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Biofuel Potential in Oregon: Background and Evaluation of Options

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Fuels old and new: A pump jack extracts oil from below this field of canola, a biofuel feedstock. Photo: Istockphoto.com.

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Summary

This study examines the economics of three biofuel options for Oregon: corn-based ethanol, canola-based biodiesel, and cellulosic wood-based ethanol. For each option, we address four questions:

1. Is the biofuel commercially viable?
2. Is it a cost-effective way to pursue our national goal of energy independence?
3. Is it a cost-effective way to pursue the goal of reducing greenhouse gas emissions?
4. On what scale might these biofuels be produced in Oregon?

The analysis finds two of the three biofuels evaluated to be commercially viable in Oregon given current prices, technologies, and subsidies. The study also shows, however, that the apparent commercial viability of a particular biofuel may not be a strong indicator of its cost-effectiveness or potential for achieving society's goals for energy independence or environmental quality. This is because there are significant differences in the amount of fossil-fuel energy required to produce a given biofuel, significant differences in the amount of energy available for combustion in a gallon of biofuel, and direct and indirect subsidies currently available to biofuel producers and blenders.

Commercial viability

Our evaluation of commercial-scale production of these fuels is based on assumptions that reflect current costs and technologies, existing market conditions, and current government incentives for the appropriate scales of operation in Oregon. We take account of likely limits on feedstock production, assuming that corn for corn ethanol would have to be imported from the Midwest, but that enough feedstock for canola biodiesel and wood-based ethanol would be available in Oregon or in Oregon and Washington. The analysis also recognizes the important role that byproducts or coproducts may play for each biofuel.

Our results indicate that corn ethanol and canola biodiesel appear to be commercially viable under current conditions. In both cases revenues cover, or nearly cover, the costs of production. Costs for wood-based cellulosic ethanol, however, appear to be at least 25 percent above revenues, suggesting that current conditions do not provide adequate incentives for commercial production.

Cost-effective means to energy independence

To address the energy independence question, we look at the energy (BTUs) contained in certain fossil fuels and biofuels compared to the fossil-fuel energy required to produce, process, and transport them. Replacing a BTU of gasoline or petroleum diesel with a BTU of biofuel will contribute to energy independence if fewer fossil-fuel inputs are required for the biofuel than for the petroleum-based fuels. For this to be the case, a biofuel's net energy balance ratio (NEB ratio) must be greater than that of gasoline or petroleum diesel.

The biofuels we consider all meet this requirement, but their NEB ratios vary considerably. The higher the NEB ratio, the lower the energy input per unit of energy available in the fuel. If a biofuel represents a small improvement in the NEB ratio, but a large increase in cost, then it is less likely to offer a cost-effective means of achieving energy independence goals. Indeed, for all three of the biofuels evaluated, energy independence is achieved at costs that are 6 to 28 times higher than for other policy options such as raising the gas tax or tightening corporate average fuel economy (CAFE) standards.

Cost-effective means to reduce greenhouse gas emissions

We find that promoting any of these biofuels as an alternative to gasoline or petroleum diesel would reduce greenhouse gas emissions, but at a cost.

We compare the cost of promoting biofuels to reduce emissions of greenhouse gases (GHGs) such as CO_2 with the cost of other types of climate-change policies, including a carbon tax, regulatory controls on CO_2 emissions, carbon sequestration actions of various types, and market-based approaches such as “cap-and-trade” programs.

Various economic studies have evaluated these policies and suggest they would reduce CO_2-equivalent emissions at a cost of zero to $50/ton of emission, depending on the scale of emission reduction. A comparison using the midpoint of the range, $25, shows corn ethanol reducing CO_2 emissions at a cost $170/ton of emission. However, emission-reduction costs for canola biodiesel and wood-based ethanol are in the range of estimates for other policy approaches: $31/ton for canola biodiesel and $27/ton for cellulosic wood-ethanol.

A shift toward biofuels will both reduce GHG emissions *and* increase energy independence. This “dual purpose” or joint-response potential is also true, however, for the main alternative policy options considered, such as a fossil fuel tax, carbon tax, or raising CAFE standards. Moreover, biofuels compare unfavorably because although two of the three biofuels evaluated here are reasonably cost-effective when considering GHG emission reductions alone, they are extremely high-cost ways of contributing to energy independence when compared to alternative approaches.

Scale of biofuel production in Oregon

The analysis finds that the potential scale of production in Oregon for each of these biofuels is quite limited by factors such as demand for coproducts and amount of land suitable for profitably growing the feedstock. Indeed, producing and using all three biofuels at our estimated maximum scales of production would represent a net contribution of less than two-thirds of 1 percent of Oregon’s current annual energy use, or less than the effect of a 1-mile-per-gallon increase in average fuel economy for motor vehicles.

I. Introduction

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

Oregon has established its own goals for renewable energy. They include using more ethanol and biodiesel in transportation and reducing greenhouse gas emissions by 1 million metric tons by 2025. Oregon's Renewable Energy Action Plan includes goals for 2 percent of diesel consumption from biodiesel and 15 million gallons of biodiesel produced from Oregon sources annually. 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 biofuel requirements are planned for state government fleets (Oregon Department of Energy 2006).

The reason for promoting a shift nationally and locally toward biofuels and other renewable energy sources, and away from exhaustible, fossil-fuel-based energy, is concern about: (a) energy independence, given our current reliance on uncertain future supplies of fossil fuels; and (b) environmental effects of fossil fuel energy sources, including air pollution and emissions of greenhouse gases (GHGs) linked to climate change.

In this context, a number of questions arise about the potential for increased biofuels production in Oregon. The main questions are:

1. Can biofuels be produced in Oregon at a cost 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, how does the fossil fuel energy required to produce a unit of biofuel energy compare to the total fossil fuel energy requirements needed to produce gasoline or petroleum diesel? How does the cost of reducing fossil fuel consumption by switching to biofuels compare to the cost of alternative ways of reducing fossil fuel consumption?
3. Do biofuels contribute to environmental protection? If so, how costly would it be to achieve environmental benefits in this way, compared to other means? In particular, how do biofuel emissions of GHGs compare to those of fossil fuels?
4. On what scale might these biofuels be produced in Oregon? How large or small a difference would they make in Oregon's energy use?

In addition to these central questions, a number of related issues deserve consideration. For example, how would increasing biofuel production directly and indirectly affect other agricultural markets, including those for coproducts and animal feed? Most biofuel production creates byproducts or coproducts that have value in other markets (e.g., animal feed, fuel for power generation), and this value needs to be counted in evaluating commercial viability and energy content of the biofuel.

This report analyzes and interprets currently available information. We draw on a range of national and regional studies and private-sector information. We also consider how sensitive our results are to variations in assumptions about prices, technology, and other factors. Our "central estimates," however, are based on the best available information for the scale and type of biofuel operations being evaluated.

There is a range of types of biofuels, feedstocks, and technologies for processing. Based on a preliminary evaluation of agronomic and economic realities in Oregon, we focus on three biofuels: corn-based ethanol; canola-based biodiesel; and lignocellulosic ethanol (which can be made from wood, straw, or other cellulosic materials).

Our analysis is quantitative and includes estimates of costs, revenues, conversion rates, etc. It is important to recognize, however, that some estimates are subject to considerable uncertainty because future prices, costs, availabilities, and technological progress cannot be known with certainty. In some cases we have only limited information on actual costs from operating commercial production facilities for processing biofuels.

This report is organized as follows. In Section II we evaluate the commercial viability of each of these three biofuels. Section III evaluates the cost of reducing fossil fuel use with biofuels. Section IV looks at the estimated reductions in GHG emissions for each fuel and the costs of those reductions. In Section V we consider how sensitive our results are to variations in assumptions about prices, technology, and other factors. Section VI looks at the potential scale of biofuel operations in Oregon, and Section VII concludes with a summary and observations.

II. Biofuel Production and Commercial Viability

This section summarizes our estimates for the cost, price, and technical parameters used to arrive at measures of the three biofuels' commercial viability.

In assessing commercial competitiveness, our analysis reflects existing government payments and subsidies that affect the costs and revenues faced by biofuel producers. Here we are interested in the private incentives necessary for biofuels to be voluntarily produced and purchased. We refer to this analysis of competitiveness as reflecting "private costs" and "private benefits" or revenues.

By contrast, when existing private incentives are not, by themselves, adequate for commercial biofuel development, there may be other public justifications for augmenting those incentives through regulations or subsidies. These kinds of public interventions nevertheless represent costs to society (e.g., to taxpayers), and so we want to recognize the costs as well as the benefits that accrue to society generally but that may not be borne by the biofuel producers or consumers. We refer to these as "social costs" and "social benefits." Social costs in this context would include both the private costs of production as well as any additional public costs (e.g., taxpayer-funded subsidies) offered to stimulate biofuel production.[1]

Many types of biofuel, biofuel technologies, and scales and configurations of production and use are *not* evaluated here. Several other biofuels were not evaluated because they appear to hold little promise for Oregon. For example, switchgrass *(Panicum virgatum),* a warm-season plant, doesn't grow well in Oregon; neither do soybeans. Alternatives such as on-farm biofuel production and use and local, small-scale oil pressing and distribution would require separate analyses. We also cannot know how future changes in prices or technologies might alter our results, but we point to some of these potential factors in the concluding section.

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

Corn-based ethanol

Corn-based ethanol production in the United States has grown rapidly over the past 15 years and is expected to exceed 5 billion gallons in 2006 (Eidman 2006). About 75 percent of this production is in "dry mills" producing ethanol, distiller's dried grains and solubles (DDGS), and carbon dioxide (CO_2). Seventy-five percent of current U.S. production is in Iowa, Illinois, Minnesota, Nebraska, and South Dakota.

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 (Gallagher 2006). There is also private-sector information from firms producing corn-based ethanol. Our analysis of corn ethanol is based on importing feedstock from the Midwest because Oregon doesn't grow enough for a single, commercial-scale (50 million gallons/year) ethanol plant. Indeed, all corn currently grown in Oregon is less than 25 percent of the feedstock needed for such a plant. We assume an ethanol plant would be near a rail terminal, to minimize costs of feedstock and coproduct transportation. Costs include feedstock based on average prices for the past 3 years ($2.35/bushel) and transportation from Minneapolis to Portland ($0.80/bushel).

Based on data from multiple sources, economic and technical factors were chosen for costs, revenues, and net energy gains, as well as for the effects of biofuels on GHG emissions.[2] These estimates should be interpreted as midpoint values in a range of estimated real-world outcomes based on recent data. We conduct sensitivity analyses to consider how our results would be affected by using different estimates.

We also acquired detailed financial data from a sample of firms. Processing and conversion costs ($1.26/gallon) are based on these private-sector results (see Appendix A, page 27) which include some overhead and capital costs (approximately $0.23/gallon) that are unlikely to have been fully reflected in the research studies' lower estimates.[3] It is noteworthy that this evidence from private-sector financial data for corn ethanol suggests that government and academic studies may tend to underestimate the actual costs of biofuel production.

A conversion rate of 2.75 gallons of ethanol per bushel of corn is based on average private-sector results. Blending subsidies of $0.51/gallon of ethanol are not included at the producer level because these generally are paid to blenders of gasoline–ethanol mixtures. These subsidies, however, are included in the social costs of current programs, as is the revenue from the sales of coproducts ($0.24 of DDGS per gallon of ethanol).

Our estimates of the private costs and revenues for an Oregon-based corn ethanol plant suggest that revenues would come very close to covering costs (Figure 1, page 10). Compared to the costs and revenues for production in the Midwest, our estimates include slightly higher costs and

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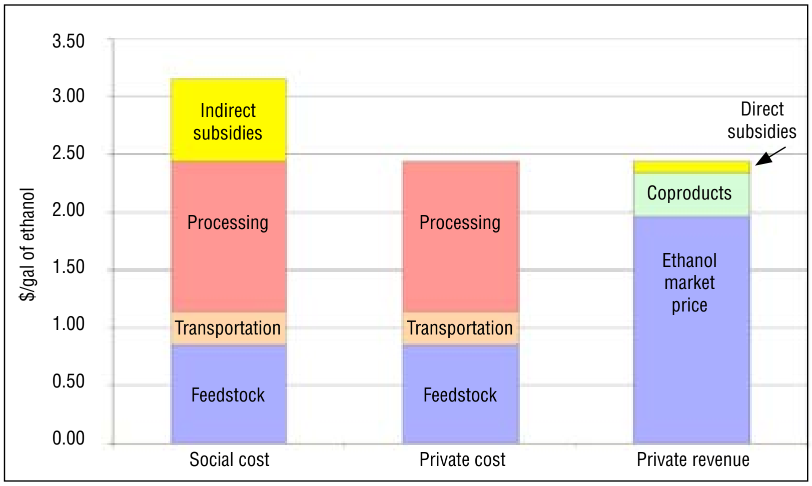
[2] CO_2 is the main greenhouse gas, although other gases such as methane also contribute to the atmospheric accumulations of gases that cause climate change. As is done elsewhere in the scientific and policy literature, we will base our analysis on a measure of "grams of CO_2-equivalent" gases, where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

[3] 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/gallon of ethanol. This cost figure includes overhead (SG&A) of $0.11/gallon and operating cost of capital of $0.12/gallon.

slightly lower revenues due to the added cost of transporting corn to Oregon from Minneapolis ($0.29/gallon) and a lower market price for ethanol from the major Midwest market if shipped to Oregon ($0.07/gallon). Our estimates suggest that corn ethanol plants in Oregon may be commercially viable for producers. There remains, however, the issue of consumer preferences and willingness to buy gasoline blended with ethanol. As evident in Figure 1, significant subsidies are offered at the postproduction stage to blenders for biofuel ethanol (see Appendix B, page 28, for details).

Figure 1.—Cost and revenue estimates for corn ethanol production in Oregon.*



*Feedstock delivered from the U.S. Midwest.

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. A variety of federal and state policies throughout the country, as well as a ban in many states on the gasoline additive MTBE, 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 at least 7.5 billion gallons of renewable fuel per year by 2012 (Eidman 2006). All these policies help ensure an active market for corn ethanol, and price adjustments can be expected to bring revenues into line 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 statewide markets. An important consideration for some biofuels is the potentially large increase in production of coproducts and their use and impact on markets. For example, one 50-million-gallon corn ethanol plant in Oregon would create an additional 165,000 tons of DDGS annually. Although DDGS has been widely used as feed for dairy, beef, pork, and poultry, it requires some time and experience before livestock producers embrace its use (Tiffany and Eidman 2003). An excess of DDGS could result in disposing of it as waste rather than selling it as animal feed.

Oregon already imports animal feed, including some DDGS. If production rose above in-state needs, exporting DDGS may be possible, given proximity to the Port of Portland. Indeed, about 700,000 metric tons of DDGS have been exported from the U.S. annually in recent years, mostly to Europe. Beginning in 2004, exports also have gone to Malaysia, Thailand, and Taiwan, raising hopes for international market development from the West Coast. The 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 competing sources.[4]

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[4] 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.

Canola-based biodiesel

In 2005, 1.5 percent of the U.S. soybean harvest was converted into 67 million gallons of biodiesel—less than 0.1 percent of U.S. annual diesel consumption (Hill et al. 2006). Fifty-three U.S. commercial biodiesel plants had a combined annual production capacity in early 2006 of 354 million gallons. Demand for biodiesel has remained relatively low, however, because until recently its cost was well above petroleum diesel's (Eidman 2006). Similar to ethanol, however, elements of recent federal legislation will continue to enhance demand. These incentives include a federal tax credit, the Renewable Fuels Standards, and new diesel fuel standards that require refiners to greatly reduce sulfur levels in diesel. Together, these could create new market demand for biodiesel as a lubricity additive (Eidman 2006).

From 2000 to 2004, soybean oil made up 57 percent of total U.S. feedstock for biodiesel, with yellow grease and "other grease" contributing 8 percent and animal sources 17 percent (Eidman 2006). Canola oil is used for a small portion of U.S. biodiesel production. Most data and studies of biodiesel focus almost exclusively on soybeans, with only rare mention of canola.

Estimates of the effect of significant increases in U.S. biodiesel production—from current levels of 91 million gallons to as much as 124 million gallons per year—suggest soybean prices would rise as a result. Eidman (2006), for example, suggests that implementing the Renewable Fuels Standards would raise soybean prices by 17 percent.

Although current canola production in Oregon would supply only about 10 percent of the needs of a 2-million-gallon-per-year biodiesel plant, there appears to be potential for increasing canola acreage in the dryland areas of the Columbia Basin if planting issues, such as dry soils in autumn, can be overcome, and if pricing is favorable. We assume that the processing location would be central to canola-growing areas and that the oilseed could be transported to processing at relatively low cost. Smaller commercial processing plants (e.g., 0.5 million gallons) are possible, but average costs per gallon are likely to be higher for smaller operations. Most available analyses assume a plant size of 2 million gallons or greater.

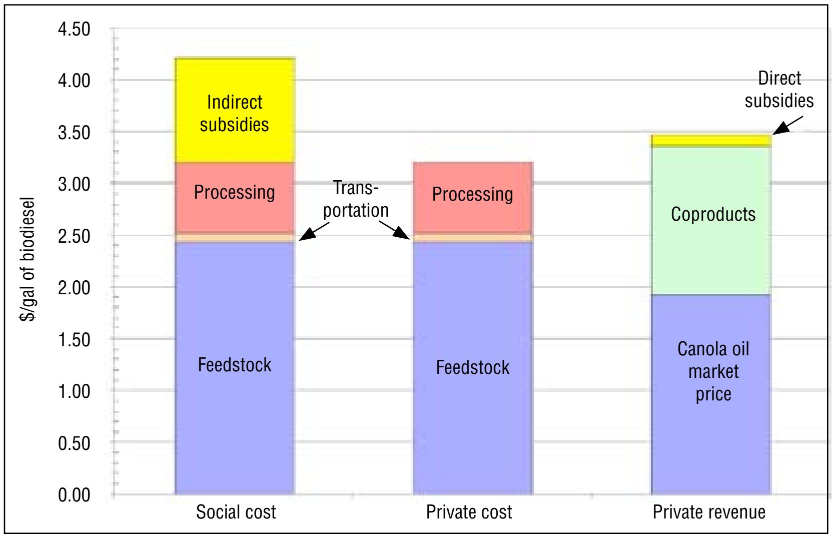
Increasing canola production in Oregon from current levels of about 3,000 acres to 30,000 acres would be challenging due primarily to the low return per acre compared to alternative crops such as winter wheat in dryland areas and many crops in irrigated areas. It is therefore unclear that current prices would motivate farmers to increase canola acreage adequately. There also is an agronomic obstacle for establishing dryland canola crops: limited available soil moisture in the fall.

A small number of biodiesel analyses address the economics, energy requirements and generation, and environmental effects (including changes in CO_2 emissions). Although 53 commercial biodiesel plants in the United States produced an estimated 91 million gallons in 2005, all are soybean-based, and no detailed financial results are available. Therefore, we rely on estimates from government and academic researchers. Some differences between canola and soybeans are taken into account here and, in more detail, in Appendix C (page 31). In particular, canola yields per acre are higher than soybean yields, and canola's oil yield is about double. Canola, however, has the disadvantage of requiring nitrogen fertilizer, unlike nitrogen-fixing soybeans.

We assess the cost of canola feedstock production and the technical conversion rates (Figure 2, page 12). 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/gallon. Processing costs are estimated to be $0.68/gallon. All conversion rates are based on studies for commercial-scale biodiesel plants processing at least 2 million gallons/year and using canola, rapeseed, and soybean feedstocks.[5] Federal and state subsidies amount to $1.10/gallon of biodiesel.

Coproducts are important components of the economics of biodiesel. For each gallon of canola oil, 17.5 pounds of canola meal are produced which, depending on market prices, may be worth nearly as much as the oil. Glycerin, another coproduct, adds an estimated $0.23/gallon of canola oil. As in the case of corn ethanol, a significant increase in these coproducts could depress their market prices. If the regional market became flooded, disposing of canola meal as waste would alter the economics of canola production significantly and make the accounting of energy inputs for canola biodiesel less attractive (see energy discussion below).

Figure 2.—Cost and revenue estimates for canola-based biodiesel production in Oregon.



Costs to produce canola vary greatly in Oregon due to differences in climate, soil, and irrigation. Average yields in the state are around 2,000 pounds/acre but can reach 4,000 pounds/acre under irrigation in some areas. As a result, individual farmers' judgments will vary considerably on whether canola-based biodiesel is economically attractive for local or on-farm use.

Given these parameters, our estimates of costs and revenues suggest that canola oil production may be commercially successful given current market conditions and government subsidies. Government support includes an indirect blender's credit of $1/gallon. This credit is not included in the revenues to producers because it generally is paid to separate firms that buy soybean or canola oil, blend it for biodiesel, and then retail the blend. Although our findings suggest canola biodiesel may be economically viable for growers, the blender's credits may be necessary to motivate blenders to buy canola oil and produce biodiesel.

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

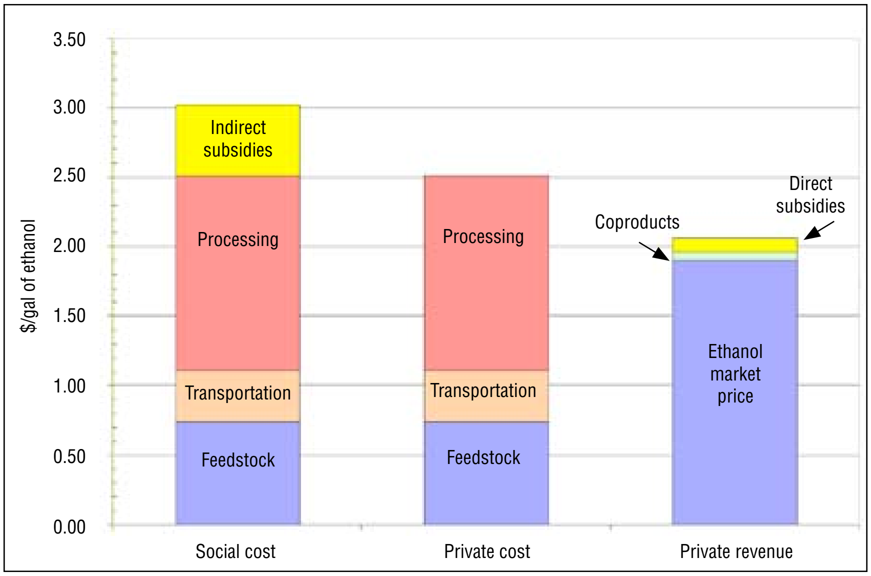
Cellulosic wood-based ethanol

For cellulosic wood-based ethanol, we assume that woody biomass is available from sources such as forest thinning (related to fire suppression), clearing invasive juniper, or waste from wood-processing operations. We don't assume specific locations for either the wood fiber feedstock or the processing facilities. The few studies available that evaluate cellulosic ethanol use a range of feedstocks including switchgrass *(Panicum virgatum)*, 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 United States or Canada (Gallagher 2006). This further limits the confidence one can have in the accuracy of the few research studies that evaluated these processes.

Feedstock production costs for forest thinning may be lower than for plantation-grown trees, but cutting and collecting woody biomass can be costly. Based on two studies of collection costs, for ponderosa pine (Aden, Wooley, and Yancey 2000) and juniper (Swan 1997), we estimate the average collection cost at $52/ton, mainly for labor. Handling and transport to a processing location also may be expensive; we estimate an average of $26/ton. Processing is estimated at $99/ton or $1.42/gallon of ethanol. Current subsidies, for the federal blender's credit and the small-producer credit, amount to $0.61/gallon. Coproducts (lignin) can generate offsetting revenue if they are sold or if they generate electricity that is then sold. Alternatively, the coproduct can represent savings if used to generate heat and power on site. We do not include cost of fertilizer for feedstock production, but this would be an added cost for plantation-grown trees.

Based on the estimates available, Figure 3 suggests that wood-based ethanol falls short of being commercially viable even with existing subsidies. For the case described in Figure 3, revenues fall about 20 percent short of costs. As expected, given the more complex processing required for cellulosic feedstocks, processing woody feedstock into ethanol costs more than processing for corn ethanol or canola biodiesel. These costs can be expected to vary considerably due to differences in the cost of feedstock collection and transportation.[6] If feedstocks are commercially grown trees, different costs must be taken into account (higher for fertilizer, lower for transportation).

Figure 3.—Cost and revenue estimates for cellulosic (wood) ethanol production in Oregon.



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

In addition, unlike corn and canola, no administrative or overhead costs were available, and so none are included.

As noted previously, these estimates are inexact and will vary by location and market conditions. Technical and cost parameters for cellulosic ethanol are not based on private-sector data or actual commercial enterprises and therefore are less reliable than those for corn ethanol and canola biodiesel, where commercial production can be observed directly. In addition, private-sector financial data for corn ethanol lead us to believe that the existing estimates for wood ethanol underestimate the actual costs of production. In the case of corn ethanol, estimates based on private-sector financial results were one-third higher than cost estimates from academic studies.

III. The Cost of Reducing Fossil Fuel Use with Biofuels

Producing biofuel takes energy. Currently, this energy comes primarily from fossil fuels. A switch to biofuels will reduce fossil fuel use to the extent that the fossil fuel requirements for biofuel are lower than for gasoline or petroleum diesel. We therefore compare the total fossil fuel requirements of biofuels and fossil fuels.

We also compare the costs of biofuels and fossil fuels, and we evaluate a switch from gasoline or petroleum diesel to a biofuel in terms of cost per unit of reduction in total fossil fuel use (e.g., reduced BTUs of fossil fuel inputs). This latter assessment is crucial for evaluating the cost-effectiveness of promoting biofuels compared to alternative ways to promote energy independence, and as a benchmark for assessing society's willingness to pay costs of this magnitude to promote energy independence.

Fossil fuel energy input requirements

Much analysis and public debate surrounding ethanol and other biofuels have focused on whether biofuels' "net energy" is positive or negative. Net energy, a standard measure in traditional engineering studies, typically refers to the difference between the total energy available in a fuel and the total energy used to produce it.

For corn ethanol, there has been a lively debate in the literature about whether the net energy balance is negative or positive. The claim that it is negative comes primarily from two studies, one by Patzek (2004) and the other by Pimentel and Patzek (2005). However, several careful reviews of these and other studies discredit the negative net energy claim conclusively on the grounds that the analyses suffer from errors of omission and other shortcomings (Farrell et al. 2006). Graphical comparisons of a range of estimates summarized in Farrell et al. are in Appendix D, page 32.

Net energy, however, is not the most appropriate measure to use for evaluating energy independence. In fact, a biofuel need not have a positive "net energy balance" in order to contribute to a reduction in overall fossil fuel use. Indeed, a biofuel need only require less fossil fuel input per unit of energy (BTU) in the fuel than the input required for an equivalent amount of the fossil fuel that the biofuel is replacing. Since petroleum fuels require more fossil fuel energy inputs than the energy contained in the final fuel product, a biofuel that generates zero net energy still would be an improvement if substituted for a petroleum fuel.

For this reason, our analysis focuses directly on comparing the energy input requirement per unit of energy in the fuel product. The lower the energy input for a biofuel, the greater the gain to be had from substituting biofuel for petroleum fuel. This comparison is reflected in the "net energy balance ratio" (NEB ratio)—a variant of the "net energy balance" measure—calculated as (energy output/energy input).[7] The higher the NEB ratio, the lower the energy input per unit of energy available in the fuel. For example, a gallon of corn-based ethanol contains 76,300 BTUs of energy, and 60,793 BTUs are used in its production.[8] Thus, corn ethanol's NEB ratio is 1.25 (=76,300/60,793). This compares to gasoline's NEB ratio of 0.80 and 0.87 for petroleum diesel. The comparable ratios for canola biodiesel and cellulosic wood-based ethanol are 1.67 and 6.25, respectively.

By combining NEB ratios with estimates of cost differences, we can evaluate how cost-effectively each biofuel would reduce fossil fuel use, compared to the cost of promoting energy independence in other ways, such as regulations, conservation, fossil fuel taxes, or research and development (R&D).

A central observation from our analysis is that a reduction in input energy per unit of output energy (compared to petroleum fuels) is necessary, but not sufficient, for the biofuel to be a desirable way to promote energy independence. If the reduction in energy inputs is small and the cost of that contribution is high, a given biofuel may be an extremely costly way to reduce our reliance on fossil fuels.

The resulting cost measures per unit of fossil fuel input may differ considerably for biofuels compared to gasoline or petroleum-based diesel. One reason is that the energy content varies by fuel, as do the energy input requirements. For example, the energy input for gasoline is 24 percent higher than the energy in the fuel. For petroleum diesel, the energy input is 15 percent higher than the energy in the fuel. In contrast, corn ethanol energy input is 20 percent *lower* than energy output. Energy input is 40 percent smaller for canola biodiesel, and 84 percent smaller for wood-based cellulosic ethanol (Table 1, page 16).

For the three biofuels, we compare the social costs associated with the reduced fossil fuel use that would result from their substitution for petroleum fuels. Social costs include all costs to produce, transport, and process the feedstock as well as current subsidy incentives for feedstock producers (farm support programs), for biofuel producers (direct subsidies), and for blenders, distributors, and consumers (indirect subsidies).

The cost per unit of fossil fuel input for corn ethanol is found to be four times that of gasoline.[9] This is due to corn ethanol's lower energy content, higher input energy use (compared to other biofuels), and higher cost of production. The cost of reducing fossil fuel use by switching to corn ethanol from gasoline is $49.27 per million BTUs of input energy.

The energy content of canola biodiesel (118,000 BTUs/gallon) is more than 64 percent greater than that of corn ethanol. At the same time, the input energy required for canola is only 15 percent

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[7] See, for example, Hill et al. (2006).

[8] The energy in the feedstock coproducts is not included in our estimates of output energy. Correspondingly, a share of the energy input is also attributed to coproduct production in proportion to its energy content. This is also the approach taken by Hill et al. (2006). See Table 1, page 16, for energy inputs and outputs for each fuel.

[9] Gasoline and petroleum diesel prices are based on average pretax prices for the past 3 years.

greater than for producing corn ethanol. As a result, we find the cost of reducing fossil fuel use by switching to canola biodiesel from gasoline is $19.69 per million BTUs of input energy.

The energy input for wood-based cellulosic ethanol (12,200 BTUs/gallon) is much lower than for either corn ethanol or canola biodiesel. This is largely due to the assumption that the feedstock is not cultivated and fertilized but grows untended in forests. The output energy is the same as corn ethanol's: 76,300 BTUs/gallon. This energy advantage for wood-based ethanol is partly offset by the higher costs associated with collecting and converting woody feedstock into ethanol; the cost of switching to wood-based ethanol is $24.26 per million BTUs of input energy.

Table 1.—Cost of reducing fossil fuel use and GHG emissions.

	Regulations & incentives*	Corn ethanol	Wood-based ethanol	Canola biodiesel	Gasoline
Energy in fuel (BTU/gal)		76,300	76,300	118,000	120,000
Fossil fuel energy inputs (BTU/gal)		60,800	12,200	70,300	148,000
Fossil fuel energy input per energy units in fuel		0.80	0.16	0.60	1.24
Cost (including subsidies) per BTU of energy in fuel ($/million BTU)		36.60	41.10	24.20	15.00
Cost of reducing fossil fuel use with:					
Promotion of biofuels ($/MM BTU)		49.27	24.26	19.69	
Increase in the gas tax ($/MM BTU)	1.75				
Raising fuel economy standards ($/MM BTU)	3.22				
Ratio of costs: biofuel promotion to gas tax		28.1	13.8	11.2	
Ratio of costs: biofuels promotion to fuel economy (CAFE) standards		15.3	7.5	6.1	
GHG emissions reduction relative to equivalent BTUs of petroleum fuel (%)		0.12	0.96	0.40	
Cost of reducing GHG emissions ($/ton CO_2)	0–50	170	31	27	
Oregon's potential biofuel capacity due to limited land, coproduct markets (MM gal/year)		50	50	10	
Share of Oregon energy use implied by capacity limitations indicated above (%)		0.16	0.41	0.07	
Potential reductions in Oregon GHG emissions implied by capacity limits (%)		0.07	0.60	0.06	

* Sources: Gas tax and CAFE standards (West and Williams, 2005; NRC, 2002); GHG reduction cost estimates (Lubowski, Plantinga, Stavins 2006); for Oregon energy use, Energy Information Administration (2000).

Interpreting the cost of promoting biofuels to reduce fossil fuel use

Petroleum fuels and biofuels are alternative ways to deliver energy to end users, in particular as liquid fuels for transportation. Other things being equal, the lowest-cost option among alternatives would be preferable. In the current context, however, society recognizes the undesirable side effects of petroleum fuels, including continued dependence on finite supplies of fossil fuels and especially on foreign sources of petroleum. Other side effects, such as greenhouse gas emissions, also are important and are considered separately below.

It would be very difficult to estimate precisely the value to society of reducing fossil fuel use (or conversely, the extra cost associated with continued reliance on fossil fuel energy). For current purposes, we approach the issue indirectly by recognizing that reducing fossil fuel use is a national goal, and by estimating the cost of achieving that goal through switching from petroleum-based fuels to biofuels. Even if we cannot evaluate biofuel costs directly against the benefits of energy independence or slowing climate change, we can compare their costs to the costs of alternative approaches to reducing our reliance on fossil fuels and reducing GHG emissions. For example, we can ask how biofuels' costs compare to the cost of tightening automobile fuel economy standards or raising the gasoline tax. Such comparisons will provide a measure of the cost effectiveness or efficiency of using biofuels to reduce fossil fuel use.

The rationale for policies such as regulations, taxes, or subsidies derives from economic principles about publicly justified interventions in the marketplace. When markets fail to take account of some public goal or negative externality (e.g., the benefit of energy independence, the damage from pollution), the most general and efficient approach is 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.[10] (In addition, revenues from that tax could be used to finance reductions in other, preexisting taxes or to fund other efforts to clean the environment, or promote energy independence such as with R&D). For example, if emissions of the pollutant sulfur dioxide (SO_2) are estimated to cause $25 of damage per ton of emission, then a corrective measure that is justified on economic grounds alone would be a $25/ton tax on SO_2 emissions; such a tax would be expected to reduce pollution to the point that balances the benefits and costs.

Quantitative measures of energy in fuel, production cost, and fossil fuel energy inputs can be combined to provide an interpretable measure of both energy accounting and economic accounting. These two considerations, however, do not include other aspects such as the environmental effects of different energy sources. One of the effects, climate change, 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. Biofuel production could make greater use of immobile energy sources to generate a mobile type of fuel to power motor vehicles. To the extent that our calculations overlook such mobility and convenience factors, they may undervalue biofuels' contribution. On the other hand, if calculations are too optimistic about the market's ability

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[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/gallon. Total subsidies for oil in the U.S. were estimated in fiscal year 1999 to be $567 million. At the same time, the federal gasoline tax of $0.184/gallon amounts to more than $20 billion, far offsetting all federal subsidies (Energy Information Administration 2000).

to absorb additional quantities of animal-feed coproducts, these biofuels' cost and energy contributions may be overly optimistic.

Government actions to decrease use of fossil fuels could include regulations, taxes on fossil fuels, or subsidies for energy conservation. "Command and control" regulations may be costly if they are too rigid or involve cumbersome and inefficient requirements. A market-based approach such as a tax on fossil fuel is likely to be a more efficient (less costly) way to reduce fossil fuel use. Such a tax would provide an incentive to individuals, firms, farmers, and investors to find alternatives to fossil fuels. In a competitive market, introducing a small fossil fuel tax will discourage fossil fuel consumption at a cost that is a fraction of the price consumers pay for fossil fuel (the current market price). Moreover, if revenues from a fossil fuel tax are used to finance reductions in distortionary taxes such as income taxes, there will be a secondary benefit or "double dividend" (Jaeger 2002, 2004). This positive secondary effect would offset a portion of the distorting cost of the fossil fuel tax.

The policy measures evaluated here substitute biofuels for petroleum fuels. For the three types of biofuel evaluated, we indicate their cost per unit of reduced fossil fuel use. In Table 1 (page 16), we summarize these estimates along with estimates of the costs for two alternative policies that could achieve the same goal: raising federal corporate average fuel economy (CAFE) standards, and increasing the gasoline tax. Cost estimates for these two alternatives come from recent studies that suggest promoting these biofuels is many times more costly than either raising fuel economy standards or increasing the gasoline tax (West and Williams 2005; National Research Council 2002). In comparison to these estimates, substituting biofuels for petroleum-based fuels is estimated here to be 6 to 28 times more costly per million BTUs of reduced fossil fuel use.

IV. Reductions in Greenhouse Gas Emissions and Their Cost

Environmental quality is the second motive we consider for promoting biofuels. Fossil fuel extraction, transport, refining, and consumption can negatively affect the environment. A leading concern is the accumulation of greenhouse gases (GHGs) in the atmosphere due, in large part, to emissions of carbon dioxide (CO_2) and other GHGs during fossil fuel combustion.

To the extent that corn ethanol, for example, produces lower GHG emissions per unit of energy in the biofuel, substituting corn ethanol for gasoline would benefit the environment. Biofuels, however, also can have negative environmental effects due to current production technologies. In corn, soybeans, or canola, these are due to the use of farm chemicals including pesticides and nitrogen and phosphorus fertilizers (Hill et al. 2006). Hill et al. consider three environmental effects: fertilizers, pesticides, and GHG emissions. They find that due to fertilizer and pesticide use, corn ethanol is much more polluting than soybean biodiesel (p. 11208).

Producing agricultural feedstocks for biofuels on a large scale also would have consequences for land use and, in irrigated production, water resources. However, our analysis considers only GHG emissions and the cost of reducing them.

Until recently, it was common to refer to some biofuels as "zero net GHG emissions" sources of energy because the carbon in the feedstock, having been drawn out of the atmosphere as the plant grew, represented the maximum amount of CO_2 that could be released. This would be true, however, only if no fossil fuel were used to produce, transport, or process the biofuel. In the case of corn ethanol, a relatively high level of fossil fuel is used in production; as a result, substituting corn ethanol for gasoline gives a relatively small reduction in GHG emissions. Indeed, for the same energy in fuel, corn ethanol gives only a 12-percent reduction in GHG emissions over gasoline. The combination of the relatively high cost of producing corn ethanol energy and the small net reduction in GHG emissions implies a cost of $170/ton of emissions to reduce GHG emissions, or nearly seven times higher than the midrange estimates of about $25/ton of emissions for other options to reduce GHG emissions (Table 1, page 16).[11]

By contrast, substituting canola biodiesel for petroleum diesel is estimated to reduce GHG emissions by 40 percent per million BTUs. Given the relative cost of canola biodiesel compared to petroleum diesel, the cost of reducing GHG emissions with canola biodiesel is estimated at only $31/ton (Table 1), which is very close to the midrange estimate for other policies intended to reduce GHG emissions.

Finally, wood-based ethanol has a very low level of GHG emissions, for two reasons: its low use of fossil fuel energy in production and processing; and the fact that, as with other biofuels, releases of CO_2 during processing and burning are mitigated by the feedstock's CO_2 absorptions from the atmosphere as the plants grow. As a result, substituting wood ethanol for gasoline reduces GHG emissions by 96 percent. This advantage is offset to some degree by the higher cost of wood ethanol. Nevertheless, the cost of using wood ethanol to reduce CO_2-equivalent emissions (as defined in footnote 2, page 9) is estimated to be $27/ton of emissions (Table 1).[12]

V. Sensitivity Analysis

This section considers how sensitive our results are to some underlying assumptions. In particular, we ask whether changes in expectations about future market prices for feedstocks, ethanol, canola oil, or coproducts would 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-percent increase or decrease in coproduct price would have a negligible effect on revenue per gallon for cellulosic wood-based ethanol (Figure 3, page 13), a small but significant effect for corn ethanol (Figure 1, page 10), and a large effect for canola biodiesel (Figure 2, page 12).

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, would likely be more consequential for bioethanol fuels than for canola biodiesel. By contrast, in the case of canola biodiesel the cost of the feedstock is greater than the cost of processing the feedstock into biofuel.

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[11] Cost estimates for regulatory policies, market-based incentives, and carbon sequestration range from zero to $50/ton for emissions reductions of up to 250 million tons/year; for more aggressive climate change policies intended to reduce emissions by 500 million tons/year, cost estimates rise to $100/ton (Lubowski, Plantinga, and Stavins 2006).

[12] None of these estimates, however, takes account of how displacing the production of food and other agricultural products by biofuels will affect other GHG emissions. For example, if some food crops are displaced to more marginal lands, increased nitrogen fertilizer use could increase GHG emissions for these food crops. If the location of food production were to shift internationally to places such as Brazil, increased deforestation could result, further exacerbating GHG emissions. By contrast, other kinds of displacement and substitutions could reduce GHG emissions.

Most of our price assumptions and sensitivity analyses are built around market price information for the past 3 years. Our base-case prices use national or regional market price information for ethanol, canola oil, DDGS, and canola meal. Revenue changes associated with variations in prices use a high and low price based on the extremes of the 2004–2006 period. The effects of these prices on revenue per gallon are reported in Appendix E (page 33) in both dollar terms and as percent changes from the baseline case. For example, given the somewhat larger fluctuations in ethanol prices, our sensitivity analysis indicates a revenue range of -19 to +22 percent for corn ethanol and -20 to +30 percent for cellulosic wood-based ethanol. Despite feedstock's large share in the total cost of biodiesel, overall production cost varies only 18 percent when Oregon canola prices are assumed to vary between \$0.07 and \$0.11/pound. Recent fluctuations in DDGS prices are shown to influence corn ethanol revenues per gallon by ± 15 percent; the range is -12 to +21 percent in the case of canola meal.

Although some very useful inferences from these results are possible, it is prudent to recognize that self-correcting mechanisms are at work in the marketplace. Incentives and regulations that may create 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, cost of reducing fossil fuel use, or GHG emissions is highly uncertain. The amount of energy used in biofuel production is one important factor affecting the extent to which biofuels contribute to the goals of energy independence and reductions in GHG emissions. Hypothetically, if a 10-percent reduction in biofuel production energy requirements were possible—due, for example, to either technological progress or substituting renewable energy for fossil fuel energy—the biofuels' contributions to energy independence would rise, and the cost of reducing both fossil fuel use and GHG emissions would decline. For corn ethanol, the cost per million BTUs would decrease by 15 percent; for canola biodiesel, by 10 percent; and for cellulosic, wood-based ethanol, by 2 percent.

VI. Potential Scale of Biofuel Operations in Oregon

The potential impact of these three biofuel options on energy independence and GHG emissions in Oregon would be quite small, given the scales of operation that appear feasible. For both corn ethanol and canola biodiesel, limits on local production and on markets for coproducts (animal feed) constrain the potential scale of production.

A 50-million-gallon corn ethanol plant would require 19 million bushels of corn annually from 100,000 acres of land (currently, Oregon grows corn on about 30,000 acres). Nineteen million bushels of corn would generate 333 million pounds of DDGS. At the nutritional maximum of 10 pounds/day/cow, this would feed 90,000 cows, approximately the number of confined cows currently fed in Oregon.*

Production of 10 million gallons of canola biodiesel per year would require 270 million pounds of canola feedstock, requiring about 135,000 acres (compared to Oregon's 2006 production on 4,000 acres). A 10-million-gallon operation would generate 176 million pounds of meal, which if fed at 5 pounds/day/cow would supply 96,000 cows, somewhat more than Oregon's current estimated herd size.

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*Russ Karow, personal communication, Feb. 21, 2007.

It is possible to feed these coproducts to other livestock and poultry. However, transportation costs and other factors may limit the potential for expanding this market. Expanding production beyond a scale for which coproducts could be sold locally would necessitate changes in the cost and energy assumptions used in this study.

The amount of woody feedstock material that could be withdrawn from Oregon forests over the next 20 years has been estimated recently (Bowyer 2006). Based on estimates of forest biomass volume and distribution and options for extracting biomass from forests, the study concludes that 1 million bone-dry tons (BDTs) of forest biomass could be available each year for 20 years. The central case scenario, however, is for eight dispersed delivery locations (potentially, electricity generating plants), and costs for collection and delivery up to $120/BDT. At delivered costs similar to those assumed in the current study, Bowyer estimates an annual volume of 1 million BDTs would be available. This, however, implies a dispersed set of eight plants each processing just over 125,000 BDTs per year. For ethanol production this would mean a plant size of less than 9 million gallons/year. Most cost estimates for cellulosic ethanol are based on plants significantly larger than this, and it is likely that costs would rise for a set of small, isolated plants in dispersed locations near forest biomass. The Bowyer study also evaluates a scenario with half as many processing facilities, and concludes that the volume of biomass available at less than $80/BDT decreases by more than half.

Taking these considerations into account, the maximum amount of added energy that could be generated (net of energy used in production) for these biofuels is estimated to be 0.16 percent for corn ethanol, 0.41 percent for cellulosic wood-based ethanol, and 0.07 percent for canola biodiesel (Table 1, page 16). Even with all three biofuels produced in Oregon at the maximum levels indicated, the total energy contribution would be only about two-thirds of 1 percent of Oregon's annual energy use.

These options' contributions to reducing GHG emissions would be similarly marginal. As indicated in Table 1, canola biodiesel and corn ethanol could reduce Oregon's GHG emissions by 0.06 percent and 0.07 percent, respectively. Cellulosic wood ethanol has the potential to reduce Oregon emissions by 0.6 percent. Over the 20-year period of the identified biomass availability in Oregon's forests, the cumulative contribution of this level of production would be 1.2 percent of 1 year's GHG emissions.

VII. Concluding Comments

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 GHG emissions—our evaluation suggests a note of caution.

We find that promoting any of these three biofuels could reduce our use of fossil fuel inputs, but at a cost much higher than the estimated cost for more direct approaches, such as a gasoline tax or raising fuel economy standards. Compared to a gasoline tax, all three options are estimated to be more than 10 times more costly for a given reduction in fossil fuel use. Compared to raising fuel economy standards, biofuels are estimated to be 6 to 15 times as costly.

Regarding GHG emissions, the current analysis indicates that two of the three biofuels could reduce GHG emissions at a cost similar to estimates for other approaches evaluated by analysts and policymakers. Most studies of the economics of reducing GHG emissions estimate the cost to be between zero and $50/ton of CO_2-equivalent emissions. Our estimates for both canola biodiesel and cellulosic wood-based ethanol fall in the middle of that range: $27 and $31/ton, respectively.

How is it that two of these biofuel options appear to be cost-effective ways to reduce GHGs but not to promote energy independence? This seems counterintuitive, since a tax on fossil fuel use is considered the most efficient way to reduce GHG emissions. While it is true that biofuel production and use is a high-cost way to reduce fossil fuel use, the production of feedstocks for biofuels absorbs additional CO_2 from the atmosphere, thereby having a significantly larger net effect on GHG emission reductions than what is reflected in their reduced fossil fuel inputs.

These observations about the cost of achieving energy independence 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 cases. This result is caused by the significant direct and indirect government subsidies as well as regulations that have contributed to the demand for biofuels (and hence, market prices that are 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.

The main results of our analysis do not depend on the regional focus of our analysis. Only small differences in cost and cost-effectiveness exist between Oregon-based corn ethanol or canola biodiesel and Midwest corn ethanol and soybean-based biodiesel. Indeed, the scale constraints also appear to be quite limiting when the input energy of biofuels is netted out of their overall contribution at the national level: if the entire U.S. corn crop were used to produce ethanol, it would make a net contribution equal to only about 1.4 percent of the petroleum-based energy consumed annually in the United States.[13]

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. Some changes could make biofuel production in Oregon more attractive and competitive; other changes could shift the balance in the opposite direction.

Future changes could advance *and* hinder biofuels. For example, higher corn or canola prices may offer the kinds of incentives necessary for Oregon to achieve production levels needed for commercial-scale plants, but higher feedstock prices also will raise the cost of biofuel production. This latter change would adversely affect the cost and competitiveness of the biofuels. Improvements in crop yield via biotechnology and increased fertilizer use could increase

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[13] Twelve billion bushels of corn could produce 16.2 billion gallons of ethanol. The net energy contribution of this ethanol would be about 542 trillion BTUs, or about 1.4 percent of U.S. petroleum energy consumption.

production and possibly lower feedstock costs; however, increased fertilizer use would reduce the net energy contribution of the biofuels, as it raises the fossil fuel input use for these alternative technologies. Finally, higher petroleum prices would make biofuels more competitive compared to gasoline and petroleum diesel, but this also would make it more costly to export coproducts to international markets.

One possibly problematic aspect of increased biofuel production in Oregon is the effect of coproduct availability on markets for those coproducts. As indicated, a 50-million-gallon corn ethanol plant will generate 333 million pounds of DDGS, or about the maximum that could be fed to Oregon's 90,000 confined cows each year. Canola meal from five 2-million-gallon biodiesel plants would be 176 million pounds, or about as much as could be fed to Oregon's cows. (Some canola meal also can be fed to other livestock and poultry.) In both cases, export opportunities may help avert downward pressure on coproduct prices, but the extent of export opportunities is uncertain. The coproduct issue is critical because a surplus of coproducts in Oregon or nationally could have large negative effects on the profitability of biofuel production; and disposing of coproducts as waste could cause negative net energy contributions, making biofuel production undesirable from an environmental as well as an energy independence perspective. Also, exporting corn ethanol and canola biodiesel coproducts would undercut the biofuels' contribution to national energy independence by reducing the net energy gain that is consumed domestically.

Two additional caveats deserve highlighting: the rapid changes in biofuel technology development and entrepreneurship, and the development of small-scale, local, and on-farm biofuel endeavors. The present analysis is limited to large-scale commercial production of biofuels. While there is evidence that "scale economies" lower product cost per gallon at 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 rapid changes in biofuel systems design, will raise new questions about future alternatives for meeting energy and environmental objectives.

Additional research issues

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 and is necessarily incomplete (e.g., it evaluates 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 deserve additional investigation and analysis. A more detailed examination of the likely impact of increased coproduct production is warranted, given coproducts' potentially large impact on the economics of biofuels and on their energy contribution (for example, if oversupply in the animal feed market led to disposal of DDGS or canola meal as waste). The possibility 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 in a few years, the cost to transport feedstocks to the plant could rise significantly over time. Also, the potential availability of biomass feedstock is uncertain after the estimated 20-year supply has been extracted from Oregon's forests. 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 cost–benefit balance for this biofuel option.

In addition, there may be complementarities among biofuel types. The value of 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 hay 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 small-scale, farm-level biofuel operations, which would require a separate analysis.

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Appendix A. Ethanol Production Cost Summary

The ethanol production budget below summarizes fiscal year 2005 audited financial results from four private-sector ethanol producers in the Midwest. Firms ranged in annual ethanol production capacity from 50 million 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 percent of total revenue comes from ethanol sales, averaging $1.58/gallon in 2005. Sales generally are forward contracted. Other revenue items include coproducts (distiller's dried grains and solids, or DDGS) at $0.24/gallon and related products and services at $0.13/gallon.

Corn is the largest single production cost, at $0.67/gallon of ethanol ($1.84/bushel). These data also indicate an average conversion rate of 1 bushel of corn into 2.75 gallons of ethanol; the range is 2.70 to 2.81 gallons. Natural gas averaged $0.26/gallon of ethanol, or $8.76/million BTUs. Return on invested capital of $0.12 represents an assumed 10-percent rate of return on assets required to produce 1 gallon of ethanol. Total book value of assets at the beginning of the production period average $1.24 and ranges from $1.19 to $1.42. Government support payments offset production expenses by $0.04/gallon. Supports are from a variety of state and federal programs, including the small-producer credit of $0.10/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/gallon federal subsidy.

Before-tax profit of $0.03/gallon suggests that a 10-percent 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.*

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*P. Gallagher, personal communication, Dec. 14, 2006.

Table A-1. Private-sector ethanol production cost summary.*

Revenues ($/gal)	
Ethanol sales	1.58
Coproducts	0.24
Related products and services	0.13
Total revenues	**1.96**
Expenses ($/gal)	
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 costs	**1.93**
Profit / (loss) before taxes	0.03

* Based on U.S. Midwest location

[1] Natural gas reported for three of four firms.

[2] Invested capital reported for three of four firms.

Source: Documentation from SEC filings. Note: Totals may not match, due to rounding.

Observations

Gallons of ethanol per bushel of corn	2.75
Corn cost per bushel ($)	1.84
Natural gas cost ($/MM BTU)	8.76
Total assets required ($)	1.24

Assumptions

Rate of return on capital (%)	0.10

Appendix B. Data and Computations for Each Biofuel

Table B-1. Assessment of costs for **corn-based ethanol** in Oregon (feedstock from U.S. Midwest).

		Social cost	Credits & subsidies	Private cost (after credits & subsidies)
Private and social cost accounting	Costs			
	Cost of feedstock production ($/bu)[1]	2.63	0.28	2.35
	Transportation and handling ($/bu)[2]	0.80		0.80
	Processing and conversion ($/bu)[3]	3.58		3.58
	Total ($/bu)	7.01	0.28	6.73
	Postproduction subsidies ($/gal)[4]	0.51	0.51	
	Total ($/gal)	3.06	0.61	2.45
	Revenues			
	Market price ($/gal)[5]			1.97
	Coproducts value ($/gal)[6]			0.37
	Other government payments[7]			0.10
	Total			2.44
Energy accounting	Energy use (BTU/gal) in:			
	Feedstock production[8]	18,995		
	Transportation and handling[8]	3,204		
	Processing and conversion[8]	38,601		
	Total[8]	60,800		
	Energy contained in biofuel (BTU/gal) [8]	76,300		
Greenhouse gas accounting	GHG emissions (gCO$_2$ eq./MM BTU) in:			
	Feedstock production			
	Transportation and handling			
	Processing and conversion			
	Distribution and marketing			
	Total [9]	89,563		
	GHG emissions from equivalent gasoline	102,235		
	Net GHG change with biofuel substitution	-12,671		
	As share of fossil fuel alternative (%)	-12.4		

[1] Corn grain cost based on national average for 2003–2005. Subsidy based on estimated direct payments.

[2] Rate for rail costs from Minneapolis to Portland.

[3] Based on financial results from four ethanol plants.

[4] Federal blender's credit of $0.51/gal for ethanol production.

[5] Average Midwest ethanol price for past 3 years ($1.90/gal); CIF Portland adds $0.07/gal.

[6] Value of DDGS is $0.24; private-sector results include an average of $0.13 for other products and services.

[7] Federal subsidy of $0.10/gal for small producers of ethanol.

[8] Hill et al., 2006. Energy units are net of coproducts and coproduct credits.

[9] Hill et al., 2006.

Table B-2. Biofuel assessment for **canola-based biodiesel**.

		Social cost	Credits & subsidies	Private cost (after credits & subsidies)
Private and social cost accounting	Costs			
	Cost of feedstock production ($/cwt)[1]	9.00		9.00
	Transportation and handling ($/cwt)[2]	0.37		0.37
	Processing and conversion ($/cwt)[3]	2.52		2.52
	Total ($/cwt)	11.89	0.00	11.89
	Postproduction subsidies ($/gal)[4]	1.00	1.00	
	Total ($/gal of fuel) [5]	4.21	1.00	3.21
	Revenues		0.230769231	
	Market price ($/gal)[6]			1.93
	Coproducts value ($/gal)[7]			1.45
	Other government payments ($/gal)[8]			0.10
	Total			3.47
Energy accounting	Energy use (BTU/gal) in:			
	Feedstock production[9]			
	Transportation and handling[9]			
	Processing and conversion[9]			
	Distribution and marketing[9]			
	Total[9]	70,300		
	Energy contained in biofuel[9]	118,000		
Greenhouse gas accounting	GHG emissions (gCO_2eq./MM BTU) in:			
	Feedstock production			
	Transportation and handling			
	Processing and conversion			
	Distribution and marketing			
	Total[10]	51,698		
	GHG emissions from equivalent diesel	86,852		
	Net GHG change with biofuel substitution	-35,154		
	As share of fossil fuel alternative (%)	40.5		

[1] Based on Oregon prices, which have averaged $9/cwt in recent years.

[2] Based on estimate of $0.10/gal of canola oil.

[3] Based on Fortenbery (2004) plus $0.11/gal overhead for sales, general, and administrative (SG&A).

[4] Federal blender's credit of $1/gal for biodiesel.

[5] Conversion rate is 27 pounds of feedstock per gallon of biodiesel.

[6] Average Canadian (Vancouver) price for past 3 years ($1.93/gal).

[7] Based on canola meal price of $0.75/lb, less $0.15/lb transportation, and a meal yield of 75%. Glycerin credit of $0.23/gal.

[8] Federal subsidy of $0.10/gal for small producers.

[9] Based on Hill et al. (2006) and adjusted for differences between soybean and canola (see Appendix C). Energy units are net of coproducts and coproduct credits.

[10] Based on Hill et al. (2006) and adjusted for differences between soybean and canola (see Appendix C).

Table B-3. Biofuel assessment for **cellulosic (wood-based) ethanol.**

		Social cost	Credits & subsidies	Private cost (after credits & subsidies)
Private and social cost accounting	Costs			
	Cost of feedstock production ($/ton)[1]	52.00		52.00
	Transportation and handling ($/ton)[2]	25.50		25.50
	Processing and conversion ($/ton)[3]	98.70		98.70
	Total ($/ton)	176.20	0.00	176.20
	Postproduction subsidies[4]	0.51	0.51	
	Total ($/gal of fuel)[5]	3.03	0.51	2.52
	Revenues			
	Market price ($/gal)[6]			1.90
	Coproducts value ($/ gal)[7]			0.07
	Other government payments ($/gal)[8]			0.10
	Total			2.00
Energy accounting	Energy use (BTU/gal) in:			
	Feedstock production			
	Transportation and handling			
	Processing and conversion			
	Distribution and marketing			
	Total[9]	12,204		
	Energy contained in biofuel[10]	76,278		
Greenhouse gas accounting	GHG emissions (gCO_2eq./MM BTU) in:			
	Feedstock production			
	Transportation and handling			
	Processing and conversion			
	Distribution and marketing			
	Total	3,846		
	GHG emissions from equivalent gasoline	102,235		
	Net GHG change with biofuel substitution	-98,389		
	As share (%) of fossil fuel alternative	96.2		

[1] Based on two studies, Aden et al. (2000) and Swan (1997), for ponderosa pine 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/gal plus $0.11/gal administrative overhead (SG&A), or $98.70/ton of feedstock.

[4] Federal blender's credit of $0.51/gal for biodiesel.

[5] Converted at an assumed yield of 70 gal/ton.

[6] Average Midwest ethanol price for past 3 years ($1.90); CIF Portland adds $0.07/gal.

[7] Based on Wooley (1999), for lignin coproduct.

[8] Federal subsidy of $0.10/gal for small producers.

[9] Based on Kemppainen and Shonnard (2005), 16% of energy in fuel used in production. Coproduct (lignin) assumed used to provide energy for processing.

[10] Hill et al., 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, as much as 43 percent of canola's weight is oil, but an oil content of 40 percent is more common and is used in this study. Soybean's oil yield is 20 percent by weight. In 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 yields 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, consistent with those for Washington, are about 100 pounds/acre of nitrogen (=112 kilograms/hectare).

Our estimates of energy inputs for canola biodiesel production are based on estimates of Hill et al. (2006, Tables 2 and 5) for soybeans, adjusted for the additional nitrogen fertilizer required for canola production. Total energy increases to 4.4 million BTUs/acre for canola; nitrogen alone accounts for 2.2 million BTUs/acre. This approach is warranted because, except for 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 inputs for canola, other than fertilizer, are assumed to be the same as for soybean production.

Oregon State University Extension estimates Oregon canola yields at 2000 pounds/acre (=2242 kilograms/hectare), which corresponds to 800 pounds/acre of oil or 1000 liters/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 pounds of oil per liter biodiesel translate into 2.24 kilograms of canola per liter of biodiesel.

Because nitrogen fertilizer is energy intensive to produce, the input energy required to produce 1 gallon of biodiesel is greater for canola (=104,100 BTUs/gallon) than for soybeans (=101,800 BTUs/gallon), despite canola's larger oil content (40 percent in canola vs. 18 percent in soybeans).

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

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

Six studies and three cases of net energy and petroleum inputs for corn ethanol and gasoline (Figure D-1b); net energy and greenhouse gas emissions for same (Figure D-1a).

Figure D-1a. (from Farrell et al. 2006)

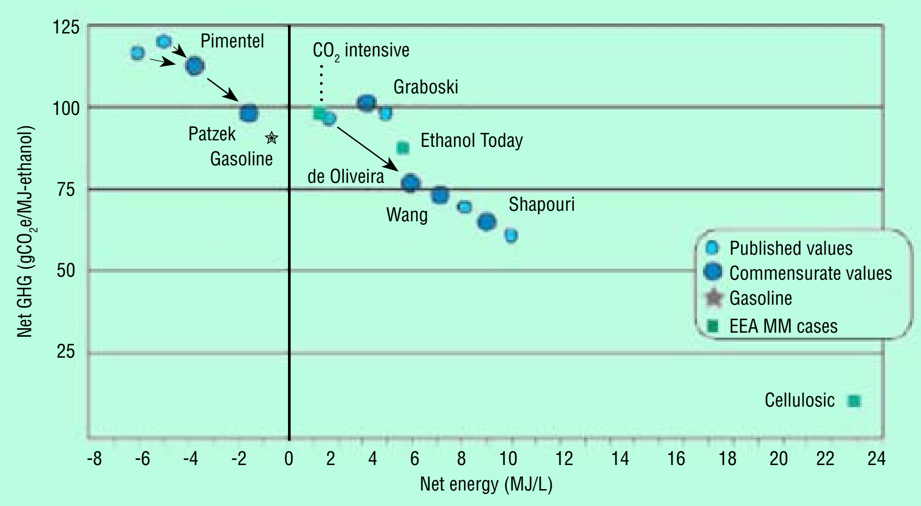
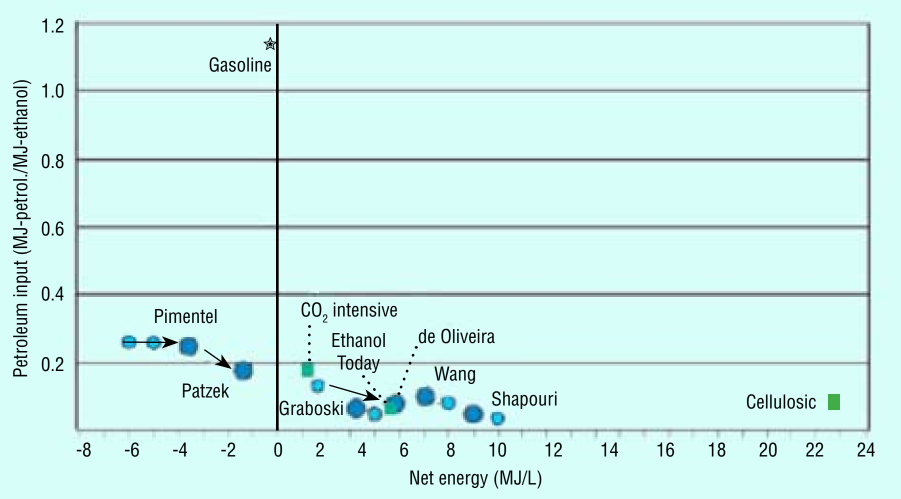


Figure D-1b. (from Farrell et al. 2006)



Appendix E. Sensitivity Analysis for Prices and Revenues

Table E-1. Sensitivity analysis for changes in economic assumptions.

			Central case	High	Low
Corn ethanol	Effect of:				
	Ethanol price and revenue	($/gal)	2.44	2.97	1.97
		% change from central case		22	-19
	Coproduct value on revenue	($/gal)	2.44	2.81	2.07
		% change from central case		15	-15
Canola biodiesel	Effect of:				
	Canola oil price on revenue	($/gal)	3.47	3.71	3.06
		% change from central case		7	-12
	Canola meal price on revenue	($/gal)	3.65	4.41	3.23
		% change from central case		21	-12
	Canola price on cost of production	($/gal)	3.13	3.69	2.58
		% change from central case		18	-18
Wood-based cellulosic ethanol	Effect of:				
	Ethanol price and revenue	($/gal)	2.00	2.60	1.60
		% change from central case		30	-20

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