Minnesota's Woody Biomass Resources and Opportunities in the Emerging Energy Industry

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Executive Summary

Recent developments in alternate energy may present new opportunities to expand the economy of northern Minnesota using wood resources. At the same time, increased wood usage in the state can affect the existing industry. The purpose of this document is to evaluate various wood resources and discuss opportunities for growth in the energy industry in the context of the existing forest products industry. Minnesota's wood products industry is an important part of the state's economy contributing approximately $6.9 billion to the state's economy. While a portion of the forest products industry is not entirely dependent on local resources for raw material, the majority of northern Minnesota's forest products industry is dependent on wood produced through harvesting of stands located within Minnesota or neighboring states and provinces of Canada. Understanding the forest resource is critical to inform decisions on policies such as harvesting plans or subsidies to an emerging energy industry to ensure that the health of the state's forest products industry and forests is maintained.

In the past, wood for fuel has been used primarily for residential heating with very little wood purchased solely for industrial energy applications. Up to this point, wood wastes produced in industrial processes such as bark, sawdust, edgings and planer shavings have been used to produce energy but use of wood exclusively for energy has not been widespread. Recently, prices of petroleum-derived energy sources such as heating oil and natural gas have risen to the point where wood might be considered an economically viable alternative to fossil fuels. A comparison of the price of fossil fuels and woody biomass shows that wood chips, and in some cases roundwood, may be considered a viable replacement to higher priced fossil fuels such as natural gas.

The capacity of the state's forest resource to provide timber supply to the forest products industry in a sustainable manner has been a subject of intense study. Minnesota is a nationally recognized leader in this area through the process of the Generic Environmental Impact Statement on Forestry. The GEIS evaluated forest resources in the context of environmental impacts including long-term soil productivity, water quality and wildlife populations. After evaluation of several harvest levels and associated impacts, the GEIS identified a level of 5.5 million cords as a sustainable long-term harvest level. This harvest level was also stated as a goal of the Governor's Task Force on the Competitiveness of the Forest Products Industry. A recent followup study to the GEIS indicates a high level of implementation of recommendations to mitigate environmental impacts. Given a sustainable harvest level of 5.5 million cords and current usage by the forest product industry of 4.2 million cords, an estimated 1.3 million cords of roundwood could be available in the future to produce energy or forest products.

In addition to roundwood harvests, forest harvest residues, specifically tops and limbs, could supply feedstock for energy production. An evaluation of the proportion of harvest residues shows that approximately one million dry tons of harvest residues are currently produced resulting from a harvest level of 3.7 million cords of pulpwood and sawtimber. Using the same ratio of harvest residues to roundwood shows that a harvest level of 5.5 million cords would produce approximately 1.5 million dry tons of harvest residue biomass. Accounting for environmental mitigation, estimates of total available harvest residues are 750,000 and 1.15 million dry tons, at harvest levels of 3.7 and 5.5 million cords, respectively. Current and

proposed facilities could demand 500,000 dry tons annually, leaving about 250,000 tons of forest harvest residues available at the present time.

Additional biomass could be obtained through a variety of sources including thinning of Red Pine plantations and Aspen. Thinning of Red Pine could contribute an additional 100,000 cords annually above current levels, or approximately 115,000 dry tons. Aspen thinning is a potential option to recover volume that is otherwise lost to mortality. The NRRI has conducted research on precommercial thinning of Aspen and estimates that ten tons per acre of ovendry biomass could be harvested at year ten to fifteen. Also, there may be opportunities to thin older stands. A need exists to conduct thinning trials using available equipment and evaluate impacts on subsequent stand growth at various ages of thinning. If Aspen thinning were widely practiced, it is possible to produce one million dry tons annually, a potentially significant amount of biomass. In addition to forests, shrublands and hybrid poplar plantations could supply woody biomass in the future. Quantifying shrubland acreage and stand density is difficult and work is underway by the Minnesota Department of Natural Resources and the UM-NRRI to develop methods to estimate shrub biomass more accurately. Using available information and conservative assumptions, shrublands may contribute an additional 400,000 dry tons annually.

Hybrid poplar plantations grown on agricultural lands enrolled in the Conservation Reserve Program have the potential to supply large quantities of woody biomass. A national study of biomass supply estimates that almost one third of the total biomass available in the future could come from dedicated energy crops such as hybrid poplar, switchgrass or prairie mixes. Assuming a yield of 3.5 ovendry tons per acre per year, the total amount of biomass available in the state may be as high as 5.6 million ovendry tons, a portion of which could be woody biomass from hybrid poplar plantations.

The potential demand for alternate energy is extremely large. Complete replacement of gasoline and coal-derived electricity in Minnesota would require a total of sixty million dry tons of biomass, a staggering number. However, progress can be made toward that goal. Technology under development to produce ethanol from cellulose focuses on two primary pathways, biochemical and thermochemical. Biochemical ethanol production employs specific enzymes and genetically modified yeasts to degrade cellulose into sugars and ultimately to ethanol. Thermochemical processes involved gasification and catalytic conversion of synthesis gas to a variety of liquid fuels including ethanol. The economics of ethanol production using local wood sources was estimated using data published in a recent study by the National Renewable Energy Laboratory. This baseline analysis was adjusted to reflect prevailing prices for wood in Minnesota. The estimated breakeven price of ethanol produced from residue chips is $1.17 and $1.44 per gallon using roundwood feedstock, an average of $1.30 per gallon. A comparison of ethanol to gasoline shows that after adjustment for reduced energy content and mileage using ethanol, the current mileage-adjusted value of ethanol that is competitive with gasoline is $1.89 per gallon. Assuming that conversion technologies advance to the point suggested in the NREL report, wood-based ethanol could be competitive with gasoline at current wood prices in Minnesota.

An alternate transportation technology that may compete with cellulosic ethanol is plug-in electric vehicles. A comparison of fuel costs between ethanol and electrically-driven vehicles shows that fuel cost is $0.10 per mile for an ethanol-powered vehicle compared to $0.02 per mile for a plug-in electric in full-electric mode. After adjustment to account for highway taxes, the cost of an electrically-powered vehicle is $0.033 per mile, roughly one third the cost of an internal combustion engine burning ethanol. A comparison of the efficiency of conversion of biomass between an ethanol-powered vehicle and a plug-in electric vehicle shows that approximately 2.5 times more miles can be derived from a ton of biomass using plug-in electric vehicles.

While there is uncertainty about the rate of oil depletion and global reserves of fossil fuels, there is no doubt that demand for alternate energy will increase. Biomass sources including roundwood, forest harvest residues, forest thinnings, brushlands and energy crops could provide a significant amount of woody biomass to be used as feedstock to produce alternate energy in Minnesota, possibly enough for three additional wood-based plants using current supplies of timber from the forest land base. Additional opportunities exist in new biomass sources such as brushlands and poplar plantations. As this industry develops, a number of points are important:

- Legislators and policymakers concerned about the economy in the forested areas of Minnesota should appreciate the potential impact of energy subsidies on the forest products industry,
- Support for research at the state level to develop conversion and biomass production technologies, specifically energy crop development, brushland biomass assessments, aspen thinning options and impacts, forest harvest residue bundling equipment and conversion technologies is needed,
- Ethanol produced from local wood resources may be competitive with gasoline at current prices,
- Smaller-scale conversion technologies that are publicly available are needed and may require targeted research and development by the State,
- Picking ultimate winners is difficult and the most competitive options will depend on technology advancements in the fields of liquid fuels conversion and batteries.

Introduction and Background

Minnesota's wood products industry is an important part of the state's economy contributing approximately $6.9 billion to the state's economy (Minnesota Forest Industries, 2007). Over 22,000 people are employed in the various facets of the forest products industry manufacturing lumber, oriented strandboard, engineered composite products as well as pulp and paper. While a portion of the forest products industry is not entirely dependent on local resources for raw material, the majority of northern Minnesota's forest products industry is dependent on wood produced through harvesting of stands located within Minnesota or neighboring states and provinces of Canada. Understanding the forest resource is critical to inform decisions on policies such as harvesting plans or subsidies to an emerging energy industry to ensure that the health of the state's forest products industry is maintained. The purpose of this document is to summarize information on Minnesota's forest products industry and provide perspective on the potential for expansion of the wood-using industry in energy production.

Energy Prices and Wood Energy Value

It is common knowledge that energy prices have risen dramatically over the past several years with the effects of energy price increases being felt in every sector of the economy and all socioeconomic levels. Concerns over long-term supply of petroleum products and continued expansion of the economies of China, India and other countries have contributed to tightening supplies worldwide. The U.S. produces only about one-third of its oil domestically and a steady petroleum supply is critical to the U.S. economy. In the past, wood for fuel has been used primarily for residential heating with very little wood purchased solely for industrial energy applications. Up to this point, wood wastes produced in industrial processes such as bark, sawdust, edgings and planer shavings have been used to produce energy but use of wood exclusively for energy has not been widespread.

Recently, prices of petroleum-derived energy sources such as heating oil and natural gas have risen to the point where wood might be considered an economically viable alternative to fossil fuels. Table 1 shows the average net realized price per unit of usable energy assuming various rates of conversion efficiency of common energy sources. After taking into account conversion efficiency, the cost per million British Thermal Units (mmBTUs) of wood-based energy is currently lower than heating oil and propane and similar to natural gas depending on wood form, either chips or roundwood. The price advantage of wood over some fossil fuels is unprecedented and will likely become greater in the future. The differential in price between heating oil or propane and wood is sufficient to encourage near-term investment to replace these higher-priced sources. Thus, the use of wood to produce energy can be expected to increase and could become a significant part of the future economic landscape of the state. While coal remains the least expensive energy source by a wide margin, permitting of new coal-burning facilities is becoming increasingly difficult due to concerns over emissions of carbon dioxide as well as other pollutants. Use of low CO_2 fuels such as natural gas or no-net CO_2 fuels such as biomass are becoming attractive options.

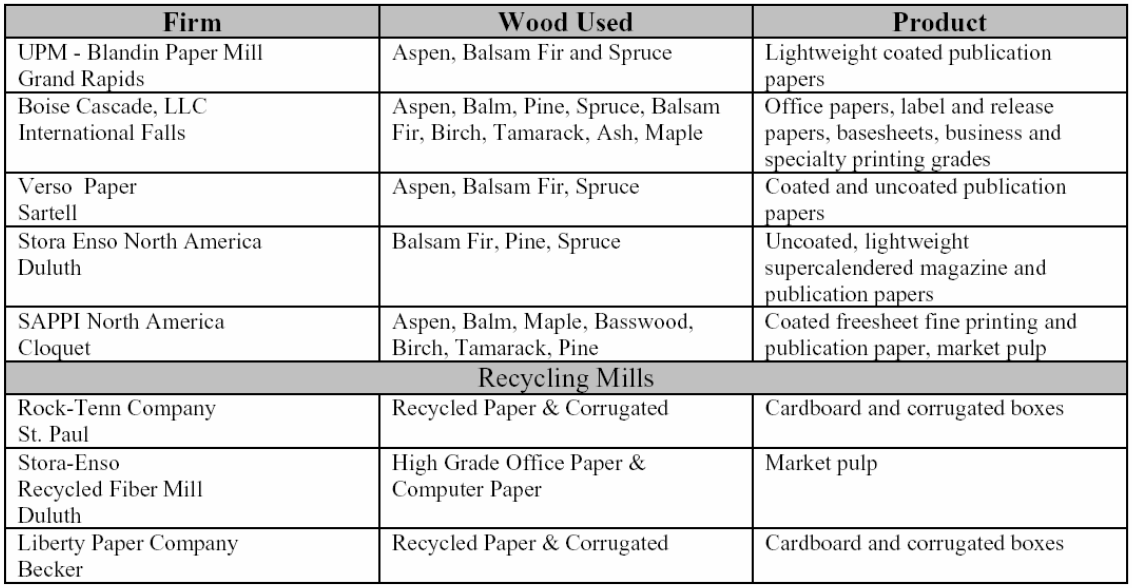
Table 1. Comparison of common fuels and net realized price per mmBTU.

Fuel Type	$/unit	Unit	$/mmBTU	Conversion Efficiency	Net Cost ($/mmbtu)
Natural Gas	$5.60	Mmbtu	$5.60	0.9	$6.22
Heating Oil	$1.99	Gallon	$14.21	0.85	$16.72
Propane	$1.20	Gallon	$13.10	0.9	$14.55
PRB Coal	$10.00	Ton	$0.57	0.6	$0.94
Round Wood	$75.00	Cord	$3.83	0.6	$7.35
Wood Chips	$25.00	Gr. Ton	$2.94	0.6	$4.90

Minnesota's Forest Products Industry Overview

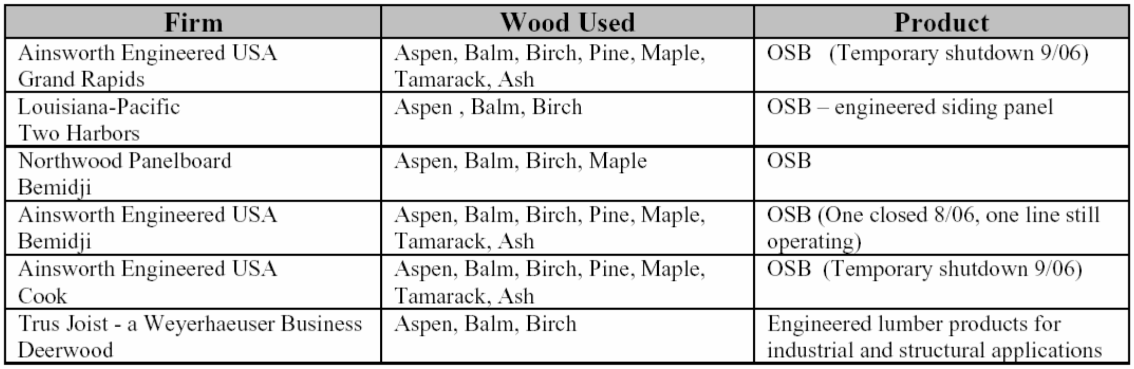
The state's forest products industry produces a range of products and is geographically dispersed with mills located across the Arrowhead and as far west as Solway, near the prairie-forest border (Minnesota Department of Natural Resources, 2006). Tables 2 and 3 show the location, type of wood used and product produced from the pulp and paper and oriented strandboard industries located in the state.

Table 2. Minnesota's pulp and paper industry (source: MN DNR, 2006 Forest Resources)



Firm	Wood Used	Product
UPM - Blandin Paper Mill Grand Rapids	Aspen, Balsam Fir and Spruce	Lightweight coated publication papers
Boise Cascade, LLC International Falls	Aspen, Balm, Pine, Spruce, Balsam Fir, Birch, Tamarack, Ash, Maple	Office papers, label and release papers, basesheets, business and specialty printing grades
Verso Paper Sartell	Aspen, Balsam Fir, Spruce	Coated and uncoated publication papers
Stora Enso North America Duluth	Balsam Fir, Pine, Spruce	Uncoated, lightweight supercalendered magazine and publication papers
SAPPI North America Cloquet	Aspen, Balm, Maple, Basswood, Birch, Tamarack, Pine	Coated freesheet fine printing and publication paper, market pulp
Recycling Mills		
Rock-Tenn Company St. Paul	Recycled Paper & Corrugated	Cardboard and corrugated boxes
Stora-Enso Recycled Fiber Mill Duluth	High Grade Office Paper & Computer Paper	Market pulp
Liberty Paper Company Becker	Recycled Paper & Corrugated	Cardboard and corrugated boxes

Table 3. Minnesota's OSB industry (source: MN DNR, 2006 Forest Resources)



Firm	Wood Used	Product
Ainsworth Engineered USA Grand Rapids	Aspen, Balm, Birch, Pine, Maple, Tamarack, Ash	OSB (Temporary shutdown 9/06)
Louisiana-Pacific Two Harbors	Aspen , Balm, Birch	OSB – engineered siding panel
Northwood Panelboard Bemidji	Aspen, Balm, Birch, Maple	OSB
Ainsworth Engineered USA Bemidji	Aspen, Balm, Birch, Pine, Maple, Tamarack, Ash	OSB (One closed 8/06, one line still operating)
Ainsworth Engineered USA Cook	Aspen, Balm, Birch, Pine, Maple, Tamarack, Ash	OSB (Temporary shutdown 9/06)
Trus Joist - a Weyerhaeuser Business Deerwood	Aspen, Balm, Birch	Engineered lumber products for industrial and structural applications

Assuming that the Ainsworth plant at Grand Rapids resumes operations in the future, the total timber demand of Minnesota’s mills is expected to be 4.2 million cords annually (Governor’s Task Force Report, 2006). However, not all of this demand is satisfied by in-state harvest and the industry is dependent to some degree on fiber imported from neighboring states and Canada. The Department of Natural Resources publishes a report of annual statewide harvest levels, prices and timber availability by species. The 2006 publication of “Minnesota’s Timber Resources” indicates that approximately 3.6 million cords are harvested in the state including pulpwood, sawtimber and fuelwood. Of this total, slightly less than 2.9 million cords, or eighty percent is pulpwood. Given the fact that mill demand exceeds in-state supply by approximately 600,000 cords, this amount is assumed to be imported from other states and Canada. As energy markets develop, it is highly possible that imported fiber may be more difficult to obtain due to high demand for timber in areas that currently ship fiber to Minnesota. As a result, mills may be more reliant on locally produced timber in the future.

Emerging opportunities in the area of energy production have the potential to complement and possibly compete with the current forest products industry. Wood resources are finite and prices and competitiveness of segments of the industry can be affected by the level of competition for raw material. The recent history of wood prices in Minnesota is a clear demonstration of the interaction of supply and demand and potential to affect the industry. For example, average stumpage prices have ranged from a low of $30.00 to a high of $60.00 during the period 2000-2005 (Minnesota Department of Natural Resources, 2006, Figure 2). If markets for forest products remain high and stable, profit margins will be sufficient to allow the industry to pay high prices for raw material and maintain competitiveness nationally and globally. However, this has not been the case and market prices for raw material and products can fluctuate widely. Over the past four years, prices for oriented strandboard in the northcentral region have ranged from $150.00 to over $400.00 per thousand square feet on a 7/16” basis (Figure 1, RISI 2000-2006). Recently, the combination of historically low prices for oriented strandboard coupled with high timber prices have led to a contraction in the industry. Consideration of any new industrial expansion in the forest products industry, be it wood products or energy, must take into account the current industry and the capacity to supply sufficient amounts of raw material at prices that allow the existing and proposed new industry to produce a profit and remain viable in the long term.

Although there is potential for competition for resource in the emerging energy industry, synergies are also possible. Many paper mills in the state are biorefineries in one sense and new markets may provide additional opportunities to expand the mix of products being manufactured, diversify the product mix and contribute to greater stability of the industry. In particular, gasification of black liquor and opportunities to add value through the production of liquid fuels has potential immediate application.

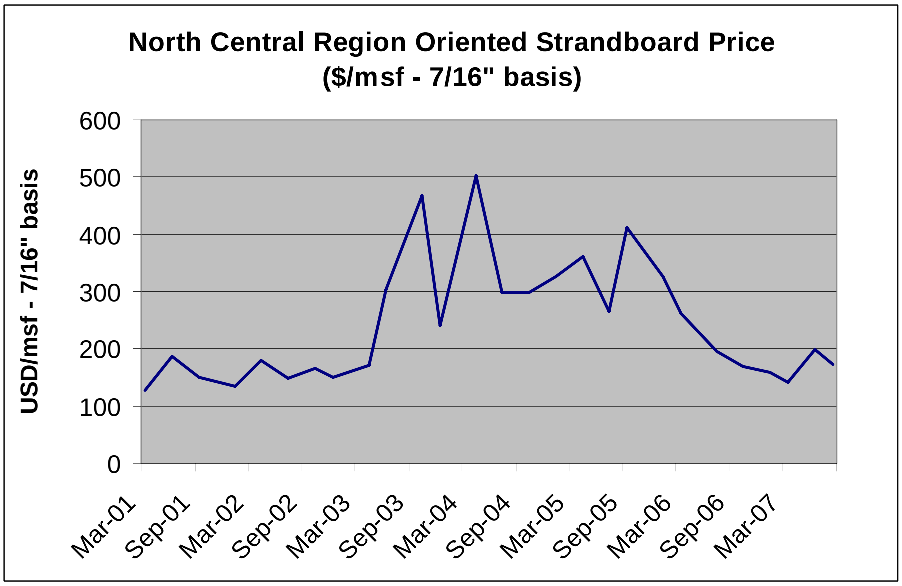


Figure 1. OSB prices - 2001-2007 (source: Crow's Reports)

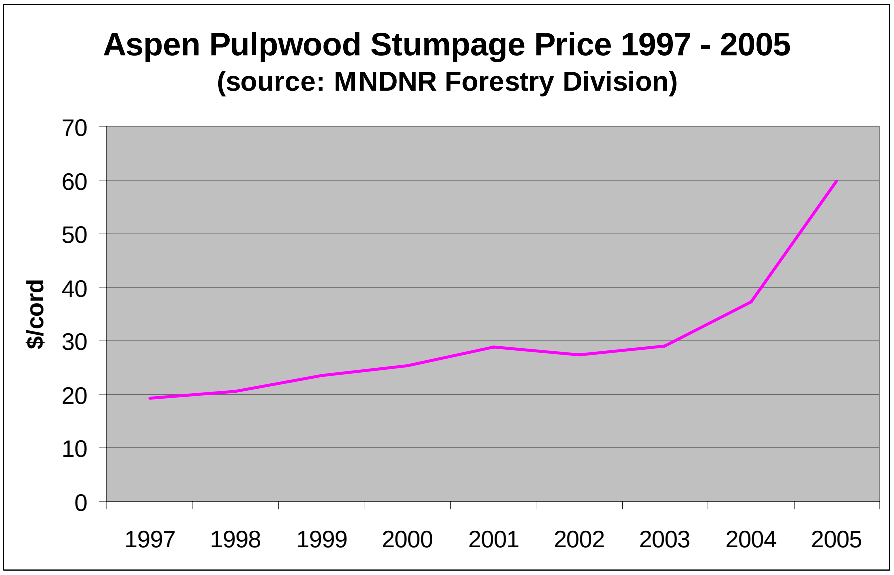


Figure 2. Historical aspen stumpage price (source: MN DNR, 2006 Forest Resources)

In addition to the forest products mills, instability in the forest products industry directly affects the logging industry. Minnesota's logging contractors employ approximately 3,000 people and the logging industry is a vital part of northern Minnesota's economy

(Minnesota Forest Industries, 2007). Obviously the economic vitality of the area's mills and loggers are directly linked and the recent downturn in the forest products industry has led to an associated reduction in output in the logging industry. Based on recent experience, the willingness of logging contractors and area bankers to invest in expanded logging capacity to supply additional raw material will likely require supply contracts that will ensure that loans on equipment can be paid back within a reasonable time. The logging industry has undergone changes over the past decade with the industry consolidating to larger logging firms accounting for a greater share of the timber production. According to the Blandin Foundation's 2004 report on a survey of the logging industry in the state, sixty percent of the total timber volume was harvested by the largest twenty five percent of the logger operations (Powers, 2004). Thus, any significant expansion of the logging industry, whether for energy or forest products, will likely take place through additional harvest from the largest logging contractors in the state, further consolidating the logging industry.

Minnesota's Forest Resource

Of the total 50.8 million acres of land in Minnesota, 16.2 million acres is forested, 26 million acres is agricultural land and the remainder is urban, water and other land types such as brushland and grassland. Of the 16.2 million acres classified as forestland in the state, slightly more than one million acres are in reserved areas such as the Boundary Waters Canoe Area and not available for commercial timber harvest. The total land area potentially available for timber harvest, referred to as timberland by the FIA, is approximately 14.7 million acres (Miles and Brand, 2007). For purposes of this report, information presented on forest resources is restricted to commercially available timberland as these lands are expected to provide the predominant wood supply in the future. Alternate wood sources such as hybrid poplar plantations on agricultural lands, brushland biomass and thinning opportunities are also discussed below.

Compared to other regions of the country such as the Southeast and Pacific Northwest, the state's forest is characterized by diversity both in terms of species mix and ownership. Minnesota's forestlands are comprised of a wide variety of species types which occur in mixed stands as well as relatively pure-species stands. Prior to settlement, a greater proportion of the forest was in climax forest dominated by longer-living species such as white pine, the source of timber that built the cities of the Midwest. Since that time, harvest of many of these stands has led to reversion to early successional species such as aspen, birch and jack pine. Also, abandonment of land that had been cleared for agriculture has accomplished the same effect of "resetting the successional clock" to early successional species. As a result, the state's forest is a mix of species, age classes and ownership with a blend of early- and late-successional forest types.

Species Composition

Using the Minnesota Department of Natural Resources cover type classifications, Minnesota's forests are comprised of nineteen major forest types (Table 4). Aspen is by far the dominant forest cover occupying about one third of the total forested acreage or

4,849,747 acres, over four times the acreage of the next largest forest type. The criteria for assignment of land to a cover type is based on plurality of stocking of a given tree species. While aspen is a large forest cover type, aspen stands are characterized by a mix of species within these stands. Aspen fiber is highly desirable both for manufacturing of oriented strandboard as well as paper. As a result, of the total pulpwood sold in Minnesota, approximately sixty percent of the volume is aspen. Compared to other tree species, aspen stands are unique in that they regenerate naturally from root sprouts (suckering) and require no replanting and little financial input to reestablish after harvest. This makes aspen attractive both from a silvicultural and financial point of view.

The next largest forest cover types are northern hardwoods with 2,050,457 acres, black spruce with 1,335,033 acres and lowland hardwoods with 1,104,834 acres followed by a mix of other covertypes as shown below.

Table 4. Minnesota's forest cover types, acreage and proportion.

Forest Type-MnDNR	Acreage	Proportion
Total	14,988,760	
Aspen	4,849,747	32%
Balsam fir	393,381	3%
Balsam poplar	464,007	3%
Birch	999,186	7%
Black spruce	1,335,033	9%
Cottonwood / Willow	107,074	1%
Eastern redcedar	25,623	<1%
Eastern white pine	151,107	1%
Jack pine	356,355	2%
Lowland hardwoods	1,104,834	7%
Non stocked	228,235	2%
Northern hardwoods	2,050,457	14%
Northern white-cedar	571,915	4%
Oak	724,512	5%
Other	79,694	1%
Other softwoods	5,665	<1%
Red pine	562,656	4%
Tamarack	868,215	6%
White spruce	111,063	1%

Land Ownership Patterns

In contrast to the southeastern U.S. where a large proportion of land is owned and managed by the timber industry, Minnesota’s forests are owned by a broad range of entities ranging from non-industrial private landowners (NIPF) to public land management agencies such as the Minnesota Department of Natural Resources, counties and the US Forest Service (Fig. 3). NIPF lands are usually held for a multiplicity of uses including hunting, recreation as well as timber production. As a result of this diverse ownership pattern, procurement of timber for the state's mills involves a very active program working with different agencies with varying purposes for their land and policies affecting management. Some landowners, such as public agencies, are actively managing their lands for multiple benefits and timber sales are an integral part of the overall forest management program. NIPF landowners may be involved in forest management organizations such as the Minnesota Forestry Association or have assistance of professional forester but this is not always the case. Diversity in land ownership is important from a timber availability standpoint because it has a direct effect on the proportion of timber resources potentially available for harvest and the rate that timber is brought to market.

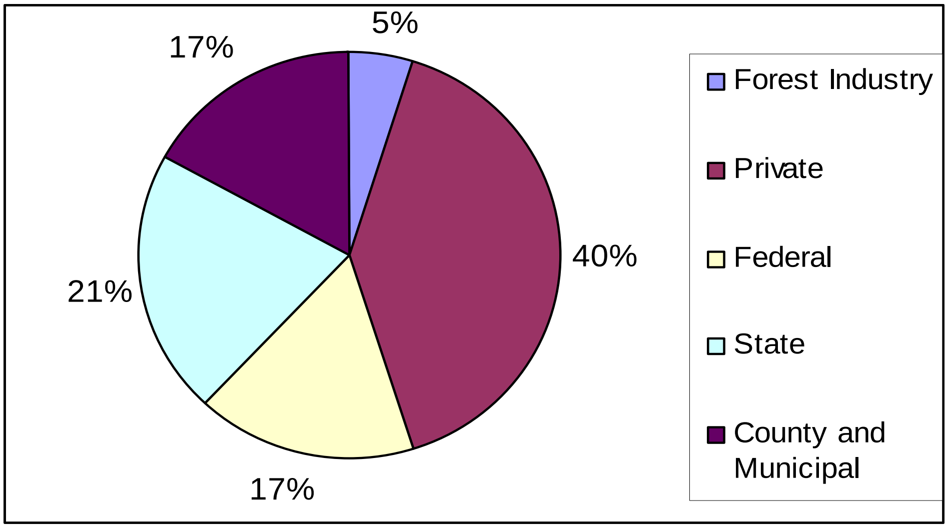


Figure 3. Ownership of forestland in Minnesota.

Land ownership affects the process by which timber is sold. Public land agencies identify stands that are ready for harvest using geographic information systems and inventory data. Once stands are identified for harvest, a forester will conduct a cruise of the stand volume using a "cruise course", a set of points within the stand where data on timber volume and species composition are collected. Using this information, the stands are put up for sale to the public, either through sealed bids or oral auction. Thus, the stumpage price will fluctuate depending on demand by mills, sometimes quite dramatically as shown above. Sale of timber volume on private lands, a significant portion of the land base, is not as formalized as sales on public lands. A landowner may be contacted by a local logger or forester and the negotiation of price is done between the landowner and the forester or logger. Thus, the process of locating stands for harvest, determining stand volume and stand value can differ depending on the land owner.

Growth and Expected Allowable Harvests

The central question related to evaluating future opportunities for development of a next-generation, wood-based energy industry is wood supply. According to the USDA-FIA Inventory (Miles and Brand, 2007), the total net annual growth of the state's forests on timberland acreage is approximately 7.0 million cords. This value includes in it the volume that is lost to mortality, estimated to be 3.8 million cords. Taken together, a combination of net growth and some portion of annual mortality represents the biological potential of available forest lands and does not take into account practices employed to accommodate other forest values such as wildlife, water quality and long term soil productivity. In 1990, in response to a citizen petition, the State of Minnesota, Environmental Quality Board commissioned a large scale study of the state's forests entitled the Generic Environmental Impact Statement (GEIS) on Forestry (Jaakko Poyry Consulting, 1994). The purpose of the GEIS was to evaluate the interaction of timber harvesting and environmental impacts on the state's forests. The GEIS on Forestry is one of the largest undertakings of its kind in the nation and serves as a model to other states.

The GEIS considered the impact of forest harvesting on environmental values at several harvest levels and recommend mitigation strategies to reduce environmental impacts. The harvest levels chosen were intended to approximate the current annual harvest level as of 1990 (4.0 million cords), expected near-term harvest levels anticipated in 1995 (4.9 million cords) and a maximum harvest level of 7.0 million cords (FIA total net growth). In addition, mitigation strategies such as extended rotation forestry, riparian buffers and uneven aged management were included in harvest simulations to estimate the effect of implementing these strategies on timber supply. This analysis was done at the FIA plot-level to allow summarization of impacts and harvest levels by forest cover type and ownership within seven major ecoregions over time.

Criteria for assessing impacts on wildlife species were based on a maximum of 25% change in a species' habitat within any of the seven ecoregions. In addition, for those species considered threatened or endangered, a maximum allowable threshold for habitat change in any ecoregion was 5%. The results of this effort, in addition to many useful background products, was an estimate of the sustainable harvest level for the state and strategies to maintain the health of forest ecosystems over the long term. Based on the GEIS analysis, the maximum harvest level that may be sustained while maintaining ecological values is estimated to be 5.5 million cords. It should be noted that this value is assuming implementation of mitigation strategies to the level assumed in the GEIS.

A followup study entitled the GEIS Report Card (Kilgore, et.al. 2005) was published to evaluate changes in harvest levels, wildlife populations, old-growth forests and application of mitigation strategies since completion of the GEIS. This report identified several changes or sources of variance from that predicted by the GEIS. First, harvest levels were found to be slightly lower than expected. Bird populations fluctuate widely with some species showing unexpected increases and some showing unexpected decreases with a net decrease in habitat for 10 of the total 136 species included in the study. The area of old forest did not increase as much as expected due to a greater amount of acreage undergoing mortality than originally assumed. Little change in designated old growth forest was noted due to changes in management of a portion of forestland managed by the Department of Natural Resources. Finally, a survey of land managers indicated widespread adoption of Best Management Practices on forestlands. Given the overall agreement of the Report Card report with conditions predicted by the GEIS, the potential harvest value of 5.5 million cords will be assumed to be a sustainable harvest level for purposes of this analysis. Related to this, the Governor's Task Force on the Competitiveness of the Forest Products Industry (Governor's Task Force on the Competitiveness of Minnesota's Primary Forest Products Industry, 2007) recommended that the annual harvest level of 5.5 million cords be a goal for the state's forests.

Estimate of Available Timber Supply

Beginning with a total sustainable harvest level of 5.5 million cords from forestlands in Minnesota and assuming that imported fiber will not be available in the future; subtracting the current demand of the forest products industry of 4.2 million cords produces an estimated 1.3 million cords potentially available annually. This is the maximum sustainable amount potentially available for industrial expansion. In addition, identification of high-risk stands and thinning may capture a portion of the estimated 3.5 million cords lost to mortality each year. An analysis of mortality by covertype and age class using the USDA-FIA Mapmaker Program shows that approximately seventy percent of the total mortality occurs in stands older than fifty years of age. This suggests that the bulk of mortality would be captured through identification of stands at risk for pathogenic mortality losses.

Additional Biomass Sources

Red Pine Thinning

Based on analysis of the FIA data, thinning of stands to capture competition-induced mortality (mortality in stands less than 50 years of age) could account for a maximum of thirty percent of the total mortality loss reported in the FIA inventory. Thinning of Red Pine and Aspen stands could contribute additional harvest volume assuming the price for thinning products and harvesting technology make thinning of these stands economically feasible. Of the total 245,000 acres of Red Pine plantations in the state, slightly more than half are less than age thirty and a large amount of acreage will be ready for first thinning over the next decade (Fig. 4). Current annual harvest of Red Pine is approximately 160,000 cords compared to a short term allowable harvest of 270,000 cords annually. As stands age and become ready for first thinning, the average annual harvest could rise to 356,000 cords, or 409,000 dry tons by 2012 and increase annually thereafter (Minnesota DNR, 2006). Based on our experience, about half of this volume is small-diameter sawbolts with the remaining half being pulpwood. Compared to current harvest levels, Red Pine thinning could supply an additional 225,000 dry tons annually including all products.

Markets for Red Pine pulpwood are soft which limit opportunities to thin plantations at this time. Because care must be taken to avoid damage to the stand, productivity of a logging operation is reduced which decreases the value of volume from thinnings. A critical factor in first-thinning of Red Pine is the amount and size of material that can be removed while still maintaining the proper number and quality of trees to maintain value in the future. For example, if a greater proportion of the larger, more valuable sawbolt-sized trees can be removed at the first thinning without impacting the future value of the stand, greater value can be extracted which offsets the cost of handling smaller diameter material that is an inevitable part of harvested volume, particularly in the first thinnings. In contrast, if only lower-valued pulpwood is able to be removed, the financial returns to the logger and landowner are reduced which limits opportunities to practice first thinning in a timely manner. Research is underway by the NRRI under the auspices of the Minnesota Forest Productivity Research Cooperative to determine the optimal mix of residual stand volume and stem size distribution for first-thinning of Red Pine plantations to maximize value to the landowner.

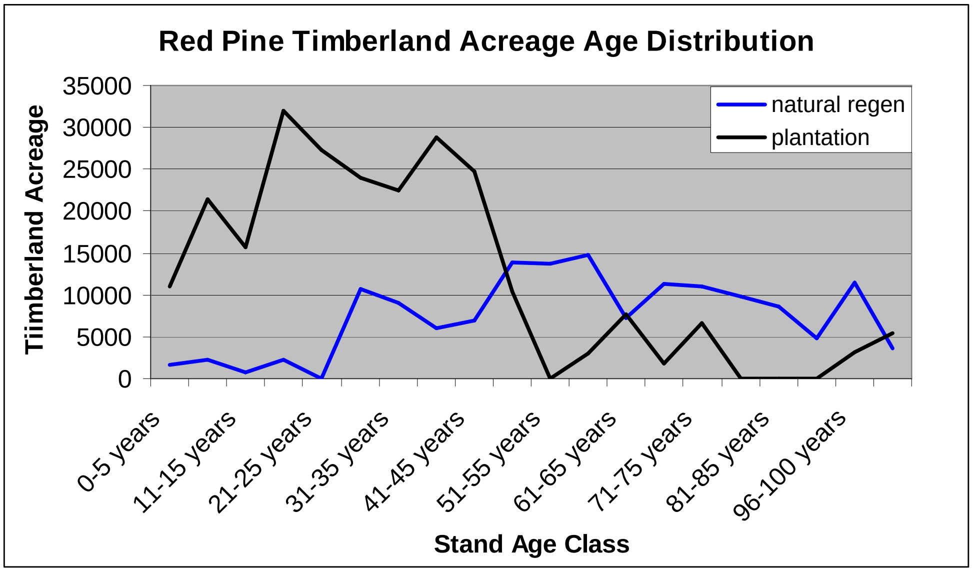


Figure 4. Age class of Red Pine timberland acreage - natural regeneration and plantations.

<u>Aspen Thinning</u>

After harvest, aspen stands are unique in that they naturally regenerate from root suckers with a very high stem density, often achieving 10,000 stems per acre. This is compared to an ultimate harvest stem number of 400 to 600 trees per acre (Fig.5). During the early stages of stand growth, stands undergo high mortality due to competition-induced effects. It may be possible to capture some of this mortality through precommercial thinning. The UM-NRRI has been involved in strip-thinning studies of aspen since 1989 and has developed a dataset of stand growth since thinning. Stands were strip-thinned at age ten to fifteen removing two-thirds of the stand basal area using skidders and bulldozers. No difference in overall stand basal area has been found after sixteen years post-thinning with thinning having the effect of changing stem-size distribution to larger tree size in thinned stands. Larger average tree size increases the recovery rate of merchantable volume depending on the top-diameter specification used by mills. The average stand biomass on sites at the time of thinning is estimated to be fifteen ovendry tons per acre. Removing two-thirds of the stand could yield ten tons per acre of small-diameter biomass material. If all of the aspen acreage were harvested on a fifty year average rotation, approximately 100,000 acres could be thinned annually for a total statewide biomass potential of one million dry tons. This is obviously the maximum amount potentially available. Also, it may be possible to thin older stands, age 20 to 30, to recover a portion of stand mortality. However, the impact of later thinning on final harvest volumes and rotation ages needs to be better understood. The technical, economic and ecological feasibility of precommercial and commercial aspen thinning and the optimum age to conduct thinning needs to be addressed before aspen thinning can be considered a viable source of biomass for energy applications.

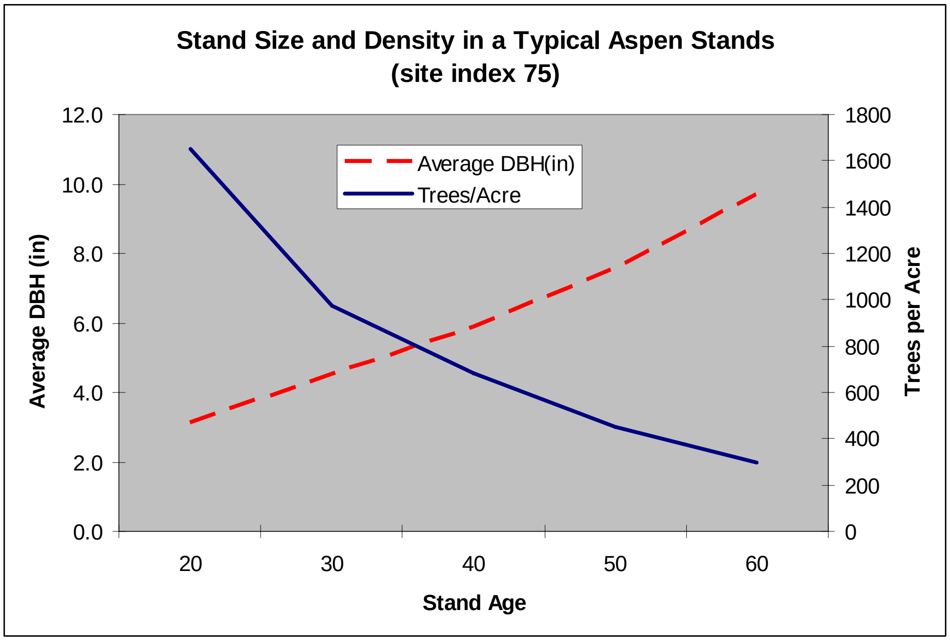


Figure 5. Average tree size and trees per acre over time in normally-stocked aspen stands.

Brushlands

In addition to native forests, brushlands could supply additional biomass for energy production. Opportunities exist to shear brushland areas both for biomass harvest and habitat improvement for sharptail grouse. Using satellite classification (adjusted GAP level 3), Minnesota’s brushland acreage totals approximately 2.4 million acres. Brushland sites are extremely variable in stand density and uniformity and, as such, estimation of the total amount of biomass on these sites is inexact. A method is needed to efficiently classify brushland cover and density before commercial brushland harvesting can be implemented. Because shearing costs are fixed on a per-acre basis, it is necessary to select sites that have a sufficient amount of biomass to distribute fixed costs over a greater amount of biomass, thereby minimizing per-ton shearing costs. Research to identify high-density sites is beginning under a cooperative project between the MN-DNR Forestry Division and the NRRI.

At this time, costs of shearing and grinding are known or can be estimated with reasonable certainty. However, the unknown cost factor in brushland harvesting is the cost of collecting sheared material. Shrub biomass is left in windrows as a result of the shearing operation. A mechanism is needed to efficiently collect this biomass and transport it to a chipper or grinder near a roadside. Tests of a modified forwarder designed to carry low-density biomass are planned for this year under a project funded by the DOE through the Laurentian Energy Authority.

The NRRI conducted a study in 1997 to evaluate the biomass density and productivity of brushland acreage in Minnesota. This study involved biomass surveys and estimated brush biomass on 16 study sites. The average brushland density for the 16 study sites is 13.2 dry tons per acre. After adjustment for non-stocked area, this value decreases to 4.2 dry tons/acre. The annual increment of the fully-stocked areas within the brushland complex is approximately 1.5 tons/acre/year. Assuming a biomass density of eight dry tons per acre (e.g. sixteen green tons/acre) is the economic threshold for brushland harvesting and that 20% of brushlands meet this criterion, the total amount of standing biomass is estimated at 3.7 million green tons. Also, based on a mean annual increment of 1.5 dry tons per acre per year, the annual production of brushlands statewide is estimated to be 400,000 dry tons per year. However, questions remain regarding identifying high-density sites, biomass amounts and costs of forwarding biomass material to a landing.

Hybrid Poplar on Agricultural Lands

Analyses of national biomass resources such as the “Billion Ton Study” (Perlack, et.al. 2005) indicate that agricultural residues (e.g. corn stover, wheat straw, other plant parts), forest harvest residues and thinnings, and energy crops are expected to be the dominant sources of available cellulosic feedstock. Of the total 1.4 billion tons identified in the Billion Ton Study, approximately one fourth (377 million dry tons) is expected to be produced annually through planting of energy crops on agricultural lands currently enrolled in the Conservation Reserve Program (CRP). At this time, there are approximately 1.6 million acres of land enrolled in the CRP in Minnesota. Most of this land is slated to be taken out of the CRP over the next three years, depending on provisions in the new Farm Bill.

There are several energy crops that could be considered included trees and grasses. The NRRI has been conducting research on tree energy crops since the early 1980s and manages one of the largest poplar breeding and field-testing programs in the United States. Also, work is underway by a number of groups to evaluate yield and management inputs of grass crops and mixed prairie species (Tilman et.al. 2006, Casler and Boe, 2003). Based on work done by the UM-Crookston, NRRI and the Agricultural Utilization Research Institute over the past decade, yields of poplar plantations on CRP sites in northwestern Minnesota, an area of high CRP enrollment, have been shown to average 3.5 ovendry tons per acre annually. Research is ongoing to better define yields of other energy crops in other areas of the state. Using an average annual yield of 3.5 tons per acre of energy crops, the total potential biomass production of this resource could approach 5.6 million ovendry tons. This resource will require a significant investment to achieve but a portion of wood supply for future energy production could come from energy crops. Work is needed to identify optimum sites, inputs needed and yields of energy crops on a range of site throughout Minnesota.

Forest Harvest Residues

The most immediately available, lowest cost source of wood for energy is residual top and limb material. Forest harvest residues are produced through delimbing and slashing of merchantable trees as a part of the logging operation. Up to this point, most of this material has been left on site due to lack of markets. Demand for harvest residuals from forest products mills producing board products have existed for decades but markets have been limited. With the construction of the biomass burning facilities in St. Paul and the Laurentian Energy Authority project on the Iron Range, demand for energy wood has increased considerably. Also, Minnesota Power is evaluating the feasibility of a 50 megawatt biomass-fired plant at the Syl Laskin location near Hoyt Lakes in northern Minnesota. The Minnesota Power project is partially in response to the recent passage of the 25 X 25 legislation in Minnesota which sets a goal to replace twenty five percent of the coal-fired electrical generation by the year 2025. While this goal will be accomplished through a variety of sources, notably a significant amount of wind power, demand for all forms of biomass will undoubtedly increase. Biomass has advantages as part of the energy mix due to the fact that it can be stored and become a dependable part of the baseload generation capacity of an electrical utility.

Harvesting Systems

The production of forest harvest residues is particularly well suited to conventional logging systems commonly in use in Minnesota today. There are two dominant logging systems in use in Minnesota; conventional and cut-to-length (CTL) systems. According to Minnesota Logger Education Program staff (Dave Chura, personal communication), conventional systems account for eighty eight percent of the timber volume harvested in the state while CTL systems are used to harvest the remaining twelve percent of volume. Conventional logging systems consist of a feller-buncher which falls trees and produces bunches of trees to accommodate skidding. Skidders then move the bunch of trees from the site of felling to a central landing area. Using a stroke delimber or processor, trees can either be delimbed near the site of felling or at the landing, depending on whether the logger wants to process tops and limbs or leave them scattered on site. If the intention of the logger is to collect harvest residues for further processing, the trees are typically skidded in whole-tree form to the landing where delimbing occurs. The main bole is then either loaded onto a truck directly in tree-length form or slashed to 100-inch lengths as shortwood, the most common form delivered to mills in the state. Due to the fact that trees can be felled and skidded to the landing in whole-tree form, there is little additional cost to transporting the tops and limbs to the landing area. However, further processing requires additional chipping or grinding equipment to produce a form of material that is easily transported and handled at the mill. Given the setup of the conventional logging system, production of harvest residues can be integrated into the current logging system with little modification. The issue of producing additional quantities of harvest residues in the future is not the need for different harvesting equipment but more a lack of steady markets to allow a logger to recoup an investment in additional equipment. As markets for energy chips become better established, the logging infrastructure could be expanded to accommodate demand through purchase of additional chippers, grinders and chip vans assuming long-term contracts are made with wood-using facilities.

In contrast to conventional systems, CTL systems buck trees in the woods at the point of felling. The CTL system is generally more flexible than a conventional system with respect to operating conditions and the type of products that can be produced. CTL systems are particularly well suited to produce a wider variety of products, such as longer length sawlog-sized material in those stands having larger diameter, sawlog quality trees. However, because the tops and limbs are severed at the point of felling, the CTL system does not lend itself as easily to collection of forest harvest residues. The residual material must be piled in windrows or piles to allow collection by the forwarder separate from the roundwood. While it is possible to produce harvest residues using the CTL harvesting system, more effort is involved which will likely add to the expense of the residue product.

An important issue for mills using forest harvest residues relates to seasonality of harvest and storage. Chips and ground material have the advantage of being easily handled and transported in vans designed to carry this material. However, storage of chips at a central wood-using facility can become an issue. Due to soil conditions in Minnesota, harvesting occurs most commonly in the winter months with the bulk of volume being produced during that time. The episodic nature of harvesting requires storage of chips or ground material for months to ensure a constant supply. Care must be given to the size of piles to prevent self-heating of piles and potential fires. Also, in most instances forest harvest residues will be delivered at field moisture content, typically fifty percent moisture (green weight basis). High moisture material will reduce the available heat due to losses associated with vaporizing water on combustion. Once chips are in piles, little drying occurs. A potential improvement over the current logging systems may be the development of cost effective bundling technology such as that developed in Scandanavia. However, up to this point, bundlers have been mounted on relatively expensive forwarders to allow collection of biomass material on sites where a CTL system has been used. While this arrangement may have advantages in Scandanavia, it adds additional expense in those instances where collection is done to a central landing such as is the case in conventional logging systems. There appears to be a need to develop cost-effective, trailer mounted bundling systems that could be used to produce bundles suitable for hauling on conventional trailers designed for hauling roundwood. Bundles could be transported to the wood-using facility, stacked and air-dried prior to chipping at a woodyard. In this way, chipping costs could be minimized due to the high utilization rate of a chipper at a woodyard. Research is needed to develop cost-effective bundling technology that is robust enough to handle the coarser type of material produced in Minnesota forests (e.g. hardwood tops and limbs) and withstand the rigors of logging conditions in the state.

Estimate of Forest Harvest Residue Volumes

The amount of biomass available from forest harvest residues is dependent on the species being harvested, top-diameter utilization criteria for roundwood, guidelines to mitigate soil and wildlife concerns as well as the overall amount of timber being harvested in the state. There are a variety of methods used to estimate forest harvest residue amounts ranging from on-site surveys, whole tree biomass measurements and individual-tree biomass estimation equations. Because of the potential impact of assumptions about forest harvest residue availability on the overall future energy industry in the northern part of the state, a review of methods and development of a reasonable estimate of harvest residue percentage is presented.

In a study done by Grigal (2004) as part of analyses associated with the LEA project, he states that crown biomass accounts for 25 and 21 percent of total biomass for hardwoods and conifers, respectively. A large dataset of equations developed on individual trees published by Jenkins (Jenkins et.al. 2004) suggests similar numbers with hardwoods and conifers accounting for 25% and 15%, respectively. These data sources generally agree that biomass of nonmerchantable material is likely to comprise approximately 25 percent of hardwood total biomass and between 15 and 20 percent of merchantable softwood stem biomass. In cooperation with the USDA Forest Service at Rhinelander, we have collected data on biomass components of hybrid poplar in plantations in Minnesota and Wisconsin for many years. While hybrid poplar and aspen are not directly comparable, they are similar in taper. Based on individual biomass of hybrid poplar trees, the average proportion of branch biomass as a percentage of total tree biomass (bole bark and wood + branch bark and wood, without foliage) is 25%. Residues percentage expressed as a proportion of total stem biomass is 33%. Over the past year, we have begun a project to evaluate harvest residue biomass on winter-logged sites with particular emphasis on aspen. The average branch and top biomass percentage using a three inch top limit was found to be 15.3% of the total main bole biomass with a minimum site average of 11% and maximum of 18%. Work is ongoing to expand this dataset. Based on the available individual-tree data, the average residue percentage value is approximately 25% with a minimum value for aspen of 15% assuming pure-aspen stands. In reality, stand-level residue percentages will be higher due to the hardwood component present in most aspen cover types having higher residue percentages. As an aside, conversations with loggers indicate that the 15% value is not uncommon in relatively pure aspen stands based on their experience of shipping one to two loads of chips per day producing 100 cords of roundwood per day on these sites.

The most extensive and recent study of stand-level residue amounts was done by the Minnesota Department of Natural Resources entitled the “Minnesota Logged Area Residue Analysis” published in August of 2006 and revised in April 2007. This project measured coarse and fine biomass on 124 sites throughout the state and included a range of forest types. The results in terms of cordage per acre of coarse and fine woody material are shown in Table 5 below.

Table 5. Coarse and fine woody debris of forest types from MN DNR Logged Area Analysis study.

Forest Cover	Coarse and Fine Woody Debris (cords/acre)	Coarse and Fine Woody Debris Biomass (green tons/ac)
Aspen	5.7	12.8
Other Hardwoods	7.54	19.2
Lowland Conifers	4.3	9.5
Upland Conifers	4.71	10.9
Unknown	6.12	13.8

While the data produced in the Logged Area Analysis study is very helpful and the best data of its kind available, a limitation to application of these data is the lack of information on stand volumes and amounts of roundwood removed from these sites. Having information on the amount of roundwood removed and stand volumes prior to harvest allows calculation of the percentage of harvest residuals which is necessary to estimate annual production of harvest residues on a statewide basis. Through the cooperation of the Minnesota Department of Natural Resources, Division of Forestry, we were provided an extensive database of sale volumes. This database contains sale data from slightly less than 60,000 acres of timber sales on state lands. Table 6 shows the DNR Cover Type, the Logged Area Analysis grouping, acres and average stand volume for each cover type in the DNR timber sale database. Using a combination of the sale data volumes and the forest harvest residue data from the Logged Area Analysis, I calculated the percent of harvest residues that can be expected to be available from within each of the Logged Area Analysis groupings.

Table 6. DNR timber sale data by cover type, average volume per acre and residue percentages calculated from a combination of sale data and residue volumes.

Cover Type	LAA Group	Acres Sold	Roundwood Cords/Acre	Group Cords/acre Wt.Average	LAA Residue Biomass (cords)	% Residue
Aspen	Aspen	29,041	22.2	22.2	5.7	25.7%
Northern Hardwoods	Hardwoods	545	14.3	16.6	7.54	45.4%
Oak Species	Hardwoods	301	15			
Paper Birch	Hardwoods	8,586	16.8			
Black Spruce	Lowland Conifers	5,189	18.8	17.4	4.3	24.7%
Tamarack	Lowland Conifers	3,362	15.3			
Balsam Fir	Upland Conifers	1,572	15.1	17.2	4.71	27.4%
Jack Pine	Upland Conifers	6,519	21			
Red Pine	Upland Conifers	4,879	12.75			

Another source of similar data is shown in the DNR Summer 2007 Marketplace publication. These data are independent estimates of percentage of harvest residues based on analysis by DNR staff and are a composite of data derived from biomass equations as well as experience (personal communication, George Deegan-DNR Forestry). While there is some difference in specific residue percentages, particularly in the pines, the residue percentages are similar overall and similar to the values discussed above based on individual tree data. Residue percentages for pine types were lower in the DNR Marketplace publication but aspen and hardwoods are in general agreement. In order to produce a conservative estimate of total harvest residues, the DNR Marketplace percentages were used in subsequent analysis. Using the combination of annual harvest data, percentage of harvest residues and cordage conversions, the total amount of residues produced each year can be estimated.

Table 7 shows the estimated timber harvest levels by species group reported by the DNR in the 2006 Forest Resources document, the percentage residues reported by the DNR Marketplace, conversions to estimate green tons from cordage and the resulting estimated amount of residues produced through harvesting of pulpwood and sawlog products.

Table 7. Volumes harvested by major species, residue percentages and estimated residue availability statewide.

	Cords (1,000s) Harvested by Product Type							
Species	Pulpwood	Sawlogs	Residential*	Commercial	Total	%Residue	Cord:gr ton conversion	Residue (gr tons)
Aspen	1794.4	69.6	16.7	0.6	1881.3	25%	2.25	1,058,231
Birch	240.2	27.1	41	6.3	314.6	33%	2.30	238,781
Balm	119.2	1.2	0	0.1	120.5	25%	2.40	72,300
Ash	17.4	8.3	15.1	0.2	41	33%	2.50	33,825
Oak	0.8	73.3	45.1	1	120.2	33%	2.75	109,082
Basswood	24.7	21.6	1.3		47.6	33%	2.30	36,128
Maple	98.9	12.7	15.8	4.7	132.1	33%	2.50	108,983
Cottonwood	0.6	11.6	0		12.2	25%	2.50	7,625
Other Hardwood	3.1	13.8	8.1		25	33%	2.50	20,625
Red Pine	46.4	114.7	2.9		164	11%	2.35	42,394
White Pine	2.4	7.6	1.4		11.4	11%	2.20	2,759
Jack Pine	155.9	147.7	1.7		305.3	11%	2.30	77,241
Spruce	164.5	18.4	0		182.9	23%	2.10	88,341
Balsam	167.1	7.2	0		174.3	23%	2.35	94,209
Tamarack	39.7	1.8	0.7		42.2	11%	2.50	11,605
Cedar	0.2	6.6	0.4		7.2	23%	1.45	2,401
Other Softwood	0.1	1.1	0		1.2	23%	2.20	607
Total Hardwood	2299.3	239.2	143.1	12.9	2694.5			
Total Softwood	576.3	305.1	7.1	0	888.5			
Total All Species	2875.6	544.3	150.2	12.9	3583			2,005,137

From the above table, the total biomass produced annually is estimated to be roughly two million green tons or one million dry tons at 50% moisture content (green weight basis). The ratio of green tons of harvest residues to the overall cordwood volume is 0.56 (2,005,137 green tons divided by 3,583,000 cords harvested). Assuming the same species mix is harvested in the future, this ratio can be applied to the maximum cordage harvest level of 5.5 million cords to estimate potentially available harvest residues assuming future harvest should approach the 5.5 million cord level. The estimated amount of harvest residues associated with this level of harvesting is 1,540,000 dry tons of forest harvest residues. This value must be reduced to account for mitigation of environmental effects. For purposes of this analysis, I have used a 25% reduction to account for management guidelines. Therefore, a more realistic maximum value is closer to 1,155,000 dry tons of harvest residues potentially available in the future.

Using a weighted average conversion of cordwood to dry tons of 1.15 (2.3 green tons/cord at 50% moisture content on a green-weight basis) and 1.3 million additional cords of roundwood potentially available yields a value of 1,495,000 dry tons of additional roundwood biomass. Taken together, the total amount of forest harvest residues and additional roundwood volume is approximately 2.7 million dry tons.

As mentioned above, demand for harvest residues has increased in the recent past and could increase significantly in the near future. At this time the total estimated demand for forest harvest residues is not known precisely and is a subject of current work being done by the DNR-Forestry Division (personal communication, Keith Jacobsen). Including current annual demand by the Laurentian Energy Authority of 125,000 dry tons, the proposed Minnesota Power project of 250,000 dry tons and an estimate of other demand at 150,000 dry tons per year (includes current Minnesota Power plants, St. Paul District Energy, SAPPI-Cloquet, Georgia Pacific-Duluth), the total near-term demand could exceed 500,000 dry tons, again assuming the proposed Minnesota Power project were to go forward. Using the above value of 1.15 million dry tons of harvest residues associated with an annual harvest level of 5.5 million cords of roundwood, the foreseeable demand could account for half of the potentially available residue material. If harvest levels were to remain at 3.7 million cords annually, the total amount of harvest residues produced in the near term is closer to 750,000 tons, accounting for a 25% reduction due to environmental mitigation practices. Based on this analysis, the potential exists to use a significant amount of available harvest residues in the near term with a maximum long term available amount of 250,000 to 500,000 dry tons left unused.

In summary, Table 8 shows biomass sources identified with estimated biomass values expressed in ovendry tons available annually.

Table 8. Estimated annual biomass availability in Minnesota currently, in the near term and future potential by source.

Biomass Source	Current	Near-Term Achievable	Future Potential	Notes
	dry tons/yr	dry tons	dry tons	
Roundwood	0	1,495,000	1,495,000	current: 3.7 million cord harvest, future 5.5 million cord harvest
Harvest Residues	750,000	1,155,000	1,155,000	residues from 3.7 million cord harvest, 5.5 million cord harvest
Red Pine Thinning	184,000	310,500	409,400	50% of total volume in first thinning assumed fuelwood
Aspen Thinning	0	0	1,000,000	100,000 acres @ 10 tons/acre
Brushlands	0	400,000	400,000	
Energy Crops	0	0	5,600,000	3.5 tons/acre/year yield, 1.6 million acres
Total	**934,000**	**3,360,500**	**10,059,400**	

Potential Energy Demand

In order to put timber demand and supply figures into context, it is instructive to consider the potential size of the biomass industry. While this subject has been visited by authors in a companion paper, it bears repeating. About 400 million gallons of gasoline are consumed daily in the United States (http://tonto.eia.doe.gov/oog/info/twip/twip_gasoline.html). Based on a national average per capita consumption rate of 1.3 gallons per day, the total demand for gasoline in Minnesota can be estimated to be approximately 2.4 billion gallons per year. Assuming an average ethanol conversion rate of 90 gallons per ovendry ton of biomass and a 15% reduction in mileage with ethanol, the potential demand for fuel with complete replacement of gasoline in the state would require roughly 32 million ovendry tons of biomass annually. In addition, coal burning plants in Minnesota have 6 gigawatts of power generation capacity with an estimated coal consumption of approximately 30 million tons (www.powerofcoal.com). The combined potential energy demand assuming 100% replacement of gasoline and coal is approximately 60 million dry tons annually. Obviously, 100% replacement of the state's energy needs is not going to occur anytime soon but it is instructive to consider the sheer volume of biomass that would be required. Even assuming a 20% replacement target, the amount of ovendry biomass required would be 12 million tons annually, roughly four times the estimated combined total amount of 2.7 million dry tons of potentially available roundwood and harvest residues. Although a significant amount of biomass is available in the agricultural sector in the form of crop residues (e.g. corn stalks, cobs, wheat straw, etc.), future demand for energy has the potential to dwarf the current total wood usage by the timber industry.

An Estimate of the Economics of Cellulosic Ethanol

Estimation of the total woody biomass amounts available and potential demand is a part of the picture. However, this information doesn't provide insight into the potential for application of new energy technologies using wood. Market demand for alternate fuels and price will ultimately determine the rate at which emerging energy technologies will be adopted and opportunities for development of the industry in the state. In order to provide some context in this regard, a brief review of available technologies and the estimated cost of production is needed. While the technology to produce liquid fuels is in a state of flux and commercial application may be several years away, it is instructive to look at the expected input costs and estimated breakeven price of ethanol produced in a theoretical cellulosic ethanol plant.

The field of liquid fuels production, particularly cellulosic ethanol, is receiving unprecedented attention. The President, in his most recent State of the Union speech emphasized the need for the United States to develop alternate sources of energy both from a standpoint of energy security and reduction of carbon dioxide emissions. The U.S. Department of Energy, in order to accelerate commercial development is supporting fundamental research at the national laboratories and universities as well as commercial scale-up of technologies to produce ethanol from cellulose on a large scale. Two primary pathways are envisioned for production of cellulosic ethanol; biochemical and thermochemical. The biochemical route relies on pretreatment and fermentation using specially developed enzymes and genetically modified yeasts to break down cellulose and hemicellulose into simpler sugars and, ultimately, to ethanol. Companies such as Iogen and Mascoma are examples of companies employing this method. The thermochemical process involves gasification of material and conversion of the synthesis gas to liquid fuels using catalytic conversion, commonly referred to as the "Fischer-Tropsch" process. Range Fuels is one such company scaling up the thermochemical process for the production of ethanol.

These processes differ in fundamental ways and feedstock requirements have an effect on the efficiency of the specific process being used. The biochemical pathway is more sensitive to feedstock than the thermochemical process. For example, bark is not amenable to conversion in the biochemical process, at least not using current technology (personal communication, Andy Aden – NREL). Also, terpenes present in pines can inhibit the fermentation process and, as such, deciduous trees or grasses are the desired feedstock for the biochemical route. In contrast, the thermochemical pathway is more robust and can use a wide variety of material. Even relatively wet materials such as green wood can be used because sufficient waste heat from the gasifier is available to dry the wood prior to gasification (Phillips et.al. 2006). In light of the greater flexibility of the thermochemical process, the thermochemical route was chosen for this analysis.

The National Renewable Energy Laboratory (NREL) at Golden, Colorado operates pilot plants to facilitate scale-up of both cellulosic ethanol production pathways. The NREL has recently published assessments of both pathways including detailed engineering, process flow diagrams and economic evaluation of the biochemical and thermochemical routes. Most recently, Phillips, et.al. (2007) published an analysis of the thermochemical route including computer modeling of the process and an economic assessment of the cost components that contribute to the final breakeven price. While the reader is encouraged to review this document in its entirety, the analysis presented here will concentrate on the breakdown of costs and implications to future wood-based ethanol production using the financial information shown in Appendix A of this report (Appendix F in the Phillips-NREL report).

Appendix A shows a detailed breakdown of cost components from the NREL report including capital, operating expense, feedstock purchase and other items. In this case, wood is assumed to be the feedstock used in the process. Among many assumptions too numerous to mention, the base case used in the economic analysis includes a $35.00 per ovendry ton feedstock cost. This analysis assumes an ethanol yield of 80.1 gallons per ton and an additional 14 gallons of higher-chain alcohols. While this yield level is not currently realized, expectations are that research will make this possible in the next five years. In conversation with representatives of Range Fuels (Patrick Wright, Range Fuels), the target conversion rate in their plants is 100 gallons of ethanol and 20 gallons of mixed alcohols, significantly higher than the assumed conversion rate in the NREL report. Using the assumptions outlined in the report, the base case economic analysis calculates a breakeven ethanol price of $1.01 per gallon FOB plant gate. While economic analysis of early-stage technology is fraught with uncertainty, this analysis helps to put the current best estimates of costs and operating parameters into a framework in which cost components can be identified and the relative effect on ultimate production price more easily understood.

As mentioned, the assumed feedstock cost in the base case is set at $35.00 per ton. This is a very low value compared to wood in Minnesota. Even if corn stover were assumed to be the feedstock, it is my opinion that the feedstock cost is too low. For purposes of this analysis, I'm assuming a delivered green chip price of $24.00 per green ton ($48.00 per ovendry ton) and a roundwood value of $80.00 per cord ($69.56 per ovendry ton) for mixed species. Actual delivered price will vary widely depending on location, species and form of the product but these prices are more in line with current local markets (personal communication, Keith Jacobsen, MN DNR). Using the NREL sensitivity analysis, the contribution of feedstock cost at $35.00 per ton to the end-product ethanol cost is $0.44 per gallon, slightly less than half of the overall per-gallon ethanol production cost. This translates to a $0.012 increase in production cost for every dollar of feedstock. Using this value, the breakeven cost per gallon of ethanol is estimated to be $1.17 and $1.44 using chips and roundwood feedstock, respectively, an average of $1.30 per gallon.

The next logical question is, can ethanol compete at these prices? In order to answer that question, a review of the components of gasoline pump price is needed. The price paid at the pump for gasoline includes the price of crude oil, refining, taxes and distribution. These components are shown in Figure 5 below. After removing taxes and distribution costs, the cost of crude oil and refining is $2.23 per gallon based on a pump price of $2.97 per gallon. Ethanol contains approximately 60% of the energy content of gasoline (75,700 BTU/gallon versus 124,000 for gasoline). However, engines designed to burn ethanol will likely get higher mileage than energy content alone would suggest due to the higher octane of ethanol and opportunities to modify engines to take advantage of higher-octane fuels. For purposes of this analysis, I've assumed that the mileage of ethanol-fueled vehicles will be reduced by 15% per gallon compared to an internal combustion engine using gasoline. At a gasoline value of $2.23 per gallon, the mileage-adjusted value of ethanol is $1.89 per gallon.

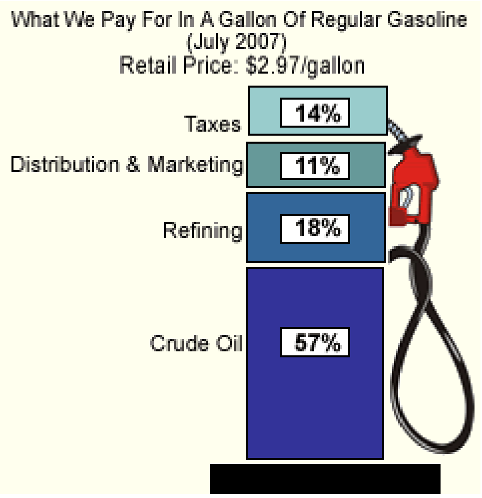


Figure 6. Breakdown of components of gasoline pump price (source: USDOE-EIA)

Based on an average breakeven price of $1.30 for wood-based ethanol cited above, it appears that it is possible to compete with gasoline at the current mileage-adjusted price of $1.89. This analysis suggests that it may even be possible to compete with current gasoline price using higher-valued roundwood at an estimated price of $1.44 per gallon. Obviously, many assumptions about production prices and processes were made in this analysis. The current state of the technology is not advanced to the point that is assumed in the NREL analysis. However, technology improvements, namely ethanol yield such as that expected by Range Fuels (100 gallons of ethanol per dry ton), could significantly reduce the breakeven price to a value lower than that assumed by NREL (80.1 gallons of ethanol per dry ton), the foundation of this analysis. The recent commercial scale-up of ethanol production technologies will help refine cost estimates and reliability of conversion technology.

Assuming a size of plant suggested in the NREL study, the biomass required annually would be 850,000 dry tons. The total estimated available biomass of roundwood and residues statewide is 2.7 million dry tons (5.4 million green tons), approximately enough for three plants of the size suggested in the NREL report. Each plant is assumed to require 54 employees including management and shift workers. Given this level of employment, the bulk of additional jobs will likely be in the logging infrastructure to support these plants and not in the plants themselves. Assuming an average harvesting rate of 100 cords per day, the total amount of 1.3 million additional roundwood would result in an additional 13,000 operating-days per year, approximately 70 additional logging operations. This does not include processing of harvest residues. Additional employment would be required to harvest and process forest residues.

My observation of the process of research and development of technology raises a concern over the future availability of improved technology. Most of the work being done at the NREL is being done under cooperative agreements with larger companies under confidential arrangements. The current model of the starch-based ethanol industry is a high proportion of local ownership located in rural Minnesota. The technology to hydrolyze and ferment corn to ethanol is well developed and not characterized by highly proprietary technology. However, new processes in cellulosic ethanol technology are based on highly confidential technology. There is a risk that, unless advanced technology is developed by universities and made publicly available, the model of local ownership of production facilities may not be possible in the future cellulosic ethanol industry. The development of catalysts in the thermochemical process is an area of need to allow smaller-scale production of ethanol by independent, locally-owned producers.

A Final Observation - Electric-Based Transportation

A potentially disruptive transportation technology could be electric vehicles. Plug-in electric vehicles have existed for over a decade with a relatively long track record of operation. Two such vehicles, the General Motors EV1 and Toyota RAV4-EV have demonstrated continued on-highway operation typically achieving mileage of 4 miles per kilowatt-hour (Boschert, 2006). Using an electric rate of $0.08 per kilowatt-hour, the fuel cost is $0.02 per mile. By comparison, an internal combustion engine using gasoline at 30 miles per gallon and $3.00 per gallon will cost $0.10 per mile, roughly five times more than an electric vehicle. Adjusting electric vehicles to account for road taxes would add another $0.013 per mile to electric transportation for a total of 3.3 cents per mile ($0.40 per gallon federal and state tax combined), roughly one third the per-mile driving cost of an internal combustion engine using gasoline. Assuming battery technology is developed to allow plug-in vehicles to be competitively priced, plug-in electric vehicles could become a significant mode of transportation in the future.

Energy independence and carbon-neutral transportation are stated goals of domestic energy policy and technologies that make the most efficient use of the biomass resources will likely be favored. Table 9 shows a comparison of transportation based on cellulosic ethanol-fueled vehicles versus electrically-based transportation. Comparing a 30 mile-per-gallon gasoline mileage vehicle (25.5 mpg running on ethanol) to an electric vehicle shows that electric vehicles could be driven roughly 2.5 times farther than an ethanol-fueled vehicle. The production and distribution network for electricity obviously exists. If biomass-fueled power plants were to become more commonplace in the future, electric vehicles could be a very efficient, carbon neutral means of transportation.

Table 9. Comparison of mileage driven per ton of biomass processed between an ethanol-fueled internal combustion engine versus electrically driven vehicle.

Cellulosic Ethanol-Fueled Vehicle		
Biomass Input (ton)	1	oven dry ton of biomass
Conversion Efficiency	100	gallons ethanol per oven dry ton (future)
Vehicle Mileage (gasoline)	30	mpg-vehicle using gasoline
Ethanol Mileage	25.5	15% deduction for reduced energy
Miles Driven	2550	miles driven per oven dry ton
Plug-In Electric Vehicle		
Biomass Input (ton)	1	oven dry ton of biomass
Conversion Efficiency	0.33	conversion efficiency biomass-to-electricity
Electricity Produced	1,643	kwh produced per ton of biomass
Vehicle Mileage	4	miles per kwh
Miles Driven	6572	miles driven per oven dry ton
	2.58	ratio of electric vehicles to ethanol-powered vehicles

Conclusion

While there is uncertainty about the rate of oil depletion and global reserves of fossil fuels, there is no doubt that demand for alternate energy will increase. In particular, the development of new means of transportation, whether liquid-fueled or electrically-driven, will result in jobs and economic growth in forested and agricultural areas having available biomass. New jobs and economic growth will be created in the fields of biomass production, collection, conversion and distribution. Biomass sources including roundwood, forest harvest residues, forest thinnings, brushlands and energy crops could provide a significant amount of woody biomass to be used as feedstock to produce alternate energy in Minnesota, possibly enough for three additional wood-based plants using current supplies of timber from the forest land base. Additional opportunities exist in new biomass sources such as brushlands and poplar plantations. As this industry develops, a number of points are important:

- Legislators and policymakers concerned about the economy of the forested areas of Minnesota should appreciate the potential impact of energy subsidies on the forest products industry,
- Support for research at the state level to develop conversion and biomass production technologies, specifically energy crop development, brushland biomass assessments, aspen thinning options and impacts, forest harvest residue bundling equipment and conversion technologies is needed,
- Ethanol produced from local wood resources may be competitive with gasoline at current prices,
- Smaller-scale conversion technologies that are publicly available are needed and may require targeted research and development by the State,
- Picking ultimate winners is difficult and the most competitive options will depend on technology advancements in the fields of liquid fuels conversion and batteries.

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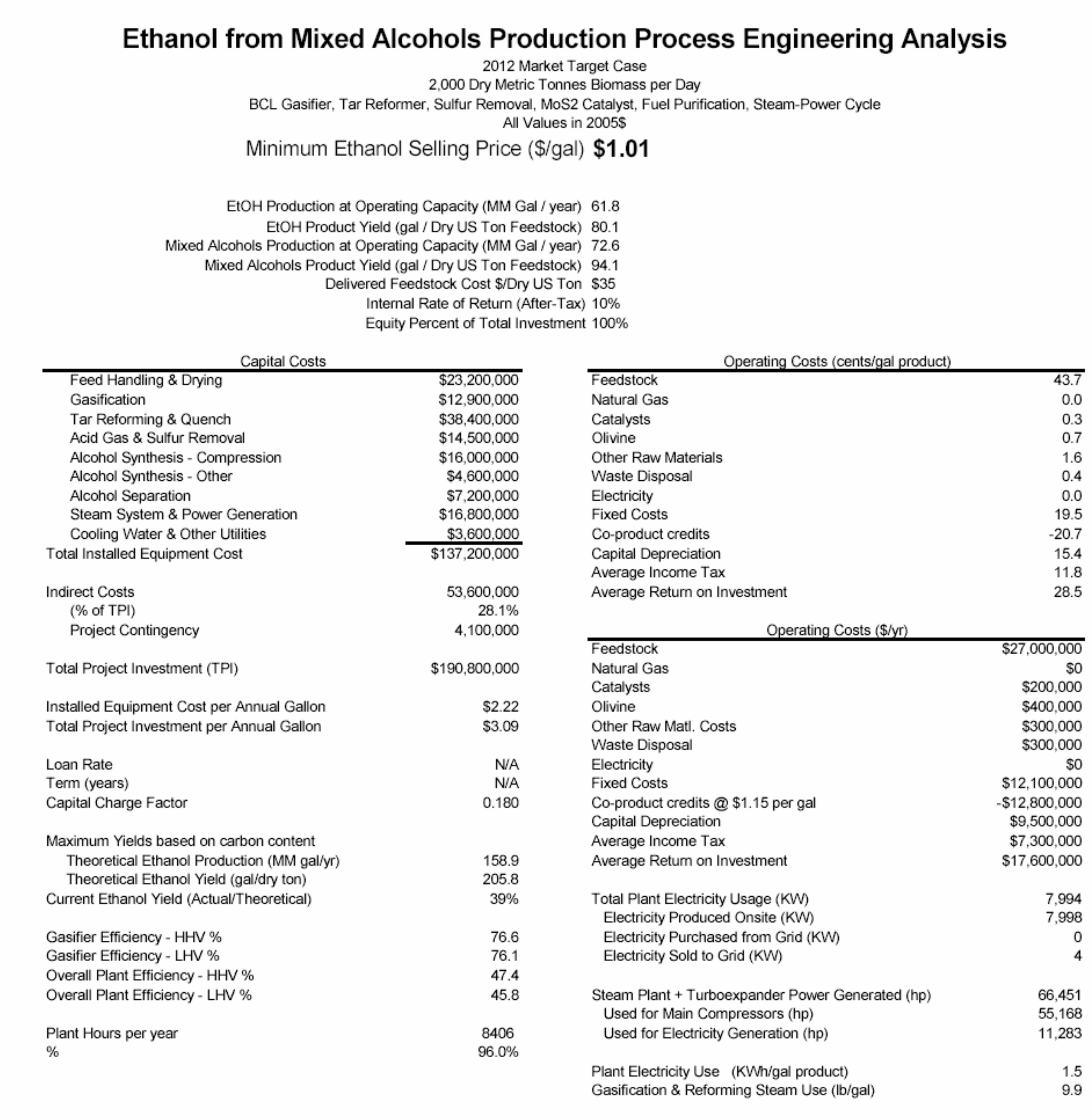
Appendix A. Operating parameters, capital costs and resulting cost per gallon of a theoretical thermochemcial ethanol plant (Phillips, et.al., 2007).



Ethanol from Mixed Alcohols Production Process Engineering Analysis

2012 Market Target Case
2,000 Dry Metric Tonnes Biomass per Day
BCL Gasifier, Tar Reformer, Sulfur Removal, MoS2 Catalyst, Fuel Purification, Steam-Power Cycle
All Values in 2005$

Minimum Ethanol Selling Price ($/gal) **$1.01**

EtOH Production at Operating Capacity (MM Gal / year)	61.8
EtOH Product Yield (gal / Dry US Ton Feedstock)	80.1
Mixed Alcohols Production at Operating Capacity (MM Gal / year)	72.6
Mixed Alcohols Product Yield (gal / Dry US Ton Feedstock)	94.1
Delivered Feedstock Cost $/Dry US Ton	$35
Internal Rate of Return (After-Tax)	10%
Equity Percent of Total Investment	100%

Capital Costs	
Feed Handling & Drying	$23,200,000
Gasification	$12,900,000
Tar Reforming & Quench	$38,400,000
Acid Gas & Sulfur Removal	$14,500,000
Alcohol Synthesis - Compression	$16,000,000
Alcohol Synthesis - Other	$4,600,000
Alcohol Separation	$7,200,000
Steam System & Power Generation	$16,800,000
Cooling Water & Other Utilities	$3,600,000
Total Installed Equipment Cost	$137,200,000
Indirect Costs	53,600,000
(% of TPI)	28.1%
Project Contingency	4,100,000
Total Project Investment (TPI)	$190,800,000
Installed Equipment Cost per Annual Gallon	$2.22
Total Project Investment per Annual Gallon	$3.09
Loan Rate	N/A
Term (years)	N/A
Capital Charge Factor	0.180
Maximum Yields based on carbon content	
Theoretical Ethanol Production (MM gal/yr)	158.9
Theoretical Ethanol Yield (gal/dry ton)	205.8
Current Ethanol Yield (Actual/Theoretical)	39%
Gasifier Efficiency - HHV %	76.6
Gasifier Efficiency - LHV %	76.1
Overall Plant Efficiency - HHV %	47.4
Overall Plant Efficiency - LHV %	45.8
Plant Hours per year	8406
%	96.0%

Operating Costs (cents/gal product)	
Feedstock	43.7
Natural Gas	0.0
Catalysts	0.3
Olivine	0.7
Other Raw Materials	1.6
Waste Disposal	0.4
Electricity	0.0
Fixed Costs	19.5
Co-product credits	-20.7
Capital Depreciation	15.4
Average Income Tax	11.8
Average Return on Investment	28.5

Operating Costs ($/yr)	
Feedstock	$27,000,000
Natural Gas	$0
Catalysts	$200,000
Olivine	$400,000
Other Raw Matl. Costs	$300,000
Waste Disposal	$300,000
Electricity	$0
Fixed Costs	$12,100,000
Co-product credits @ $1.15 per gal	-$12,800,000
Capital Depreciation	$9,500,000
Average Income Tax	$7,300,000
Average Return on Investment	$17,600,000
Total Plant Electricity Usage (KW)	7,994
Electricity Produced Onsite (KW)	7,998
Electricity Purchased from Grid (KW)	0
Electricity Sold to Grid (KW)	4
Steam Plant + Turboexpander Power Generated (hp)	66,451
Used for Main Compressors (hp)	55,168
Used for Electricity Generation (hp)	11,283
Plant Electricity Use (KWh/gal product)	1.5
Gasification & Reforming Steam Use (lb/gal)	9.9