Wheat Straw for Ethanol Production in Washington: A Resource, Technical, and Economic Assessment

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COOPERATIVE EXTENSION
WASHINGTON STATE UNIVERSITY
ENERGY PROGRAM

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Executive Summary

Washington State is one of the major wheat producing states in the country. The open field burning of straw is being reduced and possibly eliminated. Concurrently, the interest in using cellulosic materials for the production of ethanol fuels increases as the conversion technologies improves, the price of crude oil increases, the national dependence on imported oil increases, and the need for an oxygenate replacement for methyl tertiary butyl ether (MTBE) grows.

The purpose of this report is to assess the availability of wheat straw, the status of the conversion technologies, and the economics of ethanol production from wheat straw.

This report quantified the availability of wheat straw at the county level using five-year averages of crop yields. Biomass supply curves were developed to show the cost of delivering a specific quantity of biomass to a hypothetical facility in Moses Lake. In general, the marginal cost increases, as the quantity needed increases. An overview of the available conversion technologies is presented as well as their developmental status. The National Renewable Energy Laboratory ran their economic model for the hypothetical plant and developed capital and operating costs for a model facility. Oregon State University analyzed the economic impact on the region surrounding Moses Lake and for the state. Recommendations are presented on actions Washington State could take to promote the development and deployment of a biomass-to-ethanol facility.

Findings

1. The quantity of straw available for removal from a field is highly sensitive to the amount that must be left to insure long-term sustainable crop production. If the limit is 3,000 pound per acre than 3 million tons of straw are available. If the limit is 5,000 pounds per acre the availability drops to 680 thousand tons. The average price for delivering straw to a 20 million gallon per year plant also increases from $32/ton to $54 per ton as the straw availability decreases.

2. Currently, there are no biomass to ethanol plants in commercial operation, although at least five are in an advanced planning stage or actively seeking financing. The industry is very young and the real or perceived risks will only be addressed when several plants are in successful operation. To date, the cost of making ethanol from biomass is substantially greater than ethanol made from corn ($1.70 versus $1.10/gallon). As the technology matures, however, producing ethanol from cellulose will become more competitive with corn based ethanol. An expanding ethanol market will also result in increasing costs of corn, further narrowing the price difference between the fuels.

3. A straw based industry in eastern Washington would have a significant positive economic impact on the region. Just one 40 million gallons per year facility would create about 104 direct long-term jobs and 335 additional indirect and induced jobs. The counties of Adams, Franklin, Grant, and Lincoln counties would see an economic value-added of $19.6 million. In addition, there are energy and environmental advantages to using wheat straw to produce ethanol. The use of ethanol fuels offer air quality benefits to the region and could help soften petroleum price increases or supply disruptions.

Recommendations

1. The Washington Department of Agriculture, Office of Trade and Economic Development and Washington State University Cooperative Extension/College of Agriculture and Home Economics should convene an advisory committee that would represent the various stakeholders. This committee would explore in more detail the questions about straw availability and work towards guidelines that would be useful to the resource agencies, the landowners, and developers.

2. Washington State and the agricultural community should actively encourage the Federal government to commit more dollars to the full-scale demonstrations of technologies as they are proven in the laboratory. Only through actual experience with commercial scale operations can the engineering improvements be made that will move the industry from infancy to maturity. Because wheat straw is the most promising feedstock for Washington State, efforts should be made to establish a commercial facility within the state.

3. The Governor, as a member of the Governors Ethanol Coalition, and Washington State Congressional representatives should advocate for Federal financial incentives to help establish a cellulose-to-ethanol industry. Currently, there are bills in front of Congress that, if supported, would help to jumpstart this industry. Washington State should follow Minnesota's lead and begin developing a set of incentives and policies that support the production and use of ethanol fuel made from agricultural waste products. While it may be premature to institute an incentives program at this time, debating the pros and cons of various state incentives, including a renewable fuels standard, should begin.

Introduction

Ethanol production from cellulosic materials may offer a solution to some of the recent environmental, economic, and energy problems facing Washington State's agricultural sector. Nationally, energy costs are on the rise and forecasts of petroleum supply disruptions are once again making news. Washington State farmers are not immune to these events and feel the impact of rising energy prices every time they purchase gasoline, diesel or other petroleum products.

Changes in how agricultural field residues are managed further complicate farming economies in Washington State. In the past, disposal of wheat straw by burning was an accepted practice. This practice is now being challenged due to concern over the health effects of smoke from burning fields. These smoke emissions contain harmful air pollutants including particulate matter, carbon monoxide, and volatile organic compounds. In aggregate, agricultural burning in Washington State is responsible for as much as 40,000 tons of emissions annually.

The elimination of field burning is forcing growers to examine alternative management practices. Converting wheat straw, or other agricultural residues, to ethanol may provide an acceptable alternative to burning. The use of local feedstocks produced in Washington would enhance both the grower's and the state's economy by partially offsetting fuel imports and by using products which currently have little or no value. In addition, ethanol fuel offers air quality benefits to the region for both regulated emissions such as carbon monoxide, as well as carbon dioxide or greenhouse gas emissions. In the future, these emission offsets may provide added value to an ethanol operation.

While converting wheat straw to ethanol may offer some promising benefits, a number of questions need to be answered to determine the viability of a cellulosic ethanol industry in Washington State. First, is there a sufficient quantity of wheat straw available at a competitive cost? Second, is the technology for converting wheat straw to ethanol mature enough to compete with the current corn-based ethanol industry? Third, how robust is the ethanol market, and what added value does ethanol offer to the region? Finally, what are the existing barriers to establishing a cellulosic ethanol industry in Washington State and what type of incentives may be necessary to support this industry?

Converting waste agricultural residues to a high quality fuel may provide an economic opportunity for Washington State. This report examines the viability of establishing a wheat straw-to-ethanol facility in Washington, and proposes recommendations for moving this industry forward.

Wheat Straw Availability and Conversion Technologies

Wheat straw can be converted to ethanol fuel. Determining the volume of fuel that could be produced depends on both the quantities of available straw and the technology used to convert the straw-to-ethanol. The amount of straw available depends on how much is produced each year, how much can be recovered while maintaining soil fertility, and how much someone is willing to pay. The technologies for converting straw to ethanol have all been demonstrated in pilot plants. The particular technology or combinations of technologies that are chosen are mainly driven by economics. This section of the report presents the results on the availability of wheat straw, the technologies and their stage of development.

Wheat Straw Availability

Overview

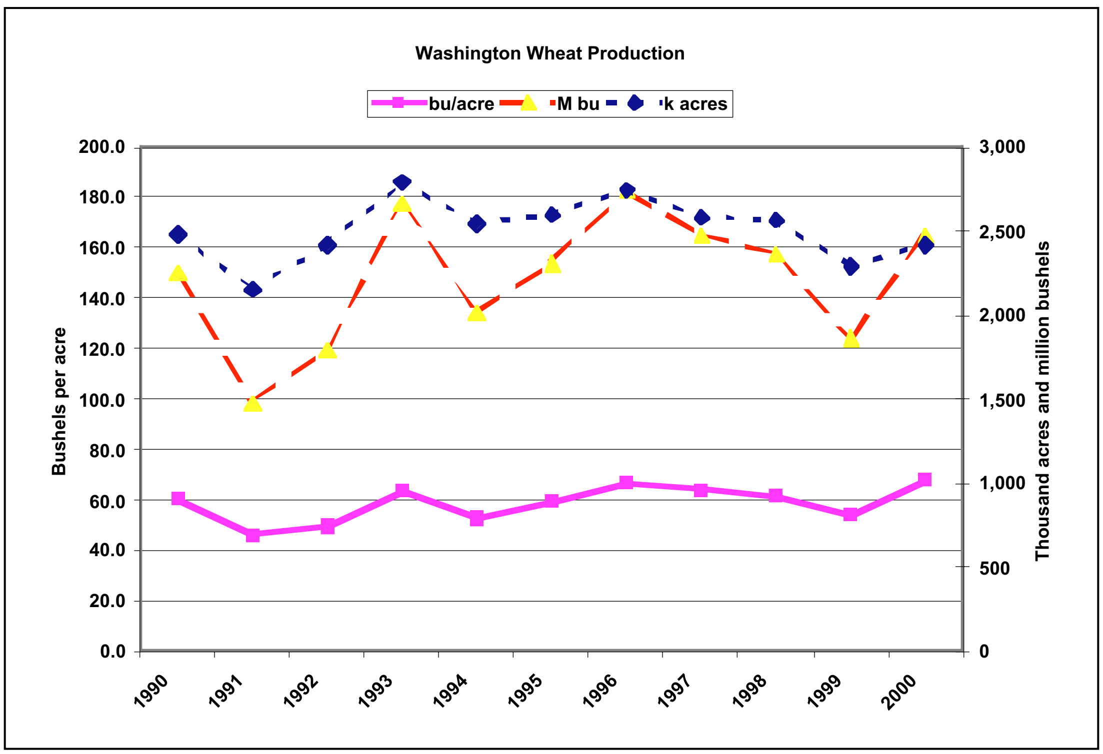
Wheat is an annual agricultural crop grown for the grain portion of the plant that is a valuable food product. The rest of the wheat plant is in the wheat straw consisting of stems and leaves, chaff that is a protective cover over the grain, and the underground root system. After the grain is harvested the fields are prepared for the next crop. The straw is burned, removed, left on the field or plowed back into the soil. The choices made by the landowner depend on a variety of factors including the quantity of material, the next crop to be planted, the weather conditions, the soil erodibility and nutrient needs, the slope of the land, and any markets that may be available for the straw.

The procedure to determine the quantity and cost of straw available for conversion to ethanol fuel is relatively straightforward. The procedure is: 1) determine the quantity of straw generated as the result of producing the wheat grain, 2) determine the quantity of straw that should be left on the field for erosion control and soil fertility, 3) determine the physical accessibility of the straw, slope of the land being the critical issue, 4) determine the cost of collecting and removing the straw, 5) determine the location and cost of storing the straw, 6) determine the cost of transporting the straw to the conversion facility, and 7) determine any other costs involved such as payment to the landowner for the straw or the nutrient value of the straw that is removed. While the procedure is well understood, the "devil is in the details". Besides getting quantitative data for many of the factors, the question of how the landowner values their land is important. Finally, crop yields and hence straw production are subject to the annual variation in weather, and the acres planted depend on world market conditions and federal farm legislation. Figure 1 shows the acres harvested, yield, and production from Washington wheat over the past decade. The yields are influenced by rainfall as illustrated by the drought years of 1991-92. The production can change drastically from year to year. Over the past five years production and acres harvested have tended to decline.

Quantity of straw generated

The National Agricultural Statistical Service of the U.S Department of Agricultural annually publishes the acres harvested and the yields by practice (irrigated and non-irrigated) and county (1). The most recent five years (1995-2000) of data was used to determine the average yields and quantity of straw generated. Some counties do not always have a wheat harvest because landowners try different crops and rotations. Therefore, we only included counties and/or practices that harvested wheat over the past three years or more. Sixteen counties in Washington have harvested some wheat over the past five years. For this study we are only including the 13 largest producers in the state, and they account for 97 percent of the total production.

Figure 1.
Historical Wheat Production



The yields of grain and straw are a strong function of the amount of moisture available for the crop. Irrigated lands have very high yields while the dry land yields closely follow the amount of rainfall.

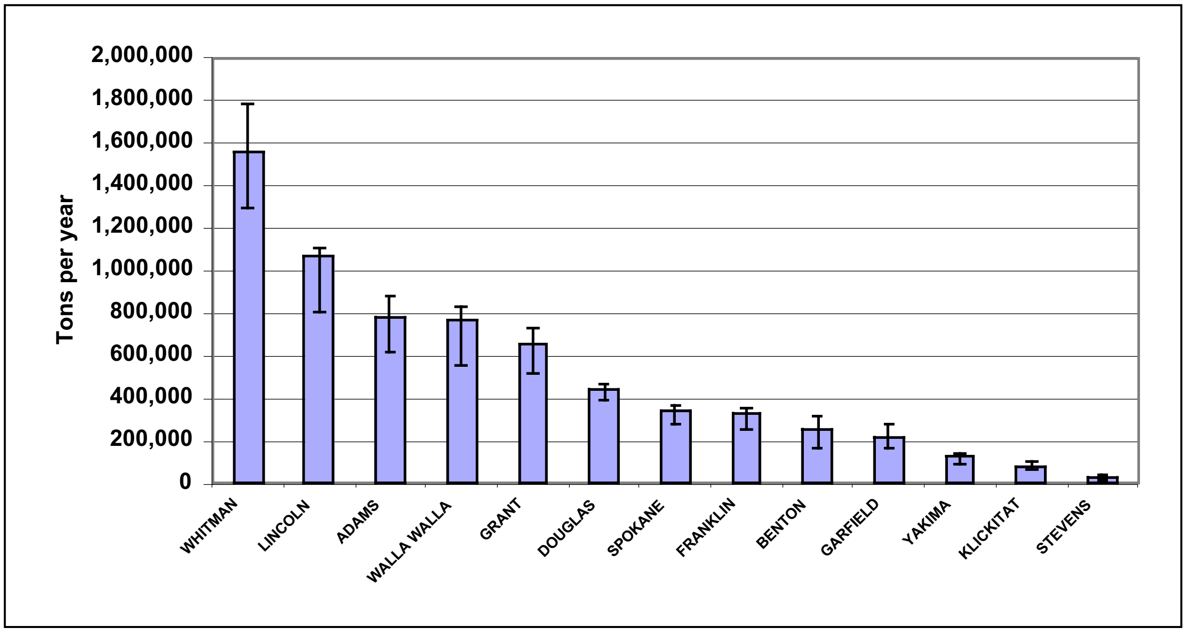
The total quantity of grain produced is the product of the yield and the number of acres harvested. Thus, counties with large acreage in wheat production and in high yield areas will produce the greatest quantity of grain and straw. The quantity of straw generated per acre depends mainly on the variety of wheat grown and the yield of the grain product. Agricultural scientists in Washington have developed a linear correlation to permit computation of the quantity of straw generated if the wheat yields are known (2). The least squares relationship is: pounds of wheat straw per acre = 69.76 x yield (bushels/acre) + 1067.7.

The quantity of wheat straw generated each year was computed using the relationships given above. The results are shown in Table 1 and Figure 2. The error bars in figure 2 represent the range of values observed over the past five years. Average volumes are typically used for resource assessments but the minimums must be considered in any decision making. The top five counties generating wheat straw during the last five years have had minimum straw volumes twenty five percent less than the average. Nevertheless, the volume is large. For example, over 100 million gallons of ethanol could be produced from just the straw generated in Whitman and Lincoln counties. However, the most important data is how much straw can be delivered to a conversion facility at a cost that permits economic operation of the facility.

Table 1
Wheat Straw Production 1996-2000

	Average, tons	Minimum, tons	Maximum, tons
STATE TOTAL	6,866,094	5,552,520	7,836,948
WHITMAN	1,562,280	1,289,261	1,787,518
LINCOLN	1,074,139	803,639	1,110,061
ADAMS	787,684	618,085	879,652
WALLA WALLA	766,083	558,145	833,560
GRANT	650,379	517,262	735,266
DOUGLAS	437,550	389,472	466,873
SPOKANE	341,954	285,324	369,045
FRANKLIN	329,360	255,392	353,891
BENTON	253,912	172,281	320,513
GARFIELD	220,318	166,692	282,263
YAKIMA	126,796	93,761	140,867
KLICKITAT	83,330	72,510	107,139
STEVENS	22,935	14,309	37,534

Figure 2
Wheat Straw Production 1996-2000



Availability

The quantity of straw generated is an easy task compared to determining the quantity of material available for recovery. We use the term "available" in a broad sense to mean the materials available after accounting for how much must be left to insure the long-term fertility of the land. This is not an easy number to quantify. The quantity that must be left depends on the weather, the crop rotation, the existing soil fertility, the slope of the land, the wind patterns, the rainfall patterns and tillage practices. We talked to several agricultural and soil scientists about this issue (3-6). They all acknowledged the difficulty of coming up with generalities that could be applied at the county level and still give a meaningful number. Some used rules of thumb such as; don't take any straw off of lands with yield of less than 60-70 bushels per acre; leave 8-10 inches of straw; and leave 5,000 pounds of residue per acre.

The US Department of Agriculture has regulatory authority in addressing this question. Landowners that want to participate in federal commodity programs must prepare a soil conservation plan for their farms if the land is classified as highly erodible. In 1997, forty percent of Washington's cropland was classified as highly erodible (7). The quantity that must be left depends on the factors addressed above: slope, soil type, crop rotations, tillage practices, wind patterns, and rainfall patterns.

The Conservation Technology Information Center (CTIC) is an off-site branch of the National Association of Conservation Districts and promotes the adoption of conservation tillage and residue management. They developed a program called CORE 4 that aims to protect and improve the land while addressing on-farm profits. They set the criteria of 30 percent residue requirement (water erosion) or 1,000 pounds of small grain residue (wind erosion) on the field per acre after the field is cultivated and replanted as the standard for conservation tillage (8). The Natural Resources Conservation Service (NRCS) supports the CTIC/CORE4 marketing plan. The quantity remaining after replanting depends on the quantity generated and on the tillage practices. For example, disk plowing removes 80-90 percent of the straw from the surface (8). This practice would essentially preclude the removal of any residue for energy purposes and still maintain soil value. Other tillage practices are much less disruptive such as a rodweeder that only removes 10-20 percent (8). The trend is to use conservation tillage practices that are much less disruptive to the soil. In 1998 about 25 percent of Washington's winter wheat had residue management classified a conservation tillage (9).

The NRCS suggested we use a value of 5,000 pounds per acre. A study done in Oregon used values from 2,685 to 7,298 based on the Lightly soil conditioning index program (10). The Fibre Futures group makes the general assumption that you can remove 25 percent of the crop residue (11).

The overall objective is to maintain soil fertility, which involves nutrient and organic management and minimizing erosion. The suggested values, such as 10 inches of stubble or 3,000 pounds per acre pertain to the quantity of residue left after any straw would be removed. The more critical number is the quantity of residue left on the field after the field is cultivated and replanted. As discussed above the quantity remaining after the cultivating and replanting field operations depend on the tillage practices. These practices are changing as more conservation tillage is practiced and as direct seeding is more widely adopted. Today's practices are not likely to be what we will see in the future. We looked at the situations of leaving 3,000 pounds/acre and 5,000 pounds per acre after straw removal and assuming that cultivation and planting practices would result in leaving enough residue on the field to meet the conservation tillage guidelines. The choices of 3-5,000 pounds/acre capture the other suggested values of 60 bushels/acre or 10 inches of stubble.

Figure 3 and Table 2 show the five-year average and range by county for the quantity of straw generated and available for removal at the 3,000 and 5,000 pound per acre limits. The choice of either 3,000 or 5,000 pounds has a dramatic effect on the quantity of straw that is available. For example, the average availability of straw from Lincoln county drops from 495,000 tons to 109,000 tons when the going from 3,000 to 5,000 lbs./acre respectively. Even more dramatic are the minimum available quantities that result when crop yields are low. Again for Lincoln county, the minimum available drops from 327,000 tons to 8,000 tons. This makes planning the supply for an ethanol facility very difficult and points out the need for conservative supply estimates and/or contingency options for years with low crop yields. Such a contingency could be carrying an inventory of straw from one year to the next.

Figure 3
Wheat Straw Availability 1996-2000

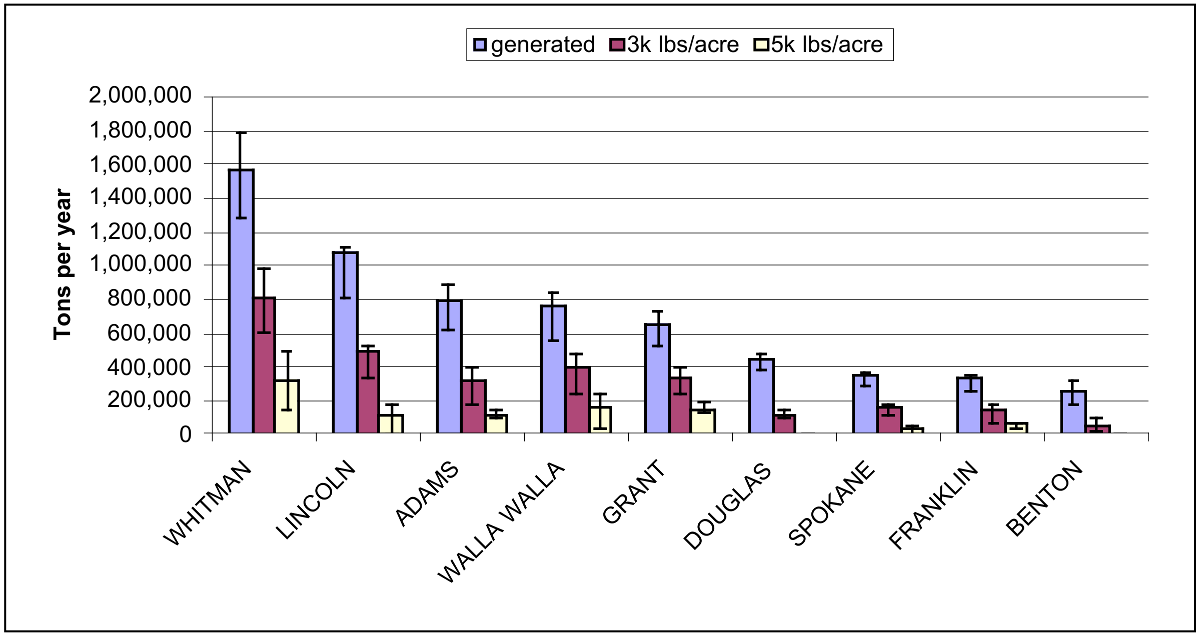


Table 2
Wheat Straw Availability 1996-2000

	3,000 lbs./acre			5,000 lbs./acre		
	Average	Minimum	Maximum	Average	Minimum	Maximum
STATE TOTAL	3,086,094	2,117,520	3,719,448	681,857	347,785	992,931
WHITMAN	815,820	605,111	986,068	318,180	149,011	484,856
LINCOLN	495,109	326,639	530,174	109,089	8,639	165,974
ADAMS	314,254	171,835	396,352	115,200	89,472	137,676
WALLA WALLA	400,793	244,345	480,160	157,266	35,145	244,560
GRANT	334,094	243,362	398,465	146,024	127,715	182,065
DOUGLAS	115,200	89,472	137,676	0	0	0
SPOKANE	155,054	115,074	177,795	30,535	1,940	51,606
FRANKLIN	141,343	71,042	172,391	58,395	37,694	61,245
BENTON	42,350	14,417	99,413	0	0	8,617
GARFIELD	100,888	60,942	140,213	23,426	0	45,513
YAKIMA	55,249	40,810	59,267	30,333	0	31,493
KLICKITAT	13,880	6,949	20,677	0	0	0
STEVENS	9,225	5,759	17,434	649	0	4,034

Supply Curves

Biomass supply curves are used to show the cost of delivering a specific quantity of biomass to a specific location. In general, the marginal cost increases, as the quantity needed increases. The basic task is to determine where available material is located and how much it costs to collect and transport to a specific location. The quantity available for energy is subject to the constraints of environmental limits, market competition, and willingness of the resource owners to supply the material. The costs are mainly collection and transportation. The methodology is relatively straightforward

The delivered cost of straw is the most important figure for the ethanol producer. The cost will include collection, storage, transportation, and fertilizer replacement costs, as well as any payment to the landowner for his straw. Generally, there is no one cost for straw that applies to all parties. As the quantity of straw needed by an ethanol facility increases with the size of the facility, materials must be brought in from longer distances.

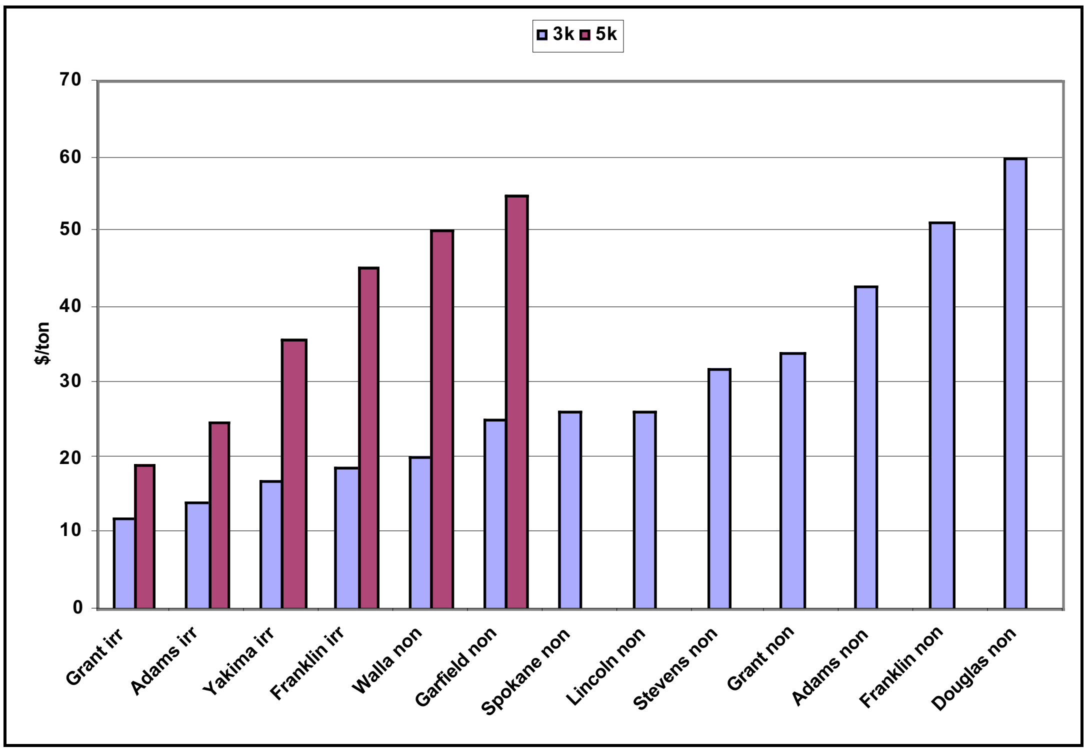
Costs of Recovering Residues

The discussion above provided quantities of wheat straw that were available after accounting for the need to keep residue on the fields for agronomic purposes. The slope of the land is another major constraint for recovery of wheat straw. Whitman County is the largest wheat-producing county in the state. However, the fields are generally on rather steeply sloped land. In fact, self-leveling combines were developed to permit efficient harvesting of the grain. However, conventional straw recovery equipment is currently not suitable for use on highly sloped lands. We make the critical assumption that virtually no straw can be recovered from Whitman county. There are of course some areas where straw could be recovered but we did not have the resources to look at this level of detail within the counties. This assumption should be reexamined as technology and markets for use of wheat straw develop.

The costs of collecting wheat straw are estimated using an engineering approach. This approach examines the equipment used, its productivity, and its costs to determine a collection cost per acre of land. Lazarus estimated recovery cost on a per acre basis for field operations (12). His costs, on a per acre basis were: swathing ($8.25), baler ($9.99) and stacker ($13.63) for a total collection cost of $32/acre. Today, straw collection costs are often quoted in units of dollars per ton. However, to recognize that the cost to recover straw from a field with only 1,000 lbs./acre must be higher then the cost of recovering from a field with 3,000 lbs./acre, we chose to use the cost per acre estimates. To determine the cost per ton we took the $32/acre cost and divided by the tons of residue per acre available for removal. This approach also tends to exclude lands with minimal volumes of residue available because the collection costs become very high.

Figure 4 shows the collection costs from irrigated and non-irrigated land in 9 counties. It also shows the costs of collection if 3,000 or 5,000 lbs./acre are left. The costs are much higher if 5,000 lbs./acre must be left because the quantity of material that can be recovered per acre is less making the cost per ton higher. The collection costs from irrigated lands are also lower than from non-irrigated lands because more straw can be removed per acre.

Figure 4
Cost of Collecting Wheat Straw at $32/acre



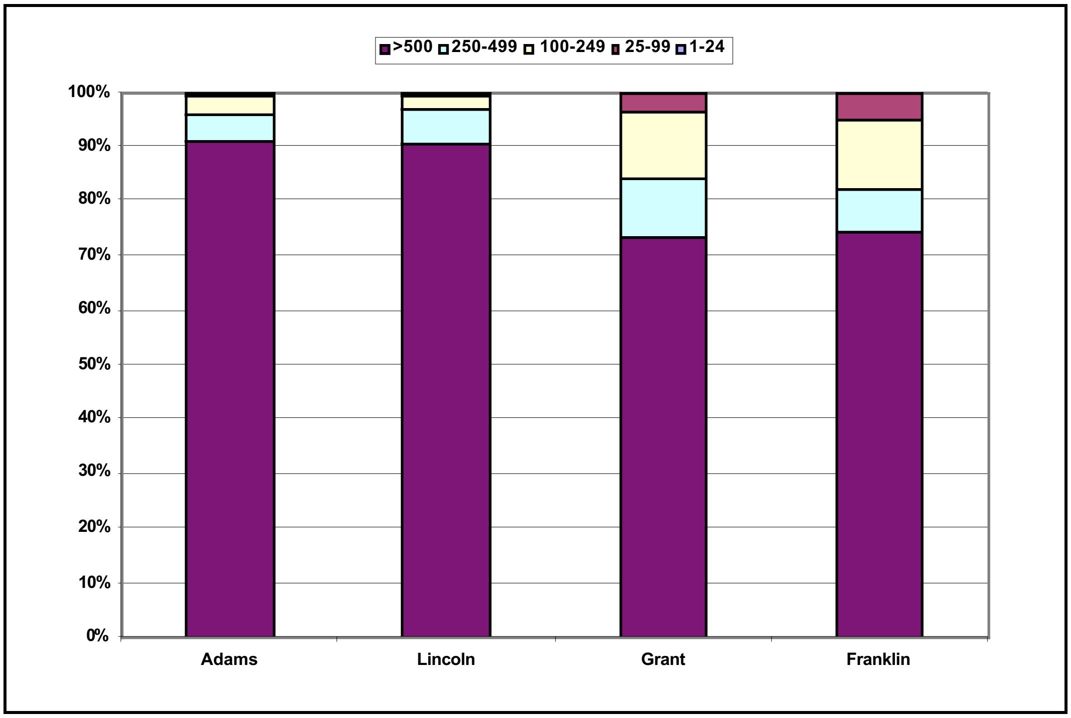
Storage costs depend on the method chosen for storage. Methods include field/road side stacked, field/road side stacked and tarped, pad stacked, pad stacked and tarped, and covered storage/pole barn. Storage costs increase with the method chosen. Selection of a storage method depends on the bale size, length of storage, location of storage, cost of storage, and degradation. Storage costs for rice straw has been estimated by the Rice Straw Venture (13) to range from zero for uncovered field side stacks to $7 - $25/ton. We assumed a storage cost of $7/ton for purposes of this study. Residue has a fertilizer value depending on the amounts of nitrogen, phosphorus, and potassium in the material. We assumed a fertilizer value of about $3/ton of residue removed that would be paid to the landowner. While this price represents the fertilizer of the residue, it may not be sufficient compensation for growers.

Logistics of recovery

The infrastructure for collection, storage and transportation of large quantities of wheat straw does not currently exist in Washington. An example of meeting infrastructure needs is available from the Isobord facility in Canada. They produce strawboard from wheat straw. They purchase straw from a farmer co-op with 450 members for $5/ton. In 1998 they harvested and transported 176,000 tons of straw to the Isobord plant. The straw was transported directly to the plant and not stored on the farm. Isobord purchased 36 tractors and balers and provided the labor for collection and transport. It's not known if this is a model for Washington, but it is an example of what others have done.

The number of landowners that an ethanol facility must contract with is a question that should be addressed. The Canadians formed a co-op so Isobord only had to deal with one entity rather than 450 individual landowners. An estimate of the number of landowners can be made for Washington based on the average farm size per county and the average quantity of available straw per acre. Figure 5 shows the size distribution for wheat farms in four Washington counties. A vast majority of the land is on farms with greater than 500 acres. The average wheat farm size for Adams, Lincoln, Grant, and Franklin counties is 1,500, 1,050, 1,300, and 1,500 acres per farm respectively. Assuming 1.2 tons/acre and an average farm size of 1,300 acres, about 150 farms could supply an ethanol plant needing 200,000 tons of straw per year. In 1997 there were 656 farms in the four counties listed above with farms greater than 500 acres. Thus, there appears to be a reasonable number of farms that could supply straw to an ethanol plant without requiring a large number of contracts. The farm supply co-op may prove to be the best contracting arrangement, but that remains to be seen.

Figure 5
Wheat Farm Size Distribution



Transportation costs

The cost of moving material from the farm to a conversion facility is mainly a function of the transportation distance. Moses Lake was chosen as the site for an ethanol facility because it is centrally located with regards to the available supply of wheat straw and also has existing infrastructure of water, gas, and waste water treatment. We chose the physical center of the wheat growing area within a county to compute the distance from the farm field to Moses Lake. The road distances from the center to Moses Lake were measure using Microsoft MapPoint and tracing the roads to be used.

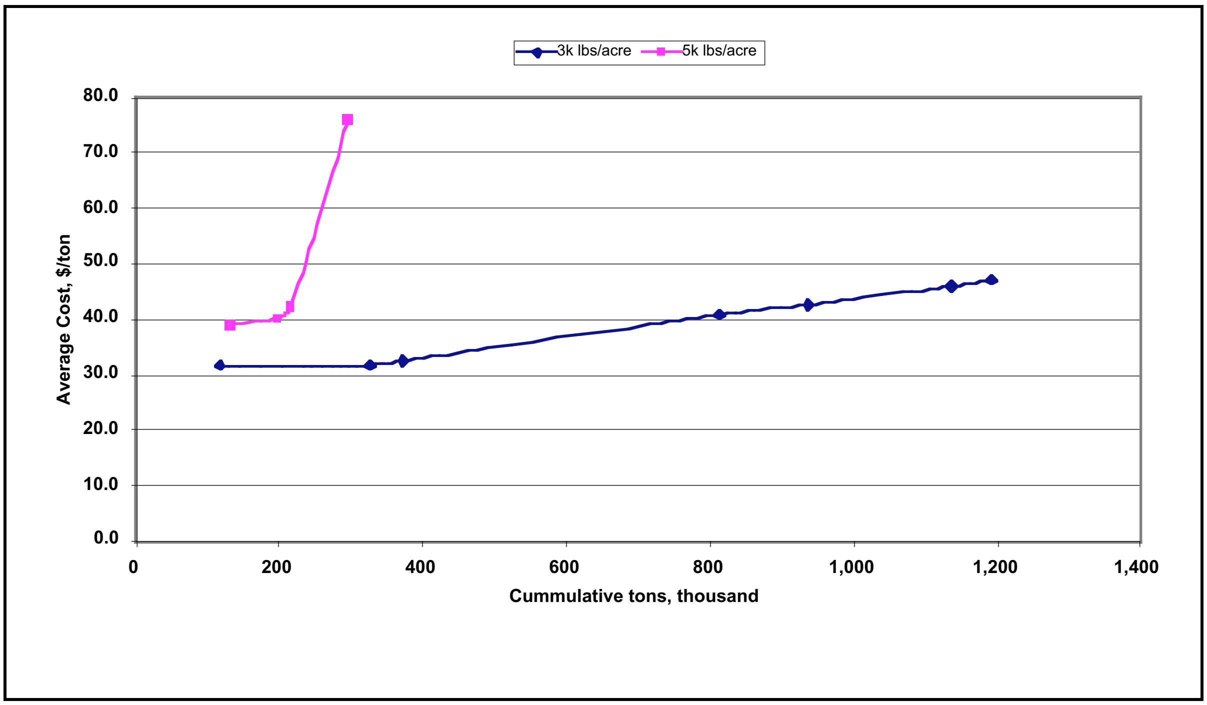
Transportation costs were taken from the Rice Straw Feedstock Study (13). The costs per ton are computed as a fixed cost of $5.50 plus a cost of $0.088 per mile. Thus, for a 50 mile haul the cost would be about $10/ton. These costs are typical of what is found in the Pacific Northwest.

Supply Curve Development

The supply curve is developed by determining the quantity of straw available in each centroid and then computing the cost of recovery and transportation to Moses Lake. The storage costs and fertilizer replacement costs are added to the collection and transportation costs. The lowest cost centroids represent the first areas that straw would come from. As the demand for straw increases, additional centroids are added. The marginal cost of straw for each centroid will increase, but it is the average cost that is most important to the ethanol facility. The average cost is the cost of supplying all the straw needed divided by the total cost from each centroid.

Figure 6 shows the supply curve for Moses Lake using the availability criteria of 3,000 and 5,000 lbs./acre. The centroids from lowest cost to highest cost are irrigated fields from Grant, Adams, and Franklin counties followed by non-irrigated fields from Lincoln, Grant, Adams, and Franklin counties. At the 5,000 lbs./acre level, the costs are higher and the total volume available at a reasonable cost is greatly reduced.

Figure 6
Wheat Straw Supply Curve for Moses Lake



Biomass to Ethanol Conversion Technologies

Ethanol, whether used for fuel or a beverage, is produced by the fermentation of sugars. The source of the sugar can be sugar cane, grapes, starch grains like corn, or, biomass. The process of producing the sugars becomes more difficult as one moves from sugar cane to biomass, because biomass is composed of cellulose, hemicellulose, lignin, ash and soluble substances called extractives. Cellulose and hemicellulose generally represent from two-thirds to three-quarters of the dry weight of most biomass materials. Cellulose is a polymer of glucose and is difficult to break down into glucose because of its crystalline structure. Hemicellulose is composed of several different sugars including the six-carbon sugars glucose, galactose, and mannose, and the five-carbon sugars arabinose and xylose. Hemicellulose is easily broken down into its individual sugars. Lignin is a complex material that acts as glue to hold the cellulose and hemicellulose together. Lignin is currently viewed as a source of fuel to provide steam and power to run the ethanol plant. Extractives can have an economic value depending on their characteristics and cost of recovery. Figure 7 shows the composition of corn and several biomass materials that have been investigated for conversion to ethanol fuel. Wheat straw contains about thirty seven percent glucose and another twenty one percent xylose. The total sugars are comparable to those from corn stover. By comparison, hardwoods are ideal feed stocks because of their high sugar and low ash contents. In corn, the six-carbon portion is composed of starch and cellulose. The extractives include protein and corn oil. The percentage of fermentable materials in corn is quite high.

Figure 7
Composition of Biomass Materials

The basic process steps in producing ethanol from biomass are:

1) Pretreatment to make the cellulose and hemicellulose components more accessible and to remove any foreign matter that may interfere with further processing steps
2) Hydrolysis to break down the polymers into their basic sugars using acids or enzymes
3) Fermentation of the six-carbon and/or five-carbon sugars into ethanol using organisms that convert sugars to ethanol
4) Separating and concentrating the ethanol produced by fermentation.

Pretreatment generally involves both a mechanical step to reduce the size of the biomass materials so they are more readily accessible to reaction with the subsequent steps and a chemical pretreatment to make the biomass more digestible. Chemical pretreatments include dilute acid, alkaline, organic solvent, ammonia, sulfur dioxide or other chemicals. In some cases the chemical reaction are run under high pressures to enhance the breakdown of the products. Care must be taken that the pretreatment does not degrade the material so it can no longer be used for ethanol production. Biological pretreatments have also been tested primarily to solubilize lignin and make the cellulose more accessible to hydrolysis and fermentation

These various pretreatment processes generally result in separating the biomass into a liquid stream composed of hemicellulose and a solid stream composed of cellulose and lignin. The separated streams are than ready for hydrolysis.

Hydrolysis is the step that breaks down the cellulose and hemicellulose polymers into their basic sugars. Some pretreatment steps also result in some hydrolysis, especially of the hemicellulose materials. The major technologies proposed for hydrolysis include dilute acid hydrolysis, strong acid hydrolysis, and enzymatic hydrolysis. Dilute acid hydrolysis is the most advanced technology, while enzymatic hydrolysis is viewed as the technology with the best chance of reducing the costs of producing ethanol from biomass.

Most current designs using dilute acid involve two stages of hydrolysis. The first stage is carried out at milder conditions of temperature and pressure and maximizes the sugar yields from hemicellulose. The second stage is optimized for the conversion of cellulose into glucose. After the sugars are released, the acid solutions must be neutralized before they can be used for fermentation. Both sulfuric acid and nitric acid have been used for weak acid hydrolysis, although there is more experience with sulfuric acid.

Enzymatic hydrolysis involves using an organism that produces enzymes that degrade cellulose into sugars. Enzymes offer the advantage of producing higher yields of sugars with few degradation products. The current challenge is to reduce the cost of producing the enzymes. The Department of Energy currently has two multi-million dollar contracts with biotechnology companies to reduce the costs of enzymes by an order of magnitude.

The third major hydrolysis technology uses concentrated acids. Concentrated acids dissolve and breakdown the crystalline structure of cellulose and when the acid is diluted with water at moderated temperatures, the conversion to glucose is rapid and complete with little degradation. The disadvantage of concentrated acids is their costs. To be economically viable the acid must be recovered and recycled. Fortunately, technologies have been developed to separate the sugars and recover the acid.

Once the cellulose and hemicellulose have been broken down into their basic sugars, it is time for fermentation. Six carbon sugars are readily converted by conventional brewer's yeast into ethanol. For biomass mainly composed of six-carbon sugars, yeast fermentation may be all that is required. However, for materials containing substantial quantities of five carbon sugars, it is not economic to simply waste them. Organisms have been developed by the University of Florida and the National Renewable Energy Laboratory that can convert both five and six carbon sugars to ethanol. The Department of Energy is funding a major effort to develop yeasts that can convert both sugars. The choice of fermenting organism depends on the sugars available, the rate at which the sugars are converted and the concentration of the resulting ethanol solution. The latter two factors have an important bearing on the economics of the process.

The final step of separating the ethanol from the fermentation solution is a well-established technology and there are many equipment manufacturers that can provide the distillation systems.

Status of the Biomass to Ethanol Industry

There is currently no operating commercial scale biomass to ethanol facilities. Research efforts have improved yields and reduced the time to complete individual steps. A few pilot plants are operating to help get better engineering data to permit the design of a commercial facility. There are several projects that are seeking funding to build the first commercial scale facility.

The technologies and feedstock that are vying to be the first to market include concentrated acid by Arkenol, five and six carbon fermentation by BC International, and enzymatic hydrolysis by Iogen. The proposed feedstocks include rice straw, sugar cane bagasse, wheat straw, and wood wastes. Each company is choosing the best combination of processes to integrate into their feedstock of choice and the particular technology niche that they hold.

BC International (BCI) holds patents for the fermentation organisms developed at the University of Florida. BCI purchased an inactive grain based ethanol facility in Jennings, Louisiana and plans to convert it to use rice hulls and sugar cane bagasse. They plan to use established technology for the basic steps of feedstock handling, hydrolysis and product recovery. Hydrolysis will be a two stage, dilute acid process to release the five and six carbon sugars from the feedstocks. They will use their patented fermentation process to produce ethanol from both the five and six carbon sugars. The facility is designed to produce 20 million gallons of ethanol per year. BCI also plans to use enzymatic hydrolysis in place of acid hydrolysis when it becomes economically viable.

BCI has tested both the hydrolysis and fermentation steps at a one ton per day pilot facility belonging to the Tennessee Valley Authority. The results from those tests confirmed material and energy balances that were used in the design and modification of the Jennings plant.

Financing for the BCI plant remains the major problem. Since there are no commercial biomass-to-ethanol facilities, the finance community requires almost each aspect of the project be guaranteed by someone. That means guarantees on the supply of feedstock, the markets for the ethanol, and most important, the conversion processes that have only been demonstrated in pilot plants. Some construction and equipment vendors will provide guarantees but at a high cost because of the risk involved. Insurance companies can also provide guarantees, but at a cost. BCI has spent over two years working on the financing of the Jennings plant and still have not closed the deal. The Department of Energy has helped address technical questions to reduce the risk factors but the costs for this first plant will be very high.

BCI is actively looking beyond Jennings and has conducted feasibility and engineering studies for other projects around the country. They intend to both develop facilities that they own and to license the technology. BCI will phase in new technologies as they are proven. Their major challenge is still to get the Jennings plant financed, and successfully operating.

Arkenol is the major company promoting the use of concentrated acid hydrolysis. The company holds patents on producing sugars using concentrated acid, the separation of acids and sugars, and the fermentation of sugars produced from concentrated acid hydrolysis. They have constructed and operated a one ton per day pilot facility in Southern California. The pilot facility is testing the critical process steps and is not a complete ethanol facility. The advantage of their process is the very high yields of glucose from the cellulose portion of the biomass. They also have adapted yeast that can convert the five carbon sugars to ethanol.

Arkenol has proposed a 12 million-gallon ethanol plant in Northern California that would use rice straw as the feedstock. They would also recover silica as a valuable co-product. They face the same financing challenges as BCI. Their technologies are technically viable but have to be shown to be economic at a commercial scale of operation.

Iogen Corporation in Canada is a major manufacturer of commercial enzymes. They also developed a pretreatment technology called steam explosion that increases the

accessibility of the enzymes to cellulosic materials. This results in both increased yields and faster reaction rates. They hold patents on both the steam explosion technology and the enzymes that hydrolyze the cellulose to sugar. They claim that their enzymes are as good or better than those under development by the Department of Energy.
Iogen is in the start-up phase of a pre-commercial demonstration facility in Ottawa. The primary product will be sugars that will be used for their conventional enzyme production activities. They will take part of the sugar stream and produce ethanol by conventional fermentation of the six carbon sugars to validate the process. They plan to enter a lease agreement to use genetically engineered yeast to ferment the five carbon sugars developed by another company.

The interesting aspect of Iogen's project is that they are using wheat straw as feedstock. Another positive attribute is that the facility they are building is much larger than the typical one ton per day pilot facility. This should reduce the risk and financing costs for a full-scale commercial plant. Finally they have an alliance with Petro-Canada that could make access to capital easier.

Cost of Production, Markets and Economic Impacts

The economic success of a wheat straw to ethanol facility depends on two critical factors. There must be a market for the product at a price that is greater than the cost of production plus a reasonable return on investment. From a broader policy perspective, the economic impact on regional and state economies from an ethanol industry is an important element in determining state policy supporting such an industry.

Cost of Production

The economic success of a wheat straw to ethanol plant depends on the selling price being greater than the cost of production, plus a reasonable return on investment. The production cost consists of both capital and operating costs. Operating costs can be split into fixed costs and variable costs. Fixed costs include labor, overhead, maintenance, insurance, and taxes. Variable costs include feedstock (wheat straw) and other raw materials, as well as waste disposal costs, and utilities. The owners of an ethanol plant will also require a return on their investment.

The National Renewable Energy Laboratory (NREL) prepared a pre-feasibility study for this project. They used their computer models to compute energy and mass balances and capital and operating costs. Feedstock costs and utility costs were provided by Washington State University Energy Program. The NREL economic model assumes 100 percent equity financing and a 10 percent after tax return on investment as their base case for financing. The results are shown primarily in terms of the minimum ethanol selling price. It represents the price that ethanol must be sold for to produce a specified return on investment. The NREL report is included in Appendix 1 and summarized below.

The technology modeled is based on the best that would be available within five years. NREL chose acid pretreatment with enzyme hydrolysis of the cellulose, and co-fermentation of the five and six carbon sugars to ethanol. Figure 8 shows the basic process flow diagram. They looked at two plant sizes; 20 million gallons per year and 40 million gallons per year. They also looked at two methods to provide steam and electricity. The first would use of a biomass boiler system that would produce both steam and electricity. The second option would use a natural gas boiler and purchase of electricity.

Figure 8
Process Diagram for Wheat Straw to Ethanol

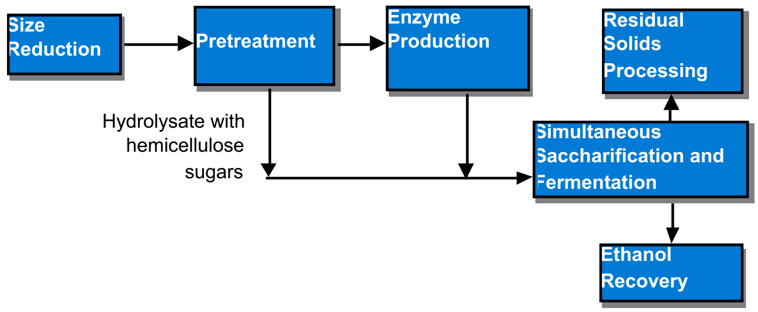


Table 3 shows the capital cost for the major process units. The equipment cost for the 40 million-gallon facility is $103,200,000 with an estimated accuracy of no better than minus 15 percent to plus 30 percent. NREL uses a factor of 42 percent to compute the total project investment cost from the installed cost of equipment. This factor represents the costs to pay for engineering, construction fees, project contingency, and site development. The total investment cost comes to $179,300,000.

The most expensive piece of equipment is the boiler/turbogenerator, accounting for over one-third of the total capital costs. The next largest cost items are for distillation and pretreatment. The use of a biomass boiler does have the advantage that it burns the lignin that remains after the cellulose and hemicellulose are separated. There is enough lignin to provide all of the steam and electrical needs for the facility plus generating an extra 4.4 kWh of electricity per gallon of ethanol produced that can be sold back into the market.

Table 3
Capital Costs for 40 Million Gallon Facility

Operation	Capital Cost, 1999$	Percent of Capital Cost
Feed Handling	$6,100,000	5.9%
Pretreatment	$14,900,000	14.4%
Neutralization/Conditioning	$8,800,000	8.5%
Hydrolysis and Fermentation	$12,400,000	12.0%
Distillation and Solids Recovery	$17,700,000	17.2%
Wastewater Treatment	$1,900,000	1.8%
Storage	$1,400,000	1.4%
Boiler/Turbogenerator	$36,000,000	34.9%
Utilities	$4,000,000	3.9%
Total Equipment Cost	$103,200,000	

The major operating costs are related to capital, feedstock, and enzyme production. Table 4 shows the annual cost and the cost per gallon of ethanol. The process produces more electricity than is consumed and the excess is sold into the market and thus shows as a negative cost.

The cost of wheat straw is taken from the supply curves. The 40 million-gallon plant would require 1,500 tons of wheat straw per day and the cost is estimated at $36/ton. The 20 million-gallon plant requires 750 tons per day at a cost of $32/ton. If straw costs could be reduced by about $10/ton, the cost of producing ethanol would be reduced by $0.15/gallon. Long-term feedstock contracts would likely be necessary for this to be possible. The assumed yield is 69 gallons of ethanol per ton of straw. If all the sugars could be recovered and fermented to ethanol the theoretical yield would be 114 gallons per ton. There is obviously room for improving conversion efficiencies.

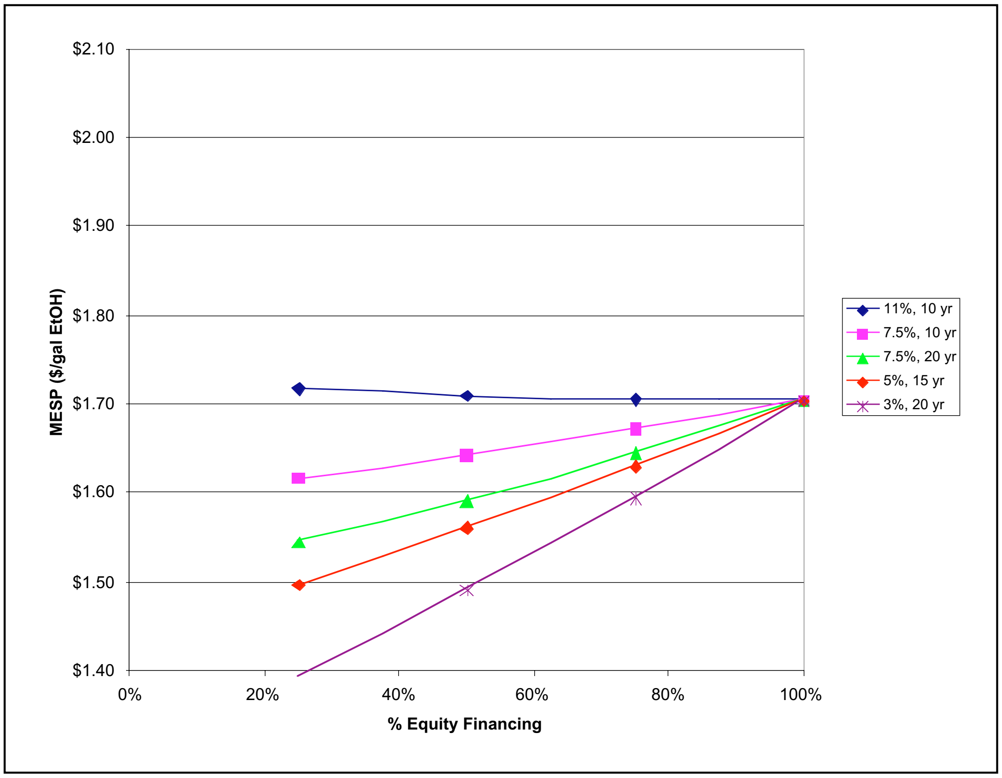
Table 4
Operation Costs for 40 Million Gallon Facility

Operation	Cost ($/year)	Cost (cents/gallon ethanol)
Wheat Straw	$20,400,000	51.0
Enzymes	$6,300,000	15.8
Other raw materials	$4,000,000	10.1
Waste Disposal	$1,200,000	3.0
Electricity	-$2,300,000	-5.7
Fixed Costs	$6,900,000	17.1
Capital Depreciation	$9,000,000	22.5
Income Tax	$6,700,000	16.7
Return on Investment	$16,000,000	39.9

The costs related to capital make up a major part of the operating costs. They are seen as capital depreciation, which represents recovery of capital, and return on investment. If an ethanol project can obtain loan dollars at rates lower than the required return on equity rate, than the operating costs would be reduced. Figure 9 shows the effect of different financing options on the minimum ethanol selling price. The lower the loans interest rate and the longer the term of the loan, the lower the required selling price.

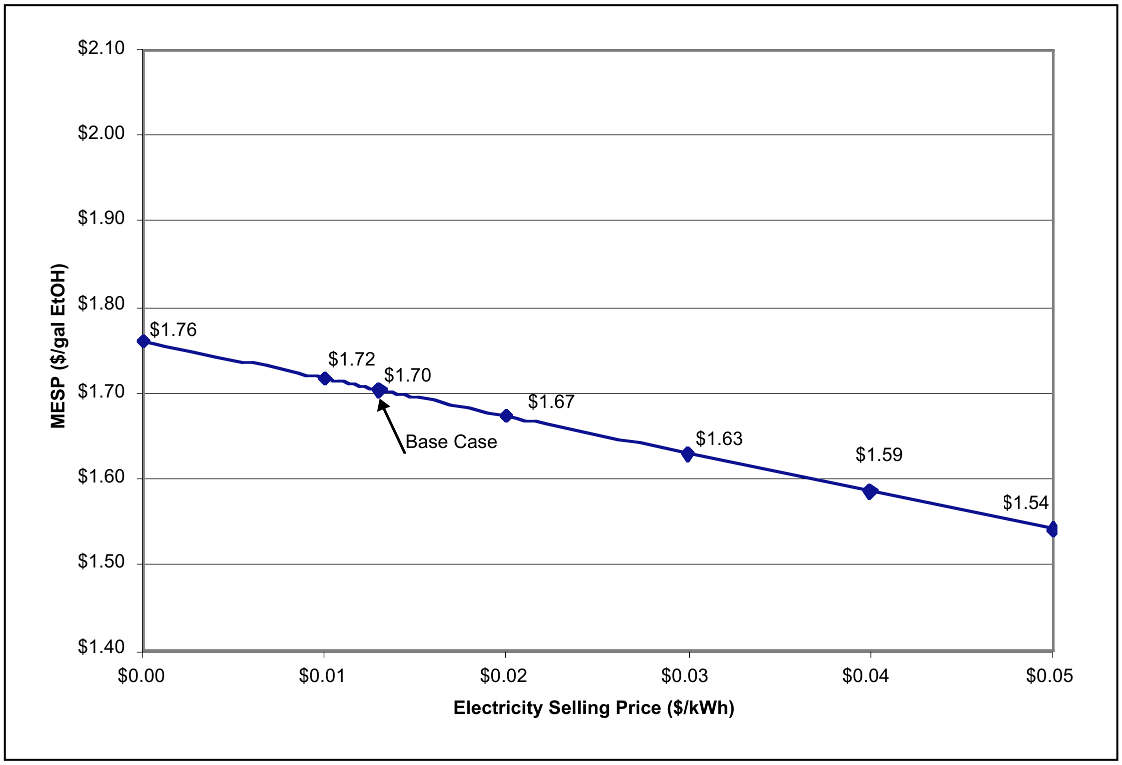
Figure 9

Project Financing Sensitivity Analysis



The credit received for selling the surplus electricity was assumed to be on the cost of electricity in Moses Lake, $0.013/kWh. It is possible that the electricity could be sold as green power and command a higher price. Figure 10 shows the relationship between minimum selling price for ethanol and the price the electricity would be sold for. At $0.04/kWh the minimum price for ethanol would decrease by over $0.10/gallon.

Figure 10
Electricity Price Sensitivity Analysis



The choice of a natural gas boiler or a biomass boiler is determined by the capital costs, the natural gas cost, the value of lignin, and the value of surplus electricity. This study assumed that lignin could not be sold for a profit but would also not be a disposal cost. A facility that could burn the lignin would pay for the transportation cost that would approximate its value as a fuel. Natural gas costs were high ($8/MBtu) when this study was conducted. At that price the minimum ethanol selling price would be $2.14/gallon. However, for the minimum price to be the same as calculated for the biomass boiler system ($1.70/gallon), the cost of natural gas would have to be about $2/MBtu.

The final comparison is related to economy of scale. NREL determined the minimum ethanol selling price for a 40 M gallon and a 20 M gallon per year plant. Even though the cost of wheat straw is lower for the smaller facility, the minimum selling price is $1.93/gallon compared to $1.70/gallon for the 40 M gallon plant.

Ethanol Markets

Production

Ethanol is produced primarily from corn, which accounts for 90% of US production and consumes 6.2% of the US corn crop (14). Agricultural feedstocks, such as grain sorghum, account for most of the remainder of production. As one would expect, the five largest corn producing states, Illinois, Iowa, Nebraska, Minnesota and Indiana, dominate the industry and produce nearly 90 % of domestic ethanol. Non-traditional feedstocks account for a small but growing production capacity, as investigators continue to refine cellulose-to-ethanol technologies and economics.

Ethanol production is also concentrated among a few large producers, with 5 companies accounting for about 60% of production capacity. As of March 2000, the ethanol production capacity for the US was 1.856 billion gallons per year (15). With 6 new plants under construction, industry capacity will be increased by 145 million gallons per year (gpy). An additional 16 projects are under consideration and represent about 400 million gpy of capacity (16). The two Washington State ethanol plants, located at the Georgia Pacific mill in Bellingham and the Miller Brewery in Olympia, have a combined production capacity of 4.2 million gallons per year. The Georgia Pacific pulp mill, which uses wood waste as a feedstock, is idle as a result of current economic conditions. Proposed cellulose to ethanol plants located in the US are presented in Table 5 (10).

Table 5
Proposed Cellulose-to-Ethanol Plants in the United States

Company	Location	Feedstock	MGPY	Proposed Start-up
BC International	Jennings,LA	Bagasse/rice hulls	20	2002
BCI Collins Pine	Chester, CA	Wood waste	20	2002
BCI Gridley	Oroville, CA	Rice straw	20	2002
Arkenol/Sacto	Sacramento, CA	Rice straw	4	2001
Ethanol Partners-MASADA	Middletown, NY Birmingham, AL	Municipal Solid Waste Municipal Solid Waste	6.6 13.5	2001 2002
Sustainable Energy Development	Central Region, OR	Wood waste	30	TBD
Sealaska	Southeast AK	Wood waste	6-8	2003
Standard Energy	Philadelphia, PA	Municipal Solid Waste	TBD	TBD

Markets

Since 1980, ethanol production has been increasing at an annual rate of nearly 12 percent. In 1998, approximately 1.4 billion gallons of ethanol were consumed in the United States (17). While significant, overall gasoline consumption in 1998 was approximately 120 billion gallons.

The primary market for ethanol is as a gasoline additive for octane enhancement. Ethanol is also used for fuel oxygenation to help control vehicle emissions as per federally mandated oxygenated fuel and reformulated gasoline programs. The two most common oxygenates are ethanol and methyl tertiary butyl ether (MTBE).

During 1997, the EPA estimated that 238 million gallons of ethanol was used in oxygenated fuel programs, while 379 million gallons was used in making reformulated gasoline (RFG) (15). The remaining 800 million gallons of fuel ethanol was used for octane improvement in gasoline.

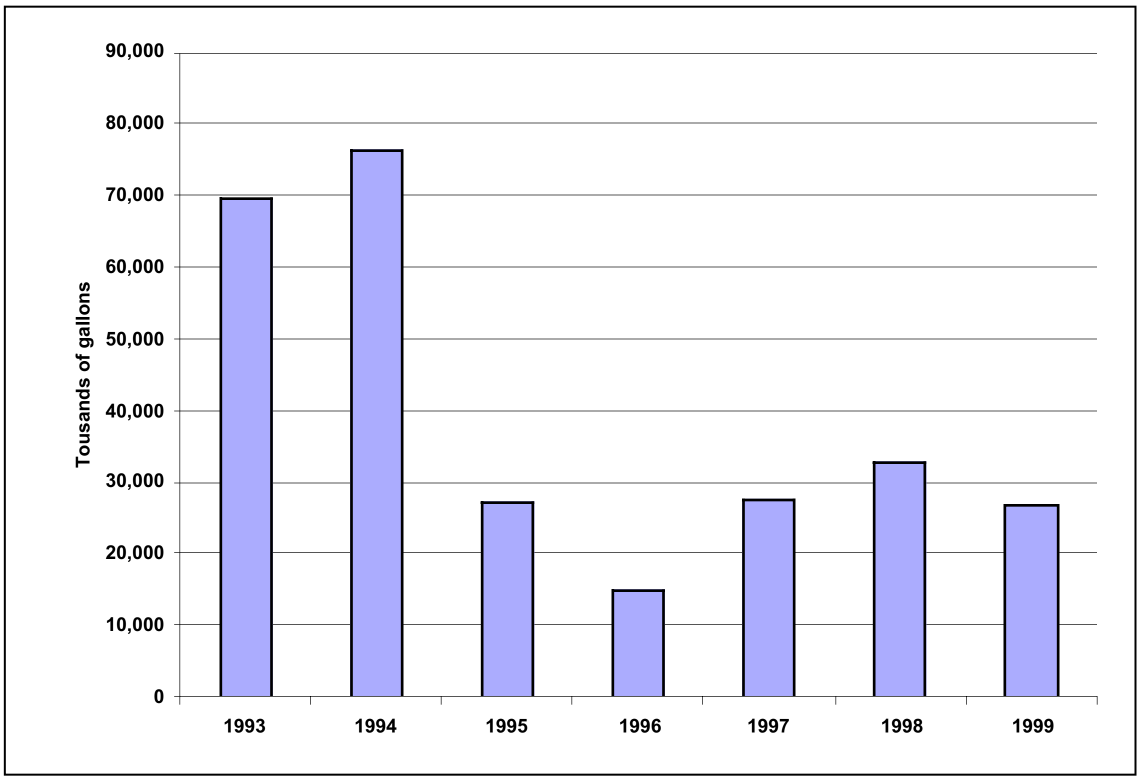
Current market conditions for ethanol may be changing however, as MTBE (methyl tertiary butyl ether) is eliminated from gasoline. MTBE is currently used in reformulated gasoline blends to meet fuel oxygen requirements. Recently, the use of MTBE, a potential carcinogen, has come under intense review. MTBE has been found in drinking water supplies in areas around the country where RFG is used. California has taken the lead in banning MTBE and is phasing out its use by December 31, 2002. Eleven other states, as well as the federal government, are expected to follow California's lead. In fact, Washington State recently banned the use of MTBE in motor fuels during the 2001 legislative session. The Washington State ban goes into effect December 31, 2003.

Ethanol is the leading candidate to replace MTBE in reformulated gasoline providing the federal oxygenate standard is retained. In order to meet the oxygenate need supplied by MTBE, ethanol production under the MTBE phase-out would have to increase to 3 billion gallons in 2004 (18). The State of California, along with a number of other organizations recently attempted to remove the oxygenate standard, arguing that similar emission benefits could be achieved without the addition of oxygenates. While their argument has substance, the debate ended when President Bush directed EPA to deny the oxygenate waiver for California (19). The ethanol market will benefit from this decision.

In Washington, ethanol is used primarily as a gasoline additive for octane enhancement. In the early to mid nineties, ethanol was also used as a fuel oxygenate to help the state meet federal carbon monoxide standards. This created a significant market for the sale of ethanol in Washington. Now, only the Spokane airshed remains out of compliance with federal CO standards. As a result, oxygenated fuels are only required in Spokane during the winter season. Figure 11 illustrates the change in demand for ethanol in Washington

State. As shown, the amount of ethanol consumed in Washington dropped from a high of 76.2 million gallons in 1994 to a low of 14.9 million gallons in 1996 (20). Since this low point, ethanol has rebounded to an annual use of around 30 million gallons. The current demand for ethanol appears fairly steady, as some Washington refiners are finding it profitable to produce sub-octane gasoline and then blending in ethanol to create a higher octane fuel.

Figure 11
Ethanol Use in Washington State



Other Markets

E-85: There are other potential transportation fuel uses that could increase ethanol demand. The use of E-85 (85% ethanol /15% gasoline) in flexible fuel vehicles (FFVs) has received the most attention. By the end of 2001 it is expected that 1.9 million FFVs will be in operation across the country, with auto manufacturers gearing up to produce even larger volumes (21). While future production is dependent on the ability of auto manufacturers to continue to receive Corporate Average Fuel Economy (CAFE) credits for FFVs, congressional support for domestically produced fuels is strong and should help keep this credit alive.

All three major US auto manufacturers produce FFVs. Because these vehicles are being manufactured primarily to receive CAFÉ credits, there has been little publicity informing consumers. In most cases, drivers are completely unaware that they are operating a FFV. Table 6 presents a list of vehicle make and models that are capable of E-85 operations (22).

Table 6
E-85 Compatible Vehicles

All 1999 and 2000 Ford 3.0-L Ranger pickups
All 1999 and 2000 Mazda 3.0-L B-3000 pickups
All 2000 GM 2.2-L S-10 pickups
All 2000 and 2001 GMC 2.2-L Sonoma pickups
All 1998, 1999, 2000 and 2001 Chrysler 3.3-L minivans
All 1998, 1999, 2000 and 2001 Dodge 3.3-L minivans
All 1998, 1999, 2000 and 2001 Plymouth 3.3-L minivans
Selected 1995-2001 Ford 3.0-L Taurus sedans
All 2002 GM Suburban 5.3-L SUVs
All 2002 GM Tahoe 5.3-L SUVs
All 2002 GMC Yukon 5.3-L SUVs

Given the current estimate of approximately 1.9 million FFVs on the road, the demand for ethanol could increase by as much as 570 million gallons per year provided the vehicles were operated 50% of the time on ethanol. In order to achieve these volumes, ethanol would need to be priced competitively with gasoline on a gallon equivalent basis.

A number of FFVs operate in Washington State. Over the last 4 years, Washington State agencies have been preferentially buying FFVs in an effort to meet federal alternative fuel vehicle purchase mandates as required by the Energy Policy Act of 1992. To date, state agencies have purchased more than 630 FFVs. A review of vehicle registration data turned up a surprising number of additional FFVs operating in Washington State. According to DOL, approximately 35,900 vehicles registered in the state of Washington are capable of operating on E-85 (23). While this represents less than one percent of the total vehicles registered in Washington, it does present a sizable market potential for ethanol sales.

While FFVs are rapidly entering the market, there is very little in the way of ethanol fueling infrastructure. Nationally, there are only 122 stations that dispense E-85 fuel, with 54 of these stations located in a single state, Minnesota (24). Although small now, the number of public stations should improve as federal and state initiatives take hold. In Washington State, there are currently no public E-85 stations open. However, the US Postal Service is in the process of putting in a captive E-85 station at its main fleet garage located in south Seattle. The project developer sees this facility as a possible icebreaker, with other stations following. Further, there is a growing interest by some state agencies and municipalities to get E-85 on the state fuel purchase contract.

Oxydiesel: Another possible market for ethanol is to blend it with diesel to produce a fuel called Oxydiesel. Oxydiesel contains about 10-15 percent ethanol and is being marketed as a way to capture fuel emission benefits in unmodified diesel engines. The fuel has been demonstrated in a number of fleets both in Europe and in the U.S. but is still in the early commercialization stage. The market potential for this fuel is large. The transportation sector alone consumes over 36 billion gallons of diesel annually (25). If Oxydiesel were to capture just five percent of this market, the demand for Oxydiesel would be 1.8 billion gallons per year, or 180 million gallons of ethanol at a 10 percent blend rate. Whether Oxydiesel can achieve any market share may depend on how successful the fuel is in helping manufacturers meet upcoming EPA diesel emission standards. Diesel operators are extremely sensitive to fuel price, and Oxydiesel is expected to command a premium of at least $0.05 to $0.07 per gallon at full production (26).

Renewable fuels requirements: There are also a number of bills circulating in Congress that could increase the market demand for ethanol if passed. One bill, entitled the Renewable Fuels Act of 2001 (S.670), would essentially triple the nation's use of ethanol over the next decade by establishing a federal renewable fuels standard. The legislation would require that 0.6 percent of all motor fuels sold in the country be renewable fuels such as ethanol or biodiesel, gradually increasing to 1.5 percent by 2011 (27). A gallon of ethanol derived from cellulosic feedstocks would count as 1.5 gallons of renewable fuel, in an effort to create greater development of this resource.

Another bill currently in front of Congress is the Value-Added Agriculture Act (S.907). This bill proposes to extend the duration of the ethanol excise tax exemption and expand the federal producer tax credit to farmer-owned cooperatives. The bill would also create a 50 percent tax credit on investments in new generation cooperatives that implement processes to add value to crops, such as ethanol production (27). In addition, both the Administration's Energy Plan and the plans being proposed by Congress recognize a continued or increasing role for ethanol in helping to meet U.S. energy needs.

Finally, a number of states have passed legislation favoring ethanol. One of the most interesting bills was passed in Minnesota, where the State has taken a very aggressive role in advancing an ethanol market. A key component of Minnesota's program is a minimum content standard which requires a 7.7 percent by volume oxygenate (ethanol) requirement for all gasoline sold in the state (28). This standard is very similar to the proposed renewable fuels standard being considered at the federal level, and has been instrumental in establishing a strong marketplace for ethanol in the state.

As shown, a fairly robust market for ethanol exists. However, this market is completely dependent on government tax support, and to a lesser degree, air quality policies. A cellulosic based ethanol industry will also remain dependent on these incentives for the near future, but offers the potential for a stand-alone industry as it matures. A discussion of various state and federal ethanol incentives is presented in Appendix 3, including a list of business tax incentives offered by Washington State. A summary of Minnesota's ethanol program is also included in Appendix 3. Minnesota is often cited as a national model for ethanol development.

Ethanol's Market Value

Overall, ethanol's market price is tied to the rack, or wholesale price of gasoline. However, for ethanol to compete with gasoline, it relies heavily on federal, and in some cases, state tax subsidies. Wholesale ethanol prices, before federal incentives, can run as much as twice that of wholesale gasoline prices. The recent run up in gasoline prices has narrowed this difference considerably. The market value of ethanol also depends somewhat on how it is used. As a supply extender, its value may be lower than if it is used as an oxygenate for regulatory compliance.

The current federal subsidy, at $0.53 cents/gallon, allows ethanol to compete as a gasoline additive. A basic pricing formula for ethanol is as follows: (15)

$$GP + FETC + SC - MI = EP$$

Where:

GP	=	gasoline price
FETC	=	Federal excise tax credit
SC	=	state credit
MI	=	margin improvement
EP	=	ethanol price

Using the current federal tax credit of $0.53 cents/gallon, no state credit, a wholesale gasoline price of $0.90 and a margin improvement of 1 cent per blended gallon (or 10 cents per gallon of ethanol used) an example of the formula would be:

$0.90 + $0.53 + $0.0 - $0.10 = $1.33 per gallon ethanol.

Without the federal tax subsidy ethanol would not be able to compete with gasoline. In 1998, Congress voted to extend the ethanol tax incentives until December 31, 2007. The effective amounts of the incentive, however, are to be reduced from the current $0.53, to

$0.52 in 2003 and 2004, and $0.51 in 2005 through 2007. Support for the ethanol tax exemption appeared in the recently released White House energy report. The report recommends "that the President direct the Secretary of the Treasury to work with Congress to continue the ethanol tax exemption" (15). In addition to the blenders tax exemption, a small ethanol producer is allowed a credit of $0.10/gallon for each gallon of ethanol produced, up to 15 million gallons/ year. A summary of federal taxes is presented in appendix 3.

Figure 12 presents the average annual price for fuel ethanol at Seattle since 1991 (4). A comparison of spot gasoline prices, ethanol price and E-85 is shown in Figure 13 for the 12 month period ending in April 2001 (29).

Figure 12
Biannual Ethanol Fuel Price -Seattle

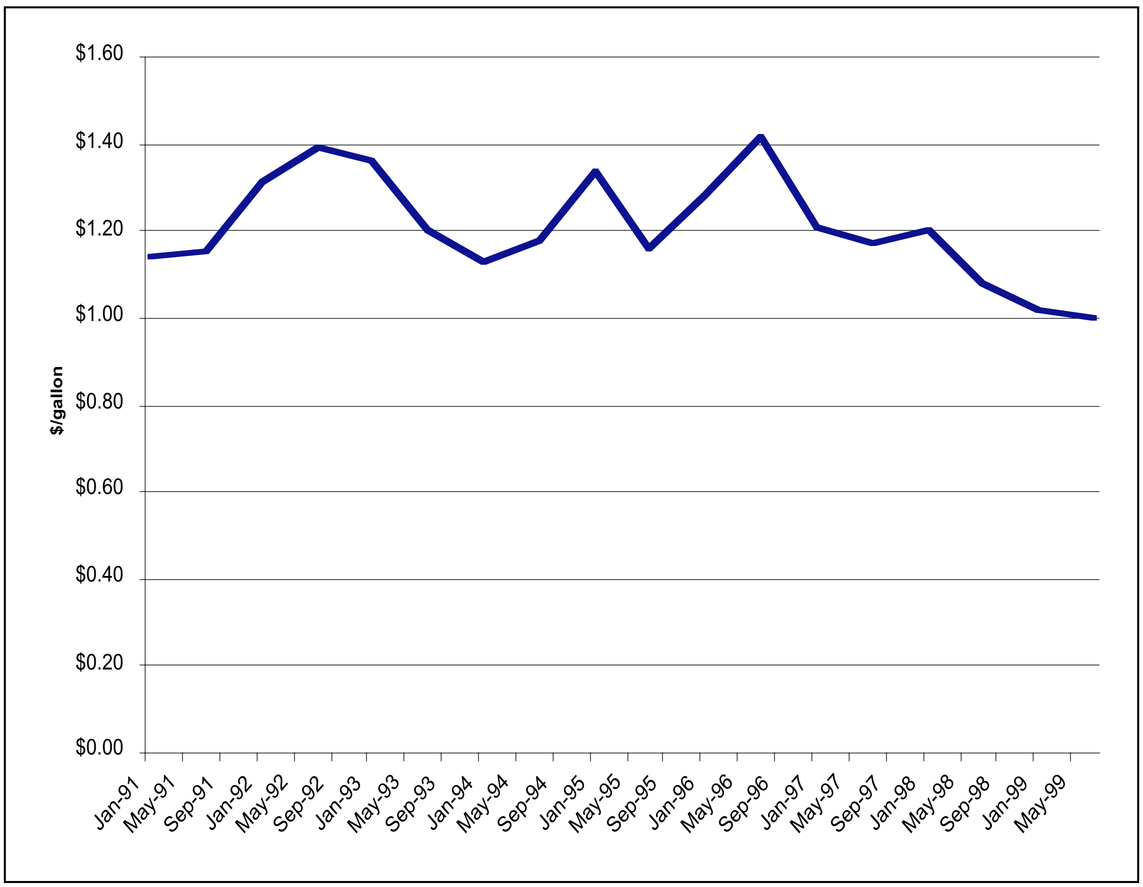
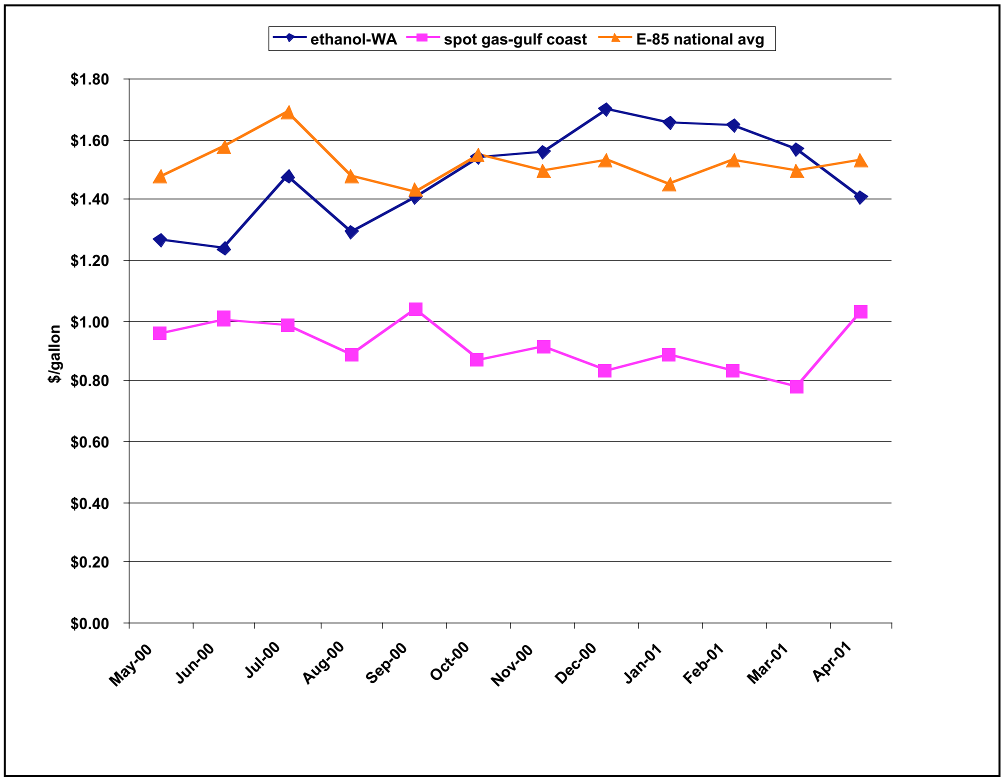


Figure 13
Comparative Fuel Prices



Economic Impacts

The development of a wheat straw based ethanol industry in eastern Washington would have an obvious economic impact on the region and state. The conversion facility was assumed to be located in Moses Lake with straw coming from Adams, Franklin, Grant and Lincoln counties. These counties define the regional area examined. Oregon State University performed an economic impact analysis using IMPLAN, an input-output (I-O) model that accounts for the flows of goods and services to producers, among producers, and finally to consumers. In building the model, we create a matrix that shows the interdependence of the different parts of the economy. Once built, the model can estimate the multiplied effects or impacts of a change within one or many sectors. More details on the economic impacts can be found in Appendix 2.

When a dollar enters the regional economy from the sale of an exported good, service or transfer payment, the dollar or a portion of it is respent many times before leaking out of the economy through the purchase of imports. This respending is the multiplier effect. Specifically, a multiplier is a ratio measure of the total effect throughout the economy of an initial change in one sector

The "direct effects are the changes in the industries (ethanol) to which a final demand change was made. Indirect effects are the changes in inter-industry purchases as they respond to the new demand of the directly affected industries. Induced effects typically reflect changes in spending from households as income increases or decreases due to the changes in production" (30)

The size of the multiplier depends on the amount of magnitude of and the extent to which impacts ripple through the economy. Larger economies generally have larger multipliers because businesses and households make a larger share of their purchases in the local economy. In small economies, businesses and households cannot purchase as much of what they need locally and so more spending "leaks out" of the economy, resulting in a smaller multiplier. This multi-county model has larger multipliers than those of the counties that make up the four county region and the statewide model has even larger multipliers

Methodology

The IMPLAN database is regularly being tested and improved, however, it is a balanced model, which must often estimate to overcome nondisclosure issues at the county level. So, to be reasonably confident that the model accurately characterized the Four County Region, we used the Holland, Geier, Schuster approach (31) to adjust the model to Regional Economic Information Service (REIS) data as provided by the U.S. Bureau of Economic Analysis. For statewide impacts a basic out-of-the-box model was used and then the ethanol sector was added, as discussed below.

National databases take time to gather, summarize, and report. The most currently available data from most of these databases, including REIS, is 1998 so the Minnesota IMPLAN Group, Inc.'s most recent data is for 1998. Calculations were made in 1998 dollars and then inflated on a sector specific basis to 2001 dollars.

The economic impacts of the ethanol plant have been described with a number of variables including the direct, indirect, and induced dollar impacts on employee and proprietor income and total sales and the potential number of jobs, which included both full and part-time, that might be created.

When considering those impacts, the reader needs to remember, an I-O model has limitations. It is completely dependent on its assumptions (e.g. source and price of input stock). We have tried to carefully describe those assumptions. An I-O model is static and linear. It does not account for major changes in markets and technological conditions. It assumes that industries can and do continue to produce goods and services in the same manner without regard to how much they produce.

Even with these limitations I-O models can be very useful for estimating the magnitude of an economic impact and understanding how that economic impact spreads throughout an economy from the backward (supplier) and forward (customer) linkages among industries. For example, an I-O model can indicate which industries will gain jobs and how many jobs will be gained due to the ethanol plant.

The I-O model has more trouble estimating the structural changes that will take place due to the establishment of this new industry in Washington (e.g. how farmers may adjust their crop mix if the value of straw changes from being a production cost or having very low value, it they should be fortunate enough to find a buyer, to increasing in value as the ethanol industry develops).

To build this model, we needed to create an ethanol sector that did not exist in the region or the state. One option would have been to build a very specific production function for the ethanol industry, specify all the values of all the inputs and treat them as direct impacts. However, due to limited resources we used proxy sectors, edited them to represent an ethanol industry, and applied the direct impacts just to those sectors.

Impacts

Construction and operation of an ethanol plant at Moses Lake, as discussed above, would primarily impact a four county area including Adams, Franklin, Grant, and Lincoln counties and to a lesser extent the surrounding counties and the state. This analysis estimates the total construction impact as one event, which could extend over many years, yet, will not continue indefinitely. It estimates the impact of operating an ethanol plant on an annual basis, which may extend indefinitely. It does not discount the stream of benefits and costs of the ethanol plant over its life span to establish a current present value. It does not project the economic activities, which might be displaced by the ethanol production (e.g. other uses for the straw or methods of producing gasoline). It does not anticipate that any state provided incentives, will be funded from net increases in taxes and therefore reduce personal consumption by taxpayers. It is reasonable to expect that other state funded programs may be reduced to fund incentives for ethanol production and the benefits of the ethanol plant will be reduced by the amount of those impacts

The impact scenario, which we analyzed with the model, is summarized below:

Table 7
Direct Impacts from Construction and Operation

Economic Event	Cost/Sales, Million dollars	Employment/Full & Part Time
Facility Construction	$132	944
Ethanol Plant	$52	104

Table 7 shows the estimated direct impacts of constructing and operating the ethanol plant. The number of jobs for each event was determined by dividing the total cost of construction and the total sales of 40 million gallons of ethanol at $1.30 per gallon by the average output per worker in the construction and ethanol industries respectively.

At the regional level we estimated that sixty percent of the construction purchases would be within the region or the Regional Purchasing Coefficient (RPC) would be equal to .6 and that all the construction purchases could be accomplished within state resulting in a statewide RPC of 1.0. The construction impacts are summarized in Table 8.

Table 8
Facility Construction Impacts

Impact Measure	Direct	Indirect	Induced	Total
Region:				
Employment	598	190	179	967
Value-Added, M$	29.2	8.1	7.4	44.7
Output, M$	79.2	14.1	11.8	105.1
State:				
Employment	945	520	503	1,968
Value-Added, M$	52.1	26.9	25.6	104.6
Output, M$	132.0	46.3	40.0	218.3

Each type of metric that is used to describe the impacts is different and some have more limitations or opportunities for overstatement than others do. Output, a measurement of all sales associated with the $132 million change in final demand for construction includes all inter-industry sales so it has a high potential for double counting. As an example; the steel manufacture sells steel to the pipe manufacturer, who sells pipe to the piping contractor, who subcontracts to the prime contractor, and the prime contractor sells the facility to the owner. The original sale of the steel is counted four times. Output is a necessary measure so this project can be compared with other projects, since output is so commonly used. However, it does not provide a net estimate of the change in economy.

Value added only counts the net changes from each transaction. The items that comprise value added are Employee Compensation (wages and salaries, benefits, and any other non-cash compensation), Proprietary Income (income received for self-employed work), Other Property Type Income (individual and corporate interests, rents, dividends, and profits) and Indirect Business Taxes (excise and sales taxes paid by individuals or businesses, yet, does not include taxes on profit or income) (30). So the pipe manufacture's value added, in the example above, would not include the cost of the steel plate, welding machinery, electricity or other intermediate inputs.

It would include the items provided by the pipe manufacturer that added value to the steel to become pipe like rolling and welding the steel plate and welding on the flanges. Employment, as noted previously, includes full and part-time jobs and is not converted to a full-time equivalent.

Table 9
Facility Operation Impacts

Impact Measure	Direct	Indirect	Induced	Total
Region:				
Employment	104	189	82	375
Value-Added, M$	11.2	5.4	3.0	19.6
Output, M$	52.0	11.3	6.1	69.4
State:				
Employment	104	222	113	439
Value-Added, M$	11.2	9.2	5.7	26.1
Output, M$	52.0	17.3	9.8	79.1

Operation of the ethanol plant will have ongoing impacts. The region could experience all the direct impacts in Table 9, which are based on place of work, each year. Indirect and induced impacts will once again be less at the regional than the statewide level due to the higher multipliers in the larger statewide region. However, operation of the ethanol plant will create a new industry in the region, increase regional employment by 1%, and significantly increase employment in a number of specific industries.

Conclusion

The new ethanol plant will have a regional impact and we have tried to maintain that regional perspective throughout the report, yet, each county may experience very different levels of benefits from the new plant. The region has approximately 77,200 jobs so the regional employment impact is just over 1%. However, Adams and Lincoln counties have approximately 14,300 jobs and rely more heavily on agricultural production. So the impacts to Adams and Lincoln counties may, in terms of their proportion of the local county economies, be two or three or more times as great as the impacts to the region as a whole.

Even with the limitations of input-output modeling and the uncertainties of how the feedstock will be produced for the plant, the economic impacts to the region are significant and broadly distributed throughout the economy.

Environmental Benefits

Wheat straw burning

Wheat growers have used burning to manage their crops for a very long time. In recent years, however, concern has been raised over the health effects of smoke from burning fields. These smoke emissions contain air pollutants including particulate matter, carbon monoxide, and volatile organic compounds. These pollutants can result in a variety of cardiovascular and respiratory illnesses, particularly in young children and the elderly. In aggregate, agricultural burning is responsible for as much as 40,000 tons of emissions annually (32).

In February, 1999, the Department of Ecology, the Department of Agriculture and the Washington Association of Wheat Growers signed a voluntary agreement to reduce field burning an average of 7 percent/year for seven years, for a total emission reduction goal of 50 percent by June 30, 2006. So far the program appears to be succeeding. During the first full crop year (fall 1999/spring 2000) after the agreement was signed, wheat-stubble burning was reduced by 27 percent (18). This success has not prevented a lawsuit brought by the Spokane-based group Save Our Summers (SOS), however. SOS contends that the agreement between Ecology and the Association of Wheat Growers does not go far enough in reducing field burning and violates the Clean Air Act and the State Environmental Policy Act. The federal court in Spokane will hear the case in July 2001. The outcome of that trial will likely determine the future of wheat straw burning in Washington State (33).

Despite what the court decides, field burning of wheat straw will eventually be phased out in Washington State. Methods for reducing field burning emissions include burning fewer residues, burning more cleanly and finding alternative practices to burning. While collecting field residues for use as feedstock for ethanol production would provide huge emission reduction benefits, other alternative uses or practices such as no-till farming could provide similar benefits. Therefore, utilizing wheat straw for ethanol production cannot claim a unique emission reduction benefit. However, lifecycle emissions from the displacement of gasoline by ethanol could offer additional air quality benefits to the region.

Soil Erosion

Removing wheat straw for alternative uses may cause soil fertility and erosion problems if too much is taken off. As was discussed above, the quantity of wheat straw that must be left on the ground depends on a host of factors including slope of the land, precipitation, soil fertility and tillage practices. In irrigated areas removing wheat straw is essential to successful operations, while in some dryland areas the amount of wheat straw that could be available for alternative uses may be to low to be practical. The overall objective is to maintain soil fertility, which involves nutrient and organic management and minimizing erosion. Therefore, care must be taken before initiating a full-scale wheat straw removal plan in order to meet the combined objectives of good tillage practices and optimizing feedstock availability.

Ethanol Use in Vehicles

Since the 1990 Clean Air Act, ethanol has played a role in improving urban air quality. Ethanol's primary contribution has been in reducing carbon monoxide (CO) emissions through federal oxygenated fuels programs. Carbon monoxide is a colorless, odorless, poisonous gas produced from the incomplete burning of petroleum fuels. As an oxygenate (ethanol contains 35 percent oxygen) ethanol enhances the combustion of gasoline and is credited for reducing CO emissions by as much as 25-30 percent (20).

In the early 1990's, Washington State had a number of airsheds that did not meet federal CO standards. The implementation of a winter oxygenated fuel program (using ethanol) coupled with the continued turnover of older vehicles, brought all but one of these airsheds into compliance with federal standards. Today, only the Spokane airshed is in noncompliance with federal CO standards and continues to use oxygenated fuels during the winter season.

Adding ethanol to conventional gasoline also reduces tailpipe emissions of volatile organic compounds (VOCs) (21). VOCs are highly reactive in the atmosphere and are significant sources of ground-level ozone formation. However, total VOC emissions appear to increase because of the increase in evaporative VOC emissions (21). This is due, in part to the federal waiver that allows a one-psi increase in Reid Vapor Pressure (RVP) for conventional fuels containing 10 percent ethanol. NOx, another ozone forming agent, also increases slightly with the addition of ethanol, primarily a result of the added oxygen in the fuel. Ethanol fuels also increase emissions of acetaldehyde and formaldehyde. However, other air toxic emissions including benzene, 1-3 butadiene, toluene and xylene are significantly reduced (20,21).

The addition of ethanol to reformulated gasoline (RFG) also decreases CO emissions. However, VOC and NOx emissions do not increase as a result of adding ethanol to RFG fuels (21). This is because RFG fuels must meet strict NOx and VOC specifications; therefore, refiners compensate for the RVP increase by producing a lower RVP fuel for blending with ethanol. RFG fuel containing ethanol also experiences a reduction in toxic air emissions of up to 30%, and only a slight increase in acetaldehyde and PAN (peroxyacetyl nitrate) emissions (21). Table 10 presents changes in emissions when ethanol is blended with conventional gasoline and RFG.

Table 10
Changes in Emissions when Ethanol is blended
with Conventional Gasoline and RFG

	Conventional Gasoline	**RFG**
Toxic air pollutants		
Acetaldehyde	increase	increase
Benzene	decrease	decrease
1,3-butadiene	decrease	decrease
Formaldehyde	increase	decrease
Criteria air pollutants		
CO	decrease	decrease
NOx	increase	no change
Tailpipe VOC	decrease	no change
Evap VOC	increase	no change
Total VOC	increase	no change
Particulates	decrease	decrease
Other		
PAN	increase	increase
Isobutene	decrease	decrease
Tolulene	decrease	decrease
Xylene	decrease	decrease

Source: D.Andress, *Air Quality and GHG Emissions Associated with using Ethanol in Gasoline Blends,* ORNL, 11X-SY838, May 2000

The biggest environmental concern surrounding fuel oxygenates is the leaching of MTBE, a potential carcinogen, into groundwater. As previously discussed, the debate has moved to the outright banning of MTBE from gasoline, with California leading the charge. Because of the concern raised by MTBE, all oxygenates including ethanol, have come under scrutiny. A scientific review conducted by the California Environmental Policy Council and the Air Resources Board examining alternatives to MTBE found that "the substitution of ethanol and alkylates for MTBE in California's fuel supply will not have any significant air-quality impacts" (22). Further, the California Environmental Policy council stated that "Ethanol is a safe, biodegradable fuel that does not pose a threat to water, soil, or public health, and has been awarded a clean bill of health" (22).

The emissions characteristics of E-85 (85 percent ethanol and 15 percent gasoline) has received less attention than lower blend fuels, but there appears to be some air quality benefits attributed to its use. Some reports cite a 30 to 50 percent reduction in ozone-forming emissions (35). However, vehicle manufacturers do not appear to have focused on emission benefits of flexible fueled vehicles. Typically, a manufacturer certifies a FFV at the same standard as their gasoline counterpart. Much of this has to due with the uncertain use of ethanol during vehicle operations. E-85 proponents often refer to vehicle emission evaluations conducted by the National Renewable Energy Labs (NREL) when assessing FFV performance. NREL emission results for FFVs tested on both gasoline and E-85 fuel reveal similar NMHC and NOx emissions, with CO2 emissions approximately 9% lower for E-85, and CO emissions as much as 17% higher for E-85 (24). Emissions of total potency weighted toxics (including benzene, 1-3 butadiene, formaldehyde and acetaldehyde) for E-85 operations were identified as 55% lower than gasoline (24). If automobile manufacturers designed FFV operations to maximize E-85 benefits, then air quality benefits from E-85 operations should be even greater.

Greenhouse gas benefits: Global climate change resulting from the combustion of fossil fuels is a persistent and growing concern in the international community. Transportation is a major contributor of greenhouse gas emissions, accounting for approximately 35 percent of carbon dioxide emissions nationally, and 60 percent in Washington State.

Although greenhouse gas emissions (GHG) are not yet regulated by the EPA, an increasing number of states, local governments, and utilities are looking at ways to limit these emissions. Biofuels, such as ethanol, are finding support as a result of producing less GHG emissions than traditional transportation fuels. Because the carbon dioxide released during combustion comes primarily from carbon dioxide taken up during photosynthesis, a net emission reduction of carbon occurs when burning ethanol. While corn ethanol offers only modest emission benefits, due to the high energy cost of growing and processing corn, cellulosic ethanol promises nearly zero net GHG emissions.

A 1999 Argonne National Laboratory report calculated the full fuel-cycle energy and GHG emissions associated with fuel ethanol (36). The ANL study tried to account for all potential GHG sources including product displacement. What they found was that corn ethanol used in E-10 currently reduces GHG emissions by approximately 1 percent per vehicle mile driven when compared to conventional gasoline. Put another way, GHG emissions are reduced by 12 percent to nearly 20 percent for every gallon of corn ethanol consumed in E-10 blends (the difference in GHG emissions is attributed to efficiency differences between dry and wet corn milling). By 2005, GHG emissions reductions for corn ethanol are expected to increase to between 24 and 26 percent due to advances in farming practices and ethanol conversion efficiencies. As expected, GHG emissions from cellulosic ethanol are considerably better. By 2005, every gallon of cellulosic ethanol used either in E-10, E-85, or E-90 blend mix is estimated to reduce GHG emissions by 84 to more than 100 percent. Table 11 presents GHG emission reductions per gallon of ethanol.

Table 11
Reductions in Greenhouse Gas Emissions per Gallon of Ethanol in Ethanol Blends

	E-10		E-85	
	Dry-Mill	Wet Mill	Dry Mill	Wet Mill
Corn ethanol-Current	19.2%	12.4%	23.8%	17.3%
Corn ethanol- near future (2005)	26.4%	24.1%	32.3%	30.1%
	Woody biomass	Herbaceous biomass	Woody biomass	Herbaceous biomass
Cellulosic ethanol-near future (2005)	130.6%	83.6%	129.7%	85.7%
Cellulosic ethanol-future (2010)	143.8%	112.0%	115.4%	85.6%

Source: M.Wang,C.Saricks,D.Santini, *Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions,* ANL/ESD-38, January 1999

Recommendations

The previous sections of this report identified opportunities and barriers to the use of wheat straw for ethanol production in Washington. The quantity of straw available for conversion to ethanol, or any other product, is critically dependent on the landowners decision as to how much straw he feels can be removed and still insure sustainable production of crops. The technology to convert straw to ethanol is yet to be demonstrated at a commercial scale facility, although pilot scale facilities have identified a choice of viable technology options. The estimated cost of producing ethanol from cellulose is currently higher than the cost of producing ethanol from corn; however, the markets for ethanol are available if the product can be produced at a competitive price. In addition, there are energy and environmental advantages to using wheat straw to produce ethanol. The use of ethanol fuels offers air quality benefits over gasoline and diesel, and could help soften petroleum price increases or supply disruptions. What actions can be taken to address these barriers and help move the industry forward in Washington State?

Straw Availability

The availability of straw is a complex issue involving science, landowners feelings about their land and their need to survive economically, and regulatory issues on conservation practices. In addition, there are questions of annual yield variability, site specific aspects of each field, the costs of collecting the straw and the effects of different tillage practices.

The National Resources Conservation Service and Washington State University have the scientific knowledge to provide recommendations as to how much straw could be removed from individual fields. In turn, the landowners have to make decisions about the benefits or costs that they may incur with removal of straw from their land. Finally, a developer will need to be assured that wheat straw is available at a competitive price and over a sufficient period of time.

Recommendation

The Washington State Department of Agriculture, Office of Trade and Economic Development, and Washington State University Cooperative Extension/College of Agriculture and Home Economics should convene an advisory committee that would represent the various stakeholders. This committee could explore in more detail the questions that have been raised about straw availability and work towards guidelines that would be useful to the resource agencies, the landowners, and the developers.

Technology

The technology to convert straw to ethanol is being developed by both the U.S. Departments of Energy and Agriculture, as well as private companies. Work is proceeding in the laboratory, pilot facilities, at one pre-commercial facility. Federal investments in improving the enzymes for hydrolysis, and the organisms for fermentation should result in improved yields, which translates into lower costs. The cellulose-to-ethanol industry is in it infancy and there should be efficiency improvements and capital cost reductions as the industry gains experience.

Recommendation

Washington State and the agricultural community should actively encourage the Federal government to commit more dollars to the full-scale demonstrations of technologies as they are proven in the laboratory. Only through actual experience with commercial scale operations can the engineering improvements be made that will move the industry from its infancy to maturity. Because wheat straw is the most promising feedstock for Washington, efforts should be made to establish a commercial facility in Washington State.

Economics

The NREL study determined a minimum ethanol-selling price of $1.70/gallon. This was based on a 10 percent return on investment and 100 percent equity financing for a 40 million gallon per year facility. The cost of financing was identified as a major expense. This could be reduced by lowering the capital cost, such as co-locating at an existing facility with biomass boilers, and by having access to low cost loans. The state of Minnesota provides producer tax credits and low cost financing for production of ethanol within the State. Their analysis shows this has a net benefit to the States' economy. In the past, the Federal government has offered low cost loans or loan guarantees to reducing the financial costs for ethanol facilities.

The IMPLAN model showed the economic benefits to the Moses Lake area from the presence of an ethanol facility. This serves as a basis for justifying investment of state dollars in an industry that will be of net benefit to all the citizens of Washington.

Recommendation

The Governor, as a member of the Governors Ethanol Coalition, and Washington State Congressional representatives should advocate for Federal financial incentives to help establish a cellulose-to-ethanol industry. Currently, there are bills in front of Congress that, if supported, would help to jumpstart this industry. Washington State should follow

Minnesota's lead and begin developing a set of incentives and policies that support the production and use of ethanol fuel made from agricultural waste products. While it may be premature to institute an incentives program at this time, debating the pros and cons of various state incentives, including a renewable fuels standard, should begin.

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Appendix 1

National Renewable Energy Report

National Renewable Energy Laboratory

Washington State Wheat Straw-to-Ethanol Study:

Pre-feasibility Study and Modeling Results

August 6, 2001

Completed by:

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Notice

Executive Summary

The Process Engineering group in the Biofuels Division of NREL was approached with the task of developing a pre-feasibility study to look at ethanol potential from wheat straw in the state of Washington. An enzymatic hydrolysis process was chosen for the base case model. Several process designs were compared and various sensitivity analyses were conducted to examine the impact of certain variables on the overall process economics. Capital and operating costs were tallied, and a minimum ethanol selling price was calculated using a discounted cash flow rate of return determination. Several suggestions for future cost savings were presented as well.

Introduction

On June 5, 2001, the Process Engineering group in the Biofuels Division of NREL was approached with the task of developing a pre-feasibility study to look at ethanol potential from wheat straw in Washington State. Dr. Jim Kerstetter, representing Washington State University and the Washington State Energy Office, is preparing a report for the Washington Office of Trade and Economic Development on the use of wheat straw for ethanol production. This report would benefit from the quantitative data generated by the NREL biomass-to-ethanol model.

Agricultural wastes and residues such as wheat straw can be used to produce ethanol, a valuable commodity. Ethanol is continuing to gain popularity as an alternative fuel or fuel additive. With recent concerns about groundwater pollution from the fuel additive MTBE, ethanol may become the fuel additive of choice. The use of ethanol as a neat fuel has also gained popularity because of its ability to reduce harmful auto emissions. Most of the ethanol produced in the US currently comes from the corn ethanol industry.

The model results will be shown primarily in terms of a Minimum Ethanol Selling Price, or MESP. This value is in $-per-gallon-ethanol. The minimum ethanol selling price can also be thought of as the ethanol production cost plus capital depreciation, a specified return on investment (10% for the base case), and income taxes. In other words, it is the price that ethanol must theoretically be sold for to produce a specified return on investment. In addition to the MESP, all capital and operating costs will be specified. Various sensitivity graphs can be found in the body of the report as well.

Developing a model that describes the technical process and its economics requires inputs from many different areas. Mass and energy balances are generated with the help of Aspen Plus process modeling software. This software package enables NREL to develop thermodynamically rigorous models, using built-in physical properties as well as properties developed at NREL. Further research results achieved at NREL are also included in this model. Using these mass and energy balances, a detailed equipment design is performed. From this design, equipment purchasing and installation costs are developed and obtained from vendor quotations when possible. Once the capital and operating costs for the plant are established, a discounted cash flow analysis is used to determine the project MESP using a set rate of return.

Process Description

There are various processes available for converting biomass to ethanol, such as Two-Stage Dilute Acid Hydrolysis, Concentrated Acid Hydrolysis, and Enzymatic Hydrolysis. An enzymatic hydrolysis process was chosen for the base case model because it was assumed that the theoretical wheat straw-to-ethanol plant would not be constructed for at least 5 years. By then, NREL envisions that enzymatic conversion technology for biomass to ethanol will be sufficiently developed and implemented. This is explained in further detail in the process description that follows.

The first application of enzymes for hydrolysis of wood in an ethanol process was obvious—simply replace the acid hydrolysis step with an enzyme hydrolysis step. This configuration, now often referred to as "separate hydrolysis and fermentation" (SHF) is shown in Figure 1. Pretreatment of the biomass is required to make the cellulose more accessible to the enzymes. Many pretreatment options have been considered, including both thermal and chemical steps. Some of the pretreated biomass is diverted to enzyme production fermentors, where organisms such as *T. reesei* are grown on the biomass to produce enzymes which can be used to hydrolyze the cellulose contained in the remaining biomass to sugars. Early versions of the process then used yeast to ferment just the glucose to ethanol.

Another important process improvement made for the enzymatic hydrolysis of biomass was the introduction of simultaneous saccharification and fermentation (SSF), as patented by Gulf Oil Company and the University of Arkansas. This new process scheme reduced the number of reactors involved by eliminating the separate hydrolysis reactor. More importantly, the SSF scheme avoids the problem of product inhibition associated with enzymes. In the presence of glucose, β-glucosidase stops hydrolyzing cellobiose. The build up of cellobiose in turn shuts down cellulose degradation. In the SSF process scheme, cellulase enzyme and fermenting microbes are combined. As sugars are produced by the enzymes, the fermentative organisms convert them to ethanol. This variant of the enzyme process is shown schematically in Figure 2.

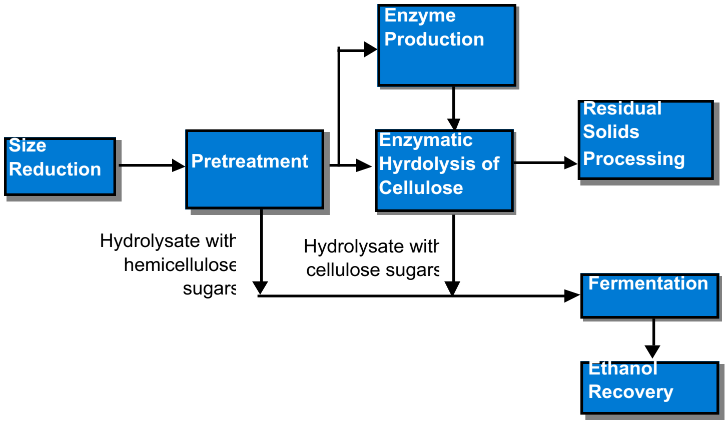


Figure 1: The Enzyme Process Configured as Separate Hydrolysis and Fermentation

Both process schemes have been able to take advantage of the recent improvements in fermenting organisms that can handle the different sugars from hemicellulose along with the glucose from cellulose.

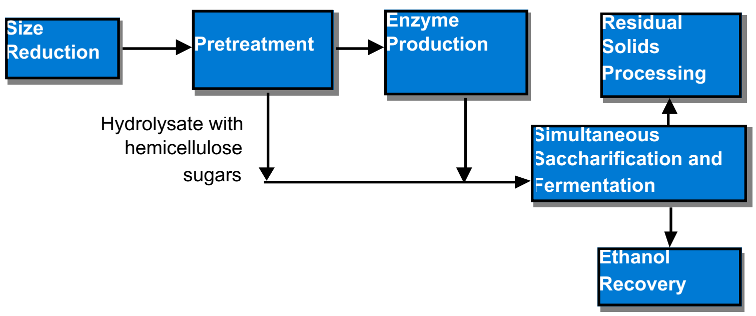


Figure 2: The Enzyme Process Configured for Simultaneous Saccharification and Fermentation (SSF)

Model Results

The carbohydrate composition of the biomass feedstock is very important for determining its ethanol potential. For this model, the wheat straw composition listed in Table 1 was used.

TABLE 1 – WHEAT STRAW COMPOSITION USED IN MODEL[1]

Component	% Dry Basis
Glucan	41%
Xylan	19%
Lignin	18%
Ash	7.2%
Soluble Solids	9.1%
Acetate	0%
Arabinan	3.5%
Galactan	2.2%
Mannan	0%
Moisture	15%

Two process designs were considered. The first design uses a biomass boiler to produce the necessary process steam, and uses a turbine generator to provide the plant's electrical needs. This design produces excess electricity, which could be sold to a nearby power consumer or sold back to the local power supplier / grid for additional revenue. Boiler feed consists of process by-products, the most important of which is a lignin-rich residue. The capital costs of this boiler and generator are relatively high.

The second design uses a natural gas boiler to produce the required process steam. The advantage of this design is that the capital cost of the natural gas boiler is much lower than the biomass boiler. However, with this boiler, natural gas fuel and electricity must be purchased instead. Also, the by-product lignin-rich residue previously mentioned must be disposed of since it can no longer be burned on-site. Gaining revenue from selling the lignin-rich residue would greatly aid the process economics.

A complete set of key process assumptions can be found in Appendix A of this report. Among these are region-specific costs (specified by J. Kerstetter) for process water ($0.92/1000 gallon), wastewater treatment ($0.152/1000 gal), electricity ($0.013/kWh), and natural gas ($8.07/mmbtu). A feedstock cost curve was also supplied for this pre-feasibility study and is found in Appendix B.

[1] Nguyen, Q. NREL 1998.

To get a rough idea of the economies-of-scale for such an ethanol plant, two plant sizes were modeled: 40 mm gal etoh/yr and 20 mm gal etoh/yr. This translates to 1500 dry tons and 750 dry tons of biomass feedstock per day respectively. Based on the feedstock cost curve given, feedstock costs of $36/dry ton and $32/dry ton were used for each plant size.

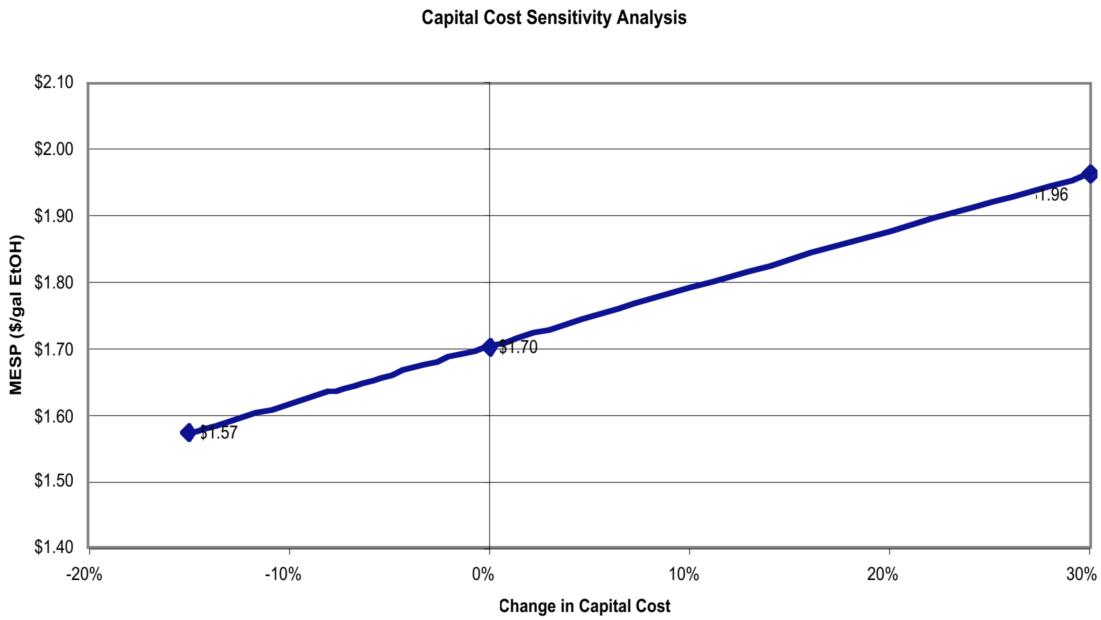
As Appendix C shows the minimum ethanol selling price calculated for the base case model was **$1.70/gallon ethanol**. Appendix C also shows that the total project capital investment would be about $180MM for the project financing parameters assumed. The largest operating cost is the feedstock cost at $20MM/yr. Because of economies-of-scale, a larger MESP ($1.93/gal etoh) was calculated for the 20-million gallon-per-year ethanol plant despite the lower feedstock cost. This is shown in Appendix D.

The MESP calculated for the natural gas boiler scenario was much higher at $2.14/gallon ethanol. This was due to the extremely high cost of natural gas ($8.07/mmbtu) and net-zero revenue obtained for the lignin-rich residue. The cost to transport the residue off-site is assumed to be covered by a nearby user, but no additional value is assumed to be obtainable. A sensitivity analysis on the cost of natural gas is provided in the discussion that follows.

Discussion

The capital cost estimate for this level of engineering analysis is no better than –15/+30%. Therefore, the capital cost of the plant in question has a large potential range. This will significantly impact the economic viability of this plant. The magnitude of such an impact can be seen in Figure 3 below. A sensitivity analysis was performed on the capital cost for the base case in order to determine its effect on the project MESP.

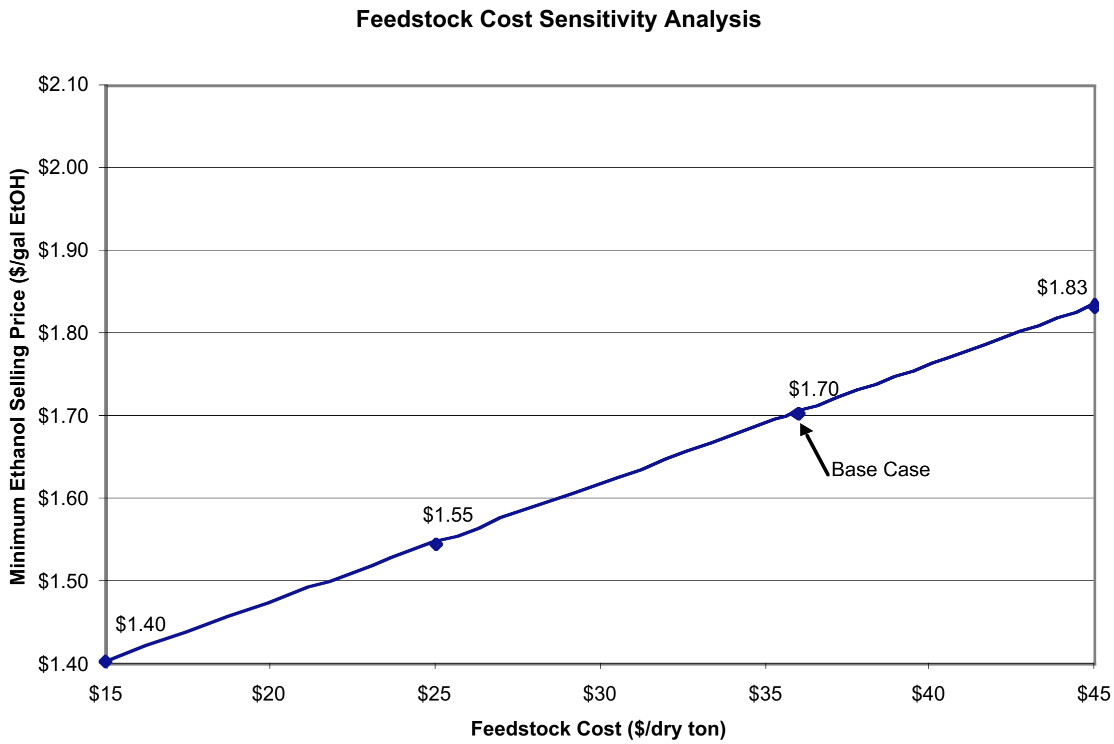
Figure 3. – Capital Cost Sensitivity Analysis



As Figure 3 shows, if the actual capital cost of the plant is 30% higher than the estimated capital cost, the MESP approaches $2.00/gal etoh. Likewise, if the actual cost dropped by 15% from the estimated cost, the MESP would decrease by $0.13/gal etoh. This range of –15/+30% corresponds to a range in capital cost of $152 MM to $233 MM.

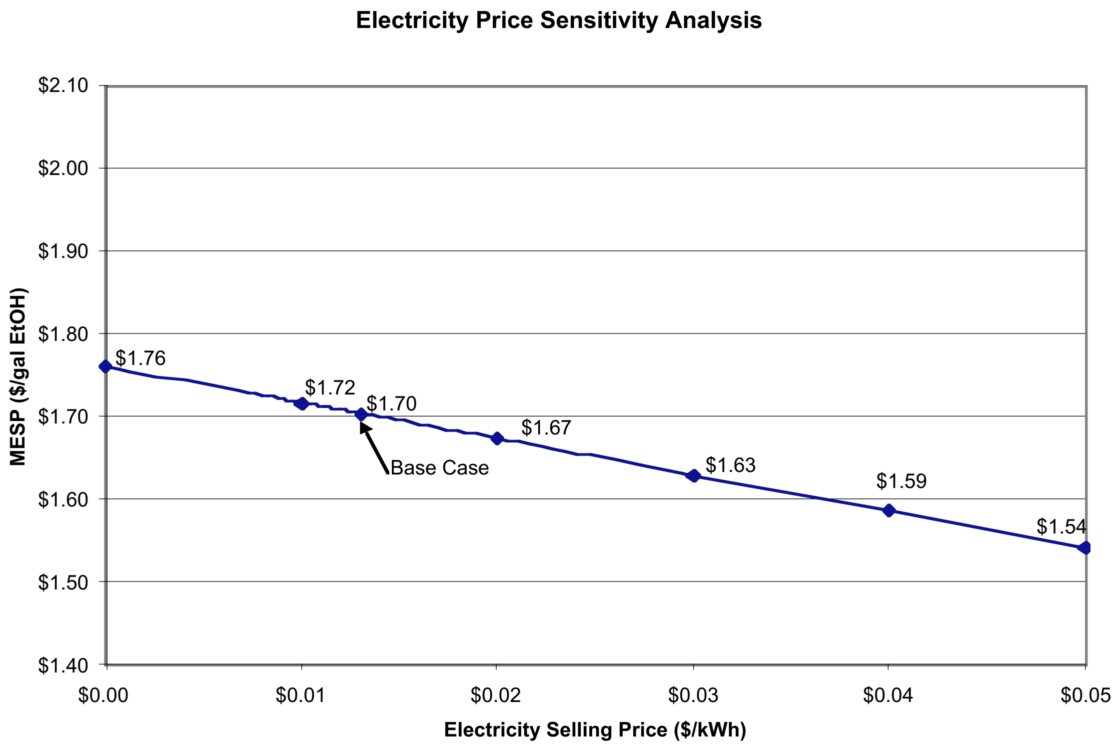
The feedstock cost has a very large impact on the overall process economics as well. A 40 mm gallon-per-year ethanol plant would require 1500 dry tons of wheat straw per day, or approximately 525,000 dry tons per year. Based on the given cost curve, this corresponds to a feedstock cost of $36/dry ton. Figure 4 shows the impact of feedstock cost on the MESP. If this feedstock cost could be reduced by about $10 per dry ton, $0.15/gallon ethanol could be saved. Long-term feedstock contracts would likely be necessary for this to be possible.

Figure 4. – Feedstock Cost Sensitivity Analysis



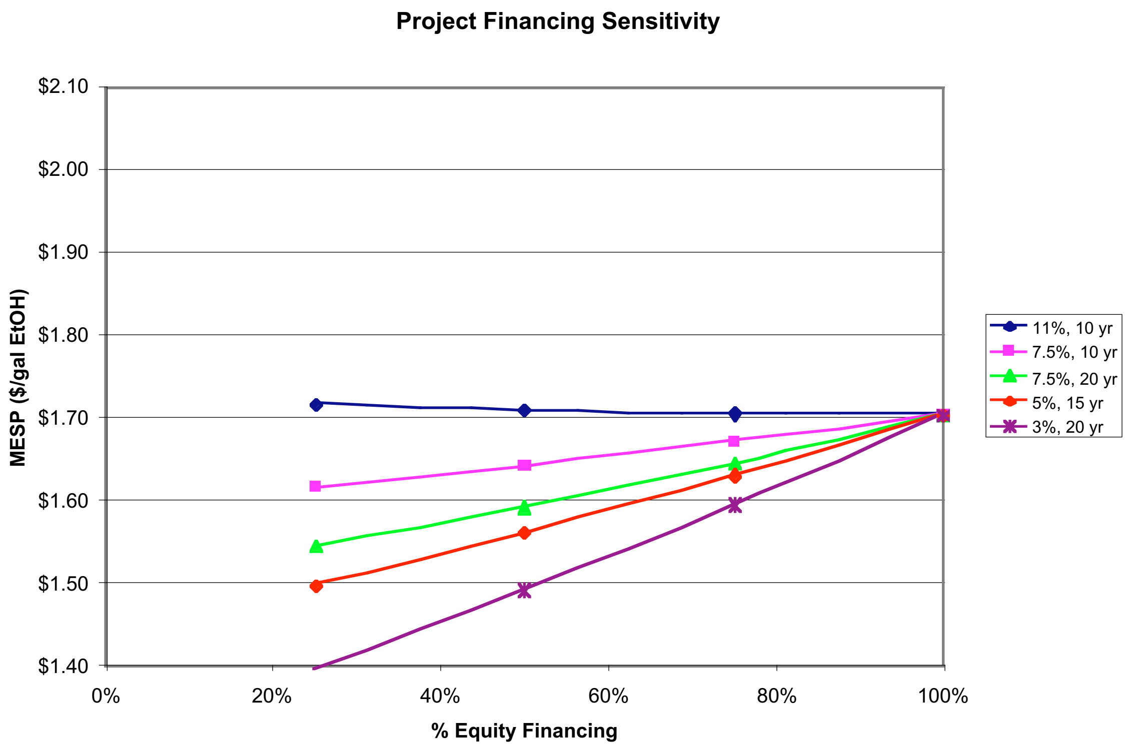
The price received for selling excess electricity back to the local power grid will also impact the MESP. For the base case, $0.013/kWh was assumed to be the price received for electricity. If this price could be raised to $0.04/kWh, the MESP would decrease by over $0.10/gal etoh. This is evident in Figure 5 below.

Figure 5. – Electricity Cost Sensitivity Analysis



The financing arrangements can play a critical role in the success or failure of a biomass to ethanol plant. Plant financing is entirely site-specific and will vary greatly from facility to facility. For the base case model, 100% equity financing was assumed. However, whoever builds the ethanol plant may not choose to finance the project in this way. He/she may finance the project partially through equity and partially through debt financing (i.e. loans). As the amount of debt financing for the project increases, the loan interest rate and period have much larger impacts. This is shown in Figure 6.

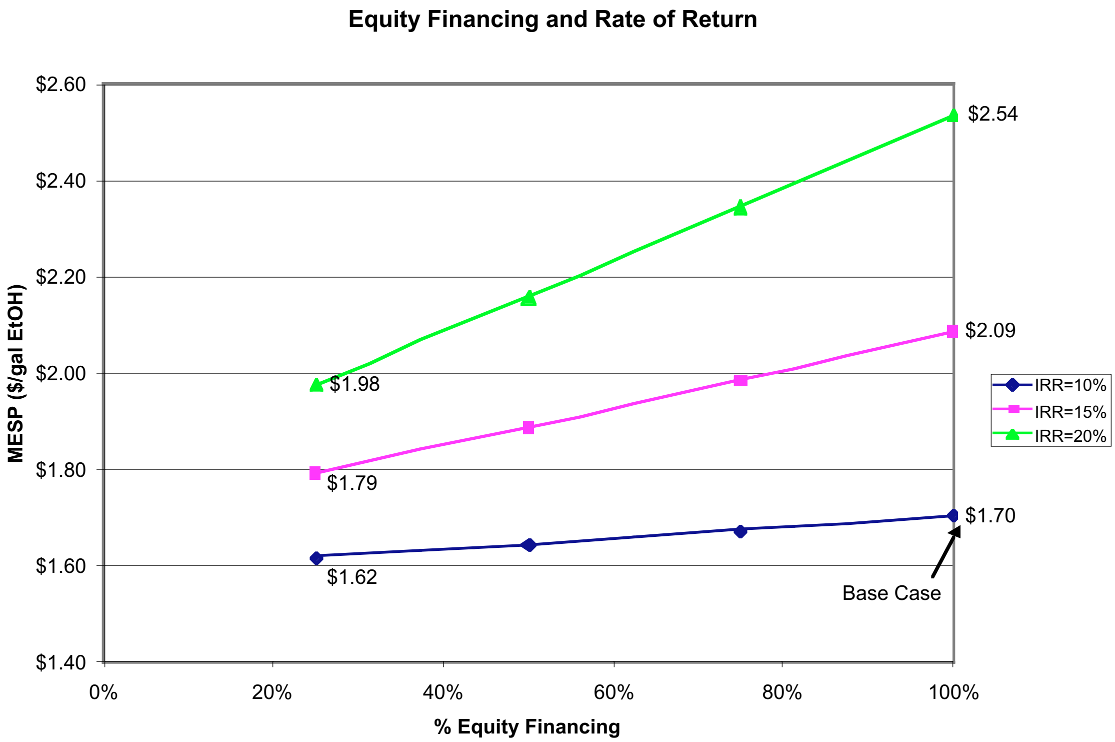
Figure 6. – Project Financing Cost Sensitivity Analysis



For a loan at 7.5% interest over 10 years, the MESP decreases as the percent of equity financing decreases. If the loan period can be extended to 20 years, or if a lower interest rate can be locked in, the MESP will decrease. For a loan interest rate of 10-11%, the amount of equity financing has little impact on the MESP.

The required return on investment for a biomass to ethanol plant will also vary greatly depending on who the project investors are. For some investors, a 10% internal rate of return (IRR) may suffice, however other investors may require at least a 20% IRR or higher before they invest their funds. The required rate of return can have a large impact on the MESP required for a plant as Figure 7 shows.

Figure 7. – Equity Financing and Rate of Return



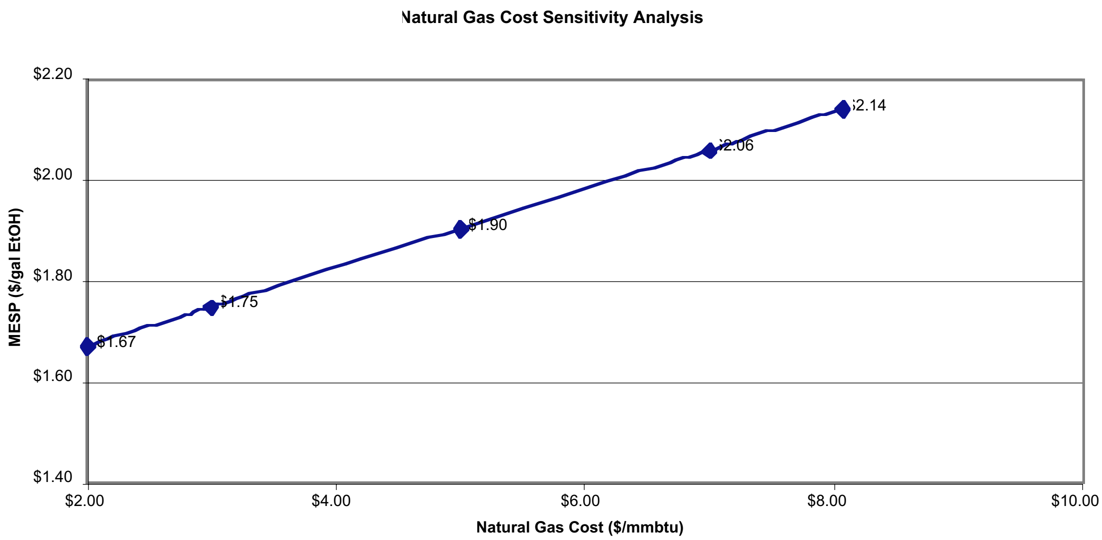
At lower percentages of equity financing, the impact of IRR on MESP is significant. As the percentage of equity financing increases, this impact grows even larger. The difference between obtaining a 10% IRR and a 20% IRR at 100% equity is almost $0.85/gal etoh!

Wastewater treatment is needed to treat waste streams from the evaporators, ion exchange columns, pretreatment flash tanks, and cooling towers (blowdown). The Biochemical Oxygen Demand (BOD) of these combined streams is too high to send directly to a municipal facility not designed to handle it. Thus, anaerobic treatment must be done onsite. This will decrease the BOD loading by roughly 90% to a level that is more manageable by wastewater treatment facilities. To lower the BOD to acceptable discharge levels, aerobic treatment must either be done onsite or the wastewater must be sent offsite for treatment at a nearby facility.

The benefit of doing aerobic treatment onsite is that municipal charges are avoided and most if not all of the water can be recycled back into the process once treated, thus cutting down on process water costs. A sensitivity analysis was done to determine which process option was more economical. Because the site-specific WWT costs given were low ($0.152/1000 gal is an order of magnitude lower than the $1.50/1000 gal I typically see) the MESP was lower for the case of shipping the wastewater to a local treatment facility instead of treating it further onsite.

The final sensitivity analysis is for the cost of natural gas for the natural gas boiler scenario. As Figure 8 shows, this scenario produces a higher MESP than the base case when the cost of natural gas is higher than about $2.50/mmbtu.

Figure 8. – Natural Gas Cost



Conclusions

There are many variables that can impact the process economics of a biomass to ethanol facility. Some have been alluded to in the discussion above. Others parameters, such as process yields, can also have large impacts on the process efficiency and economics. No sensitivity analyses were performed for process yields. However, increasing the process conversion yields from the base case will undoubtedly provide a plant with better economics.

Methods of improving the process economics are as follows:

- Keep feedstock costs low
- Process large feedstock supplies
- Improve process conversion yields
- Work to obtain generous financing parameters (i.e. lower interest rates, longer loan periods, etc.)
- Decrease process capital costs
- Sell byproducts for more $ (i.e. Lignin or electricity)
- Lower other operating costs (i.e. enzyme or natural gas)

NREL is working on several fronts to improve some of these issues. However, given the correct site characteristics and regional conditions, a wheat straw to ethanol plant in Washington State may prove to be economically feasible in the near future.

Appendix A

	Base Case Assumptions	
Process Area	**Year Research Achieved at Bench Scale**	**2004**
	Year Research Can be Commercialized	**2008**
Feedstock:	Feedstock Flow (dry metric ton/day)	1500
Wheat Straw	Feedstock Cost ($/dry ton)	$36
	Solids Fraction	85.0%
	Cellulose Fraction	41.0%
	Xylan Fraction	19.0%
	Arabinan Fraction	3.5%
	Mannan Fraction	0.0%
	Galactan Fraction	2.2%
	Lignin Fraction	18.0%
Pretreatment	Type	Dilute Acid
	Reactor Residence Time (min)	10 min.
	Acid Concentration (acid/liquor)	0.5%
	Temperature (C)	190
	Xylan to Xylose Yield	75%
	Mannan to Mannose Yield	75%
	Galactan to Galactose Yield	75%
	Arabinan to Arabinose Yield	75%
Conditioning	Type of Conditioning	IX/OL
	S/L separation	Yes
	Gypsum removed	Yes
	Acetic Acid Removal	80%
	O-Lime Addition Factor	0.0033
Enzyme Production	Produced In-house or Purchased	Purchased
	Purchase Price ($/gal ethanol)	$0.15
Saccharification and	Hydrolysis Residence Time	7 days
Fermentation	Hydrolysis Temperature	30°C
	Fermentation Residence Time	SSCF
	Fermentation Temperature	SSCF
	Effective Solids Concentration	20%
	Corresponding Ethanol Max. Conc. (g/L)	67
	Nutrient Requirement	0.25% CSL + DAP
	Cellulose to Glucose Yield	80%
	Glucose to Ethanol Yield	92%
	Xylose to Ethanol Yield	85%
	Arabinose to Ethanol Yield	0%
	Galactose to Ethanol Yield	0%
	Mannose to Ethanol Yield	0%
Other	Chilled Water Fraction	20%
	Contamination Loss	7%
Utilities	Electricity Credit ($/kW h)	$0.013
	COD level leaving plant	108 ppm
	Wastewater Treatment Cost	$0.152/1000 gal

Appendix B

Wheat Straw Supply Curve
$50
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
Avg Cost ($/ton)
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
Cumulative Supply (Tons/yr)

Appendix C

Ethanol Production Process Engineering Analysis

NREL Benchmark Case Co-Current Pretreatment & Enzymatic Hydrolysis
Kerstetter Wheat Straw Feasibility Study - 40 mm gal/yr - $36/BDT fdstk cost
Process Water Cost = $0.92/1000 gal, Electricity = $0.013/kWh, WWT cost = $0.152/1000 gal
All Values in 1999$

Minimum Ethanol Selling Price **$1.70**

Ethanol Production (MM Gal. / Year)	40.1	Ethanol at 68°F
Ethanol Yield (Gal / Dry US Ton Feedstock)	69.2	
Feedstock Cost $/Dry US Ton	$36	
Internal Rate of Return (After-Tax)	10%	
Equity Percent of Total Investment	100%	

Capital Costs	
Feed Handling	$6,100,000
Pretreatment	$14,900,000
Neutralization/Conditioning	$8,800,000
SSCF	$12,400,000
Distillation and Solids Recovery	$17,700,000
Wastewater Treatment	$1,900,000
Storage	$1,400,000
Boiler/Turbogenerator	$36,000,000
Utilities	$4,000,000
Total Equipment Cost	$103,200,000
Added Costs	$76,100,000
(% of TPI)	42%
Total Project Investment	$179,300,000
Loan Rate	N/A
Term (years)	N/A
Capital Charge Factor	0.177
Denatured Fuel Prod. (MMgal / yr)	42.0
Denatured Fuel Min. Sales Price	$1.65
Denaturant Cost ($/gal denaturant)	$0.544
Theoretical Yields	Ethanol MM Gal/year
Total Maximum (MM Gal/yr)	66.0
Maximum Yield (Gal/ton)	113.9
Current Yield (Actual/Theor)	61%

Operating Costs (cents/gal ethanol)	
Feedstock	51.0
CSL	3.6
Cellulase	15.8
Other Raw Materials	6.5
Waste Disposal	3.0
Electricity	-5.7
Fixed Costs	17.1
Capital Depreciation	22.5
Average Income Tax	16.7
Average Return on Investment	39.9

Operating Costs ($/yr)	
Feedstock	$20,400,000
CSL	$1,400,000
Cellulase	$6,300,000
Other Raw Matl. Costs	$2,600,000
Waste Disposal	$1,200,000
Electricity	-$2,300,000
Fixed Costs	$6,900,000
Capital Depreciation	$9,000,000
Average Income Tax	$6,700,000
Average Return on Investment	$16,000,000
Excess Electricity (KWH/gal)	4.37
Plant Electricity Use (KWH/gal)	2.33
Plant Steam Use (kg steam/gal)	22.1
Boiler Feed -- LHV (Btu/lb)	4,160
Boiler Feed -- Water Fraction	0.502

Appendix D

Ethanol Production Process Engineering Analysis

NREL Benchmark Case Co-Current Pretreatment & Enzymatic Hydrolysis
Kerstetter Wheat Straw Feasibility Study - 20 mm gal/yr - $32/BDT fdstk cost
Process Water Cost = $0.92/1000 gal, Electricity = $0.013/kWh, WWT cost = $0.152/1000 gal
All Values in 1999$

Minimum Ethanol Selling Price **$1.93**

Ethanol Production (MM Gal. / Year)	20.0	Ethanol at 68°F
Ethanol Yield (Gal / Dry US Ton Feedstock)	69.2	
Feedstock Cost $/Dry US Ton	$32	
Internal Rate of Return (After-Tax)	10%	
Equity Percent of Total Investment	100%	

Capital Costs	
Feed Handling	$3,800,000
Pretreatment	$9,800,000
Neutralization/Conditioning	$6,100,000
SSCF	$7,100,000
Distillation and Solids Recovery	$11,100,000
Wastewater Treatment	$1,400,000
Storage	$900,000
Boiler/Turbogenerator	$21,800,000
Utilities	$2,500,000
Total Equipment Cost	$64,500,000
Added Costs	$47,700,000
(% of TPI)	43%
Total Project Investment	$112,200,000
Loan Rate	N/A
Term (years)	N/A
Capital Charge Factor	0.176
Denatured Fuel Prod. (MMgal / yr)	21.0
Denatured Fuel Min. Sales Price	$1.87
Denaturant Cost ($/gal denaturant)	$0.544
Theoretical Yields	Ethanol MM Gal/year
Total Maximum (MM Gal/yr)	33.0
Maximum Yield (Gal/ton)	113.9
Current Yield (Actual/Theor)	61%

Operating Costs (cents/gal ethanol)	
Feedstock	45.3
CSL	3.6
Cellulase	15.8
Other Raw Materials	6.5
Waste Disposal	3.0
Electricity	-5.0
Fixed Costs	25.2
Capital Depreciation	27.9
Average Income Tax	20.8
Average Return on Investment	49.9

Operating Costs ($/yr)	
Feedstock	$9,100,000
CSL	$700,000
Cellulase	$3,200,000
Other Raw Matl. Costs	$1,300,000
Waste Disposal	$600,000
Electricity	-$1,000,000
Fixed Costs	$5,000,000
Capital Depreciation	$5,600,000
Average Income Tax	$4,200,000
Average Return on Investment	$10,000,000
Excess Electricity (KWH/gal)	3.84
Plant Electricity Use (KWH/gal)	2.89
Plant Steam Use (kg steam/gal)	22.0
Boiler Feed -- LHV (Btu/lb)	4,163
Boiler Feed -- Water Fraction	0.501

Appendix 2

Economic Impacts

Opportunities for Cellulose to Ethanol in Washington - Economic Impacts

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September 2001

Methodology

Economic analysis of an ethanol plant located in Moses Lake was completed at both the regional and statewide levels. The region or primary study area, which was expected to experience most of the economic impacts of the ethanol plant included Adams, Franklin, Grant and Lincoln counties.

There were a number of economic models that could have been used to estimate these types of impacts. After reviewing California's ethanol cost-benefit study (Unnasch, et. al. 2001), an input-output modeling approach using a proprietary software package, IMPLAN, was chosen for the analysis. The choice was based on similar evaluation criteria as those used by California - the relative ease of understanding IMPLAN's results, the ability to customize the model structure and create a functional economic region, its predictive as well as descriptive abilities, and its reasonable cost.

To provide a theoretical context for our analysis, the reader may find some background on input-output analysis useful. An input-output (I-O) model accounts for the flows of goods and services to producers, among producers, and finally to consumers. In building the model, we create a matrix that shows the interdependence of the different parts of the economy. Once built, the model can estimate the multiplied effects or impacts of a change within one or many sectors/industries.

When demand changes and expenditures for an economy's exported goods, services or transfer payments increase (or decrease), which impact will ripple through the economy. Intermediate goods and/or services are purchased to produce the exported item and income received, primarily by households, from the production of exported or intermediate goods or services is also used to purchase goods or services in the economy. Eventually, these ripples subside as expenditures leak out of the economy through the purchase of imports. This rippling of impacts through the economy is the multiplier effect. The more comprehensive Type II form of an economic multiplier is shown below (Johnson et al. 1994; 4):

[2] The author appreciates the many helpful suggestions from Dave Holland, WSU, and Jim Cornelius and Bruce Weber, OSU.

$$M_{II} = \frac{\text{Direct Effects + Indirect Effects + Induced Effects}}{\text{Direct Effects}}$$

As used in IMPLAN, the "direct effects are the changes in the industries (ethanol) to which a final demand change was made. Indirect effects are the changes in inter-industry purchases as they respond to the new demand of the directly affected industries. Induced effects typically reflect changes in spending from households as income increases or decreases due to the changes in production (MIG, Inc. 1999; 102)."

Note that multipliers are applied only to economic activities that bring income into the region from the outside, such as sales of goods to some firm or person outside the region. Multipliers are not appropriately applied to sales by a local business to another local business. Such transactions are captured in the multiplier of the other local business when it exports its products or services.

The size of the multiplier depends on the magnitude of and the extent to which the impacts ripple through the economy. Larger economies generally have larger multipliers because businesses and households make a larger share of their purchases in the local economy. In smaller economies, businesses and households cannot purchase as much of what they need locally and so more spending "leaks out" of the economy, resulting in a smaller multiplier. The multi-county or regional model in this study has larger multipliers than those of the individual counties that make up the region and the statewide model has even larger multipliers.

These multipliers when applied to a change in final demand for impacts like the construction or operation of an ethanol plant determine the direct, indirect, and induced effects, which are described later. Once an I-O model is built, individual multipliers are available for each type of effect, each variable and each industry.

Until recently, I-O models were very labor intensive to develop because detailed data often needed to be gathered from individual businesses within the area that was being modeled. The resulting models were not comprehensive and could become quickly outdated. Beginning in the 1970's, the Forest Service in cooperation with FEMA, BLM, the University of Minnesota, and eventually a private company, the Minnesota IMPLAN Group, created and refined a computer program to synthesize more than thirty, primarily federal, data bases and produce an I-O model. The software is now called IMPLAN Professional and comes with a number of data base options that can be used to model economies.

The IMPLAN database is regularly being tested and improved, however, it is a balanced model with inputs equaling outputs. To achieve this balance, IMPLAN must often estimate some values to overcome nondisclosure issues at the county level. So, to refine the estimates and increase our confidence in the estimates, we used the Holland, Geier, Schuster Approach (Holland et. al. 1997) to adjust the regional model to Regional Economic Information Service (REIS) data as provided by the U.S. Bureau of Economic Analysis. For statewide impacts a basic out-of-the-box model was used.

National databases take time to gather, summarize, and report. The most currently available data from most of these databases is from 1998 so the Minnesota IMPLAN

Group, Inc.'s most recent data for the model is from 1998. Calculations were made in 1998 dollars and then inflated on a sector specific basis to 2001 dollars.

The economic impacts of the ethanol plant have been summarized below using three variables and three types of effect. In addition, a number of detailed reports including Type II multipliers were calculated and are available.

When considering the estimates of impacts provided in this report, the reader needs to remember, an I-O model has limitations. It is dependent on its assumptions of how things are produced or their production functions, the price of inputs, and the percentage of purchases that are made within the study area. An I-O model is static and linear. It does not account for major changes in markets and technological conditions. It assumes that industries can and do continue to produce goods and services in the same manner without regard to how much they produce.

Even with these limitations I-O models can be very useful for estimating economic impacts and understanding how they ripple throughout an economy from the backward (supplier) and forward (customer) linkages among industries. For example, an I-O model can indicate which industries will gain jobs and how many jobs will be gained due to the ethanol plant construction and operation.

The I-O model has more trouble estimating the structural changes that will take place due to the establishment of this new industry in Washington. It does not predict how farmers may adjust their crop mix if the value of straw changes from being a byproduct with a production cost or having very low value to increasing in value as the ethanol industry develops.

When building this model, we needed to create an ethanol sector that did not exist in the region or the state. One option would have been to build a very specific production function for the ethanol industry, assign all the values of all the inputs and treat them as direct impacts, much like California's study. However, due to limited resources we used proxy sectors, edited them to represent an ethanol industry, and applied the direct impacts to those sectors.

<u>Impacts</u>

Construction and operation of an ethanol plant at Moses Lake, as discussed above, would primarily impact a four county area including Adams, Franklin, Grant, and Lincoln counties and to a lesser extent the surrounding counties and the state. This analysis estimates the total construction impact, as one event, which could extend over many years, yet, will not continue indefinitely. It estimates the impact of operating an ethanol plant on an annual basis, which may extend indefinitely. It does not discount the stream of benefits and costs of the ethanol plant over its life span to establish a current present value. It does not project the economic activities, which might be displaced by the ethanol production (e.g. other uses for the straw or methods of producing gasoline). It does not anticipate how any state provided incentives will be funded. It is reasonable to expect that other state funded programs may be reduced to fund incentives for ethanol production and the benefits of the ethanol plant will be reduced by the amount of those impacts.

The impact scenario, which we analyzed with the model, is summarized below:

Table 1
New Ethanol Plant

Economic Event	Cost/Sales*	Employment - Full & Part-Time
Facility Construction (Region/State)	**$178 / $297**	**1,346 / 2,126**
Ethanol Plant Operation	**$117**	**234**

***Millions Dollars**

Table 1 shows the estimated direct impacts of constructing and operating the ethanol plant. The number of jobs for each event was determined by dividing the total cost of construction and the total sales of 90 million gallons of ethanol at $1.30 per gallon by the average output per worker in the construction and ethanol industries respectively.
The direct cost/sales and employment construction impacts above are delineated for the state and regional level since it was assumed that a portion of the direct construction expenditures would be imported from outside the four county region.

At the regional level we estimated that sixty percent of the construction purchases would be within the region or the Regional Purchasing Coefficient (RPC) would be equal to .6. We assumed all the construction purchases could be accomplished within the state resulting in a statewide RPC of 1.0. The construction impacts are summarized in Table 2

Table 2

Facility Construction Impacts

Impact Measures	Direct	Indirect	Induced	Total
		Effects		
Region:				
Employment	1,346	427	402	2,175
Value-Added*	65.619	18.306	16.777	100.703
Output*	178.200	31.652	26.634	236.486
State:				
Employment	2,126	1,171	1,131	4,428
Value-Added*	117.180	60.472	57.537	235.189
Output*	297.000	104.194	89.907	491.102

***Millions Dollars**

Each type of metric that is used to describe the impacts is different and some have more limitations or opportunities for overstatement than others. Output, a measurement of all sales associated with the $297 million change in final demand for construction includes all inter-industry sales so it has a high potential for double counting. As an example; the steel manufacture sells steel to the pipe manufacturer, who sells pipe to the piping contractor, who subcontracts to the prime contractor, and the prime contractor sells the facility to the owner, and on and on. The original sale of the steel is counted at least four times just to the point of facility completion and could be counted many more times before the ethanol is rolling down the road. Output is a necessary measure, since output is commonly used in these types of analyses so it has been included here to allow for an easier comparison with other projects. However, changes in output do not provide a net estimate of the change in economy.

Value added only counts the net changes from each transaction. The items that comprise value added are Employee Compensation (wages and salaries, benefits, and any other non-cash compensation), Proprietary Income (income received for self-employed work), Other Property Type Income (individual and corporate interests, rents, dividends, and profits) and Indirect Business Taxes (excise and sales taxes paid by individuals or businesses, which does not include taxes on profit or income) (MIG, Inc. 1999; 249). So the pipe manufacture's value added, in the example above, would not include the cost of the steel plate, welding machinery, electricity or other intermediate inputs. It would include the items provided only by the pipe manufacturer that added value to the steel to become pipe like rolling and welding the steel plate, welding on the flanges, drilling the bolt holes, etc. Employment, as noted previously, includes full and part-time jobs.

As discussed earlier, larger areas are more likely to provide the types of and capacities within industries to meet the needs of a change in final demand. In this case, the change in final demand is an increase in the construction industry of $297 million to build the new ethanol plant.

The impacts of the change are greater at the state level than they are at the regional level. Still, based on 1998 REIS data, the construction of an ethanol plant would have a significant impact on the region. It could increase total employment by 2.8% and employment in the construction industry by 40%. It is important to remember that this impact is over a limited period of time.

Operation of the ethanol plant will have ongoing impacts. The region could experience all the direct impacts in Table 3, which are based on place of work, each year. Indirect and induced impacts will once again be less at the regional than the statewide level due to the higher multipliers in the larger statewide region. However, operation of the ethanol plant will create a new industry in the region, increase regional employment by 1%, and significantly increase employment in a number of specific industries.

For this analysis, the Hay & Pasture industry was used as the most representative of the industries available in IMPLAN to reflect the processes necessary to produce the wheat straw for the plant.

Facility Operation Impacts

		Effects		
Impact Measures	**Direct**	**Indirect**	**Induced**	**Total**
Region:				
Employment	**234**	**382**	**164**	**780**
Value-Added*	**25.284**	**12.175**	**6.811**	**44.270**
Output*	**117.000**	**25.404**	**13.777**	**156.181**
State:				
Employment	**234**	**500**	**254**	**988**
Value-Added*	**25.284**	**20.725**	**12.854**	**58.863**
Output*	**117.000**	**39.031**	**22.060**	**178.092**

***Millions Dollars**

We have tried to be conservative in our estimates. Only the incremental farming activity necessary to rake, bale, and stack the wheat straw was included as an indirect production impact of supplying the ethanol operation. The other production costs are already accounted for in the model as part of wheat production. Since the value of the wheat straw is likely to increase, an induced impact of five dollars per ton income to the farmer was also included. The price per ton may be greater than five dollars, however, there is some nutrient value of the straw that is being lost, possibly as much as three dollars per ton. Also there may be some reduced operating costs to the wheat farmer who will no longer need to burn or plow the straw back into the field. The five dollars per ton plus the returns on the additional baling activity seemed like a reasonable net increase in farm income.

An important consideration that is not included in this analysis is the impact on the soil's natural capital. Further refinement is necessary to obtain a precise straw output level on a site-specific basis that balances straw production and soil organic matter. This is necessary to preserve the soil's natural capital and also meet USDA organic matter criteria to continue to receive support for soil maintenance efforts. When those estimates are available the economic impacts can be adjusted.

Table 4 provides a detailed summary of the industries, which could experience employment changes of more than five jobs at the regional level.

Table 4

Regional Employment Impacts
Industries with Greater than Five Full or Part-Time Jobs Change

	Effects			
Industries	**Direct**	**Indirect**	**Induced**	**Total**
Ethanol Production	**233.9**	**0.0**	**0.0**	**233.9**
Hay and Pasture	**0.0**	**201.0**	**0.1**	**201.2**
Eating & Drinking	**0.0**	**13.1**	**24.8**	**37.9**
Motor Freight Transport and Warehousing	**0.0**	**28.2**	**1.6**	**29.9**
Wholesale Trade	**0.0**	**21.7**	**6.8**	**28.5**
Agricultural Services	**0.0**	**14.4**	**0.5**	**14.9**
Miscellaneous Retail	**0.0**	**0.3**	**13.1**	**13.4**
Maintenance and Repair Other Facilities	**0.0**	**12.0**	**1.0**	**13.0**
Doctors and Dentists	**0.0**	**0.0**	**13.0**	**13.0**
Hotels and Lodging Places	**0.0**	**6.3**	**3.8**	**10.1**
Food Stores	**0.0**	**0.1**	**9.9**	**10.0**
Automotive Dealers & Service Stations	**0.0**	**0.2**	**8.6**	**8.7**
Automobile Repair and Services	**0.0**	**5.5**	**2.1**	**7.6**
Banking	**0.0**	**3.6**	**3.8**	**7.4**
Real Estate	**0.0**	**3.8**	**2.9**	**6.8**
Accounting- Auditing and Bookkeeping	**0.0**	**5.9**	**0.8**	**6.7**
Other State and Local Govt Enterprises	**0.0**	**5.4**	**1.3**	**6.6**
Railroads and Related Services	**0.0**	**6.1**	**0.1**	**6.2**
Services To Buildings	**0.0**	**4.8**	**0.4**	**5.1**
General Merchandise Stores	**0.0**	**0.1**	**5.0**	**5.1**

The direct employment impacts are in the ethanol industry. Indirect employment impacts are the jobs that are created to provide intermediate inputs like the wheat straw (Hay & Pasture Sector) or transporting the ethanol to the petroleum manufacturer (Motor Freight Transport and Warehousing Sector) or to supply the suppliers like fixing the balers (Agriculture-Services Sector). The induced impacts are the result of employees, proprietors, and investors spending their income to buy goods like food (Food Stores Sector) or services like health care (Doctors and Dentists Sector). Many of the industries experience both indirect and induced impacts.

It is important to note that these employment impacts include full and part-time jobs. An example is that in the Hay & Pasture industry the model estimates average earnings per worker of $4,103. So the 201 jobs in Hay & Pasture are not all full time equivalent jobs, however, they can still be an important component of a regions' employment structure.

Although only the industries that gained more than five employees are listed in Table 4, the model predicts some level of employment impact to 115 industries in the region. Industries may have very different output and value added per job values so the industrial composition of the detailed output impact and value added impact reports are different than the employment impact report. More service sectors and retailers have significant value added impacts and more wholesale traders, transporters, and utility providers have high output impacts.

Conclusions

Constructing a new ethanol plant in the region is likely to have significant short-term impacts, which IMPLAN predicts will spread over 190 of the 199 industrial sectors in the region. Output or total sales impacts greater than $100K could affect 69 sectors and output impacts greater than $10,000 could affect 126 sectors. Value added impacts greater than $100,000 could affect 46 sectors and value added impacts greater than $10,000 could affect 104 sectors.

While operating the ethanol plant will have total impacts to the region that are more modest than the construction impacts, the operating impacts are indefinite and will still affect 194 of the 199 sectors in the region. Operating output or total sales impacts greater than $100,000 could affect 48 sectors and output impacts greater than $10,000 could affect 110 sectors. Value added impacts greater than $100,000 could affect 34 sectors and value added impacts greater than $10,000 could affect 85 sectors.

Additionally, this model is built on the current structure of the regional economy, which may markedly change when the wheat straw's value increases and if financial viability is reached with the addition of this plant for sectors that currently do not exist in the region or have low regional purchasing coefficients. It is likely that the ethanol plant's backward linkages to suppliers may stimulate the development of new groups or clusters of industries particularly in the wholesale trade and transportation sectors.

The new ethanol plant will have a regional impact and we have tried to maintain that regional perspective throughout the report, yet, each county may experience very different levels of benefits from the new plant. The region has approximately 77,200 jobs so the regional employment impact is just over 1%. However, Adams and Lincoln counties have approximately 14,300 jobs and rely more heavily on agricultural production. So the impacts to Adams and Lincoln counties may, in terms of their proportion of the local county economies, be two or three or more times as great as the impacts to the region as a whole.

Even with the limitations of input-output modeling and the uncertainties of how the feedstock will be produced for the plant, the economic impacts to the region are significant and broadly distributed throughout the economy.

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Appendix 3

Ethanol Incentives

Ethanol Incentives

Washington State Incentives

Up until mid-1990, Washington State offered a generous set of ethanol tax incentives. Starting in 1980, ethanol fuel was exempt from the state motor fuel excise tax. In 1981, an additional credit of 60 percent of the excise tax was provided for alcohol blended with motor fuel, if the blend contained at least 9.5 percent alcohol by volume. In 1993, the combined state exemption and credit for gasohol containing a 10 percent blend of ethanol was 3.68 cents per gallon of blended fuel, or 36.8 cents per gallon of ethanol.

The State's excise tax exemption and credit were eliminated in 1994, as fuel tax revenue losses due to the sale of alcohol blended motor fuels exceeded $27 million dollars in FY 1993. Most of the tax benefits were being enjoyed by companies operating outside of the state and in some cases, outside of the country. As a result, Washington legislators broadly supported the elimination of these incentives.

While Washington State does not currently offer any direct incentives for ethanol use or production, the State does provide a number of business-related tax incentives that could support ethanol. A list of Washington State tax incentives that could benefit an ethanol production facility is presented below.

Washington State Business Tax Incentives

Incentive	*Description*	*RCW/Code*
Manufacturing Machinery Sales and Use Tax Exemption	New or replacement manufacturing machinery and equipment is exempt from retail sales and use tax if it is used in a manufacturing operation. Both materials and installation labor are included for machinery, equipment, pollution control equipment, and the internal use portion of co-generation equipment. Also included are repair parts and labor for manufacturing machinery, manufacturers R&D equipment, testing equipment, and certain logging and rock-crushing activities.	82.08.02565
Research and Development	A 15 percent business and occupation tax credit can be taken on research and development expenditures other than	82.04.4452

Incentive	*Description*	*RCW/Code*
Credit	capital improvements. The specified activities the credit can be applied to are advanced computing, advanced materials, biotechnology, electronic device technologies, and environmental technologies. The credit is limited to $2 million per year.	
Rural County Sales Tax Deferral	This sales tax deferral program is available for new or remodeled buildings and/or equipment used in manufacturing or research and development activities in rural counties or community empowerment zones. Prior application with Department of Revenue is required.	82.60.040
Business and Occupation Tax Credit for New Jobs	A $2,000 or $4,000 (if wages exceed $40,000) credit against the business and occupation tax is available for each new employment position created and filled by a manufacturing, research and development, or computer service firm in rural counties and community empowerment zones. Prior application with the Department of Revenue is required.	82.62.045
Warehouse Remittance	Warehouses over 200,000 square feet in size and grain elevators with more than one million bushel capacity are eligible for an exemption for the state sales and use tax paid on purchases of machinery and equipment and on labor and materials for construction of such facilities.	82.08.820
Credit for Job Training Services	Twenty percent of the cost spent on job training by firms eligible for the rural county sales tax deferral/exemption may be taken as a business and occupation tax credit. The training is required to enhance job performance in a state-approved program sponsored or provided by the employer. The amount of credit for a particular firm is limited to $5,000 annually.	82.04.4333
Work Opportunity Tax Credit (WOTC)	The Work Opportunity Tax Credit can reduce a business' federal tax liability by as much as $2,400 per new qualified employee.	Section 51 of the IRS Code
Straw Board Base Products Exemption and Credits	Tax exemptions and credits for structures and equipment used to reduce agricultural burning of cereal grains, field and turf grass grown for seed.	82.08.840

Federal Incentives

The federal government has long supported ethanol fuel for its value in reducing imported petroleum fuels, improving urban air quality and diversifying farm income. More recently, ethanol's role in helping to curb greenhouse gas emissions has been recognized by scientists and legislators alike. In 2001, three carbon sequestration bills were introduced to Congress. These bills are still pending legislative action, but would provide additional support for ethanol if passed.

Federal Tax Credit for Blenders: The Energy Tax Act of 1978 established an exemption for 10-percent alcohol blended gasoline, or gasohol. While the provision has changed several times since then, the federal credit now stands at $0.53 per gallon.

There are two ways to receive this credit, the excise tax exemption or the blender's income tax credit. The producer of the finished product (ethanol blended gasoline) responsible for collecting tax from the consumer is the only party that can assume the tax benefits. Typically, this is the blender of ethanol who is marketing the fuel at retail. An ethanol producer cannot claim these credits. Regardless of how the credit is taken, the net cost of ethanol as a blending agent is $0.53 per gallon less than the market price because of the federal tax incentives.

The blender's credit will sunset December 31, 2007 unless extended. The effective amounts of the incentives, however, reduce from the current $0.53 per gallon to $0.52 in 2003 and 2004, and $0.51 in 2005 through 2007. The current Bush Administration energy plan indicates support for an extension of the credit beyond 2007.

Excise Tax Exemption. The federal excise tax for gasoline is currently at 18.3 cents per gallon. Blenders can receive a federal excise tax exemption of 5.3 cents per gallon for gasoline blends which are 10% ethanol. Blends of less than 10% are prorated, however, blends above 10% do not qualify at this time. For qualified alternative fuels of 75 percent ethanol or greater, the blenders tax credit must be used.

Blender's Income Tax Credit. A blender may elect to receive a federal income tax credit of 53 cents per gallon of ethanol used, instead of the excise tax exemption, for any percentage of ethanol sold as a fuel. The blender must have a tax liability to apply the credit against.

Small Producers Credit. A small ethanol producer (up to 30 million gallons of annual capacity) is allowed a federal income tax credit of 10 cents per gallon for each gallon of ethanol produced up to 15 million gallons. The small producer tax credit is scheduled to sunset December 31, 2007.

Other State Incentives for Ethanol

Other states recognize the public benefits of ethanol and offer tax incentives supporting its use and production. A list of state tax incentives is presented below. In addition to production related incentives, a number of states require state agencies and other governmental jurisdictions to purchase ethanol blended fuels wherever practical. Other incentives offered by states include income tax credits and or rebates for the purchase of alternative fueled vehicles; and income tax credits for the construction of alternative fuel refueling facilities.

State Incentives for Ethanol

State	Incentives
Alaska	Fuel containing 10 percent alcohol by volume is exempt from an $0.08 per gallon tax.
Arkansas	The advanced biofuels tax credit (HB 2153) offers an income tax credit for manufacturers of advanced biofuels. Advanced biofuels include ethanol, methanol, or any derivatives thereof, which are produced through biological means other than direct fermentation of a food crop. The amount of the credit allowed shall be equal to 30 percent of the cost of buildings equipment, higher education partnerships and licenses necessary to manufacture advanced biofuels.
California	Excise taxes on alcohol fuels, ethanol, and methanol are reduced to one-half the rate imposed on gasoline, because of their lower BTU content. Neat (100%) alcohol fuels are exempt from fuel taxes. The tax for gasoline is $0.17/gallon.
Hawaii	Gasoline blended with 10% by volume of biomass-derived alcohol sold in the state is exempt from the 4 percent sales tax. At current rates, the value of the exemption is about $0.30 to $0.50 per gallon of ethanol
Iowa	In April 1998, the state legislature passed an extension for the $0.01 sales tax exemption for ethanol-blended fuels through 2007.
Idaho	The state provides an excise tax exemption for the ethanol or biodiesel portion of fuel for blends up to 10 percent. The state fuel tax is $0.25 per gallon.
Illinois	SB 1455 (1998) provides that the rate of the taxes imposed by the Use Tax Act, the Service Use Tax Act, the Service Occupation Tax Act, and the Retailers' Occupation Tax Act applies to 70% of the proceeds of the sales of gasohol made before July 1, 2003, and to 100% of the proceeds of the sales thereafter.

Indiana	HB 1302 (1996) provides a 10% gross income tax deduction for improvements to ethanol producing facilities or soy diesel producing facilities.
Minnesota	The state currently provides a number of incentives to ethanol producers (see case study).
Missouri	The state provides a $0.20/gallon financial incentive for ethanol produced in Missouri and a $0.02/gallon excise tax exemption for ethanol blends of 10 percent or more sold in the state.
Montana	SB 374 (1993) establishes a production-based ethanol tax incentive if funding is available. A $0.30/gallon ethanol producer payment for production of fuel is provided for state producers.
North Dakota	SB 26 (1995) extended the ethanol incentives and appropriated up to $3,657,000 in funds for an incentive of $0.40 per gallon for agricultural fuel produced and sold in North Dakota
Nebraska	The state provides a $0.20/gallon direct producer incentive for fuel ethanol produced in the state for plants 25 percent operational by December 31, 1995, with a cap of $25 million per plant. Beginning June 1, 2000, any ethanol facility shall receive a credit for ethanol production from the Ethanol Production Incentive Cash Fund. Not more than ten million gallons of ethanol produced during any year at a facility can be eligible for the credit.
Ohio	The state provides a $0.01/gallon income tax credit for sale of E10, with a maximum of $15 million per year.
South Dakota	The state offers $0.02 tax exemption for ethanol blends. $0.20 per gallon producer credit up to $1 million per year, per plant. $10 million total cap per plant.
Wyoming	Under HB 120 any person who has a tax liability for the sale of ethanol based motor fuel or gasoline sold for the purpose of blending into an ethanol based motor fuel may redeem a valid credit with the Department of Revenue until July 1, 2003. To be eligible to receive this credit an ethanol producer shall purchase at least $1,000,000 of Wyoming origin grain stocks during the year the tax credits were earned. The total credits redeemed shall not exceed $2,000,000 per year.

Source: USDOE- Clean Cities Guide to Alternative Fuel Vehicle Incentives and Laws.

State Program Highlights

Minnesota: While a number of states offer support for ethanol, Minnesota is considered the national model for policies that support ethanol production. Minnesota is also working the market side of ethanol use and has instituted a minimum content requirement for all gasoline sold in the state. The main components of the Minnesota Ethanol Program are:

1. A 2.7 percent oxygenated fuel statute that requires statewide oxy-fuel (ethanol) use,
2. A 20-cent per gallon ethanol producer incentive for every gallon of Minnesota produced ethanol.
3. Low-cost financing through the state Agricultural Department. $550 million in total corn/ethanol plant project spending for construction and startup costs. $370 million in private sector financing contingent on local equity capitol. $180 million local equity capitol raised by over 8,000 farmers and local businesses.
4. $240 million worth of corn is committed for processing annually by local farmers.

The goals of the program include:

1. To build a new market for the state's largest crop (corn).
2. To develop corn processing/ethanol production facilities in Minnesota.
3. To increase the number of New Generation Farmer Coops (NGC).
4. To replace 10 percent of imported petroleum we use for gasoline. ($100 million annual savings)
5. To help the Twin City Area meet U.S. EPA standards for carbon monoxide.

Results to date:

1. 130 million bushels of corn (17% of Minnesota crop) is made into ethanol and other products.
2. Minnesota's 14 plants can produce over 260 million gallons of ethanol per year.
3. Twelve of Minnesota's 14 ethanol plants are New Generation Farmer Coops and involve 8,945 cooperative members.
4. In 1999, in-state ethanol plants produced over 190 mm gallons, supplying 95% of the state's ethanol consumption. Nearly 10% of Minnesota's gasoline is being replaced by ethanol each year.
5. The Twin Cities Area met EPA's carbon monoxide standard and has recently achieved "attainment" status. The continued use of ethanol is required to keep emissions low.

The 20-cent per gallon ethanol producer payment initially provided the security required by lenders to invest in the small, farmer owned ethanol facilities. In addition to opposition from the petroleum industry, bankers were concerned that the in-state ethanol plants could not compete in the market with large agribusiness processors. At that time most ethanol production occurred in large corporate mills outside the state.

Although these ventures have been successful to date, margins have been squeezed by periods of record high corn prices and low ethanol prices. State planners anticipate that ten years of payments will allow plants to retire debt, increase efficiency and to develop new products so they can survive the competition and price fluctuations in agricultural and petroleum markets. Unique aspects of the ethanol industry made these incentive payments necessary, but Minnesota's ethanol industry will contribute over $350 million in net benefit to the state.

California: The California legislature directed the Energy Commission to evaluate the feasibility of developing a cellulose-to-ethanol industry in California. The study, " Costs and Benefits of a Biomass-to-Ethanol Production Industry in California" , was initiated in part to help evaluate options for replacing MTBE in gasoline. The demand for ethanol in California could reach over 700 million gallons per year, 40 percent of the nation's current output, when MTBE is completely phased out in 2003.

The study assumed that California could develop a 200 million gallon per year ethanol industry (based on a conservative estimate of available biomass sources), with an investment of $500 million in State supported incentives. State incentives would be similar to Minnesota's and would include a producer payment of $0.20 per gallon and a 10 percent capital cost support for new plant construction. The benefits to California's economy are estimated to exceed $800 million from new jobs and increased tax revenues over a 20 year period. Additional benefits that were not directly quantified include reduced air emissions from the burning of agricultural wastes, reduced greenhouse gas emissions, and providing an alternative to landfilling of waste materials. California could have biomass-to-ethanol production facilities in place as early as 2004-2005, according to the report.

Oregon: The State of Oregon recently commissioned a study to evaluate the near-term potential of an Oregon cellulose-based ethanol industry. The report, " Oregon Cellulose Ethanol Study" was completed in June, 2000, and concluded that Oregon has abundant sources of cellulose feedstocks, which could potentially be used for ethanol production. Estimates of economically available feedstocks, which include forest thinnings and wheat straw, would provide sufficient material to support about 170 million gallons of ethanol production annually. Production capacity could more than double if policies were put in place to insure long-term supplies of biomass materials.

Although the report did not evaluate the overall cost-effectiveness of a cellulose to ethanol program, economic analysis of a wheatstraw to ethanol facility showed potential returns on investment of 13 to 18 percent. The estimated returns were very sensitive to ethanol pricing, feedstock costs and gasoline prices, however. The report, while warning against the present day commercial viability of cellulosic ethanol, recommended three public policy initiatives that would spur on the successful development of an ethanol industry in Oregon. These include: a) maintaining the current oxygen requirement for gasoline; b) development of a statewide forest management strategy that encourages selective thinning operations; and, c) adopting a renewable fuel requirement of 1 to 2 percent, or establishing a greenhouse gas emission standard to help ensure a market for ethanol. The report also recommended the state offer tax incentives for ethanol production to aid in project financing. Oregon currently offers a Business Energy Tax Credit for renewable energy projects. The tax credit is 35% of the eligible project costs up to $10 million per project each year, and is taken over 5 years. Ethanol fueling facilities could benefit from this credit.