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The Economic Feasibility of Producing Ethanol from Corn Stover and Hardwood in Minnesota[1]

Vernon Eidman, Daniel Petrolia, Le Pham, Huajiang Huang and Shri Ramaswamy[2]

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The purpose of this project was to determine the impact of plant size on the profitability of second generation biorefineries using cellulosic biomass commonly available in Minnesota. The two feedstocks selected were corn stover for Southern Minnesota and hardwood for Northern Minnesota. Because much of the hardwood produced in Minnesota is currently used to produce paper, a third option considered is the integration of an ethanol production unit into the current infrastructure of a pulp and paper mill.

The study estimated the costs of harvesting and delivering corn stover and hardwood to efficiently located biochemical processing plants. The cost of delivering the required supply of both types of biomass increases as the amount of feedstock required by a plant increases, because the biomass must be harvested from a larger area and transported to the plant. Larger plants are expected to enjoy economies of size, offsetting some portion of the higher biomass cost. This study estimates the profitability of various sizes of commercial plants considering both the increasing cost per ton of supplying larger quantities of biomass to a fixed location, and the economies of operating larger plants.

[1] Funding for this research was from the University of Minnesota Initiative for Renewable Energy and the Environment Project (Number LG-B23-2005) titled “Liquid Fuels from Biomass: An Integrated Biorefinery Approach.”

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This paper estimates the profitability of the plant based on the private costs and returns such a biorefinery is expected to incur. The analysis assumes the business complies with all existing regulations and laws, including all environmental requirements, and includes the costs and returns a firm would incur to do so.[3]

The first section of the report estimates the profitability of a biorefinery to produce ethanol and electricity from corn stover. The refinery is assumed to be located in an area of concentrated corn production where the cost of supplying the stover is relatively low. The second section provides similar estimates for production of ethanol and electricity from ground hardwood. The feedstock is primarily aspen, but also includes other hardwood species. This analysis assumes the biorefinery is located in Northern Minnesota, in the major supply area for hardwood in the State. A more limited analysis of the profitability of integrating an ethanol production unit into an existing pulp and paper plant is summarized in the third section.

The measure of profitability used in this study is the internal rate of return (IRR). The IRR is defined as the discount rate which equates the present value of a project's expected cash inflows to the present value of a project's costs (Brigham and Houston). Firms considering this investment would compare the estimated IRR to the "hurdle rate of return" they require to enter into new projects. These hurdle rates differ somewhat across firms. Two hurdle rates are used in this analysis to facilitate discussion. A relatively low rate is sometimes used by firms with an interest in promoting industry in a specific area. This study uses 12% as this low rate. A more common hurdle rate used by many firms is

[3] A companion study takes the analysis a step further, by evaluating the environmental impacts of operating these plants to produce these products. This companion study describes the environmental consequences of operating these plants and estimates the social costs and returns of these plants. Combining the private and social costs and benefits results in what is commonly referred to as full-cost accounting.

20 %. While the hurdle rate varies from firm to firm, these two rates are used to provide some perspective on whether these biorefineries may be attractive investments.

There are many price and technical values that are required to complete the profitability calculations. Five that usually have the greatest impact on profitability are analyzed in this study. They are the gallons of ethanol produced per ton of feedstock (corn stover or hardwood), the investment cost, the price the plant pays for feedstock, the net price the firm receives for electricity sold to the grid, and the net price the firm receives for the ethanol produced. The impact of changes in each of the five variables on the IRR of plants using corn stover and those using hardwood are analyzed in the sections that follow.

Many state and federal incentives may be made available to cellulosic ethanol plants built in Minnesota. At this time the number and size of the incentives, as well as the conditions under which they will be paid, are still being developed. However, the federal government has passed legislation containing two incentives, a small producer tax credit and a cellulosic biofuel producer tax credit that are available to cellulosic ethanol plants for 2009 through 2012. Small plants, defined as those with a productive capacity of less than 60 million gallons per year, are eligible to receive a $0.10 per gallon small producer income tax credit. In addition, the 2008 Farm Bill includes an income tax credit to all sizes of cellulosic plants equal to $0.56 per gallon of ethanol produced. The estimated impact of these credits on the IRR of corn stover and hardwood plants is discussed at the close of the respective sections to illustrate the impact of incentives on plant profitability.

Corn Stover

Crop residues are commonly considered an important source of biomass for the United States and for the State of Minnesota. Gallagher et. al. estimated that corn stover makes up 68 percent of the potential supply of biomass from crop residues in the contiguous 48 states. A recent study estimates that corn stover comprises 80 percent of the crop residue available in Minnesota (Butcher). Corn stover is currently harvested on only a small portion of the land devoted to corn production, making corn stover one of the currently available sources of biomass for biofuel production.

The location selected for the hypothetical cellulosic ethanol plant to process corn stover is Fairmont, Minnesota. This location has more available corn stover within a radius of 25, 50 and 75 miles than other potential locations within the State, and should have a lower cost of corn stover supply for various amounts the plant may want to acquire. The location also has access to rail and interstate highways, additional factors contributing to its low cost of operation. While this location should have low costs, other sites in Southern Minnesota and Northern Iowa could be selected that would have very similar costs of corn stover supply and conversion plant operation. Thus, the results can be used to provide an initial approximation of the profitability for similar plants sited at other locations within the area.

Cost of Supplying Corn Stover

The plant was assumed to be able to draw corn stover from all of Minnesota and border counties in Iowa, South Dakota and Wisconsin producing more than 10 million bushels of corn. The quantity of forage produced was estimated based on the county average corn grain yield and the acreage of corn produced in the county. The maximum amount that could be harvested was restricted by the requirements for ground cover to prevent wind and water erosion, and by the limits of the harvesting technology.

The study compared two commonly used harvesting systems, a round bale system and a square bale system (Petrolia 2006a). The analysis showed that the costs of delivering corn stover to the plant would be lower with a square bale system and only that system is discussed here. This system produces bales in three passes over the field. A tractor pulls a 20 foot stalk shreader on the first pass, followed by another tractor pulling a twin rake to form windrows. The third pass bales the stover, producing 36"x48"'x96" bales weighing 1342 pounds with an average density of 13.98 pounds per cubic foot. The wrapped bales are loaded on a bale mover and transferred to a semi at the edge of the field for movement to storage at a regional storage area. The bales are kept under roof at the regional storage center until they are moved to the plant for processing. The bales are hauled to the conversion plant via semi trailer throughout the year as they are needed to supply the plant. The analysis assumes a telescopic handler is used to load the semi trailer at the edge of the field, to unload and stack bales at the regional storage area, and to reload the semi-trailer for shipment to the ethanol plant. It also assumes a semi-trailer would be limited to 27 bales to stay under the 46,000 pound load limit.

The procedures used to estimate the cost of harvesting and delivering corn stover to the ethanol plant are described in detail in previous publications (Petrolia 2006a and 2008). These costs were estimated in late 2005. Given the increase in fuel and fertilizer prices that occurred during 2007, the costs were updated to the 4th quarter of 2007 for this profitability analysis. The resulting cost per delivered dry ton assumes \$23.66 per acre for baling the stover, \$4.60 for wrapping and hauling it to the edge of the field, \$10.64 for replacement of the fertility removed by the stover, and \$12.94 for storage. It also includes the cost of transport to the ethanol plant at commercial rates, and a payment of $20 per dry ton ($17.00 per ton of 15 percent moisture stover) to the producer. The resulting cost of supplying forage by county is shown in Table 1 for the 29 counties having the lowest supply cost for a plant at Fairmont, Minnesota.

The counties are listed in Table 1 from lowest cost to highest cost supplier of corn stover. Martin County, Minnesota, where Fairmont is located, is the lowest cost supplier. The data indicate they can supply up to 160,411 dry tons at a cost of $74.53 per ton. Fairbault County Minnesota is the next lowest cost source with an average cost of $76.58. The two counties could supply up to 305,899 dry tons of corn stover. The profitability analysis assumes the plant sources its corn stover from the several counties that can provide the amount needed at the lowest cost. For example the smallest size plant analyzed requires 386,084 tons per year and would draw the stover it processes from Martin, Fairbault and Watonwan counties in Minnesota. It would pay $76.75 per dry ton. The second size of plant analyzed requires twice as much stover, 772,168 tons, and would source it from the first 7 counties on the list, paying $81.05 per dry ton. The largest plant analyzed requires 1,930,420 tons of stover per year. It would source the stover it processes from the top 17 counties on the list, paying $87.07 per ton.

Total Project Investment

The hypothetical plant analyzed uses acid prehydrolysis and enzymatic hydrolysis to produce ethanol and electricity. The analysis is based on an updated version of the process described by Aden, et. al. The total capital investment for the plants was developed by Huang and Ramaswamy with ICARUS cost estimation software. They used Aspen Plus software to model the material and energy balances that provide the basis for the variable cost estimates developed in this study.

The installed equipment cost was estimated for the feed handling, pretreatment/neutralization/conditioning, saccharification/fermentation, distillation and solids recovery, wastewater treatment, storage, boiler/turbogenerator, and utilities parts of the plant. The total installed equipment costs were used to estimate the site development cost, warehouse cost, field expenses, office and construction fees and the project contingency. Adding the land cost and working capital provided the total project

Table 1: Estimated Corn Stover Production By County, Amount that Could be Harvested, and the Delivered Cost to a Plant in Fairmont Minnesota

County	State	County Total Production	Cumulative Total production	Available for Harvest Total	Available for Harvest Per Acre	Available for Harvest Cumulative	Delivered Cost
		dry tons	dry tons	dry tons	dt/ac	dry tons	$/Dry Ton
Martin	MN	802,054	802,054	160,411	1.526	160,411	**$ 74.53**
Faribault	MN	727,443	1,529,496	145,489	1.496	305,899	**$ 76.58**
Watonwan	MN	460,167	1,989,663	92,033	1.518	397,933	**$ 76.75**
Emmet	IA	425,724	2,415,387	85,145	1.484	483,077	**$ 77.50**
Jackson	MN	622,612	3,037,999	124,522	1.398	607,600	**$ 78.08**
Dickinson	IA	314,849	3,352,849	62,970	1.457	670,570	**$ 80.71**
Palo Alto	IA	580,144	3,932,993	116,029	1.518	786,599	**$ 81.05**
Brown	MN	532,724	4,465,718	106,545	1.471	893,144	**$ 81.28**
Cottonwood	MN	585,452	5,051,170	117,090	1.394	1,010,234	**$ 82.69**
Blue Earth	MN	655,687	5,706,857	131,137	1.479	1,141,371	**$ 82.81**
Kossuth	IA	1,130,659	6,837,516	226,132	1.521	1,367,503	**$ 83.21**
Freeborn	MN	645,484	7,483,000	129,097	1.503	1,496,600	**$ 83.47**
Nicollet	MN	420,600	7,903,600	84,120	1.520	1,580,720	**$ 84.43**
Winnebago	IA	450,245	8,353,845	90,049	1.483	1,670,769	**$ 85.79**
Clay	IA	528,081	8,881,926	105,616	1.462	1,776,385	**$ 86.61**
Nobles	MN	612,759	9,494,685	122,552	1.310	1,898,937	**$ 86.92**
Worth	IA	392,694	9,887,379	78,539	1.455	1,977,476	**$ 87.07**
Pocahontas	IA	659,969	10,547,348	131,994	1.547	2,109,470	**$ 87.33**
Humboldt	IA	496,795	11,044,143	99,359	1.572	2,208,829	**$ 87.35**
Sibley	MN	478,609	11,522,752	95,722	1.500	2,304,550	**$ 87.43**
Waseca	MN	423,360	11,946,112	84,672	1.505	2,389,222	**$ 88.06**
Osceola	IA	400,417	12,346,529	80,083	1.454	2,469,306	**$ 88.07**
Hancock	IA	626,276	12,972,805	125,255	1.530	2,594,561	**$ 88.96**
Le Sueur	MN	317,240	13,290,045	63,448	1.458	2,658,009	**$ 89.07**
Mitchell	IA	481,945	13,771,990	96,389	1.508	2,754,398	**$ 89.23**
Mower	MN	615,684	14,387,674	123,137	1.424	2,877,535	**$ 89.30**
Buena Vista	IA	595,344	14,983,019	119,069	1.490	2,996,604	**$ 90.58**
Steele	MN	364,373	15,347,392	72,875	1.460	3,069,478	**$ 91.56**
Sioux	IA	868,925	16,216,317	173,785	1.568	3,243,263	**$ 91.67**

investment for the size of plant analyzed.

Five sizes of plant were considered to estimate how the economies in ownership and operating costs of the plant are offset by the increase in feedstock costs as plant size increases. The five sizes considered are plants that require multiples of 45.93 dry tons of corn stover per hour, or 386,084 short tons per year. The totals for the five sizes are shown in Table 2, where the tons are rounded off to multiples of 46.

Table 2 shows the total gallons of denatured ethanol produced annually, the amount of electricity sold annually, and the total project investment per gallon of ethanol by plant size and conversion efficiency[4]. The total project investment varies with the conversion efficiency achieved for two reasons. First, a plant processing a given amount of biomass per day that converts more of the biomass to ethanol has less biomass left to produce steam, resulting in less electricity production. Second, the Icarus software designs the size of the boiler/turbogenerator to efficiently convert the amount of biomass available to steam, resulting in lower investments for plants producing fewer gallons of ethanol per ton of feedstock. Thus, the total project investment per gallon decreases as conversion rate increases both because the total project investment to process a given amount of stover decreases, and because the gallons of ethanol produced increases. For example, the total investment per gallon of ethanol produced by the smallest size of plant with the lowest conversion rate decreases from $6.26 to $4.86 for the same size of plant operating at the highest conversion rate. Also notice that the amount of ethanol increases from 29.34 million gallons per year to 36.29 million gallons per year, while the amount of electricity sold annually decreases from 100.5 million kWh to 57.3 million kWh.

[4] The gallons per ton and the gallons produced per year are gallons of denatured ethanol. The study assumes 4% denaturant is used in all cases analyzed.

Investment cost for a given conversion rate decreases as the size of plant increases because of economies in building larger equipment and plants. With a conversion rate of 81.8 denatured gallons per ton for example, the investment cost per gallon declines from $5.74 per gallon of annual output to $3.43 per gallon for a plant processing 5 times as much biomass per hour.

Table 2: Total Project Investment/ Gallon of Annual Denatured Ethanol Production

Stover/Hour	**Dry Tons**	**46**	**92**	**138**	**184**	**230**
Stover/Year	**Dry Tons**	**386,084**	**772,168**	**1,158,252**	**1,544,336**	**1,930,420**
Gallons/Ton 76.0	**Mil. Gal./Yr.**	**29.34**	**58.71**	**88.06**	**117.32**	**146.50**
	Mil. kWh/Yr.	**100.5**	**225.7**	**349.4**	**474.4**	**606.6**
	$/Gal./Yr.	**$6.26**	**$4.97**	**$4.38**	**$4.00**	**$3.74**
81.8	**Mil. Gal./Yr.**	**31.61**	**63.22**	**94.83**	**126.31**	**157.67**
	Mil. kWh/Yr.	**87.2**	**199.2**	**312.3**	**424.1**	**541.3**
	$/Gal./Yr.	**$5.74**	**$4.56**	**$4.02**	**$3.67**	**$3.43**
87.8	**Mil. Gal./Yr.**	**33.92**	**67.86**	**101.75**	**135.50**	**169.09**
	Mil. kWh/Yr.	**72.7**	**172.0**	**272.5**	**370.3**	**474.8**
	$/Gal./Yr.	**$5.28**	**$4.19**	**$3.69**	**$3.37**	**$3.15**
93.8	**Mil. Gal./Yr.**	**36.29**	**72.59**	**108.83**	**144.89**	**180.75**
	Mil. kWh/Yr.	**57.3**	**144.1**	**230.3**	**318.5**	**406.1**
	$/Gal./Yr	**$4.86**	**$3.86**	**$3.40**	**$3.11**	**$2.90**

Profitability of the Base Case Using Corn Stover as the Feedstock

The base case assumes the firm receives net prices of $2.00 per gallon for ethanol and the weighted average annual price Excel Energy would pay in 2007 for electricity sold to the grid, $0.056/kWh. The plant receives no federal, state, or local subsidies. The firm is assumed to pay the price on the supply schedule (Table1) for the corn stover required. The analysis is completed for each of four levels of technical efficiency described below. The firm is assumed to invest the amount of money indicated above and to finance the investment and operation with equity capital. No money is borrowed. The analysis assumes the equipment in the plant is depreciated over seven years for tax purposes, with other depreciable assets depreciated over a 20-year life. The firm is assumed to pay federal and State of Minnesota corporate income tax on taxable income.

The gallons of ethanol produced per ton of corn stover, a measure of technical efficiency, is very important to the profitability of the plant. Because the industry does not have a history of commercial production to indicate the level of technical efficiency plants can achieve, this study analyzes a range of efficiencies to indicate its impact on plant profitability. The theoretical yield of ethanol from corn stover is 112.6 gallons of anhydrous (or 117.3 gallons of denatured) ethanol per ton. This analysis estimates profitability for each of four levels of theroretical yield; 64.8%, 69.7%, 74.8% and 80.0 %. These percentages of the theoretical yield result in production of approximately 76.0, 81.9, 87.9 and 94.0 gallons of denatured ethanol per ton for the four levels, respectively. This appears to be an appropriate range of technical efficiency to analyze for 1st generation cellulosic ethanol plants.

The price each size of plant is expected to pay for corn stover is shown in Table 3. The amount paid per dry ton increases from $76.75 for the smallest size plant to $87.07 for the largest plant size. The smallest plant can source all of the stover required from 3 counties. The remaining plant sizes could source the required stover from 7, 11, 13, and 17 counties, respectively. The smallest plant would require about 2 truckloads of stover per hour, while the other plants would use 4, 6, 8, and 10 semi-truck loads per hour, respectively. No effort was made to analyze the costs of coordinating the arrival, unloading and departure of this amount of traffic, but the difficulties may pose significant diseconomies for the larger plant sizes that have not been included in the profitability calculations presented here.

The IRRs for alternative base case situations are given in Table 3. The IRR varies from 5.6% for the smallest plant with the lowest conversion rate to 17.7% for the largest size plant with the highest conversion rate. The data suggest the small plant will have difficulty achieving an attractive IRR for any of the four conversion rates, and that the IRR may be less than desired for even the largest plants operating at the highest conversion rates analyzed. The IRR is lower than 12% for all sizes of operation with a conversion rate of 76.0 gallons per ton. It exceeds 12 % for the 3 largest plant sizes with a conversion rate of 81.9 gallons per ton, and for the largest 4 sizes of plant operating at the two highest conversion rates. However, none of the situations produced an IRR of 20% or more.

Table 3: Profitability W/ Ethanol at $2.00/ Gallon and Electricity at $.056/ kWh

Stover/Hour	**Dry Tons**	**46**	**92**	**138**	**184**	**230**
Stover Cost	**$/DryTon**	**$76.75**	**$81.05**	**$83.21**	**$84.43**	**$87.07**
Gallons/Ton 76.0	**IRR**	**5.6%**	**8.8%**	**10.2%**	**10.9%**	**11.3%**
	$/Ton Stover 12%IRR	**$35.96**	**$63.47**	**$74.26**	**$79.09**	**$84.05**
	$/Ton Stover 20% IRR	**$(34.17)**	**$7.76**	**$25.17**	**$34.3**	**$42.24**
81.9	**IRR**	**7.7%**	**10.7%**	**12.2%**	**13.0%**	**13.5%**
	$/Ton Stover 12% IRR	**$47.93**	**$73.61**	**$84.42**	**$89.10**	**$93.91**
	$/Ton Stover 20% IRR	**$(21.28)**	**$18.60**	**$35.96**	**$44.90**	**$52.67**
87.9	**IRR**	**9.3%**	**12.5%**	**14.2%**	**15.0%**	**15.6%**
	$/Ton Stover 12% IRR	**$58.46**	**$84.02**	**$94.79**	**$99.35**	**$104.03**
	S/Ton Stover 20% IRR	**$(9.80)**	**$29.73**	**$47.02**	**$55.80**	**$63.36**
94.0	**IRR**	**11.0%**	**14.3%**	**15.6%**	**17.0%**	**17.7%**
	$/Ton Stover 12% IRR	**$69.56**	**$94.70**	**$103.01**	**$109.88**	**$114.33**
	S/Ton Stover 20% IRR	**$2.27**	**$41.18**	**$56.00**	**$66.96**	**$74.28**

The markets for corn stover are not well developed and some plants may be able to purchase stover at lower prices than indicated by the supply function. Others may need to pay more, particularly in areas where competition exists for available stover supplies. The table provides additional information on how much a plant could pay for stover and achieve a 12 or 20 % IRR, everything else remaining the same. For example, a plant processing 184 tons of stover per hour and achieving a yield of 81.9 gallons of ethanol per dry ton, could pay $89.10 per dry ton and achieve a 12% rate of return The same plant would need to pay no more than $44.90 per ton to achieve a 20% IRR.

Sensitivity to Changes in Key Price Levels

The impact of changes in the investment costs, the price paid for stover, and the price received for electricity and ethanol sold on the IRR are summarized in Table 4. Increases of either 20% in the investment costs or $10 per ton in the cost of the feedstock reduce the IRR, as expected, but the pattern is somewhat different. The 20% increase in the investment cost reduces the IRR from 1.1% to 2.5%, with the greater decreases

Table 4: Sensitivity of Internal Rate of Return to Changes in Key Price Levels

Stover/Hour	Tons	46	92	138	184	230
Gallons/Ton 76.0	Base Case	5.6	8.8	10.2	10.9	11.3
	Increase Investment Cost 20%	4.5	7.2	8.5	9.0	9.4
	Increase Stover Cost $10/Ton	3.9	6.8	8.0	8.5	8.9
	Sell Electricity for $0.065/kWh	6.3	9.3	10.8	11.4	11.9
	Sell Ethanol for $2.20/Gallon	8.4	11.4	13.0	13.8	14.4
81.9	Base Case	7.7	10.7	12.2	13.0	13.5
	Increase Investment Cost 20%	6.2	8.9	10.3	10.9	11.4
	Increase Stover Cost $10/Ton	5.9	8.8	10.2	10.8	11.3
	Sell Electricity for $.065/kWh	8.0	11.1	12.7	13.4	14.0
	Sell Ethanol for $2.20/Gallon	10.1	13.3	15.0	15.9	16.6
87.9	Base Case	9.3	12.5	14.2	15.0	15.6
	Increase Investment Cost 20%	7.7	10.5	12.0	12.8	13.3
	Increase Stover Cost $10/Ton	7.7	10.8	12.3	13.0	13.5
	Sell Electricity for $.065/kWh	9.6	12.8	14.5	15.4	16.0
	Sell Ethanol for $2.20/Gallon	11.8	15.1	17.0	18.0	18.7
94.0	Base Case	11.0	14.3	15.6	17.0	17.7
	Increase Investment Cost 20%	9.1	12.1	13.4	14.6	15.2
	Increase Stover Cost $10/Ton	9.5	12.6	13.9	15.1	15.7
	Sell Electricity for $.065/kWh	11.2	14.5	15.9	17.3	18.0
	Sell Ethanol for $2.20/Gallon	13.4	17.0	18.5	20.0	20.9

for larger plants and for plants with a higher conversion rate. A $10 increase in the cost of the feedstock/dry ton reduces the IRR 1.5 % to 2.5%. The reduction from an increase in the cost of the feedstock is greater for larger than smaller plants, and somewhat more for low than high conversion rates.

Increasing the price of the products the plants sell, electricity and ethanol, increases profitability. An increase in the price of electricity from $0.056 to $0.065/kWh (an increase of 16%) raises the IRR 0.2% to 0.7%, with the impact being greater on plants with lower conversion rates because they sell more electricity per gallon of ethanol. Increasing the price of ethanol from $2.00 to $2.20 per gallon has a greater impact on the profitability of plants with a higher conversion rate, as expected. The increase in the IRR varies from 2.4% to 3.2%. With an increase in the price received for either electricity or ethanol, more of the alternative plant size/conversion rate combinations have an IRR above 12%. However, only the two largest plant sizes with the highest conversion rate and a price of $2.20 for ethanol achieve an IRR of 20% or higher.

Impact of Small Producer Tax Credit and the Cellulosic Biofuel Tax Credit on IRR

The small producer tax credit ($0.10 per gallon of annual production for plants producing less than 60 million gallons per year) and the cellulosic biofuel producer tax credit ($0.56 per gallon of sales) can only be used to offset federal income tax. Unused credits can be carried forward for up to 15 years. While the current law limits tax credits to fuel produced from 2009 through 2012, this analysis assumes the program will be continued over the 20 years the plant is in production. While these provisions provide plant owners with some flexibility in using the tax credits, it is important to note that the tax credits in excess of the income tax reductions will not be paid to the producer, and the credits produce no benefit to producers who have no income tax liability. Thus, the impact on the IRR is closely related to the amount of federal tax the plant would pay in the absence of the tax credit.

Considering the base case with ethanol at $2.00 per gallon, the two provisions provide more dollars of tax credits than are needed to offset every dollar of federal tax the plants are projected to owe for each of the 5 plant sizes and 4 production rates. The smallest plant is eligible for $2.934 million (when producing 76 gallons per ton) to $3.629 million (when producing 93.8 gallons per ton) of small producer tax credit per year. In addition the smallest plant is eligible for $16.430 to $20.322 million of cellulosic producer tax credits per year. These credits, $19.364 to $23.9510 million per year, exceed the federal tax the plant is expected to owe when ethanol is sold at $2.00 per gallon. The largest plant accrues $82.04 (when producing 76 gallons per ton) to $101.22 (when producing 93.8 gallons per ton) million of producer tax credits per year. Again the amount of tax credits exceeds the federal income tax the plant is expected to owe for the various production rates per ton of biomass.

As noted in Table 3, the profitability of the plant increases as the size of plant increases and as the amount of ethanol produced per ton increases. Further, the amount of tax increases with profitability. Hence, the impact of the tax credits increases as size of plant and production level per ton increase. The data in Table 5 indicate that the IRR increases by 1.9 to 3.7 % for the lowest production rate, raising it above 12% for the largest three sizes of plant, and the IRR increases to 20% or more for the largest two sizes of plant when they are operating at the two higher production rates.

Table 5: Impact of Tax Credits on the IRR for the Corn Stover Base Case

Stover/Hour	Dry Tons	46	92	138	184	230
Gallons/Ton 76.0	Increase in IRR	1.9	3.0	3.4	3.5	3.7
	IRR w/Tax Credits	7.5	11.8	13.6	14.4	15.0
81.9	Increase in IRR	2.5	3.5	4.1	4.2	4.5
	IRR w/Tax Credits	10.2	14.2	16.3	17.2	18.0
87.9	Increase in IRR	3.1	4.1	4.6	5.0	5.2
	IRR w/Tax Credits	12.4	16.6	18.8	20.0	20.8
94.0	Increase in IRR	3.6	4.7	5.2	5.7	5.9
	IRR w/Tax Credits	14.6	19.0	20.8	22.7	23.6

Now consider the impact of the tax credits on the IRR for changes in the key price levels. The impact on the IRR is somewhat less for each plant size/production rate combination when profitability is lower than the base case, and somewhat greater when profitability is greater than the base case. Thus, the increase in the IRR will be somewhat less than the base case for higher investment costs and higher prices for the biomass, while the increase will be greater than the base case when electricity is sold at a higher price. Increasing the price of ethanol 10% to $2.20 per gallon has the greatest impact on profitability and hence the tax credits have a greater impact on increasing the IRR for the various plant size/production rate combinations. Like the base case, the tax credits are sufficient to more than offset all federal taxes owed in each case. The impact on the IRR for each plant size/production rate combination is shown in Table 6.

The higher ethanol price increases both the profitability of all plant size/production rate combinations and the income taxes to be paid. More of the available tax credits can be used, increasing the IRR compared to the base case. Notice that the IRR is greater than 12 % for all plant size/production rate combinations except the smallest plant at the lowest rate. The IRR is 20% or more for the largest three plant sizes when production is 81.9

Table 6: Impact of Tax Credits on the IRR for Corn Stover W/Ethanol at $2.20/Gallon

Stover/Hour	Tons	46	92	138	184	230
Gallons/Ton 76.0	Increase in IRR	2.8	3.8	4.2	4.5	4.7
	IRR w/Tax Credits	11.2	15.2	17.2	18.3	19.1
81.9	Increase in IRR	3.4	4.4	5.0	5.3	5.5
	IRR w/Tax Credits	13.5	17.7	20.0	21.2	22.1
87.9	Increase in IRR	3.9	5.1	5.6	6.0	6.3
	IRR w/Tax Credits	15.7	20.2	22.6	24.0	25.0
94.0	Increase in IRR	4.4	5.6	6.3	6.8	7.0
	IRR w/Tax Credits	17.8	22.6	24.8	26.8	27.9

gallons per ton, and at the four largest plant sizes when production is at the highest two production rates. The production tax credits have the potential to increase the IRR by 7 to 8% when the plant is sufficiently profitable to make complete use of the tax credits.

Hardwoods

Aspen and other hardwoods are the second feedstock considered to support a second generation cellulosic ethanol plant in Minnesota. The northern counties of the State make up the major hardwood producing area. Hibbing, Minnesota was selected as the location for the hypothetical processing plant. Hibbing is well located with respect to the potential supply of hardwood residue available in Minnesota. This location is served by a good network of roads and highways that are essential for delivering the feedstock from Minnesota production areas and for delivering ethanol to markets. It also has access to railroads and utilities, making it an efficient location for a cellulosic ethanol plant using hardwood as a feedstock.

The northern counties have an active pulpwood market that utilizes much of the hardwood production from the area. Given this competition for the roundwood produced in the area, this study explores the collection of forest residue as a low cost supply of hardwood for the ethanol plant. Forest residues are composed of growing–stock (tree tops and limbs) and non-growing-stock (bolewood, tops and limbs). Supplying this material requires assembling and transporting the residue for distances up to several miles to a roadside grinding site, grinding the residues, and transporting the ground hardwood to the ethanol plant. As the amount to be supplied to the plant increases, the supply area must be expanded, increasing the marginal cost of the feedstock delivered to the plant. As the delivered cost of the forest residue increases to the price level for pulpwood, it is assumed that the ethanol plant can compete for the pulpwood produced in the area. Thus, the analysis assumes the ethanol plant is supplied with ground hardwood forest residue when the cost of supplying it is less than using roundwood as feedstock. It also assumes ground roundwood (or the ground harvest of whole trees) will make up the remainder of the plant’s supply when the roundwood market value is less than the cost of bringing residue to the plant from more distant sources.

Cost of Supplying Hardwood

The estimated quantities of aspen and other hardwood residue that could be harvested were based on the average of the 2000-2004 annual county level volumes of roundwood product harvested (Piva, 2006). The percentage for each component of the tree is given in Table 7. The shares of growing stock tops and limbs (16%), the non-growing stock boles (12%), and non-growing top and limbs (3%) make up 31% of the biomass produced. Dividing by the percentage of bolewood, 53%, the residue is equal to 59% of the roundwood product produced. The residues available per year are estimated as 59% of the roundwood product harvested.

Table 7: All Hardwood Livetree Biomass on Timberland by Component for Minnesota, 1990 (Miles, Chen, and Leatherberry, 1992)

Component	**Percent Share**
All Live 1-5" Trees	11
Growing-stock Stumps	4
Growing-stock Boles	53
Growing-stock Tops and Limbs*	16
Non-growing-stock stumps	1
Non-growing –stock Boles*	12
Non-growing –stock Tops and Limbs*	3
Total	100
All residues as % of growing-stock-boles	59
Growing residues as % of growing-stock boles	30

*Residue

The amount available for harvest is limited to 75 percent of the total in the county to allow for nonparticipation by some land owners. The remaining amount available for harvest is further reduced by 25 percent to provide for nutrient replenishment, wildlife habitat and miscellaneous harvest losses. Thus, the amount of hardwood residue that can be supplied is limited to 1 x 0.59 x 0.75 x 0.75 or 0.33 of the total roundwood harvested in the county. A detailed discussion of the procedures to estimate the amount of hardwood residue available by county is given by Petrolia (2006b).

A firm harvesting residue will not want to move its equipment to an area unless there is a substantial amount of residue available. The minimum threshold for a county to be included as a potential source of ground hardwood residue is 20,000 tons (green residue) available for a given year, after accounting for all of the above deductions.

The component costs estimated to harvest, grind and deliver the hardwood to the cellulosic ethanol plant are summarized in Table 8. Harvest costs were based on Berguson, Maly and Buchman (2002) and adjusted to 4th quarter 2007 price levels. Stumpage prices were estimated as $9.12 per short ton (green) (Minnesota Department of Natural Resources). Costs to harvest the residue include a knuckleboom loader and

Table 8: Parameters For Forest Residue Collection and Transport Cost

Residue Harvest Years	2000-04
Wood Species Included	Aspen and all hardwoods
Forest Land Participation rate	75%
County Residue minimum Threshold Tons /year (green)	20,000
All Residue as a % of Roundwood Product	59%
Green Residue as a % of Roundwood Product	30%
Wildlife/Nutrient Mitigation/Other deduction	25%
Mg (green) per cubic meter (Aspen)	0.95
Mg (green) per cubic meter (All other hardwoods)	0.96
Dry weight to green weight ratio	0.54
Harvest/Hauling Costs	
Stumpage fee for hardwood residues/green ton	$9.12
Knuckleboom/green ton	$0.78
Container Truck/green ton	$4.64
Loader/ green ton	$3.12
Grinder/green ton	$4.14
Trucking ground hardwood to plant	27.5 tons/load
0-50 miles	$4.85/mile
51-175 miles	$ 2.56/mile
176+ miles	$2.17/mile
Pulpwood Price/dry ton	$82
Pulpwood grinding/dry ton	$8

container truck to gather and transport the refuse to the roadside grinder site. A loader and grinder were assumed to process the residue. The total delivered costs of the ground hardwood are estimated to be $21.80 per green ton ($40.37 /dry ton) plus the cost of transport to the plant. Trucking rates for the logging industry were not available and the costs per loaded mile were based on grain transport data taken from the USDA-AMS Grain transportation Report (2008) for the 4th quarter of 2007. These rates were applied to the shortest highway distance from each county seat to the proposed conversion facility at Hibbing Minnesota. A more detailed discussion of the way the transportation costs were calculated is given by Petrolia (2006b).

The 40 counties in the study area having the lowest estimated cost for delivered ground hardwood residue to the plant at Hibbing, Minnesota are listed in Table 9. The amount of residue available is in dry short tons and the cost to deliver it is in dollars per short ton. Itasca County Minnesota has the lowest cost, $52.50 per dry ton. A total of 113, 926 dry tons could be supplied from Itasca County at this cost per ton. The next lowest cost source is Saint Louis County, which can supply 184,615 tons at $53.80 per ton. The cost increases as residue is sourced from more distant counties. These data indicate there are only 22 counties that can supply ground hardwood residue to the plant at a cost of less than $90 per ton, the estimated cost of purchasing and grinding roundwood. These 22 counties could supply a total of 1,095,198 tons per year. This analysis assumes that when a plant requires more than this amount of ground hardwood, it would purchase and grind roundwood to provide the additional feedstock.

Total Project Investment

The hypothetical plant to convert hardwood into ethanol and electricity uses the same process as the corn stover plant; acid prehydrolysis and enzymatic hydrolysis. The total capital investment for the five sizes of plant and four conversion rates were developed by Huang and Ramaswamy with ICARUS cost estimation software. They used Aspen Plus

Table 9: Hardwood Residue Available by County and Delivered Cost of Ground Residue to a Plant in Hibbing, Minnesota

County	State	Cumulative Residue Available Dry Tons		Delivered Cost Ground Feedstock $/Dry Ton
Itasca	MN	-	113,925.81	$52.90
Saint Louis	MN	113,926.81	298,540.38	$53.80
Douglas	WI	298,541.38	341,654.69	$68.32
Carlton	MN	341,655.69	362,458.73	$69.35
Aitkin	MN	362,459.73	417,550.86	$71.11
Koochiching	MN	417,551.86	529,800.56	$71.57
Beltrami	MN	529,801.56	596,221.93	$71.80
Lake	MN	596,222.93	621,956.72	$74.58
Cass	MN	621,957.72	688,698.70	$74.73
Crow Wing	MN	688,699.70	723,642.21	$75.22
Hubbard	MN	723,643.21	761,201.91	$77.85
Clearwater	MN	761,202.91	789,552.13	$79.43
Pine	MN	789,553.13	834,002.30	$80.04
Kanabec	MN	834,003.30	844,292.98	$80.36
Burnett	WI	844,293.98	861,824.02	$82.53
Ashland	WI	861,825.02	906,465.07	$82.53
Bayfield	WI	906,466.07	957,855.24	$83.69
Sawyer	WI	957,856.24	1,033,795.64	$83.99
Morrison	MN	1,033,796.64	1,041,059.37	$84.19
Mille Lacs	MN	1,041,060.37	1,050,886.97	$84.63
Washburn	WI	1,050,887.97	1,087,909.21	$85.74
Wadena	MN	1,087,910.21	1,095,198.14	$88.14
Lake of the Woods	MN	1,095,199.14	1,118,984.42	$91.26
Becker	MN	1,118,985.42	1,141,494.65	$91.61
Mahnomen	MN	1,141,495.65	1,147,286.16	$92.17
Barron	WI	1,147,287.16	1,166,249.81	$93.63
Iorn	WI	1,166,250.81	1,206,152.91	$93.92
Gogebic	MI	1,206,153.91	1,254,486.79	$95.68
Cook	MN	1,254,487.79	1,271,025.54	$95.91
Polk	WI	1,271,026.54	1,283,241.46	$98.31
Rusk	WI	1,283,242.46	1,325,724.45	$100.06
Price	WI	1,325,725.45	1,372,149.30	$103.28
Otter Tail	MN	1,372,150.30	1,378,383.81	$103.66
Chippewa	WI	1,378,384.81	1,400,836.84	$104.44
Marshall	MN	1,400,837.84	1,412,510.68	$106.20
Eau Claire	WI	1,412,511.68	1,423,660.27	$107.66
Roseau	MN	1,423,661.27	1,438,615.44	$107.92
Pierce	WI	1,438,616.44	1,444,574.19	$111.75
Vilas	WI	1,444,575.19	1,475,430.40	$114.97
Ontonagon	MI	1,475,431.40	1,536,893.46	$115.26

software to model the material and energy balances for each of the 20 size/conversion rate combinations. The output from the Aspen Plus analyses provided the estimated amount of ethanol and electricity produced, and the basis for the variable cost estimates used in the profitability analysis.

The total project investment includes the total installed equipment cost, site development cost, warehouse cost, field expenses, office and construction fees, land cost, project contingency and working capital as explained for the plants using corn stover as feedstock.

Five sizes of plant were considered to estimate how the economies of ownership and operation are offset by the increase in feedstock costs as plant size increases. The five sizes are similar to the corn stover plants, requiring multiples of 45 tons of dry ground hardwood per hour of operation, or 377,976 tons per year. The total feedstock required per year and the amounts of denatured ethanol and electricity sold per year are shown in Table 10 for each of the 20 size/conversion rate combinations.

The level of technical efficiency, indicated in gallons of ethanol per ton of ground hardwood, is very important to the profitability of the business. The industry does not have a history of commercial production to indicate the level of technical efficiency these plants are likely to achieve. The theoretical yield from hardwood used in this study is 116.2 gallons of anhydrous (or 121.0 gallons of denatured) ethanol per ton, somewhat higher than the theoretical yield for corn stover. Note, however, that the hardwood in the study is largely aspen which tends to have a higher theoretical yield than other hardwoods and higher than corn stover. Conversion efficiencies of 63.9%, 69.3% 75.0% and 80.9% were applied to represent the range of conversion efficiencies cellulosic plants might achieve.

These percentages of theoretical yield result in production of 77.3, 83.9, 90.7, and 97.7 gallons per ton, respectively. The percentages of theoretical yield are very similar to those used for corn stover, but the amount of ethanol produced is slightly higher because of the higher theoretical yield.

The total project investment cost per gallon of annual output decreases as the size of the plant increases and as the conversion rate increases. For a given conversion rate (gallons of ethanol per ton of biomass), the investment cost declines as the size of plant increases because of the economies of building larger plants. For example, a plant designed to process 45 tons of biomass per hour with an operating efficiency of 83.9 gallons per ton has an investment cost of $5.71 per gallon, while a plant 5 times as large operating at the same conversion efficiency has an investment cost of $3.44 per gallon of annual output.

Table 10: Total Project Investment/Gallon of Annual Denatured Ethanol Production

Hardwood/Hour	Dry Tons	45	90	135	180	225
Hardwood /Year	Dry Tons	377,976	755,952	1.133,929	1,511,905	1,889,882
Gallons/Ton 77.3	Mil. Gal./Yr.	29.24	58.50	87.75	116.93	145.98
	Mil. kWh/Yr.	115.7	254.9	395.4	540.1	688.4
	$/Gal./Yr.	$6.29	$5.02	$4.43	$4.05	$3.79
83.9	Mil. Gal/Yr.	31.76	63.53	95.27	126.91	158.38
	Mil. kWh/Yr.	99.9	224.8	351.0	481.9	612.8
	$/Gal./Yr.	$5.71	$4.56	$4.02	$3.68	$3.44
90.7	Mil. Gal/Yr.	34.34	68.70	103.00	137.14	171.09
	Mil. kWh/Yr.	84.3	194.4	308.2	420.9	535.1
	$/Gal./Yr.	$5.20	$4.15	$3.66	$3.35	$3.13
97.7	Mil. Gal/Yr.	36.99	74.00	110.92	147.61	184.10
	Mil. kWh/Yr.	67.5	161.7	258.0	355.6	454.2
	$/Gal./Yr.	$4.76	$3.79	$3.34	$3.05	$2.86

Increasing the conversion efficiency for a given size of plant has two effects that reduce the total investment cost per gallon of ethanol produced. First, a plant with a higher conversion rate uses more of the biomass to produce ethanol. This leaves less biomass for boiler fuel to produce steam and electricity and a somewhat smaller total investment (in the boiler and turbogenerator) is required. Second, a plant with a higher conversion rate also produces a larger number of gallons of ethanol. Both effects reduce the total investment cost per gallon of ethanol produced. For example, the largest size of plant with a conversion efficiency of 83.9 gallons per ton produces 158.38 million gallons of ethanol per year and has an investment cost of $3.44 per gallon. If a plant of the same size can operate at a conversion efficiency of 97.7 gallons per ton, it will produce 184.1 million gallons of ethanol per year and have an investment cost of $2.86 per gallon of annual ethanol production. Notice that increasing the conversion efficiency from 83.9 to 97.7 reduces the amount of electricity sold to the grid from 612.8 million kWh to 454.2 million kWh per year. With ethanol and electricity at current prices ($2.00 and $.056, respectively), the additional ethanol has a higher value than the electricity given up, suggesting the plant manager should operate the plant to enhance conversion efficiency if she wants to maximize profitability.

Profitability of the Base Case Using Hardwood as the Feedstock

The base case assumes the firm receives net prices of $2.00 per gallon for ethanol and the weighted average annual price Excel Energy paid in 2007 for electricity sold to the grid, $0.056/kWh. The firm is assumed to pay the price for the ground hardwood indicated on the supply schedule in Table 9. The firm is assumed to invest the amount of money indicated in Table 10 above and to finance the investment and operation with equity capital. No money is borrowed. The analysis assumes the equipment is depreciated for tax purposes over seven years, with other depreciable assets depreciated over a 20 year life. The firm is assumed to pay federal and State of Minnesota corporate income tax on taxable income.

The amount the plants pay for feedstock and the IRRs for alternative base case situations are given in Table11. Note the smallest size of plant can purchase all of the feedstock from 5 counties and pay $71.11 per ton. The second size of plant would need to expand its supply area to include 11 counties and pay $77.85 per ton. The three larger sizes of plant require more hardwood biomass than can be provided from residue by the 22 counties having a supply cost of less than $90 per ton. The analyses assume these three sizes would use a combination of residue from these 22 counties and roundwood to supply the feedstock needs.

The IRR for the 20 size/conversion efficiency combinations varies from a low of 7.9% for the smallest plant with a conversion efficiency of 77.3 gallons per ton to 18.5% for the largest plant size operating at a conversion efficiency of 97.7 gallons per ton. For a conversion rate of 83.9 gallons, the IRR ranges from 9.7% for the smallest plant to 14.0% for the largest size of plant. In general the four largest sizes of plants at conversion rates of 83.9 and 90.7 gallons per ton, and all five sizes at the highest conversion rate, exceed an IRR of 12 %. However, none of them exceed a 20% IRR.

The amount the firm could pay per dry ton of hardwood for each of the 20 plant alternatives and achieve a 12% or a 20% IRR is also given in Table 11. For example the largest size plant operating at a conversion rate of 83.9 gallons per ton could pay $99.34

per ton and achieve a 12% rate of return, everything else remaining the same. The same plant could pay only $56.89 per ton of hardwood to achieve a 20 % IRR.

Sensitivity to Changes in Key Price Levels

Sensitivity of the IRR for each of the 20 plant size/conversion rate combinations to increases in investment and feedstock costs, and to prices received for ethanol and

Table 11: Profitability W/Ethanol at $2.00/Gallon and Electricity at $.056/kWh

Hardwood/Hour	Dry Tons	45	90	135	180	225
Hardwood Cost	$/Dry Ton	$71.11	$77.85	$90.00	$90.00	$90.00
Gallons/Ton 77.3	IRR	7.9%	10.2%	9.6%	10.6%	11.6%
	$/Ton 12% IRR	$42.77	$67.31	$77.95	$83.41	$88.18
	$/Ton 20% IRR	-$28.90	$10.14	$27.48	$37.27	$45.09
83.9	IRR	9.7%	12.2%	11.9%	13.0%	14.0%
	$/Ton 12% IRR	$54.48	$78.83	$89.43	$94.77	$99.34
	$/Ton 20% IRR	-$16.17	$22.43	$39.71	$49.31	$56.89
90.7	IRR	11.4%	14.1%	14.0%	15.2%	16.3%
	$/Ton 12% IRR	$66.57	$90.70	$101.25	$106.42	$110.80
	$/Ton 20% IRR	-$3.06	$35.10	$52.31	$61.69	$69.03
97.7	IRR	13.0%	15.9%	15.9%	17.4%	18.5%
	$/Ton 12% IRR	$78.93	$102.86	$111.76	$118.31	$122.53
	$/Ton 20% IRR	$10.38	$45.15	$63.66	$74.39	$81.49

electricity are shown in Table 12. Increasing the investment cost lowers the IRR for the base case by 2.1 to 3.0 %. For the 83.9 conversion rate, the IRR for the small plant is reduced from 9.7 to 7.5, or 2.2 %, while the IRR of the largest plant declines from 14.0 to 11.4, or 2.6%. Increasing the cost of the feedstock has a somewhat smaller impact on the

IRR. An increase in the cost of the feedstock of $10 per ton reduces the IRR 1.3 to 2.3 %, with higher impacts on the lower conversion rates. For a conversion rate of 83.9 gallons per ton, the IRR is reduced from 9.7 to 8.2% for the smallest plant, or1.5%, and from 14.0

Table 12: Sensitivity of Internal Rate of Return to Changes in Key Price Levels

Aspen/Hour	Dry Tons	45	90	135	180	225
Gallons /Ton	Base Case	7.9	10.2	9.6	10.6	11.6
	Increase Investment 20%	5.8	8.0	7.4	8.3	9.2
77.9	Increase Aspen Cost $10/Ton	6.2	8.4	7.5	8.3	9.3
	Sell Electricity for $0.065/kWh	8.4	10.7	10.3	11.3	12.3
	Sell Ethanol for $2.20/Gallon	10.3	12.8	12.6	13.7	14.8
	Base Case	9.7	12.2	11.9	13.0	14.0
	Increase Investment 20%	7.5	9.8	9.5	10.5	11.4
83.9	Increase Aspen Cost $10/Ton	8.2	10.4	9.9	10.9	11.8
	Sell Electricity for $0.065/kWh	10.0	12.6	12.4	13.5	14.5
	Sell Ethanol for $2.20/Gallon	12.0	14.8	14.9	16.1	17.2
	Base Case	11.4	14.1	14.0	15.2	16.3
	Increase Investment 20%	9.0	11.5	11.5	12.5	13.5
90.7	Increase Aspen Cost $10/Ton	10.0	12.5	12.2	13.3	14.3
	Sell Electricity for $0.065/kWh	11.6	14.4	14.5	15.6	16.7
	Sell Ethanol for $2.20/Gallon	13.8	16.7	17.1	18.4	19.5
	Base Case	13.0	15.9	15.9	17.4	18.5
	Increase Investment 20%	10.6	13.2	13.2	14.5	15.5
97.7	Increase Aspen Cost $10/Ton	11.7	14.4	14.2	15.6	16.7
	Sell Electricity for $0.065/kWh	13.2	15.9	16.2	17.8	18.9
	Sell Ethanol for $2.20/Gallon	15.5	18.7	19.0	20.6	21.8

to 11.8%, or 2.2%, for the largest size of plant.

Increasing the price of the products the plant sells, electricity and ethanol, increases the IRR as expected. Increasing the price the plant receives for electricity from $.056 to $0.065 per kWh (an increase of 16%) has a relatively small effect on the IRR, ranging from less than 0.1% to 0.7%. The larger impacts occur in plants with lower conversion rates because these plants sell more electricity per gallon of ethanol. Increasing the price of ethanol has a greater impact on increasing profitability. A 10% increase in the ethanol price, $2.00 to $2.20 per gallon, increases the IRR 2.4 to 3.3 %, with the greater increases occurring in the larger plants. For example, with a conversion rate of 83.9 gallons per ton, the IRR of the smallest plant increases from 9.7% to 12.0% (2.3%), while the largest plant increase from 14.0% to 17.2% (3.2%). With an ethanol price of $2.20 per gallon, the two largest plants operating at a conversion rate of 97.7gallons per ton exceed a 20% IRR.

Impact of Small Producer Tax Credit and the Cellulosic Biofuel Tax Credit on IRR

Hardwood plants are also eligible for the small producer tax credit ($0.10 per gallon of annual production for plants producing less than 60 million gallons per year) and the cellulosic biofuel producer tax credit ($0.56 per gallon of sales). Tax credits can only be used to offset federal income tax, but unused credits can be carried forward for up to 15 years. While the current law limits tax credits to fuel produced from 2009 through 2012, this analysis assumes the program will be continued over the 20 years the plant is in production. While these provisions provide plant owners with some flexibility in using the tax credits, it is important to note that the tax credits in excess of the income tax reductions will not be paid to the producer, and the credits produce no benefit to producers who have no income tax liability. Thus, the impact on the IRR is closely related to the amount of federal tax the plant would pay in the absence of the tax credit.

Considering the base case with ethanol at $2.00 per gallon, the two provisions provide more dollars of tax credits than are needed to offset every dollar of federal tax the plants are projected to owe for each of the 5 plant sizes and 4 production rates. The smallest plant is eligible for $2.924 million (when producing 77.3 gallons per ton) to $3.699 million (when producing 97.7 gallons per ton) of small producer tax credit per year. In addition the smallest plant is eligible for $16.374 to $20.714 million of cellulosic producer tax credits per year. These credits, $19.298 to $24.413 million per year, exceed the federal tax the plant is expected to owe when ethanol is sold at $2.00 per gallon. The largest plant accrues $81.75 million (when producing 77.3 gallons per ton) to $103.096 million (when producing 97.7 gallons per ton) of producer tax credits per year. Again the amount of tax credits exceeds the federal income tax the plant is expected to owe for the various production rates per ton of biomass.

As noted in Table 11, the profitability of the plant increases as the size of plant increases and as the amount of ethanol produced per ton increases. Additionally, the amount of tax increases with profitability. Hence, the impact of the tax credits increases as size of plant and production level per ton increase. The data in Table 13 indicate that the IRR increases 2.7 to 3.8 percent for the lowest production rate, raising it above 12% for the largest four sizes of plant. The IRR increases to 20% or more for the largest two sizes of plant when they are operating at the 90.7 gallons per ton and at the four largest when operating at the highest production rate.

Now consider the impact of the tax credits on the IRR for changes in the key price levels. The impact on the IRR is somewhat less for each plant size/production rate combination when profitability is lower than the base case, and somewhat greater when profitability is greater than the base case. Thus, the increase in the IRR will be

Table 13: Impact of Tax Credits on the IRR for the Hardwoods Base Case

Hardwood /Hour	Dry Tons	45	90	135	180	225
Gallons /Ton 77.3	Increase in IRR	2.7	3.4	3.2	3.5	3.8
	IRR w/Tax Credits	10.6	13.6	12.8	14.1	15.4
83.9	Increase in IRR	3.2	4.0	3.9	4.2	4.6
	IRR w/Tax Credits	12.9	16.2	15.8	17.2	18.6
90.7	Increase in IRR	3.7	4.6	4.7	5.0	5.4
	IRR w/Tax Credits	15.1	18.7	18.7	20.2	21.7
97.7	Increase in IRR	4.3	5.3	5.3	5.8	6.2
	IRR w/ Tax Credits	17.3	21.2	21.2	23.2	24.7

somewhat less than the base case for higher investment costs and higher prices for the biomass, while the increase will be greater than the base case when electricity is sold at a higher price. Increasing the price of ethanol 10% to $2.20 per gallon has the greatest impact on profitability and, hence, the tax credits have a greater impact on increasing the IRR for the various plant size/production rate combinations. Like the base case, the tax credits are sufficient to more than offset all federal taxes owed in each case. The impact on the IRR for each plant size/production rate combination is shown in Table 14.

The higher ethanol price increases both the profitability of all plant size/production rate combinations and the income taxes to be paid. More of the available tax credits available can be used, increasing the IRR compared to the base case. Notice that the IRR is greater than 12 % for all plant size/production rate combinations. The IRR is 20% are more for the two largest plant sizes when production is 83.9 gallons per ton, and at the four largest plant sizes when production is at either the 90.7 or the 97.7 production rate. The production tax credits have the potential to increase the IRR by 7 to 8% when the plant is sufficiently profitable to make complete use of the tax credits.

Table 14: Impact of Tax Credits on the IRR for Hardwoods W/Ethanol At $2.20 /Gallon

Hardwood/Hour	Dry Tons	45	90	135	180	225
Gallons/Ton 77.9	Increase in IRR	3.3	4.2	4.2	4.6	4.9
	IRR w/Tax Credits	13.6	17.0	16.8	18.3	19.7
83.9	Increase in IRR	4.0	4.9	4.9	5.3	5.7
	IRR w/Tax Credits	16.0	19.7	19.8	21.4	22.9
90.7	Increase in IRR	4.5	5.6	5.6	6.1	6.6
	IRR w/Tax Credits	18.3	22.3	22.7	24.5	26.1
97.7	Increase in IRR	5.1	6.2	6.4	7.0	7.5
	IRR w/Tax Credits	20.6	24.9	25.4	27.6	29.3

An Integrated Forest Biorefinery

This part of the report analyzes the profitability of two ways to incorporate ethanol production into an existing pulp and paper mill. The process, described by Huang and Ramaswamy, involves pre-extraction of hemicellulose prior to pulping, with conversion of the hemicellulose to ethanol. The second alternative produces a larger amount of ethanol from a given amount of feedstock by both separating the hemicellulose, and by isolating the short and long (cellulose) fiber after pulping, with both the hemicellulose and the short cellulose fiber converted to ethanol. The long fibers are used to produce paper in both cases.

The pulp and paper plant is assumed to use 2000 metric tons (2,204.6 short tons) of wood fiber per day. The profitability of adding each of these two alternatives to the existing pulp and paper mill are analyzed by considering only the additional investment costs, along with the increased and decreased revenue and expense streams. The investment costs were estimated by Bruce Henry. The material and energy balances, and the variable inputs were estimated by Huang and Ramaswamy with Aspen Plus.

The additional investment required to retrofit the pulp and paper mill, and the changes in receipts and expenditures that would result are given for the two plants in Table 15. The pulp and paper mill consumes 2000 metric tons of aspen per day. By diverting the hemicellulose for ethanol production, the plant reduces steam production and also uses less steam, resulting in a net loss of 535,294 GJ/year. Electricity production is also reduced, resulting in sales of 5,937 fewer kWh per year. Conversion of the hemicellulose is expected to produce 4.6 million gallons of denatured ethanol per year. The change in process is expected to increase the pulping yield from 53.5 to 54.0 %. The second process also converts the cellulose fines to ethanol. In this case the reduction in power sales is not as great, and more ethanol is produced.

The additional investment costs to add the ethanol production unit to the pulp and paper mill is relatively large in both cases. For the hemicellulose conversion, the additional investment to produce ethanol is estimated to be $53.3 million, $11.47 per

Table 15: Changes in Inputs and Outputs for the Pulp and Paper Mill, and Profitability of the Ethanol Unit

	Unit	Convert Hemicellulose to Ethanol	Convert Hemicellulose & Short Fiber Cellulose to Ethanol	Price
Feedstock per Day	Metric Tons	2000	2000	
	Short Tons	2,204.6	2,204.6	
Change in Input &Output				
Reduction in Steam Produced	GJ/Yr.	535,294	535,294	$7.895Mill.
Reduction in Electricity Produced	kWh	5,973	5,600	
Reduction in Hog Fuel Used	Mg/Yr	6,724.8	6,724.8	$70.Mill
Ethanol Produced	Mil.Gal/Yr.	4.6	10.5	
Increase in Pulp Yield		3,500	3,500	$650/Million
Total Project Investment	$	$53,318,954	$66,307,010	
	$/Gal./Yr.	$11.47	$6.31	
IRR				
Base Case	%	-9.5	10.7	
Increase Investment 20%	%	-11.7	8.7	
Sell Electricity for $.065	%	-15.0	10.3	
Sell Ethanol for $2.20/Gal.	%	-3.1	12.7	

gallon of ethanol. If the plant converts both the hemicellulose and short fiber cellulose to ethanol the additional investment cost increases to $66.3 million, but with the increased ethanol production, the investment cost per gallon decreases to $6.31.

The two add-on units are assumed to require the same work force, further penalizing the plant that converts only the hemicellulose. The combination of the high investment and labor cost per gallon result in an IRR of -9.5% for the base case (ethanol selling for $2.00 and electricity sold for $0.056 per kWh). Increasing the investment 20% lowers the IRR, as expected. Because these alternatives reduce the amount of electricity the mill will sell to the grid, increasing the price of electricity reduces the IRR compared to the base case. Increasing the price of ethanol to $2.20 per gallon improves the IRR for the plant converting only hemicellulose, but not enough to make it positive. Raising the price of ethanol to $2.20 per gallon for the plant converting both hemicellulose and short fiber cellulose to ethanol increases the IRR to 12.7%.

The two plants should be eligible for both the small producer tax credit of $0.10 per gallon and the cellulosic biofuel tax credit of $0.56 per gallon. The plant converting only hemicellulose to 4.6 million gallons of ethanol per year is eligible for $3.036 million in tax credits annually. However, the ethanol part of the operation does not produce sufficient revenue under either the base case or the increased price of $2.20 per gallon to incur any federal income tax. It is unclear whether tax credits generated by the ethanol part of the operation could be used to offset income tax on profits generated by the paper production process. Because the profitability of the related paper production is not estimated as part of the analysis in this study, the tax credits are assumed to be lost in this case.

The plant that converts both hemicellulose and short fiber cellulose to ethanol would generate $6.93 million of tax credits per year. This is more than enough to offset all of the federal income tax earned on the ethanol part of the business. Assuming the plant uses the tax credits to offset the federal income taxes owed, the IRR for the base case is raised by 3.5% to 14.2%. The increase in the IRR when ethanol is sold at $2.20 per gallon is 4.2%, resulting in an IRR of 16.9%.

Summary

This study estimates the profitability of producing ethanol and electricity from two sources of biomass commonly available in Minnesota. The feedstocks and location of the hypothetical plants selected for analysis are a plant processing corn stover in Fairmont, Minnesota and a plant processing ground hardwood in Hibbing, Minnesota. The hypothetical plants analyzed are based on the process described by Aden, et. al., and uses acid prehydrolysis and enzymatic hydrolysis to produce ethanol and electricity. The capital investment for the plants was developed with ICARUS cost estimation software. The material and energy balance were estimated using Aspen Plus software. These two programs provided estimates of the total capital investment, the variable inputs and the outputs used to estimate the profitability of the plants.

Plant Size: Five sizes of plant were considered for both feedstocks to estimate how the economies in ownership and operating costs of the processing plant are offset by the increase in feedstock cost as the size of plant increases. The smallest plant analyzed to process corn stover requires approximately 46 dry tons per hour, or 386,084 dry tons per year. The other four sizes are multiples of 46 tons per hour, with the largest requiring 230 dry tons per hour, or 1,930,420 dry tons per year. The five sizes of plants to process ground hardwood range in size from 45 to 225 dry tons per hour, or 377,976 to 1,889,882 dry tons per year. The analysis indicates that, within the range of plant size considered in this study, the economics of operating larger plants exceed the diseconomies of hauling the biomass from a larger area. As noted in the following paragraph, some congestion costs may not have been adequately considered.

Supply Price of Feedstock: The cost of harvesting and delivering the feedstock to the plant as needed was estimated for both corn stover and ground hardwood. A square bale (36”x48”x96” in size) system was the lowest cost method to harvest and deliver corn stover to the Fairmont plant. The delivered costs varied from a low of $74.53 per dry ton for Martin County, where Fairmont is located, and increased with higher transportation costs for counties more distant from the plant. The small size of plant requires stover from 3 counties at a delivered cost of $76.75 per dry ton, while the largest size of plant requires stover from 17 counties at a delivered cost of $87.07 per dry ton. It should be noted that providing the amount of stover would require about 2 truckloads of stover per hour for the small plant, increasing to about 10 truckloads per hour for the large plant. The reader should note that the cost of coordinating the arrival, unloading and departure of this number of trucks has not been included in these cost estimates. The difficulty of coordinating the delivery of the biomass may pose significant diseconomies for the larger plant sizes that have not been included in these cost estimates.

Given the active market for pulpwood in the northern counties, this study explores the collection of forest residue as a low cost supply of hardwood to supply an ethanol plant. The amount of residue that can be harvested per year is estimated to be 59 percent of the roundwood product produced. The cost of supplying ground hardwood to the plant in Hibbing from Itasca County is estimated to be $52.50 per dry ton. The cost increases as residue is sourced from more distant counties. This study estimates that only 22 counties could supply ground residue to a plant in Hibbing for less than the estimated cost of purchasing and grinding roundwood, $90 per ton. These 22 counties could supply a total of 1,095,198 tons per year. The small plant would need to draw on residue supplies from five counties and pay an estimated supply price of $71.11 per dry ton. The second size of plant would consume residue from 11 counties and pay $77.85 per dry ton. The three largest plant sizes would consume all of the residue available from the 22 counties that can supply it for less than $90 per ton and obtain the balance of their supply on the roundwood market at an estimated cost of $90 per ton. Thus the estimated supply price of ground hardwood increases from $71.11 for the smallest plant, to $77,85 per ton for the second size of plant, to $90 per ton for the three largest sizes of plant analyzed.

Ethanol Yield per ton of Feedstock: Given the infant nature of this industry, the expected ethanol and electricity output per ton of dry feedstock is very uncertain. The analysis completed considers ethanol yields of approximately 65, 70, 75, and 80 percent of the theoretical maximum for each feedstock. The theoretical yield of ground hardwood is greater than corn stover, resulting in higher yields of ethanol for hardwood than corn stover for each percentage level chosen. All yields are presented in denatured (with 4 percent denaturant) gallons of ethanol. The four yield levels are 76.0, 81.8, 87.8, and 93.8 gallons per dry ton of corn stover. The comparable yield levels for ground hardwood are 77.3, 83.9, 90.7, and 97.7 gallons per dry ton.

Investment Cost in Processing Plant: The investment cost per gallon of annual ethanol production decreases for a given ethanol yield level as the size of plant increases. For the corn stover plant producing 76 gallons per ton, the investment cost declines from $6.26 per gallon of annual capacity for the plant processing 46 tons per hour to $3.74 per gallon for the plant processing 230 tons per hour (Table 2). The investment cost per gallon of annual ethanol production also decreases as the yield of ethanol per ton increases. For example, the investment cost per gallon of annual capacity for the largest corn stover plant (processing 230 tons per hour) is $3.74 for a yield of 76.0 gallons per ton, decreasing to $2.90 per gallon when the yield is 93.8 gallons per ton. The investment costs per gallon of annual capacity for the hardwood plants are very similar in magnitude to those of the corn stover plants, and they display the same pattern of decline as the size of plant and ethanol yield per ton of feedstock increase.

Production Incentives for Cellulosic Ethanol: The federal government has passed legislation containing two incentives, a small producer tax credit and a cellulosic biofuel producer tax credit that are available to cellulosic ethanol plants for 2009 through 2012. Small plants, defined as those with a productive capacity of less than 60 million gallons per year, are eligible to receive a $0.10 per gallon small producer income tax credit. In addition, the 2008 Farm Bill includes an income tax credit for all sizes of cellulosic plants equal to $0.56 per gallon of ethanol produced. This analysis assumes that these tax credits will remain in effect over the life of the project. It is important to note that these are tax credits, and can only be used to pay federal income tax owed on the income generated by the sale of ethanol and electricity by the plant.

The profitability of the alternative plants was estimated without tax credits and with the tax credits to indicate how much of the estimated return is dependent on these incentives. Knowing this difference should be helpful in evaluating other local, state and federal incentives that may be made available to encourage the development of a cellulosic ethanol industry.

Profitability Estimates for Corn Stover and Hardwoods: The price level of all investment and operating costs was adjusted to 4th quarter 2007 levels for the first year of operation of the plant. The base case assumes the firm receives net prices of $2.00 per gallon for ethanol and the weighted average price Excel Energy would have paid in 2007 for electricity sold to the grid, $0.056/kWh.The analysis assumes all of the investment and operating costs are financed with equity capital. No money is borrowed. The equipment in the plant is depreciated over 7 years and other depreciable assets over a 20-year life for tax purposes. The firm is assumed to pay federal and State of Minnesota corporate income tax on taxable income.

The introduction notes that firms often use a “hurdle rate of return” in making investment decisions. It was suggested that a relatively low rate of 12% might be used by investors with an interest in promoting industry in a specific area. But a more common rate used by many firms, particularly those considering a range of investment alternatives over a large geographic area, is 20%. While the hurdle rate will vary from firm to firm, these two rates are used in this study to place the profitability of the many plant sizes and conversion efficiencies in perspective.

Consider the internal rate of return, IRR, for the base case without tax credits. Plants operating at the lowest yield efficiency analyzed (65% of theoretical yield) have an IRR less than 12 % for all sizes of plant for both corn stover (Table 3) and hardwood (Table 9). In general, the four largest size of plants operating at the second yield level (70% of theoretical yield) or higher exceeded the 12% hurdle. The largest size of plant operating at the highest conversion efficiency analyzed achieved IRRs of about 18 %, but none of the plants reached a 20% IRR with the base case assumptions and no tax credits.

The sensitivity of the base case results to changes in major input and product prices is summarized in Table 4 for corn stover and Table 10 for hardwood. The impact of a 20% increase in investment cost, a $10 increase in the supply price per dry ton of feedstock, an increase in the price received for electricity to $0.065per kWh and an increase in the price the plant receives for ethanol to $2.20 per gallon is presented for each size and yield level of plant considered. The 20% increase in investment costs reduced the IRR from the base case 1.1 to 2.9% for the various stover and hardwood cases. Increasing the cost of feedstock $10 per dry ton also reduces the IRR 1.3 to 2.5%. Increasing the price the plant receives for electricity to $0.065 per kWh raises the IRR 0.1 to 0.7%. However, raising the price received for ethanol to $2.20 per gallon increases the IRR 2.4 to 3.3%. While the increase in product prices increases profitability, only the two largest size of plant operating at the highest yield level achieved an IRR of 20% or greater without consideration of the tax credits.

Including the tax credits raises the IRR for all corn stover and hardwood plants for both the base case and for the increase in ethanol price. The amount of increase is related to the amount of taxable income the plant generates and, hence, the amount of the tax credits the plant can use. The IRR increases 1.9 to 5.9 % for the corn stover base case (Table5) and 2.7 to 6.2% for the hardwood base case (Table 13). Raising the ethanol price to $2.20 per gallon increased profitability, the tax liability, and the impact of the tax credit. The increase for corn stover was 2.8 to 7.0% (Table 6) and 3.3 to 7.5 % for hardwoods (Table 14). Including the tax credits raises almost all of the situations analyzed above the 12% hurdle rate for both corn stover and hardwood. It also increases the IRR to more than 20% for the larger plants operating at the 75 and 80% conversion rates.

An Integrated Forest Biorefinery: The final section of the study analyzes the profitability of incorporating ethanol production into an existing pulp and paper mill that uses 2,204.6 short tons of aspen per day. Two alternatives are considered. One process involves pre-extraction of hemicellulose prior to pulping, with conversion of the hemicellulose to ethanol. The second alternative produces a larger amount of ethanol from a given amount of feedstock by converting both the hemicellulose and the short cellulose fibers to ethanol. The long cellulose fibers are used to produce paper in both alternatives.

The first alternative has an expected production of 4.6 million gallons per year. Investment costs are quite high, $11.47 per gallon of annual capacity. The IRR is negative for this alternative for the base case and for increased prices for electricity and ethanol. Because of the low returns, this alternative does not generate any income tax liabilities and including the tax credits does not improve its IRR.

The second alternative produces 10.5 million gallons of ethanol per year and has an investment cost of $6.31 per gallon of annual capacity. The IRR for the base case is 10.7%. Increasing the price of ethanol to $2.20 increases the IRR to 12.7%. Including the tax credits raises the IRR for the base case to 14.2% and for the increased ethanol price to 16.9%. While these results are more favorable for the second alternative (converting both the hemicellulose and the short cellulose fibers to ethanol) than the first, more work is needed to refine the technology and to reduce the investment and operating costs to make these alternatives financially attractive.

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