	0.00	11.89
5	Post production subsidies ($/gal)	1.00	1.00	
6	Total ($ per gallon of fuel)	4.21	1.00	3.21
7				
8	Revenues		0.230769231	
9	Market price ($/gallon)			1.93
10	Coproducts value (per gallon)			1.45
11	Other government payments			0.10
12	Total			3.47
13				
14	Energy Accounting			
15	Energy use in:	(BTU/gallon)		
16	Feedstock production			
17	Transportation and handling			
18	Processing and conversion			
19	Distribution and marketing			
20	Total	55,626		
21	Energy contained in biofuel	178,604		
22	Net energy produced per gallon	122,978		
23	As share of energy in biofuel	68.9%		
24				
25	Greenhouse gas accounting			
26	GHG emissions in:	(gCO2eq./ million BTU)		
27	Feedstock production			
28	Transportation and handling			
29	Processing and conversion			
30	Distribution and marketing			
31	Total	51,698		
32	GHG emissions from equivalent diesel	86,852		
33	Net GHG change with biofuel substitution	-35,154		
34	As share of fossil fuel alternative	-40.5%		
35				
36	Social cost of net energy ($/mm BTU)	$35.05		
37	Compared to cost of diesel (market price)	$15.60		
38				
39	Social cost of reduced GHG emissions			
40	($ per ton of CO_2 equivalent)	$502		
41	Compared to Kyoto policy estimates:	$50		

Notes for Table B2. Assessment of canola biodiesel in Oregon

Line no.	Notes
1	Based on Oregon prices which have averaged $9 per hundred weight in recent years.
2	Based on estimate of $0.1 per gallon of canola oil
3	Based on Fortenbery (2004), plus $0.11 SG&A
5	Federal blenders credit of $1.00 for biodiesel
6	Conversion rate is 27 pounds of feedstock per gallon
9	Average Canadian (Vancouver) price for past three years, $1.93.
10	Based on canola meal price of $0.75/lb, less $0.15 transportation and a meal yield of 75%. Glycerin credit of $0.23 per gallon
11	Federal subsidy of 10 cents for small producers.
16-22	Based on Hill et al. (2006) and adjusted for differences between soybean and canola (see Appendix C)
31	Based on Hill et al. (2006) and adjusted for differences between soybean and canola (see Appendix C)
32	Energy contained in petroleum diesel is 132,000; net energy for gasoline is 85%.
36	Lines 5 plus 11, divided by 22
37	Average price for past three years, $1.75/gallon for 112,200 BTU/gallon net energy.
40	Lines 36 minus 37, divided by (negative of) 33, and converted to new units.
41	See Lubowski, Plantinga and Stavins (2006)

Table B3. Biofuel Assessment for cellulosic (wood based) ethanol

		Social cost	Credits & subsidies	Private cost (after credits, subsidies)
	Private and Social Cost Accounting			
	Costs			
1	Cost of feedstock production ($/ton)	52.00		52.00
2	Transportation and handling ($/ton)	25.50		25.50
3	Processing and conversion ($/ton)	98.70		98.70
4	Total ($/ ton)	176.20	0.00	176.20
5	Post production subsidies	0.51	0.51	
6	Total ($ per gallon of fuel)	3.03	0.51	2.52
7				
8	Revenues			
9	Market price ($/gallon)			1.90
10	Coproducts value (per gallon)			0.07
11	Other government payments			0.10
12	Total			2.00
13				
14	Energy Accounting			
15	Energy use in:	(BTU/gallon)		
16	Feedstock production			
17	Transportation and handling			
18	Processing and conversion			
19	Distribution and marketing			
20	Total	12,204		
21	Energy contained in biofuel	76,278		
22	Net energy produced per gallon	64,074		
23	As share of energy in biofuel	84.0%		
24				
25	Greenhouse gas accounting			
26	GHG emissions in:	grams CO2eq./ million BTU		
27	Feedstock production			
28	Transportation and handling			
29	Processing and conversion			
30	Distribution and marketing			
31	Total	3,846		
32	GHG emissions from equivalent gasoline	102,235		
33	Net GHG change with biofuel substitution	-98,389		
34	As share of fossil fuel alternative	-96.2%		
35				
36	Social cost of net energy ($/mm BTU)	$48.81		
37	Compared to cost of gasoline (market price)	$19.61		
38				
39	Social cost of reduced GHG emissions			
40	($ per ton of CO_2 equivalent)	$269		
41	Compared to Kyoto policy estimates:	$50		

Notes for Table B3. Assessment of cellulosic wood-based ethanol in Oregon

Line no.	Notes
1	Based on two studies, Aden et al.(2000) and Swan (1997), for ponderosa and juniper. Inflated to 2006 dollars.
2	Based on estimate of trucking costs for 50 mile radius.
3	Based on Wooley (1999), and adjusted for inflation to $1.30 per gallon, plus $0.11 administrative overhead (SG&A), or $98.70 per ton of feedstock
5	Federal blenders credit of $0.51 for biodiesel
6	Converted at an assumed yield of 70 gallons per ton.
9	Average midwest ethanol price for past three years (1.90), cif Portland adds 7 cents.
10	Based on Wooley (1999), for lignin coproduct.
11	Federal subsidy of 10 cents for small producers.
20	Based on Kemppainen and Shonnard (2005), 16% of energy in fuel used in production.
21	Source: Hill et al., 2006.
32	Energy contained in gasoline taken to be 120,000 BTU/gallon. Net energy for gasoline is 76.5%.
36	Lines 5 plus 11, divided by 22
37	Average price for past three years, $1.80/gallon for 91,800 BTU/gallon net energy.
40	Lines 36 minus 37, divided by (negative of) 33, and converted to new units.
41	See Lubowski, Plantinga and Stavins (2006)

Appendix C: Estimating canola energy inputs and outputs

Like soybeans, canola can be crushed into canola oil and canola meal. Depending on the canola variety, approximately 40% of the weight of canola is oil. Values can reach as high as 43%, but an oil content of 40% is more common and used in this study. This compares with 20% for soybean oil yield by weight. In units of liters of oil per kilogram of grain, the yields are 0.44 and 0.20 for canola and soybeans, respectively.

These two feedstocks also differ in terms of their yield per acre, and in production inputs. The greatest difference in producing canola compared to soybeans is that canola requires substantial amounts of nitrogen fertilizer. Estimates for Oregon are consistent with those for Washington and are about 100 lbs of nitrogen per acre, so we assume 100 lbs/acre (=112 kg/ha).

Our estimates of input energy to biodiesel production from canola are therefore based on Hill's et al. (2006) estimates for soybeans (tables 2 and 5 in Hill et al., 2006), adjusted for the additional nitrogen fertilizer required for canola production (total energy per hectare increases to 11570 MJ/ha for canola; nitrogen alone accounts for 5765 MJ/ha). This approach is warranted because with the exception of nitrogen and fossil fuel all other input variables are relatively small, and positive and negative deviations are likely to cancel out, leaving the overall error marginal. Fossil fuel input for canola is assumed to be the same as for soybean production.

OSU extension estimates Oregon canola yields at 2000 lbs/acre (=2242 kg/ha), which corresponds to 800 lbs of oil/acre or 1000 liter/hectare. Assuming that the conversion ratio of oil to biodiesel is the same for soybean oil and canola oil, the estimates of Hill et al. (2006) of 1.98 lbs of oil per liter biodiesel translate into 2.24 kg of canola per liter biodiesel.

Because nitrogen fertilizer is energy intensive in its production, the input energy required to produce one liter of biodiesel is greater for canola (=29.01MJ/liter) than for soybeans (=28.38 MJ/liter), despite canola's larger oil content (40% canola vs. 18% soybeans).

As use and processing of soybeans and canola are similar (crush into oil and meal component), the coproduct credit for canola is computed using the ratios employed in Hill et al. (2006) for soybeans, but adjusted for the lower meal content of canola.

Appendix D: Comparisons of Studies of Net Energy and Greenhouse Gases

From Farrell et al. (2006). Six studies and three cases of net energy and petroleum inputs for ethanol and for gasoline (B); net energy and greenhouse gas emissions for same (A).

Figure 1(B) from Farrell et al. (2006)

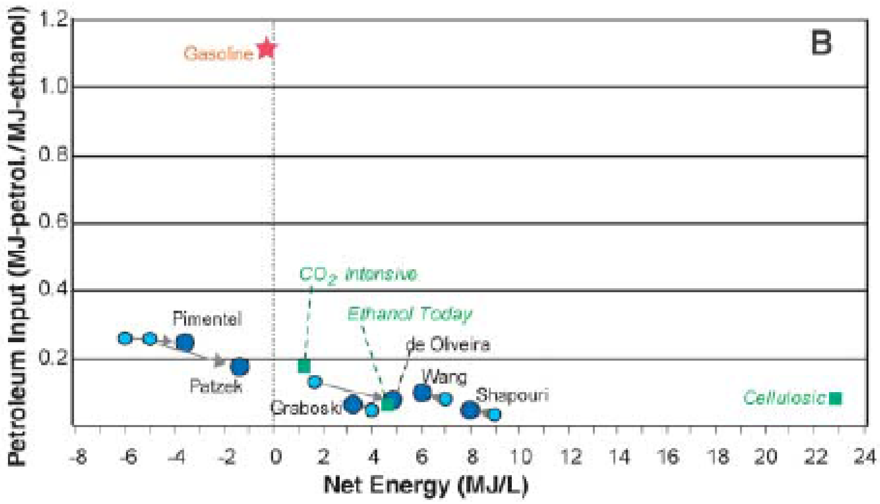
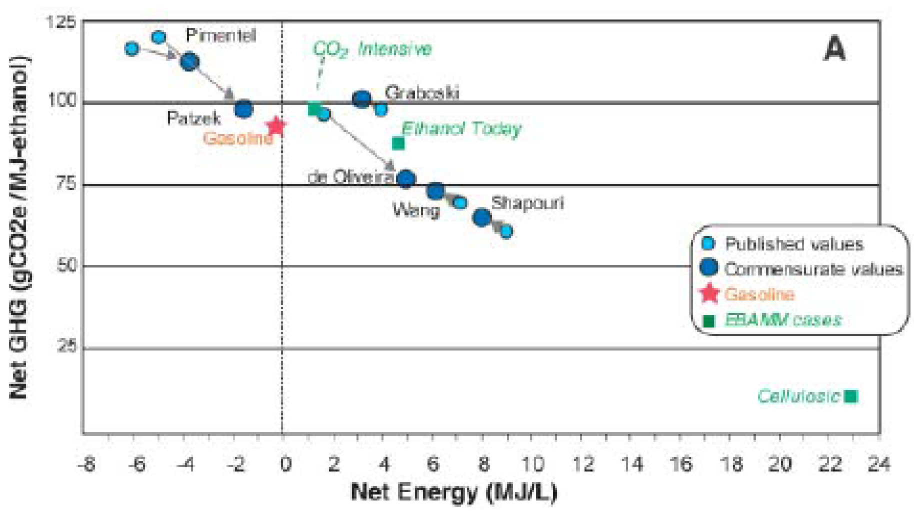


Figure 1 (A) from Farrell et al. (2006)



Appendix E. Sensitivity analysis

Table E1. Sensitivity analysis for changes in economic assumptions

Corn ethanol. Effect of:		Central case	High	Low
Ethanol price and revenue	($/gallon)	2.44	2.97	1.97
	% change from central case:		22%	-19%
Coproduct value on revenue	($/gallon)	2.44	2.81	2.07
	% change from central case:		15%	-15%
Corn price on net energy cost	($/million Btu)	196.53	261.76	163.33
	% change from central case:		33%	-17%
Canola biodiesel. Effect of:				
Canola oil price on revenue	($/gallon)	3.47	3.71	3.06
	% change from central case:		7%	-12%
Canola meal price on revenue	($/gallon)	3.65	4.41	3.23
	% change from central case:		21%	-12%
Canola price on cost of production	($/gallon)	3.13	3.69	2.58
	% change from central case:		18%	-18%
Canola price on net energy cost	($/million Btu)	35.14	37.51	32.78
	% change from central case:		7%	-7%
Wood-based cellulosic ethanol. Effect of:				
Ethanol price and revenue	($/gallon)	$2.00	$2.60	$1.60
	% change from central case:		30%	-20%
Feedstock cost on net energy cost	($/million Btu)	$48.81	$51.12	$46.50
	% change from central case:		5%	-5%
Feedstock cost on GHG reduction cost	($/ton CO_2)	$269.00	$291.00	$248.00
	% change from central case:		8%	-8%