Appendix A

National Renewable Energy Laboratory

Oregon Biomass-to-Ethanol Project:

Pre-feasibility Study and Modeling Results

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Completed by:

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Executive Summary

Recently at NREL, modeling and analysis work was performed at the request of Bryan and Bryan, Inc. (BBI) to determine the economic feasibility of a biomass-to-ethanol plant if it were built in the state of Oregon. Several lignocellulosic biomass feedstocks and feedrates were specified by BBI for the modeling study. Results show that the most economically attractive scenarios would be from the Forest Residue and Wheat Straw feedstocks, with projected Internal Rates of Return of 19 percent and 18 percent, respectively. However, this analysis hinges on many pending issues, such as lignin by-product utilization, biomass feedstock cost, ethanol market price, and project financing. These issues will be described clearly in this report. If the project is to succeed, these issues will need to be properly addressed.

Introduction

In the past few years, many forested regions in the western United States have been recognized as having high fuel loading. This could potentially contribute to catastrophic fires to these regions. Thinning these forested regions may be the solution to alleviate the high fuel loading. If this is done, the question still remains of what to do with those trees that are cut down. If lumber mills or other forest product utilization facilities do not exist in that region, the forest thinnings will have little-to-no value. The agricultural sector also has its own waste utilization concerns. Once grains are harvested, the straws from crops such as wheat, rice and rye are often left in the fields, and are either plowed under, burned, or left for grazing.

These forest and agricultural wastes and residues 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 recently gained popularity because of its ability to reduce harmful auto emissions. Most of the ethanol produced in the U.S. comes from the corn ethanol industry; however, it can also be produced from other biomass sources, such as forest thinnings, wheat straw, and even waste paper.

This report contains the modeling and economic analysis results for the biomass feedstocks and feedrates seen in Table 1. Each feedstock was modeled individually and there were no mixed-feedstock models. For better utilization, feedstocks with very low availability, such as pulp/paper sludge and urban greenwaste, could be mixed with other feedstocks instead of being used individually. The technical and economic assumptions used in these models can be found in Appendix A:A at the end of this report.

Table 1. – Biomass Feedstocks and Feedrates

Biomass Feedstock	Feedrate (tons/day)
Forest Residue	1,369
Mixed Waste Paper	682
Ryegrass Seed Straw	1,232
Wheat Straw[1]	2,739
Pulp and Paper Sludge	180
Urban Greenwaste	400

The model results will be shown in terms of an IRR, an Internal Rate of Return. This is a measure of how profitable the proposed ethanol plant will be. Sensitivity analyses will then be displayed, which show the impact certain variables have on the calculated IRR. Sensitivity graphs can be found in the body of the report.

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 IRR using a set cost of ethanol production.

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. A two-stage dilute sulfuric acid hydrolysis process was chosen for this project over enzymatic hydrolysis because it is felt to be more economical at this time. Further, by using a two-stage dilute acid process, enzymatic hydrolysis can be introduced in the future to achieve even higher ethanol yields. This upgrade is not possible with the concentrated acid process. This is explained in further detail in the process description that follows.

After a century of research and development, the dilute acid hydrolysis process has evolved into the general concept outlined in Figure 1. The hydrolysis occurs in two stages to accommodate the differences between hemicellulose and cellulose. The first stage can be operated under milder conditions, which maximize yield from the more readily hydrolyzed hemicellulose. The second stage is optimized for hydrolysis of the more resistant cellulose fraction. The liquid hydrolysates are recovered from each stage and fermented to alcohol. Residual cellulose and lignin left over in the solids from the hydrolysis reactors may serve as boiler fuel for electricity and steam production.

While a variety of reactor designs have been evaluated, the percolation reactors originally developed at the turn of the century are still the most reliable. Though more limited in yield

[1] Two numbers are shown for wheat straw to bracket the economics better. The initial number was considered too optimistic after feedstock availability was more fully assessed.

than the percolation reactor, continuous co-current pulping reactors have been proven at industrial scale. NREL recently reported results[1, 2] for a dilute acid hydrolysis of softwoods in which the conditions of the reactors were as follows:

- Stage 1: 0.7-percent sulfuric acid, 190°C, and a 3-minute residence time
- Stage 2: 2.5-percent sulfuric acid, 210°C, and a 3-minute residence time

These pilot-plant scale tests confirmed the potential to achieve yields of 89 percent for mannose, 82 percent for galactose and 55 percent for glucose. Fermentation with *Saccharomyces cerevisiae* achieved ethanol conversion of 90 percent of the theoretical yield.

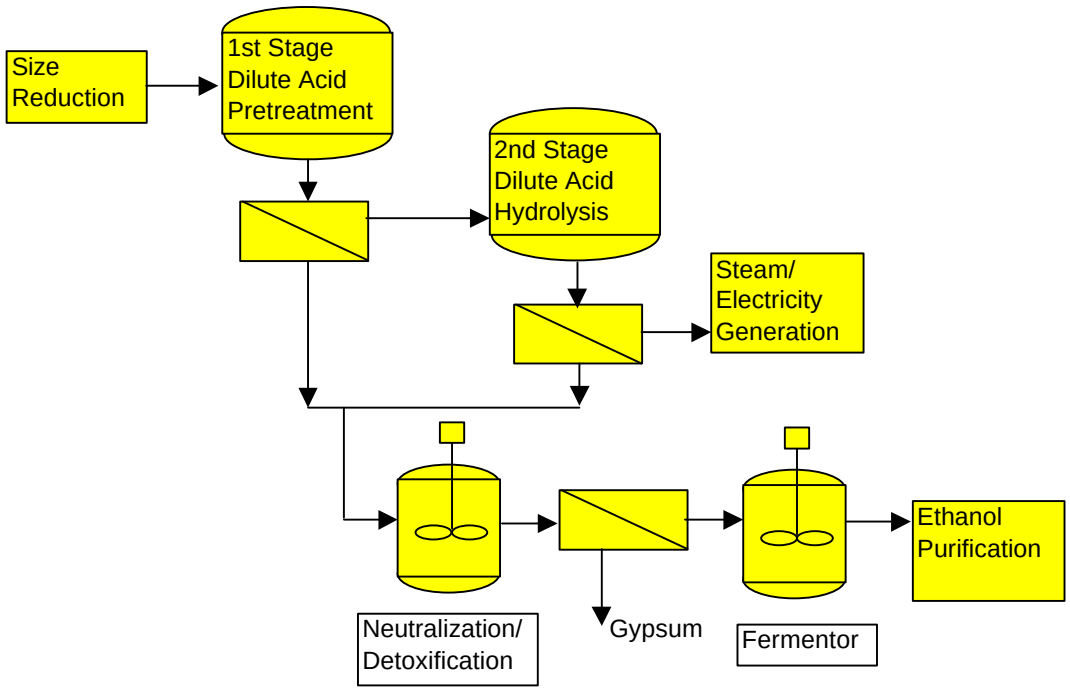


FIGURE 1: GENERAL SCHEMATIC OF TWO-STAGE DILUTE ACID HYDROLYSIS PROCESS

Model Results

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. In order for this design to be economical, revenue <u>must</u> be gained from the lignin residue.

Each of these designs was modeled for each feedstock. The results are shown in Table 2a for the biomass boiler option and Table 2b for the natural gas boiler option. The upper half of the table provides the overall plant performance results. The lower half of the table provides the required demands of the plant.

Table 2a. – Project Results – Biomass Boiler Design

Oregon Project Results

As of: 4/13/2000

Feedstock	Forest Residue	Wheat Straw	Urban Greenwaste	Mixed Waste Paper	Rye Grass Straw	Paper/pulp Sludge
Boiler Model Used	Biomass Boiler	Biomass Boiler	Biomass Boiler	Biomass Boiler	Biomass Boiler	
Model	A0001B1	A0001C	A0001F	A0001D	A0001E	Not Modeled
Feedrate (BDT/day)	1369	2739	400	682	1232	180
Feedstock Cost ($/BDT)	$28	$30	-$20	$20	$35	$10
Ethanol Plant Capital Cost ($ MM)	$85.6	$120.6	$40.8	$54.4	$74.9	
(denatured) Ethanol Sales Price ($/gal)	$1.25	$1.25	$1.25	$1.25	$1.25	
Ethanol Yield (Gal/BDT feed)	58	53	52	55	53	
Ethanol Production (MM gal/yr)	29	54	8	14	24	
IRR	***13.2%***	***13.1%***	***11.8%***	***3.1%***	***-0.6%***	***??***
Other Results:						
Excess Electricity (kW)	12,820	11,831	1,068	2,205	5,847	
Makeup Water Flow (gpm)	650	1,100	130	320	430	

Comparing the natural gas boiler design to the biomass boiler design shows that the natural gas design is more economically attractive with an IRR of 19 percent. However, this greatly hinges on the assumption of finding a nearby buyer for the lignin-rich residue. This will be addressed further in the discussion section of this report. Since this process design gave a larger IRR, it was used to model the other feedstocks.

For comparison purposes, the same hydrolysis and fermentation yields that were used for the forest residue models were also used for the other models. It should be noted that although the same yields were used for each of the different feedstocks, in reality, each feedstock would have different properties and would react differently to the hydrolysis and fermentation conditions. Research would have to be conducted with each specific feedstock for the most accurate results and optimization.

Table 2b. – Project Results – Natural Gas Boiler Design

Oregon Project Results

As of: 1/11/2000

Feedstock	Forest Residue	Wheat Straw	Urban Greenwaste	Mixed Waste Paper	Rye Grass Straw	Paper/pulp Sludge
Boiler Model Used	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	
Model	A9912H2	A9912H4B	A9912H7	A9912H3	A9912H5	Not Modeled
Feedrate (BDT/day)	1369	2739	400	682	1232	180
Feedstock Cost ($/BDT)	$28	$30	-$20	$20	$35	$10
Ethanol Plant Capital Cost ($ MM)	$50.1	$74.5	$30.5	$34.7	$47.7	
(denatured) Ethanol Sales Price ($/gal)	$1.25	$1.25	$1.25	$1.25	$1.25	$1.25
Ethanol Yield (Gal/BDT feed)	58	53	40	55	53	
Ethanol Production (MM gal/yr)	29	54	6	14	24	
IRR	***19.0%***	***18.3%***	***14.0%***	***7.0%***	***-1.3%***	***??***
Other Results:						
Electricity Demand (kW)	9,519	17,102	4,000	5,310	8,621	
Natural Gas Demand (lb/hr)	13,664	23,534	4,500	7,093	10,254	
Flow to WWTP (gpm)	700	1,340	250	375	620	
Wastewater COD (ppm)	232	305	260	172	365	
Lignin-residue Heating Value (MM BTU/hr)	615	1,006	205	291	447	
Makeup Water Flow (gpm)	1,150	2,000	380	600	850	

Table 2b shows that the forest residue and wheat straw feedstocks are the most economically attractive at their given feedrates with the natural gas boiler design. A 19.0 percent IRR was achieved from the forest residue feedstock and an 18.3 percent IRR was achieved from the wheat straw feedstock. While the wheat straw model feedrate was considerably larger than the forest residue model, its IRR was slightly less because of a larger feedstock unit cost, and also because wheat straw has a lower carbohydrate composition, which leads to a lower overall ethanol yield.

The urban greenwaste model was unique because it used a negative feedstock cost, meaning that the feedstock would actually provide revenue for the plant instead of costing the plant money. Because of this fact, it was difficult to assume a price for the lignin-rich residue. It is unknown if the small amount of residue produced from this plant would fetch the same price as residue produced from larger plants. For comparison purposes, this model used the same residue price of $2/million Btu (MMBtu), which gave a 14 percent IRR.

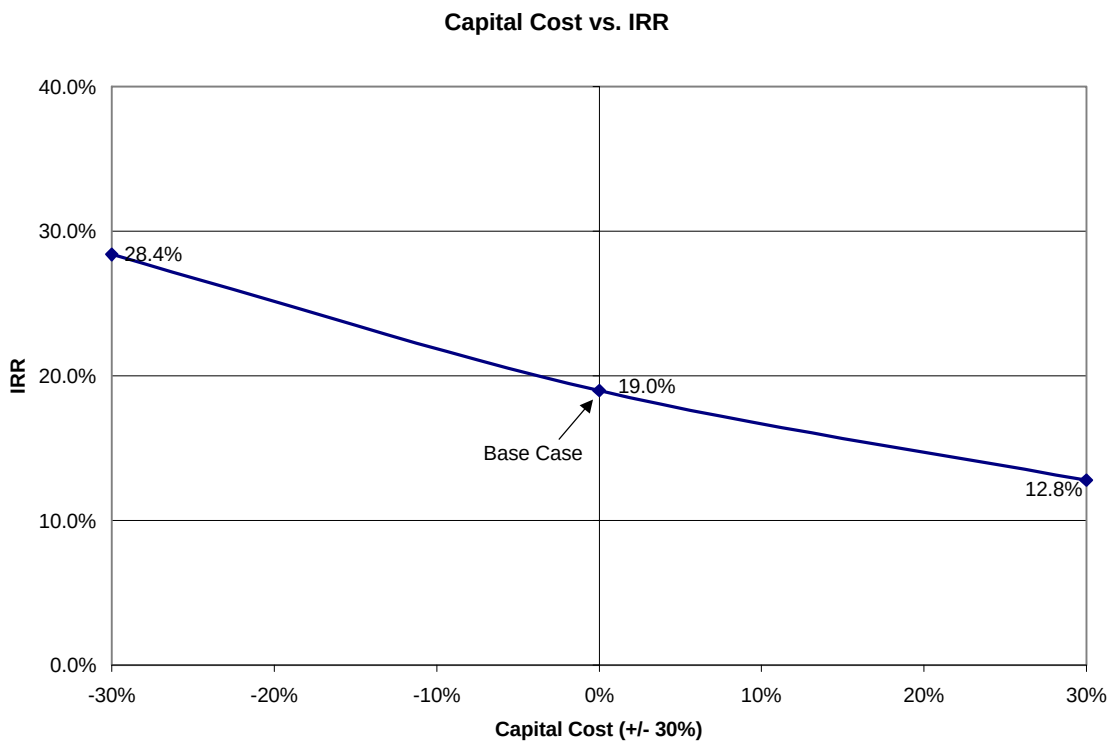
The other feedstock models have much lower IRR's. This occurred for a variety of reasons. The mixed waste papers model was set back by its low biomass feedrate (larger plants are generally more profitable due to economies-of-scale). The Rye Straw Grass IRR was greatly affected by its large feedstock cost. The negative IRR achieved through this model shows that the plant would actually lose money at these conditions. The choice was

made not to model the pulp/paper sludge because of its extremely low specified feedrate. Past NREL experience has shown that IRR's for these sets of assumptions are often well below zero.

Discussion

The capital cost estimate for this level of analysis is no better than +/- 30 percent. Therefore, the capital cost of the plant in question has a large potential range. This will have a significant impact on the economic viability of this plant. The magnitude of such an impact can be seen in Figure 2 below. A sensitivity analysis was performed on the capital cost for the base case model (forest residue, natural gas boiler) in order to determine its effect on the project IRR.

Figure 2. – Capital Cost Sensitivity Analysis



Theoretically, the cost of this plant could range from $35 million to $65 million. As shown, the +/- 30 percent range also produces a wide range of IRR, from 28 percent to 13 percent. Considerable detailed engineering and pilot scale experimental work would be required to more accurately estimate the plant capital cost.

In addition, sensitivity analyses were performed on various process parameters recognized as having the potential to affect the process. The results of these analyses are presented in the following sections of this report. All sensitivity analyses started with the forest residue, natural gas boiler model as a "base case." This model was used because it gave the largest IRR.

There were four parameters that stood out because of their very significant impact on the process. They are:

- Lignin-rich residue utilization / revenue
- Delivered feedstock cost
- Project financing
- Ethanol selling price

Each of these will now be discussed in further detail. It is important to stress that any future work on this project should begin with attaining a firm understanding of these issues.

Most Important Parameters

Lignin-rich By-product Utilization

If a biomass boiler is used to create process steam, the lignin-rich by-product can be used as boiler feed material, if it is dried to less than 60-percent moisture. This not only eliminates waste from the plant, but it eliminates the need to purchase boiler fuel separately. As mentioned earlier, however, this boiler is quite expensive, with capital costs greater than $20 million. To lower the required capital costs, a different style of boiler, such as a natural gas boiler, should be considered. Natural gas must consequently be purchased as boiler fuel, and the by-product residue must be dealt with some other way. Sending it off-site would no doubt bring associated transportation costs.

If the residue could be sold for profit, additional revenue could be brought to the ethanol plant. This brings forth two important concerns:

1) What economically beneficial use could the residue have, either on-site or off-site?
2) What price could the residue be sold for?

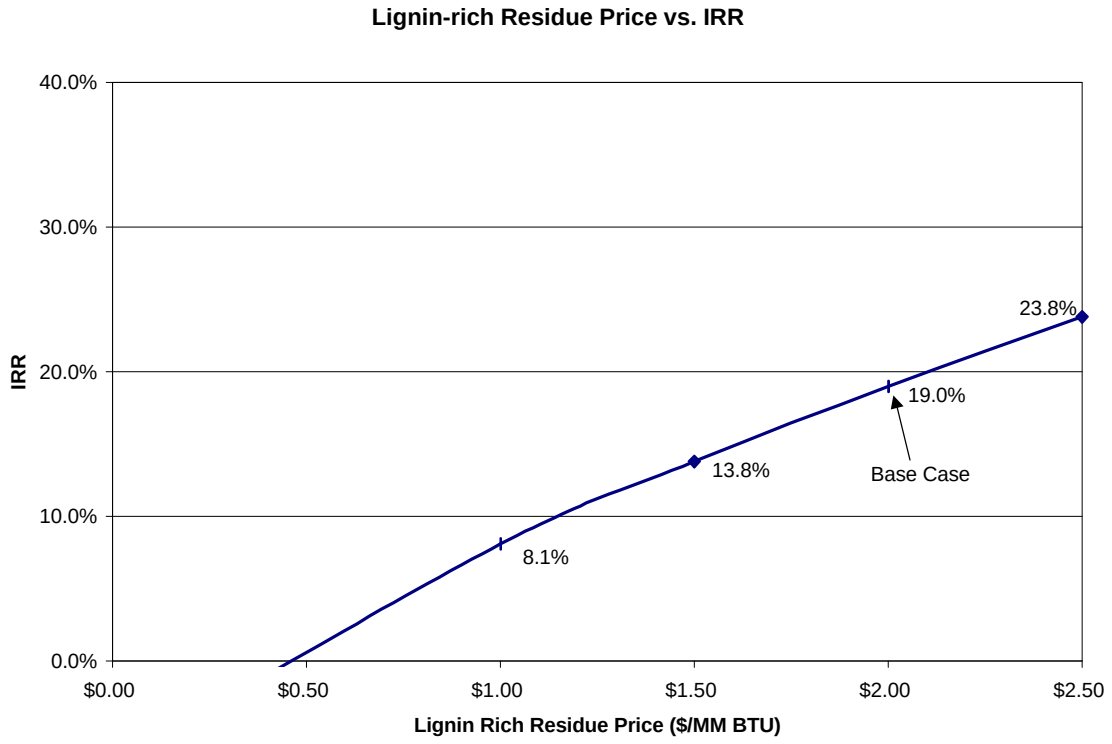
A possible use for this residue would be for burning, either by some yet-unnamed local user, or by a nearby biomass or coal-fired power plant, if one exists. There would be some incentive for the user to purchase the residue if it were less expensive than the user's current fuel, or if it were a cleaner burning material, which allowed the user a "green" credit.

Fuel material can be purchased on a $/MMBtu basis or on a $/ton basis. Charging on a $/MMBtu basis allows the material to be purchased based upon its ability to produce energy. This also allows a way to account for the water in the fuel. For these models, a price of $2/MMBtu was assumed. This number was derived as described in the following paragraph.

The competition for lignin residue as a fuel will be the same raw biomass feedstock used as feed to the bioethanol process. For this analysis, $28/dry ton was given as the cost for raw biomass feedstock. This corresponds to $2.20/MMBtu of delivered heat to the combustion process. Evaporation of all the water in the feedstock has been compensated for in this number. Because these two fuel sources are in competition, a corresponding value of $2/MMBtu delivered heat for the lignin residue provides further incentive to purchase it. The corresponding value per dry ton is $24/dry ton of lignin residue.

In Figure 3 below, the value of the by-product residue is varied and its effect on the project IRR is seen.

Figure 3. – Lignin Price Sensitivity Analysis



For the base case, the by-product was assumed to be sold for a value of $2/MMBtu, based on its lower heating value[3]. Notice that the residue price has a large impact on the IRR. When the selling price is cut in half ($1/MMBtu), the IRR drops to 8 percent. If a potential buyer for the lignin is not found, and the selling price drops to $0, the IRR drops well below zero. Thus, this graph shows how important a potential residue market is. It also shows that small price changes can lead to significant IRR changes.

The residue will not likely be transported at zero cost either. Therefore, transportation costs would warrant that the potential user be located nearby. The base case assumptions were a $1.25/mile/load[4] transportation charge, and a user within a 10-mile radius. No sensitivity analysis was performed on transportation cost because it was likely not to impact the IRR as greatly as the residue price.

As alluded to earlier, a biomass boiler would offer a more self-sufficient plant design. Waste residue would be utilized on-site to create steam and electricity. Any excess steam or electricity could then be sold for additional revenue. The forest residue models show that for $2/MMBtu, the natural gas boiler is more economical. However, once the residue price drops below $1.50/MMBtu, the biomass boiler design becomes more economical.

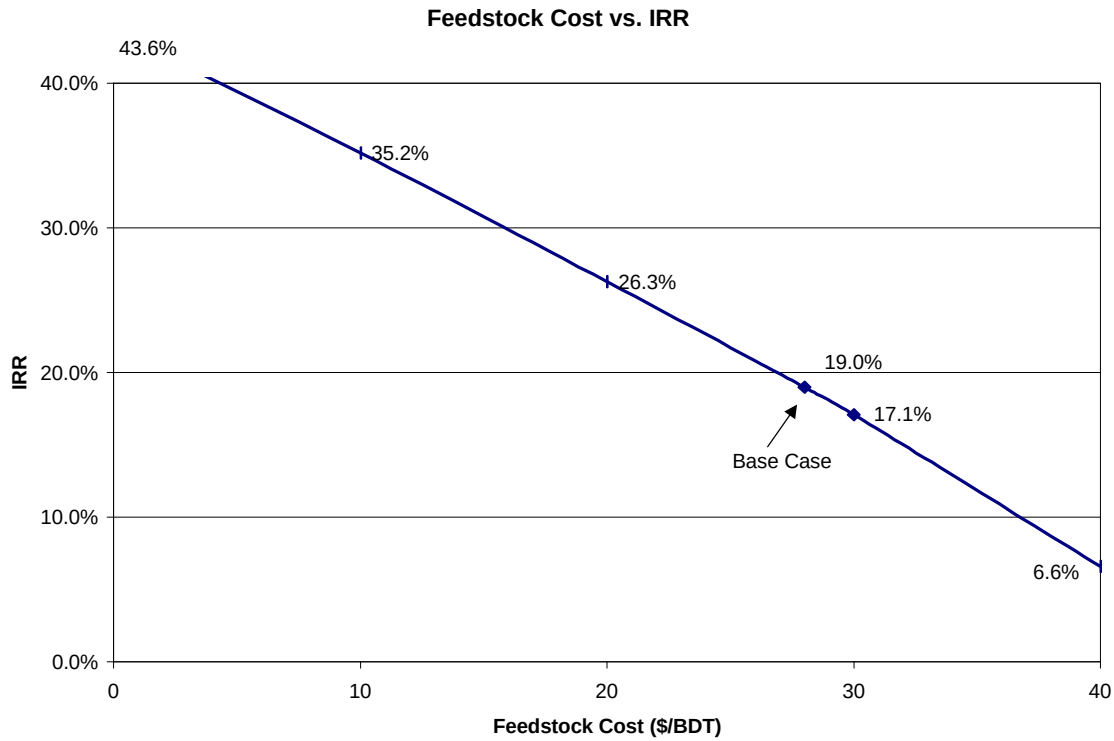
The biomass boiler design offers other benefits as well. It does not require establishing a by-product market. Certain plant designs could also utilize additional on-site waste and eliminate the need to send material to the local wastewater treatment plant. If this wastewater is sent through an evaporator system to concentrate the solids, they could be burned in addition to the waste residue while the evaporator condensate is then recycled

within the plant. In fact, this is how the biomass boiler was designed for that particular forest residue model.

Delivered Feedstock Cost

Feedstock costs typically have large impacts on the overall process economics, and this project is no exception. Figure 4 below demonstrates the impact of feedstock cost on the IRR. The feedstock cost provided to NREL of $28 per bone dry ton (BDT) was used in the base case.

Figure 4. – Feedstock Cost Sensitivity Analysis

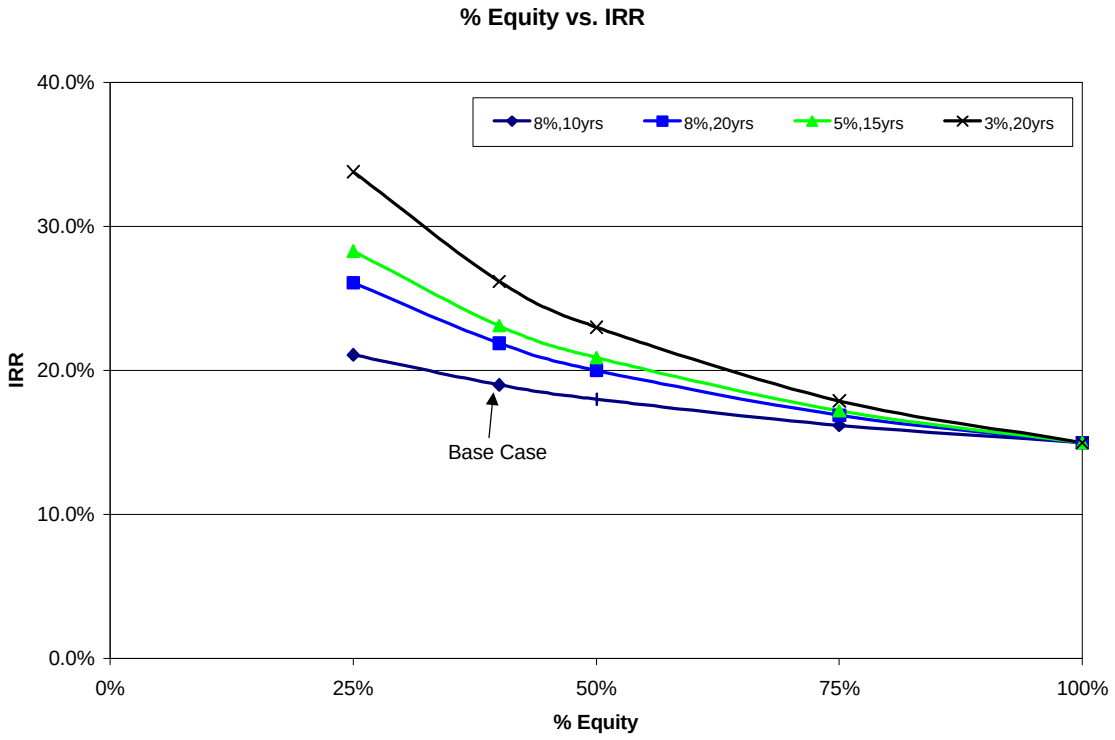


Lowering the feedstock cost to $20/BDT raises the IRR from 19 percent to 26 percent. Likewise, raising the feedstock cost to $40/BDT drops the IRR down to 6.6 percent. Thus the importance of obtaining accurate feedstock cost is critical. Small changes in feedstock cost can and do lead to large changes in IRR. Compared to other feedstock research NREL has performed and monitored, $28/BDT is reasonable. For example, the delivered cost for a corn stover feedstock is expected to be at least $25/BDT[5]. $20/BDT has been used as a cost estimate for California softwood feedstocks.[6]

Project Financing

The method of financing this project is also a matter of concern that should be addressed early in its life. The percentage of the project that is equity financed is important and has varying degrees of impact on the IRR, depending on the loan interest rate and loan term. Figure 5 nicely depicts the effect percent equity can have on the IRR.

Figure 5. - percent Equity Sensitivity Analysis



The base case conditions were set at 40 percent equity financing, with the rest of the project assumed to be financed through loans with an 8 percent interest rate on a 10-year loan. With this relatively high loan cost, Figure 5 shows that the percent equity has only a moderate impact on the project IRR. The IRR ranges from 21 percent at 25 percent equity down to 15 percent at 100 percent equity. However, changes in loan costs can cause the percent equity to have greater impact on the IRR. For example, this graph shows that merely extending the loan period from 10 to 20 years with an 8 percent interest rate can increase the IRR by up to 5 percent. Similarly, if the interest rate is lowered to 5 percent or even to 3 percent, the percent equity can have an even larger impact on the IRR. According to the graph, at 25 percent equity, going from an 8 percent 10-year loan to a 5 percent 15-year loan can raise the IRR to 28 percent.

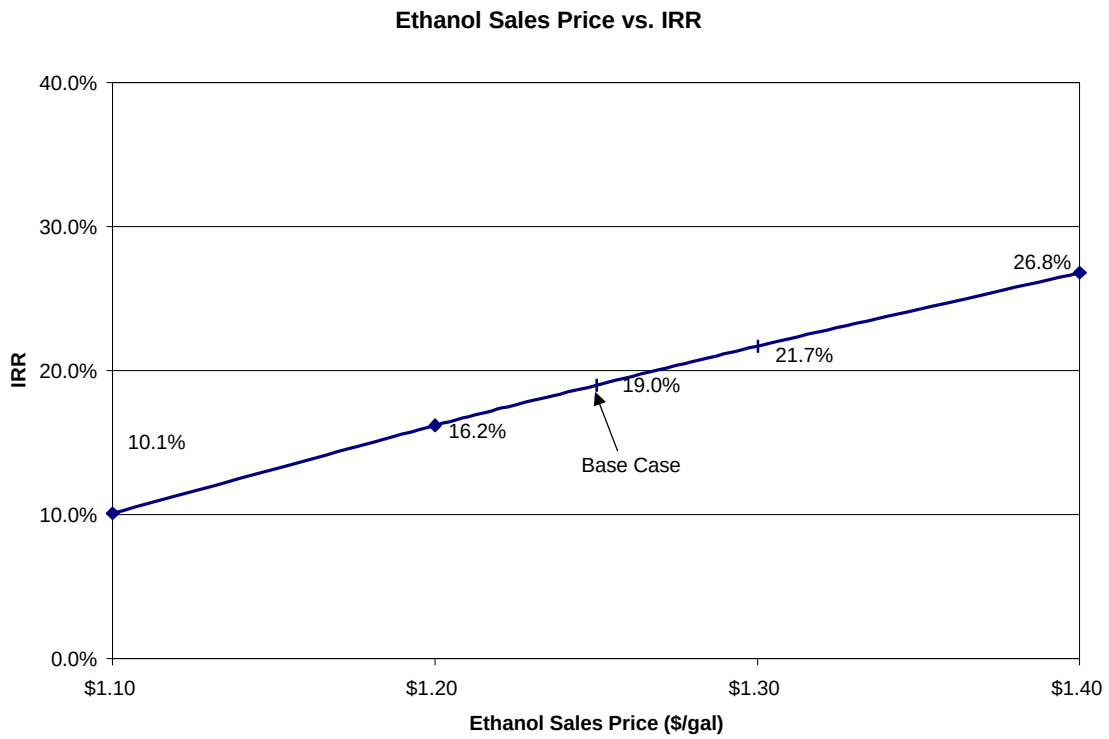
Thus, the importance of project financing can be seen. Lower loan costs and lower percent equity are favorable conditions to achieve. In fact, this is one way in which state and federal agencies have encouraged companies to build pioneer ethanol plants. If it were decided that additional incentive was needed to establish an ethanol plant in Oregon, project-financing incentives would be a good place to begin.

Ethanol Selling Price

Ethanol is the main source of revenue for the plant. As a result, the ethanol selling price will directly affect the plant's rate of return. The magnitude of the impact is shown in Figure 6 below. For the base case, ethanol was assumed to be sold at $1.25 per gallon. This includes a federal tax incentive that has been extended until the year 2007. However, this analysis

also assumes the federal tax incentive will be extended *beyond* 2007. The federal tax credit and the ethanol market in general are issues requiring careful analysis.

Figure 6. – Ethanol Selling Price Sensitivity Analysis



This graph shows the importance of attaining the best selling price possible. In order to maintain an IRR greater than 15 percent, the ethanol must be sold for $1.20/gal or greater. Changing the sales price by $0.05/gal in either direction causes the IRR to shift by almost 3 percent. Selling the ethanol for less than $1.10/gal causes the IRR to dip to 10 percent while selling the ethanol for over $1.40/gal causes the IRR to approach 30 percent.

Additional Important Parameters

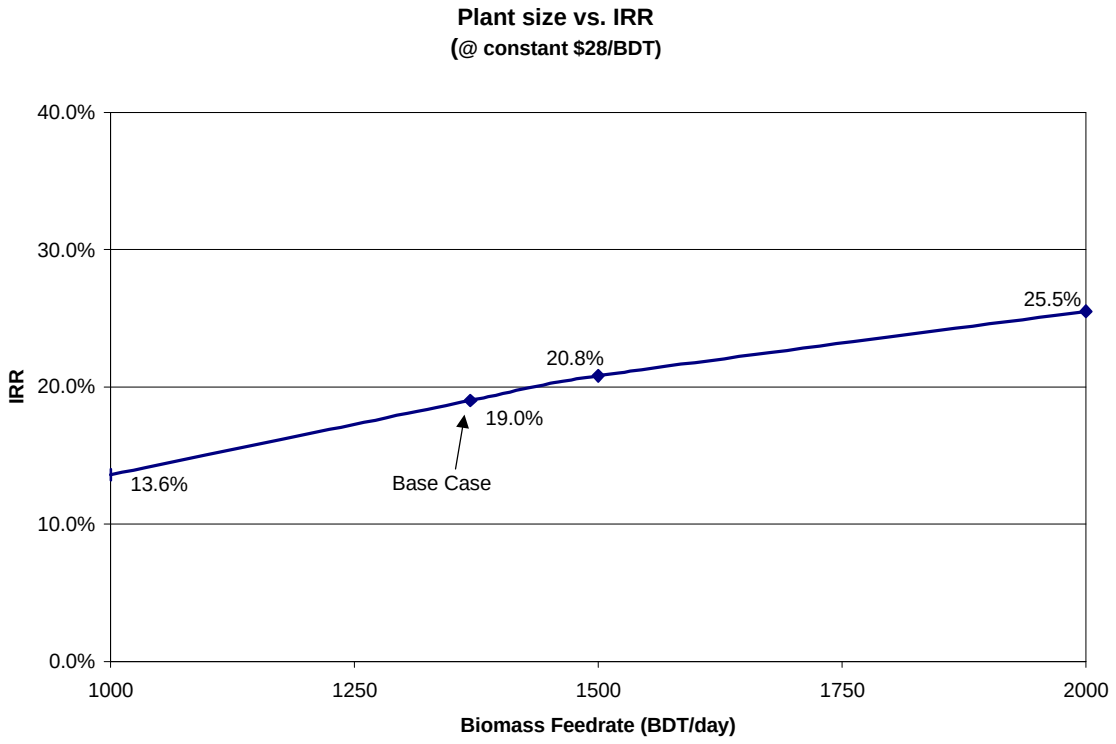
The following parameters were found to affect the project IRR, but not as severely as those previously discussed. The other parameters are:

- Plant size
- Xylose fermentation efficiency
- Glucose hydrolysis yield
- Natural gas cost
- Purchased electricity cost
- Wastewater treatment

Plant size

Figure 7 shows the effect that biomass feedrate (i.e. plant size) can have on the IRR.

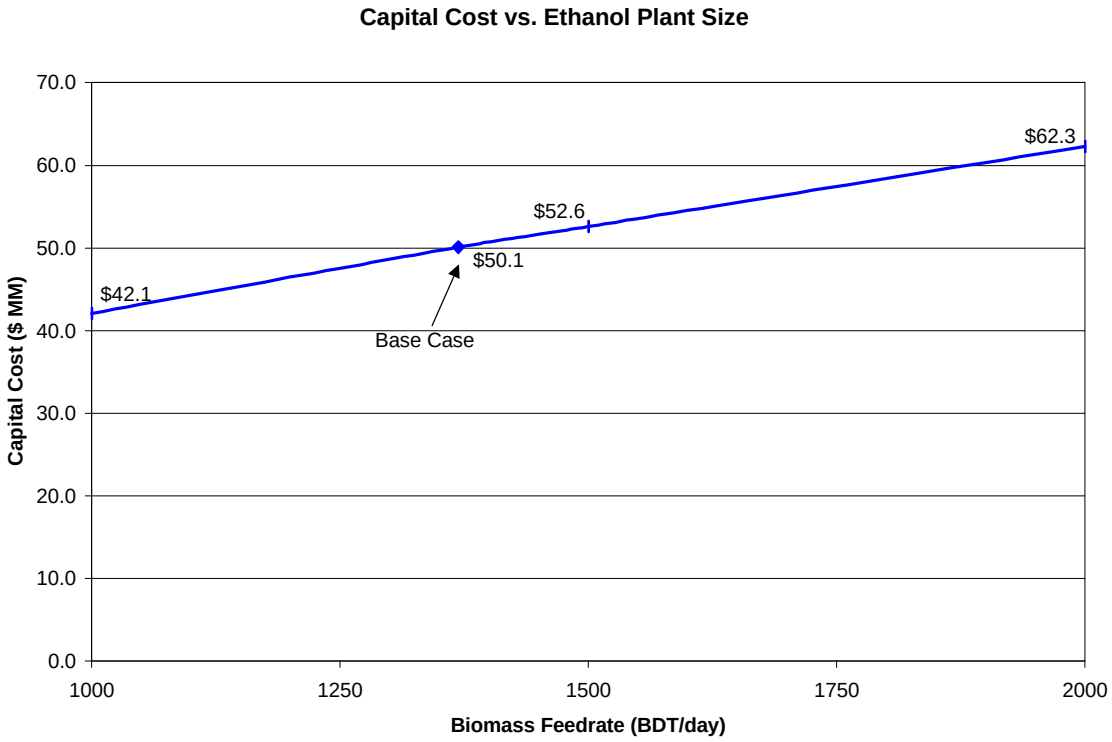
Figure 7. – Plant Size Sensitivity Analysis



The base case feedrate is 1369 BDT/day. As the biomass feedrate is increased the feedstock cost logically increases, but because of economies of scale, the capital cost per gallon of ethanol produced is lower and the IRR increases accordingly. For a constant feedstock unit cost ($28/BDT), a 25 percent IRR would be attained if the feedrate were increased to 2000 BDT/day. At larger feedrates, the impact on IRR becomes less pronounced than at lower feedrates.

Figure 8 shows the subsequent change in capital cost for this range of feedrates.

Figure 8. – Effect of Plant Size on Capital Costs



The base case ethanol plant has a Total Capital Investment (TCI) of $50.1 million. As Figure 8 shows, an additional $2.5 million in capital would have to be spent to increase the plant capacity to 1500 BDT/day. As the graph shows, plant sizes from 1000 BDT/day to 2000 BDT/day have a $20 million range of capital cost associated with them, $42 million to $62 million.

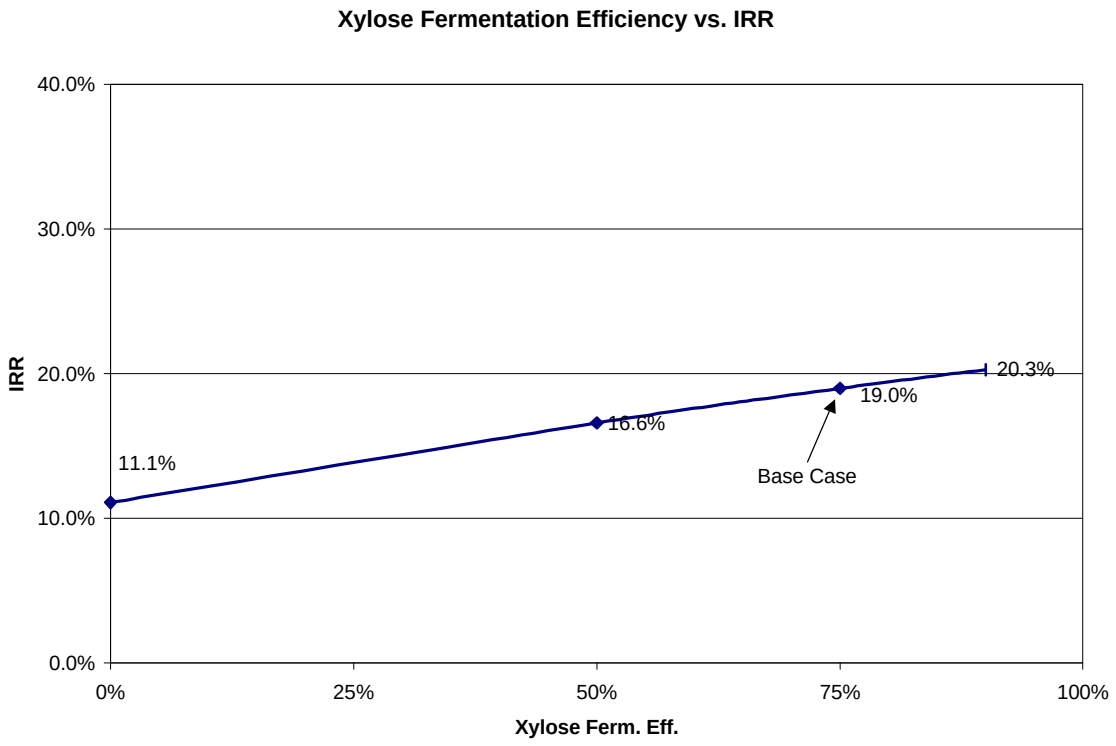
Xylose fermentation efficiency

Currently, the most popular choice for fermentation organism for the corn ethanol industry is a yeast, *Saccharomyces cerevisiae.* This yeast has the ability to ferment biomass-derived six-carbon sugars (glucose, mannose, and galactose) to ethanol, but does not have the ability to ferment any of the five-carbon sugars (xylose and arabinose). If the five-carbon sugars are not fermented, they are sent downstream and end up being burned or wasted. More ethanol could be produced from the same amount of feedstock if an organism with the ability to ferment five-carbon sugars was utilized.

Research is currently being conducted worldwide to make this possible, using recombinant genetic techniques. Domestic research teams at Purdue University, the University of Florida, the USDA, and NREL have developed organisms with the capability of fermenting six-carbon sugars as well as xylose, and in some cases arabinose. None of these new recombinant organisms have yet to be used commercially, however. Many industries that use fermentation are interested in this research, as it will lead to better ethanol yields.

Figure 9 below shows the impact that xylose fermentation efficiency has on the model.

Figure 9. – Xylose Fermentation Efficiency Sensitivity Analysis



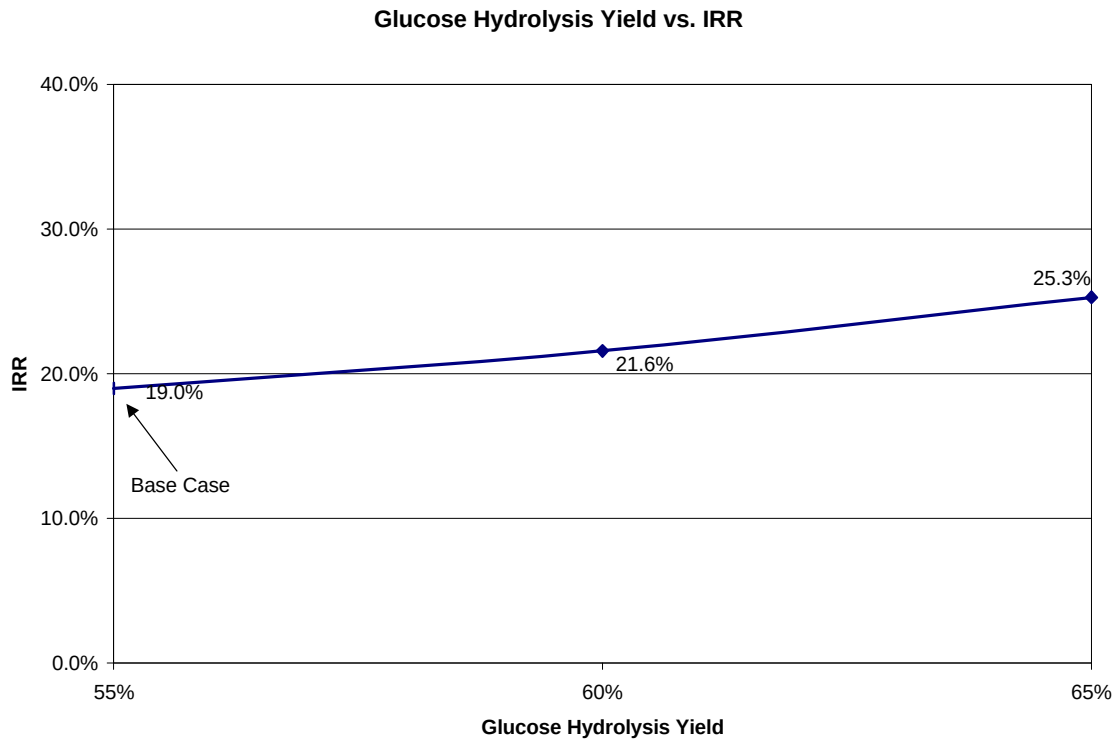
In the base case model, it is assumed that a xylose-fermenting organism will be available when the plant is built, and that it will be capable of fermenting 75 percent of the xylose to ethanol. It is important, though, to remember that this is still an assumption. If the process were to use a fermenting organism that fermented only C6's, the IRR would fall close to 11 percent. Thus, the fermentation efficiency, though not as great as other parameters, is still seen as a significant assumption.

Glucose Hydrolysis Yield

Most of the ethanol yielded in the process comes from glucose. As explained previously, cellulose is more resilient to hydrolysis than hemicellulose. As more of the cellulose is broken down (hydrolyzed) into glucose, higher ethanol yields will be achieved. Currently, NREL's two-stage dilute acid research has consistently attained an overall glucose yield of 55 percent from cellulose. Yields as high as 59 percent have been reached very recently. Certain catalyst use has brought this yield as high as 62 percent. As more research is performed, and the process conditions are further optimized, this yield will continue to increase. Some researchers in other parts of the nation have even claimed 65 percent glucose hydrolysis yield from softwood feedstocks.[7]

Figure 10 shows the economic effect this will have on the process.

Figure 10. – Glucose Yield Sensitivity Analysis



As this figure shows, the 59 percent yield that has been achieved recently at NREL brings the IRR to almost 21 percent. Another 5 percent yield after that brings an extra 4 percent increase in IRR. Therefore, the continued research focus in this area appears economically justified.

Natural Gas and Electricity Costs

As mentioned earlier, the biomass boiler design needs no supplemental off-site fuel to operate. It produces steam, which can be used to power an electric generator, supplying the plant's power needs. This design is more self-sufficient than the natural gas design. However, with the assumed selling price of by-product residue, the natural gas design provides a better IRR. If this design is used, then the operating costs for natural gas and electricity will be a concern.

Figures 11 and 12 show the effects of natural gas and electricity costs (respectively) on IRR.

Figure 11. – Natural Gas Cost Sensitivity Analysis

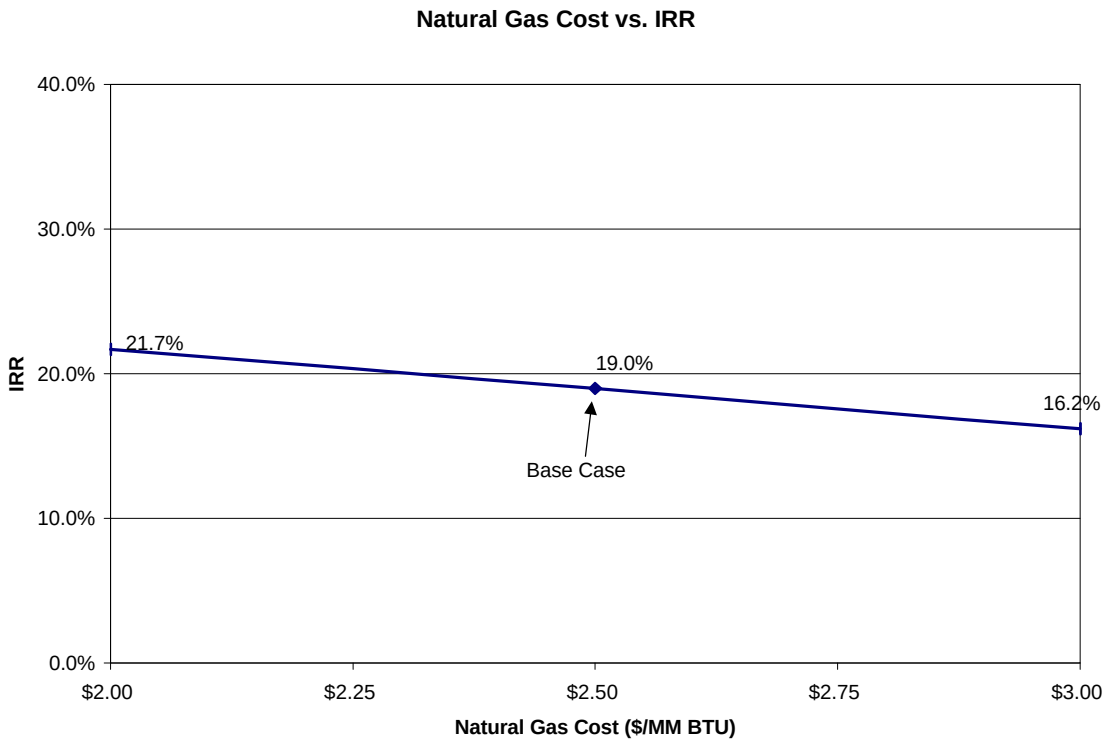
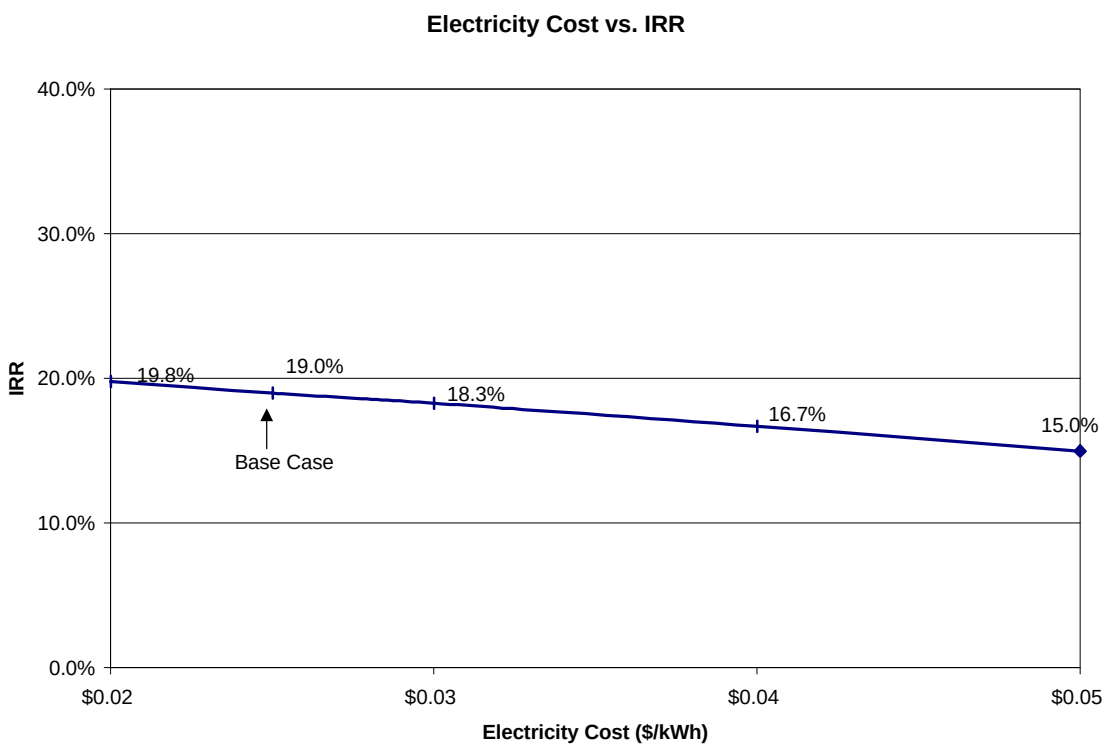


Figure 12. – Electricity Cost Sensitivity Analysis



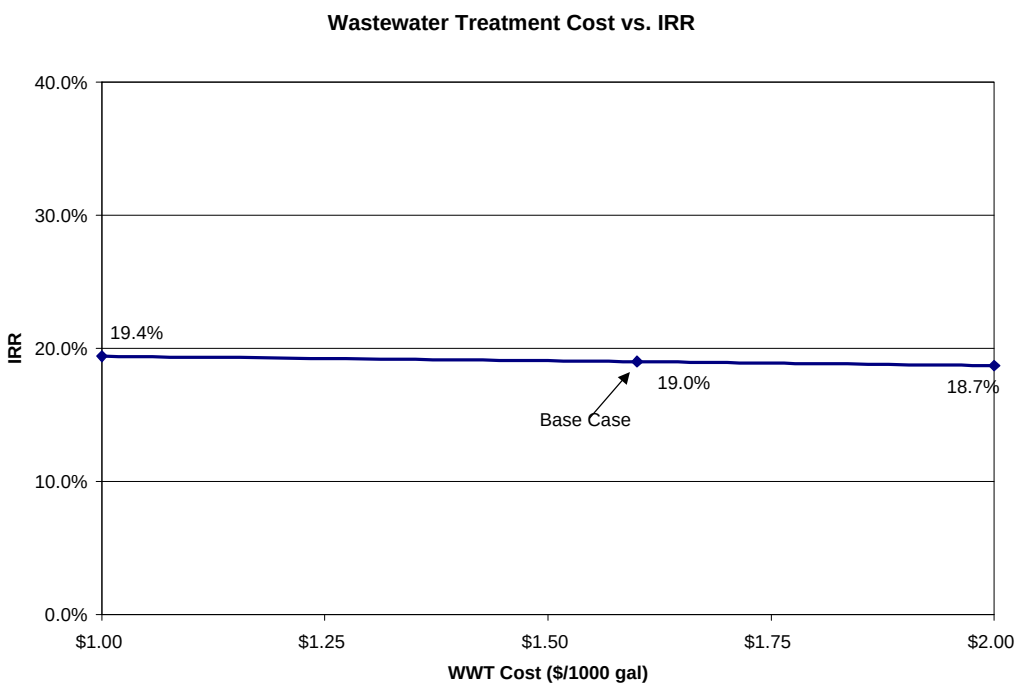
The costs of these required energy sources have mild impacts on the IRR. The natural gas cost has a slightly larger impact than the electricity cost. A $0.50/MMBtu change in natural gas leads to nearly a 3-percent change in IRR, whereas a $0.01/kWh change in electricity price only offers a 1.5-percent change in IRR. Realistically, electricity cost might not be able to get much lower than $0.025/kWh but current natural gas prices are relatively high and could conceivably go lower than the $2.50/mm Btu, depending on the availability in the considered region.

Wastewater Treatment

Wastewater treatment (WWT) was also a parameter that was investigated, but was found to have little impact on the IRR. Previous studies[8] have shown that the wastewater would have to be treated on-site with aerobic and anaerobic treatment because of its large COD (Chemical Oxygen Demand) concentrations[9]. COD is a commonly used indicator of organic pollutants in the water. After treatment at the plant site, wastewater is assumed to be sent to a local municipal treatment plant for further treatment. A typical charge from the municipal plant would be $1.60/1000 gallons[10], as long as the COD was less than 300 ppm, and the hydraulic load (gallons per minute or gpm) was not too large. COD concentrations greater than 300 ppm would take more time and money to treat. For the biomass boiler design, no wastewater was sent to the local treatment plant, as mentioned earlier.

The base case assumed a $1.60/1000 gallons cost for the wastewater. A sensitivity analysis was performed on the cost of wastewater, but was found to have very little impact on the IRR, as is seen in Figure 13. Future design work in the wastewater treatment area may focus on developing better treatment designs in hopes of being able to bypass further treatment costs incurred by the municipal plant.

Figure 13. – WWT cost sensitivity analysis



Conclusions

A proposed biomass-to-ethanol facility for the state of Oregon does appear promising from an economic standpoint. However, the following tasks should be performed as this project develops further:

1) affirming lignin-rich residue potential markets and prices
2) investigating the long-term feedstock costs, availability, and competing uses
3) investigating the potential for low-interest, long-term loans and other economic incentives, such as state and federal tax credits
4) raising and/or affirming the proposed market price for ethanol

If the residue cannot be utilized for revenue, a biomass boiler would probably be used in place of the natural gas boiler. This would eliminate the need to find a market for the residue, and it would help to eliminate other operating costs, such as WWT, natural gas, and electricity. Selling extra electricity off-site would provide additional profit. However, a much larger capital cost does exist with this scenario. Being able to sell the extra electricity for $0.04/kWh, as now currently assumed, would help to defer these costs.

The most economically attractive feedstocks appear to be Forest Residues and Wheat Straw. These models provided good IRR's because of their combination of biomass availability, feedstock cost, and potential ethanol yield (i.e. carbohydrate content). Further work should be done to attain accurate feedstock costs and availability data. Small changes in feedstock cost can have large impacts on the project IRR.

Working to attain low-interest, long-term loans through state, government, or other programs will help to achieve larger IRR's as well. Establishing competitive ethanol market prices will also be beneficial to the future plant.

[1] Nguyen, Q., "Evaluation of a Two-Stage Dilute Acid Hydrolysis Process," Internal Report, NREL, Golden, CO, 2/11/98.

[2] Nguyen, Q., "Preliminary design of an ethanol demonstration plant based on two-stage dilute acid hydrolysis technology," Internal Report, NREL, Golden, CO, 7/15/99.

[3] The heat content of the lignin residue is penalized for its water content.

[4] This assumes that each truck load is approximately 20-25 tons.

[5] Wooley, R., M. Ruth, J. Sheehan, K. Ibsen, *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis: Current and Future Scenarios,* p. 9, NREL, Golden, CO, Report TP-580-26157, July 1999.

[6] "Softwood Biomass to Ethanol Feasibility Study," NREL Subcontract AXE-8-18020-01, Merrick & Company, June 14, 1999.

[7] Harris, J.F., et al., "Two-stage, Dilute Sulfuric Acid Hydrolysis of Wood: An Investigation of Fundamentals," USDA General Technical Report FPL-45, 1985.

[8] Aden, A., et al., "Black Hills Biomass-to-Ethanol Project," NREL, Sept. 16, 1999.

[9] COD was used for convention as opposed to Biochemical Oxygen Demand (BOD) because it is a more direct measure of the organic matter present.

[10] Joe Rucco, Phoenix Bio-systems, Inc., via personal communication, phone call, Tuesday, Sept. 7, 1999.