Maine Bioproducts Business Pathways
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Abstract

Energy use in the United States and Maine is heavily reliant on imported fossil fuels. Finding a way to produce renewable fuels in the State of Maine that can replace these fossil fuels will address national security threats, sustainability concerns inherent in the use of fossil fuels, and keep manufacturing in Maine. An important alternative fuel for the near term is ethanol, and producing it from a cellulosic feedstock allows the fuel source to remain independent of the food chain.

Kraft pulp mills in Maine have an opportunity to evolve and meet the demand for alternative fuels, by utilizing the “near-neutral” extraction process developed at the University of Maine. By incorporating this process within the pulping process itself, ethanol and acetic acid can be produced while still producing pulp, allowing Kraft pulp mills to expand beyond their current processes to become biorefineries and produce additional products.

This paper discusses the different processes that can be utilized in a Maine biorefinery to produce ethanol and acetic acid as initial products, with an emphasis on the “near-neutral” process. We also analyze potential investment and production costs for a biorefinery, based upon studies that have looked specifically at this type of evolution, as well as cellulosic biorefineries that are based upon other types of processes. Included in the economic analysis are transportation costs for potential biorefineries in Maine. We also identify pulp mills and proximities to wood resources and product transport costs to potential wholesale and retail customers in the state.

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Any errors within the report are purely the responsibility of the authors alone.

1. Introduction

In his State of Union Address in January 2007, President George W. Bush set forth a goal of reducing gasoline usage in the United States by 20% in the next 10 years. This 20-in-10 goal relies predominantly on a rapid expansion of renewable and alternative fuel production. The Energy Independence and Security Act of 2007 (EISA), signed on December 19, 2007, has a mandate for 36 billion gallons of renewable fuels by 2022. Of this amount, 21 billion gallons is to be made from cellulosic ethanol and other advanced biofuels (2007a; 2007b). In 2005, total U.S. ethanol production was 3.9 billion gallons, or 2.9 percent of the total gasoline pool (2007b). Almost all of this is produced by domestic corn-based production.

In 2008, Governor John E. Baldacci announced the formation of a wood to energy initiative, mandated to decrease the State of Maine's dependence on imported fuels and increase the use of wood for energy in the state (Baldacci, 2008). Both of these actions provide businesses and researchers in Maine the initial road map in which to encourage the evolution of pulp mills into biorefineries.

To achieve the goals and mandates at both the State and Federal levels a rapid and unprecedented expansion of renewable and alternative fuel production is required. The bulk of the increase is to be derived from a variety of cellulosic biomass materials, including forest residues, wood chips, grasses, agricultural wastes, and woody biomass crops grown specifically as a feedstock for biorefineries. Beyond the specific volumes of renewable and alternative fuels required under EISA, certain quantities of the fuels must have lower greenhouse gas (GHG) emissions.

There will not be one panacea for replacing the petroleum used in the United States and Maine. There are a number of possible fuels and other products that could be made from homegrown sources that will provide part of the solution for petroleum replacement. One process that is being studied at the University of Maine is converting Kraft pulp mills into a "biorefinery" capable of producing not just the pulp needed for their primary business, but also petroleum fuel replacements and other chemical products.

Maine is the most forested state in the United States with almost 90% of the state covered with trees (2007). The pulp industry in Maine is experienced in managing resources, adhering to and understanding the economic, cultural and regulatory climate in Maine. As it stands now, pulp mills in Maine have made many efficiency changes and cutbacks in the face of competition from mills in other locations in the United States and abroad. For pulp mills to continue to be a viable business enterprise in the Northeast, and in Maine in particular, it is necessary for them to continue their evolution. One of the most promising routes is for pulp mills to become biorefineries – producers of products and fuels made from their base source of wood.

Cellulosic biorefineries can have two different pathways: biochemical (also known as fermentation), and thermochemical. The biochemical pathway focuses on using chemical processes (including enzymes) to convert sugars present in the cellulose, while the thermochemical focuses on gasification and pyrolysis of the biomass. Both pathways are being studied as part of the Forest Bioproducts Research Initiative (FBRI) at the University of Maine, and both could be incorporated into a pulp mill biorefinery, either individually or in sequence. Further explanation of these two processes is provided in Sections 3.1 and 3.2.

There have been a number of studies that have looked at the economic feasibility of having either a stand-alone biorefinery, whose sole purpose is making ethanol, or the conversion of a pulp and paper mill into a biorefinery that can produce a number of products as well as pulp (Mitchell, 2006; Biorefinery "Financial Case" Team, 2007; Mao, 2007; Larson, et al., 2006; van Heiningen, 2006; Mao, et al., 2008). Mitchell and Larson, in particular, completed particularly comprehensive analyses of a standalone facility vs. an existing Kraft pulp mill, and found the best return on investment involves co-locating a biorefinery at an already existing Kraft pulp mill, even with necessary conversion costs. What this paper addresses:[1]

A solid body of research makes it clear that a brand-new, stand-alone biorefinery is not cost-effective under current business conditions. Our research focuses on the viability of a co-located facility.

- The fuels and products that can be produced from the conversion of a pulp mill into a biorefinery.
- How pulp mills can undergo an evolution into a biorefinery, and an economic summary of that evolution.
- Possible biorefinery facilities and locations in Maine.
- How biofuels could get to the end user.
- Summary of feedstock availability and geographic location.
- Transportation costs.

2. Fuels and Products from a Maine Biorefinery

It is generally accepted that the best model for cellulosic biorefineries is to consider them analogous to petroleum refineries. [A short list of examples can be found with (Mitchell, 2006; Mao, 2007; Jechura, 2002; Paster, et al., 2003; Zwart, 2006; Lynd, et al., 2005; van Ree and Annevelink, 2007; Huber, 2008).] Modern petroleum refineries began by producing kerosene, and then moved onto other petroleum products such as gasoline, diesel fuel and petrochemicals (2008a; 2008b). Biorefineries will likely follow the same route, producing chemicals and/or fuels with currently available technologies and a market that can be economically reached.

Given the current state of alternative fuel infrastructure, as well as the current state of technology and plant economics, it makes the most sense for a Maine biorefinery to begin by focusing on those products that can be made concurrent with pulp: ethanol and/or butanol, and acetic acid (Biorefinery "Financial Case" Team, 2007; Huber, 2008; van

[1] Determining the ideal forest harvesting situation, especially with regards to roundwood, residues and the differences between them, is being addressed by other FBRI researchers and will not be part of this report.

Heiningen, 2008a; van Heiningen, 2008b; Kampman, et al., 2005). (For definitions/descriptions of these products, please see Appendix A: Glossary of Terms.)

Although the use of ethanol in Maine is not mandated as it is in many other states (for environmental and economic development purposes), producers in Maine would be able to sell ethanol, either directly to distributors for use in 10% blends with gasoline (E10), or to be shipped by rail to markets throughout the Northeast and the Midwest (Meyer, 2008a). The recently passed 2008 Farm Bill has ensured that an excise tax credit of $0.51/gallon for the first 7.5 billion gallons of produced or imported ethanol (reduced to $0.45/gallon after that) will remain in effect until the end of 2012 (2008c).

The initial transformation of a pulp mill into a biorefinery will be based upon the fuels and products that have the most demand, either due to immediate use or as a result of governmental policies. Second and third generation products likely could be added to the refining process as the biorefinery expertise continues to evolve and expand. Pulp mills that are interested and able to evolve into biorefineries should consider modifying their process lines with expansion in mind, so that as new products become available the biorefinery is able to transform with the markets.

2.1. Current Fossil Fuels Used in Maine

Maine has no petroleum reserves of its own (2008d), so all petroleum products, whether fuel or chemical, must be brought in from outside the state. Maine ranks 20th in the country in per capita consumption of energy use, and almost 80% of Maine's residential households use fuel oil for heating (2008d). Table 1 shows petroleum and natural gas sales in Maine, as well as the 2006 average price paid for these products.

As can be seen in Table 1, Maine consumers spent $3.9 billion in 2006 on petroleum products and natural gas for energy uses. Most of the imported natural gas (~90%) is used for electrical generation and perhaps as much as 75% of the natural gas generated electricity is exported to rest of New England.[2]

[2] Maine is part of ISO New England. Exact amounts of natural gas used for in-state and out-of-state generation are not available. The estimate of 25% of natural gas used for in-state generation is rough calculation based a report to the Maine State Legislature, data provided by Tim Vrabel, Deputy Director, Energy Programs Division, Maine Public Utilities Commission, 18 March 2008.

Table 1: Petroleum and Natural Gas Sales in Maine

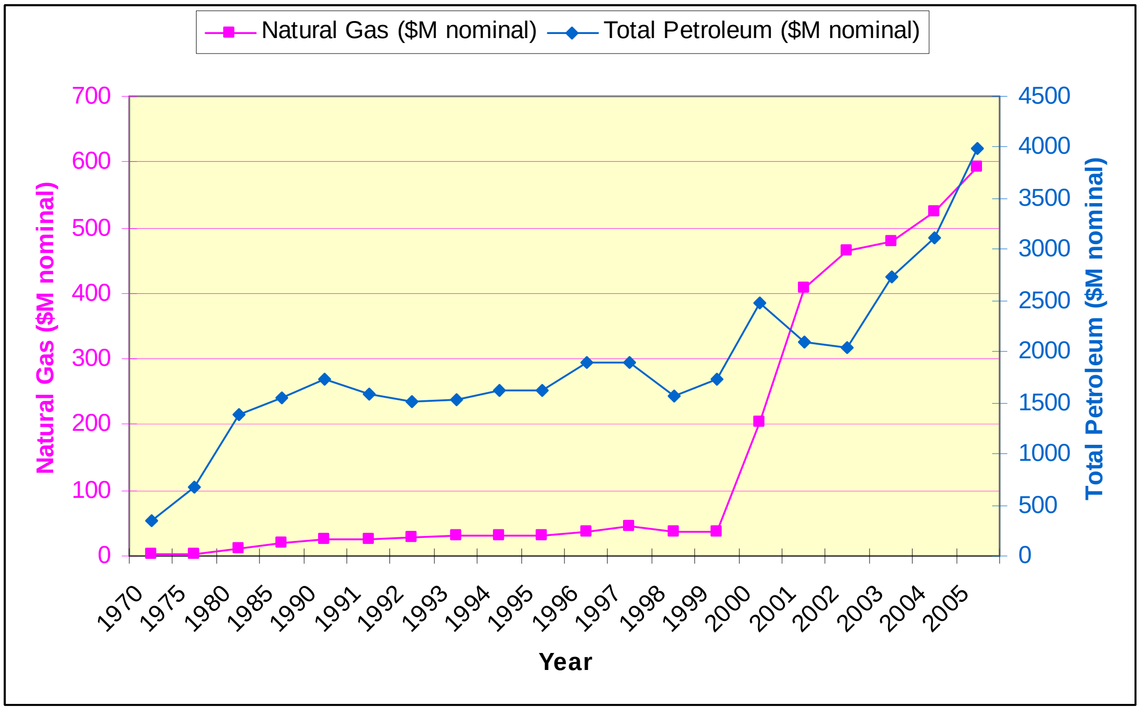
All Data from 2006

Maine	**Gallons (a)**	**Average Price/gal**	**Amount Paid**	
Gasoline	727,440,000	$2.146 (b)	$1,561,086,240	$1.6 Billion
Distillate Fuel				
Residential	303,024,000	$2.294 (b)	$695,137,056	$695 Million
Commercial	106,326,000	$2.089 (b)	$222,115,014	$222 Million
Industrial	14,836,000	$2.120 (b)	$31,452,320	$31 Million
Farm	9,295,000	$3.367 (b)	$31,296,265	$31 Million
Electric Power	266,000	$2.205 (b)	$586,530	$0.6 Million
Railroad	49,000	$2.205 (b)	$108,045	$0.1 Million
Vessel Bunkering	8,708,000	$2.205 (b)	$19,201,140	$19 Million
On-Highway	178,890,000	$2.205 (b)	$394,452,450	$394 Million
Military	5,411,000	$2.205 (b)	$11,931,255	$12 Million
Off-Highway	9,305,000	$2.205 (b)	$20,517,525	$21 Million
Kerosene (c)	66,330,000	$2.293 (b)	$152,094,690	$152 Million
	Thousand Cubic Feet	**Average Price/Thousand Cubic Feet**	**Amount Paid**	
Natural Gas (2006a)	49,605,000	$15.983 (d)	$792,853,250	$746 Million
Total for Petroleum Products and Natural Gas			**$3,932,831,780**	**$3.9 Billion**

(a) Gasoline consumption data is from 2005; distillate fuel data is from 2006.
(b) Price excludes taxes. Information from: (2006b; 2006c; 2006d; 2006e)
(c) Specific Maine data is not available for Kerosene -- it is withheld to avoid disclosure of individual company data. Price used is for the East Coast.
(d) Number here is the average of the Residential Price ($17.90), Commercial Price ($15.66) and Industrial Price ($14.39).

While the total amount spent in 2006 is less than the total from 2005 ($4.6 billion), the energy expenditure trend for the State of Maine has been consistently increasing since 1970 (Figure 1). If there was an opportunity to spend even a fraction of that amount on companies based in Maine, the impact on the state economy as a whole may be significant. The companies that could benefit from a state-based source of fuel would include not just those who would make the alternative fuels, but also companies that are involved in the transport and delivery of those fuels.

Figure 1: Maine Energy Price and Expenditure Estimates by Source, Selected Years, 1970-2005 (2008e)



Governor John Baldacci, in his State of the State address in January 2008, announced a "'Wood-to-Energy Initiative' to bring Maine-made sources of heat to the homes and businesses of Maine." The task force has been charged by Baldacci to "lead my Administration's efforts on a conversion initiative that will use our forests and natural resources to relieve consumption of nonrenewable oil" (Baldacci, 2008). The task force highlights the lead role the State of Maine can play in using domestic sources as the raw material for replacing many petroleum products, and allows the State to use its greatest natural resource to address these needs. Additionally, it provides an opportunity for a number of mature industries to be a part of the state-based solution for replacing imported petroleum.

There are no petroleum refining facilities in Maine. There is one facility (Safe Handling, Inc., Auburn) in Maine that has the capability to store and ship both ethanol and butanol, with ethanol and biodiesel currently at the facility (Meyer, 2008b). Several other facilities in the state have the capability to upgrade their systems to be able to mix ethanol into gasoline if ethanol demand increases enough to justify the expense of installing a mixing rack. Distribution infrastructure issues are a concern as pulp mills determine the amount and type of product they will produce.

3. Evolution of Pulp Mills into Integrated Biorefineries

Pulp mills are well suited to respond to the ongoing global demands for increased production of biofuels. The evolution from pulp mill to biorefinery can be done without major changes in current wood procurement and transportation networks and, by design, pulp mills are located near to existing biomass supplies. The last brand-new pulp mill built in Maine was the Westbrook paper mill (owned by S.D. Warren), built in the 1990's, which has since been shut down. The Skowhegan Mill (owned at that time by Scott Paper) built in 1974, is the next "newest" pulp mill. All other mill upgrades in the state have been undertaken to meet environmental regulatory compliance mandates (Bilodeau, 2008) (Bilodeau, 2008) (Bilodeau, 2008). Pulp mills in Maine must continue to evolve to meet competition from newer mills in other parts of the country and the world.

There are many different biorefinery pathways being investigated throughout the world for converting biomass into liquid fuels and other products, most based upon the use of either a biochemical (fermentation) or a thermochemical pathway. Both of these pathways are being studied as part of the FBRI. Although an exhaustive overview of these two methods is far beyond the reach of this paper (many scholarly papers, journals and books have been devoted to each topic), an introductory general overview of each is provided below.

Based upon the research being conducted at the University of Maine, it is most likely that the best evolution for Maine pulp mills performing the Kraft process would be to incorporate the biochemical route first, and then expand the process to include the thermochemical route. Figures 2 through 4 provide a pictorial representation of a pulp mill evolution utilizing both routes, based upon this evolution (van Heiningen, 2008c). Figure 2 identifies the flow of material at a typical Kraft Pulp Mill. Figure 3 illustrates the flow of material at a Kraft Pulp Mill that is using a Biochemical Pathway. And, Figure 4 provides a flow diagram of a Kraft Pulp Mill using both Biochemical and Thermochemical Pathways.

Figure 2: Flow Diagram for a Kraft Pulp Mill

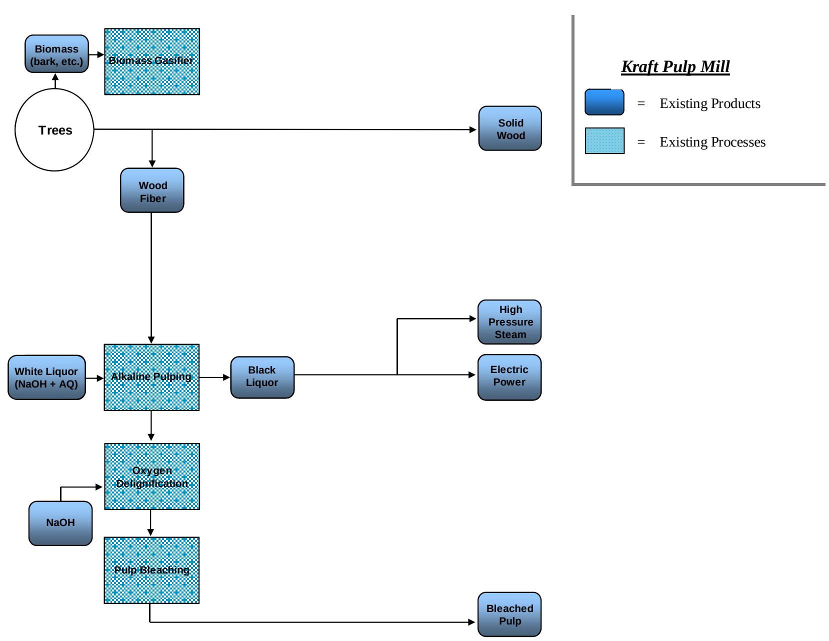


Figure 3: Flow Diagram for a Kraft Pulp Mill with a Biochemical Pathway

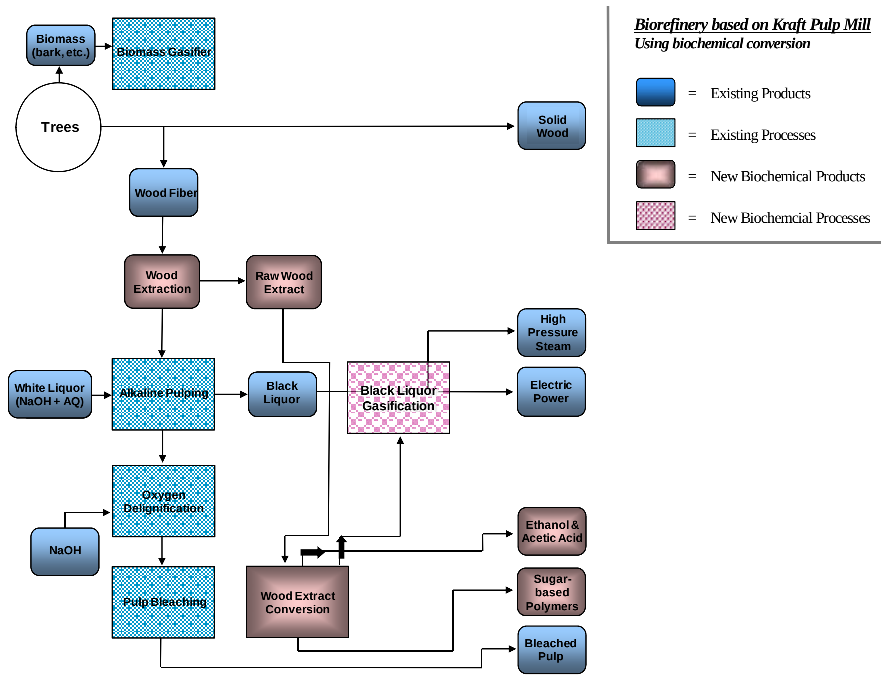
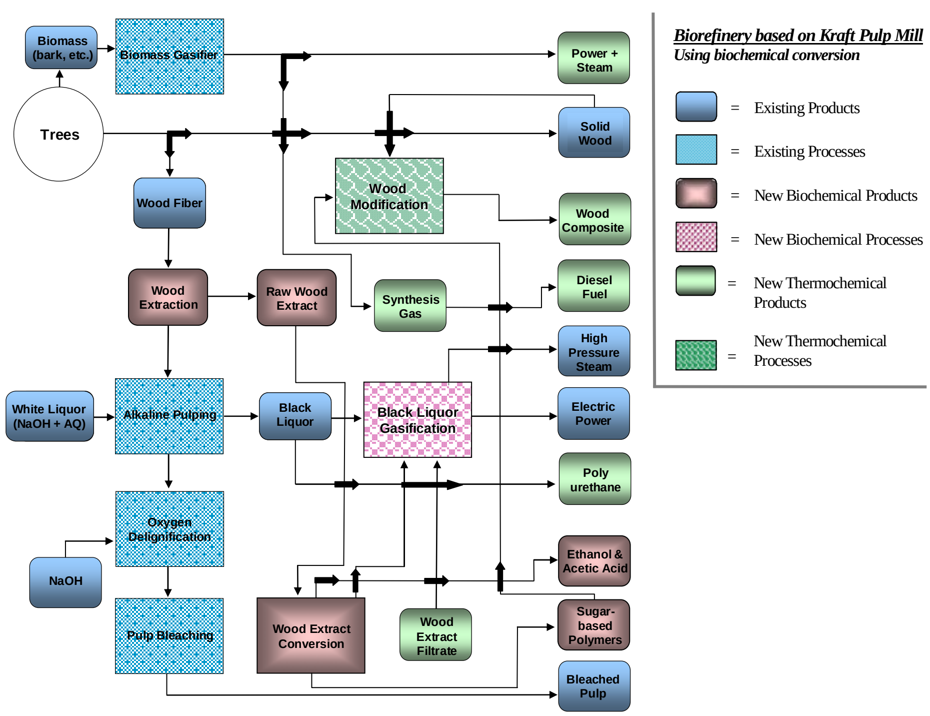


Figure 4: Flow Diagram for a Kraft Pulp Mill using Biochemical and Thermochemical Pathways



3.1 Biochemical Pathway for an Integrated Biorefinery

A biochemical pathway in development at the University of Maine is known as the "near-neutral" extraction process. It is used with the Kraft pulping process and hardwood chips. The near-neutral process allows for the extraction of hemicellulose polymers and sodium acetate from the wood prior to pulping in order to make additional products from these materials. (The definitions of key parts of the process are provided in Appendix A: Glossary of Terms.)

The near-neutral process relies on the use of wood chips, as is currently used in the pulp mills, and hardwood chips in particular. The near-neutral extraction process cannot currently be accomplished with softwood chips (van Heiningen, 2008c). In addition, the current near-neutral process can only be used with Kraft pulping operations. There are Maine pulp mills that use a groundwood process rather than the Kraft process, and the near-neutral process that is discussed here is not applicable to this process. However, the thermochemical pathway discussed below could be used with the groundwood pulping process.

A Kraft pulp mill that utilizes the near-neutral process can use the same hardwood feedstock that they currently use for producing pulp. The difference in the process is in the chemical treatment of the woodchips prior to the pulping operation. The pulping line needs to have an extraction vessel installed after pre-steaming the chips and prior to the pulping digester. This pretreatment allows for the controlled removal of hemicellulose from the wood chips. Once the hemicellulose is removed, it is hydrolyzed into fermentable 5-carbon sugars, which can be further fermented into other products, including ethanol. In addition, sodium acetate is extracted from the hardwood and is converted to acetic acid. Acetic acid is used in a variety of processes and products, including in the production of other chemicals as well as a food additive and as vinegar.

A Kraft pulp mill that utilizes the near-neutral process increases the number of products it produces, while the pulping operation continues to produce pulp that meets the same quantity and quality as found in a standard Kraft pulping operation. Thus, the pulp mill becomes an integrated facility with multiple products.

3.2 Thermochemical Pathway for an Integrated Biorefinery

The thermochemical pathway for a biorefinery could be considered a next step once the biochemical line has been established, much like petroleum refineries changed their processes and products as engineering capabilities and consumer demands became more sophisticated.

For the thermochemical pathway the entire biomass can be used and is not limited to the use of wood based sugars, as in the biochemical pathway. Using high-temperature treatment, the thermochemical process results in either pyrolysis oil or syngas (a mixture of carbon dioxide and hydrogen). From this point, numerous other products, including replacements for petroleum fuels, can be made. As noted previously, the thermochemical pathway also can be used in those facilities that make their pulp via the groundwood process.

4. Economic Evaluations for a Biorefinery

It is virtually impossible to provide a comprehensive direct comparison of the economics among different facilities that could become biorefineries. Each facility has its own unique characteristics, and when not building from scratch, these different characteristics come into play. There have been many specific case studies that provide a full-scale analysis of individual facilities. The following sections provide brief summaries of some of the research and provide a hint of the complexities involved in a specific economic analysis for a biorefinery.

4.1 Investment Costs for Conversion of Pulp Mill into an Integrated Biorefinery

Although the investment costs required to convert an existing pulp mill are substantial (see Table 2), the potential return on investment coupled with the ability to increase the diversity of the product line provide an incentive for pulp mills to consider becoming biorefineries. Pulp mills in Maine have an experienced workforce that does not need to learn the pulping business, so converting a pulp mill to a biorefinery will not require extensive new training of personnel. Furthermore, fuel developed from the biorefinery may be used on site for power or for transportation. Investment costs for both pulp mill conversion, as well as other types of biorefineries, have been analyzed by numerous researchers. A few sample cases are summarized in Table 2.

Table 2: Investment Costs Summary for Various Types of Biorefineries

All amounts in 2007 U.S. Dollars (2008f)

Facility type	Total Project Investment Cost (Millions 2007 $)
Mao: New Extraction Vessel. 1000 tonne wood/day	$68.1
Mitchell: Greenfield site. 1102.5 tons wood/day	$188.4
Mitchell: Co-Location site A * 1102 tons wood/day	$130.1
Mitchell: Co-Location site B * 1102 tons wood/day	$110.0
Mitchell: Co-Location site C * 1102 tons wood/day	$87.6
Aden: Greenfield site. 2000 MT Dry Corn Stover/day	$203.0

* Co-Location Case A. Locate Ethanol Plant at an Existing Pulp Mill with Spare Power Generation Capacity.
* Co-Location Case B. Locate Ethanol Plant at an Existing Pulp Mill with Spare Power Generation Capacity and also Purchase Cellulase Enzyme.
* Co-Location Case C. Locate Ethanol Plant at Existing Pulp Mill with Spare Power Generation Capacity, Waste Treatment and Wood Yard Facilities plus Purchase Cellulase Enzyme.

The investment costs for the studies listed in Table 2 are not directly comparable, as they involved different processes as well as different feedstocks. In addition, prices of raw materials, fuel and end products have all increased. Mao's work involved the analysis of hemicellulose extraction process prior to Kraft pulping. Mitchell evaluated the production of ethanol from "white-wood" (bark free wood) (Genco, 2008). And Aden's analysis looked at "an updated process design and cost basis for the process using a corn stover feedstock" (Aden, et al., 2002).

Two studies found particular situations where conversion to a biorefinery could almost always be worth the investment costs. Mao determined that having an available digester (either in the form of an extra extraction vessel or impregnation vessel, perhaps due to a shut down pulping line in which the equipment was still available) would be critical for making the pulp mill evolution profitable, given the economic assumptions made concerning fuel and ethanol. Larson found that Kraft pulp mills could make the transition profitable when replacing the Tomlinson boiler by incorporating a new gasification system. Both reports used costs for oil that are significantly less than current oil prices (Mao used fuel oil costs of $2.20/gallon and Larson used the price of $50/barrel) (Mao, 2007; Larson, et al., 2006). Current oil prices are $4.60 for heating oil in Maine (2008g) and $125.93/barrel (2008h). The difference in oil prices from the studies referenced to current prices could impact the economic analysis of the current investment costs for a biorefinery.

There are fossil fuels used in Kraft paper mills that would be affected by the change in process described by both Mao and Larson. Mao found that less steam would be produced in the recovery boiler since approximately 10% of the organic matter from the wood chips is extracted. However, there is also a decrease in the amount of fuel oil that is needed for the lime kiln. Specific analysis of each addition and reduction of fuel use (provided by natural gas, fuel oil or biomass) will provide each Kraft mill an opportunity to determine how sensitive their operations are to rising costs of fossil fuels.

Larson, et al. (Larson, et al., 2006) looked at seven different thermochemical pathway biorefinery designs for a Kraft pulp mill and determined that all designs would have a higher energy efficiency than current Kraft pulp mills due to both process efficiencies and electricity generation. Thus, a biorefinery based upon a Kraft pulp mill would not have as much sensitivity to increases in fossil fuel prices as mills that do not convert.

4.2 Production Costs for Conversion of Pulp Mill into an Integrated Biorefinery

Table 3 provides an overview of the production costs of ethanol and acetic acid that Mitchell and Mao have determined for biorefineries in Maine. There are some assumptions made in each report listed in Table 3 that make a direct comparison between the unit production costs difficult. Mao's analysis involves an existing pulp mill that upgrades in some way to produce ethanol and acetic acid along with pulp – the biorefinery model. For this case, Mao determined the unit production cost based upon the total operation cost at the facility, and allocated the costs of ethanol and acetic acid according to the mass production ratio of each (Mao, 2007). Mitchell's facility analysis considered two different cases: 1) an ethanol plant independent of any other operations, and 2) an ethanol plant adjacent to Kraft pulp mill to share facilities (Genco, 2008). For the Greenfield site in Mitchell's work, the facility would convert wood to ethanol, with no other processes occurring. For the co-location sites studied, the facility would be on the same property as a pulp mill and share some of the costs (such as wastewater treatment or electricity generation/use), but the wood to ethanol part of the plant would remain independent from the pulping operation.

Table 3: Unit Product Costs Summary, Multiple Biorefineries

All amounts in 2007 U.S. Dollars (2008f)

Facility type	Cost to produce Ethanol ($/gal)	Cost to produce Acetic Acid ($/gal)
Mao: New Extraction Vessel. 1000 tonne/day	$2.28	$3.02
Mao: Utilities and waste treatment facility upgrade needed. 1000 tonne/day	$1.51	$2.01
Mao: No Waste Treatment System Upgrade. 1000 tonne/day	$1.38	$1.83
Mao: Extraction Vessel Available and Utility Upgrade Needed. 1000 tonne/day	$1.77	$2.34
Mao: Extraction Vessel Available and No Utility Upgrade Needed. 1000 tonne/day	$1.63	$2.17
Mao: New Extraction Vessel and Utility Upgrade Needed. 1000 tonne/day	$2.15	$2.85
Mao: New Extraction Vessel and No Utility Upgrade Needed. 1000 tonne/day	$2.02	$2.68
Mitchell: Greenfield site. 1102.5 tons/day	$2.46	
Mitchell: Co-Location site A * 1102 tons/day	$2.32	
Mitchell: Co-Location site B * 1102 tons/day	$2.23	
Mitchell: Co-Location site C * 1102 tons/day	$2.06	
Aden: Greenfield site. 2000 MT Dry Corn Stover/day	$0.60	
Lynd: Near-Term Corn Stover facility. 10,000 dry tons/day	$1.10	
Lynd: Advanced biorefinery, using poplar. 10,000 dry tons/day	$0.53	

* Co-Location Case A. Locate Ethanol Plant at an Existing Pulp Mill with Spare Power Generation Capacity.
* Co-Location Case B. Locate Ethanol Plant at an Existing Pulp Mill with Spare Power Generation Capacity and also Purchase Cellulase Enzyme.
* Co-Location Case C. Locate Ethanol Plant at Existing Pulp Mill with Spare Power Generation Capacity, Waste Treatment and Wood Yard Facilities plus Purchase Cellulase Enzyme.

As good as these studies are, the costs of production attributable to ethanol and acetic acid are somewhat arbitrary in that mass ratio of production, or a proportion of total operating costs, is not a traditionally defined way of determining costs with an economic analysis. Mitchell's cost estimates are more straightforward since ethanol is the only product. Mitchell's cost estimates are based upon the yearly operating costs of a facility which included: raw materials, waste disposal, total salaries, overhead for maintenance, maintenance per se, taxes and insurance, and capital recovery (Mitchell, 2006).

Aden and Lynd both followed a biorefinery model with ethanol and electricity generation as the two products of the biorefinery. The ethanol costs are based on presumed facility designs that could be built based upon pilot projects or demonstration facilities (Lynd, et al., 2005; Aden, et al., 2002). A final important piece when comparing these studies is the dollar year used as a basis for the reports and the type of energy presumed for each facility (Table 4).

Table 4: Economic Base Year and Energy Use Presumed

Report	Base year used for economic analysis in report	Process Energy for Facility
Aden	2000	Biomass
Mao	2007	Biomass or fossil fuel
Lynd	2001	Biomass
Mitchell	2005	Fossil fuel/fossil fuel and shared capacity in co-located facility

4.3 Potential Biorefinery Revenues

Table 5 provides a summary of estimated revenues for a biorefinery based upon research conducted as part of the FBRI. Mitchell analyzed a stand-alone (Greenfield) facility, while Mao looked at the conversion of a Kraft pulp mill using the near-neutral process. As a result, the only products in the Mitchell analysis are ethanol and electricity, while in Mao's the main product remains hardwood Kraft pulp with ethanol and acetic acid by-products.

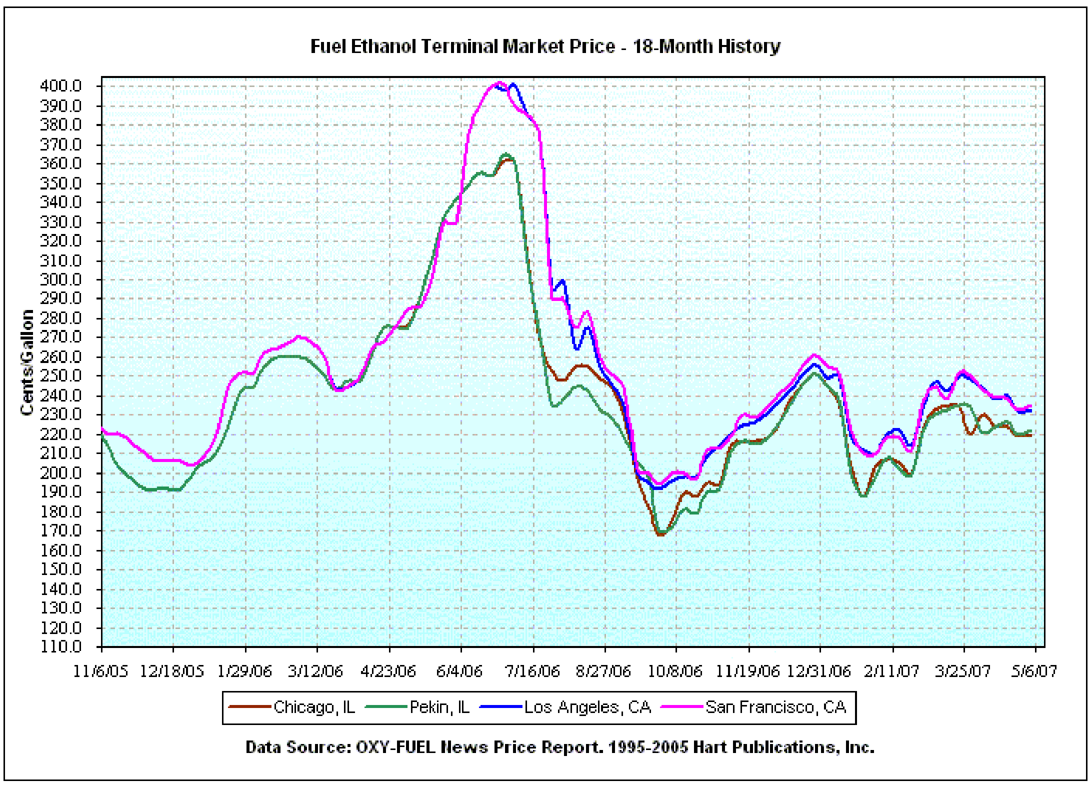
Figure 5 provides an 18 month overview of the price of ethanol and is provided to give some insight into ethanol pricing trends.

Table 5: Revenue Estimates Summary

Revenue amounts in 2007 U.S. Dollars (2008f)

Facility type	Unit Price (gallon) [3]	Production Rate (gallons/day)	Production Rate (Million gallons/year)	Estimated Revenue/year ($Millions) in 2007 $
Mao: Modified Kraft mill. 1000 tonne/day Ethanol	$2.56	13,212	4.8	$12.3
Acetic Acid	$4.41	11,354	4.1	$18.1
Mitchell: Greenfield facility. 1102 ton/day Ethanol	$2.56		26.1	$66.7

Figure 5: Fuel Ethanol Terminal Market Price November 2005-May 2007 ("2005-2007")



[3] Ethanol data comes from TradingCharts.com Inc., "TFC Commodity Charts." Last updated: Copyright 2008. Accessed: 12 May 2008. Daily data for Commodity pricing: http://futures.tradingcharts.com/chart/AC/68/?saveprefs=t&xshowdata=t&xCharttype=b&xhide_specs=f&xhide_analysis=f&xhide_survey=t&xhide_news=f., using the lowest price per pound from 2005 ($0.51/lb), the latest available data. The acetic acid data comes from Kirschner, M. "Acetic Acid." *Chemical Market Reporter* Vol. 269, no. 9(2006): 1., using data for 9 May 2008.
Price given is plant gate number, determined by taking the delivered price of ethanol and subtracting the trucking costs of ethanol, using the costs estimated from Old Town to Auburn (see Table 12).

5. Environmental Impacts

As discussed, the evolution of a pulp mill into a biorefinery will involve modifications to the facility, including the process. As a result, there are some impacts to both energy use and environmental emissions that have been quantified by a number of researchers.

In addition to the process itself, there has been a significant amount of research in recent years to determine the environmental impact of biofuels, both their use and production.[4] The research that has been done has looked at everything from using biofuels in current automobile engines and the emissions that result, to a full Life Cycle Assessment for the production of ethanol via corn. We provide a brief review of this research as it pertains to a pulp mill biorefinery and the initial products that can be produced.

5.1 Biorefinery Process

Larson and Mao studied possible environmental impacts with regards to emissions and energy use for transforming a pulp mill into a biorefinery. Larson looked at gasification (a thermochemical pathway) and Mao the near-neutral process (a biochemical pathway). For the gasification process, Larson found that the biorefinery would have higher energy efficiencies and lower air emissions than a comparable pulp-only mill (Larson, et al., 2006; Larson, et al., 2007).

Mao's analysis of the near-neutral process determined that the amount of methanol present in black liquor was reduced by approximately 40%; the total reduced sulfur was decreased; the pulping time needed was shorter; and energy use was reduced in parts of the process, in particular at the lime kiln. However, a pulp mill biorefinery would also produce about 35% less steam and lose energy during the extraction process. Finally, Mao found that there was also an increase in the production of carbon dioxide, gypsum, furfural and methanol (Mao, 2007). The 35% less steam production results from the energy associated with producing the ethanol plus the loss in energy content of the residual pulping liquor used to generate steam.

Energy use and emissions for producing cellulosic ethanol compared to both corn-based ethanol and gasoline has been studied by many different research groups (including (Mao, 2007; Zwart, 2006; Dufey, 2006; Fulton, et al., 2004; Larson, 2005; Farrell, et al., 2006)) and summarized by the U.S. Department of Energy on their website (2008j). Dufey in particular, noted that the amount of energy used to produce cellulosic ethanol was significantly less than both corn-based ethanol and gasoline. However, given that the technologies referred to are pre-commercial and emerging, precise estimates are not available.

The greenhouse gas emissions of biofuels produced from different feedstocks have also been studied and compared to gasoline. The U.S. Department of Energy noted that cellulosic ethanol could potentially reduce greenhouse gas emissions by up to 86%, as

[4] As noted throughout this paper, the production of bioproducts such as carbon fibers and bioplastic production is considered to be 3rd or 4th generation products for a biorefinery. As such, only the biofuels that can be produced in the very near term are addressed.

compared to gasoline, when the whole fuel cycle is looked at – not just the fuel produced, but also the fuel consumed to make the fuel (2008j).

5.2 Properties of the Biofuels

Cellulosic ethanol is no different from ethanol produced from corn. Once produced, the benefits relative to gasoline are the same when used in vehicles. Ethanol has been used as a replacement for methyl tertiary butyl ether (MTBE) to oxygenate gasoline in areas of the country where there are noncompliance issues regarding smog. Ethanol can also be mixed into gasoline (the resulting fuel contains up to 10% ethanol, known as E10) without any modification to the vehicles, thereby reducing the amount of gasoline used. There is a lower energy content in fuels with ethanol, and vehicle miles per gallon will be reduced as ethanol blends in gasoline increase.

Although the initial biorefinery products are expected to be ethanol, acetic acid and pulp, bio-butanol and bio-based diesel may be more promising. Initial research shows that butanol can also blend with gasoline, with a significant advantage over ethanol due to both the higher energy content (Skinner, et al., 2007), and indications that no large modifications to gasoline engines are necessary (van Walsum, 2008).

Bio-based diesel fuel can be produced from the thermochemical pathway. This diesel fuel has been shown to have virtually no sulfur or aromatics and a high cetane number, resulting in much lower nitrogen oxide and particulate matter emissions when used in a vehicle. In addition, it can be used in diesel engines as is – no modifications to the diesel engines are required (Zwart, 2006). Once this fuel process is established, it is conceivable that a significant amount of diesel fuel (as well as home heating oil) could be produced from renewable resources.

5.3 Land Use

Another important aspect of summarizing the full impact of biofuels is the impact on land use. There has been recognition that the full environmental impact of biofuels on cropland, food production, and overall impact is just beginning to be addressed, and there are conflicting assessments these impacts (Rosenthal, 2008; 2008k). Much of the recent work has focused on cropland and not on the forest lands currently used for the forest product industry. This paper has addressed the evolution of pulp mills into biorefineries using the near-neutral process as researched and developed at the University of Maine. As noted earlier, the infrastructure via the forest products industry is already well-established in Maine, and does not need to be modified for the initial pulp mill transformation. It is expected that the impact on land use will not change from current systems for the present or near-future and, in fact, provides an opportunity for forest land owners and managers to continue their contracts with pulp mills.

6. Possible Biorefineries in Maine

Maine currently has eleven pulp mills in operation consisting of Kraft pulping, mechanical pulping (which includes the groundwood process and/or thermomechanical process) and recycled pulp (Figure 6). Of these eleven mills, six use the Kraft process for making pulp. A list of the current pulp mills in Maine, using either the Kraft or groundwood process, is provided in Table 6 (Barden, 2008; 2008l; 2007; 2008m; 2005) along with information about equipment at the facility that could be necessary for a biorefinery. Table 7 provides a list of mills in Maine that use or manufacture recycled pulp.

Figure 6**: Location of Pulp Mills and Other Pulp Facilities in Maine**

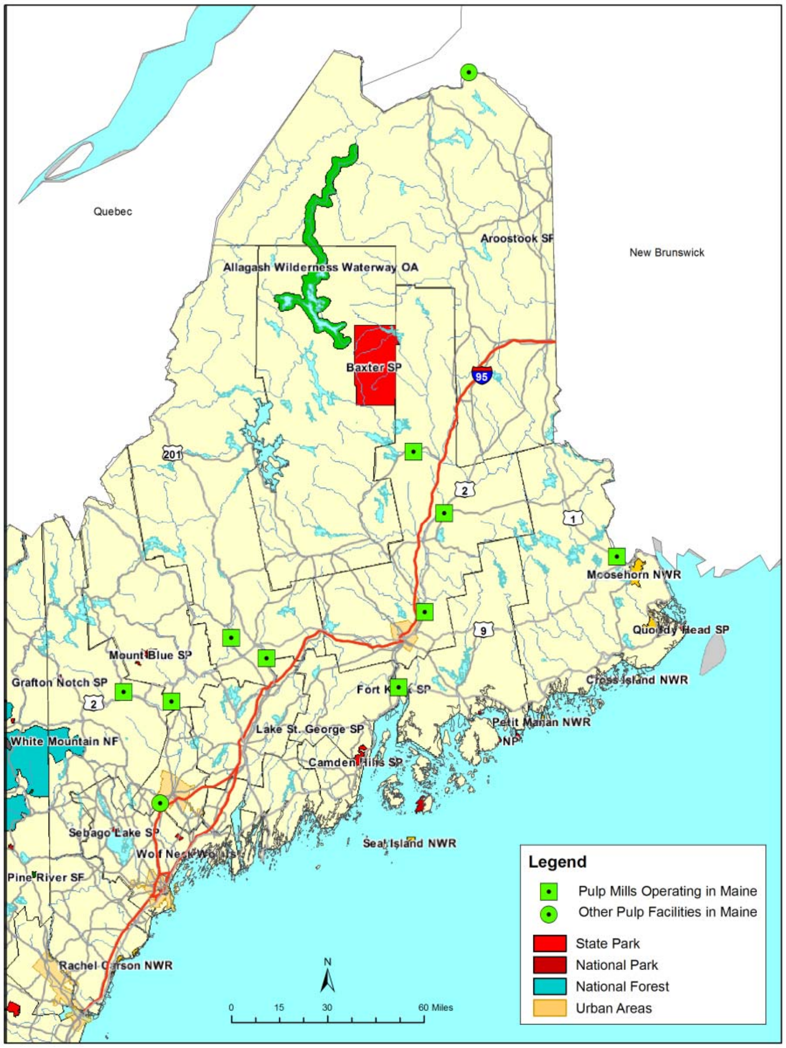


Table 6: Pulp Mills Operating in Maine

Pulp Mill	Location	Type of Pulp & Wood Type	Process Lines & Equipment	Additional Notes
Domtar Industries Inc.: Woodland Mill	Baileyville	Kraft pulp Hardwood	1 continuous digester 1 recovery boiler installed in 1989	Kraft Mill built in 1965
Katahdin Paper Company, LLC	East Millinocket	Groundwood pulp; recycled pulping	2 pulp lines	Operated and Managed by Fraser Papers 1 power boiler 3 steam turbines
Lincoln Paper & Tissue	Lincoln	Kraft pulp Hardwood	2 continuous digesters 1 recovery boiler installed in 1972	4 power boilers Fuels used: bark/biofuel, oil 2 steam turbines (6.5 MW)
Madison Paper Industries: Madison Mill	Madison	Groundwood pulp	5 pressurized grinders 2 pulpers for stock preparation, paper and paperboard mill	3 power boilers
NewPage Mill	Rumford	Kraft and groundwood pulp. Hardwood Softwood	10 batch digesters 1 continuous digester 1 recovery boiler, installed in 1980, rebuilt in 1992 3 pulpers for stock preparation, paper and paperboard mill	2 power boilers Fuels used: bark/biofuel, coal, oil, sludge 6 hydro turbines (39.4 MW) 2 steam turbines (95 MW)
Red Shield Environmental, LLC	Old Town	Kraft Pulp Hardwood	2 continuous digesters	1 Recovery Boiler 1 Biomass Boiler
Sappi Fine Paper North America: Somerset Mill	Skowhegan	Kraft Pulp Hardwood Softwood	1 continuous digester 1 recovery boiler, installed 1976, rebuilt 1991	Pulp mill built in 1974 Fuels used: bark/biofuel, oil 2 steam turbines (108 MW)
Verso Paper: Androscoggin Mill	Jay	Kraft and groundwood pulp. Hardwood Softwood	2 continuous digesters 2 recovery boilers, installed 1966, 1977; rebuilt 1987 (RB1)	3 power boilers Fuels used: bark/biofuel, oil
Verso Paper: Bucksport Mill	Bucksport	Groundwood and thermomechanical pulp (TMP)	1 conventional grinder 1 TMP system	3 power boilers Fuels used: bark/biofuel, oil, sludge

Table 7: Other Pulp Facilities in Maine (2007)

Facility & Location	Operation	Pulp Grade (2007)	Equipment	Additional Notes
Cascades Auburn Fiber, Inc.: Auburn Mill . Auburn	Produce de-inked pulp from Office papers, coated papers and white ledger.	Recycled pulping		
Fraser Papers Inc.: Madawaska Mill, Madawaska	Primarily paper manufacturer. Pulp mill at facility, built in 1919.	Sulfite and groundwood pulps imported from sister mill in Canada	4 pulpers for stock preparation for paper and paperboard mill	1 power boiler Fuel used: 99% bark/biofuels, 1% oil. 1 steam turbine (45 MW)

As shown in Table 6, there are a number of pulp mills in Maine that could evolve into biorefineries by using the near-neutral process developed as part of FBRI. These facilities may not have the immediate capability to convert, but all have the opportunity to consider whether evolving into a biorefinery makes sense for their operations and long-term viability. Since the near-neutral process relies on using hardwood, the pulp mills that have a dedicated hardwood line or two separate fiber lines – a hardwood line and a softwood line – have the highest potential for conversion. Next would be the mills that switch back and forth between hardwood and softwood pulping. Hardest to convert would be those mills that run a blend of the two types of fiber.

7. Transportation of Biofuels

The transportation costs of getting the biofuels and bioproducts to market is a key component of financial viability for biorefineries. Although a comprehensive analysis of transportation costs is best done on a case-by-case base, some generalized cost components can be addressed.

7.1 Biomass Transportation to Biorefinery

When looking at transportation issues for biofuels from biomass, the cost of getting the biomass material to the biorefinery is a necessary component of the analysis. Fortunately, the transport of biomass to Maine pulp mills has been going on for decades and the costs have been well established. In general, the pulp mill contracts with either the logger (contractor) or the land owner to supply wood to the facility for up to one-year (Benjamin, 2008). The use of these contracts would be exactly the same as the pulp mills currently use, so there is no need to adjust these transportation costs beyond what is already in place. In the northeastern United States, the estimated delivery costs for a green ton of hardwood pulpwood is $36.00 (2008n). These costs, however, may rise with the higher costs of diesel fuel.

Both Figure 7 and Figure 8 provide 60 mile radii (known as a wood drain circle) around the eleven pulp mills/facilities in Maine (found in Figure 6), with the area for each of the eleven mills noted in Table 8. The wood drain of 60 miles was chosen as the approximate economic limit of a one-way haul for trucking biomass (Laustsen, 2008a). Figure 7 identifies each of the eleven mills, and the resulting radius around those mills. Figure 8 shows the 60 mile wood drain radii as they overlap with one another for each mill, as well as the major transportation routes available to each mill: railroad, Interstate Highways, US Highways and State Highways.

Table 8: Pulp Mills and Other Pulp Facilities in Maine (2007)

Facility	Location	Wood Drain Area (Figure 7)
Cascades Auburn Fiber, Inc	Auburn	Area 1
Domtar Industries Inc	Baileyville	Area 6
Fraser Papers Inc.	Madawaska	Area 7
Katahdin Paper Company, LLC	East Millinocket	Area 5
Lincoln Paper & Tissue	Lincoln	Area 5
Madison Paper Industries	Madison	Area 3
NewPage Mill	Rumford	Area 2
Red Shield Environmental, LLC	Old Town	Area 4
Sappi Fine Paper North America	Skowhegan	Area 3
Verso Paper: Androscoggin Mill	Jay	Area 2
Verso Paper: Bucksport Mill	Bucksport	Area 4

Figure 7: 60 Mile Wood Drain for Pulp Mills and Facilities in Maine

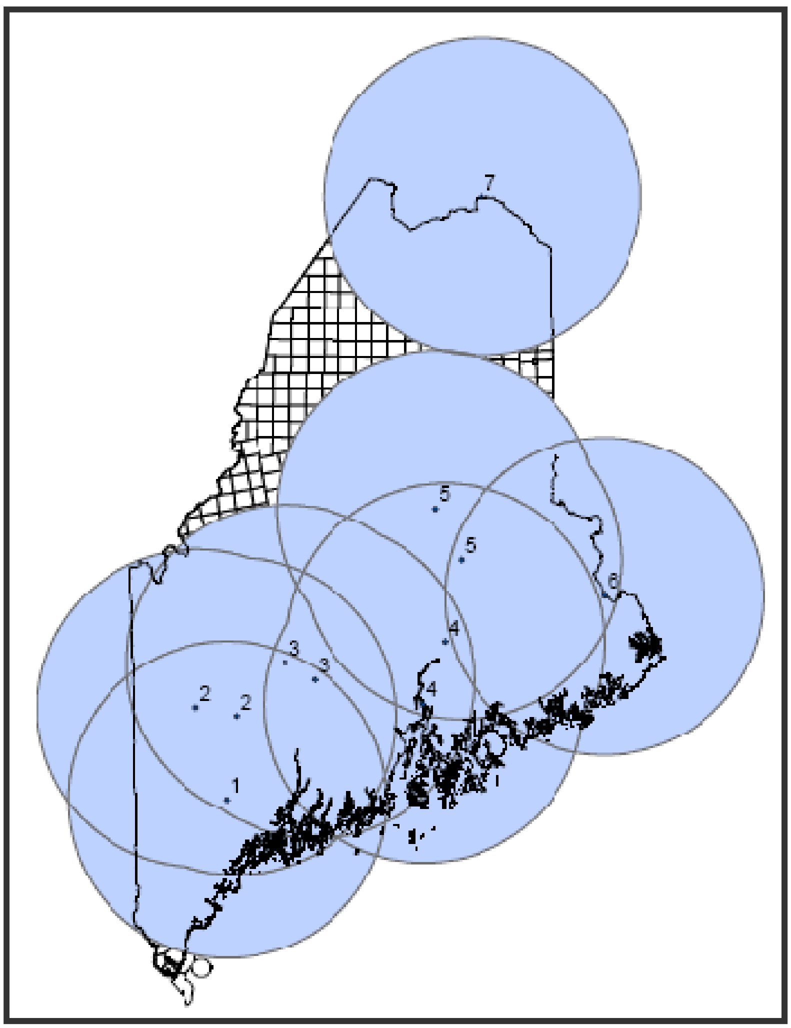
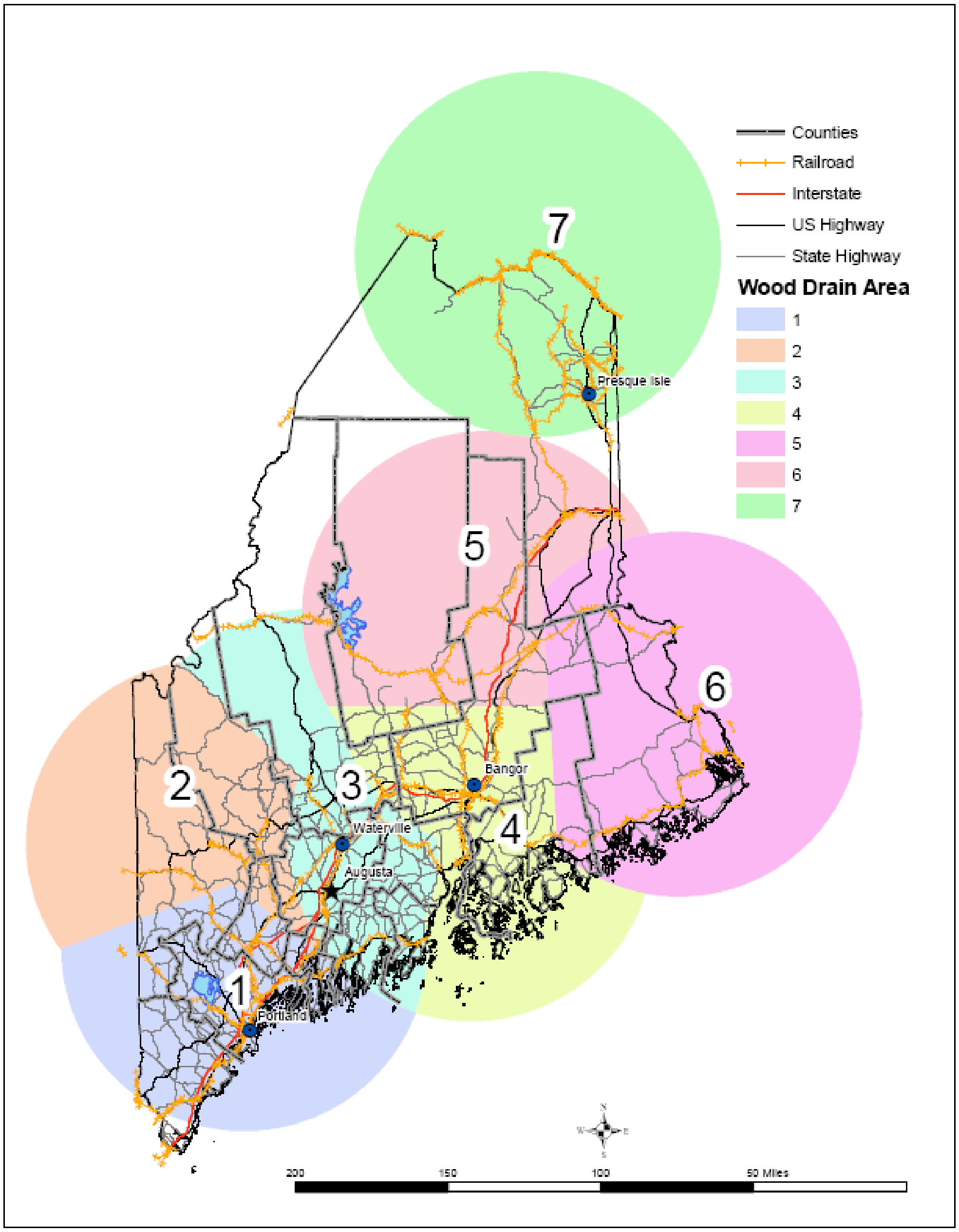


Figure 8: 60 Mile Wood Drain for Pulp Mills and Facilities in Maine with Major Transportation Routes



The Maine Forest Service has determined the amount of timberland for each of the 7 wood drain radii identified in Figures 7 and 8 (Table 9). In addition, the amount of hardwood biomass available and the average annual net change of growing-stock volume for hardwood has also been identified (Table 10) (Laustsen, 2008b).

Table 9: Acreage Basis within Wood Drain Areas 1-7 (Laustsen, 2008b)

(Numbers are from 2006)

Wood Drain Area	Timberland
1	1,452,856
2	2,012,179
3	2,061,906
4	1,708,323
5	3,808,705
6	2,314,922
7	2,041,395

Table 10: Hardwood Biomass Available and Average Annual Net Change of Growing-Stock Volume on Timberland for Wood Drain Areas (Laustsen, 2008b)

Wood Drain Area	Available Hardwood Biomass (thousands of dry tons)	Average annual net change of growing-stock volume for hardwoods (thousands of cubic feet)
1	93,388	23,931
2	144,008	-30,522
3	73,806	-12,408
4	50,670	-6,208
5	103,923	465
6	42,935	-5,627
7	61,345	-5,503

Biomass is 1.0+ dbh, dry weight

As shown in Table 10, only Areas 1 and 5 have a positive net change of current growing stock volume for hardwoods. It is not unusual for the net change of species to range from positive to negative and back to positive. Net change is "a response variable dependent on past growth, mortality, and harvest" (Laustsen, 2008a). It is a tool that is used to determine the sustainability of Maine forest resources as they are used for different manufacturing processes.

For the two wood drain areas with a net increase, only the Lincoln Paper & Tissue mill in Area 5 is a Kraft pulping operation using hardwood. For the areas that have a net decrease, the following mills use the Kraft process:

- Area 2: NewPage Mill (both hardwood and softwood). Verso Paper, Androscoggin Mill (also uses groundwood process; hardwood and softwood).
- Area 3: Sappi Fine Paper North America (hardwood and softwood).
- Area 4: Red Shield Environmental, LLC (hardwood).
- Area 6: Domtar Industries Inc. (hardwood).

In Area 7, the pulp mill is Fraser Papers, Inc., and it is primarily a paper manufacturer using imported pulp.

The amount of hardwood needed for the mills is based upon both how much pulp they make (approximately four tons of hardwood makes one ton of pulp), and how much wood they burn, based upon the boiler in use. As an example, a 50 MW boiler uses approximately 900 tons of biomass per day (Bilodeau, 2008). The biomass can be either softwood or hardwood.

7.2 Biorefinery Product Transportation Costs

Once the biorefinery has produced ethanol and/or acetic acid it is necessary to get them to market. (Pulp will not be addressed, as this is the current business of the pulp mills in Maine.) Liquid transport costs have been fairly steady until recent months with the rise in cost of gasoline and diesel. The estimates used for this report are provided in Table 11.

Table 11: Liquid Transportation Costs (Meyer, 2008b; Parker, et al., 2008)[5]

	Marine	Trucking	Rail
Loading/unloading	$0.015/gallon	$0.02/gallon	$0.015/gallon
Fixed Cost	$1.40/100 gallons		$8.80/100 gallons
Distance Dependent	$0.015/mile/100 gallons	$1.30/mile/truckload	$0.0075/mile/100 gallons
Time Dependent		$32/hr/truckload	
Barge Capacity	1.26 million gallons		
Truck Capacity		8,000 gallons	
Rail Car Capacity			33,000 gallons

Based upon the locations of the pulp mills and other pulp facilities in Maine, a summary of transportation costs is provided in Table 12. The costs provided should be used as a general guide. The price of fuel, and expense for on-loading/off-loading trucks and rail cars will be dependent on market costs as well as rail yard and pulping facilities capabilities.

5 Assumptions made for the transport costs: Trucking costs for “all types of dry biomass feedstock are the same on a wet ton basis.” The price per gallon of diesel used was $2.50. And, “the cost of transporting all liquids (oils, grease, and fuel products) is considered to be the same on a volumetric basis.” Parker, N., et al. "Western Governors' Association: Clean and Diversified Energy Initiative. Strategic Development of Bioenergy in the Western States. Development of Supply Scenarios Linked to Policy Recommendations." Draft Final Report, March 2008.

Table 12: Transportation Costs for products from Pulp Facilities

		Trucking Costs per Gallon of Fuel Used			Rail Costs per Gallon of Fuel Used		
Facility	**Town**	**Auburn**	**Bangor**	**Portland**	**Auburn**	**Bangor**	**Portland**
Cascades Auburn Fiber, Inc	Auburn	$0.02	$0.04	$0.03	$0.02	$0.02	$0.02
Domtar Industries Inc	Baileyville	$0.06	$0.04	$0.06	$0.02	$0.02	$0.02
Fraser Papers Inc.	Madawaska	$0.08	$0.06	$0.09	$0.02	$0.02	$0.02
Katahdin Paper Company, LLC	East Millinocket	$0.06	$0.03	$0.06	$0.02	$0.02	$0.02
Lincoln Paper & Tissue	Lincoln	$0.05	$0.03	$0.05	$0.02	$0.02	$0.02
Madison Paper Industries	Madison	$0.04	$0.03	$0.04	$0.02	$0.02	$0.02
NewPage Mill	Rumford	$0.03	$0.04	$0.04	$0.02	$0.02	$0.02
Red Shield Environmental, LLC	Old Town	$0.04	$0.02	$0.05	$0.02	$0.02	$0.02
Sappi Fine Paper North America	Skowhegan	$0.03	$0.03	$0.04	$0.02	$0.02	$0.02
Verso Paper: Androscoggin Mill	Jay	$0.03	$0.04	$0.03	$0.02	$0.02	$0.02
Verso Paper: Bucksport Mill	Bucksport	$0.04	$0.03	$0.04	$0.02	$0.02	$0.02

Note: used the address for Safe Handling, Inc. for distances to Auburn. Used the zip codes for Bangor and Portland (Congress St) for those respective distances.

All pulp facilities are on a rail line, but loading and offloading capabilities have not been confirmed.

8. Conclusion

It will not be possible or feasible to produce only pulp one day, and completely incorporate biochemical and thermochemical processes at the facility the next. Presently, the most important product produced at Kraft pulp mills in Maine is pulp. As the mills evolve into biorefineries, pulp will still be the most viable and profitable product in the initial stages of biorefining. It is the ability and opportunity to produce additional products concurrent with pulp that is the key aspect of the near-neutral process.

The near-neutral process developed at the University of Maine currently only works with hardwood chips. The biochemical process that has been discussed will work best as a first step for a pulp mill becoming a biorefinery, with the understanding that the process would be used when pulp is made from hardwood chips. A similar process for softwood chips has not been achieved as of yet (van Heiningen, 2008c).

There are drawbacks with using hemicellulose from the wood for the near-neutral process. As it is pulled out of the wood, it is both relatively dilute and present as a small stream. The advantage of using hemicellulose is that it is retrieved at low cost; if not pulled out of the wood, it will be burned as part of the energy production of the facility (van Heiningen, 2008c).

The investment costs necessary to convert mills to either a biochemical or thermochemical pathway are substantial, but some studies indicate that in some situations the costs are almost always worth the investments. These analyses were based upon fuel oil costs of $2.20/gallon when looking at a biochemical conversion, and $50/barrel when studying a thermochemical pathway. With current fuel costs substantially higher, the investment costs could be much more favorable. Both studies also found that pulp mills that convert to either the specific biochemical pathway of the near-neutral process or a thermochemical pathway would not be as sensitive to increased fossil fuel costs as mills that remain making only pulp. For the thermochemical pathway, there are process efficiencies obtained when converting the Kraft pulp mill. In the near-neutral process, energy efficiencies are found in some parts of the facility, and there are energy losses in other parts, making the overall energy use not that different.

Not only does the near-neutral process use the same or less energy when producing the pulp, ethanol and acetic acid, both energy use and emissions have been found to be favorable for cellulosic ethanol compared to corn-based ethanol and gasoline production. Additionally, greenhouse gas emissions from cellulosic ethanol are greatly reduced when the whole fuel cycle is studied.

The thermochemical pathway has been found to use the same or less energy than a pulp mill that does not utilize this pathway. The diesel fuel that can be produced at a biorefinery using the thermochemical pathway has emissions of sulfur and aromatics emissions that are much lower than that of petroleum diesel.

Of the eleven pulp mills in Maine six currently use the Kraft Process. These would the most likely to be the first to expand beyond pulp and produce other products via the near-neutral process. Based upon utilizing the near-neutral process as the first step, it is expected that there should be an adequate supply of available hardwood for those pulp mills that need it. Overall land use is not expected to be impacted, given the use of the land for pulp wood already.

The expanding process will allow a biorefinery to make products that can directly benefit Mainers. One example is home heating oil. As noted, home heating oil is the main fuel for the vast majority of Mainers. The possibility of making heating oil out of wood, rather than funding a full-scale conversion of home heating to wood products themselves, offers an opportunity for Maine to address one of its greatest energy needs with a Maine energy source.

Currently available technologies are still in the development stage and any pulp mill that transforms itself into a biorefinery is choosing to be a pioneer in this area. As a result, there will be a subsequent increase in short-term risks compared to those companies that do not take this route.

As the biochemical line of a biorefinery becomes established, there are additional processes and products that can be studied. One area would be to have a biorefinery partner with a petroleum refinery, so an expansion into the thermochemical process and the resulting "green crude" produced could be sent to the existing refinery and further processed there. As noted, further processes will be researched and additional feedstocks added to the mix. The near-neutral process discussed in this paper is but one route that can begin to be carried out in Maine.

The push for alternatives to petroleum and sustainable feedstocks is coming not just from a small percentage of consumers, but also from Federal and State government policies that are trying to find a home-grown solution to energy and environmental demands for the country. A great deal of research is happening both in the United States and around the world, to determine the best way for facilities that are already in the wood products field to continue to use their knowledge and expand into many more and different bioproducts than those they have been producing for decades. The processes and products described in this paper are but a first step in a continuing path towards both energy independence and product sustainability that can start with one of the oldest industries in the state of Maine.

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Appendix A: Glossary of Terms

The following terms are provided from the references noted.

Acetic Acid: (CH3CO2H) colorless liquid that has a characteristic pungent odor, boils at 118°C, and is miscible with water in all proportions; it is a weak organic carboxylic acid (see carboxyl group). Glacial acetic acid is concentrated, 99.5% pure acetic acid; it solidifies at about 17°C to a crystalline mass resembling ice. Acetic acid is the major acid in vinegar; as such, it is widely used as a food preservative and condiment. For industrial use concentrated acetic acid is prepared from the oxidation of acetaldehyde. Acetic acid is also a product in the destructive distillation of wood. It reacts with other chemicals to form numerous compounds of commercial importance. These include cellulose acetate, used in making acetate rayon, nonflammable motion-picture film, lacquers, and plastics; various inorganic salts, e.g., lead, potassium, and copper acetates; and amyl, butyl, ethyl, methyl, and propyl acetates, which are used as solvents, chiefly in certain quick-drying lacquers and cements. Amyl acetate is sometimes called banana oil because it has a characteristic banana odor.

From the Columbia Encyclopedia, Sixth Edition. 2001-2007. Accessed January 30, 2008. (http://www.bartleby.com/65/)

Acetic acid is one of the simplest carboxylic acids (the second-simplest, next to formic acid). It is an important chemical reagent and industrial chemical that is used in the production of polyethylene terephthalate mainly used in soft drink bottles; cellulose acetate, mainly for photographic film; and polyvinyl acetate for wood glue, as well as synthetic fibres and fabrics. In households diluted acetic acid is often used in descaling agents. In the food industry acetic acid is used under the food additive code E260 as an acidity regulator.

The global demand of acetic acid is around 6.5 million tonnes per year (Mt/a), of which approximately 1.5 Mt/a is met by recycling; the remainder is manufactured from petrochemical feedstocks or from biological sources.

Acetic acid is produced both synthetically and by bacterial fermentation. Today, the biological route accounts for only about 10% of world production, but it remains important for vinegar production, as the world food purity laws stipulate that vinegar used in foods must be of biological origin. About 75% of acetic acid made for use in the chemical industry is made by methanol carbonylation, explained below. Alternative methods account for the rest.

From Wikipedia, accessed January 30, 2008 (http://www.wikipedia.org/)

Butanol: or butyl alcohol (sometimes also called biobutanol when produced biologically), is a primary alcohol with a 4 carbon structure and the molecular formula of C4H10O. It is primarily used as a solvent, as an intermediate in chemical synthesis, and as a fuel. Butanol at 85 percent strength can be used in cars without any change to the engine (unlike ethanol) and it produces more power than ethanol and almost as much power as gasoline.

From Wikipedia, accessed January 30, 2008 (http://en.wikipedia.org/wiki/Butanol/)

Dimethyl ether (DME): A colorless gas at ambient temperature and pressure, with a slight ethereal odor. It liquefies under slight pressure, much like propane. It is relatively inert, noncorrosive, non-carcinogenic, almost non-toxic, and does not form peroxides by prolonged exposure to air [25]. Today, DME is used primarily as an aerosol propellant in hair sprays and other personal care products, but its physical properties (Table 2) make it a suitable substitute (or blending agent) for liquefied petroleum gas (LPG, a mixture of propane and butane). It is also an excellent diesel engine fuel due to its high cetane number and absence of soot production during combustion.

From "The Case for the Integrated Thermochemical Forest Products Biorefinery," Biorefinery "Financial Case" Team. 2007.

Fischer-Tropsch process: A method for the synthesis of hydrocarbons and other aliphatic compounds. Synthesis gas, a mixture of hydrogen and carbon monoxide, is reacted in the presence of an iron or cobalt catalyst; much heat is evolved, and such products as methane, synthetic gasoline and waxes, and alcohols are made, with water or carbon dioxide produced as a byproduct.

The Columbia Encyclopedia, Sixth Edition. "FISCHER-TROPSCH PROCESS." Copyright 2007 Columbia University Press. Accessed 17 April 2008. (http://www.bartleby.com/65/fi/FischerT.html)

Furfural: A colorless, sweet-smelling, liquid made from corncobs and used as a solvent in petroleum refining and as a fungicide and weed killer. It turns reddish brown when exposed to air and light. Furfural is an aldehyde of furan. Chemical formula: $C_5H_4O_2$.

From The American Heritage® Science Dictionary. Houghton Mifflin Company. Accessed 16 April 2008. (<Dictionary.com http://dictionary.reference.com/browse/furfural>.)

Groundwood Pulp: A wood pulp that contains the natural wood impurities and has not been chemically processed. Also known as mechanical pulp.

From International Paper. 2008. Groundwood Pulp. In Learn Paper Terms; International Paper; online Knowledge Center. Accessed 17 April 2008. (http://glossary.ippaper.com/default.asp?req=glossary/term/1009&catitemid=)

A wood pulp consisting of groundwood that has not been cooked or chemically treated, used for making newsprint and other poorer grades of paper.

From Dictionary.com Unabridged (v 1.1). Random House, Inc. "groundwood pulp." Accessed 17 Apr. 2008. (<Dictionary.com http://dictionary.reference.com/browse/groundwood pulp>*.)*

Kraft Pulping Process: The kraft pulping process involves the digesting of wood chips at elevated temperature and pressure in "white liquor", which is a water solution of sodium sulfide and sodium hydroxide. The white liquor chemically dissolves the lignin that binds the cellulose fibers together.

From Environmental Protection Agency. 2008. AP 42, Fifth Edition, Volume I. In Chapter 10: Wood Products Industry (Section 10.2: Chemical Wood Pulping), Factors CfIaE (ed.);

Technology Transfer Network, Clearinghouse for Inventories & Emissions Factors. (http://www.epa.gov/ttn/chief/ap42/ch10/final/c10s02.pdf)

Background: …The invention of the recovery boiler by G.H. Tomlinson in the early 1930s, was a milestone in the advancement of the kraft process.[2] It enabled the recovery and reuse of the inorganic pulping chemicals such that a kraft mill is almost closed-cycle with respect to inorganic chemicals, apart from those used in the bleaching process. For this reason, in the 1940s, the kraft process surpassed the sulfite process as the dominant method for producing wood pulp.

Pulp produced by the kraft process is stronger than that made by other pulping processes. Acidic sulfite processes degrade cellulose more than the kraft process, which leads to weaker fibers. Kraft pulping removes most of the lignin present originally in the wood whereas mechanical pulping processes leave most of the lignin in the fibers. The hydrophobic nature of lignin[8] interferes with the formation of the hydrogen bonds between cellulose (and hemicellulose) in the fibers needed for the strength of paper[1] (strength refers to tensile strength (strength refers to tensile strength tensile strength and resistance to tearing).

Kraft pulp is darker than other wood pulps, but it can be bleached to make very white pulp. Fully bleached kraft pulp is used to make high quality paper where strength, whiteness and resistance to yellowing are important.

The kraft process can use a wider range of fiber sources than most other pulping processes. All types of wood, including very resinous types like southern pine[9] and non-wood species like bamboo and kenaf can be used in the kraft process.

From Wikipedia, accessed January 30, 2008. (http://en.wikipedia.org/wiki/Kraft_process)

Levulinic acid: a white or colorless, water-soluble solid, $C_5H_8O_3$, produced by the hydrolysis of cane sugar, starch, or cellulose; used chiefly in the organic synthesis of nylon, plastics, and pharmaceuticals.

From Dictionary.com Unabridged (v 1.1). Random House, Inc. "Levulinic acid." Accessed 16 Apr. 2008. (<Dictionary.com http://dictionary.reference.com/browse/Levulinic acid>)

Methanol: is used as a solvent for varnishes and lacquers, as an antifreeze, and as a gasoline extender in the production of gasohol. Large amounts of it are used in the synthesis of formaldehyde. Because of its poisonous properties, methanol is also used as a denaturant for ethanol. Methanol is often called wood alcohol because it was once produced chiefly as a byproduct of the destructive distillation of wood. It is now produced synthetically by the direct combination of hydrogen and carbon monoxide gases, heated under pressure in the presence of a catalyst.

From The Columbia Encyclopedia, Sixth Edition. 2001-2007. Accessed January 30, 2008. (http://www.bartleby.com/65/me/methanol2.html)

Appendix B: Biofuel Definitions

These definitions are from the American Coalition for Ethanol[6]

Conventional Biofuels (Corn Ethanol)

Renewable fuel that is derived from corn starch. The renewable fuel produced from facilities that commence construction after the date of enactment (December 19, 2007) must achieve a 20% reduction in greenhouse gas (GHG) emissions compared to baseline lifecycle GHG emissions of gasoline and diesel.

Advanced Biofuels

Renewable fuel other than ethanol derived from corn starch, that is derived from renewable biomass and has lifecycle GHG emissions, as determined by the EPA Administrator that are at least 50% less than baseline GHG emissions. This term includes "cellulosic biofuels" and "biomass-based diesel." The schedule for Advanced Biofuels includes the schedule for Cellulosic Biofuels, Biomass-Based Diesel, and Undifferentiated Advanced Biofuels.

Cellulosic Biofuels

Renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle GHG emissions, as determined by the EPA Administrator, that are at least 60% less than the baseline lifecycle GHG emissions.

Biomass-Based Diesel

Renewable fuel that is biodiesel as defined in section 312(f) of the Energy Policy Act of 1992 (42 U.S.C. 13220(f), which according to the EPA is, a diesel fuel substitute produced from nonpetroleum renewable resources that meets the registration requirements for fuels and fuel additives established by the EPA under section 7545 of the Clean Air Act." It is derived from renewable biomass and has lifecycle GHG emissions, as determined by the EPA Administrator that are at least 50% less than baseline GHG emissions. It does not include the co-processing of biomass with a petroleum feedstock, which is classified as an "advanced biofuel."

Undifferentiated Advanced Biofuels

Renewable fuel other than ethanol derived from corn starch, that is derived from renewable biomass and has lifecycle GHG emissions, as determined by the Administrator that are at least 50% less than baseline GHG emissions. This term includes "cellulosic biofuels," "biomass-based diesel" and "co-processed renewable diesel."

[6] American Coalition for Ethanol, http://www.ethanol.org/index.php?id=78&parentid=26, accessed 16 April 2008.

Appendix C: Additional information/sources

Web-based Resources (accessed 18 April 2008; 29 April 2008):

- Agenda 2020 Technology Alliance (http://www.agenda2020.org/). A special project of the American Forest & Paper Association, dedicated to collaborative partnerships to create innovation in the forest products industry's processes, materials, and markets.

- Bioenergy Feedstock Information Network (http://bioenergy.ornl.gov/main.aspx). BFIN is a gateway to a wealth of biomass feedstock information resources from the U.S. Department of Energy, Oak Ridge National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, and other research organizations.

- Biomass Energy Centre (http://www.biomassenergycentre.org.uk/portal/page?_pageid=73,1&_dad=portal&_schema=PORTAL). The BIOMASS Energy Centre (BEC) is owned and managed by the UK Forestry Commission, via Forest Research, its research agency.
  A steering group comprised of representatives from the biomass industry and related sectors oversee the BEC and bring with them their own expertise that the BEC draws upon on.
  The BIOMASS Energy Centre aims to be a one stop shop able to provide information, advice and guidance to UK individuals and organizations - signposting to other specialised sources of advice as necessary - on a wide range of biomass fuels and conversion technologies.
  This initiative has been undertaken in support of Government's response to recommendations made by the Biomass Task Force.

- Biomass Energy Resource Center (BERC) (http://www.biomasscenter.org/). Our home is in Montpelier, Vermont, and we work on projects around the country to install systems that use biomass fuel to produce heat and/or electricity. Our partners in these projects have included schools, communities, colleges, businesses, utilities, and government agencies.

- Biomass Research and Development Initiative (BRDI) (http://www.brdisolutions.com/default.aspx). The multi-agency effort to coordinate and accelerate all Federal biobased products and bioenergy research and development. BRDI is administered by the Designated Federal Officer at the U.S. Department of Energy (DOE) and the Liaison as U.S. Department of Agriculture (USDA).

- Bioproducts Alberta (http://www.bioproductsalberta.com/). BioProducts Alberta has been established as a federal not-for-profit corporation to be a catalyst for the growth of a vibrant bioproducts industry across western Canada.

Industry led, BioProducts Alberta will drive economic development by promoting and facilitating collaboration in bioproducts research, technology commercialization, information exchange, and industry development.

- Energy Biosciences Institute (EBI) (http://www.energybiosciencesinstitute.org/). A new research and development organization that harnesses advanced knowledge in biology, the physical sciences, engineering, and environmental and social sciences to devise viable solutions to global energy challenges and reduce the impact of fossil fuels to global warming. The world's first research institution solely dedicated to the new field of energy bioscience, is initially focusing on the development of next-generation biofuels, but will also look into various applications of biology to the energy sector.

  The EBI represents a unique collaboration between the University of California, Berkeley, the Lawrence Berkeley National Laboratory, the University of Illinois, and BP, which will support the Institute with a 10-year $500-million grant. The EBI hosts approximately 25 research teams, housed at the University of California, Berkeley, campus and at the University of Illinois.

- Forest Bioproducts Research Initiative, University of Maine (http://www.forestbioproducts.umaine.edu/). FBRI's Vision: To advance understanding about the scientific underpinnings, system behavior, and policy implications for the production of forest-based bioproducts that meet societal needs for materials, chemicals and fuels in an economically and ecologically sustainable manner.

- National Renewable Energy Laboratory (NREL), Science & Technology, Biomass Research, Energy Analysis and Tools (http://www.nrel.gov/biomass/energy_analysis.html).

- Northeast Regional Biomass Program (http://www.nrbp.org/). The Northeast Regional Biomass Program (NRBP) is one of five Regional Biomass Energy Programs established and funded by the U.S. Department of Energy (DOE). The Northeast region consists of eleven states including: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

  The program's mission is to evaluate biomass technologies and fuels and to provide objective, reliable information to consumers and policy leaders. The NRBP carries out its mission through an extensive network of local, state, and national government organizations, and partnerships with private industry. Biomass in the context of this program is defined as renewable organic materials including: forestry and agricultural crops and residues; wood and food processing wastes; and municipal solid waste (MSW).

- Refuel (http://www.refuel.eu/home/). The refuel project is designed to encourage a greater market penetration of biofuels. To help achieve this goal, we will develop a biofuels road map, consistent with EU biofuel policies and supported by stakeholders involved in the biofuels field. Starting early 2006, the project involves seven renowned partners and will take 24 months to complete. Refuel is financed by the European Commission under the 'Intelligent Energy - Europe' programme.

- Renew (http://www.renew-fuel.com/home.php). Sustainable energy systems for transport. This project assesses the production routes for such biomass-to-liquid (BTL) fuels and will lead to recommendations for the future realisation of the technology. The projects devides into six subprojects, four of which are dedicated to the optimisation, analysis of the fuel production process and production routes for biofuels from lignocellulosic feedstock.
  A pan-European project, supported under the European Commission's 6th Framework Programme.

- U.S. Department of Agriculture, USDA Biobased products and Bioenergy Coordination Council (http://www.ars.usda.gov/bbcc/)

- U.S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program (http://www1.eere.energy.gov/biomass/index.html)

- U.S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program, Information Resources, Information Resources, Biofuels Data (http://www1.eere.energy.gov/biomass/biofuels_data.html)

- U.S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program, Information Resources, Biomass Publications (http://www1.eere.energy.gov/biomass/publications.html#vision)

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