

CHISAGO-ISANTI-PINE

**BIOFUELS
FEASIBILITY
STUDY**

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CHISAGO, ISANTI, AND PINE COUNTIES **BIOFUELS FEASIBILITY STUDY**



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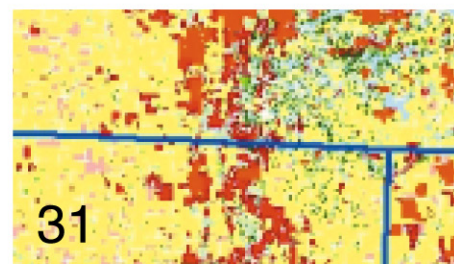
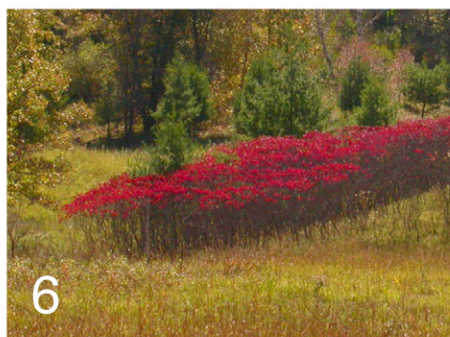
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ON THE COVER

A streak of red sumac creates colorful contrasts against a Minnesota prairie. Photo by Clarence Lehman.



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This study presents a detailed analysis of the economic and technical feasibility of utilizing existing biomass resources in the east Central region of Chisago, Pine and Isanti counties (CIP) to develop a renewable energy biofuels demonstration facility. It also considers the capacity of the seed bank at Wild River State Park to expand the existing prairie grass in the CIP region.

The key to attracting investment in a liquid biofuels conversion plant is a sustainable and affordable supply of biomass. Biomass can be obtained from a variety of sources such as forest biomass, agricultural residues, and grasslands. However, these resources must be harvested sustainably to ensure a supply well into the future while avoiding any negative environmental or wildlife habitat impact. Forest biomass has a very long regeneration time and is also valuable and necessary to the paper and wood industries. The quantity of agricultural residue such as corn stover is determined by the acreage planted in corn.

Grasslands and SRWC (hybrid poplar) could be a primary crop grown specifically as feedstock for conversion to liquid biofuels. Unfortunately, the acreage planted now in grasslands or SRWC in the CIP region is barely adequate to support a single 30 million gallon per year plant if it could all be harvested. The practicality of full harvest is very questionable since some of these grasslands are hay fields used for pasture and the plantings are not contiguous. The conclusion is that to attract investment the planting of grasslands needs to be given high priority. It may not be a *field of dreams* but it is certain that if the biomass supply is not there they will not come!

Biomass resources were quantified through gathering and analysis of extensive field data that resulted in a model for predicting biomass productivity in future managed landscapes. From these data and other agronomic data, supply curves have

been developed that will predict supply response to change in price of biomass. The analysis shows where biomass feedstocks might be grown and how the resulting prices affect the financial performance of the biofuels plant.

Detailed economic and technical analysis of the various biomass conversion platforms to produce renewable fuels has led to several important conclusions, namely: 1) Ethanol from cellulosic biomass is not ready for commercialization and requires significant improvements to the underlying technology to become profitable; 2) Capital costs for cellulosic ethanol plants are significantly higher than those for corn ethanol plants (about 2-3 times higher per gallon of ethanol produced); because of the increased level of complexity; 3) Significant government subsidies to the producer will be required indefinitely to achieve even modest profitability for ethanol plants under optimistic scenarios for future technical improvements.

Ethanol, whether from cellulosic biomass or corn, should therefore be viewed as a transition biofuel that will ultimately be replaced by technologies based on converting biomass to syn gas and thence to transportation fuels such as dimethyl ether (DME), gasoline, diesel or jet fuel that are compatible with present distribution systems and usage patterns for transportation fuels. Ethanol will continue to be utilized as an oxygenate and also to supplement synthetic gasoline supplies.

For synthetic gasoline and other biofuels produced from cellulosic biomass to be economically viable and commercially sustainable requires crude oil prices to be high enough for gasoline retail prices to exceed \$2.60 per gallon with current government tax credits of \$1.01 per gallon on a permanent basis and for the desire to reduce foreign oil independence and carbon dioxide emissions to become national priorities backed by policy

and subsidies. If gasoline retail prices exceed \$3.50 per gallon then tax incentives are not necessary to achieve a sustained profitability.

The amount of biomass needed to supply either cellulosic ethanol or synthetic biofuels plants is significant. A single 50 million gallon per year plant would require 670,000 - 750,000 tons (15% moisture) yearly of biomass. This equates to the biomass that can be sustainably harvested from 305,000 -350,000 acres. The CIP area could support two 50 million gallon per year cellulosic conversion plants if all eligible acreage were producing biomass at sustainable levels to also provide ecosystem benefits such as soil, water and wildlife protection.

A biomass fuel pellet plant in the CIP area appears to be an economically and technically feasible opportunity to take a first step towards developing a biofuels business based on cellulosic biomass. A business plan to achieve this has been developed. If the biomass is harvested sustainably the land is protected and in fact is improved by the restoration of perennial prairies which sequester carbon dioxide in the root system, act as filters to mitigate agricultural runoff from polluting ground and surface water and also serve as additional wildlife habitat. A pellet manufacturing facility will provide an opportunity to develop expertise in manufacturing and a work force to form the core for potential future ventures in biofuels production. Cash flow from a pellet operation could be the source for funding of future ventures in prairie restoration as well as expansion of the initial pellet manufacturing operation as market conditions permit.

In upcoming decades the CIP region can use the infrastructure and materials developed in the first decade to support a facility that converts their cellulosic biomass to transportation fuels through a syn-gas route. ■

The Chisago, Isanti and Pine Counties Biofuels Feasibility Study was funded under Minnesota Session Laws 2007 Chapter 45 for the purpose of conducting a detailed study of the economic and technical viability of developing a multi-stream renewable energy biofuels demonstration facility on Chisago, Isanti or Pine (CIP) county land to utilize existing biomass resources to produce biofuels or bioenergy.

The study must consider the capacity of:

The seed bank at Wild River State park to expand the existing prairie grass, woody biomass, and cellulosic material resources in CIP;

Willing and interested landowners in CIP to grow cellulosic materials;

The Minnesota Conservation Corps, the sentence to serve program, and other existing workforce programs in east central Minnesota to contribute labor to these efforts.

CHISAGO-ISANTI-PINE

BIOFUELS FEASIBILITY STUDY

This study posed three major questions that form the basis for the analysis and conclusions;

- ▶ How much biomass exists now and how much could be produced in future managed landscapes?
- ▶ How much will the various forms of biomass cost and what impact will its production have on the environment?
- ▶ What are the best technologies for converting biomass to fuels or energy from the standpoint of technical feasibility and economic viability?

The path forward

The Chisago, Pine and Isanti counties region (CIP) has a supply of renewable biomass that can be developed and further expanded sustainably to provide bioenergy and related jobs now and into the future while contributing to the energy independence of the nation and reduction of green house gas emissions. The path forward is defined by three major goals;

Goal 1, long term: The ultimate target is a renewable energy facility to convert the region's cellulosic biomass into environmentally sus-

tainable, carbon-neutral liquid transportation fuels.

Goal 2, intermediate term: The grasslands in the region are not adequate to supply a commercial size conversion plant. Furthermore, there is not an adequate supply of diverse prairie grass seed to seed the region in high productivity, low input grasslands. CIP can begin a concentrated seed development project utilizing the Wild River State Park seed bank and supplementing with other sources of mixed prairie seed to establish 16,000 acres of diverse low input prairie within 10 years. This would

form the basis for more extensive plantings to support future conversion plants.

Goal 3, near term: Investing in a wood-pellet plant can establish the initial biofuels manufacturing infrastructure with a yearly payroll in excess of \$1 million.

This three-phase economic development of the region's supply of bioenergy will improve the environment for wildlife and humans alike and provide economic stimulus to the CIP region while increasing the energy self-sufficiency of the area.

How much biomass exists, and how much could be produced in future managed landscapes?

To fill large gaps in data and to be sure conclusions are drawn from accurate premises, field samples of grasses and woody shrubs that would be suitable for biomass energy were gathered in fall of 2007 and 2008. Resources from the Minnesota Conservation Corp partially supported this effort. These data were analyzed for composition and quantity to generate the most accurate view of present and future managed landscapes. Combined with geographic maps, these field samples show that a considerable supply of biomass grows within the region, very little of which is presently being used for bioenergy. The seed bank at Wildlife River state park is useful but not adequate to supply the seed necessary to expand the biomass plantings in the project region.

The current sustainable biomass supply from the five-county project region, irrespective of price, includes 170,000 as-delivered tons (15% moisture) of crop residues from 186,000 acres of annual crop land and over 1,500,000 as-delivered tons (50% moisture) of forest biomass from 786,000 acres of forest land. Additionally, 392,000 as-delivered tons (50% moisture) could be sustainably produced from 223,000 acres of brushland.

Grasslands and hay fields in the region, excluding those that are enrolled in the Conservation Reserve Program or on public lands, could produce biomass from 264,000 acres. If these grasslands produced an average of 2.2 as-delivered tons (15% moisture) per acre with one quarter of the field left for wildlife habitat and other ecosystem services, over 440,000

as-delivered tons (15% moisture) could be sustainably produced with few inputs. The practicality of full harvest, however, depends on market price. As market price for biomass changes, the biomass type and supply also changes.

For perspective, consider that a single 50-million-gallon-a-year plant converting prairie grass to ethanol would require 670,000 to 765,000 tons/yr of grass (at 15% moisture) produced on approximately 305,000 to 350,000 acres.

Based on current technology for converting all forms of biomass to ethanol, the current capacity in the project region would be almost 126 million gallons per year if all eligible acreage were producing biomass at sustainable levels. This would represent two plants whose feasibility and profitability would depend on market conditions and the type of technology employed to convert the biomass to ethanol or other forms of biofuel. ■

How much will the various forms of biomass cost and what impact will its production have on the environment?

The economic viability of biofuel conversion plants is strongly dependent on the price of biomass. This became abundantly

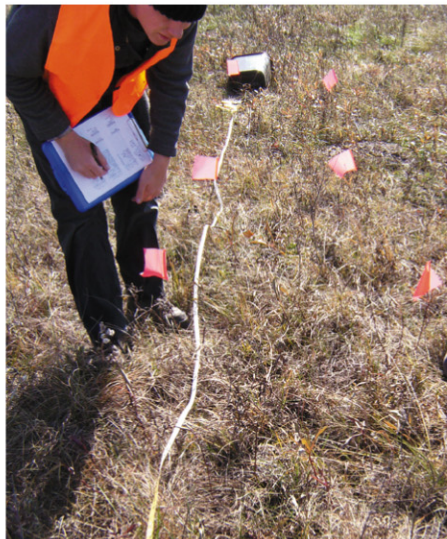
clear in 2007-2008 when corn prices per bushel rose from \$ 3.00/bu to as much as \$ 7.00 and then fell back to \$3.00. The prof-

itability of corn ethanol plants vanished when corn hit \$7.00 and some companies that had hedged in the wrong direction were forced

into bankruptcy while still others sharply curtailed plans for new corn ethanol plants.

Therefore, great care must be exercised in assessing a realistic cost for the various forms of biomass. This report strives to avoid problems that often occur when numbers arising from several sources, derived using different methods are inadvertently combined and propagated, sometimes without proper vetting. There are several areas of concern:

- 1) Costs are often stated without specifying moisture content. This can be very misleading since it is like comparing the cost of a pound of grapes to a pound of raisins.
- 2) There is a legacy dating back to initial work reported by governmental agencies in the 1990's that is often quoted without being properly updated to reflect current market conditions.
- 3) Biomass costs are often reported on a *farm gate* basis. Our costs are on a *plant gate* or delivered basis.
- 4) Opportunity cost is not always applied to new forms of biomass that are not yet items of commerce.



In cases having an established price structure, such as with green round logs, that price has been used and moisture content has been taken into account. This applies as well to corn. Otherwise we assign cost based on the methodology that follows.

In summary, hundreds of thousands of tons of biomass are currently growing in the project area. Essentially none is being currently used for energy production. That is because no facility exists to pay the price needed to encourage landowners to switch from existing crops to the crop desired by the facility.

Supply curve analysis

The objective of the supply curve analysis is to predict the supply response to changes in price, assuming the bioenergy plant offers enough money that producers in an area stop growing soybeans and instead grow switch grass for biomass.

We estimate the delivered cost for each feedstock by combining production, harvest, and transportation costs from each "field" in the project area. The logic of the analysis is based on the premise that if the price offered by the bioenergy plant is high enough, the field's owner will switch from whatever was being grown before (if different) to the demanded crop. As the price increases, increasingly more expensive biomass will become available.

The analysis permits us to show where biomass feedstocks might be grown and how the resulting prices affect the financial performance of the bioenergy plant.

What are the best technologies for converting biomass to fuels or energy from the standpoint of technical feasibility and economic viability? ■

What are the best technologies for converting biomass to fuels or energy from the standpoint of technical feasibility and economic viability?

The technologies evaluated ranged from simple to complex and included biomass(wood or grass) pellets, combined heat and power, cellulosic ethanol by enzymatic hydrolysis and fermentation, gasification to mixed alcohols and gasification with catalytic conversion to gasoline.

► **Combined Heat and Power (CHP).** For CHP about 70-75% of the biomass energy is convert-

ed to heat with the remainder converted to electricity. The economics are driven by the heat generated in the process. If the application does not utilize the heat it is not economically viable. To make CHP viable one would need to partner with a large user of heat such as a potato dehydrating plant, a pasta plant or similar energy intensive manufacturing. Installation in an industrial park could provide an

incentive to attract potential occupants and also an acceptable return for CHP investors.

Considerable economic and technical data are available for the **corn-ethanol** conversion platform. This was used as the **baseline for comparison** of conversion technologies for cellulosic ethanol plants and for platforms for higher value-added products ranging from mixed alcohols to gasoline.



▲ Above and opposite page, Peter Gillitzer of the University of Minnesota grassland team records information on a sample grassland plot.

Cellulosic Biomass vs. Corn Ethanol Platforms

Note: all comparisons are based on corn at \$3.75/bu, prairie grass at \$90/ton with moisture of 15%, ethanol selling price of \$2.00 per gallon. Prices for ethanol and gasoline are rack prices F.O.B Omaha, averaged over the period 2003-2007. Capital and operating costs are based on models developed by the National Renewable Energy Laboratory (NREL). Since these models were

developed from 2002 to 2007, the capital cost were inflated to today's dollars and installation factors were adjusted according to generally accepted engineering practice to properly reflect construction, engineering and construction management costs.

Government subsidies to the producer are a tax credit. As such they can generate a positive cash flow even if the taxes due are less than the credit. The tacit assumption in such a case is that

the producer has other operations that are profitable where the tax credit can be utilized.

► Cellulosic ethanol is significantly more capital intense.

Much more complex and require more equipment than corn ethanol. A 50 million gal./yr corn ethanol plant would cost about \$104 million (\$143 MM if biomass is used as energy source instead of fossil fuel) whereas the same capacity cellulosic ethanol plant would cost \$340 million.

► Operating costs are higher.

Cellulosic ethanol requires expensive enzymes, acid and other chemicals. For a 50 million gal/yr plant the production cost is about 28% higher than corn ethanol (\$2.34/gal vs. \$1.82/gal) for corn at \$3.75/bu and prairie grass at \$90/ton.

► Government subsidies (tax credits) are essential for cellulosic ethanol to be profitable.

Considering a 50 million gal/yr plant, the after tax IRR (internal rate of return) is 7% (NPV=-\$40 MM) with a tax credit of \$0.56/gal to the producer in addition to the current \$0.45/gal to the blender. Without the producer subsidy the IRR is -10%. As a point of reference a corn ethanol plant, with process heat generated from corn stover, of the same capacity has an after tax IRR of 12% (NPV= \$12MM).

► **Scale is critical for profitability.** Increasing plant size from 50 million gal/yr to 100 million gal/yr. raises the after tax IRR from 7% (NPV=-\$40) to 14% (NPV=\$86MM), both with \$0.56/gal subsidy. The capital increases from \$340 million to \$540 million.

► Can the economics of cellulosic ethanol be improved?

Production costs could be lowered if enzyme cost were significantly reduced or eliminated.

Capital cost could be reduced if the hydrolysis/fermentation part of the process could be dramatically streamlined through discovery of new microorganisms or introduction of more efficient recombinant strains.

► **Best case scenario for cellulosic ethanol.** If enzymes were eliminated and a *super bug* were found to eliminate the capital associated with the conversion of the cellulose to fermentable sugars a 11.5% after tax IRR (NPV=\$20MM) could be achieved in such an *ideal* plant with a capital investment of \$318million and a manufacturer subsidy of \$0.56/gal. The IRR without the tax credit is -4% (NPV=-\$151MM).

Gasification and catalytic conversion of cellulosic biomass. Fermentation of the sugars contained within cellulosic biomass is a technology that mimics the corn ethanol platform in the conversion of sugars to ethanol that is accomplished by fermentation. An alternative technology is based on the conversion of cellulosic biomass to syngas (essentially a mixture of carbon monoxide and hydrogen) and subsequent catalytic conversion to any number of high value added products ranging from mixtures of ethanol and other alcohols to gasoline, jet fuel and aromatic hydrocarbons. These technologies are referred to as **Thermochemical Platforms**.

► **Syn gas and catalytic conversion to mixed alcohols (ethanol, methanol, propanol, butanol and others).** The economics are better than the best case cellulosic platform for several reasons. No enzymes are required. Fewer tanks and vessels are required which translates to lower capital. Butanol and propanol are valuable by-prod-

ucts. A 24% after tax IRR (NPV=\$125MM) can be realized at a scale of 50million gal/yr and a capital cost of \$193 million with a manufacturer subsidy of \$0.56/gal. Without the subsidy the IRR is 4% (NPV=-\$45MM).

► **Syn gas and catalytic conversion to gasoline and LPG (propane).** At a scale of 50 million gal/yr and an investment of \$265 million and a rack price of \$1.69/gal (retail pump price of \$2.53/gal.) plus the \$1.01 /gal tax credit for producing gasoline instead of ethanol from cellulosic biomass the after tax IRR is 17.5% (NPV=\$86MM). This is significantly better return than the 'ideal' cellulosic ethanol plant. In addition, the intangible benefits of gasoline are significant since it fits perfectly with existing distribution systems and the platform has been tested on a large scale.

Conclusions for liquid fuels from cellulosic biomass

► **Ethanol from cellulosic biomass with current technologies is not ready for commercialization.**

► **Significant technological discoveries and developments are required** to make liquid phase fermentation based cellulosic ethanol conversion platforms marginally profitable.

► **Regardless of promised potential technical improvements the capital cost will still be significantly higher than corn ethanol plants of similar capacity.**

► **Under the best -case scenarios the biochemical platform is dependent on government subsidies to be even marginally profitable. The profit is entirely in the subsidies.**

► **Ethanol can be more economically produced by gasification of biomass and subsequent catalytic conversion to mixed alcohols.** However, this **technology has yet to be demonstrated** at a commercial scale.

► **Ethanol should be viewed as a transition biofuel.** Ultimately synthesis gasoline and diesel fuel based on cellulosic biomass should prevail.

► **Syngas catalytic conversion to gasoline appears to offer the best potential for conversion of cellulosic biomass to liquid fuels** that are compatible with current usage and distribution patterns. This technology was utilized in New Zealand during the energy crisis of the 70's.

► **Syngas** platforms will become economically and strategically compelling when:

1) **Crude oil prices get high enough (gasoline rack price of \$1.70/\$2.55 retail or higher); and,**

2) **Foreign oil independence and reduction of carbon dioxide emissions become national priorities.**

Biofuel pellets as a renewable energy source

In addition to the conversion platforms above, the conversion of woody biomass and grasses to pellets suitable as a heat source in pellet stoves or larger pellet furnaces and boilers was investigated as a low tech way of getting started with converting cellulosic biomass to a biofuel.

A biofuels demonstration facility for CIP

A biomass fuel pellet manufacturing facility in the CIP area



▲ The University of Minnesota grassland team includes, from left to right, Peter Gillitzer, Nick Reeps, Yana Sorokin and and Brian Newman.

represents an opportunity for economic development with a proven technology and a product with established and growing markets. Fuel pellets based on either wood or prairie grasses are a viable and economical option for space heating especially in areas not served by natural gas distribution. Fuel pellets are essentially carbon dioxide neutral and are considered non-polluting by the EPA. If the biomass is harvested in a sustainable manner carbon dioxide is recycled and the land is protected and in fact improved by restoration of natural prairie

grasses on the landscape. Perennial prairie grasses sequester carbon dioxide in the root system, act as filters to prevent agricultural run-off from polluting ground and surface water and also serve as additional wildlife habitat.

Multistream renewable energy biofuels demonstration facility.

It is recommended that a biomass pellet manufacturing facility be constructed and operated in the CIP area. The project can be implemented in two stages to spread capital infusion over a few years and for stage 1 to serve as

a demonstration and training facility and an immediate job creation vehicle.

Stage 1: Build a 7 ton/hr demonstration plant operating 6 days/week and 3 shifts /day. The plant would use 95,000 tons/yr of 50% moisture wood.

Economic Parameters

- ▶ Capital investment = \$12.1MM
- ▶ Yearly payroll = \$930,000
- ▶ Production = 51,000 tons/yr
- ▶ IRR = 9% (after-tax, 15 year life); yearly cash flow = \$2.0MM at selling price of \$180/ton.

EXECUTIVE SUMMARY

Stage 2: Add an additional 7 tons /hr capacity in year 4. If prairie grass were available it would take about 100,000 acres of prairie grass to supply these needs.

Economic Parameters

- ▶ Incremental capital = \$ 10.1MM in year 4 dollars.
- ▶ Total payroll = \$1,200,000
- ▶ Production capacity = 84,000 tons/yr
- ▶ IRR = 14% (after-tax, 15 year life); yearly cash flow = \$3.0MM at selling price of \$180/ton. Biomass cost of

\$40/ton (@ 50% moisture)


Rationale

- ▶ The plant operation provides stable, good paying jobs with an annual payroll of over \$900,000.
- ▶ A pellet demonstration plant is an opportunity to gain experience in the logistics and management skills required for more complex manufacturing operations.
- ▶ A physical plant would provide a developed site to support future ventures.
- ▶ A trained work force would be

the core group for potential new ventures in liquid biofuels.

- ▶ Cash flow from a pellet operation could be the source of funding for opportunities such as biomass gasification to supply syngas for future liquid biofuel manufacture.
- ▶ Implementation of stage 2 would be significant motivation for local landowners to establish prairie grass plantings to support the pellet plant. ■





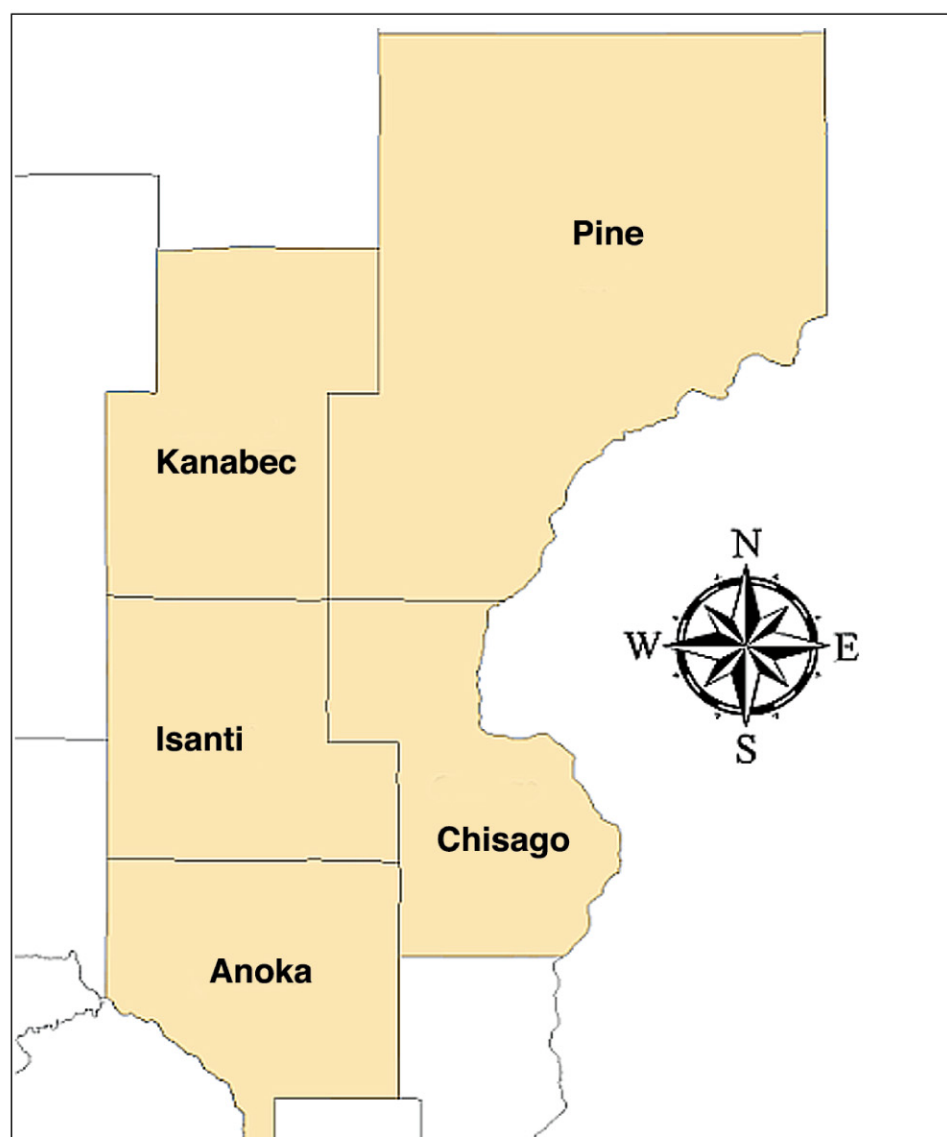
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BIOMASS RESOURCES

This section of the report quantifies the location and source of biomass from the landscape while maintaining long-term yields and mitigating the impact on soil and water quality. In addition to the biological supply capacity of agricultural and forest landscapes, there is a need to examine the cost of supplying biomass at different scales.

BIOMASS RESOURCES

In response to this need, the east central Minnesota counties of Isanti, Chisago and Pine have partnered with the university of Minnesota Biotechnology Institute. These counties, along with Anoka and Kanabec, will hereafter be referred to as the 'project region.' (Figure 2.1). One of the goals of this partnership is to address the biomass supply of local landscapes including agriculture, forests, brushlands and grasslands (Figure 2.2). A GIS-based model has been established to develop source-specific supply curves and associated maps highlighting the regions where biomass could be sourced. From these maps and supply curves, various conversion platforms, such as gasification, biochemical cellulosic ethanol, thermochemical cellulosic ethanol and thermochemical catalytic gasoline can be correctly sited, scaled and evaluated financially. Similarly, environmental impacts, such as carbon sequestration or nitrate runoff, can be estimated dependent on the biomass supply. ■



▲ Figure 2.1. Map of the project area. The Chisago-Isanti-Pine project also included Kanabec and Anoka counties in the analysis.

METHODOLOGY

Quantitative data on the agricultural and forestry yields and associated feedstock properties is well documented (BioPet, 2008). The potential supply of unimproved grasslands in Minnesota, such as those enrolled in the Conservation Reserve Program, is little known. Additionally, information about the supply of biomass that is available from brushland is limited (Connelly & Grigal, 1986). The baseline yield and acreage for agriculture and forest landscapes was derived from published information and the brushland and grassland data from two years of field work.

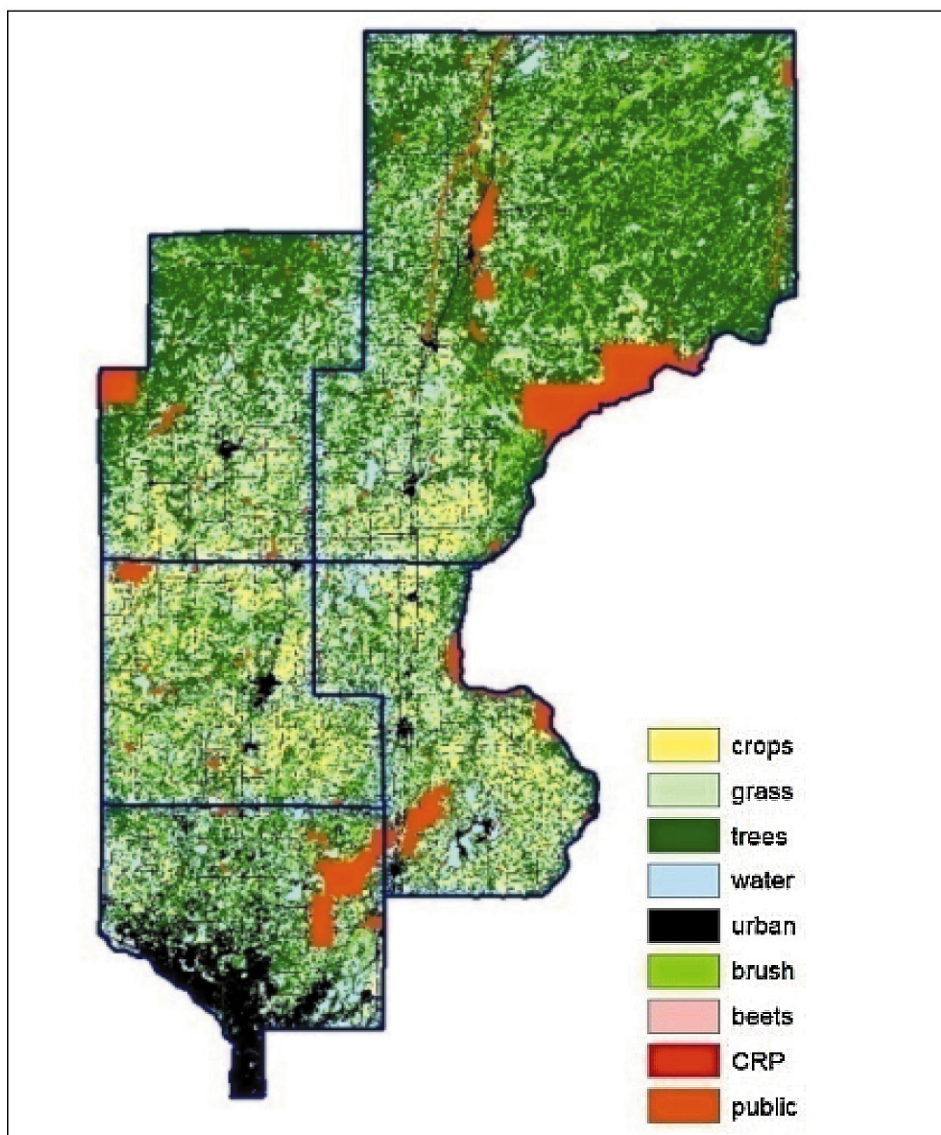
Geographic Information System (GIS) data

Yield information for agriculture was derived from Soil Survey Geographic Database (SSURGO) maps and acreage information from the 2007 USDA Cropland Datalayer (USDA, 2007). Forest yields were derived from published information and field plots (D. Grigal, personal communication, Sept. 2008) and acreage extent from the GAP Analysis datalayer. Grassland yields were derived from two years of field work and acreage extent derived from 2007 USDA Cropland Datalayer, MN Statewide Conservation Reserve Program datalayer (MN

Conservation Reserve Program database, 2007) and USDA National Agricultural Statistics Service (MN NASS, 2008). Brushland yields were derived from field work and GAP analysis level III datalayer (GAP, 2008).

► 2007 USDA Cropland Datalayer

The information on specific crop acres was derived from the USDA Cropland Datalayer. The digital



▲ **Figure 2.2** Map of the project region with major land categories delineated. The data was aggregated into major land use categories: annual crops, CRP, grassland, brushland, water (lakes and wetlands), urban, and non-harvestable public land.

data layers are geo-referenced imagery from ResourceSat-1 AWiFS satellite sensor. Maps are released on all major agricultural regions every couple of years. This data layer allowed the research team to determine the crops grown on specific soil types, in year 2006, the most recent year available.

► **GAP land cover analysis**

The information for brushland

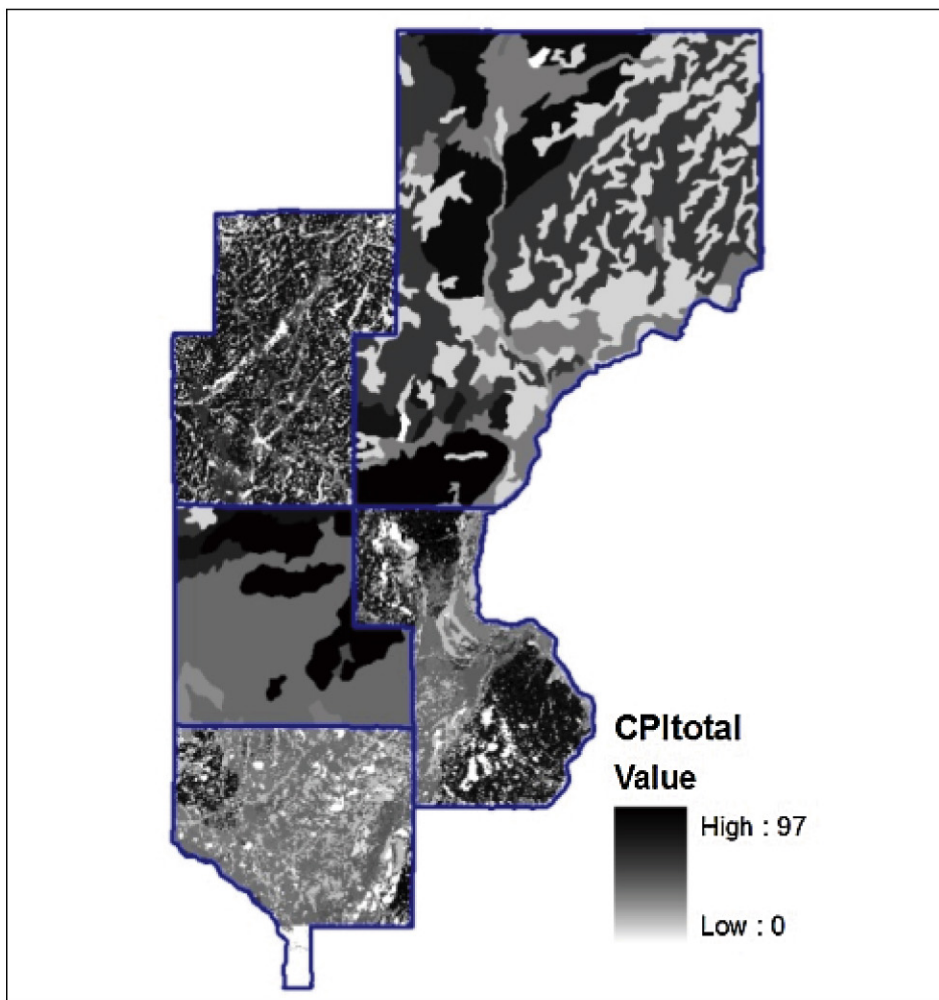
and forestland was derived from the Minnesota GAP land cover analysis data layer (GAP, 2008). The baseline data used to create this layer was generated from satellite imagery from summer 2000 and 2001. We used level three cover type categories that have demonstrated 80-90% accuracy through standardized groundtruthing.

Crop Productivity Index

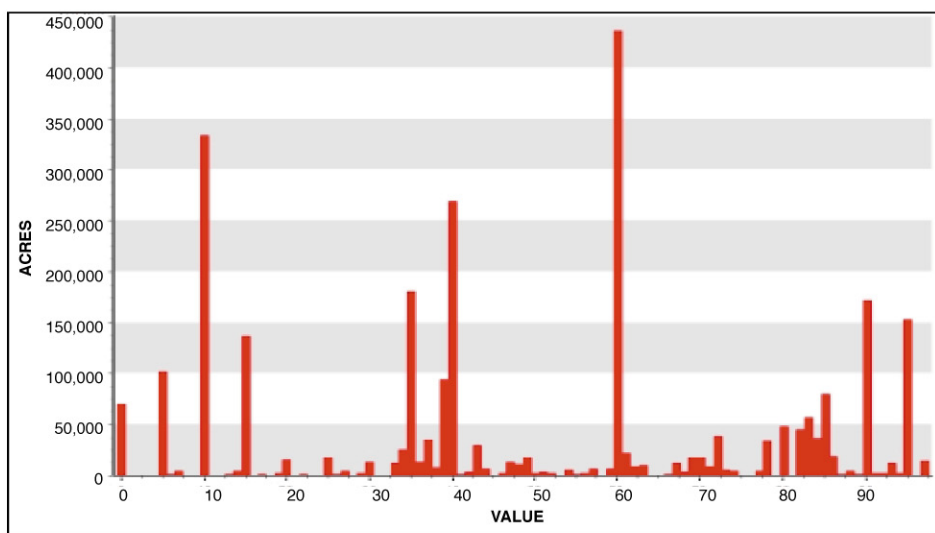
In order to estimate potential crop yields, a new index was employed that was developed by the University of Minnesota, the Minnesota Board of Water and Soil Resources, and the USDA NRCS, supported by a grant from the State of Minnesota. Using detailed soil survey data from the national SSURGO database, all of Minnesota's mapped soils have been scored according to their inherent ability to support vegetation. The soil properties are based upon SSURGO soil maps that have been field-referenced and digitized for use in GIS. Cropland Productivity Index (CPI) scores range from 0 (ill-suited for annual crops) to 100 (the best soil in the county) (Figure 2.3) CPIs can be logically compared with those in nearby counties but not across the whole state because of precipitation and growing degree days differences. Values for each Minnesota soil, as well as aggregated averages for any desired geographic area, are available at Minnesota Land Economics (<http://landeconomics.umn.edu>; see Soils Data section).

Unlike the previous Minnesota land productivity system (the Crop Equivalent Rating) which incorporated relative (at the time the CER was calculated) crop prices and local cropping patterns, the new Minnesota CPI is based strictly upon each soil's physical properties.

Consequently, changes in relative crop prices or cropping patterns do not change the CPI from year to year. Two crop management assumptions were necessary for the construction of the CPI. First, if a soil could be drained to improve crop production, it was assumed that it has already been drained. Second, if a soil could be irrigated to improve productivity, it was assumed that it has



▲ **Figure 2.3 Crop Productivity Model.** The darker colors are soils with higher CPI rating. Isanti and Pine county soils are generalized because these counties do not yet have published detailed soil maps.



▲ **Figure 2.4 Frequency of soil CPI ratings in the project region.** Higher frequencies of some CPI ratings are due to the lack of detailed soil maps for Pine and Isanti.

not been irrigated. Both assumptions are consistent with general Minnesota agronomic practice. Distributions are displayed for most biomass sources to demonstrate the frequency of each CPI rating (Figure 2.4). The higher the bar at any given level of CPI, the more acres in the project area are assigned that CPI value. The large 'spikes' at a few levels, such as CPI ratings of 40 or 60, are an artifact of the assignment of CPI data to the large soil association maps for Isanti and Pine counties. This was necessary because these two counties lack a modern soil survey with the detailed, digitized soils physical characteristics. This absence required that much broader soil association map boundaries for these two counties be used. Because the same CPI was assigned to any instance of these broader categories, the distribution of CPI values in those counties was not bell-shaped (Figure 2.4). Similar 'spikes' for the other major categories-annual crops, grassland, and forest land-are due to the same factor.

Crop yields

The CPI was correlated to yields on a crop-specific basis to predict crop yields across soil types. To estimate crop yields from fields not now growing these crops, a relationship between the field's productivity and the expected yield if that field were to be planted to a given crop was established. For this, existing Natural Resource Conservation Service estimated yields for each soil type in the county were arrayed against the yield for that soil. If there was insufficient county-level data for a crop or if the county has no soils data (Isanti and Pine), the regional average relationship

was used.

These relationships were used to estimate crop yields (in as-received tons) for each field, given its productivity rating. A simple linear relationship was fit from available data: $\text{yield} = \text{intercept} + (\text{CPI} \times \text{slope})$.

Corn, soybeans, and spring wheat have sufficient NRCS data for county-level estimates (Figures 2.7 - 2.8).

The other crops' relationships came from two sources: expert opinion for short-rotation woody crops, high-fertilization grasses,

and forest and from the study-sponsored field work for low-fertilization grasses/legumes and brushland. For example, if a field has a CPI of 50, the annual yield for high fertilization grasses was estimated to be: $2 + (50 \times .04) = 4$ tons per acre per year. ■

ANNUAL CROP BIOMASS

The five-county region contains 181,000 acres of annual cropland (Figures 2.5 and 2.6). Corn and soybeans dominate the agricul-

tural landscape. In addition to corn grain, which is currently used as the feedstock for ethanol production, agricultural residues,

such as corn stover and wheat straw, are potential source of biomass. The feasibility of agricultural residues will depend upon the economics of harvesting and transporting the biomass and competing uses such as animal feed, bedding and soil fertility. The agricultural residue is important for building organic matter, recycling nutrients and protecting against water and wind erosion.

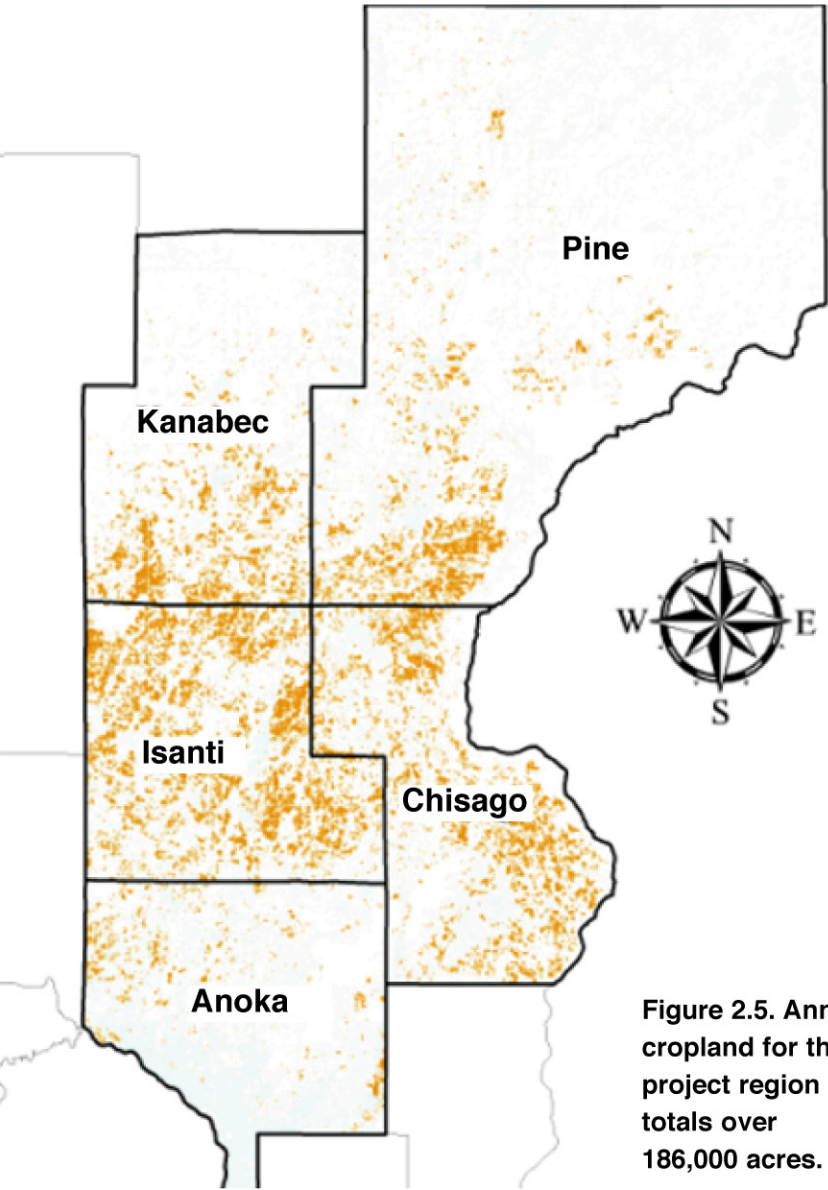


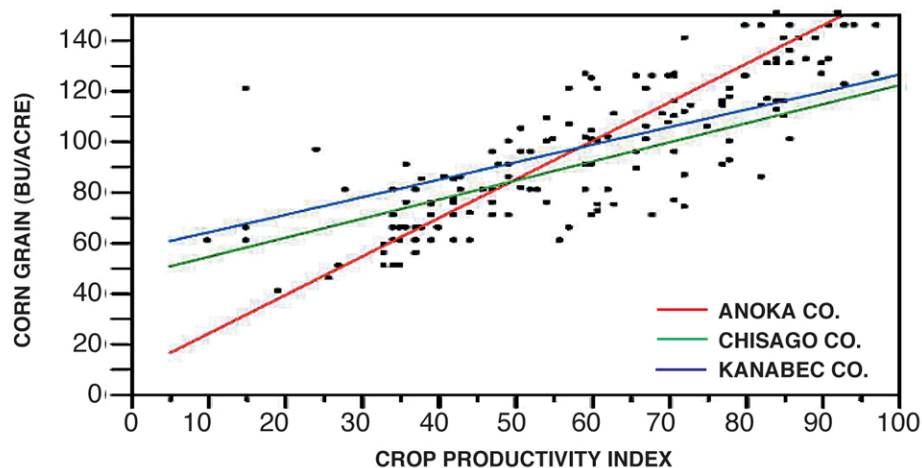
Figure 2.5. Annual cropland for the project region totals over 186,000 acres.

Annual crop acres

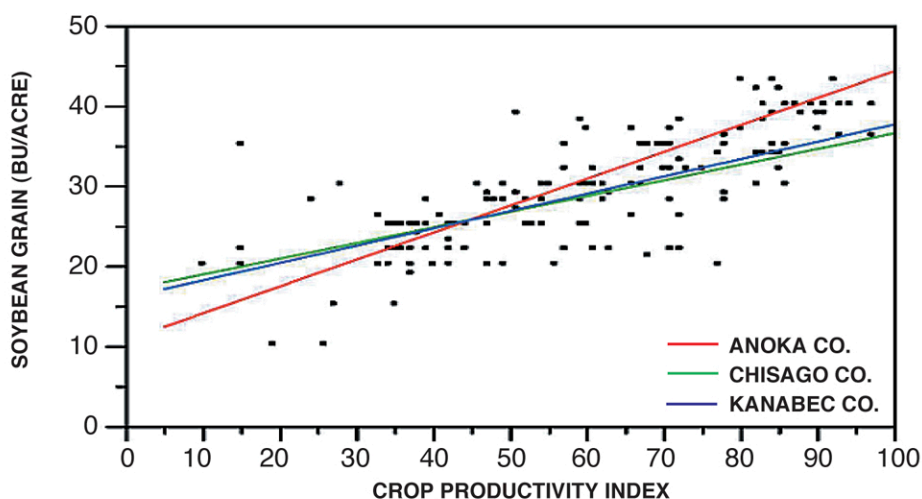
| ANNUAL CROP | ACRES |
|--------------|----------------|
| Corn | 75,000 |
| Soybeans | 91,000 |
| Spring Wheat | 3,500 |
| Rye | 4,300 |
| Oats | 600 |
| Alfalfa | 11,500 |
| Misc. | 800 |
| TOTAL | 186,700 |

▲ Figure 2.6. Breakdown of annual crop acres in the five-county region for 2006.

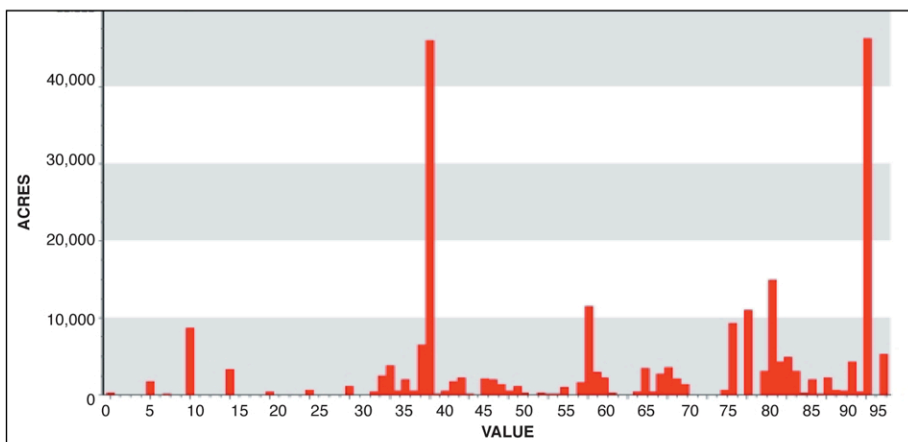
Yields estimated by Crop Productivity Index



▲ Figure 2.7. Yields for corn grain in the region are dependent on CPI rating (need to change axis)



▲ Figure 2.8 Yield for beans, by county, in the project region. Counties for which there are published soil maps only.



▲ Figure 2.9 Distribution of CPI ratings in the project region.

Potential annual crop residue

The major candidates for annual crop feedstocks in this region are: 1) small grain straw, and 2) corn stover. This assumes that the grain is currently used for animal and human consumption and not available as a bioenergy feedstock. The residues from the other annual crops are assumed to be unavailable due to low residue yields or other undesirable properties, such as high moisture or high nutrient content. For example, soybeans have high nitrogen content residue and this is important for soil fertility in the current agricultural system. Residue that is deposited on the soil surface after harvest is difficult to collect and may have lower feedstock quality due to soil particle contamination.

Corn grain and stover

Corn was grown on approximately 75,000 acres in 2006 (Figure 2.6). Depending upon the soil type and management practices about 50% of the total stover may be technically and sustainably removed. The 6-year average dryland yield in the region is approximately 108 bushels per acre. Assuming a harvest index of 0.5, approximately 50 lbs of corn stover is produced, but not necessarily recoverable, for every bushel of corn grain. Baling the windrow is estimated to recover 38%, raking and baling recovers about 50% and mowing, raking and baling could recover about 65-75% of total stover (Petrolia, 2008).

Currently, the International Harvester 1460 combine with a row bean head and a Hesston standard will simultaneously harvest corn grain and collect stover with a single pass (Schechinger and Hittenhaus, 2004). The intent of this equipment is to increase the feedstock quality by reducing soil contamination and increase the percentage of recoverable stover

| COUNTY | % OF TOTAL CORN GRAIN ACRES IN REGION | 6-YEAR CORN YIELD AVERAGE* (BU/ACRE) |
|---------|---------------------------------------|--------------------------------------|
| Kanabec | 11% | 96 |
| Anoka | 8% | 100 |
| Chisago | 30% | 117 |
| Isanti | 38% | 109 |
| Pine | 13% | 105 |

*years 2001-2006; excludes 2007 as an outlier due to drought.

▲ **Figure 2.10.** According to state agriculture statistics, the six-year corn yields average is 108 bushels per acre (MN NASS, 2008).

| YEAR | TOTAL CORN ACRES HARVESTED | TOTAL TONS STOVER BIOMASS* |
|------|----------------------------|----------------------------|
| 2006 | 75,000 | 113,000 |
| 2007 | 94,000 | 141,000 |

* assume 1.5 dry tons per acre sustainable harvest.

▲ **Figure 2.11** Total stover produced in 2006 and 2007 for region. Note the volatility in yields and acres from year-to-year.

| GRAIN | RESIDUE/GRAIN RATIO | AVERAGE RESIDUE DM TONS/ACRE |
|---------------------------|---------------------|------------------------------|
| Oats (74 bu/acre) | 2 | 2.4 |
| Barley (67 bu/acre) | 1.5 | 2.4 |
| Spring wheat (50 bu/acre) | 1.3 | 2.0 |

▲ **Figure 2.12.** Small grain residue depends upon the residue/grain ratio. Wheat, which is planted on approximately 8,800 acres in the region, averages 2.0 tons (0% moisture) per acre. The residue is important for soil quality and it may be neither technically nor economically feasible to recover.

(Wilham et al, 2006). However, the capital investment required would be reflected in the price of stover.

Corn acres in the region are increasing dramatically as corn grain prices increase. The region saw a 25% increase in planted

corn acres from 2006 to 2007 (Figure 2.10 and 2.11). In 2006 an estimated 75,000 acres of corn were harvested whereas 94,000 acres of corn were harvested in 2007 (NASS, 2007). The change in corn stover acres in the region translates to volatility in stover supply and availability.

Wheat, oat and barley grain and straw

Small grains are produced on about 8,800 acres in the project region (Figure 2.6). Depending upon the soil type and management practices, some operations may remove up to 50% of the residue every other year (Wiersma, personal communication, 2008). Average grain yields for wheat, oat and barley are 50, 74, and 67 bushels per acre, respectively (J. Wiersma, personal communication, Dec. 2008). The residue/grain ratio is 1.3 to 2 for these small grains producing an average of 2.3 dry tons per acre (Figure 2.12). The NRCS recommends returning between 1.5 to 2.5 tons per acre of small grain residue to maintain soil quality (SQI, 2000). Depending upon the cultural practices, such as crop rotation and tillage practices, and soil type, small grain straw may be able to contribute to feedstock supply.

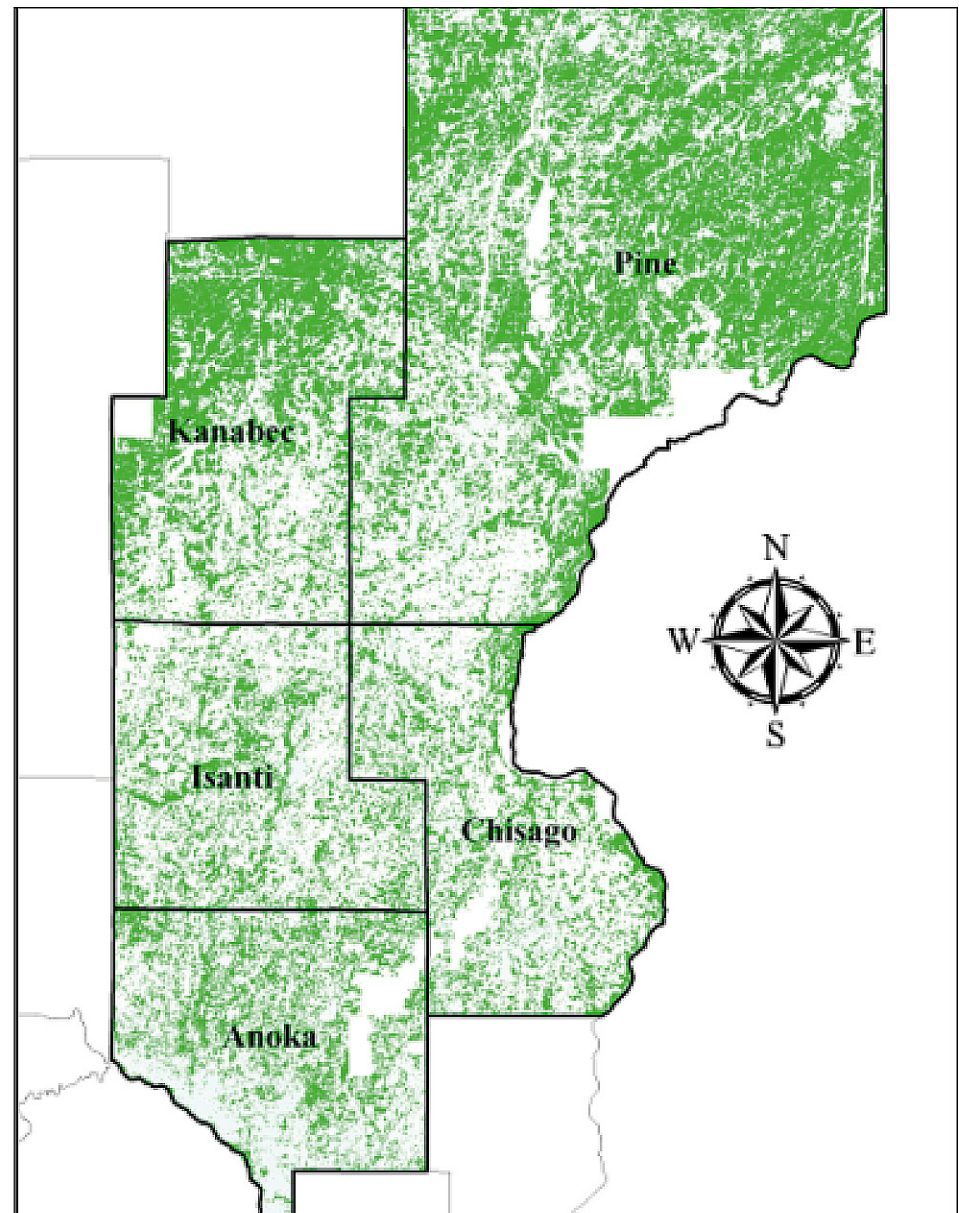
The nutrient content of the straw, as in any agricultural feedstocks, should be taken into account when considering removing residue. Land managers must decide if the limiting nutrients exported from the site, along with other benefits such as erosion control, are greater than then net return of the straw removed. According to the NRCS nutrient removal calculator (<http://npk.nrcs.usda.gov>), a 50 bushel spring wheat crop contains approximately 34 lbs of nitrogen (Crop Nutrient Tool, 2009). Assuming a cost of \$0.70/lb of N, the opportunity cost of removing nitrogen alone is \$24. Additionally, because residue contributes to higher soil organic matter levels, which break down over time and release limiting nutrients, a reduction in yield would be expected over time at any removal rate. ■

FOREST BIOMASS

The supply of biomass feedstocks from forested landscapes depends upon the management goals, policies and markets of the supplying region. Several biological, technical and engineering challenges exist for forest-derived biomass.

Potential forest-derived biomass issues

Utilizing pulp and sawlogs for bioenergy production may not be economically feasible or poorly received by competing industries. These problems may be avoided by integrating bioenergy production into pre-harvest treatments, such as the removal of low-value species. The majority of these practices are performed for the benefit of future income. Forest residues, largely the tops and limbs of trees remaining after logging, have also been identified as potential feedstocks. Depending upon the harvest treatment and equipment used, these residues may reside in central or distributed piles or scattered throughout the harvest area. Removing distributed residues may reduce regeneration costs by exposing mineral soil or lower risks of insect pests by removing potential breeding material (Stupak et al, 2007). However, low yields, collection difficulties and increased equipment traffic will make residue harvest from distributed piles or biomass scattered on forest soil unlikely. Residue that is located in central piles near landing areas has the potential to be utilized. Current options include bundling residue for offsite densification or chipping onsite to increase bulk density and lower transportation costs. Currently, the Central Minnesota Ethanol Cooperative in Little Falls, MN purchases chipped forest residue



▲ **Figure 2.13** Approximately 786,000 acres of forest land are present in the region. Note the large, forested regions within Pine County and northwestern Kanabec County.

that is simultaneously densified at the harvest site with a tub-grinder and conveyed into a semi-truck trailer for transport.

Energy supply industries may be interested in utilizing forest-derived biomass. Forest biomass is often from local or regional sources thereby increasing the security of supply in many cases. There are significantly less SO₂ emissions than fossil fuels and, depending upon the forest sys-

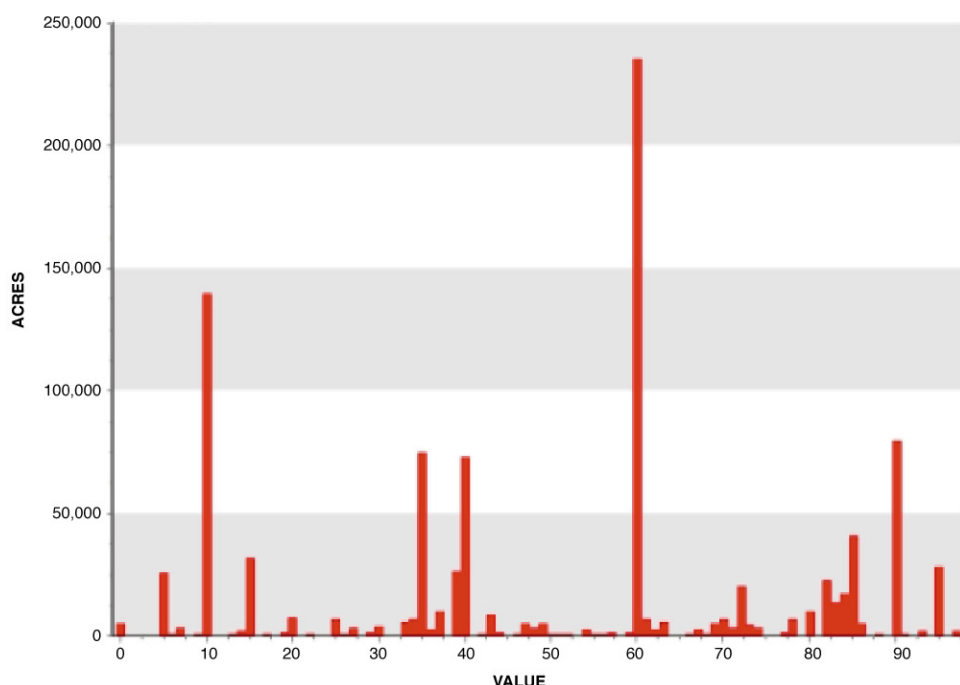
tem and harvesting practices, fewer net carbon emissions. Waste production at thermochemical conversion facilities may also be lowered. Wood contains 0.5-2% ash compared to concentrations of 7-10% for lignite coal (McKendy, 2002). If efficient distribution and application procedures are developed, the ash may be used in fertilization, thereby lowering landfill tipping fees.

| FOREST TYPE | ACRES |
|-------------------------|----------------|
| Pine | 32,400 |
| Lowland conifer | 22,600 |
| Spruce/Fir | 8,100 |
| Tamarack | 16,200 |
| Aspen/Paper Birch | 446,000 |
| Oak | 121,000 |
| Maple/Basswood | 25,500 |
| Lowland deciduous | 94,400 |
| Conifer-deciduous mixed | 19,500 |
| TOTAL | 786,700 |

▲ **Figure 2.14 Breakdown by type of forest cover in the region according to the GAP Analysis datalayer. The forest in this region is dominated by aspen, paper birch and oak.**

| OWNERSHIP | ACRES |
|-----------------------------------------|----------------|
| Public land: WMA, NWR, SNA, State Parks | 62,000 |
| Public land: county and state forests | 166,000 |
| Private | 558,000 |
| TOTAL | 786,000 |

▲ **Figure 2.15 Land ownership in the region. About one-quarter of the forest land are publically managed for forest products. Residues remaining after harvest or thinnings from management activities could be used as a source of biomass.**



▲ **Figure 2.16. Frequency distribution of acres across the CPI.**

Another challenge is maintaining dependable supplies while limiting soil compaction, retaining diversity of residue-dependent soil microorganisms, and lowering nutrient export. The Minnesota Forest Resource Council has developed forest biomass harvesting guidelines to address these sustainability issues. (MN Forest Resource Council, 2007). Bioenergy development that plans to utilize forest feedstocks should consider the current issues to develop mitigation and contingent plans.

Forest acres and yield.

The five-county region contains about 786,000 acres of forest of 37% of the land area. (Figure 2.13). Aspen, paper birch and oak dominate the forest cover (Figure 2.14). Ownership in the region is a mix of private, state and county (Figure 2.15). Public land that is currently managed for forest products is abundant and may fit well with current management goals. ■

GRASSLANDS

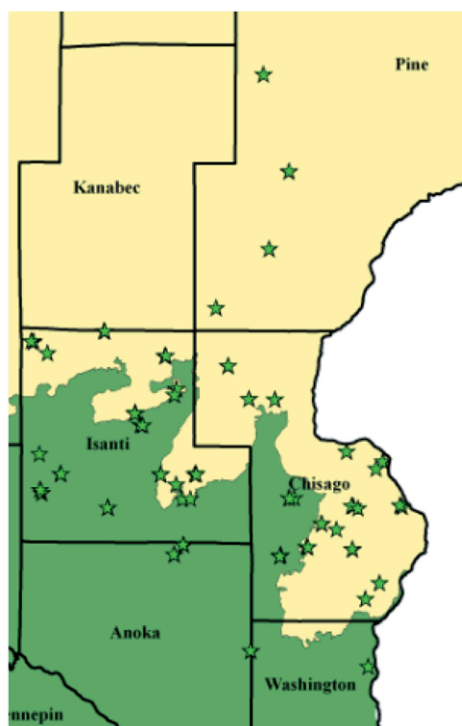
Introduction

Grasslands, such as those enrolled in the Conservation Reserve Program, have been identified as important sources of biomass for bioenergy (Perlack et al, 2005). There are limitations to harvesting these grasslands, which total 1.7 million enrolled acres in Minnesota (FSA, 2007). Yields and feedstock properties vary widely depending upon annual precipitation, soil type and species composition (Schmer 2005; Epstein 1997). To date most studies have examined these grasslands in the context of forage quality, however, such tests are imperfect estimates of feedstock properties of interest for bioenergy production (Jung

and Lamb, 2004). Previous studies have found that Minnesota CRP lands contain significant variation in species within and among sites (Jewett et al 1996, Florine et al 2006). The diversity within these unimproved grasslands provides challenges to agronomists growing the feed-stocks and engineers designing conversion facilities.

Methodology

Baseline data on the availability of grassland biomass is not currently available from the region. In October of 2007 and 2008, crews from the University of Minnesota and Minnesota Conservation Corps surveyed 65 locations within the project region (Figure 2.17). Grasslands were further sub-classified as those dominated by cool-season forage species (C3) (Figure 2.18), such as smooth brome, Kentucky bluegrass, fescue and reed canary grass, and those dominated by warm-season native grasses (C4) (Figure 2.19), such as switchgrass, Indian grass and big bluestem. To select the sites, ArcGIS random location generator (ArcGIS, 2008) was used to place 4-6 sites within each of the major soil and vegetation regions as defined by the DNR Ecological Classification System (DNR, 2005). Local land managers from the US Fish and Wildlife Service, Minnesota Department of Natural Resources and Soil and Water Conservation Districts were used to identify accessible sites nearest to randomly generated locations. At each location a 50x50 m plot was placed near site access and three randomly chosen transects were located within the 50x50m plot using compass and tape. At each transect, which measured 0.75m x 5m, all species were identified and percent cover was taken.



▲ Figure 2.17. Sixty-five sites were harvested within the region on conservation program enrolled grasslands and abandon agriculture lands. Major ecological regions are delineated by color.



▲ Figure 2.19. C4-dominated grassland site. In the project region, many warm-season dominated grasslands are composed of big bluestem, Indian grass, switchgrass and with forbs and legumes.

The transects were harvested at height 3-5cm and weighed onsite. Five soil cores were taken to a depth of 30cm within each transect in 2007.

A 500g subsample was taken from each transect, dried at 60C and weighed to determine dry matter yield. Samples were then reduced with a hammer mill, homogenized and ground to 1mm with a cyclone mill. Plant tissue mineral composition was measured at AgVise Laboratories (Benson, MN) laboratories for N, P, K, S, Cl, Na and Ca. Cell wall carbohydrates were measured using NREL's two-step acid hydrolysis (NREL, 2008). This procedure involved breaking down the cellulosic material with a strong sulfuric acid, applying

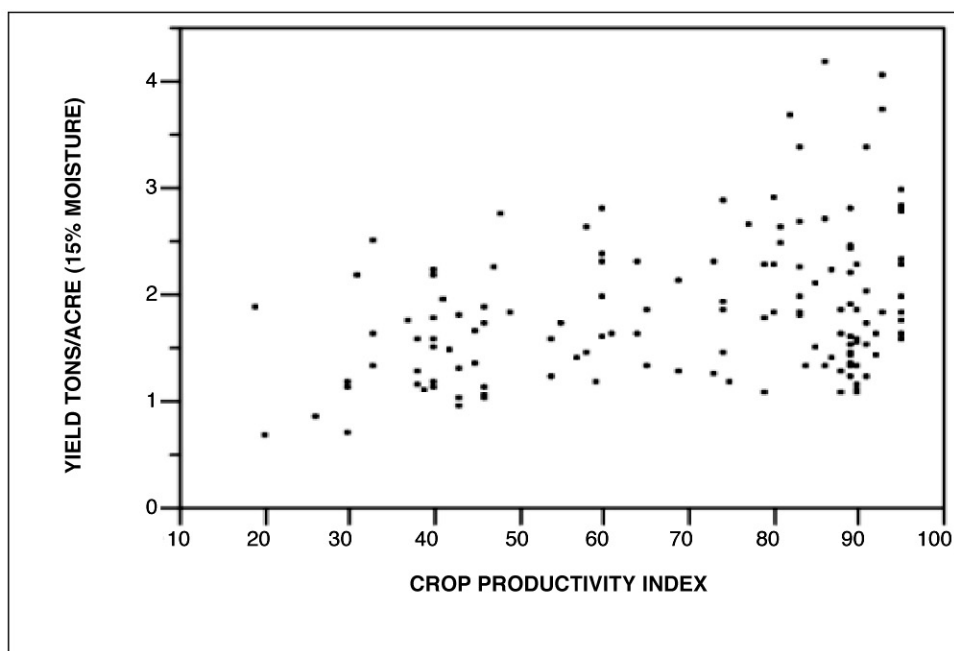
heat and pressure via autoclave and filtering through a glass microfiber. The resulting filtrate is characterized for C5 and C6 sugar (glucose, xylose, galactose, arabinose and mannose) via high performance liquid chromatography (HPLC). Sugar concentration is used to determine theoretical ethanol yield via the National Renewable Energy Laboratory ethanol calculator (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html). The remaining un-fermentable portion left after filtration was combusted and the difference was used to determine lignin concentration. The samples were also weighed, combusted at 430C, and weighed again to determine inorganic (ash) concentration.



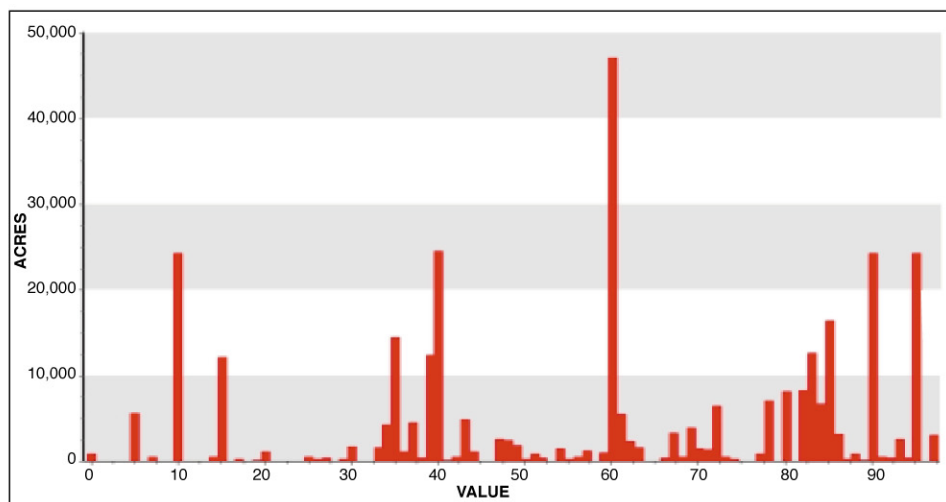
▲ Figure 2.18. C3-dominated grasslands site. Fescue, Kentucky bluegrass, smooth brome, timothy and reed canary grass are dominate species in the project region.

| | 2007 | 2008 |
|--------------|------|------|
| C3-dominated | 1.89 | 1.93 |
| C4-dominated | 1.92 | 1.84 |

▲ Figure 2.20. Grasslands average 1.9 tons per acre (0% moisture) in the region. Yields broken down by year and dominant covertype. Both C3 and C4 covertypes are present in the region on public wildlife areas and private CRP lands.



▲ Figure 2.21. Yield as a function of Crop Productivity Index. The field work conducted in 2007 and 2008 provided data to develop regression; $\text{yield (tons/acre)} = .02(\text{CPI}) + 1.19$.



▲ Figure 2.22. Distribution of CPI ratings from grassland acres in the region.

Results

Biomass yield

Grassland yields for 2007 and 2008 is shown in Figure 2.20. Grassland yield as a function of soil quality via the CPI shows that the yield depends upon a number of factors (Figure 2.21) Cultural practices used to estab-

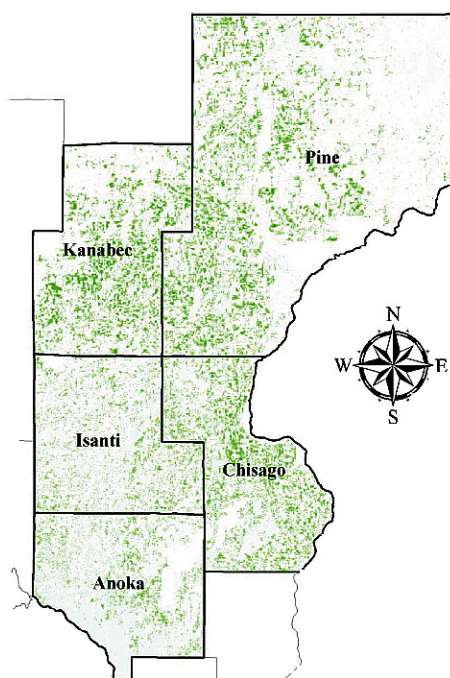
lish the plantings, the types of grassland species present and previous soil management practices may also impact yield. Figure 2.22 shows how CPI ratings vary in regions for grassland acres.

Biomass acreage

According to the USDA Cropland Datalayer, a total of 270,000

acres of grassland and pasture are in the five-county region, however, much of this available land is currently dedicated to other uses, such as hay fields, CRP and public hunting lands (Figures 2.23 and 2.24).

The CRP accounts for a small portion of the grassland in the region (2,600 acres). Currently,



▲ **Figure 2.23. Map of grasslands in project region.** 270,000 acres of grassland are in the five-county region. These include conservation lands, hayfields, public wildlife management areas and abandon agricultural fields.

the CRP acres are not available for harvest except under emergency grazing and haying conditions during droughts (FSA, 2007). Wild hay production for animal bedding and feeding are competing interests for lower-value grassland biomass feedstocks. According to the USDA National Agricultural Statistics Service, 85,000 acres in the region are currently dedicated to non-alfalfa hay production (NASS, 2008). Currently these lands are used for forage production and will only contribute to bioenergy production with significant impacts on the livestock forage supply. Many of these grasslands are also managed public hunting areas or preserves. Public grasslands under management by the DNR and USFWS total 3,000 acres. These acres are currently managed for

| GRASSLAND SOURCE | ACRES |
|---------------------------------------------|----------------|
| Conservation Reserve Program | 2,600 |
| WMA,WPA and National Wildlife Refuges acres | 3,000 |
| Non-alfalfa hay lands | 76,000 |
| Pasture land and other | 188,000 |
| TOTAL | 270,000 |

▲ **Figure 2.24. Grassland management in the region is a diverse mix of hay fields, set-aside programs and public wildlife acres.**

wildlife habitat and conservation and would not likely contribute to biomass supply within the region. Lastly, little information exists on pastureland within the region, these lands would likely not contribute to biomass without significant impacts on dairy and beef production. Taking into consideration all these regulations and competing interest, approximately 264,000 acres are currently available for production.

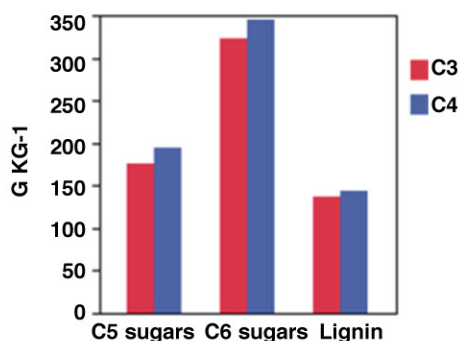
Feedstock properties

High yields relative to other sources of biomass that could be achieved on the same landscape are important drivers of the types of biomass produced. Grasslands in the region produce about 1.9 tons (0% moisture) per acre with minimal inputs on marginal soils ill-suited for row crop production (Figure 2.20). With these yields, about 176 gallons of ethanol could theoretically be produced. Compared to corn-grain ethanol, which is the beneficiary of breeding, increased inputs and often grown on higher quality soil, about 288 gallons per acre could be produced with region average yields of 108 bushels.

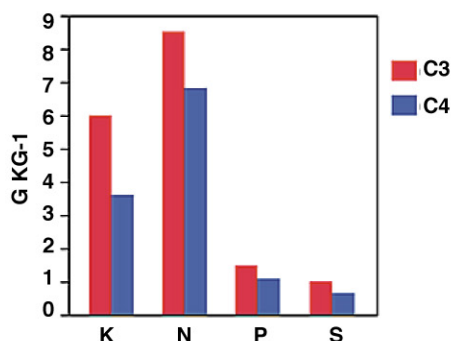
Feedstock properties are impor-

tant in engineering of the conversion facility and sustainability of the supply. The specific material properties of interest are dependent upon the conversion platform and include moisture content, ash content, mineral composition and cellulose/lignin ratio (McKendry, 2002). To covert biomass into sugars accessible to microorganisms for fermentation into ethanol, biomass with high cellulose and low lignin concentrations is desired. The cellulose portion is broken down by thermochemical pretreatment and then made available to microorganisms with highly-specific enzymes. The lignin portion is not as easily degradable and not available for fermentation. Therefore, feedstocks that have higher concentration of cellulose in relation to lignin will increase the ethanol yield per ton of biomass (Figures 2.25 and 2.26). Additionally, homogeneous feedstocks that can be processed using the same type of enzymes are important for efficient conversion and lowered costs.

Lignin comprises anywhere from 10% to 25% of the biomass on a dry weight basis. Generally, herbaceous feedstocks, such as grass, have lower lignin concentration than woody feedstocks, such as forest residues. In the project region, lignin concentration was about 15% on a zero-moisture basis for grassland or about 0.20 tons of lignin per acre are harvested, processed and utilized at the ethanol facility (Figure 2.23) Currently, engineers propose combusting the lignin and producing electricity and heat for the conversion plant and selling excess electricity to the grid. There are several challenges to using this lignin. The lignin portion does contain inorganic minerals which yield ash after combustion. Approximately, 30% of the residue remaining



▲ Figure 2.25. Fermentable sugar concentration is slightly different between C4- and C3- dominated grasslands. These graphs are read as part per thousand on a zero-moisture basis (i.e. 100 g/kg equals 10%)



▲ Figure 2.27 . Nutrient concentration of C3 and C4 dominated grasslands.

after fermentation is ash by weight. The high silica content of the ash can cause problems in the boiler or gasifier chamber. In addition, several thousand tons of ash will have to be dealt with at the facility.

Thermochemical feedstock conversion, either by gasification or combustion, requires information about the calorific value, and ash, moisture and nutrient concentration of the biomass. The combustion of biomass produces ash residue, which is anywhere from 2-8% of the biomass on a dry weight basis, and may increase operating and/or disposal costs (McKendry, 2002). Ash may form a liquid mobile phase at elevated temperatures called

| SOURCE | YIELD (TON/ACRE, 0% MOISTURE) | ETHANOL CONCENTRATION (GALLONS/DRY TON) | ETHANOL YIELD (GALLONS/ACRE) |
|--------------|-------------------------------|-----------------------------------------|------------------------------|
| C3-dominated | 1.85 | 87 | 161 |
| C4-dominated | 1.85 | 94 | 174 |

▲ Figure 2.26. Due to the higher sugar concentrations, theoretical ethanol yield is higher for C4 dominated grasslands. This increase in sugar concentration, equate to an additional 13 gallons per acre advantage of C4 dominated grassland over C3 dominated grasslands.

| | NITROGEN (LBS/ACRE) | PHOSPHORUS (LBS/ACRE) | POTASSIUM (LBS/ACRE) | SULFUR (LBS/ACRE) |
|--------------|---------------------|-----------------------|----------------------|-------------------|
| C3-dominated | 32 | 5 | 22 | 4 |
| C4-dominated | 25 | 4 | 13 | 2 |

▲ Figure 2.28. The mineral concentration of the plant tissue export nutrients from the grassland that have to be replaced through fertilization or, in the case of nitrogen, through nitrogen-fixing legumes.

'slag,' thereby reducing plant throughput. The ash content may be inherent in the biomass material or the result of harvesting, such as soil contamination of the feedstock. The grasslands in the biomass region averaged 6% ash on a dry weight basis.

Calorific values are defined as the heat value of the 0% moisture biomass when combusted in air. The higher heating value (HHV) of the biomass is a measure of the energy content per unit mass, including the latent heat in the water vapor. For most conversion technologies the latent heat cannot be used effectively, therefore, the lower heating value (LHV) is the one often used. Most biomass feedstocks have LHVs of 17-19 MJ/kg and are processed thermochemically at moisture contents of <20% (McKendry, 2002). The LHV of the grassland biomass in the project region is ~18 MJ/kg and could be delivered to the plant in bales of 15-18% moisture.

The nutrient concentration of the

biomass feedstock is important for future decisions about soil fertility and pollution-abatement equipment at the conversion facility. High levels of nutrients in the biomass, such as nitrogen and phosphorus, can 'mine' the soil of important minerals. Reapplying the nutrients to the harvest site has been suggested. See figure 2.28 for nutrient concentrations in the project area.

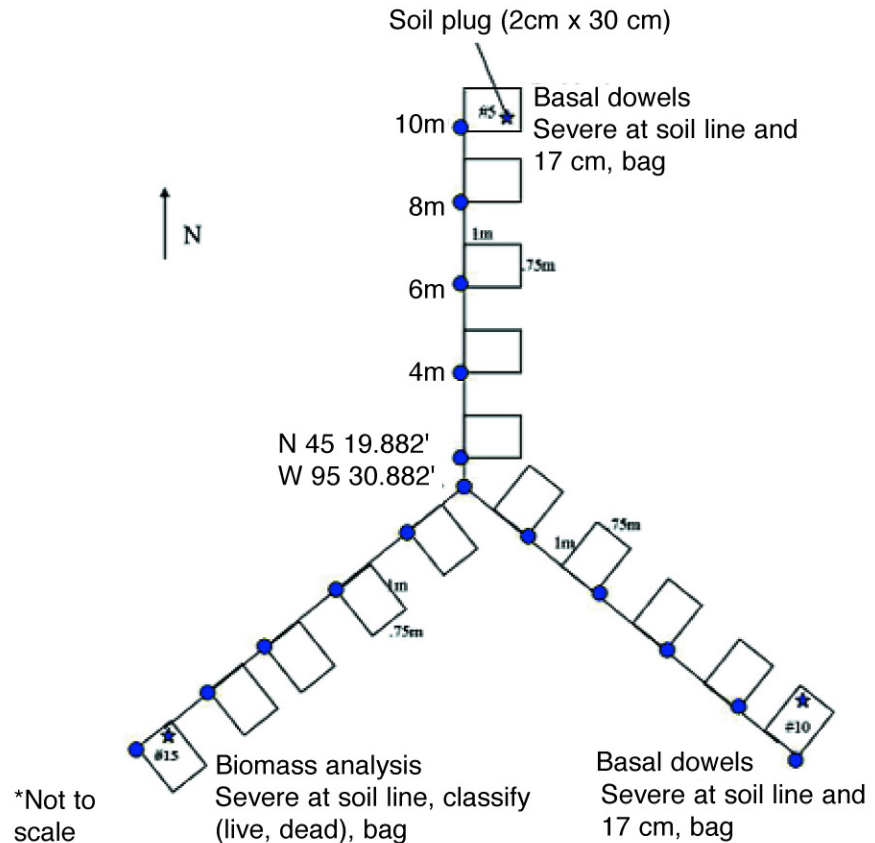
These nutrients have to be replaced on an annual basis through fertilization with manure, inorganic sources or in the case of nitrogen, by N₂-fixing leguminous species. To reduce the levels of these nutrients in the feedstock, a dormant season harvest after a killing frost and before spring growth is recommended. However, the high precipitation and low temperatures during this period may make harvesting and drying the biomass to baling moisture conditions difficult (Adler et al, 2006). At a thermochemical conversion facility, feedstocks with high nutrient concentrations may lead to nitrous- and sulfur-oxides

formation and require appropriate mitigation equipment. Figure 2.28 illustrates the amount of some macronutrients removed from a post-killing frost harvest. ■

BRUSHLANDS

Introduction

Brushlands are seral communities of short-lived, multi-stemmed woody species. In the project region upland brush communities are comprised of hazel (*Corylus* spp), aspen (*Populus tremuloides*) and oak (*Quercus* spp). These species occur in regions of recent disturbance, such as fire or grazing, and often are found at transition periods between grassland and forest (Figure 2.29). Lowland brushlands occur in wetlands and are dominated by alder (*Alnus* spp), willow (*Salix* spp) and dogwood (*Cornus* spp) (Figure 2.30). Like their upland counterparts, many lowland brushlands are maintained through disturbance, such as periodic flooding. These brushlands can occur on the edges of lakes and bogs, on the transition between open water and upland forest, or in wetlands that are seasonally dry. In the region, most lowland brushlands were found to be between 8 and 12 years old. Periodic flooding from high or prolonged rainfall events or beaver activity, are the main disturbances. About 223,000 acres of brushland are present in the region (Figure 2.33). Currently, brushland harvesting is limited to sheering for wildlife habitat for such species as ruffed grouse or woodcock. Equipment and technical recommendations for brushland harvesting are limited. Research by the Department of Natural Resource and University of Minnesota are ongoing to determine the feasibility of utilizing this expansive source of biomass.



▲ Figure 2.31. Diagram of harvest plots for fifty-one brushlands within region.



▲ **Figure 2.30. Lowland brushland dominated by alder (*Alnus* spp), willow (*Salix* spp) and dogwood (*Cornus* spp).**



▲ **Figure 2.29 Upland brushland dominated by hazel (*Corylus* spp), Aspen (*Populus* spp), and oak (*Quercus* spp).**

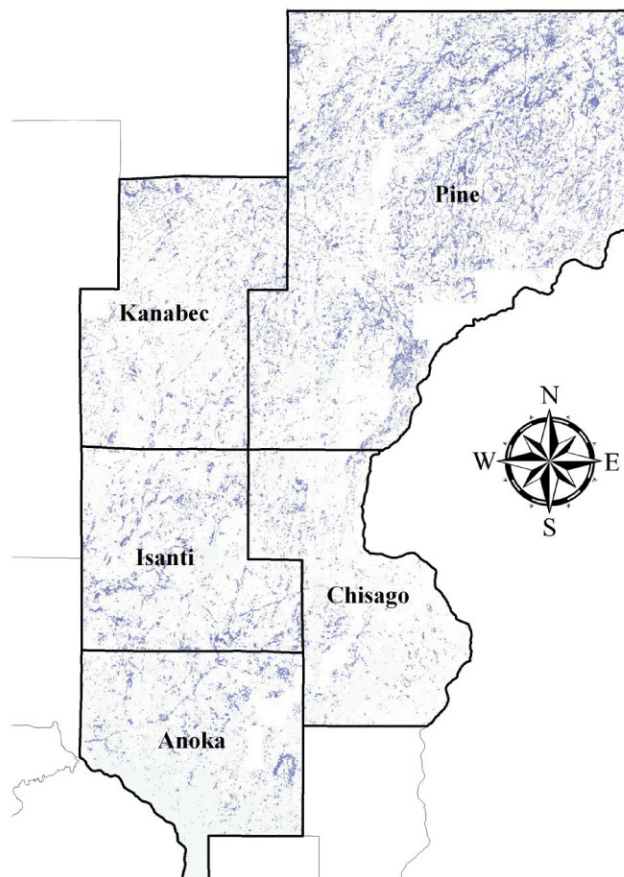
Methodology

During the winter of 2008, fifty-one brushland plots were sampled. Randomly chosen sites within both upland and lowland brushlands were chosen with ArcGIS random location generator (ESRI, 2008). Local land managers from Soil and Water Conservation Districts, Department of Natural Resource

and USFWS provided access to sites. GPS locations at least 100 meters from ditches or roads were randomly chosen within the sites and three transects were established (see sampling diagram in figure 2.31). Five 1m² plots were established at each transect. Within each 1m² plot all species were identified and stems counted. Mortality status

| BRUSHLAND TYPE | CURRENT STANDING BIOMASS (0% MOISTURE TON/ACRE) | ESTIMATED ANNUAL PRODUCTIVITY (0% MOISTURE TON/ACRE/YR) |
|----------------|----------------------------------------------------|------------------------------------------------------------|
| Upland | 2.7 | 1.0 |
| Lowland | 4.2 | 1.2 |

▲ **Figure 2.32. Current standing brush which include both standing dead and actively growing brush. Through ring counts the project was able to estimate the annual productivity of the brushlands.**



◀ **Figure 2.33 Brushlands within the region. Note that many of the brushlands are geographically isolated and therefore, not conducive to commercial harvesting.**

was recorded to determine actively growing stock from standing dead. At 15cm from soil level or root crown the diameter (mm) was taken and yield determined using diameter-to-mass equations from published studies conducted in Minnesota (Connelly and Grigal, 1985, Ohman et al, 1977, Ohman and Grigal, 1986) Two plots per site were harvested completely, dried, ground and used to determine moisture content and feedstock properties. Analytical techniques for deter-

mining feedstock properties are identical to those described in the Grassland Biomass section.

Cross-sections of the stems from two plots were taken to determine annual ring count. Live stems were sorted by species and growth rings were counted using dye and a dissecting scope. Approximately, 75 stems were counted for each species. Regression equations were developed on a species-specific basis to estimate age via diameter.

Annual productivity (tons/acre) was determined by subtracting predicted 2006 diameter from observed 2007 diameter. For example, in 2007 the diameter for a single willow stem is 50 mm and contains eight growth rings, or years. The polynomial regression equations estimate that one year ago (age seven) the same willow in this stand was approximately 40 mm in diameter. The difference in mass between a seven and an eight-year old willow is then determined from a diameter-to-mass equation and stand density used to determine mass per acre.

Results

Yield

Current standing and annual productivity of brushlands are presented in figure 2.32. The brushlands were further classified into 1) upland and 2) lowland brushlands. These are estimates from plots taken on Sherburne National Wildlife Refuge and state and county forests.

The Crop Productivity Index is not related to yield for brushland. The CPI is based on SSURGO maps which are derived from soil surveys that better classify the upland, agriculturally-important soils. The physical and biochemical properties of lowland soils, where the majority of the brushlands in the project area occur, are not classified in detail. Yields in the project region were based on field work and estimated to be approximately 2.2 tons as delivered per acre per year annualized over 10 year harvest schedules.

Acreage

Totaling 223,000 acres, brushlands occupy about 10% of the landscape in the five-county region (Figure 2.33). About 17,000 acres of brushland are on state and county public land; the

| SOURCE | C5% SUGAR | C6% SUGAR | % LIGNIN |
|---------------|-----------|-----------|----------|
| Upland brush | 13 | 41 | 13.5 |
| Lowland brush | 13 | 41 | 14 |

▲ **Figure 2.34. Feedstocks of interest for biochemical conversion, such as cellulosic ethanol.**

| SOURCE | YIELD (ZERO-MOISTURE TON/ACRE) | ETHANOL CONCENTRATION (GALLONS/TON) | ETHANOL YIELD (GALLONS/ACRE) |
|---------------|--------------------------------------|-------------------------------------------|---------------------------------|
| Upland brush | 3.9 | 95 | 371 |
| Lowland brush | 5.5 | 95 | 523 |

▲ **Figure 2.35. The upland and lowland brush are nearly identical in terms of sugar concentration, however, the increased yields of lowland sites provide a distinct advantage over upland sites.**

| SOURCE | MOISTURE % | ASH % | LHV | N% | P% | K% | S% |
|---------------|------------|-------|------|-----|-----|-----|-----|
| Upland brush | 45 | 1.7 | 18.5 | .55 | .08 | .26 | .03 |
| Lowland brush | 48 | 1.8 | 18.5 | .57 | .07 | .17 | .04 |

▲ **Figure 2.36. Feedstock properties of interest for thermochemical conversion routes, such as gasification.**

| SOURCE | NITROGEN (LBS/ACRE) | PHOSPHORUS (LBS/ACRE) | POTASSIUM (LBS/ACRE) | SULFUR (LBS/ACRE) |
|---------------|------------------------|--------------------------|-------------------------|----------------------|
| Upland brush | 11 | 2 | 5 | <1 |
| Lowland brush | 13 | 2 | 4 | <1 |

▲ **Figure 2.37. The nutrient content of the feedstock is important for maintaining soil fertility. The amount of nutrient removed annually from brushland-derived biomass.**

larger sites within county and state forest land are the best candidates for harvesting as these sites may best fit with current management objectives. The majority of brushland acreage is unmanaged and provides wildlife habitat and water quality protection, among other ecological services. The potential of this landscape to produce biomass for bioenergy production, while maintaining its functional role in the ecosystem, deserves further investigation.

Upland brushlands occupy 8,000 acres while lowland brushlands

occupy 215,000 acres in the region. In reality, the quantity would not be available to conversion facilities due to a number of economic and technical criteria. Firstly, brushland-derived feedstocks are currently non-existent due to the economic constraints of harvesting. Current harvest protocol consists of bulldozers which shear and windrow the brush under frozen soil conditions. Many lowland soils do not freeze completely to withstand heavy equipment loads. If the soils conditions are suitable, there are technical difficulties of transporting bulky shrubs to a

landing area where densification (i.e., chipping) and loading occur. The harvest site must also be sufficiently large to make equipment transport worthwhile. Local experts from the University of Minnesota-Duluth suggest that at least four-days of work or approximately 200 acres of well-stocked brushland would need to be available to warrant transporting equipment to the location (B. Berguson personal communication, 2008). Lastly, little information is known about the amount of standing brushland needed to maintain refuge areas for wildlife within a harvest site.

Feedstock properties

For a detailed description of the analytical methods used and the importance of feedstock properties see the Grassland Biomass section. Feedstocks of interest are presented in figures 2.34 - 2.37. ■

DEVELOPING AND HARVESTING NATIVE GRASSLAND PLANTS

Native grasslands in the region could provide a perpetual supply of biomass with limited inputs of fertilizer and pesticides. The biomass could be produced on a range of soil types and could provide auxiliary environmental services such as wildlife habitat and water purification. Biological surveys conducted during this project also show that grasslands in the region produce more annual biomass per acre than do most brushlands, and literature surveys suggest that they would also produce more than woodlands. Therefore, grasslands should be considered as part of the future bioenergy plans for the region.

However, a limited amount of native grassland is presently available in the area-or for that

matter elsewhere in the entire state. Therefore, plans to use low-maintenance native grasslands for future bioenergy must begin with plans for planting. That leads to two issues; 1) obtaining suitable seed, and 2) producing it in sufficient quantity to cover a large enough portion of the landscape to contribute significantly to the energy future and ecosystem health of the region.

Land presently idle in the region that is potentially available for grassland bioenergy totals 77.3 square kilometers or about 19,000 acres (Figure 2.38). Suppose 16,000 of those acres would actually be available, and assume enough suitable local native seed could be sustainably harvested from available sources, including restored prairie areas in Wild River State Park, to sow one-quarter section of new native grassland each and every year (160 acres). With a simple direct seeding that would require a prohibitive 100 years to complete the project. Therefore, a *bootstrapping* approach should be applied, using seed from recently established areas to sow subsequent areas. Under that approach the same result could be accomplished in as little as 10 years. (Figure 2.39).

The scenario represented in Figure 2.39 assumes that each year 160 new acres are seeded from the existing lands in the region, then seed is taken from the newly established lands as seed becomes ready. New lands are assumed in this scenario to produce no seed until they are two years old. Then each acre of 2-year old prairie is taken to produce enough seed to establish one more acre (1:1 ratio), each acre of 3-year old prairie to establish 2 acres (2:1), and each acre of 4-year and older prairie to establish 3 acres (3:1 ratio). Also in this scenario, each year

| ID | AREA (KM ²) | AVAILABLE (KM ²) | RATIO | COUNTY |
|--------|-------------------------|------------------------------|-------|---------|
| C27025 | 1,146 | 24.6 | 2.1% | Chisago |
| C27059 | 1,170 | 23.2 | 2.0% | Isanti |
| C27115 | 3,716 | 29.5 | 0.8% | Pine |

▲ **Figure 2.38. Idle land potentially available for biofuel, based on USDA census reports of idle land, minus CRP land not suitable for biofuel. Columns: ID, county identification code; Area, total area of the county, square kilometers; Avail, land available for biofuel production, square kilometers; Ratio, fraction of land available, percent; County, name of the county.**

| YEAR | NEW (ACRES) | AGE 1 (ACRES) | AGE 2 (ACRES) | AGE 3 (ACRES) | AGE4+ (ACRES) | TOTAL (ACRES) |
|------|-------------|---------------|---------------|---------------|---------------|---------------|
| 1 | 160 | 0 | 0 | 0 | 0 | 160 |
| 2 | 160 | 154 | 0 | 0 | 0 | 314 |
| 3 | 160 | 154 | 149 | 0 | 0 | 464 |
| 4 | 309 | 154 | 149 | 144 | 0 | 758 |
| 5 | 598 | 299 | 149 | 144 | 139 | 1,331 |
| 6 | 1,017 | 578 | 289 | 144 | 274 | 2,304 |
| 7 | 1,562 | 983 | 559 | 279 | 405 | 3,790 |
| 8 | 2,494 | 1,510 | 950 | 540 | 662 | 6,158 |
| 9 | 4,178 | 2,411 | 1,460 | 919 | 1,162 | 10,131 |
| 10 | 6,946 | 4,039 | 2,330 | 1,411 | 2,012 | 16,740 |

▲ **Figure 2.39. Establishment of 16,000 acres of grasslands using seed from recently established grasslands to sow subsequent areas.**

approximately 3% of the established prairies are assumed to be lost to some cause, for example to withdrawal of the land for other purposes such as housing (30-year average longevity of the prairie). More or less existing land made available as a continual seed source would reduce or increase the time needed to establish 16,000 acres.

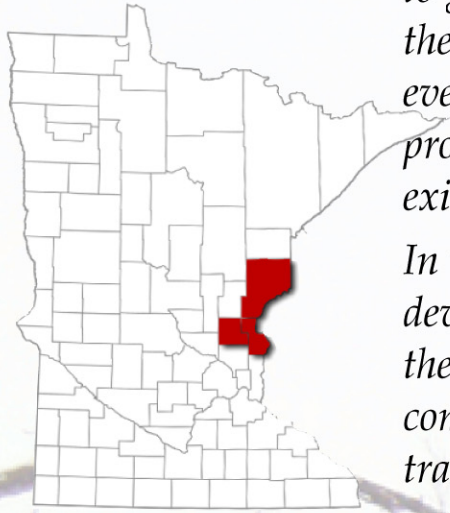
Seeding a large area across the region presents several opportunities and challenges. Federal and state land management policies now emphasize protecting the structure and function of natural ecosystems by restoring lands and roadsides to native plant species whose geographical origin is known and verifiable (*identity-preserved*). Seeds could be collected and processed with methods that preserve the identity of the seeds, thereby providing potential addi-

tional markets for the seed. Also, the bootstrapping method will favor species that set seed late in the season, near harvest time, at the expense of early-seeding species, such as certain legumes that have useful biofuel properties. The challenge is to maintain diversity as seed is collected from newly established areas, and the opportunity is for local seed companies or local landowners to supply supplemental seed to maintain species diversity. There is also an opportunity for directed research to develop the best practices and management techniques for fields that are used simultaneously for bioenergy and seed production.

The ultimate idea is to provide controlled seed sources and methods that expand with, stays ahead of, and informs the developing restoration and bioenergy industries. ■

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BIOMASS SUPPLY MODEL

Hundreds of thousands of tons of biomass are currently growing in the project area. None of this biomass, however, is currently being used for energy production, because no facility exists that is willing to pay the price to get landowners to cultivate and harvest the necessary feedstock. Price is insufficient even to encourage landowners to collect, process, and haul waste materials from existing land management activities.

In this section, a new biomass supply model developed for this project is used to estimate the delivered cost for each feedstock by combining production, harvest, and transportation costs from each field in the project area. The logic of the analysis is simple: if the price offered by a bioenergy plant is high enough, a field's owner will grow desired feedstock. As price increases, more expensive biomass will be made available. In addition, different lands will be converted to biomass feedstock production, which could alter the environmental profile of the landscape if land uses are changed from current levels and locations.

The analysis determines where biomass feedstocks might be grown, given different scale and feedstock scenarios and permitting crop-switching in response to price changes. It also shows how resulting prices affect the financial performance of bioenergy plants and how these plants influence the flow of environmental services within the project area.

THE MODEL

NOTE: *The biofuels facility modeled here is in the City of North Branch, Chisago County. The project area for the purposes of this section are the three counties in the consortium, plus Kanabec and Anoka Counties. Potential deliveries from outside the project area are not considered here.*

The core of the biomass supply schedule estimation is a spreadsheet model that mimics farmer crop selections for each field at each biomass price level. The essential components are crop choices, crop yields, crop production costs (including shipping and handling), and crop prices. Farmers are assumed to select that crop that promises the highest annual net return. The entire procedure is designed to produce essentially one chart: the delivered volume of feedstocks for each feedstock price level. (Specific questions on the model should be addressed to Steven J. Taff, sjtaff@umn.edu.)

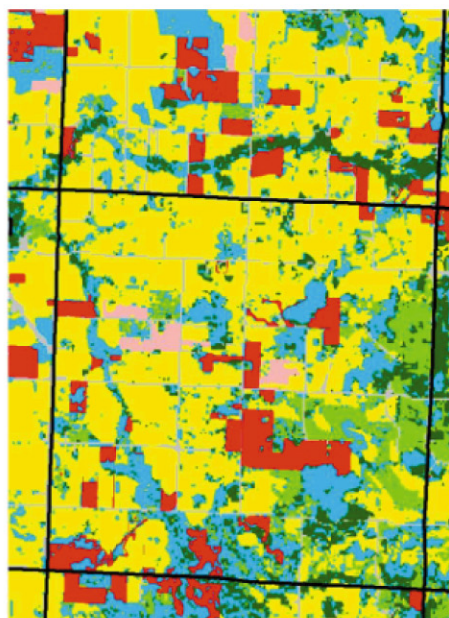
Crop choices

The *major land use* categories mapped in Section 2 form the geographic core of the model. In the estimation of supply curves themselves, we disaggregate these categories somewhat: corn grain only, corn grain with stover harvest, stover harvest only, soybeans, wheat, sugar beets, brushland, short rotation woody crops (hybrid poplar), and forest residues. (Non-harvestable public land and CRP lands are held unchanged, reflecting the ownership and contract relationships.)

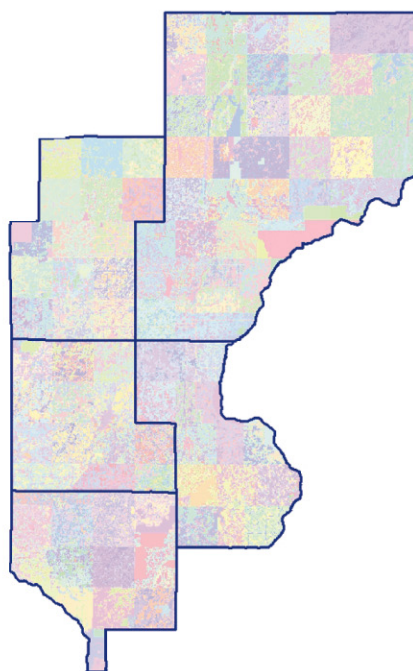
Field delineation

Decisions on crop selection are made at the multi-acre field level. There are literally thousands of real fields in the project area, far too many to represent with any

plausibility. In the model, a *field* is defined as all acres of a given major land use in a given township. Figure 3.1 shows a single township for illustration. In the example, Field #1 is defined as all annual crop acres (yellow) in the township, Field #2 as all brushland acres (yellow green), #3 as all



▲ **Figure 3.1: Example of field delineation.**



▲ **Figure 3.2: Overview of project area fields**

CRP acres (red), and so forth. Most townships have only a subset of these potential uses at present: there are 1,116 fields so-defined in the project area. The fields are mapped in Figure 3.2. The colors in this figure are chosen simply to distinguish field boundaries. If one zoomed into any township, the fields would show detail similar to Figure 3.1.

Field productivity

In order to estimate potential crop yields, we employ the new Minnesota Cropland Productivity Index (CPI) scores detailed in Section 2. These range from 0 (worthless for annual crops) to 100 (the *best* soil in the county). Values for each Minnesota soil, as well as aggregated averages for any desired geographic area, are available at Minnesota Land Economics: <http://landeconomics.umn.edu>, in the Soils Data section.

Combining the CPI and the fields maps, the acreage-weighted CPI for each of the 1,116 fields, using the assigned CPI for each soil that lies within that field, was calculated.

Crop yields

In the previous section, a relationship between productivity and NRCS crop yield was charted, and a linear relationship was calculated for each crop in each county, for the region, or for the state as a whole, depending upon data availability. The resulting parameters are repeated in Figure 3.3 for corn, soybeans, and spring wheat, the crops for which NRCS data is available, and for low-fertilization grasses/legumes and brushland from the field work summarized in the previous section. Expert opinion was relied upon for SRWC, high-fertilization grasses, and forest wood.

The relationship takes the following form: $\text{yield} = \text{intercept} + (\text{CPI} \times \text{slope})$. For example, if a field has a CPI of 50, its annual high

fertilization grasses yield was estimated to be $2 + (50 \text{ times } .04) = 4$ tons per acre per year. These equations were used to estimate a yield for each crop on each field, for use in the profit estimation process discussed in a subsequent section.

Crop production budgets

Recently developed regional production budgets from the University of Minnesota (Lazarus (a) and (b)) were used to estimate costs for producing each crop in each field. These costs are summarized in Figure 3.4. Corn budgets are available for the East Central region, in which the project area lies. For wheat, which is not a major crop in the project area, the West Central wheat budget was used. The same held for soybeans.

The UM production budgets include, for the first time, estimates of establishment and maintenance costs for corn stover harvest, low-fertilization (prairie) and high-fertilization (switchgrass) perennial crops, as well as for short rotation woody crops, represented in the UM budgets by hybrid poplar production. These cost estimates are not region-specific: the statewide estimates are used in this report.

All costs, including establishment, are annualized. The UM budgets include \$3 per zero-moisture ton for transportation; this is removed from the harvest machinery budgets in the table. In the model, forest wood and brushland harvests are each assumed to incur additional \$2/T costs for each stage of handling: loading, unloading, and stacking (stumpage prices are \$30/cord). All products are assumed to bear a \$5/T storage cost. Hauling costs \$0.15/T/mile, and mileage is calculated as rectangular distance between the center of each field and the plant at North Branch.

| | ANOKA | | CHISAGO | | ISANTI | | KANABEC | | PINE | |
|------------------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | INTERCEPT | SLOPE | INTERCEPT | SLOPE | INTERCEPT | SLOPE | INTERCEPT | SLOPE | INTERCEPT | SLOPE |
| Low fertilization grasses/legumes (tons) | 1.2 | .02 | 1.2 | .02 | 1.2 | .02 | 1.2 | .02 | 1.2 | .02 |
| High fertilization grasses (tons) | 1 | 0.4 | 1 | 0.4 | 1 | 0.4 | 1 | 0.4 | 1 | 0.4 |
| Corn grain (bushels) | 9 | 1.53 | 47 | .75 | 28 | 1.23 | 58 | .69 | 28 | 1.23 |
| Corn stover (tons) | .13 | .02 | .66 | .01 | .39 | .02 | .81 | .01 | .39 | .02 |
| Soybeans (bushels) | 10.9 | .34 | 17 | .2 | 11 | .33 | 16 | .22 | 11 | .33 |
| Wheat (bushels) | 23 | .31 | 23 | .31 | 23 | .31 | 23 | .31 | 23 | .31 |
| SRWC (tons) | 1 | .4 | 1 | .4 | 1 | .4 | 1 | .4 | 1 | .4 |
| Forest wood (tons) | .5 | .9 | .5 | .9 | .5 | .9 | .5 | .9 | .5 | .9 |
| Brushland (tons) | 22 | 0 | 22 | 0 | 22 | 0 | 22 | 0 | 22 | 0 |

▲ **Figure 3.3: CPI/Yield equations used in yield estimates for Chisago-Isanti-Pine project area (as-received moisture)**

| Costs per acre | CORN GRAIN | CORN GRAIN WITH STOVER HARVEST | SOYBEANS | WHEAT | HIGH-FERTILIZATION GRASSES/LEG. | LOW-FERTILIZATION GRASSES | SRWC | BRUSH-LAND | TIMBER |
|------------------------------------------|------------|--------------------------------|----------|-------|---------------------------------|---------------------------|------|------------|--------|
| Preharvest machinery | 35 | 35 | 35 | 59 | 7 | 6 | 31 | 0 | 0 |
| Seed (for grasses, amortized stand est.) | 75 | 75 | 40 | 22 | 4 | 12 | 10 | 0 | 0 |
| Fertilizer & lime | 112 | 153 | 16 | 77 | 56 | 10 | 16 | 0 | 0 |
| Crop chemicals | 22 | 22 | 24 | 38 | 2 | 1 | 9 | 0 | 0 |
| Crop insurance | 20 | 20 | 13 | 9 | 0 | 0 | 0 | 0 | 0 |
| Miscellaneous | 6 | 5 | 8 | 5 | 8 | 8 | 8 | 0 | 0 |
| Harvest machinery | 33 | 81 | 27 | 17 | 41 | 26 | 49 | 30 | 30 |
| Non-machinery labor & management | 46 | 50 | 30 | 22 | 32 | 24 | 58 | 5 | 5 |
| Interest on preharvest var. costs | 12 | 12 | 5 | 8 | 5 | 4 | 7 | 0 | 0 |

▲ **Figure 3.4: Crop budgets used in supply schedule estimation (dollars per acre per year)**

Source: Lazarus (a) and (b). Adapted by the authors for brushland and forest wood and by the CIP Steering Committee for corn.

To reflect the (unknown) effects of different soils and landscapes on production costs, fertilizer and harvest machinery costs from the UM budgets are adjusted by the field's expected yield relative to the state average yield. This implicitly makes the cost of pro-

duction a direct function of land productivity: more highly productive fields will have higher yield expectations, which in turn lead to higher harvest costs and more required nutrient replacements to make up for removed materials. Because there exists no consistent annual rent information for the

BIOMASS SUPPLY MODEL

project area, the detailed land value database underlying Minnesota Land Economics (<http://landeconomics.umn.edu>) was used to estimate rents. The county average 2008 estimated land value for each county's farmland is multiplied by a capitalization rate of 5% to estimate *typical* annual rents in the area. (*Real* capitalization rates can vary widely around this average.) The county rent is then adjusted by the relative CPI for each field: for example, if the county rent is \$90 and the field has a weighted average CPI of 70 (out of a hundred), a rent of \$63/acre/year was assigned to that field.

Landowner crop selection decision

The task is to predict what a profit-maximizing landowner would plant in each field, given the field's production characteristics and prevailing (or hypothetical output) prices. The model supposes a situation where landowners are deciding which crop to grow, not whether or not they want to stay in business. Consequently, land rent is treated as a fixed cost that is ignored in the crop selection decision — only the actual cost of growing and harvesting each crop is considered. Because the interest here is only in crop switching and residue harvest decisions, a condition that net revenues less rent must be positive for a change to occur is appropriate. This is the same as setting the standard financing condition that gross revenues must exceed average variable costs for the firm to continue operation. Thus, the landowner is modeled as staying in business even if expected profits are negative. Of course, in the long run this situation would not be expected to hold; the landowner would look for other income opportunities, including selling the land. Corn stover is a special case. In

| | MARKET PRICE PER BUSHEL | MARKET PRICE PER TON | HARVEST INTERVAL (YEARS) | ESTABLISHMENT PERIOD | STAND LIFE |
|-----------------------------------------|-------------------------------|----------------------------|--------------------------------|-------------------------|---------------|
| Corn stover | | \$10.00 | 1 | N/A | 1 |
| Corn grain | \$4.00 | \$142.86 | 1 | N/A | 1 |
| Low fertilization grasses/legumes | | \$10.00 | 1 | 4 | 20 |
| SRWC | | \$10.00 | 8 | N/A | 16 |
| Forest wood | | \$10.00 | 50 | N/A | 50 |
| Brushland | | \$10.00 | 10 | N/A | 10 |
| High fertilization grasses | | \$10.00 | 10 | N/A | 10 |
| Wheat | \$6.50 | \$216.67 | 1 | N/A | 1 |
| Soybeans | \$9.25 | \$308.33 | 1 | N/A | 1 |

▲ **Figure 3.5: Baseline prices used in supply curve generation (as-received basis)**

the model, stover collection occurs only if the net revenue from combined stover and grain exceeds grain alone OR if stover alone exceeds grain alone or grain plus stover. Grain alone need not necessarily show positive returns; it is sufficient that the combined returns be positive if stover is to be delivered. All costs for corn production are allocated to the grain, except certain stover harvest costs and any nutrient replacement costs due to stover removal.

The model assumes complete removal for each crop, roundwood in forested areas included. The harvest levels are only those that occur as a result of the biofuels plant paying sufficiently to obtain product. We first calculate, for a given price, which lands would be harvested at that price, then divide that total by the appropriate number N of years in the rotation interval (see Figure 3.5) to obtain the average volume supplied each year to the plant. Forest wood,

brushland, and SRWC are modeled to be harvested at 50, 10, and 8 year intervals, respectively. One can think of the entire set of responding fields as a new biofuels procurement project that is scheduled to be harvested at a rate of 1/N of the acres each year.

Crop prices

Default prices, those that are held constant as the price of the feedstock in question is varied, are those expected to prevail over the next several years in the project area. In this version of the model, crop prices are independent; for example, corn and soybean prices are not linked. Furthermore, local commodity prices are not sensitive to the actions of the biofuels plant; it is assumed that even the purchase of several hundred thousand tons of material from the local market will not affect the region-wide prices, because even this is a relatively *small* amount of material compared to the production possibilities of the project area.

| FROM: | Annual crops | Grass | Trees | Water | Urban | Brush | Beets | CRP | Public |
|-----------------------------------|--------------|-------|-------|-------|-------|-------|-------|-----|--------|
| TO: | | | | | | | | | |
| Corn | X | X | | | | | | | |
| Low fertilization grasses/legumes | X | X | | | | | | | |
| SRWC | X | X | | | | X | | | |
| Forest wood | | | X | | | | | | |
| Brushland | | | | | | X | | | |
| High fertilization grasses | X | X | | | | | | | |
| Wheat | X | X | | | | | | | |
| Soybean | X | X | | | | | | | |
| Sugar Beets | | | | | | | X | | |
| CRP | | | | | | | | X | |
| Non-harvestable public | | | | | | | | | X |

▲ **Figure 3.6: Crop conversion options; conversions are permitted where marked by an "X".**

Crop switching costs

The model assumes that it is costless to convert to and from grass and annual crops, other than the costs shown in the budgets detailed in the preceding sections. An arbitrary, large conversion cost is used to ensure that certain crops remain in their current use, reflecting legal or agronomic constraints. Switching is permitted among all annual crops and grasses, as well as short rotation woody crops (SRWC, here represented by hybrid poplar trees), but forested and brushland areas are restricted to remain as they are, no matter how high the offer for other feedstocks. All conversion options are shown in Figure 3.6.

SUPPLY SCHEDULES

The delivered cost for each feedstock can now be estimated by combining production, harvest, and transportation costs from each *field* in the project area. The logic of the analysis is that if the price offered by the biofuels plant is high enough, the owner of a field

now growing a different crop will switch to the demanded crop. Similarly, if the price is high enough, the owner of a field not now supplying residues (corn stover and forest wood) will have the incentive to do so. The crop with the highest net return for a given field's costs and revenues is assigned to all acres in the field.

For each set of price assumptions for all crops, the crop choice for each of the fields in the project area is calculated. For the modeled production size of the biofuels plants, we know the required feedstock quantity, which then gives us the price necessary to bring that feedstock to the plant. The cheapest feedstock is not necessarily the closest, because crop yields and certain production costs vary for each field according to its productivity. Prices for all other crops are held constant at baseline values, while the price of the crop under scrutiny is varied systematically and the delivered products measured and aggregated.

For each crop in each field, the estimated yield and the estimated production costs per ton can now be calculated. Coupled with each price for each product, the net returns (exclusive of rent) for each crop can also be calculated. So, for example, grass might return $\$50/T * 3T/ac. - \$120/ac. = \$30/ac.$, while corn might return $\$142/T * 3T/ac. - \$300/ac. = \$126/ac.$

In this example, even though grass would generate a positive net return, the landowner would still choose to grow corn, because the expected net return is even larger. However, if the landowner could get $\$90/T$ for grass, the net return for grass would become $\$150/ac.$ With this price from the biofuels plant, the landowner would switch to grass production and delivery. Obviously, the example shown here could play out differently in different fields, depending upon relative yields and production costs, as well as different relative prices.

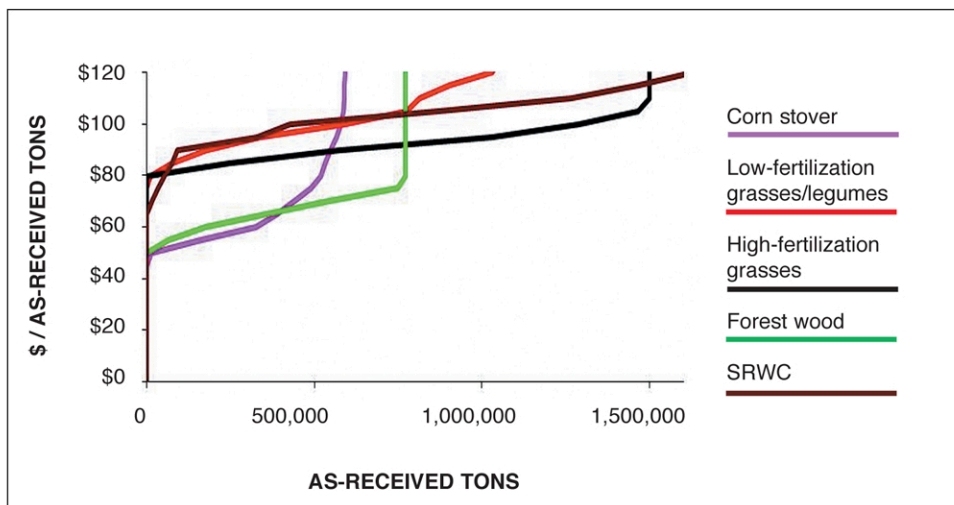
The model calculates all the possible net returns for all fields, ranks them, determines the crop with the maximum (positive) net return, and then adds up production and acquisition costs for each crop at each price level. These aggregates determine the supply schedules. (Each supply schedule is calculated independently of the other crop prices. The base condition is the set of prices shown in Figure 3.5. If the relative prices change, the crop selection will change, and so will the supply schedules.)

The end result is a series of supply curves (a graphical representation of tabular supply schedules), summarized in Figures 3.7 to 3.9, showing the estimated delivered feedstock volume (measured in as-received tons) zero-moisture tons, and million BTUs for each price level.

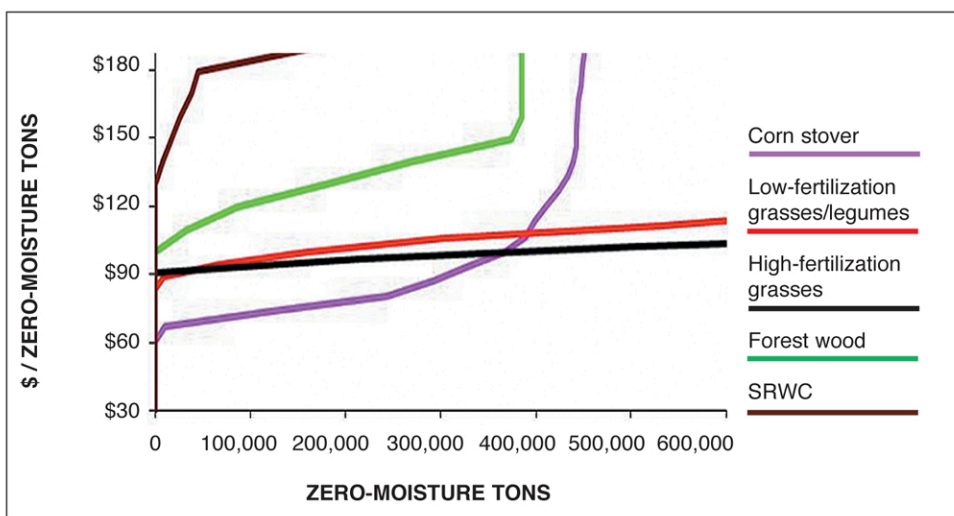
BIOMASS SUPPLY MODEL

Like all supply curves, these reflect the fact that increasing the demand for product (moving to the right on the horizontal axis) requires a higher and higher price to bring in that amount of product. One can read the charts in either of two directions: if you want to know how much material will be delivered for a given price, start on the vertical axis at that price and read straight across until you reach the curve representing the crop in which you're interested, then straight down to read off the volume procured at that price. If you want to know how much a given amount of material will cost to obtain, start on the horizontal axis at that volume and read straight up to the appropriate curve, then straight left to determine the price. (The model we developed to generate these curves can also calculate this directly, for specific prices, but all of the relevant results are captured in these supply curves.)

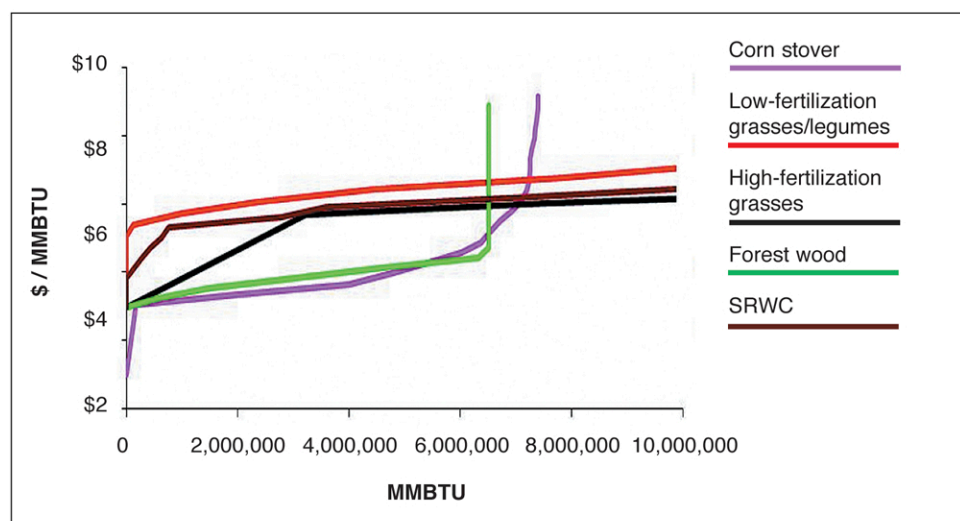
The *jumps* in the supply curve in figures 3.7-3.9 are partly attributable to the fact that the model has only one set of production budgets for the entire project area and that there is only a relatively narrow range of productivity (and hence, yield and production costs) index values for large portions of the project area. There is also the single price paid for product at the plant and the relatively small influence of transportation costs in the final product cost. Consequently, many of the fields are similar with respect to key profit determinants like yield and cost. When a price from a biofuels plant reaches a threshold level, a great many fields come into production at once, causing the abrupt changes in the shape of the supply curves. If there existed more detailed production cost data, for example at the county level, these curves might be *smoother* and thereby might lend themselves to additional fine examination.



▲ Figure 3.7. Estimated supply on as-received ton basis



▲ Figure 3.8. Estimated supply on zero-moisture ton basis



▲ Figure 3.9. Estimated supply on MMBTU basis

| FEEDSTOCK (MOISTURE CONTENT) | DESIRED VOLUME (AS-RECEIVED TONS) | REQUIRED DELIVERED PRICE (DOLLARS PER AS-RECEIVED TON) |
|---------------------------------------------|--------------------------------------|-----------------------------------------------------------|
| Corn stover (15%) | 650,000 | Insufficient land in project area |
| Low-fertilization grasses/ legumes (15%) | 670,000 | 103 |
| Forest wood (50%) | 1,600,000 | Insufficient land in project area |

▲ **Figure 3.10: Required delivered price for three biofuels feedstocks**

On average, the estimated delivered feedstock prices shown in the figures are consistent with other recent research (Eidman et al., Lazarus (b)), but they are higher than some estimates published earlier in the decade. This is in part due to the dramatic increase in all commodity prices in the past few years, even with the equally dramatic plunge in recent months. Current (January 2009) forecasts for the next several years show the price for most crops leveling off considerably below the peak in early 2008 but still considerably above the levels that prevailed in the early 2000s when some of the earlier feedstock price studies were completed. Too, not all previously-reported estimates are on a consistent zero-moisture basis such as that shown in Figure 3.8, and reports frequently differ on their as-received moisture content assumptions. In addition, some estimates are calculated at the farm gate while others (such as the present report) are estimated at the plant gate.

A major departure from some earlier reports is that landowners are modeled here to switch crops only if the new crop exceeds the profit of all other crops, rather than to produce whenever profits are non-negative. Finally, in this report, while land costs are excluded from the landowner decision, the model does include most of the other costs incurred in the farming oper-

ation, such as insurance and labor, not just the costs of crop removal, fertilizer supplements, and transport equipment.

Using the charts

There is a wealth of information summarized in these supply schedules, information that can be used explicitly in the biofuels production processes modeled in the final section of this report. For plants of a given size, how much will feedstocks cost? In this report, the biofuels plant produces 50 million gallons each year. Because of different feedstock characteristics and different plant types, the required feedstock volume is different for each feedstock. That desired volume is shown in the second column of Figure 3.10. Reading off the charts, the required price that is sufficient to cause the feedstock to be grown, harvested, pre-processed, and delivered can be determined.

The overall stover cost is relatively low for the first 500,000 tons, but above 550,000 tons the required price rises steeply as increasingly expensive product is brought to market. The project area simply cannot supply all 650,000 required tons, because even at a high stover price, no new land can be brought into corn production. Imports from outside the project area would be required if a stover biofuels plant of this size is built at North Branch.

A similar situation occurs with respect to forest wood as a feedstock. Required prices stay relatively low for lower volumes of material (up to 750,000 tons), but there is a dramatic increase at that price as a large block of new forest land is brought in only if the price goes up substantially. There is not sufficient potential wood supply in the region for the 50 million gallon plant.

It is not apparent in the figures shown here, but at the default corn prices and costs, most of the corn is produced at a negative-profit level. As noted above, however, we employ the standard economic analysis assumption that a producer will continue in operation over the short-run, even if profits are negative, as long as variable costs are covered by product sales – as they are for most of the land in the project area under most prices for corn grain and stover.

By their nature, the supply schedules treat the movement of prices for each feedstock independently. Each curve is calculated independently of possible movement in any of the other prices from their baseline levels. The model could also be used, however, to calculate delivered volumes of any given feedstock when more than one price is changed from baseline levels at the same time.

There are obviously hundreds of possible combinations of prices that could be so-analyzed. In Figure 3.11, for example, we systematically alter the prices of corn stover, grass, and wood in the same direction. This could be thought of as replicating a situation in which the biofuels plant is *omnivorous*: it doesn't care what sort of biomass it gets as long as it can offer the same price for any biomass (on a zero-moisture-weight basis) that comes in the

door. (We have adjusted the prices internally to reflect the fact that the price for as-received product would differ for each feedstock, depending upon its moisture content.) Because of differences in productivity and production costs, different price levels would call forth different relative volumes of material, depending upon which crop *wins* each field under different price levels.

There is an interesting dynamic that occurs with corn stover production. The supply of stover is dependent not just upon its own price but also the underlying price of corn grain. The higher is the latter, the more likely it is that the highest profit crop for a field will be corn and the more likely it is that even a lower offered price for stover will be sufficient to pull stover out of the field. (Recall that the model produces stover delivery only when the combined grain plus stover profit exceeds other options, including corn grain alone.) And because higher corn prices result in more acres planted to corn and, hence, fewer to grass, say, we expect that changing the background corn price in the model would change the resulting delivery for other possible feedstocks as well. In Figure 3.12, the delivered volume for each feedstock at \$90/zero-moisture ton, when corn grain price varies between \$2 and \$6 per bushel, a range experienced within the past few years in the region. Low corn prices substantially limit the availability of corn stover at \$90, but have little effect on the other two feedstocks, although for different reasons. Corn land and forest land are not competitive in the model, so corn price should have zero effect on delivered forest wood volumes at any wood price level. However, corn land and grass land are interchangeable in the model. Initially, higher grass

| PRICE PER ZERO-MOISTURE TON | DELIVERED VOLUME (THOUSAND ZERO-MOISTURE TONS) | | |
|--------------------------------|------------------------------------------------|--------------------------------------|-------------|
| | CORN STOVER | LOW-FERTILIZATION GRASSES/LEGUMES | FOREST WOOD |
| \$50 | 0 | 0 | 0 |
| \$90 | 421 | 20 | 0 |
| \$130 | 403 | 373 | 359 |

▲ **Figure 3.11: Delivered product under different price levels for omnivorous plant**

| CORN GRAIN PRICE PER BUSHEL | DELIVERED VOLUME WITH COMMON \$90 PER ZERO-MOISTURE TON DELIVERY PRICE | | |
|--------------------------------|---------------------------------------------------------------------------|--------------------------------------|-------------|
| | CORN STOVER | LOW-FERTILIZATION GRASSES/LEGUMES | FOREST WOOD |
| 2.00 | 0 | 20 | 0 |
| 4.00 | 421 | 20 | 0 |
| 6.00 | 559 | 0 | 0 |

▲ **Figure 3.12: Delivered product under different price levels for corn grain**

prices bring in more grass, but eventually, higher corn prices move much of the available land to corn, thereby reducing the delivered volume of grasses even at high prices for grass.

CHANGES IN ENVIRONMENTAL SERVICE FLOWS

When crop selections change, environmental services (water pollution and greenhouse gas emissions, here) change as well, because of changes in bare soil exposure, evapo-transpiration rates, rainfall infiltration and runoff, commercial fertilizer use, etc. The crop switching model developed and used in this report to estimate supply responses can also be used to assess changes in certain environmental services. This requires knowledge of how different crops on different fields affect water movement and greenhouse gas emissions.

Ideally, this data would be known for each crop on each soil. Then, when a price for a biomass feedstock becomes sufficiently high to encourage crop switching or residue harvesting, the change in environmental services could be assessed. For example, if a row crop results in 50% of the potential soil erosion reaching a stream while grasses result in 25%, (these numbers are illustrative only!), then a biofuels plant paying enough for grass deliveries causes the field to be changed from crops to grass and, hence, sediment from the field to be reduced by half. Knowing how many acres are switched to grass, we can then calculate the tons of sediment delivery brought about by the biomass plant's purchases. Alternatively, if each crop on each soil can be associated with a stated quantity of pollutants per acre, the biomass plant's effect on the flow of chemicals from that field can be calculated in the same fashion.

| | |
|------------------------|------|
| Annual crops | 100% |
| Grass | 5% |
| Trees | 20% |
| Water | - |
| Urban | 100% |
| Brush | 10% |
| Sugar beets | 100% |
| CRP | 5% |
| Non-harvestable public | 5% |

▲ **Figure 3.13: Erosion factors**
(percent of potential erosion)

| | |
|------------------------|----|
| Annual crops | 10 |
| Grass | 2 |
| Trees | 3 |
| Water | 0 |
| Urban | 10 |
| Brush | 2 |
| Sugar beets | 10 |
| CRP | 2 |
| Non-harvestable public | 2 |

▲ **Figure 3.14: Nitrate losses on**
non-tiled fields (pounds per acre
per year)

| TO | FROM | | | | | | | | |
|--------------|--------------|-------|-------|-------|-------|-------|-------|-------|--------|
| | ANNUAL CROPS | GRASS | TREES | WATER | URBAN | BRUSH | BEETS | CRP | PUBLIC |
| ANNUAL CROPS | 0.00 | -1.60 | -5.50 | -4.50 | 0.00 | -5.50 | 0.00 | -3.00 | -3.00 |
| GRASS | 1.60 | 0.00 | -3.90 | -2.90 | 1.60 | -3.90 | 1.60 | -1.40 | -1.40 |
| TREES | 5.50 | 3.90 | 0.00 | 1.00 | 5.50 | 0.00 | 5.50 | 2.50 | 2.50 |
| WATER | 4.50 | 2.90 | -1.00 | 0.00 | 4.50 | -1.00 | 4.50 | 1.50 | 1.50 |
| URBAN | 0.00 | -1.60 | -5.50 | -4.50 | 0.00 | -5.50 | 0.00 | -3.00 | -3.00 |
| BRUSH | 5.50 | 3.90 | 0.00 | 1.00 | 5.50 | 0.00 | 5.50 | 2.50 | 2.50 |
| BEETS | 0.00 | -1.60 | -5.50 | -4.50 | 0.00 | -5.50 | 0.00 | -3.00 | -3.00 |
| CRP | 3.00 | 1.40 | -2.50 | -1.50 | 3.00 | -2.50 | 3.00 | 0.00 | 0.00 |
| PUBLIC | 3.00 | 1.40 | -2.50 | -1.50 | 3.00 | -2.50 | 3.00 | 0.00 | 0.00 |

▲ **Figure 3.15: Changes in CO2 sequestration through crop switching**
(metric tons per acres per year)

As biofuel feedstock prices increase, more and more crop switching occurs, which accentuates any changes in environmental conditions in the project area. These changes can be captured in a *pollutant supply curve*, analogous to the product delivery supply curves developed above. The new curves can be read in similar fashion, although some will move in reverse directions: as the price increases, more crops are switched to grasses, so fewer pollutants are released to the environment. The pollutant supply curves measure changes from base conditions, so they can be

negative or positive. In the present model, all pollutants are assumed to be conserving, in that they don't dissipate as they move across the landscape: consequently, field-edge pollution estimates can be combined into the aggregates reported here. Based on the environmental parameters listed in Figures 3.13 to 3.15, pollutant supply curves can be calculated for each of the several biomass feedstocks. First, erosion rates are calculated for each field in a fashion similar to that used for the average field CPI in the earlier analysis. Potential water erosion rates have been calculated

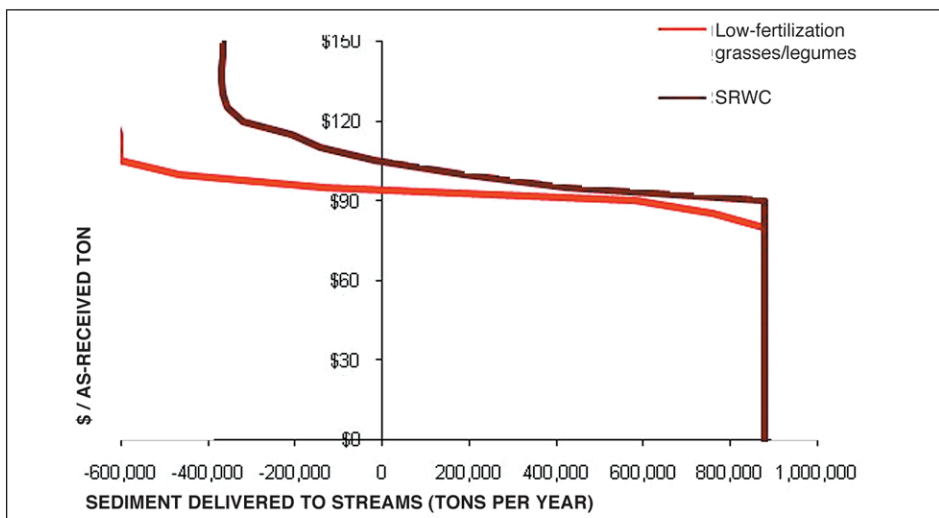
for each soil in the state and are available at Minnesota Land Economics (<http://landeconomics.umn.edu>) in the Soils Data section. (Isanti and Pine Counties lack detailed soils data, so-as for the CPI in these counties-erosion factors are assigned to known soil aggregations based upon calculations for similar soils in adjacent counties.)

These rates are coupled with the Erosion Factors in Figure 3.13 and multiplied by the number of acres delivered under each price on the environmental services supply curve shown in Figure 3.16. As before, these curves are calculated independently from each other. They are presented on the same charts simply for ease in exposition.

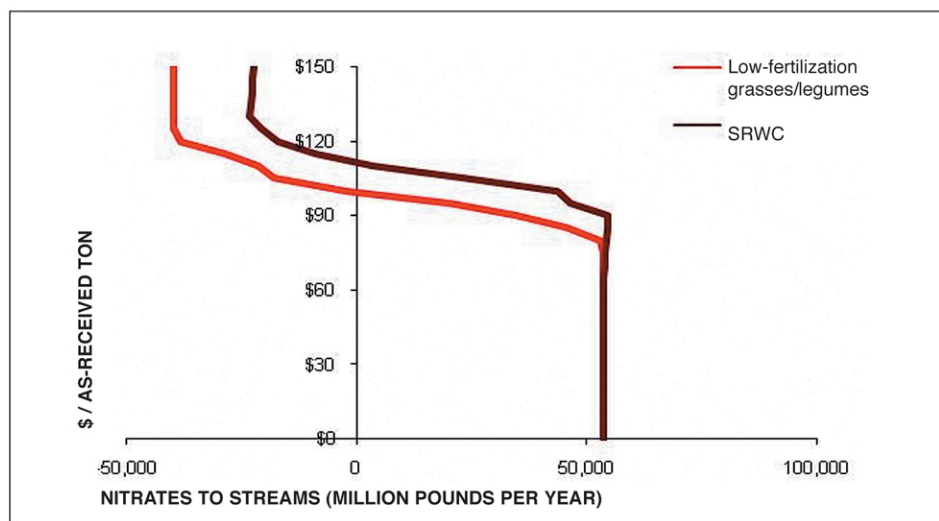
Similarly, changes in field nitrate losses, which are shown on a per-acre basis in Figure 3.14 are calculated by multiplying the number of acres in each field for the before- and after-switch crops, then summed and graphed in Figure 3.17.

Changes in net CO2 sequestration brought about by changes in crop selection as prices increase can be calculated using the conversion data in Figure 3.15. Changing from crops, say, to perennial grasses results in a carbon sequestration increase of 1.6 metric tons per year. Multiplying the number of acres so-changed by this factor yields the aggregate sequestration curves shown in Figure 3.18. Like the sediment and nitrate loss curves, these could move in either direction, depending upon which crops enter the mix at each price level.

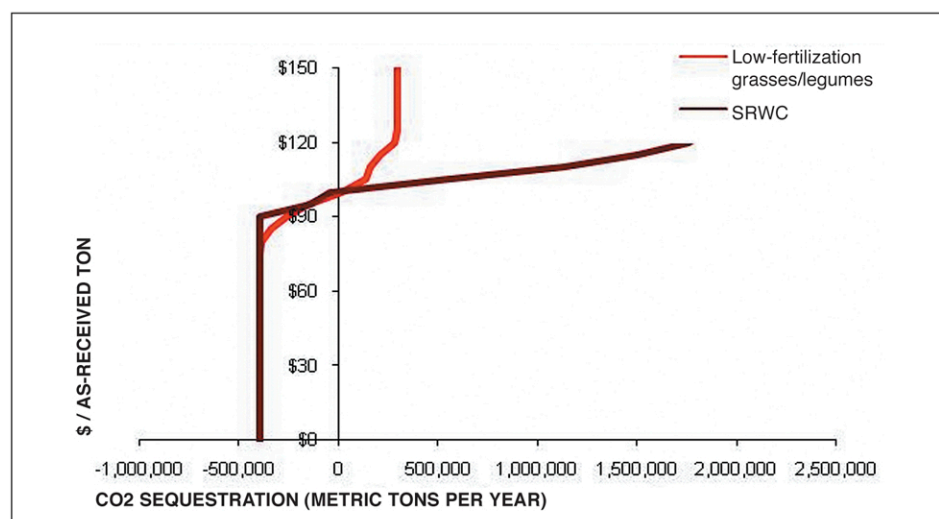
These curves, like the product supply curves, show "jumps" at certain price levels. This is an artifact of the underlying data, as discussed on page 36.



▲ Figure 3.16: Changes in sediment loss due to biofuels plant purchase price



▲ Figure 3.17: Changes in field nitrate loss due to biofuels plant purchase price



▲ Figure 3.18: Changes in CO2 sequestration due to biofuels plant purchase price

Unfortunately, none of these numbers are known with sufficient precision for the reporting of more than very cautious estimates of environmental changes resulting from biofuels production. The figures show changes brought about by production and delivery of low fertilization grasses/legumes and short rotation woody crops (hybrid poplar). Their calibration is entirely dependent upon the validity of the assumptions shown in the data tables, and these really require additional scientific scrutiny, hopefully to be conducted in a future study. ■

CITATIONS

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► **Lazarus, W.**, Minnesota Crop Cost and Return Guide - 2009. University of Minnesota Extension, October 2008.

► **Minnesota Land Economics**, <http://landeconomics.umn.edu>

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CELULOSIC BIOMASS

CONVERSION PLATFORMS

Many technologies are available for the conversion of biomass to energy. This study evaluated conversion platforms ranging from the simple to the complex with the common goal of converting renewable biomass to some useful form of energy that is called biofuel.

The questions to be answered by this analysis are:

- ▶ How do the various conversion platforms differ?
- ▶ How does plant scale affect economic performance?
- ▶ What are capital costs and return on investment for the platforms?
- ▶ What is financial impact of biomass cost and rack prices of ethanol and gasoline?
- ▶ How much biomass is required for different platforms?

PLATFORMS CONSIDERED

- ▶ Combustion or Gasification for heat or combined heat and power.
- ▶ Corn based ethanol as a reference point for cellulosic based technologies.
- ▶ Cellulosic ethanol via chemical/enzymatic hydrolysis and fermentation (Biochemical conversion).
- ▶ Gasification of biomass to "syn" gas (a mixture of primarily hydrogen and carbon monoxide) with catalytic conversion to mixed alcohols, predominantly ethanol. (Thermochemical conversion)
- ▶ Gasification of biomass to syngas and catalytic conversion to gasoline and aromatic hydrocarbons. (Thermochemical conversion)

Biofuel pellets as a renewable energy source

In addition to the conversion platforms above, the conversion of woody biomass and grasses to pellets suitable as a heat source in pellet stoves or larger pellet furnaces and boilers was investigated as a low tech way of getting started with converting cellulosic biomass to a biofuel. This is presented as a separate case in section 5 along with pertinent market data to support a business plan.

Conversion Platforms

Cellulosic biomass comes in many forms such as wood, prairie grass, switchgrass, corn stover, other agricultural residues and the like. While the exact chemical composition varies between the different sources the macro-composition consists of a few major components in all of the species. This inherent macro-

WHAT IS BIOMASS?

CLEAN biomass:

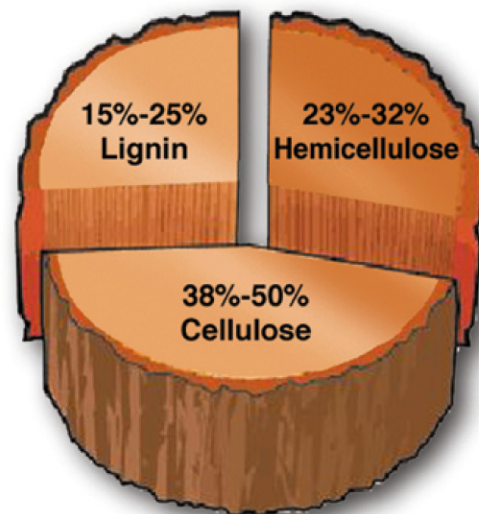
Forest
Hybrid poplar
Switch grass
Prairie grass
Shrubs

RESIDUAL biomass:

Forest & agricultural residues
- Corn stover
- Wheat straw
Process residues
- Hulls
- Sawdust

URBAN biomass:

MSW (typically > 50% biomass)
Construction/demolition wood



- 50% CARBON
- 6% HYDROGEN
- 44% OXYGEN

▲ Figure 4.1. Macro-composition of biomass.

composition is depicted in Figure 4.1.

In addition to the major components of cellulose, hemi-cellulose and lignin, small quantities of elements such as phosphorous, potassium, sulfur, nitrogen as well as silica may be present in varying quantities depending on the particular species.

For the purpose of converting biomass to a liquid fuel such as ethanol, methanol, dimethyl ether, or gasoline the object is to convert as much as possible of the biomass into the desired liquid fuel. A variety of technologies have been proposed to accomplish this. There are basically two broad categories of conversion platforms. These are Biochemical platforms and Thermochemical platforms. The most familiar of the Biochemical conversion platforms are the corn ethanol plants currently in operation. Biochemical refers to the technology for breaking down or

hydrolyzing the starch contained in corn to simple sugars that can be fermented by yeasts or other microorganisms to produce ethanol as a product of their metabolism. For cellulosic biomass the process is more complicated since the sugar units contained in cellulose are connected in a different fashion than in starch and are more difficult and expensive to hydrolyze. An additional step is also required to break down the sugars contained in the hemi-cellulose fraction of the biomass.

Thermochemical platforms generally start with the thermal conversion of biomass to syngas (a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen) by gasification. Gasification is combustion of the biomass under reduced oxygen conditions to convert the biomass to syngas that can then be treated as a raw material for subsequent chemical and catalytic processing to make fuels such as

methanol, dimethyl ether and gasoline.

Pyrolysis is an alternative thermochemical conversion platform. It is the heat induced chemical decomposition of organic materials such as cellulosic biomass in the absence of oxygen. The products of biomass pyrolysis are char, bio-oil and gases. Whereas syngas is a relatively simple mixture of gases, bio-oil is a complex mixture of hundreds of chemical compounds including saccharides, aldehydes, furans, ketones and alcohol carboxylic acids. The high water and oxygen content of pyrolysis oils make them inferior to hydrocarbon fuels. Bio-oils are not stable during extended storage and have a tendency to separate and polymerize. They are also corrosive and could require stainless steel or plastic storage vessels. Many of the chemicals found in bio-oils are toxic and carcinogenic. This is a serious concern, for example, with the potential contamination of groundwater due to spills during production or transportation of bio-oils. Considerable research is required to resolve these issues. The ultimate benefit of bio-oil would appear to be as a feedstock for refineries for conversion to more conventional fuels. Pyrolysis was not given further consideration since there is a large research gap between the actual fast pyrolysis conversion to bio-oil and eventual utility as a transportation fuel. Too many problems are as yet unresolved.

Combined Heat and Power

Conceptually, combined heat and power appears to be a simple but effective way of converting renewable biomass resources for the generation of electricity and heat. It offers the very important benefit of essentially eliminating incremental carbon dioxide emis-

GASIFICATION VS. COMBUSTION

GASIFICATION

Chemical conversion using limited amounts of oxygen:

C to CO
H to H₂
S to H₂S, then pure S
N to N₂

High temps (1300-2700 F)
and high pressure

Purpose: Create usable syngas

COMBUSTION

Complete oxidation using excess air:

C to CO₂
H to H₂O
S to SO₂
N to NO_x

Lower temps (1500-1800 F) &
atmospheric pressure (0 psig)

Purpose: Generate heat

▲ Figure 4.2. Comparison of gasification and combustion.

sions and greatly reduces emissions of sulfur dioxide and mercury that are emitted from conventional coal fired power plants. One method is burning of the biomass to form hot combustion gas that can be utilized to produce steam and thence drive a steam turbine for electricity production. An alternative is to convert the biomass to syngas via gasification and utilize the syngas as fuel for an internal combustion engine, a steam turbine, or a combined cycle process (gas turbine & steam turbine) to generate the electricity. The waste heat would be recovered for heating purposes. The difference between combustion and gasification as means to convert biomass is depicted in figure 4.2. Each method has advantages and disadvantages and a particular selection is dependent on the specific application and has to take into account the type of biomass and the financial payback. Figure 4.3 shows a gasifier.

Koda Energy, LLC.

A current example of a local application of combined heat and power is Koda Energy, LLC which is a partnership between Rahr Malting Co. and the Shakopee Mdewakanton Sioux



Source: BEASL

▲ Figure 4.3. Biomass gasification unit.

Community (SMSC, Mystic Lake Casino). Rahr will purchase all the heat from the operation and both Rahr and SMSC will purchase electricity with the surplus being sold on the grid as a supply of *green* electricity.

Koda Energy combines the heat and power needs of the partners

in an effective way.

- ▶ 16.5mw of electricity plus 125 million BTU/hr of thermal energy.
- ▶ Capital cost of \$55 million
- ▶ Biomass comes from Rahr malting operations and purchases within a 50 mile radius.
- ▶ \$6 million per year in outside biomass purchases.
- ▶ Yearly payroll of \$750,000.

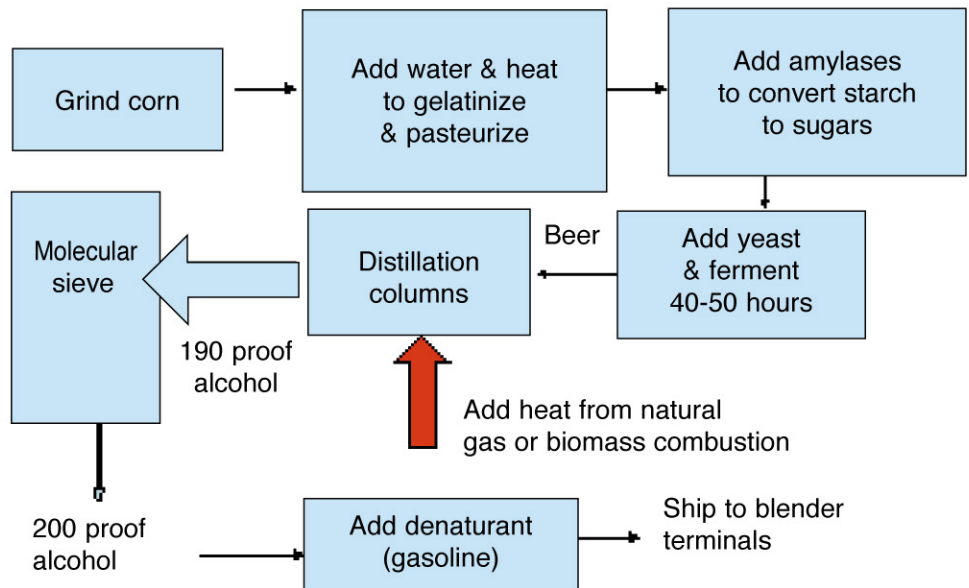
The amount of heat generated in combined heat and power is similar to a coal-fired power plant. Approximately 70% of the biomass energy converts to thermal energy with only 30% being converted to electricity. To be economically viable all the heat must be utilized. Koda is an ideal partnership in that all the heat is being properly utilized and not dumped into the environment.

Can Combined Heat and Power (CHP) be employed in the CIP area?

Since the energy split in a combined heat and power operation is about 70/30 heat/electricity the economics are driven by the steam production and not the electricity.

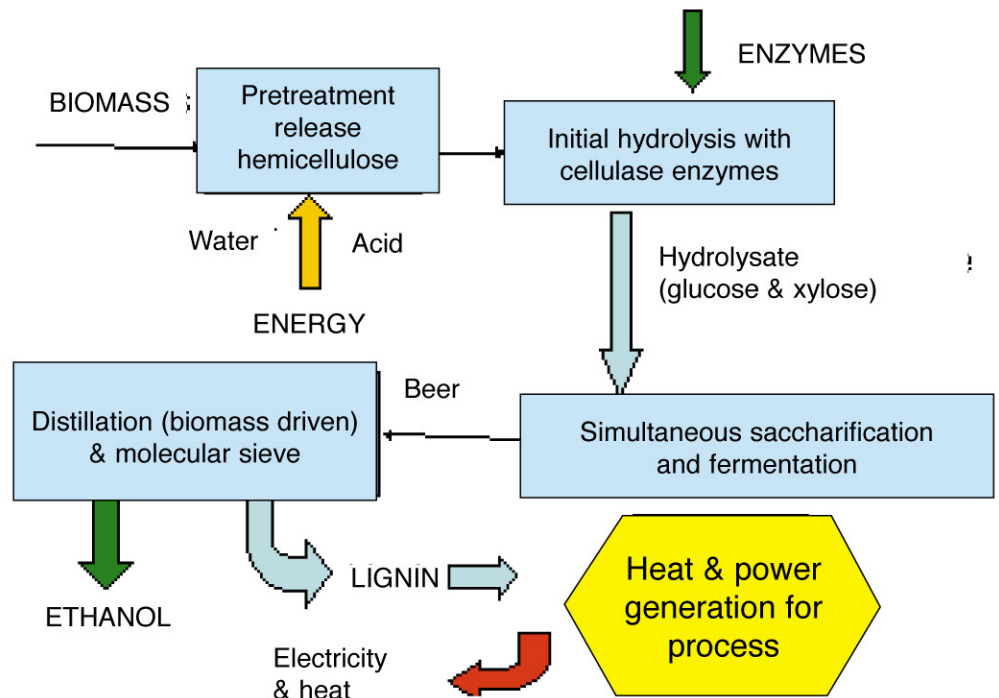
To get an acceptable return the CHP venture would have to emulate the Koda Energy model. Good candidates would be operations such as a potato processing plant, a pasta plant, a food dehydrating plant, a greenhouse operation and the like. CHP could be an advantage for an industrial park. The key is to find a user that needs all the thermal energy. Any excess electricity could be sold on the grid to the local power company since they will need carbon offset credits in the future. ■

Corn ethanol process - dry milling



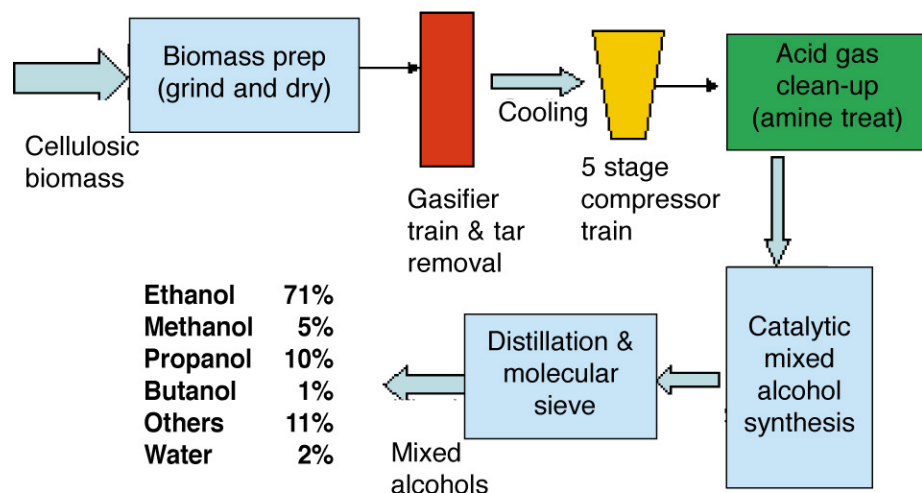
▲ Figure 4.4. Corn ethanol process

Cellulosic ethanol



▲ Figure 4.5. Cellulosic ethanol process flow chart

Gasification and catalytic conversion to mixed alcohols



▲ Figure 4.6. Thermochemical conversion to mixed alcohols

BIOCHEMICAL CONVERSION PLATFORMS

Corn based ethanol is only the first step on the long path to significant levels of renewable energy. The dry milling corn ethanol process is selected here as the reference for alternative biomass conversion platforms and feedstocks. There is considerable controversy regarding the actual benefit corn ethanol provides relative to reduction of carbon dioxide emissions or carbon footprint. When fossil fuel such as natural gas or coal is used as the source of energy for the corn ethanol refining process (distillation) the carbon footprint is reduced by about 13 - 20% compared to gasoline (Farrell et. al., 2006, *Ethanol Can Contribute to Energy and Environmental Goals*, Nature, Vol. 311, pp. 505-508). If biomass is combusted to provide process heat then the carbon footprint reduction rises to about 50 % (Wang et. al., 2007). The negative environmental impact of plowing established prairie lands to produce more corn for conversion to ethanol has recently been raised by

(Fagione et al, 2008). Their calculations show that the sequestered carbon that would be released would take about 80 years to recover based on the reduction in carbon footprint associated with corn ethanol. This does not mean that corn ethanol is inherently bad for carbon dioxide emissions. Rather it points out that the prairies would be much better utilized if kept intact and the grasses were harvested and converted to ethanol. In this way the perennial plants of the prairies would continue to sequester carbon dioxide in their crowns and roots. Of course, that is contingent on having a cellulosic conversion platform that is as economically viable as the corn ethanol platform and a price for prairie grass that is competitive with crops such as corn as discussed in the previous section.

Another point of controversy is the alleged competition between food and fuel uses of corn. This was fueled by the spike in corn prices that occurred in 2007-2008. The reasons for the spike are not clear. What is clear, how-

ever, is that the profitability in corn ethanol manufacture vanishes as corn prices approach about \$4.25 per bushel. The recent price increases have caused plans for new plants to be shelved, others to be shut down and at least one large company has been driven to bankruptcy because of taking an unfortunate hedging position just before corn prices came down in the fall of 2008 (Mario Parker, Minneapolis Star Tribune, Jan. 10, 2009, *VeraSun Energy shuts 3 distilleries*).

The corn ethanol process flow chart is shown in figure 4.4.

Cellulosic Ethanol

Today there is no full- scale cellulosic ethanol plant. Several demonstration plants are currently under construction or at least in the design phase in various locations in North America. Cellulosic ethanol is the next logical progression from corn ethanol but it is still in the development stage with many significant issues to be resolved to make the platform economically viable. It is not clear if this will come to fruition even with major technological breakthroughs without perpetual government subsidies not only to the blender but also to the ethanol manufacturer. This is not an economically robust business model long term. Cellulosic ethanol suffers from the same inherent flaw as corn ethanol. The conversion of sugars to ethanol is accomplished through fermentation by microorganisms or yeasts. The ethanol concentration in the fermented beer is relatively low, usually 4 to 7 percent. This means that considerable energy must be expended to concentrate the beer to the purity required to serve as a transportation fuel. This is inherently expensive. The

flow chart for cellulosic ethanol is shown in figure 4.5. ■

THERMOCHEMICAL CONVERSION PLATFORMS

► Thermochemical conversion platforms are a significant technological departure from biochemical approaches to converting cellulosic biomass to transportation fuels. With the exception of the feedstock being cellulosic biomass, the process would also work with coal as the feedstock with some modifications and changes in operating parameters. The process flow for conversion to mixed alcohols is shown in figure 4.6.

The most significant differences compared to biochemical conversion are:

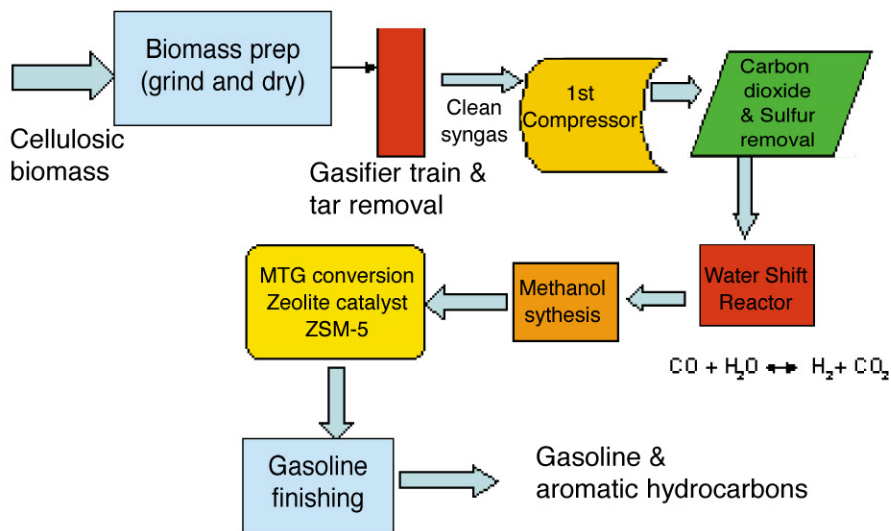
- No enzymes
- Butanol, propanol, methanol, etc. are valuable by-products that add about 10% to the income stream.
- Fewer expensive tanks and vessels that reduces capital cost by about 40%.

Gasification and catalytic conversion to gasoline.

The thermochemical conversion from cellulosic biomass to gasoline uses a commercially available methanol catalyst followed by another commercially available process for converting methanol into gasoline. Methanol production from syn gas has been practiced commercially for many years using a catalyst based on copper and zinc oxide supported on alumina.

The conversion of methanol to gasoline has also been demonstrated at a large scale, but until the recent increases in the cost

Gasification of biomass and catalytic conversion to gasoline



▲ Figure 4.7. Thermochemical conversion to gasoline

of crude oil, gasoline made using the MTG process (also called M-gasoline) was not cost competitive with oil-derived gasoline. The process is based on dehydration of methanol using a zeolite catalyst, ZSM-5, developed by Mobil Oil in the 1970s. The technology was practiced on a commercial basis (14,500 barrels/day) in New Zealand from 1981-1984. (Huber et. al., 2006). The platform produces LPG as a saleable by-product. The process flow is shown in Figure 4.7.

Conversion Platform Process Models

The platforms discussed above form a baseline for comparison between technologies and also for sensitivity analysis with respect to biomass prices and selling prices for the resulting products. To maintain consistency in the analysis, the process models developed by the National Renewable Energy Laboratory (NREL) were utilized. These models are very thorough and represent a considerable effort and expertise that results

in comprehensive and useful reports. The reports contain material and energy balances developed through Aspen process software, complete flow sheets and equipment lists, labor and utility costs, environmental impact and an economic analysis based on discounted cash flow methods. The NREL models were developed over several years beginning in 2000 through 2008.

During the intervening years there was considerable inflation in equipment cost due to large increases in material costs as well as escalation in construction labor which impacts installation cost. To make comparisons across models with varying start dates it is essential to bring all costs into 2007 dollars. It is also essential to be consistent between models with regard to practical engineering details such as installed equipment cost multipliers, indirect costs (design, construction management, permitting, etc.), and contingency. To this end the NREL models were adjusted by inflating equipment costs to 2007 dollars and

adjusting install factors to correctly reflect plant construction dynamics in 2007. To inflate equipment cost to 2007 dollars the Producer Price Index (PPI) was utilized for 16 types of equipment commodities instead of the Chemical Engineers Plant Cost Index as specified by NREL. This resulted in an average annual inflation rate of 5.6%, which for the most part is fairly conservative. Other engineering details such as design, construction management, contingency and the like were adjusted within the install factors. This is the most practical and accurate approach when working from an equipment list as opposed to a complete engineering design that is well beyond the scope of this study. To arrive at a composite ratio of equipment cost to total project cost the methodology was as follows:

- The installed equipment multiplier of 2.5 was chosen as representative of these types of plants. This is a function of the complexity of vessels, associated piping, controls, electrical installation, etc. These platforms are most like pharmaceutical or food plants with a design that permits thorough cleaning to avoid contamination and well instrumented to provide adequate process and quality control.

- Indirect cost multiplier was 35% of total installed equipment cost to cover design, construction management, permitting and the like.

- Contingency was taken at 10% of installed equipment cost. This contingency tends to be optimistic. It is typical for projects characterized by a completed engineering design. A more conservative contingency would be 20%!

- In this manner the total pro-

ject cost to equipment cost ratio becomes 3.63.

Each NREL model was developed for a specific feedstock. For example, the Aden model (Aden, 2002) for conversion of cellulosic biomass to ethanol was developed for corn stover as the feedstock. The Phillips model (Phillips, 2007) for mixed alcohols was based on aspen wood chips. To maintain consistency when evaluating alternative feedstocks such as prairie grasses, hybrid poplar, switch grass and the like, the conversion tables published by the Department of Energy (DOE), (Biomass Feedstock Composition & Property Database, www1.eere.energy.gov/biomass/feedstock_databases.html), were utilized to convert yield data from one species to another. The tables are based on sugar content of the specific biomass source. These numbers were determined experimentally from samples gathered during field studies whenever applicable. Otherwise, literature values were utilized. ■

FINANCIAL ANALYSIS AND FEASIBILITY

Economic viability of a project such as the manufacture of cellulosic ethanol or synthetic gasoline can be determined by several different methods. These range from single value ratios such as average annual rate of return to more comprehensive methods such as internal rate of return (IRR) and net present value (NPV), which are based on discounted cash flow and take into account the time value of money. These methods do not give equivalent answers to the question of economic viability. Consistent with industrial practice and the NREL models, this study utilizes discounted cash flow methods to calculate IRR

and NPV. Generally, a business entity will determine a minimum rate of return (IRR) or hurdle rate for new projects. This establishes whether or not a particular project meets the hurdle rate but one cannot compare IRR's from competing projects to select from a slate of projects that all meet the hurdle rate. IRR measures only one dimension of a financial proposal. Since it is actually a ratio, it ignores the absolute magnitude of the opportunity. Net present value (NPV) is a way of measuring the cash flow generated at the required hurdle rate.

NPV = Cumulative discounted cash flow (computed @the hurdle rate) - investment

The protocol then is to compute IRR to be sure the project meets or exceeds the hurdle rate and then compute the NPV at the hurdle rate to be able to compare between competing projects. This study has generated interactive spread sheets that incorporate these calculations and allow parametric sensitivity analysis to be performed around variables such as feedstock cost, yield, and selling price of the biofuel as well as the impact of existing and proposed subsidies and tax credits. (Specific questions regarding the financial model utilized in this report should be directed to K. Valentas, valentas@umn.edu). The hurdle rate selected in this study is 10% on either before tax or after tax basis.

How does plant scale affect economic performance?

Economy of scale is a significant factor in determining the economic viability of a manufacturing operation that involves processing such as in the biochemical and thermochemical platforms considered in this study.

But what are the drivers for achieving economy of scale? There is no short answer to this question since engineering scale up can be very complicated and involve many factors. Consider these factors that arise in all scale up calculations:

1. **Manpower or labor per unit of product**
2. **Installed equipment cost.**
3. **Infrastructure**

► **Labor:** Doubling the capacity or size of a plant does not require a doubling of labor. For example, an operator can just as easily operate and control a 20,000 gallon vessel as a 10,000 gallon vessel. Doubling size does not double the administrative and managerial staff necessary to operate the facility. The higher the level of automation the lesser will be the impact of labor on scale up. There are, of course, limits dictated by the nature of the particular process under consideration.

► **Equipment cost:** Doubling the size of a process vessel does not necessarily double its cost. For example with a cylindrical vessel the volume or capacity is proportional to the diameter squared or cross section. But, the amount of material required is proportional to the first power of diameter, or circumferential area, which means diameter must only increase by a factor of 1.414 (square root of 2) to double the capacity of the vessel with length held constant. Installation costs include piping, electrical wiring, controls and the associated construction labor. Again, doubling the capacity of a given tank will not require double the amount of these materials nor double the labor to make the necessary connections.

► **Infrastructure:** A plant requires site development, utili-

ties, roads, offices and the like. Doubling the capacity of a plant does not require a doubling of all of these services. For example roads would be similar for both sizes. Similarly, an electric substation for a 2x plant design will not cost 2x of the smaller plant cost. Some things such as switch gear and transformers may need to be doubled but ancillary equipment and improvements will not.

Very often engineers utilize scale up factors when considering various capacity plants. There is great risk in simply applying these scale- up factors without considerable thought given to what can and cannot be scaled in this manner. For example if one were to try and scale down a plant designed for 50MM gallon capacity to one at 25MM capacity certain unit operations might not be reducible below certain sizes and still be functional. In addition labor and administrative content may not be able to be scaled down and still achieve good operation.

Scaling up or down in plant size is not a trivial matter. It is risky to stray too far from the design capacity without an in depth engineering evaluation of the impact. Simply applying scale factors across the board can lead to serious errors in capital cost estimation that subsequently affects the economic analysis. Any scaling that was necessary in this analysis was maintained within the range of accuracy of the design as dictated by good engineering practice. For much of the analysis a plant size of 50 million gallon per year was used as a common size or standard. The range of scaling was increased up to a maximum of 38% and scaled down by no

more than 20%.

The financial impact of scale is illustrated in Table 4.1 for a conventional corn ethanol plant. **The baseline for this case and all others in this study is corn at \$3.75/ bushel and a rack price of \$2.00/gallon for ethanol at a nominal plant capacity of 50 million gallons per year.** The NREL models for corn ethanol (McAlloon, 2000) were utilized as described previously. Doubling plant capacity to 100 million gallons improves IRR from 10.5% to 15.6%. But what does this mean in absolute dollars? To answer this question one utilizes the Net Present Value (NPV). In doubling size the NPV increases from \$2.1MM to \$39MM both at a hurdle rate or IRR of 10%. Decreasing plant size from 50 to 25 million gallons results in a drop in IRR from 10.5 to 6.1 and more importantly a decrease in NPV from \$2.1 MM to negative \$10MM. This is why there is a minimum size plant for economic viability. Another indicator is the capital cost per gallon of ethanol capacity. In downsizing from 50MM to 25MM gallons the capital cost/gallon increases from \$2.08 to \$2.70/gallon. ■

CAPITAL COSTS AND RETURN ON INVESTMENT

Cellulosic Ethanol

The baseline conditions for financial modeling of cellulosic conversion platforms is biomass (switch grass, prairie grass or corn stover) at \$90/ton (15% moisture) and an ethanol rack price of \$2.00/gal for a plant capacity of 50 million gallons per year with a capital cost of \$340 MM. An analysis of this nature can be strongly biased by the prices

NOTE: < > bracketing denotes negative figures

| CAPACITY MM GAL. | CAPITAL \$MM | IRR % AFTER TAX | NPV (NET PRESENT VALUE) | CAPITAL \$/GAL. |
|------------------|--------------|-----------------|-------------------------|-----------------|
| 50 | 104 | 10.5 | 2.1 | 2.08 |
| 75 | 135 | 13.4 | 19.3 | 1.80 |
| 100 | 161 | 15.6 | 39 | 1.61 |
| 25 | 67 | 6.1 | <10> | 2.7 |

▲ **Table 4.1. Effect of plant scale for corn ethanol plant**

| CORN PRICE \$/BUSHEL | IRR % AFTER TAX | NPV (NET PRESENT VALUE) |
|----------------------|-----------------|-------------------------|
| 3.75 (base case) | 10.5 | 2.1 |
| 4.125 (+10%) | 3 | <26.8> |
| 4.5 (+20%) | <10.4> | <64> |
| 3.375 (-10%) | 16.7 | 31 |
| 3.00 (-20%) | 22.3 | 60 |

▲ **Table 4.2. Corn price financial sensitivity for 50MM gal/year corn ethanol plant with +/- 20% range of corn prices. Ethanol rack price of \$2.00/gal.**

selected for feedstocks and products.

The price of feedstock was addressed through appropriate agronomic models that incorporate the realities of agricultural economics. The production models generated from experimental field data and accepted production models support assigning a price of \$90/ton (15% moisture) for biomass as a reasonable value. There is a tendency for some to assign lower values especially for corn stover. There are many issues associated with the pricing of corn stover that differ from biomass such as switchgrass, prairie grasses, hybrid poplar and forest products. Removing corn stover from the land has impact on the soil and requires a different type of harvesting than is practiced today. Contrary to popular belief, corn stover is not free for the taking. There is also the question of the quantity of corn stover that would be available for use in biomass conversion plants, especially in the northern half of the state.

Corn stover is also very different than grasses and forest biomass

with respect to carbon emissions and sequestration. The perennial crops will sequester carbon dioxide within the crowns and roots whereas corn does not sequester significant quantities of carbon unless all of the stover is retained in the field. Even then corn is not as effective as grasses and forest plantings for sequestration. If carbon sequestration and reduction of green house gases is indeed a national priority then it would favor increased plantings of prairie grasses over more tillage for corn production (Tilman et al, 2006).

For these baseline conditions the financial model predicts an after tax IRR of 7% and a NPV of <\$40MM> when a tax credit of \$0.56/gallon for the producer is applied in the financial discounted cash flow spread sheet. This is in addition to the \$0.45/gal credit that is currently given to the blender for using ethanol as a fuel additive. It is important to realize the impact of the \$0.56/gal credit on the economics of cellulosic ethanol as a business model. Computing the financial parameters with the tax credit removed yields an after

tax IRR of <10%> and a NPV of <\$211MM>!

How important is this? Recall that for a corn ethanol plant of 50MM gallon capacity and with corn at \$3.75 per bushel and an ethanol price of \$2.00/gal, the IRR is 10.5% and the NPV is \$2.1MM. This is with no tax credit subsidy to the producer. The point of this example is not to argue which is a better business model. Corn ethanol has come under financial pressure recently when corn prices rose dramatically. Profitability is highly leveraged against corn prices as shown in Table 4.2. It is not difficult to understand how a significant increase in corn prices can cause producers to temporarily cease operations when a 20% increase in corn can turn a positive 10% IRR to a negative 10% IRR. Corn ethanol is not the final nor best solution but has it's place and should be viewed as the first step on a long path to significant levels of renewable energy.

Biochemical cellulosic ethanol, on the other hand, is not a viable business model without government tax credits and other government subsidies. The biochemical process is inherently more complex than corn ethanol and requires a significantly higher capital investment per gallon of capacity of about \$6.00 vs. corn ethanol at about \$2.00 per gallon capacity. The biochemical process also suffers from higher variable operating costs due to the need for expensive enzymes and acid pre-treatment to release the sugars for subsequent fermentation. The bottom line for conventional biochemical conversion of cellulosic biomass to ethanol is that any profitability is in the tax credits and subsidies offered by the government. This is reinforced by the sensitivity analysis results presented in tables 4.3 and 4.4. To achieve profitability,

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even with tax credits, requires either high ethanol prices (> 2.10/gal) or low biomass costs (< \$80/ton). Unfortunately these tend to move in opposite directions. Ethanol prices tend to follow the rack price of gasoline. Rising fuel costs however will result in higher costs for growing and harvesting biomass and that has a negative impact on profitability. It is unrealistic to use artificially low values for the cost of biomass in financial projections since it is likely that as demand increases prices will not remain low. These results are also presented graphically in figures 4.8 and 4.9.

The likely prices for biomass is discussed fully in section 3 of this report. The baseline value for biomass of \$90/ton at 15% moisture was selected with prairie grasses or similar crops in mind. The premise is that the *going price* for biomass will be determined by the relative profitability compared to a crop such as corn. The supply models in section 3 speak to this issue.

Why are the financial numbers so discouraging for the conventional biochemical cellulosic biomass conversion platform? If this is to be the next logical step to move from corn based ethanol to cellulosic based ethanol what makes it so expensive? Comparison of the differences between the two conversion platforms is shown in Figure 4.10.

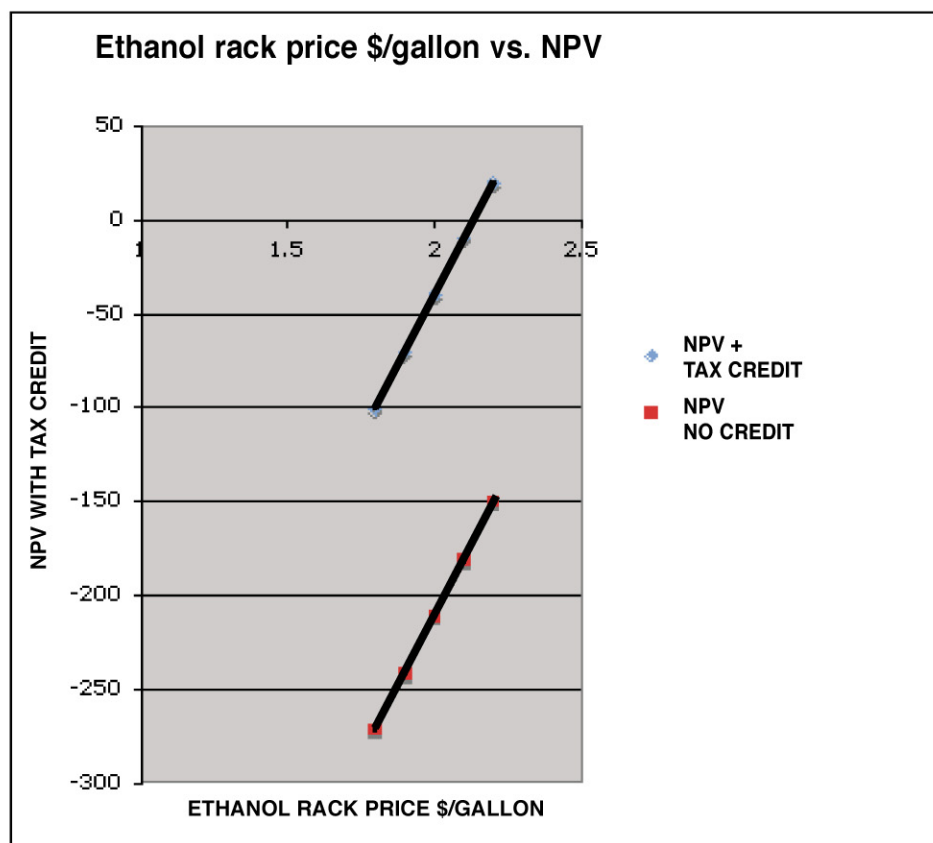
The process steps that are highlighted are major differences that add either to capital or operating cost. Note that the corn ethanol platform has the option of providing process heat via a biomass gasification unit. To keep the comparison on an equitable basis the capital cost for the corn ethanol platform will include a gasification unit to generate

| | RACK PRICE \$/GALLON | 1.80 | 1.90 | 2.00 | 2.10 | 2.20 |
|---------------------------------------|-------------------------|-------|-------|-------|-------|-------|
| No credits | IRR | -21.6 | -15 | -10 | -6 | -3 |
| | NPV | <272> | <242> | <211> | <181> | <150> |
| Producer tax credit \$0.56/gal. | IRR | 2 | 4.5 | 7 | 9 | 11.5 |
| | NPV | <101> | <71> | <40> | <10> | 20 |

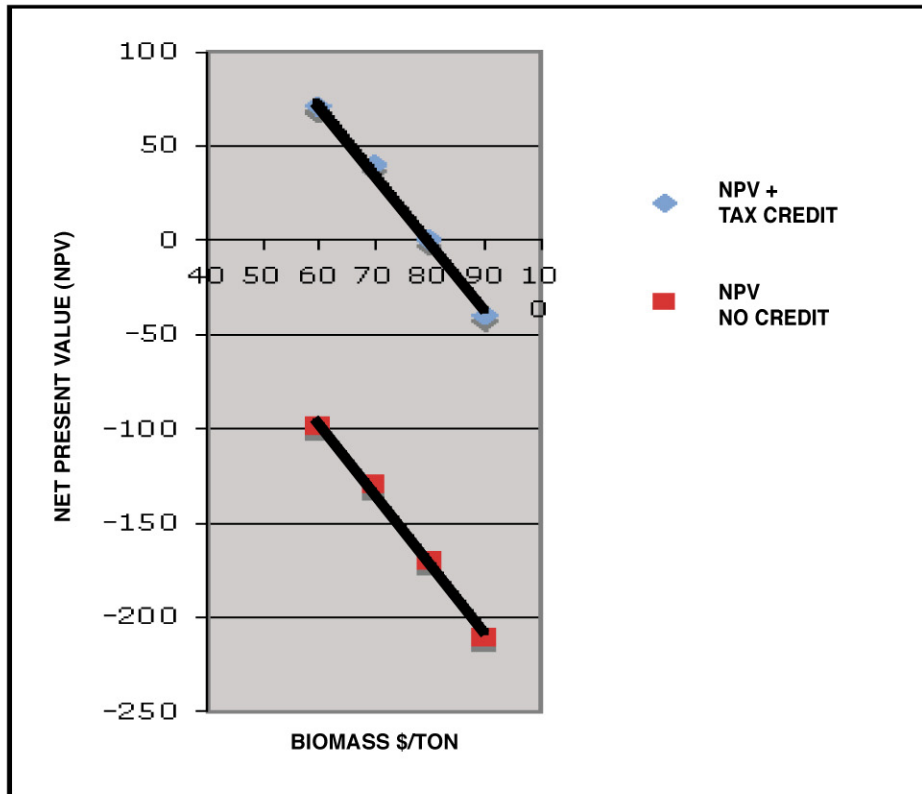
▲ **Table 4.3. Effect of ethanol rack price for conventional biochemical conversion platform with biomass cost of \$90/ton @ 15% moisture**

| | BIOMASS \$/TON | 90 | 80 | 70 | 60 |
|---------------------------------------|-------------------|-------|-------|-------|------|
| No credits | IRR | -10 | -5 | -4 | 2 |
| | NPV | <211> | <170> | <130> | <99> |
| Producer tax credit \$0.56/gal. | IRR | 7 | 10 | 12.8 | 15 |
| | NPV | <40> | 0 | 40 | 71 |

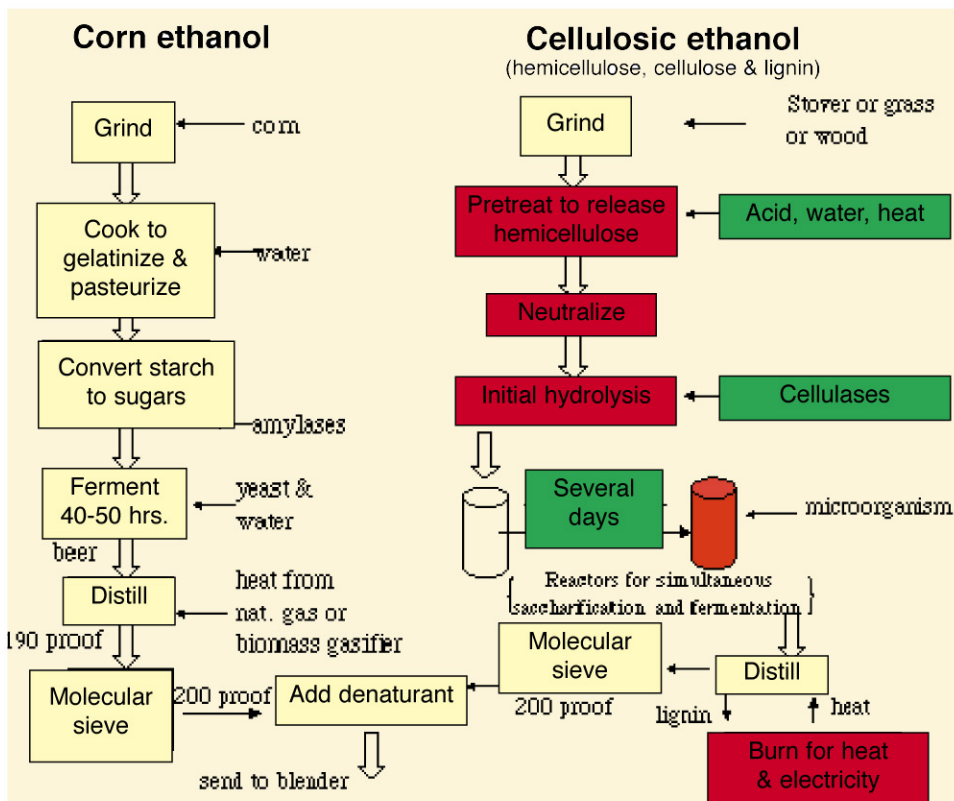
▲ **Table 4.4. Effect of Biomass cost @ 15% moisture with ethanol rack price of \$2.00/gal**



▲ **Figure 4. 8. NPV versus ethanol rack price**



▲ Figure 4.9. NPV versus biomass cost \$/ton



▲ Figure 4.10. Process flow diagrams for Corn Ethanol and Cellulosic Ethanol Platforms

process heat from biomass such as corn stover. What then are the major differences between the two platforms?

Major factors differentiating corn ethanol and biochemical ethanol conversion platforms

Capital Cost

- ▶ Biochemical platform is significantly more than corn ethanol platform, \$340MM vs. \$143MM for 50 MM gallons per year capacity. Both generate process heat from biomass.

- ▶ Biochemical platform requires additional vessels/tanks for pretreatment and initial enzymatic hydrolysis.

- ▶ Biochemical platform requires multiple reactors for simultaneous hydrolysis and fermentation.

Variable operating expense

- ▶ Enzymes add significant cost on the order of \$0.10/gal of ethanol.

- ▶ Acids and base used in pretreatment add cost.

- ▶ On a per gallon of ethanol basis, the variable cost in a biochemical plant are \$0.26 and only \$0.156 in a corn ethanol plant utilizing corn stover for process heat.

Other issues

- ▶ Acid pretreatment produces chemical by-products that are fermentation inhibitors. There will be some cost associated with their mitigation or removal.

What is being done to resolve some of these issues that prevent the biochemical cellulosic platform from being economically competitive with the corn ethanol platform?

There is considerable research activity to address the major problem areas as well as others

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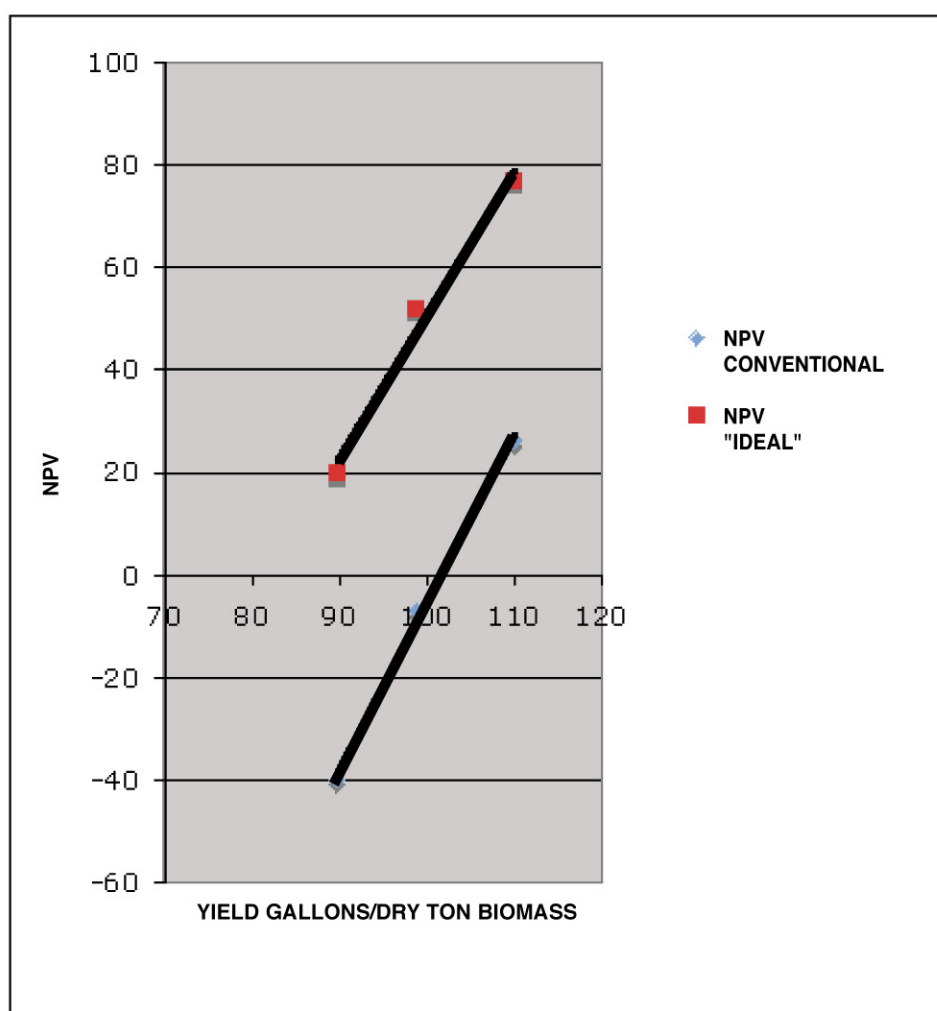
not specifically mentioned here. Proprietary technology is being developed in Universities and private companies both small and large. The key question lies in the scalability of the various technologies currently under development. At this time, there is only one operating demonstration plant in North America, Iogen's 1 MGY plant in Ottawa, Canada, which utilizes wheat straw as a feedstock. A second, 1.6 MGY unit is currently under construction by Verenium in Jennings, Louisiana, with sugar cane bagasse as the primary feedstock. The next scale would be for commercial plants, of which there are three currently in the design phase. Two of them are combinations with corn ethanol plants, utilizing corn stover, corn fiber, and corn cobs as primary cellulosic feedstocks. These are Poet's Project Liberty in Emmetsburg, Iowa, and Abengoa Bioenergy's new facility in Hugoton, Kansas. The third is a free-standing plant by Iogen in Saskatchewan based on wheat-straw. All these facilities have received significant financial support from their respective governments.

Research activity that is being conducted to improve the biochemical cellulosic biomass conversion platform

- ▶ Enzyme cost and performance improvements.
- ▶ Elimination or removal of fermentation inhibitors.
- ▶ Organisms that can tolerate inhibitors.
- ▶ Better organisms for simultaneous fermentation of 5 and 6 carbon sugars.
- ▶ Evaluation and optimization for various feedstocks such as corn stover, switch grass, prairie grass, hybrid poplar and the like.
- ▶ Organisms that will simultaneously hydrolyze cellulose and ferment the resultant sugars in a single continuous reactor. This is

| | | CAPITAL \$MM | IRR% AFTER TAX | NPV \$MM |
|--------------------------|-------------------|-----------------|-------------------|-------------|
| Corn ethanol | stover@ \$60/ton | 143 | 12 | 12 |
| Biochemical conventional | \$0.56 tax credit | 340 | 7 | <40> |
| | No credit | 340 | <10> | <211> |
| "Ideal" biochemical | \$0.56 tax credit | 318 | 11.5 | 20 |
| | No credit | 318 | <4> | <151> |

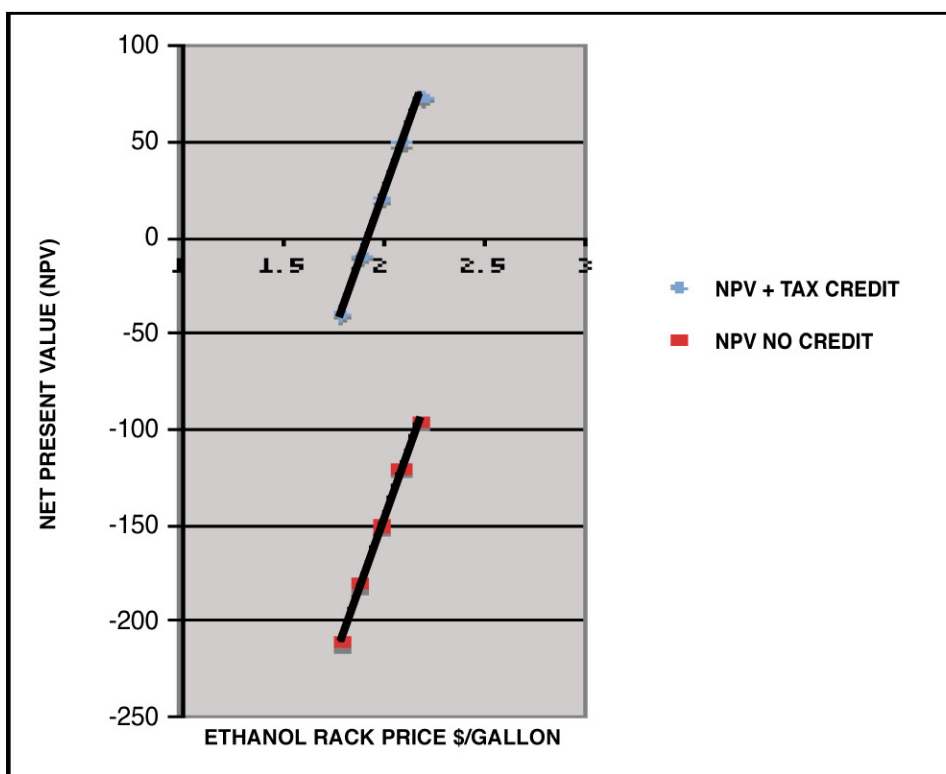
▲ Table 4.5. IRR and NPV for Ideal cellulosic ethanol platform



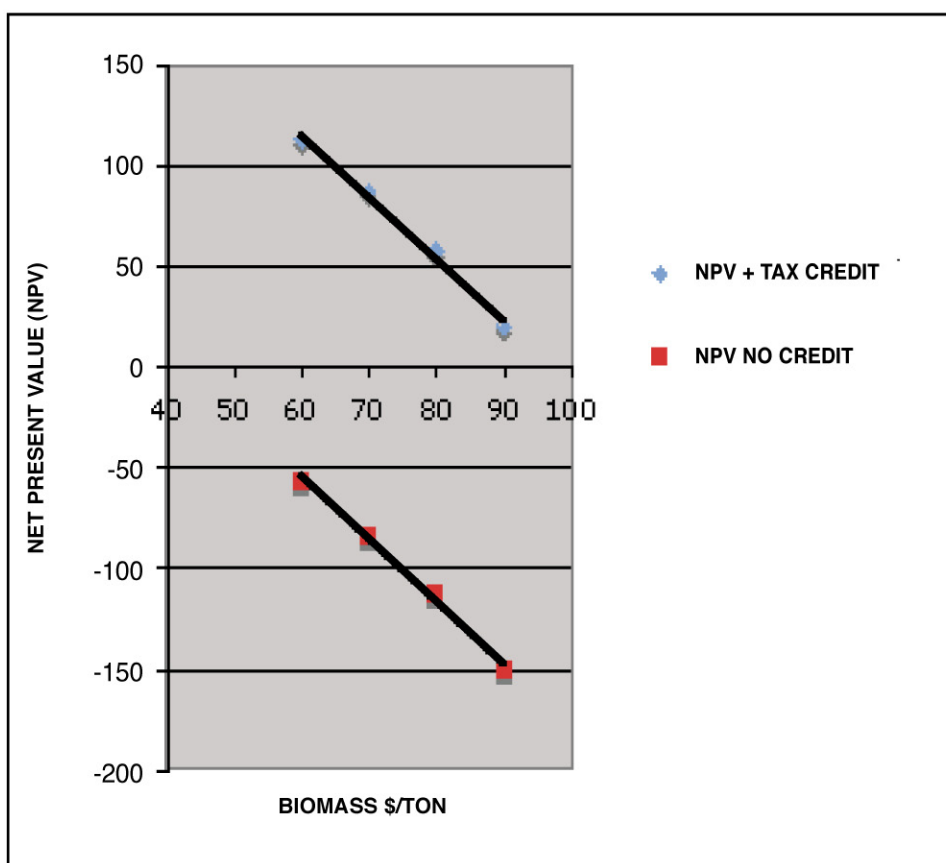
▲ Figure 4. 11. Effect of biomass conversion rate on NPV for Cellulosic Ethanol platforms

the *consolidated bioprocessing* approach. (Lynd, 2005).
Is there a best- case scenario for the biochemical cellulosic ethanol platform?

Much of the research being performed today is aimed at reduction of enzyme cost, elimination of inhibitors and developing better organisms. This research is



▲ Figure 4.12. Effect of ethanol rack price for *ideal* biochemical platform.



▲ Figure 4. 13. Effect of biomass cost for *ideal* biochemical platform.

not necessarily being conducted in an integrated holistic manner. The consolidated bioprocessing approach would seem to provide the potential for a best-case scenario to emerge. How much could such an **ideal platform** improve the economics of biochemical conversion of cellulosic biomass to ethanol? The ideal platform would eliminate exogenous enzymes and the resultant capital associated with this unit operation. In addition, there would be some reduction in the number of vessels required for the fermentation since it would occur simultaneously with saccharification.

To get some measure of what impact the *ideal* approach would have on the biochemical conversion platform the NREL model (Aden. et. al., 2002) was modified by eliminating all enzyme cost and all capital associated with enzyme hydrolysis. This reduces variable operating cost from \$0.26 to \$0.16 per gallon of ethanol and capital cost from \$340 MM to \$318 MM for a 50 MM gallon per year plant. Comparing the results to the corn ethanol baseline plant (table 4.5), the ideal plant has comparable IRR and NPV but only with the \$0.56/gal producer credit applied. Without the tax credit, even the *ideal* plant is not economically attractive. The business model is being driven by government tax credits.

Potential yield improvements

Since neither of these platforms is currently operating under commercial conditions there is always the hope that projected NREL yields could be improved in any number of ways ranging from process optimization to development of new strains of microorganisms that have improved efficiency. The NREL Aden model assumes an 80% conversion effi-

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ciency which amounts to 89.8 gallons of ethanol per ton of dry biomass (0% moisture). The widely accepted maximum theoretical yield is 112.7 gal/ton for corn stover. The sensitivity analysis around conversion is shown in figure 4.11. For the conventional biochemical platform, yield would have to increase by at least 10% to see acceptable returns. The NPV is only \$26MM for the biochemical plant vs. \$77MM for the ideal plant with yields approaching maximum theoretical. The probability of achieving such high levels of yield is relatively low.

Sensitivity to biomass cost and ethanol rack price

A sensitivity analysis around biomass cost and ethanol rack price is summarized in Figures 4.12 and 4.13

The results are similar to the conventional cellulosic ethanol platform but with a positive offset that mitigates the impact of high biomass cost or lower ethanol rack prices. However, the conclusion made at baseline conditions is still valid. The business model is based on tax credits and without them is not economically viable.

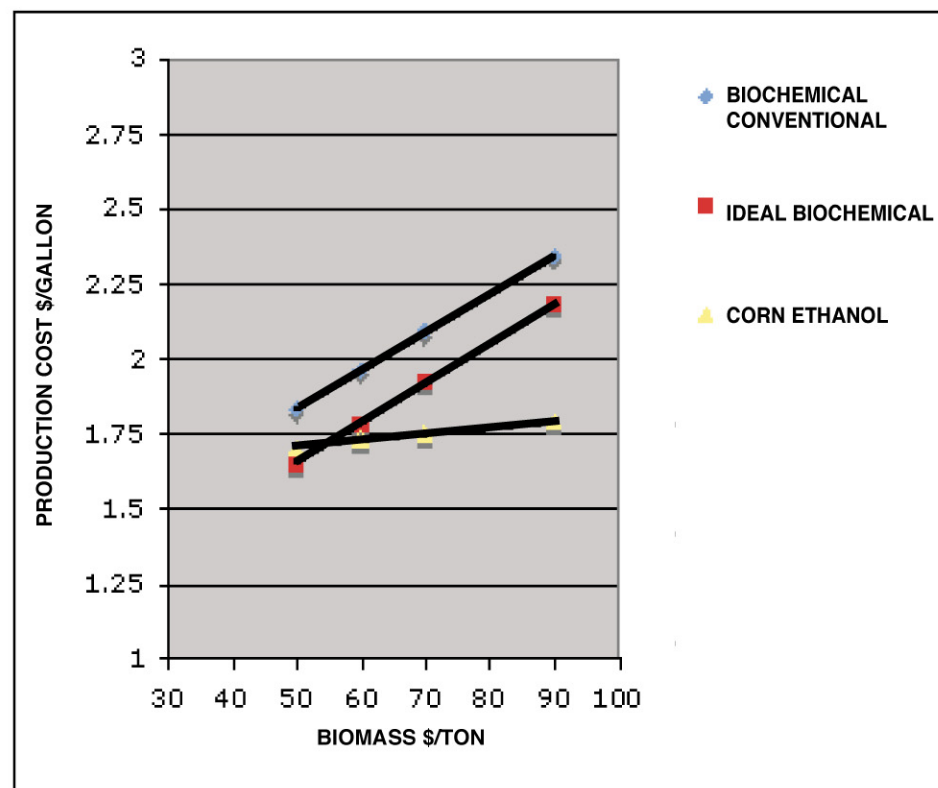
Production cost comparison

An alternative way to understand the financial dynamics of the various conversion platforms is to look at production cost as a function of biomass cost. Production cost includes raw material cost, variable cost, fixed costs, wages and salaries, and depreciation. By -product and electricity generation credits are applied to compute production cost per gallon of alcohol. The results are shown in Table 4.6 and also in figure 4. 14.

The gap between corn ethanol and biochemical cellulosic ethanol production costs is quite apparent.

| BIOMASS \$/TON | 90 | 70 | 60 | 50 |
|-----------------------------------------|------|------|------|------|
| Conventional biochemical | 2.34 | 2.09 | 1.96 | 1.83 |
| "ideal" - no enzymes | 2.18 | 1.92 | 1.78 | 1.65 |
| Corn ethanol base case | 1.82 | 1.82 | 1.82 | 1.82 |
| Corn ethanol with biomass energy source | 1.79 | 1.75 | 1.73 | 1.70 |

▲ Table 4.6. Production costs (\$/gallon) of ethanol for biochemical cellulosic platforms with corn ethanol platform as base case (corn @ 3.75/bu.).



▲ Figure 4.14. Production costs for ethanol platforms

Biomass cost would have to < \$50/ton to achieve parity.

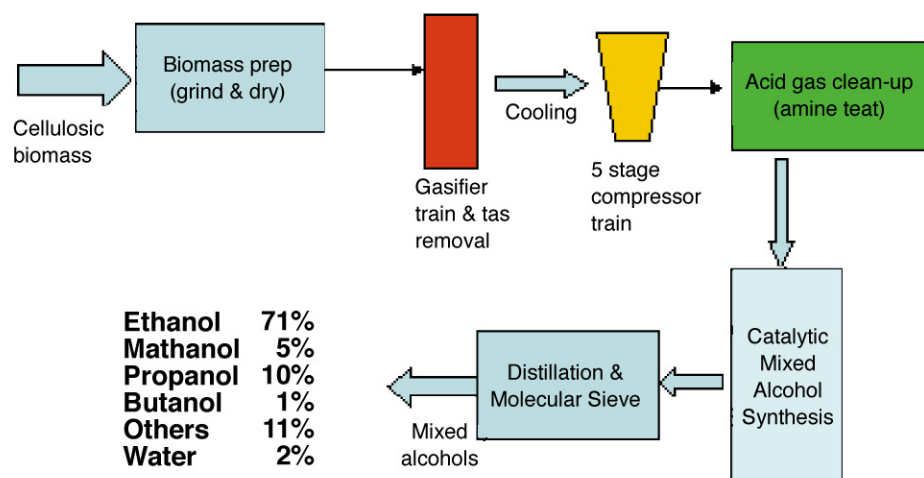
Thermochemical Conversion Platforms

Fermentation of the sugars contained within cellulosic biomass is a technology that mimics the corn ethanol platform in the conversion of sugars to ethanol that is accomplished by fermentation. An alternative technology is based on the conversion of cellulosic biomass to syngas (essen-

tially a mixture of carbon monoxide and hydrogen) and subsequent catalytic conversion to any number of high value added products ranging from mixtures of ethanol and other alcohols to gasoline, and aromatic hydrocarbons. These technologies are referred to as Thermochemical Platforms.

The conceptual differences between fermentation based platforms and thermochemical

Gasification and catalytic conversion to mixed alcohols.



▲ Figure 4.6. Thermochemical conversion to mixed alcohols

| | | CAPITAL \$MM | IRR% AFTER TAX | NPV \$MM |
|----------------------------|-------------------|-----------------|-------------------|-------------|
| Corn ethanol | stover@ \$60/ton | 143 | 12 | 12 |
| Biochemical conventional | \$0.56 tax credit | 340 | 7 | <40> |
| | No credit | 340 | <10> | <211> |
| "Ideal" biochemical | \$0.56 tax credit | 318 | 11.5 | 20 |
| | No credit | 318 | <4> | <151> |
| Mixed alcohol/gasification | \$0.56 tax credit | 193 | 24 | 125 |
| | No credit | 193 | 4 | <45> |

▲ Table 4.7. Comparison of cellulose - ethanol conversion platforms with corn ethanol as reference.

| BIOMASS \$90/TON (15% MOISTURE) | \$/GALLON |
|-----------------------------------------|-----------|
| Conventional biochemical | 2.34 |
| "Ideal"- biochemical no enzymes | 2.18 |
| Mixed alcohol/gasification | 1.92 |
| Corn ethanol base case | 1.82 |
| Corn ethanol with biomass energy source | 1.79 |

▲ Table 4.8. Production cost for cellulosic ethanol conversion platforms

platforms have a significant impact on economic viability. Fermentation processes are similar to brewing in that the intermediate product is a beer with relatively low concentration of 2 to 14 % (depending on the feed-stock) of ethanol as one of the major constituents. This beer must be concentrated by distillation to separate water from ethanol followed by molecular sieves to achieve desired puri-

ties. This is energy intensive and adds about \$0.30 per gallon of alcohol in energy cost for fossil fuel in a corn ethanol plant. An alternative of gasifying biomass to provide a renewable syngas as fuel reduces the energy cost to about \$.10 per gallon of ethanol but increases capital cost by about 38% for a 50 MM gal/year corn ethanol plant.

A cellulosic ethanol biochemical conversion platform is similar in that a beer is produced that must subsequently be concentrated by distillation and molecular sieves just as in the corn ethanol plant. While there is no DDG by-product there is excess electricity produced from biomass gasification and that adds an electricity credit of about \$0.114 per gallon of ethanol to the cash flow. Yield from corn stover, as the biomass source, is about 90 gallon per ton of dry feed (15% moisture).

For the thermochemical conversion platform (Phillips et al, 2007) that combines gasification to convert biomass to syngas and subsequent conversion to mixed alcohols via catalytic reactions the situation is different. There are two major product streams; the first is ethanol and the other is a mixture of methanol and higher alcohols. The respective yields are about 80 gallons of ethanol and 9.5 gallons of mixed alcohols per ton of dry biomass (15% moisture). This is a composite yield of 89.5 gallons per ton biomass. The mixed alcohols are valued at \$1.15/ gallon in the Phillips model but this is somewhat arbitrary and conservative. Its value would most likely be closer to or greater than ethanol based solely on its higher heating value as a fuel. With the \$1.15/gallon value the mixed alcohols contribute about \$0.22/gallon of ethanol as by-product credit.

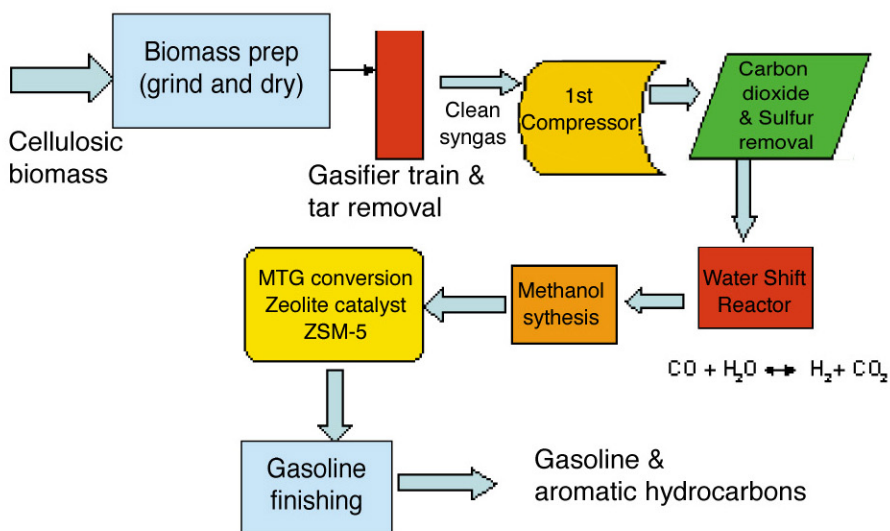
More importantly the separation of ethanol from the by-products is by condensation which is considerably less energy intensive than distillation. Gasification of the biomass means that there are no expensive enzymes involved in the process. In addition much of the process heat and electricity is provided by recovery of waste heat from the gasification process through heat recovery as well as combustion of the tars recovered from the syngas purification step in the process. To summarize:

Advantages of Mixed Alcohol/Gasification platform vs. Biochemical platform

- ▶ No enzymes
 - ▶ Less energy in product separation/purification
 - ▶ Valuable by-product stream of methanol and higher alcohols
 - ▶ Reduced capital due to fewer tanks, vessels and piping
- For convenience, figure 4.6 for the gasification of biomass and catalytic conversion to mixed alcohols is reproduced here.

A financial comparison of the conventional biochemical, ideal biochemical and mixed alcohol/gasification conversion platforms is shown in Table 4.7 with corn ethanol as the reference. The mixed alcohol/gasification platform is clearly the preferred technology on the basis of IRR and NPV. As with the biochemical platforms, the producer tax credit provides most of the profitability in the alcohol/gasification platform. Without the credit it would be a marginal business opportunity. The numbers in table 4.7 were computed for baseline conditions of a rack price of \$2.00 /gal for ethanol and biomass cost of \$90/ton (@ 15% moisture) and corn at \$3.75/bu. An increase in ethanol rack price or a decrease in biomass cost would improve the economics proportionately

Gasification of biomass and catalytic conversion to gasoline



▲ Figure 4.7. Thermochemical biomass to gasoline conversion platform.

with respect to the biochemical platforms.

The production costs for the mixed alcohol/gasification platform (Table 4.8) are the lowest of the cellulosic conversion platforms and within striking distance of the corn ethanol reference platform. The difference between the *ideal* biochemical platform and the alcohol/gasification platform of \$0.26/gal translates to \$13MM more in cash flow, this is significant. The difference in cash flow compared to the conventional biochemical platform is \$0.42/gal or \$21MM more in cash flow.

There currently is a small scale commercial plant under construction by Range Fuels. The Phillips model from NREL is based on the assumption that ethanol via thermochemical pathways is expected to be demonstrated at the pilot plant level by 2012. The Phillips model published in 2007 attempts to incorporate:

- ▶ Currently established and published technology.
- ▶ Technology currently under development or shortly to be under

development from the DOE Office of Biomass Program funding.

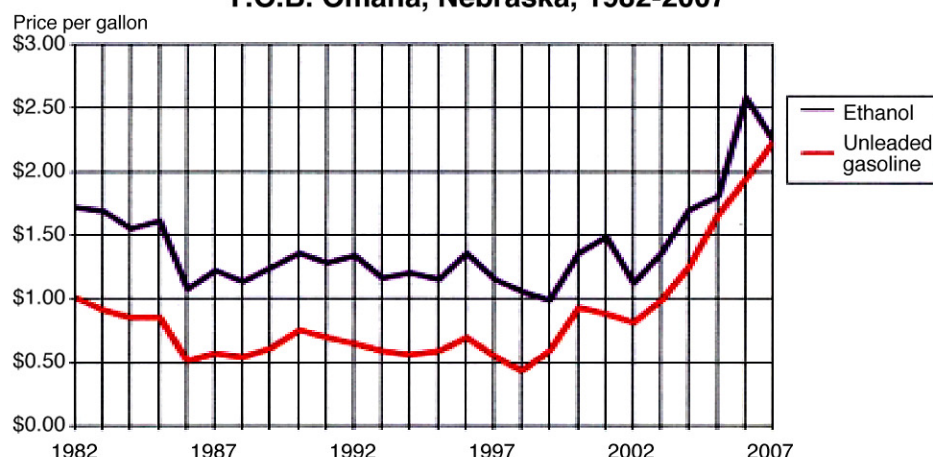
- ▶ Biomass resource availability in the 2012 time frame consistent with the Billion Ton Vision study.

Gasification of biomass to syngas and catalytic conversion to gasoline

The gasoline thermochemical platform is based on the well known process for converting syngas to methanol and subsequently utilizing the commercially demonstrated MTG process to convert the methanol to products such as dimethyl ether (DME), gasoline and other aromatic hydrocarbons (Phillips, 2008).

The conversion of methanol to gasoline has been demonstrated at a large scale, but, prior to the recent increases(2008) in the cost of crude oil, gasoline made using the MTG process (also called M-gasoline) was not cost competitive with oil-derived gasoline. The process is based on dehydration of methanol using a zeolite catalyst, ZSM-5, developed by Mobil Oil in the 1970s. The technology was practiced on a commercial basis

Ethanol and unleaded gasoline rack prices F.O.B. Omaha, Nebraska, 1982-2007



▲ Fig.4.9. Rack prices for gasoline and ethanol from official Nebraska Government website.

| | MTG gasoline platform | IRR % after tax | NPV \$MM | Capital \$MM |
|------------|-----------------------|-----------------|----------|--------------|
| 50MM gal | Tax credit \$1.01/gal | 17.5 | 86 | 265 |
| 50 MM gal | No tax credit | N/A | N/A | 265 |
| 75 MM gal | Tax credit \$1.01 | 26 | 231 | 316 |
| 75 MM gal | No tax credit | N/A | N/A | 316 |
| 100 MM gal | Tax credit \$1.01 | 32 | 383 | 361 |
| 100 MM gal | No tax credit | <11> | <232> | 361 |

▲ Table 4.9. Financial parameters for MTG gasoline platform

(14,500 barrels/day) in New Zealand from 1981-1984. (Huber, 2006) because of the 1980's world wide oil crisis. The platform produces LPG as a saleable by-product. For convenience, figure 4.7 showing the process flow is reproduced here.

Baseline conditions for the MTG biomass to gasoline platform

For all of the previously considered platforms the baseline conditions were selected as follows:

- ▶ Biomass \$90/ton at 15% moisture content.
- ▶ Corn \$3.75/bushel
- ▶ Alcohol rack price \$2.00/gallon
- ▶ Plant capacity 50 million gal-

lons per year

But what is the appropriate price to assign for gasoline? It is clear that the price of gasoline at the retail level rises and falls with the price of crude oil. How does this differ from the pricing of ethanol that appears at the gas pump as part of the gasoline being dispensed?

Gasoline and alcohol prices can be obtained from published rack (wholesale) prices that are reported on a yearly basis. Rack prices are closer to what the producer would realize upon sale to blenders or distributors. To factor in the variability inherent in these markets the rack prices

were taken as the average over the years 2003-2007 inclusive. This avoids the spike in crude oil and gasoline prices experienced in the first 8 months of 2008 which would bias the results too much in favor of the MTG biomass to gasoline platform. The ethanol and unleaded gasoline prices F.O.B. for the period 1982-2007 from the official Nebraska Government website are shown in Figure 4.9. The prices reported from 2003-2007 were adjusted for an inflation rate of 3% per year. Following this procedure the baseline rack price of gasoline was determined to be \$1.69/gallon and ethanol was calculated to be \$2.00/ gallon.

The spike in ethanol prices from 2006 to 2007 is in part due to the phase-out of MTBE and the mandatory switch to ethanol as an oxygenate additive. With minor fluctuations, the ethanol rack prices follow gasoline.

If ethanol were to be priced at its actual fuel energy value (i.e. LHV - lower heating value) compared to gasoline, it would be in proportion to the ratio of LHV alcohol/LHV gasoline which is 0.66. Based on a gasoline rack price of \$1.69, this would be a price of \$1.32 for ethanol.

Financial analysis of MTG biomass to gasoline platform

NOTE: The NREL MTG model developed by Phillips was used as the basis for financial analysis.

The tax credits for producing gasoline from biomass include the blender credit of \$0.45/gal as well as the producer credit of \$0.56/ gal for a total tax credit of \$1.01. In this case the producer and blender are one in the same so both credits will apply! This is a significant factor in financial calculations.

CONVERSION PLATFORMS

The results of the discounted cash flow calculations are presented in Table 4.9.

With the baseline conditions selected the MTG platform shows negative IRR's when there are no tax credits. This is true even when plant size is doubled to take advantage of economy of scale. With tax credits the results are better than biochemical platforms and only slightly below the mixed alcohol/gasification platform as shown in Table 4.10. Note that the capital investment is also considerably less than the biochemical platforms and the tax credits are both the producer and blender credits that total \$1.01/gallon.

The production cost for all the platforms is shown in table 4.11. The MTG gasoline production cost is between the mixed alcohol/gasification and ideal biochemical platforms.

Sensitivity Analysis for MTG gasoline platform.

As with the platforms already discussed both biomass cost and gasoline rack price have a significant impact on the IRR and NPV. The results are shown in figure 4.15 and Figure 4.16.

As the sensitivity analysis indicates the financial attractiveness of the MTG gasoline platform is highly dependent on the cost of biomass and the rack price of gasoline. The cost of biomass is dependent on agricultural production costs and to a greater extent on the price of corn. Farmers will put land into prairie grass or switch grass when they can make more than they can realize on corn. If incentives were to be offered this would shift the balance toward lower biomass costs just as tax credits and other producer credits impact the producer's bottom line. If our nation is serious about reduction of our

| | | CAPITAL \$MM | IRR% AFTER TAX | NPV \$MM |
|----------------------------|-------------------|-----------------|-------------------|-------------|
| Corn ethanol | stover@ \$60/ton | 143 | 12 | 12 |
| Biochemical conventional | \$0.56 tax credit | 340 | 7 | <40> |
| | No credit | 340 | <10> | <211> |
| "Ideal" biochemical | \$0.56 tax credit | 318 | 11.5 | 20 |
| | No credit | 318 | <4> | <151> |
| Mixed alcohol/gasification | \$0.56 tax credit | 193 | 24 | 125 |
| | No credit | 193 | 4 | <45> |
| MTG gasoline | \$1.01 tax credit | 265 | 17.5 | 86 |
| | No credit | 265 | N/A | N/A |

▲ **Table 4.10. Comparison of financial parameters for 50 million gallon capacity cellulosic biomass liquid fuel conversion platforms with biomass at \$90/ton (15% moisture) and corn ethanol as reference (corn = \$3.75/bu.)**

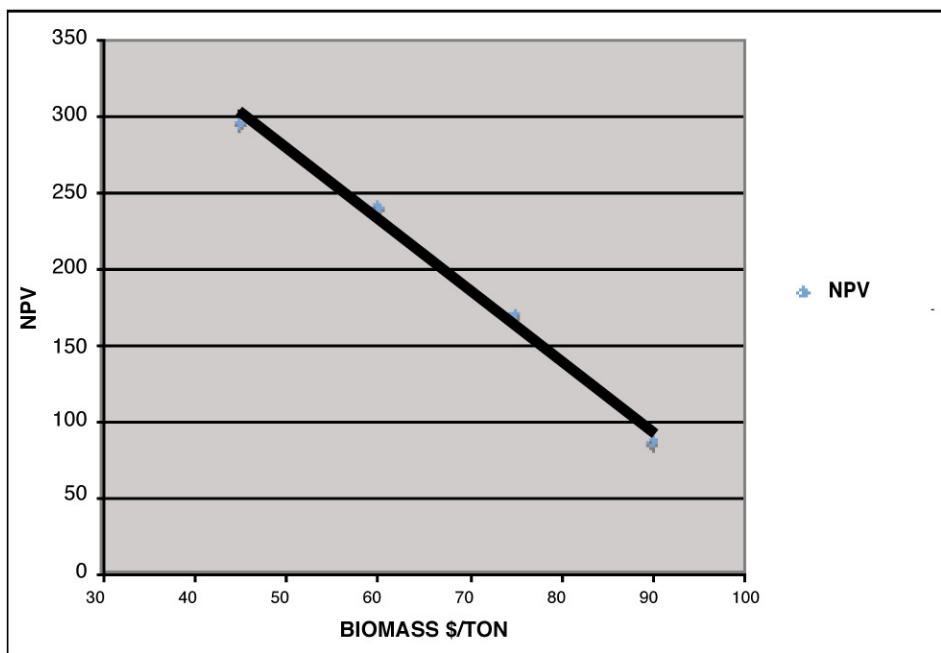
transportation fuel carbon footprint then it would seem wise to provide the farmer some incentive to raise crops with a significantly smaller carbon footprint than corn. Gasoline rack prices will follow the price of crude. In the first 8 months of 2008 crude oil soared to over \$140/bbl and gasoline prices reached \$4.00/gal at the retail level. This would translate to a rack price of about \$2.90/gal *. The sensitivities in figure 4.16 are computed at 10% incremental increases above the baseline rack price of \$1.69/gal. It is clear that even a 10% increase in rack price translates to an increase of over 55% in NPV (from \$86MM to \$134MM). Of course in the last quarter of 2008 crude prices fell to the \$40's and gasoline was available at \$1.65 (rack price of \$0.98/gal.) or less at retail as the world entered a severe recession.

Whichever platform is selected has to be robust enough economically to withstand such feast and famine business cycles.

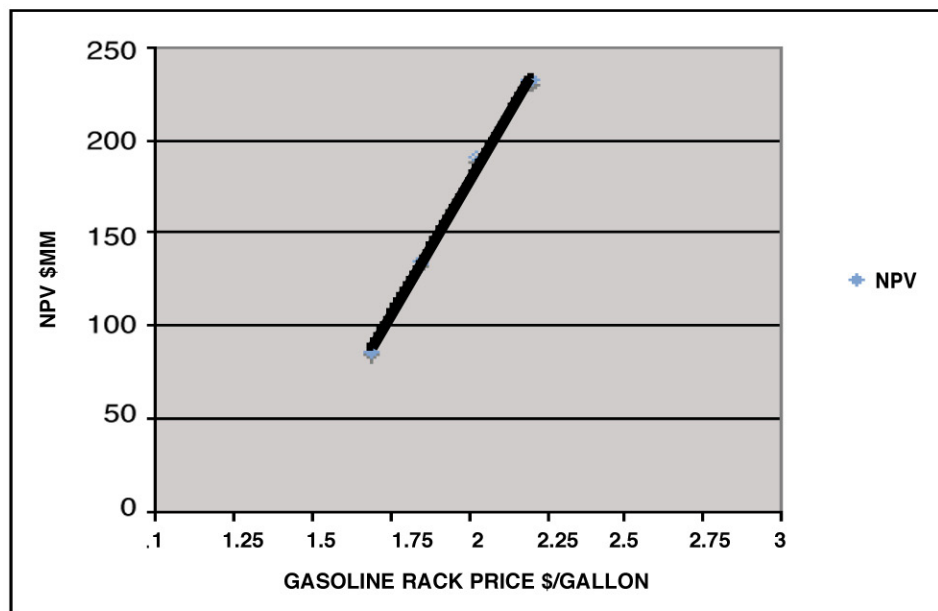
| BIOMASS \$90/TON (15% MOISTURE) | \$/GALLON |
|-----------------------------------------|-----------|
| Conventional biochemical | 2.34 |
| "Ideal"- biochemical no enzymes | 2.18 |
| MTG gasoline | 2.16 |
| Mixed alcohol/gasification | 1.92 |
| Corn ethanol base case | 1.82 |
| Corn ethanol with biomass energy source | 1.79 |

▲ **Table 4.11. Production costs for cellulosic biomass conversion platforms to liquid transportation fuels. Reference is corn ethanol with corn at \$3.75/bu.**

* Retail prices were calculated by estimating the spread between tabulated rack and retail prices net of taxes. (Opis regional Rack-To-Retail margin report, Opisnet.com) Taxes were estimated based on published differences between actual and net retail. For the Midwest the spread between rack and net retail is a factor of 1.23. Taxes are approximately \$0.45/gal. Then for a rack price of \$2.90 the retail price would be $(\$2.90 \times 1.23) + \$0.45 = \$4.00$



▲ Figure 4.15. Effect of biomass cost on NPV (\$MM) for MTG platform.



▲ Figure 4.16 . Effect of gasoline rack price on NPV (\$MM) for MTG platform.

Advantages of the MTG gasoline platform.

- ▶ Established and proven technology at commercial scale.
- ▶ Products (gasoline and LPG) that fit existing distribution and usage patterns.
- ▶ Minimal external fossil fuel since the MTG platform uses biomass for

heat and power requirements.

- ▶ Capital (\$265MM) significantly lower than biochemical cellulosic platforms (\$318MM - \$340MM).

With all these advantages why has this not happened?

The drivers that will encourage investment in technologies such as the MTG gasoline platform are:

- ▶ Gasoline rack prices greater than \$1.70 (retail of \$2.55/gal.) on a sustained basis
- ▶ Moving toward energy independence, most likely through subsidies and tax credits to encourage investment in processing plants.
- ▶ Incentives for farmers to substantially increase the plantings of sustainable, renewable prairie grasses to provide the biomass necessary to take a serious step towards reduction of carbon dioxide emissions. ■

BIOMASS REQUIREMENTS AND CONCLUSIONS FOR LIQUID FUELS

How much biomass is required for the various platforms?

The biomass requirements are dependant on the particular platform under consideration. For the conventional 50MM gallon capacity biochemical or *ideal* biochemical platforms the required biomass is 670,000 tons/ year. For the 50MM gallon capacity thermochemical mixed alcohol platform the requirement is 765,000 tons/year. For the 50MM gallon MTG gasoline platform the requirement is 750,000 tons/year. Both thermochemical platforms appear to require comparatively more biomass than the biochemical platforms. This is for two reasons: 1) The thermochemical platforms produce by-products in addition to the ethanol or gasoline. (Mixed alcohols or LPG). 2) The gasification step in the thermochemical platforms does not convert 100% of the biomass to syngas since some is converted to carbon dioxide as part of the chemistry of the process.

The sustainable removal rate of prairie grass or similar forms of biomass is about 2 tons per acre (15% moisture). However, it is not accurate to equate 50MM gallons of gasoline to 50MM gallons of ethanol. The accepted method is to compare LHV (lower heating value) of the respective fuels. Thus, LHV gasoline/LHV ethanol = 1.513. This means that the 50MM gallons of gasoline would be equivalent to 75.7MM gallons of ethanol. From a biomass standpoint, the requirement would be $750,000\text{t} \times 1/1.513 = 500,000$ tons, which equates to 250,000 for acres.

Based on current technology for converting all forms of biomass to ethanol, the capacity in the White Earth region would be about 166 million gallons per yr if all eligible acreage were producing biomass at sustainable levels to also provide ecosystem services such as soil, water, and wildlife protection. This would represent 3 biofuel plants, whose feasibility and profitability would depend on market conditions and the type of technology employed to convert the biomass to ethanol or other forms of biofuel. Thus the MTG platform has the highest fuel yield, on a BTU basis, per unit biomass input, the equivalent of 76MM gallons of ethanol.

Conclusions for liquid fuels from cellulosic biomass

- ▶ Ethanol from cellulosic biomass with current technologies is not ready for commercialization.
- ▶ Significant technological discoveries and developments are required to make liquid phase fermentation based cellulosic ethanol conversion platforms profitable.
- ▶ Regardless of promised

potential technical improvements the capital cost will still be significantly higher than for corn ethanol plants of similar capacity.

- ▶ Under the best -case scenarios the biochemical platform is dependent on government subsidies to be profitable. The profit is basically in the subsidies.

▶ Ethanol can be more economically produced by gasification of biomass and subsequent catalytic conversion to mixed alcohols. However, this technology has yet to be demonstrated at any significant scale.

- ▶ Ethanol should be viewed as a transition biofuel. Ultimately synthesis gasoline and diesel fuel based on cellulosic biomass should prevail.

▶ Syn gas catalytic conversion to gasoline appears to offer the best potential for conversion of cellulosic biomass to liquid fuels that are compatible with current usage and distribution patterns. This technology was utilized in New Zealand during the energy crisis of the 80's.

▶ Syn gas platforms will become economically and strategically compelling when 1. Crude oil prices get high enough (gasoline rack price of \$1.70/ retail of \$2.55/gal or higher) and 2. Foreign oil independence and 3. reduction of carbon dioxide emissions become national priorities.

- ▶ Regardless of which platforms prevail commercially the supply of sustainable renewable biomass must be increased dramatically to supply the needs of conversion platforms. ■

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AN OPPORTUNITY FOR CHISAGO



WOOD PELLETS

ISANTI &
PINE COUNTIES

Wood pellets are a viable and economical renewable energy source for space heating, especially in areas not served by natural gas. They are a relatively new energy choice competing with more common options like fuel oil, propane, natural gas and electricity.

WOOD PELLETS

Wood pellets first became an option in the late 1970's/early 1980's after the energy crisis made fossil-based fuels much more expensive. The North American market has been growing at a compound annual rate of about 4.5% per year since 1994 mostly due to growth in the Northeast U.S. Growth has accelerated in the past 10 years with the introduction of dozens of innovative new automated pellet fuel appliances including free-standing stoves, fireplace inserts, furnaces and boilers. The sale and use of these appliances is the primary driving force in generating demand for wood pellets in the US.

Wood pellets offer significant environmental benefits

- ▶ They are almost carbon dioxide neutral. The carbon footprint is only about 15% of that for the comparable fossil fuels used for space heating. Carbon dioxide is essentially being recycled when the biomass is harvested in a sustainable manner.

- ▶ Wood or biomass pellet stoves are considered non-polluting by the EPA. Wood pellet stoves have less than 10% of the emissions of burning cordwood.

- ▶ Wood pellets burn with 80-85% efficiency in modern pellet stoves whereas cord wood burns at about 60% or less efficiency.

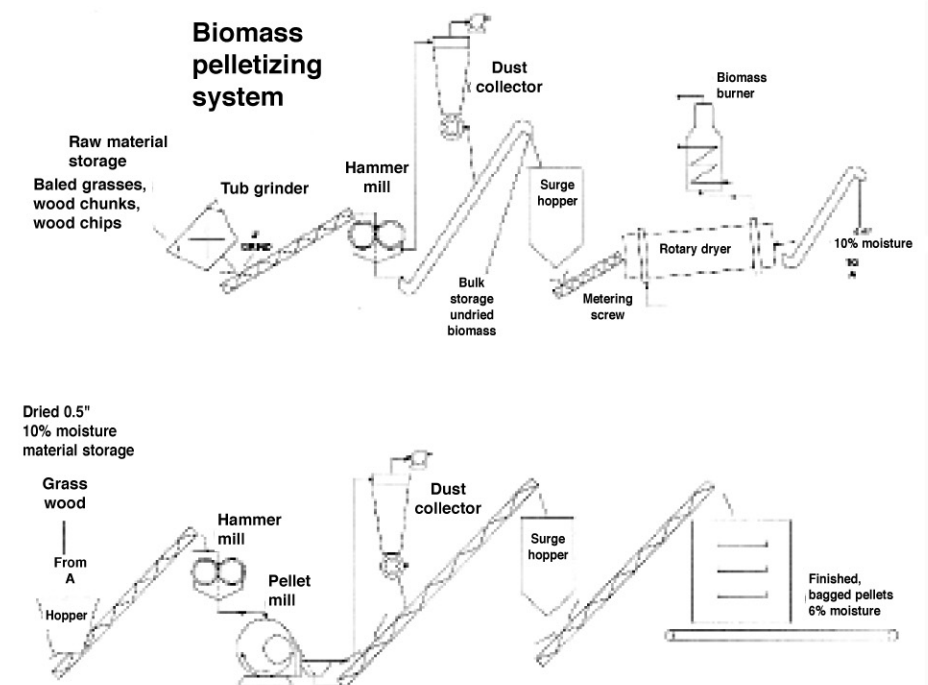
Comparison of Wood Pellets versus Other Heating Choices

Wood pellets are a standardized fuel that competes with other forms of energy including fuel oil, electricity and propane.

Currently, in Minnesota, the cost of wood pellet heat competes favorably with oil, propane and electricity (Figure 5.1). The Minnesota Department of Commerce estimates that an average Minnesota home uses about 100 million Btu for heat during a typical year. Using nat-

| | WOOD PELLETS | CORDWOOD | OIL | GAS | PROPANE |
|-----------------------------|--------------------|---------------------|--------------------------|-----------------------------------------------|--------------------|
| Energy comparison | 1 ton | 1.5 cords | 120 gal. | 16,000 ft ³ | 170 gal. |
| Cost/unit (current MN) | \$200/ton | \$150/ton | \$2.95/gal. | \$0.9044/therm \$9.89/1000 ft ³ | \$2.00/gal. |
| Appliance efficiency | 80% | 60% | 78% | 80% | 78% |
| Energy/unit | 16,500,000 btu/ton | 20,000,000 btu/cord | 138,690 btu/gal. | 1,031,000 btu/1000 ft ³ | 91,333 btu/gal. |
| Cost per net MMBTu | \$15.24 | \$12.50 | \$27.40 | \$11.75 | \$27.23 |
| Fuel advantage over pellets | N/A | 18% cheaper | 79% more expensive | 23% cheaper | 79% more expensive |
| Storage needs | Dry storage area | Dry storage area | In- or above-ground tank | Piped in | Above-ground tank |




▲ Figure 5.1. Consumer Fuel Choice Comparison



▲ Figure 5.2. Biomass palletizing process flow diagram

ural gas, this would cost about \$1,000 (2008 prices). Heating with propane would cost about \$2,700 during a typical year; heating with fuel oil would cost about \$2,000. The Minnesota Department of Commerce and

the Minnesota Propane Gas Association estimate that about 200,000 Minnesota homes are heated with propane, and about 90,000 homes are heated with fuel oil. This represents a sizable potential market for pellet appli-

| | | | | |
|--------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| |  |  |  |  |
| Type of Appliance | Pellet burning fireplace insert | Free standing pellet stove | Pellet furnace | Pellet boiler |
| Medium | Air and radiant heat | Air and radiant heat | Forced air | Water |
| Design Use | Intermittent | Intermittent | Daily | Daily |
| Capacity | Spot | Spot | Whole house | Whole house |
| Cost | \$1,000 - \$3,000 | \$1,000 - \$4,500 | \$2,500- \$5,000 | \$2,500 - \$5,000 |
| Storage Type | Built-in | Built-in | Built-in and remote | Built-in and remote |

▲ **Figure 5.3. Selected Types of Pellets Appliances**

ances. With a high-efficiency wood pellet furnace, heating a home with wood pellets at \$200/ton would cost about \$1,500 annually. This would be about \$1,200 less than the cost to heat with propane, and \$500 less than with fuel oil. Cordwood is cheaper but is also highly polluting and its use is limited in some areas.

Wood Pellet Manufacturing

Wood fuel pellets are typically made from sawmill waste and wood residue. Wood pellets are manufactured in pellet mills that are usually located at or very near the feedstock supply - usually a sawmill operation. The feedstock is usually sorted to remove impurities and size reduced to 0.5 inch if needed, dried to 10% moisture, size reduced to fine granulation, compressed and forced through a cylindrical die with hundreds of holes milled into it. As the small cylindrical pellets are extruded out a cut-off blade shears the pellets off at a standard length -

usually about 3/8" to 1" long at 6% moisture. The pellets end up looking like rabbit feed. Nothing is added to the pellets, such as fillers or glues, during the manufacturing process. Pellets are then either stored for bulk shipment or packaged and palletized - typically 40 pounds/bags, 50 to a pallet - for retail sale. A process flow diagram is shown in figure 5.2. ■

WOOD PELLET MARKET DYNAMICS

Wood Pellet Appliance Market

The key driving force in the demand for wood pellets in the US is the installed base of pellet burning appliances. There are currently between 900,000 and 1.1 million homes in North America using wood pellets for heat in freestanding stoves, fireplace inserts and furnaces.

Pellet fuel appliances are specifically designed to burn premium

wood pellet fuel. Some multi-fuel models can also burn nutshells, corn kernels, and small wood chips. They are more convenient to operate and have much higher combustion and heating efficiencies than ordinary wood stoves or fireplaces. As a consequence of this, they produce very little air pollution. In fact, pellet stoves are the cleanest solid fuel-burning residential heating appliances. With combustion efficiencies of 78%-85%, they are also exempt from United States Environmental Protection Agency (EPA) smoke-emission testing requirements. Pellet stoves have heating capacities that range between 8,000 and 90,000 Btu per hour. They are suitable for homes as well as apartments or condominiums.

There are a wide variety pellet fuel appliances manufactured today ranging from relatively simple and compact free-standing pellet stoves to complex, high Btu output commercial furnaces and boilers (Figure 5.3).

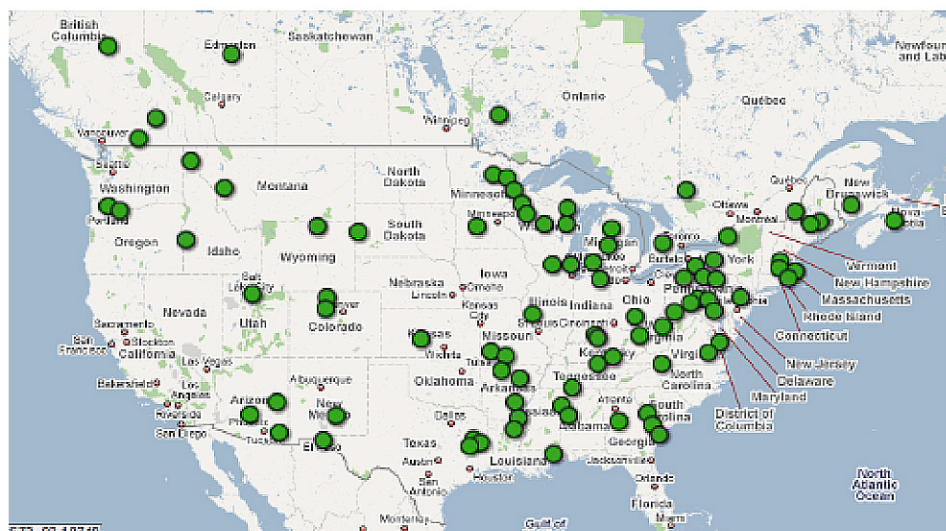
The average pellet stove user will consume fuel at the rate of about one 40 lb bag of wood pellets every 24 hours of use. Pellet consumption varies depending on overall home efficiency and stove settings. Most freestanding stoves are used intermittently throughout the winter months - not as a primary heat source. All pellet fuel appliances have a fuel bin/hopper to store the pellets until they are needed for burning. Most hoppers hold one to three bags of fuel, which will last a day or more under normal operating conditions. A feeder device, like a large screw, drops a few pellets at a time into the combustion chamber for burning. How quickly pellets are fed to the burner determines the heat output. The exhaust gases are vented by way of a small flue

pipe that can be directed out a sidewall or upwards through the roof. More advanced models have a small computer and thermostat to govern the pellet feed rate.

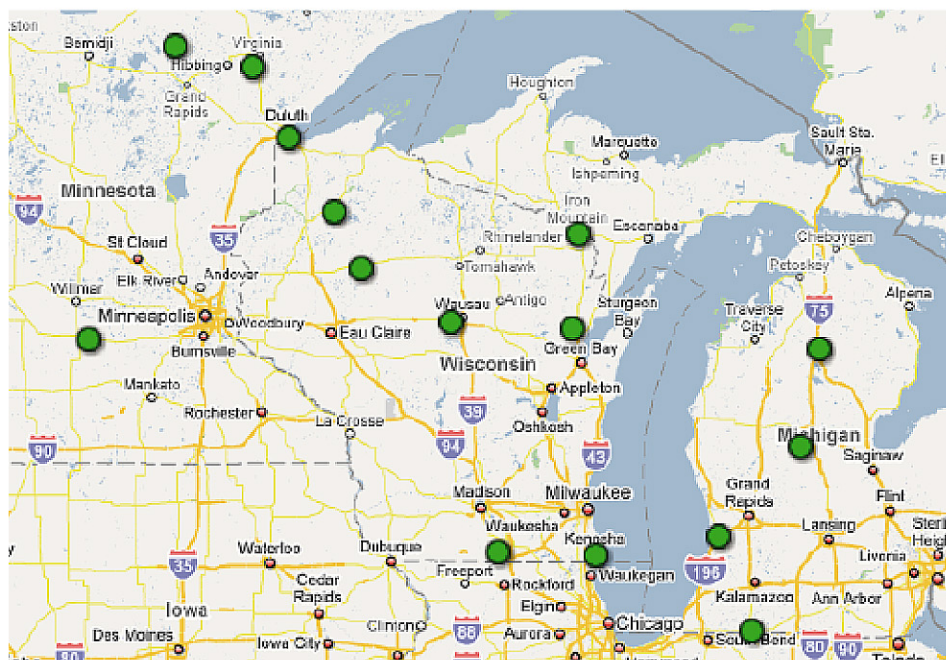
Most pellet stoves cost between \$1,700 and \$4,000. However, a pellet stove is often cheaper to install than a cordwood-burning heater. Many can be direct-vented and do not need an expensive chimney or flue. As a result, the installed cost of the entire system may be less than that of a conventional wood stove. Since pellet stoves burn fuel so completely, very little creosote builds up in the flue, posing less of a fire hazard.

Market Size and Growth Trends
North American pellets are produced in manufacturing facilities in Canada and the United States. There are currently over 90 pellet mills in North America producing biomass pellets for use in pellet stoves (Figure 5.4). In Minnesota and Wisconsin there are currently 8-10 wood pellet manufacturing plants capable of producing approximately 350,000+ tons of pellets per year (Figure 5.5). Actual annual production by state is not currently available.

According to data collected by the Pellet Fuels Institute (PFI), a record 1,148,000 tons of pellet fuel were sold in the US during 2006 - 11% more than the record 1,030,000 tons shipped the year before. Over the past six years, the total tonnage of pellet fuel shipped in the U.S. increased 79%, from 641,000 tons shipped in 2000 to 1,148,000 tons shipped in 2006 (Figure 5.6). In 2007, an estimated 1.3 million tons of pellets were shipped (not including European exports).



▲ Figure 5.4. North American Wood Pellet Mills



▲ Figure 5.5. Midwest Pellet Mills as of 2007

North American Regional Sales Trends

Since 1999, pellet sales in North America have been steadily trending upward. Annual growth has been approximately 5% per year since 2000. Different regions have been growing at significantly different rates with the Northeast region in the US seeing the most significant growth from 1999-2003. The Northeast continued this trend growing 20% between the

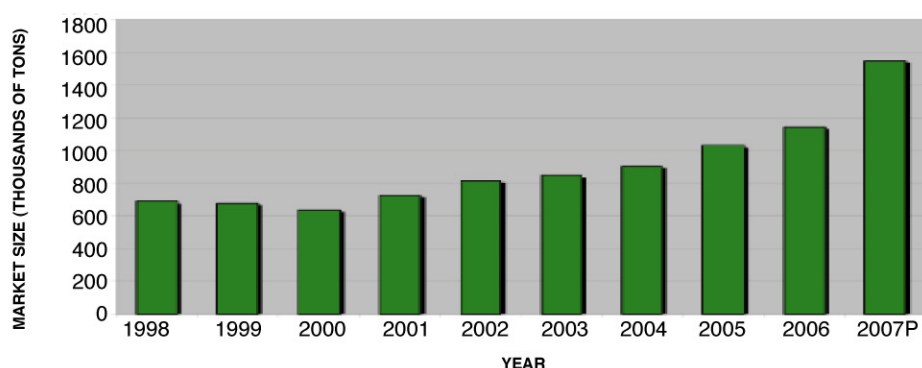
2004/2005 and 2005/2006 seasons (Figure 5.6).

Minnesota is part of the Central Region that also includes North Dakota, South Dakota, Iowa, Missouri, Kansas, Nebraska, Oklahoma, Arkansas, Louisiana and Texas. Data for individual states is not available but demand is obviously higher in the northern states than southern. The Central Region states represent about 8.6% of North

| | HENNEPIN CO., MN | RAMSEY CO., MN | WASH. CO., MN | ANOKA CO., MN | KANABEC CO., MN | PINE CO., MN | ISANTI CO., MN | CHISAGO CO., MN | WRIGHT CO., MN | SHERBURNE CO., MN | MILLE LACS CO., MN | BURNETT CO., WI | POLK CO., WI | ST. CROIX CO., WI | TOTAL 50 MI RADIUS |
|-----------------------|---------------------|-------------------|------------------|------------------|--------------------|-----------------|-------------------|--------------------|-------------------|----------------------|-----------------------|--------------------|-----------------|----------------------|--------------------------|
| Owner occupied | 315,678 | 131,626 | 70,896 | 99,586 | 5,795 | 8,871 | 12,488 | 15,350 | 36,284 | 24,715 | 7,900 | 6,613 | 14,530 | 23,667 | 773,963 |
| Utility gas | 294,860 | 119,922 | 64,098 | 92,416 | 1,548 | 2,849 | 5,212 | 10,936 | 25,495 | 18,220 | 3,089 | 1,189 | 4,570 | 14,722 | 659,126 |
| Bottled/tank/LP gas | 3,989 | 967 | 1,645 | 1,647 | 2,608 | 3,405 | 4,968 | 2,326 | 5,677 | 2,985 | 2,794 | 3,265 | 6,378 | 5,240 | 47,894 |
| Electricity | 12,589 | 7,891 | 3,742 | 3,240 | 437 | 838 | 843 | 698 | 3,057 | 2,123 | 621 | 722 | 962 | 1,793 | 39,546 |
| Fuel oil/kerosene/etc | 1,953 | 1,941 | 812 | 1,225 | 497 | 657 | 511 | 576 | 1,033 | 493 | 579 | 554 | 916 | 932 | 12,679 |
| Coal or coke | 60 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 74 |
| Wood | 494 | 184 | 419 | 805 | 634 | 1,005 | 702 | 653 | 820 | 803 | 703 | 850 | 1,513 | 827 | 10,412 |
| Solar energy | 40 | 89 | 10 | 9 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 | 19 | 14 | 189 |
| Other fuel | 1,200 | 515 | 132 | 185 | 36 | 117 | 172 | 147 | 176 | 87 | 106 | 26 | 161 | 139 | 3,199 |
| No fuel used | 493 | 117 | 38 | 45 | 9 | 0 | 80 | 14 | 26 | 0 | 8 | 3 | 11 | 0 | 844 |

Note: only includes owner occupied housing – rental and vacant housing units not included in statistics. Kanabec and Burnett County data includes all housing units – no data available for owner occupied only.

▲ **Figure 5.7. Number of Housing Units by Type of Heating Fuel Usage**

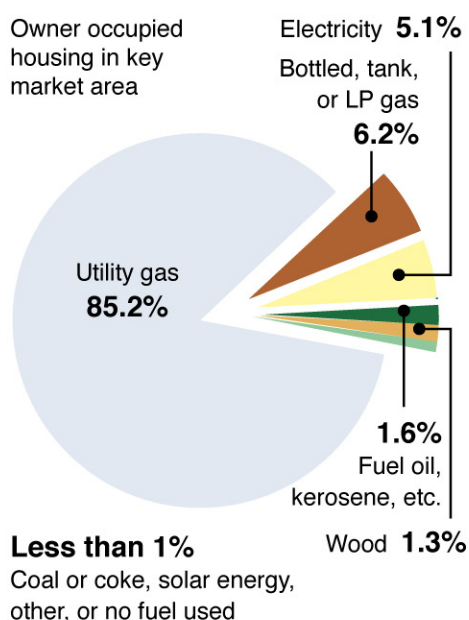


Source: Wood Pellet Association of Canada

▲ **Figure 5.6. North American Pellet Sales, 1998-2007**

Fuel usage

Owner occupied housing in key market area



Source: US Census Data

▲ **Figure 5.8. Fuel Usage - Owner Occupied Housing Units in 14 County CIP Market Area**

American sales or about 9.4% of US sales. Since there are an estimated 900,000 pellet burning appliances installed in the US, there are probably about 84,000 pellet appliances in the Central Region. Minnesota probably represents between 25-35% of the total (among 11 states) or about 21,250-29,400 pellet appliances.

Future Market Potential - CIP Market Area

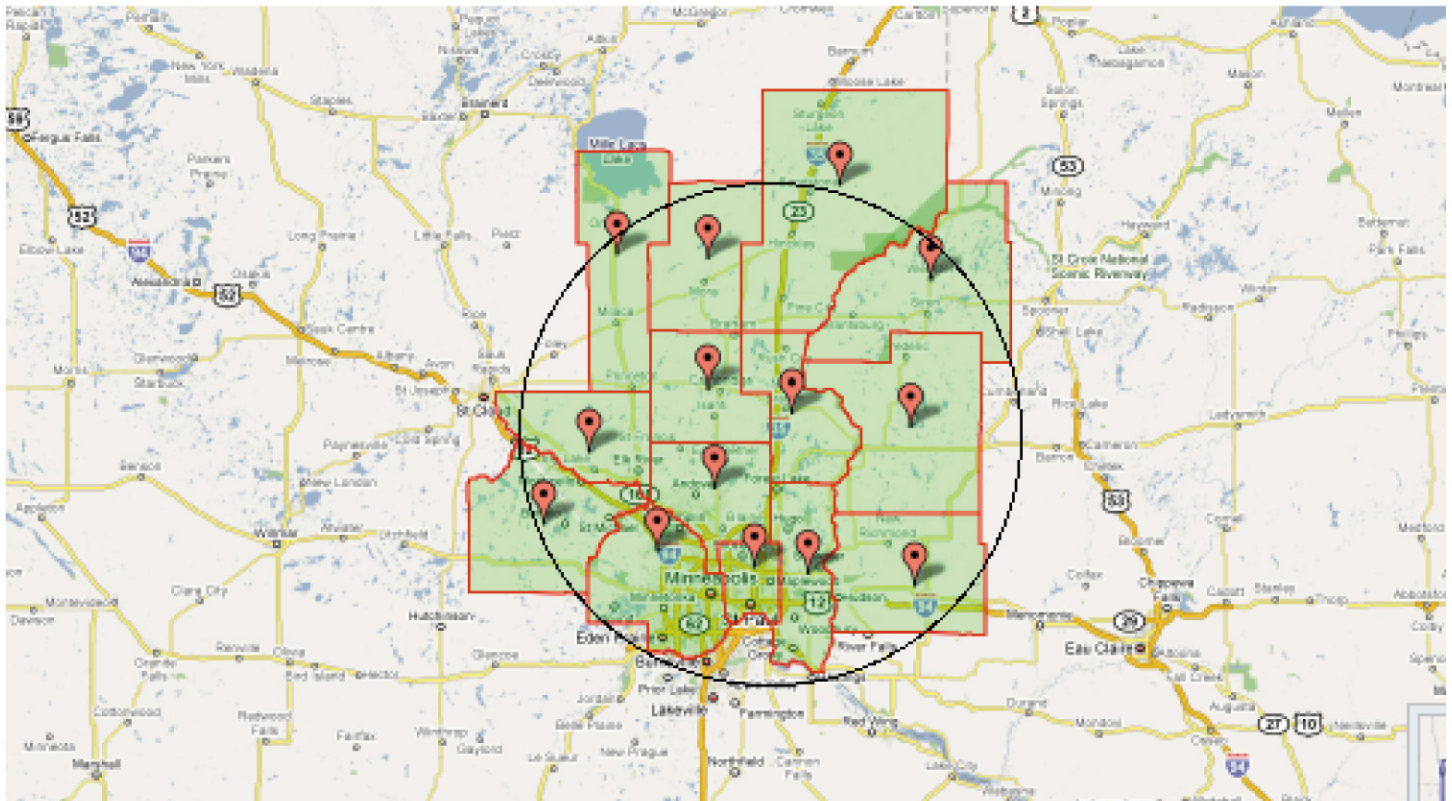
The future market potential for a CIP Pellet Mill is dependent on many factors including future growth in pellet appliance sales. For the 14 Minnesota/Wisconsin counties surrounding the CIP location (centered approximately at North Branch), 2000 Census data shows that there are about 774,000 owner occupied households in the area (Figure 5.7). Of these, 85%% use utility gas, while 13% use less cost effective energy sources like propane, fuel

oil and electricity (Figure 5.8). These 13% or 100,000 homes represent a key potential market in the future. If the pellet appliance market continues to grow at 5% per year, 500-700 new pellet appliances will be sold in the CIP market area increasing pellet demand by 250-840 tons per year. If only 50% of these 100,000 homes converted to pellet fuel, the total added potential market would be about 60,000 tons/year of pellets per year given current average U.S. rates of usage of 1.2 tons per appliance and more likely 100,000 tons/year at a rate of 2.0 tons /year since Minnesota has a colder climate than average in the U.S.

There are a variety of forest resources available in the CIP region and surrounding counties including standing wood, waste wood, and residue that could be used as a feedstock for a pellet mill. A plant centrally located in the CIP region should be able to economically distribute pellets to customers in a 14 county area including the densely populated Twin Cities metro area - a potential advantage over pellet mills located farther north and east in Minnesota and Wisconsin respectively (Figure 5.9).

Factors Effecting Market Growth

There are many factors affecting growth in the pellet fuel market overall and in Minnesota in par-



▲ Figure 5.9. CIP Prime Market Area

tical. Growth in the housing market (new homes, remodeling and vacation homes), oil and gas prices and environmental regulations and policies all contribute to growth. For a wood pellet enterprise to be successful the plant capacity must be fully utilized and operated on a regular basis to provide stable and dependable employment. Depending only on home sales in the 14 county area surrounding CIP may not be sufficient to achieve success since it is not likely that 50% of potential users will convert to wood pellets fast enough to sustain the business in the near term. There also will be competition from other pellet manufacturers in the region.

The key to selling out the plant capacity is to develop a market comprised of a mix of individual home consumers, large users and the export market.

Large Users

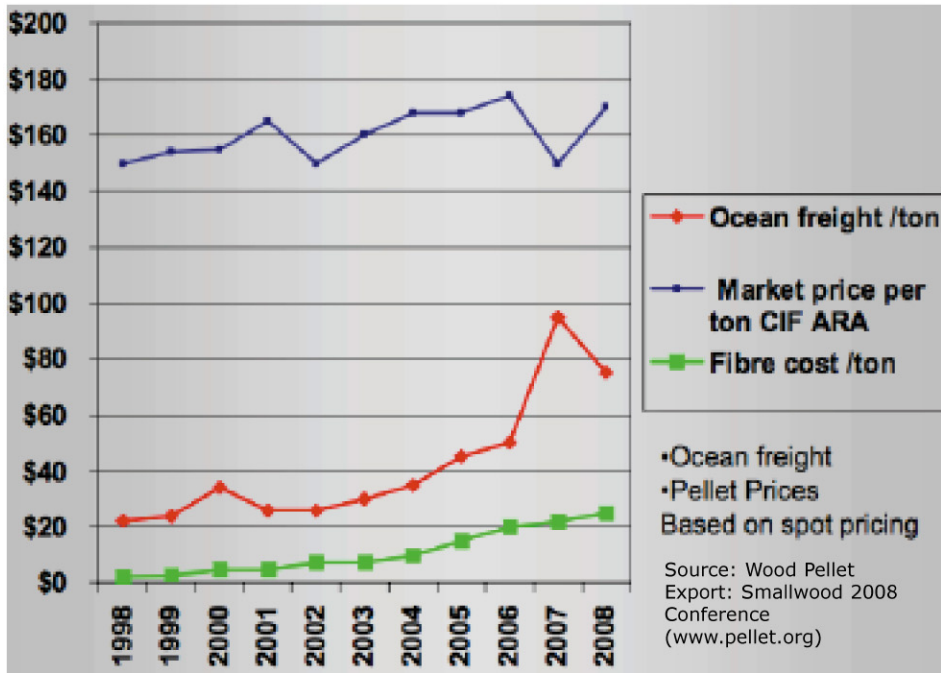
For example one co-firing electric plant would use enough wood pellets to be equivalent to tens of thousands of homes. Other potential large users would be commercial plants, schools, and government offices and facilities. The utilities would be interested in co-firing wood pellets with coal to satisfy the 2007 Minnesota mandate that 25% of electricity must be generated using renewable resources by 2025. Generally this means wind or firing biomass such as wood pellets. Applications that replace fuel oil or propane as the heating fuel would benefit from the significant cost savings offered by wood pellets and at the same time would help reduce incremental carbon dioxide emissions that result from burning fossil fuels. There would be capital cost to install pellet furnaces but the payback is typically less than two years.

Some examples of larger scale pellet users in Minnesota include:

- ▶ Itasca County YMCA, Grand Rapids, MN (installed 1986-87, 500+ green tons of pellets or briquettes per year)
- ▶ Goodridge School District, Goodridge, MN (installed 1982/83, 85 dry tons/year, 50 mi radius)
- ▶ Northome School District, Northome, MN (installed 1981, 270 dry tons/yr, local manufacturer)
- ▶ Swanville Public Schools, Swanville, MN (installed 1981, 350 dry tons/yr, 50-100 mi radius)
- ▶ Blackduck School, Blackduck, MN (installed 1983, 321 tons/yr)

Export Market

Global trade of wood pellets reached over three million tons in 2007. Canada produces over



▲ Figure 5.10. Market Price Versus Fiber/Freight Cost for Export Market

1.5 million tons of pellets each year with most going into the export market. Canada exported 600,000 tons of wood pellets to the European market. Most of the overseas volume was shipped from British Columbia to Belgium, the Netherlands and Sweden, this despite the costly 15,000-kilometer journey from the Interior of British Columbia to the European market (Figure 5.9). The low costs for raw-material (shavings and sawdust) at large lumber mills in Canada and the high prices for wood pellets in Europe is driving this trend (Figure 5.10).

Much of the increase in shipments is the result of policies implemented by European governments to generate more green energy based on renewable resources as a substitute for fossil fuels - all of which tend to increase the relative cost of fossil fuels and increase the incentive to use renewable and biomass fuels. These policies have also generated significant demand by affecting large-scale use of wood

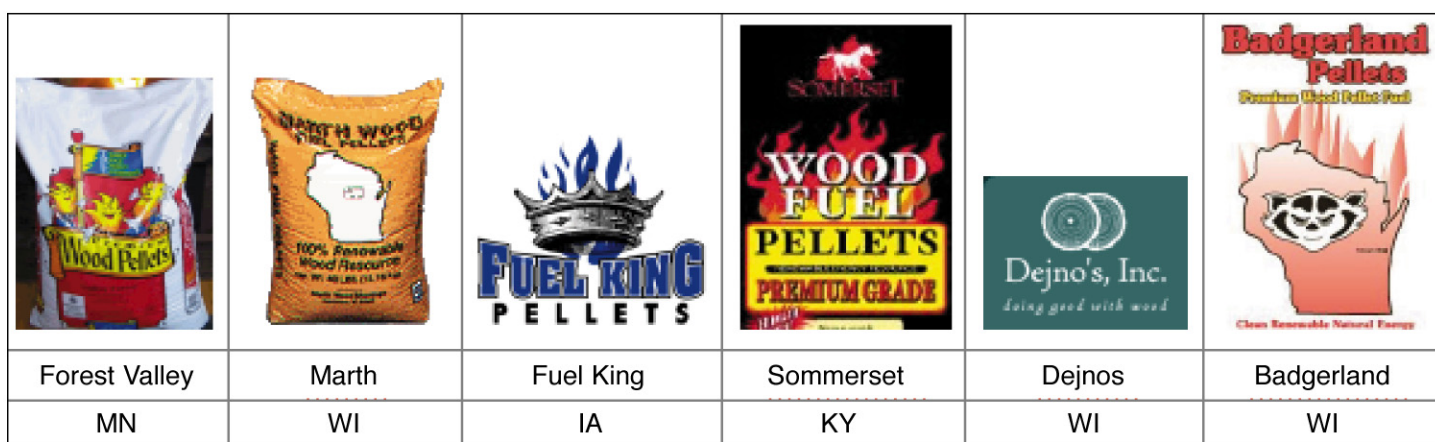
pellets like co-firing plants, co-generation and biomass fueled electric power generation. One co-firing plant can require enough wood pellets to heat tens of thousands of homes. It doesn't take many of these opportunities to create large opportunities for pellet suppliers. Most major North American pellet mills exporting product to Europe are located in Canada primarily on the Atlantic and Pacific coasts near large port facilities. In Canada several pellet mills have a capacity in the 200,000 tons per year range. Average plant size in Canada is 50-60,000 tons per year. The average US plant is less than 20,000 tons. The average plant size in Europe is only about 7,500 tons per year. Pelletizing facilities in Canada have been designed to serve the export market and are located near world-class sawmills that generate huge volumes of sawdust, planer shavings and other residue. Export plants are located primarily near the east and west coasts near ports and rail facilities.

Large-scale pellet mills built to serve the export market may be coming to Minnesota. Kedco Group of Cork, Ireland have been in talks with the Duluth Seaway Port Authority about suitable sites for a wood pellet processing facility at the port and shipping the product to Ireland. Planning is in the early stages to build a massive plant in Duluth's inner harbor designed produce 500,000 tons of wood pellets every year to ship to Europe's power plants. A plant this size would dwarf most existing plants in North America. The facility would be Minnesota's largest wood-processing plant, creating as many as 400 permanent jobs. At full production the facility would convert each year 1.2 million tons of fresh-cut wood harvested with 60 miles of Duluth into 500,000 tons of dried pellets for shipment to power plants in Europe. Extrapolating from published numbers from wood pellet plants planned in Wisconsin and Michigan, the Duluth plant likely would cost between \$85 million and \$100 million to build. At full production it would directly employ at least 250 full-time plant workers and at least 150 loggers.

To put this into perspective, sustainable harvest of forest lands is about 1 ton per acre per year. 1.2 million tons per year of green wood would require 1.2 million acres of forest. There would likely be major issues with conservation groups and the logistics are large scale. To compete for export markets a CIP pellet plant needs to be located near a rail line to Duluth for shipment to Europe.

Market Segments

The market for wood pellets in the US and Minnesota is now primarily residential customers (figure 5.11).



▲ Figure 5.12. Selected Regional Brands of Wood Pellets

Energy is a commodity and wood pellets compete with all other fuel choices for residential, commercial, industrial and utility use. Users will make their energy decisions based on price, ease of use, energy content and application. Some customers might be willing to spend \$6 per bag for wood pellets at their local convenience store because they only need a few bags to run their pellet stove for a few hours on the weekend whereas another customer might only be willing to pay \$4.50 per bag because they are buying 150 bags for the whole heating season. Selling price, of course, is only a part of the cost picture. The primary issue is the cost of energy, which is measured in dollars per million British thermal units. Pellets purchased at \$200 per ton and burned in a typical pellet stove cost about \$15.24 per million Btu, a figure that is less than the cost of electric heat, propane and fuel oil. The recent steep drop in the cost of fuel oil has made wood pellets less competitive and many users have probably reduced their pellet usage in favor of the convenience of fuel oil.

Brands

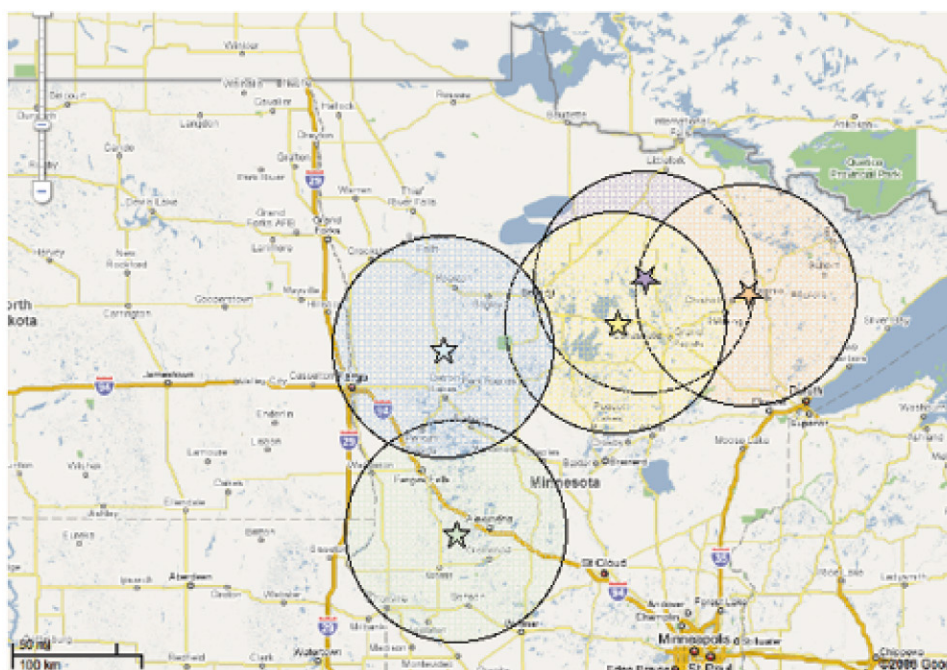
Product branding can have a huge impact on market demand. Even though wood pellets are a commodity product (all retail

| | RESIDENTIAL | COMMERCIAL | INDUSTRIAL | UTILITY |
|-----------------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------|
| Type of building | Homes, apartment units, condo units | Apartment buildings, offices, shopping centers, hospitals, etc. | Factories, warehouses | Power plants, co-generation plants, district heating plants |
| Need | Space heating | Space heating | Process heat and general facility heating requirements | Produce steam for turbines and heat for network |
| Biomass fuel options | Pellets, wood chips, | Pellets, wood chips | Pellets, wood chips | Pellets, wood chips, wastewood |
| Type of appliance | Free standing stove, fireplace, insert, furnace, boiler | Central furnace, boiler system | Boilers | Steam boilers |
| Quantity of fuel | <3 tons/yr | 10 - 1000 tons/yr | > 100 tons | >10,000 tons |
| Notes | Generally buy retail, mostly for intermittent space heating to supplement heat supply | Buy wholesale, by contract, mostly use wood chips because of cost and equipment design considerations | Buy in bulk on long term contracts or use materials generated onsite. | Buy in bulk on long term contracts, low cost sources. |

▲ Figure 5.11. Wood pellet market segments

wood pellet brands advertise their product as "Premium Grade") customers still may prefer one brand over another either because of perceived benefits, in-home testing, or because of direct marketing efforts (Figure 5.12). Even though basic product specifications and quality are controlled by voluntary industry standards, different brands can vary significantly in the real world. Some brands work better

in different appliances - at least customers seem to think so. Differences in size, moisture content, type of feedstock, ash content and other factors can all affect how a customer views how much a particular brand is worth (and many customers are willing to share their opinions and preferences in online chats and blogs). Customers will pay more for brands that have proven consistent, create less ash, require



- Valley Forest Pellet Mill, Marcell, MN
- Timber Mountain Pellet Mill, Mountain Iron, MN
- Bio Pellet Mill, Deer River, MN
- Proposed White Earth Pellet Mill, White Earth Reservation
- Sunrise Agra Pellet Mill, Kensington, MN

▲ **Figure 5.13. Plot of Midwest Wood Pellet Plants**

| COMPANY | VALLEY FOREST WOOD PRODUCTS LLC | MOUNTAIN TIMBER WOOD LLC | BIOPELLETS INC. | SUNAGRA ISLAND PELLETS |
|-----------------|------------------------------------------|------------------------------------------|-----------------------------------------------|--------------------------------------------------------------|
| LOCATION | Marcell, MN | Mountain Iron, MN | Deer River, MN | Kensington, MN |
| WEBSITE | vfpellets.com | mttimber.com | forestpellets.com | sunriseagrafuels.com |
| SIZE | 6 mm & 8 mm 1/4" & 3/8" | 6 mm & 8 mm 1/4" & 3/8" | 1/4" & 3/8" | 1/4" |
| AVAILABLE | Bulk, 40 lb bags, by the pallet, bulk | Bulk, 40 lb bags, by the pallet, bulk | 40 lb bags - 50/pallet, tote bags, bulk | 40 lb bags, bulk by ton & 2000 lb tote bags |
| ANNUAL CAPACITY | 50,000 tons | 80,000 tons | 50,000 tons | |
| OTHER PRODUCTS | Animal bedding products | Animal bedding products | Animal bedding products | |
| AVAILABLE | MN, WI, Int'l | N/A | Deer River, Aitkin, Winnebago | MN and WI |
| COST | \$130/ton bulk \$175/ton-40lb bags | N/A | \$120/ton bulk \$165/ton-40lb bags | \$3.75/40 lb bag retail |
| NOTES | Started production 12/07 | Plant const. not begun | New in Fall 2008 Div. of Weerts Co. | Agri-waste based for special stoves. not in full prod. |

▲ **Figure 5.14. Minnesota Pellet Producers**

less maintenance or are a good value. There are hundreds of different brands in the US although, because of transportation costs and logistical limitations, most customers will only have three or four choices (at most) in their market area. A given retailer may only offer one or two brands, usually at different price points. ■

COMPETITION

Major Direct Regional Competitors

Only two pellet mills are located in Minnesota currently and both are relatively new to the market (Figure 5.13). A third - Timber Mountain in Mountain Iron - has been approved but construction has been delayed. (A fourth mill - Sunrise Agra produces agri-pellets that compete more with corn-fired burners but could be a significant competitor in future years).

Although some wood pellets are shipped in from out-of-state, transportation costs usually limit the prime market to an area within 50 miles of the mill location. Longer distance delivery can be profitable if the feedstock cost is low (*free* lumber mill waste versus forest residue shipped in from surrounding area), production costs are lower than the competition (sawdust onsite versus standing timber) or a customer is buying in large volume (semi load versus a pallet load). Easy access to low cost transportation (railroad, river barge, or ship) can be a significant competitive advantage. A compilation of Minnesota pellet producers is shown in figure 5.14.

Valley Forest Wood Products

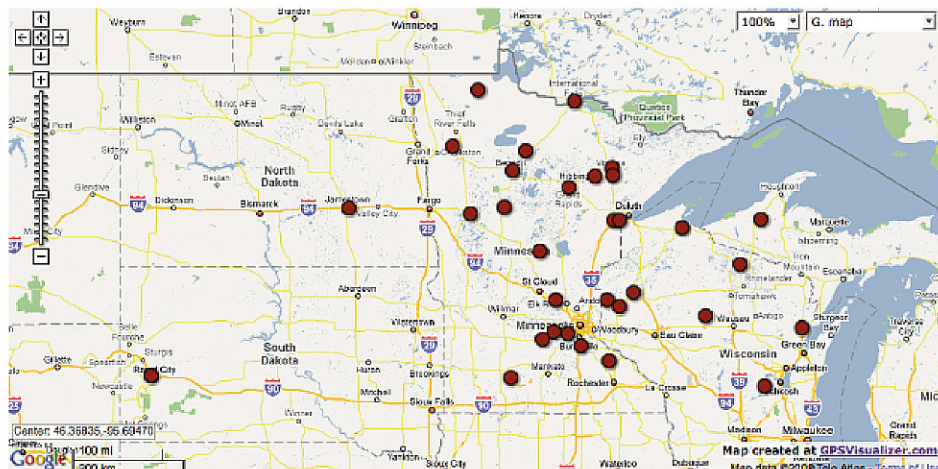
Investors led by Bircherm Logging bought an existing lumber mill in Marcell, MN and are

investing \$3 million to start Valley Forest Wood Products. Valley Forest began producing pellets on Dec. 29, 2007. The plant has a capacity of 50,000 tons of pellets per year and will employ up to 13 people full-time at about \$14/hr (when operating 24 hours). The plant will consume about 120,000 green tons/year of wood. The plant is located in a tax-free MN Jobz zone. According to information online, they seem to be producing about 3,000 tons per month at \$150/ton fob plant. They are currently employing about 5 people full-time on a single shift.

Valley Forest sells its wood pellets through dozens of retailers spread all over Minnesota, North and South Dakota and Wisconsin (Figure 5.15). In addition to retail sales, Valley Forest also sells pellets to commercial wood chip customers including Black Duck School Black Duck; MN Department of Natural Resources French River Hatchery, Duluth, MN; Northome School, Northome, MN; Red Lake Gaming, Red Lake, MN; Swanville School, Swanville, MN; and the YMCA, Grand Rapids, MN. The plant also sells animal bedding materials.

Mountain Timber Wood Products

Investors led by Bircham Lumber have also proposed a second pellet mill - Mountain Timber Wood Products in Mountain Iron, MN. The project has a design capacity of 100 tons/hr with first year production capacity estimated at about 80,000 tons. The mill will consume about 200,000 tons/year of both soft and hardwood biomass from harvestable forests in a 60 mile radius of the plant. The plant is located in a tax-free MN Jobz zone. The plant will employ 8-20 people depending on production level.



Source: Valley Forest website

▲ **Figure 5.15. Retail Locations for Valley Forest Wood Products**

The plant received their air pollution permit in July 2008, and was supposed to be operational by fall 2008. (As of late December, construction had not begun and the city of Mountain Iron does not know why the project has been delayed or when the construction process will begin. The company's webpage makes it seem like they are in business but they are likely selling pellets produced at their sister plant in Marcell, MN).

A key investor and partner in the Mountain Timber project is Spanish partner CGC Biomass. CGC has taken a 25% stake in the company and committed to purchase 60,000 tons of wood pellets per year until U.S. demand catches up with Europe. The same owners are also considering a Wisconsin location to expand further.

Bio Pellets, Inc.

Bio Pellets is also a relatively new Minnesota wood pellet producer. Bio Pellets is a subsidiary of Weetz Company in Winnebago, MN. The Bio Pellets mill can produce up to 50,000 tons of pellets per year although it is likely operating at a much lower capacity presently. Bio Pellets operation is co-located with Rajala Lumber

Company in Deer River MN which supplies it with sawdust and other feedstock materials.

Sunrise Agra Fuels

Although not a wood pellet producer, Sunrise Agra Fuels is a future potential competitor if agricultural waste-based pellets become more popular. Sunrise Agra produces a biomass fuel pellet out of a variety of agricultural waste products such as corn stover. After initially producing less than 1000 tons of pellets in 2007 using contract producers, Sunrise Agra Fuels is now producing biomass fuels at a production facility in Kensington, Minnesota. Fuel can be purchased at the production site or at various dealer locations. (It is interesting to note that their distribution network extends well outside a 50 mile radius - as far as Grand Rapids Michigan). Sunrise Agra Fuel Island Pellets are a corn/agricultural residue biomass pellet specially formulated to burn in most biomass corn stoves and certain wood pellet stoves. Ash production levels are higher than wood but comparable to corn but soft - without the rock hard clinkers found with shell corn. Very few pellet appliances are designed to burn agri-pellets (mostly because of the high ash

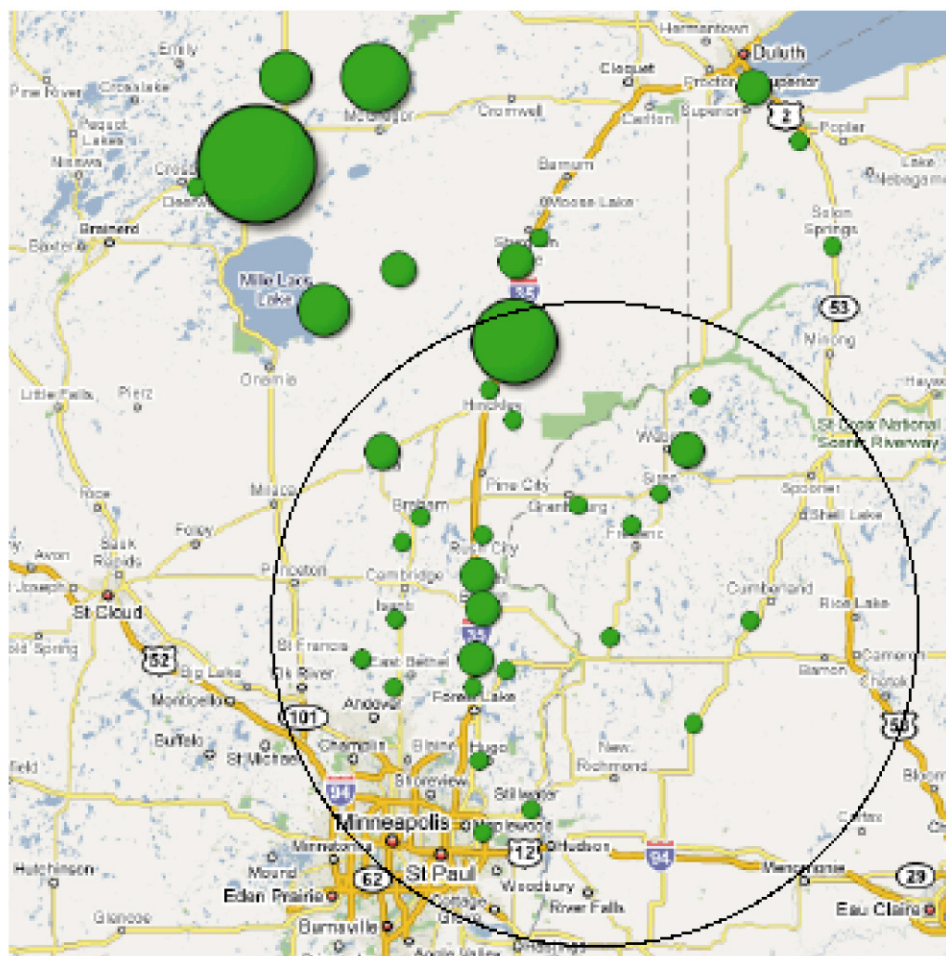
content) although some corn burners can use both fuels.

Corn can be competitive with wood pellets depending on the relative prices. Corn has a lower BTU content than wood pellets (7015 BTU/lb @ 15% moisture vs. wood pellets at 8100 BTU/lb @ 6% moisture). With corn prices at \$4.00 per bushel a therm (100,000 BTU's) cost \$1.01. For wood pellets at \$160/ton a therm costs \$0.97. The price dynamics are dependent on values assigned to corn and wood pellets and can be easily calculated by ratio of the numbers above. Wood pellet stoves are not designed for corn and there is considerably more ash with corn. Using corn as a heat source also raises the issues of alternative use as food and carbon sequestration being less with corn especially if land now in prairie or woodland is converted to corn production.

Factors Effecting Wood Pellet Competition

Two key factors affect wood pellet competition: feedstock availability and transportation costs. Wood pellets are a commodity. Manufacturing wood pellets does not require proprietary technology. Wood pellet manufacturers with a built-in supply of sawdust have a cost advantage over a pellet mill using standing green wood. This is the primary reason the large mills in Canada can be profitable even though they are shipping their product 15,000 miles to Europe.

Pellet mills located near large population centers with many pellet fuel customers have much lower transportation costs than pellet mills located in sparsely populated regions far from potential customers. Pellet mills in the northeast US have been very successful developing retail



▲ Figure 5.16. Sawmills in CIP Region. Larger circles represent multiple plants in the same area.

distribution networks within reasonable transportation distances because of the greater population density. Establishing sophisticated logistics solutions that support delivering a bulky fuel supply over large geographic areas is expensive and challenging especially with a seasonal commodity product where margins are very tight. Pellet mills with long term contracts to supply large commercial, industrial or utility customers also have a distinct competitive advantage.

A key factor affecting the viability and profitability of a CIP Pellet Mill will be the availability and cost of feedstock within a reasonable transportation distance of the plant location. As with marketing, transportation cost is

a key issue when assessing the feasibility of a particular pellet mill location. There are a number of sawmill operations in the CIP region, but most seem to be relatively small operations (Figure 5.16). The availability and economics of using sawdust and other residue from these operations depends on distance from the CIP plant, quality of material, competition, transportation costs and general economic conditions. Sawdust prices vary considerably depending on local demand, quality (green or dry), type of wood, location, transportation costs and volume available. Sawdust and shavings are available in Minnesota for anywhere from free to over \$30 per dry ton. Prices will be higher in areas with

WOOD PELLETS

high demand (such as for bedding material for farm animals, feedstock for particle board plant or near other pellet mills. Dry sawdust is worth more than green sawdust. Nearby suppliers are more valuable than those farther away. The quantity of sawdust available can be volatile and is directly dependent on the housing industry and general economic conditions. (Currently, many pellet mills in the U.S. are looking for additional feedstock supplies because sawmills have cut back production of lumber with the downturn in the U.S. housing market). More research is recommended on the cost and availability of potential feedstock's for a future CIP plant. ■

MARKETING MIX

Product

The primary market for wood pellets in the US is for premium grade pellets with an ash content of less than 1%. The CIP pellet mill should produce primarily premium grade pellets although, if demand is developed from large-scale users such as a utility or other commercial users, standard or utility grade pellets could be part of the mix. CIP pellets should be available in bulk and packaged in 40 pound bags.

Pricing Strategy

Wholesale Pricing

Wholesale prices vary by quantity, packaging requirements, region, the time of year, demand and source. Wholesale wood pellet prices (Pellet Fuel Institute Quarterly Survey) by region and season for 2007 and 2008 are summarized in Figure 5.17.

Notice that in this short span of time wholesale prices ranged from a low of \$90/ton in the Southeast in July 2008 to a high of \$215/ton in the Northeast in

| REGION | FEBRUARY 2007 | JULY 2007 | APRIL 2008 | JULY 2008 | OCTOBER 2008 |
|------------------|---------------|-----------|------------|-----------|--------------|
| Northeast | \$130-185 | \$125-212 | \$120-179 | \$120-180 | \$150-215 |
| Midwest | \$125-189 | \$125-159 | \$120-159 | \$110-152 | \$150-185 |
| Southwest | \$135-159 | \$125-159 | \$110-168 | \$110-135 | \$150-178 |
| Southeast | \$125-150 | \$100-159 | \$90-150 | \$90-155 | \$105-185 |
| Northwest & Mtn. | \$135-159 | \$125-169 | \$120-169 | \$120-162 | \$155-178 |
| Canada | \$175-185 | \$125-212 | \$170-180 | \$135-170 | \$170-215 |

Source: Pellet Fuel Institute Newsletter - Average price per ton, medium to large wholesale customer, FOB plant.

▲ **Figure 5.17. Regional Wholesale Prices 2007-2008**

| DATE | LOCATION | CITY, STATE | PRICE | BRAND |
|---------------|---------------------------|------------------|--------------------------|------------------------------|
| Aug. 20, 2008 | Bio Pellets | Deer River, MN | \$120/ton | Bio Pellets/bulk (MN) |
| Aug. 11, 2008 | Valley Forest | Marcell, MN | \$150/ton | Valley Forest/bulk (MN) |
| July 16, 2008 | Skersick Heating | Bemidji, MN | \$195/ton | |
| Dec. 16, 2008 | Walmart | Bemidji, MN | \$4.96/bag | Pennington Natures Heat (MO) |
| Dec. 16, 2008 | Menards | Baxter, MN | \$4.28/bag | OHP (Ozarks Hardwood) (MO) |
| Dec. 15, 2008 | Heat Source | Park Rapids, MN | \$5.80/bag | Kentucky Comfort (KY) |
| Dec. 15, 2008 | LM Fleet Supply | Park Rapids, MN | \$4.99/bag \$5.79/bag | Marth (WI) and Gremily (TN) |
| Dec. 15, 2008 | Northland Feed and Seed | Park Rapids, MN | \$4.99/bag | |
| Jan. 9, 2009 | Menards | Cambridge, MN | \$4.28/bag | Dejnos (WI) and OHP |
| Jan. 9, 2009 | Home Depot | Monticello, MN | \$4.28/bag | |
| Jan. 9, 2009 | Menards | Forest Lake, MN | \$4.28/bag | Somerset (KY) |
| Jan. 12, 2009 | Lowes | Rogers, MN | \$5.97/bag | Somerset (KY) |
| Jan. 12, 2009 | Northern Tool | Hermantown, MN | \$4.99/bag | Big Heat (IL) |
| Jan. 12, 2009 | Home Depot | Duluth, MN | \$4.28/bag | Future Fuels (AR) |
| Jan. 12, 2009 | Elk River Farm Supply | Elk River, MN | \$4.90/bag | Dejnos (WI) |
| Jan. 12, 2009 | Little Falls Fleet Supply | Little Falls, MN | \$4.29/bag | Oak Creek Pellets (MN) |

Source: Internet and telephone survey, 40 lb. bags.

▲ **Figure 5.18. Sample Wood Pellet Prices - CIP Market Area**

October 2008. Wide wholesale price differences are typical even within the same region during the same period.

Wholesale prices for Premium

CIP wood pellets will need to range from \$125 to \$185 depending on the time of year, competition, demand and type of product. Although demand for

WOOD PELLETS

high demand (such as for bedding material for farm animals, feedstock for particle board plant or near other pellet mills. Dry sawdust is worth more than green sawdust. Nearby suppliers are more valuable than those farther away. The quantity of sawdust available can be volatile and is directly dependent on the housing industry and general economic conditions. (Currently, many pellet mills in the U.S. are looking for additional feedstock supplies because sawmills have cut back production of lumber with the downturn in the U.S. housing market). More research is recommended on the cost and availability of potential feedstock's for a future CIP plant. ■

MARKETING MIX

Product

The primary market for wood pellets in the US is for premium grade pellets with an ash content of less than 1%. The CIP pellet mill should produce primarily premium grade pellets although, if demand is developed from large-scale users such as a utility or other commercial users, standard or utility grade pellets could be part of the mix. CIP pellets should be available in bulk and packaged in 40 pound bags.

Pricing Strategy

Wholesale Pricing

Wholesale prices vary by quantity, packaging requirements, region, the time of year, demand and source. Wholesale wood pellet prices (Pellet Fuel Institute Quarterly Survey) by region and season for 2007 and 2008 are summarized in Figure 5.17.

Notice that in this short span of time wholesale prices ranged from a low of \$90/ton in the Southeast in July 2008 to a high of \$215/ton in the Northeast in

| Region | February 2007 | July 2007 | April 2008 | July 2008 | October 2008 |
|-------------------|---------------|-------------|-------------|-------------|--------------|
| Northeast | \$130-\$185 | \$125-\$212 | \$120-\$179 | \$120-\$180 | \$150-\$215 |
| Midwest | \$125-\$189 | \$125-\$159 | \$120-\$159 | \$110-\$152 | \$150-\$185 |
| Southwest | \$135-\$159 | \$125-\$159 | \$110-\$168 | \$110-\$135 | \$150-\$178 |
| Southeast | \$125-\$150 | \$100-\$159 | \$90-\$150 | \$90-\$155 | \$105-\$185 |
| Northwest and Mtn | \$135-\$159 | \$125-\$169 | \$120-\$169 | \$120-\$162 | \$155-\$178 |
| Canada | \$175-\$185 | \$125-\$212 | \$170-\$180 | \$135-\$170 | \$170-\$215 |

Source: Pellet Fuel Institute Newsletter - Average price per ton, medium to large wholesale customer, FOB plant.

▲ Figure 5.17. Regional Wholesale Prices 2007-2008

| Date | Location | City, State | Price | Brand |
|--------------|---------------------------|------------------|-----------------------|------------------------------|
| Aug 20, 2008 | Bio Pellets | Deer River, MN | \$120.00/ton | Bio Pellets/bulk (MN) |
| Aug 11, 2008 | Valley Forest | Marcell, MN | \$150.00/ton | Valley Forest/bulk (MN) |
| Jul 16, 2008 | Skersick Heating | Bemidji, MN | \$195.00/ton | |
| Dec 16, 2008 | Walmart | Bemidji, MN | \$4.96/bag | Pennington Natures Heat (MO) |
| Dec 16, 2008 | Menards | Baxter, MN | \$4.28/bag | OHP (Ozarks Hardwood) (MO) |
| Dec 15, 2008 | Heat Source | Park Rapids, MN | \$5.80/bag | Kentucky Comfort (KY) |
| Dec 15, 2008 | LM Fleet Supply | Park Rapids, MN | \$4.99 and \$5.79/bag | Marth (WI) and Gremily (TN) |
| Dec 15, 2008 | Northland Feed and Seed | Park Rapids, MN | \$4.99/bag | |
| Jan 9, 2009 | Menards | Cambridge, MN | \$4.28/bag | Dejnos (WI) and OHP |
| Jan 9, 2009 | Home Depot | Monticello, MN | \$4.28/bag | |
| Jan 9, 2009 | Menards | Forest Lake, MN | \$4.28/bag | Somerset (KY) |
| Jan 12, 2009 | Lowe's | Rogers, MN | \$5.97/bag | Somerset (KY) |
| Jan 12, 2009 | Northern Tool | Hermantown, MN | \$4.99/bag | Big Heat (IL) |
| Jan 12, 2009 | Home Depot | Duluth, MN | \$4.28/bag | Future Fuels (AR) |
| Jan 12, 2009 | Elk River Farm Supply | Elk River, MN | \$4.90/bag | Dejnos (WI) |
| Jan 12, 2009 | Little Falls Fleet Supply | Little Falls, MN | \$4.29/bag | Oak Creek Pellets (MN) |

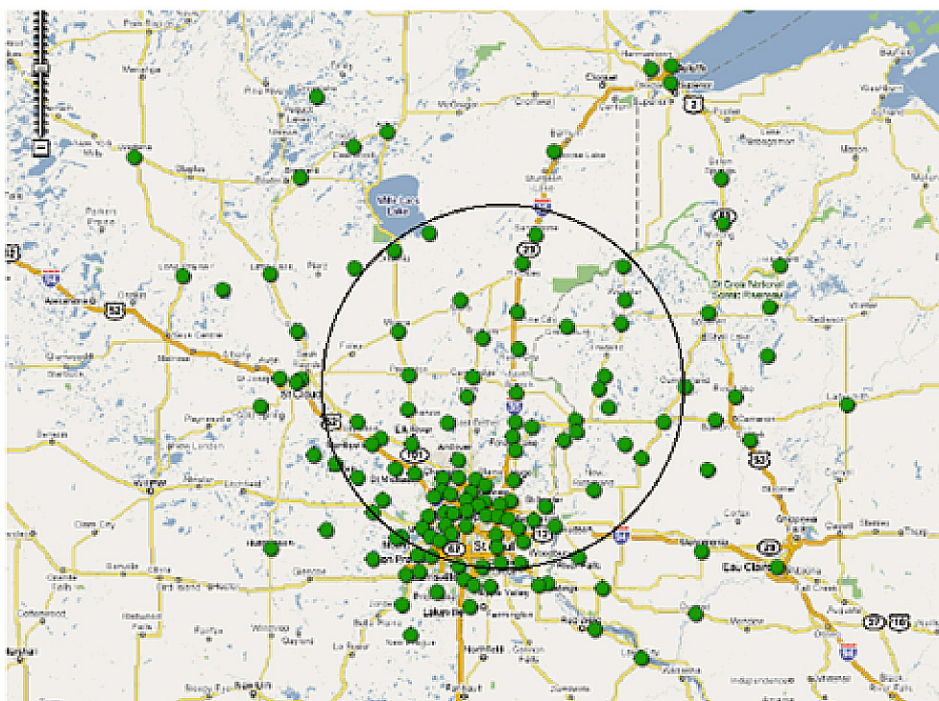
Source: Internet and telephone survey; 40 lb bags

▲ Figure 5.18. Sample Wood Pellet Prices - CIP Market Area

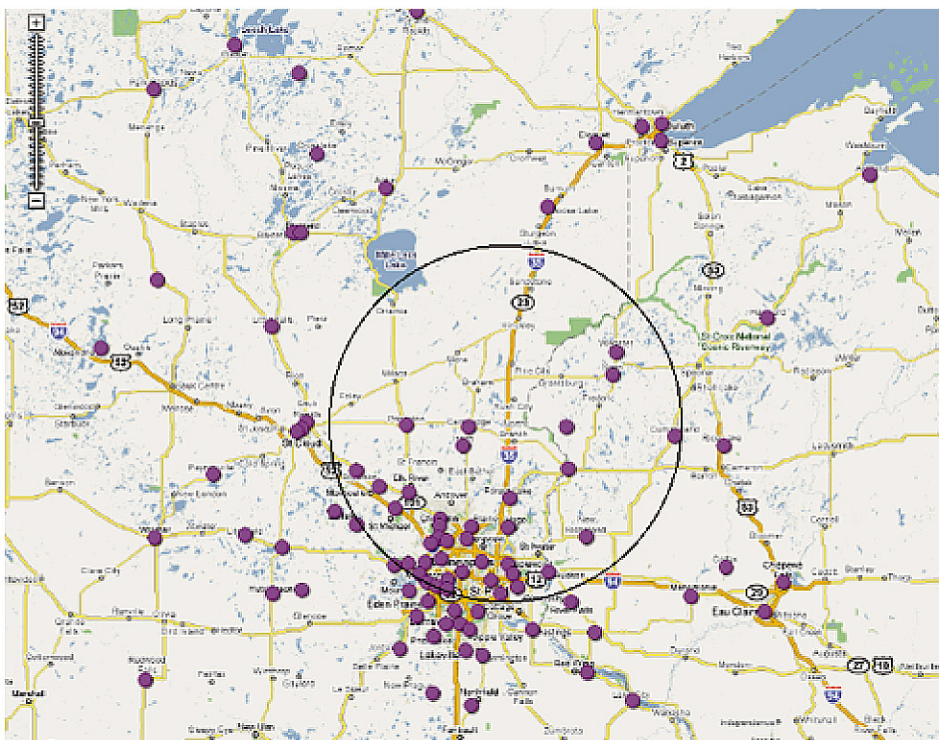
October 2008. Wide wholesale price differences are typical even within the same region during the same period.

Wholesale prices for Premium

CIP wood pellets will need to range from \$125 to \$185 depending on the time of year, competition, demand and type of product. Although demand for



▲ Figure 5.19. Hardware Stores in Region



▲ Figure 5.20. Fireplace and Wood Stove Dealer in Region

pellets has been going up steadily in the US, the downturn in the economy, lower fuel oil prices and the addition of large new suppliers will tend to lower demand for biomass alternatives and/or put downward pressure

on prices for the next 2-3 years. When crude oil prices return to their pre-recession levels wood pellets will track at the high end of the wholesale price range.

CIP pellets will have to compete

with both Minnesota-made pellets and pellets imported from Wisconsin, the Dakotas and from Canada. Average retail margins on wood pellets are about 30%. Some sample retail price reports for wood pellets in Minnesota are listed in (Figure 5.18).

Retail prices vary plus or minus 20% or more depending on product quality, distribution channel, transportation costs, demand, time of year, brand and quantity ordered. Generally, retail prices in Minnesota range from \$4.00 to \$6.00 per 40 pound bag. (It is interesting to note the number of brands, source and range of prices in a small sample of Minnesota vendors). The retailer sets the price although CIP could influence pricing through volume discounts, special promotions and sales incentives. ■

DISTRIBUTION CHANNELS

Local Direct/Bulk Sales

The pellet fuel market in Minnesota is immature, widely dispersed and highly competitive. The CIP Project will have to address these issues by developing partnerships with key customers and distributors early in the business development process. Opportunities in the immediate neighborhood that should be considered:

- ▶ Converting the oil-fired heating plants at regional schools and/or government buildings to fire with wood pellets would save money and provide a captive market for CIP wood pellets.

- ▶ Working with local power utilities to add the ability to co-fire coal with wood pellets would create a stable long term market for wood pellets from a CIP pellet mill and reduce pollution.

- ▶ Exploring opportunities to replace fossil fuels, that may be

currently used at the two casinos in the CIP area, with wood pellets. If the casinos currently use fuel oil or propane for heating the payback for installing pellet furnaces and switching to environmentally friendly wood pellets is about two years.

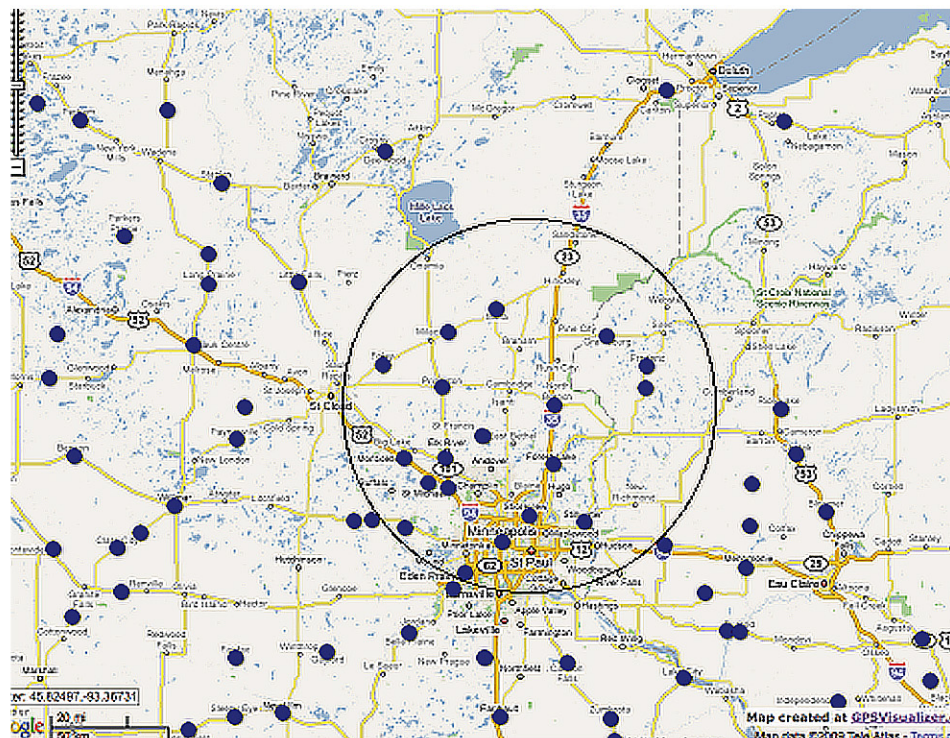
Some customers may be interested in bulk or volume sales. A semi can typically hold 22-25 tons of pellets in 40-pound bags, 50 to a pallet. Most large retailers would expect delivery to a central warehouse this way. A railcar can hold 67-92 tons.

Retail

Developing a retail distribution network for CIP pellets will take time and require specialized expertise. A multi-state network of hundreds of hardware stores, chain retailers (Walmart, Menards, Home Depot), farm and feed stores and fireplace/stove dealers will have to be developed to create sufficient demand for CIP pellets to support a profitable business. The distribution of these potential retail dealers is shown in Figures 5.19, 5.20 and 5.21. The market for wood pellets in the primary market area (50 mile radius) is significant, but a much larger target market may have to be served - a 150-mile radius or more - to sustain a 42,000+-ton facility. A network of dealers in major markets such as Minneapolis/St. Paul, St. Cloud and Duluth/Superior will need to be developed to support the proposed CIP pellet mill.

Financial Considerations

Economic viability of a project such as the manufacture of wood pellets can be determined by several different methods. These range from single value ratios such as average annual rate of return to more comprehensive methods such as internal rate of return (IRR) and net present



▲ Figure 5.21. Farm and Feed Dealers in Region

value (NPV), which are based on discounted cash flow and take into account the time value of money. These methods do not give equivalent answers to the question of economic viability. Consistent with industrial business practice, this study utilizes discounted cash flow methods to calculate IRR and NPV. Generally, a business entity will determine a minimum rate of return (IRR) or hurdle rate for new projects. This establishes whether or not a particular project meets the hurdle rate but one cannot easily compare IRR's from competing projects to select from a slate of projects that all meet the hurdle rate. IRR measures only one dimension of a financial proposal. Since it is actually a ratio, it ignores the absolute magnitude of the opportunity. Net present value (NPV) is a way of measuring the cash flow generated at the required hurdle rate.

NPV = Cumulative discounted cash flow (computed @the hurdle rate) - investment

The protocol then is to compute IRR to be sure the project meets or exceeds the hurdle rate and then compute the NPV at the hurdle rate to be able to compare between competing projects. The study has generated interactive spread sheets that incorporate these calculations and allow parametric sensitivity analysis to be performed around variables such as biomass cost, wholesale selling price, power rates, and factors such as start-up cost, and working capital required to run the business. Specific questions regarding the financial model utilized in this report should be directed to K. J. Valentas at valentas@umn.edu. The hurdle rate selected in this study is 10% after taxes.

Critical business variables for wood pellet manufacture

The manufacture of wood pellets is a non-proprietary, established technology and the product is a commodity. The ultimate finan-

cial success of a wood pellet plant will be determined primarily by three economic factors:

1. The cost of biomass feedstock (wood or prairie grass)

2. The wholesale selling price of the wood pellets

3. The scale of the plant

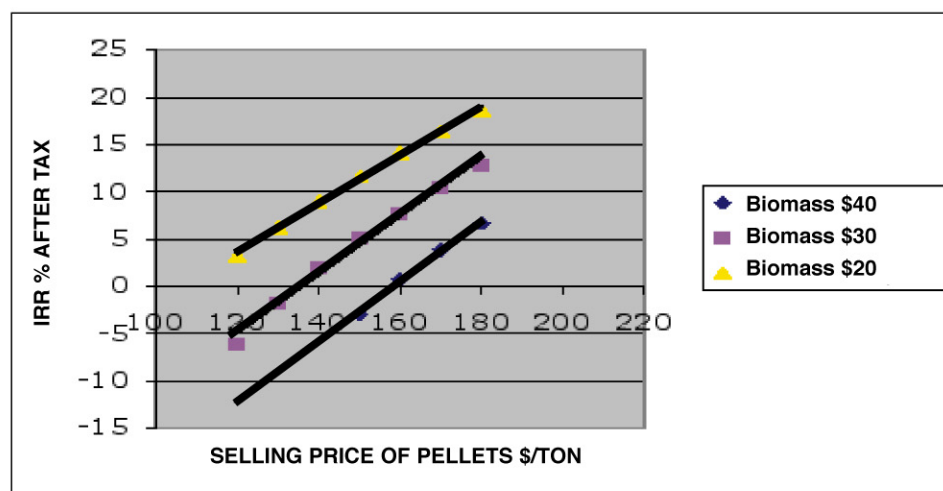
As previously noted many of the companies currently involved in the wood pellet business have a relationship with a sawmill wherein they can access sawdust and waste wood at a cost below the equivalent 'green' wood cost. This is particularly true in Canada. However, recent activity in Minnesota is such that some of the proposed ventures (Mountain Iron and the Kedco Group in Duluth) would have to purchase green timber on the open market to secure their biomass feedstock to supply the pellet mills. In the longer term it is expected that the demand for sawdust and wood waste will exceed the supply.

CIP Pellet Mill - Stage 1 operating on a 5day/3 shift basis

A 7 ton/hr demonstration pellet mill operating 5 days/week and 3 shifts per day (5/3). The plant would use 95,000 tons/year of green timber or equivalent in sawdust or wood wastes.

Economic Parameters

- ▶ Capital investment = \$12.1 MM; Project life = 15 years
- ▶ Yearly payroll = \$930,000
- ▶ Production = 42,000 tons / year pellets at 6% moisture
- ▶ Start -up costs
No income for first two weeks
2 weeks materials and labor
Working capital = 4 months wages + biomass + electricity
Working capital pay back in two years
- ▶ 4 weeks inventory



▲ Figure 5.22. Internal Rate of Return (IRR) vs. pellet selling price for various biomass costs for a 5/3 operation.

A sensitivity analysis was performed with biomass cost and wholesale selling price as the variables and IRR, Net present Value (NPV) and yearly cash flow as the responses.

The results for IRR are shown in figure 5.22 for values of biomass cost ranging from \$40/ton (green) to \$20/ton (green) and wholesale selling price of pellets ranging from \$120/ton to \$180/ton.

IRR is a strong function of biomass cost. The hurdle rate of 10%, after tax, is not achievable when biomass costs \$40 or more per ton. If biomass cost was \$30/ton the selling price would have to be \$170/ton or greater and if biomass cost \$20/ton the selling price would have to be \$145/ton or greater. Previously it was mentioned that some plants are associated with sawmills and are processing waste sawdust and lumber scraps instead of green wood. This then represents the lowest cost operation. One should not conclude that sawdust and wood scrapes are *free* since there are products that are fabricated from them and other uses

such as poultry bedding. Costs up to \$30/dry ton are known. The biomass costs used in the sensitivity analysis are on a green wood basis which is taken as 50% moisture. The sawdust basis is air-dried or 15% moisture. The relationship between these two bases is:

1 ton of green wood at 50% moisture is equivalent to 0.588 tons of air-dried wood at 15% moisture. Alternately, it takes 1.7 tons of green wood to equal 1 ton of air-dried wood. Then if sawdust were priced at \$12/ton it would be equivalent to green wood at \$20/ton. Conversely, green wood priced at \$51/ton would be the equivalent of sawdust at \$30/ton. The range of green wood (50% moisture) prices of \$40 to \$20/ton used in the sensitivity analysis spans a range of sawdust (15% moisture) prices from \$23.5/ton to \$11.76/ton.

Operating the plant for 5 days a week is essentially covering the burden but does not generate substantial profit except at the higher range of pellet selling price. This could be a marketing constraint in a highly competitive environment where competitors

will low ball prices just to cover fixed costs. Adding another day of operation changes the economics considerably.

CIP Pellet Mill - Stage 2 operating on a 6 day/3 shift basis

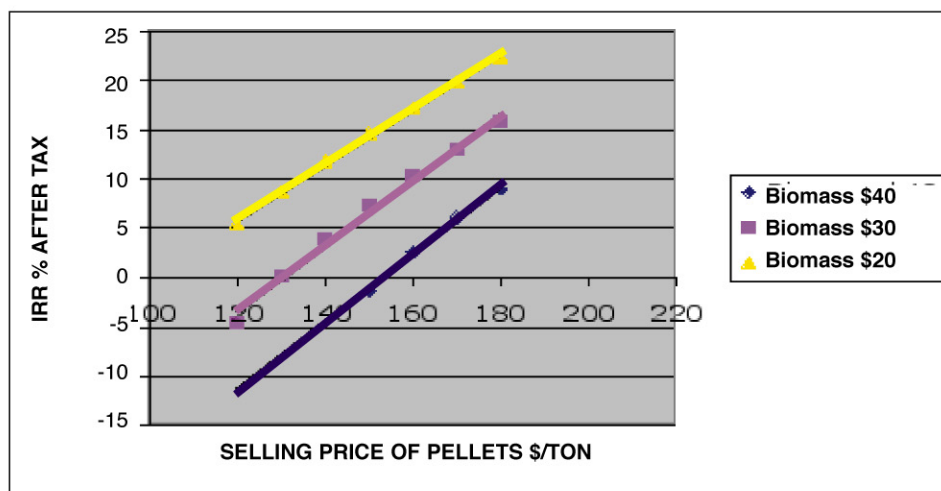
A 7 ton/hr demonstration pellet mill operating 6 days/week and 3 shifts per day (6/3). The plant would use 114,000 tons/year of green timber or equivalent in sawdust or wood wastes.

Economic Parameters

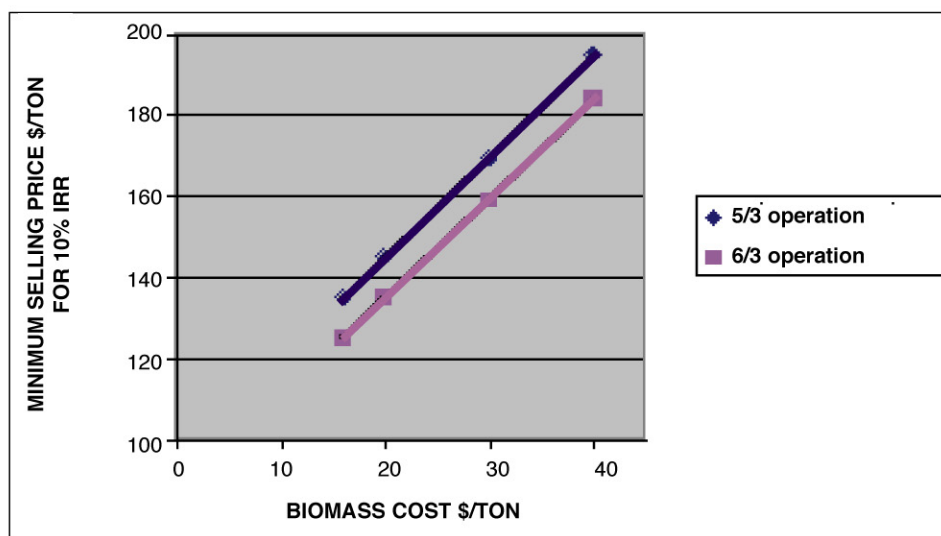
- ▶ Capital investment = \$12.1 MM; Project life = 15 years
- ▶ Yearly payroll = \$1,116,000
- ▶ Production = 51,000 tons / year pellets at 6% moisture
- ▶ Start -up costs
No income for first two weeks
2 weeks materials and labor
Working capital = 4 months wages + biomass + electricity
Working capital pay back in two years
- ▶ 4 weeks inventory

The effect of selling price of pellets and biomass cost are shown in figure 5.23. The economics are considerably improved as the operation more closely approaches full utilization of the investment. A 10% hurdle rate is still not possible with biomass costs of \$40/ton but can be achieved with biomass at \$30/ton and a selling price of at least \$160/ton. At a biomass cost of \$20/ton the selling price could be as low as \$135/ton and still deliver a 10% IRR.

The difference between the two operational options for the 7 ton /hr. plant is shown in figure 5.24. The region above the lines represents the area of minimum selling prices to achieve a 10% IRR. For example, if biomass costs \$30/ton then any pellet price at or above \$155/ton would give an IRR of at least 10% for a 6/3 operation. Conversely, if the market wholesale price for pel-



▲ Figure 5.23 Internal Rate of Return (IRR) vs. selling price of pellets for various biomass costs in a 6/3 operation.



▲ Figure 5.24. Minimum selling price to achieve 10% IRR for 7 ton plant

lets was \$170/ton then the plant could afford to pay as much as \$35/ton for biomass and still achieve a 10% IRR.

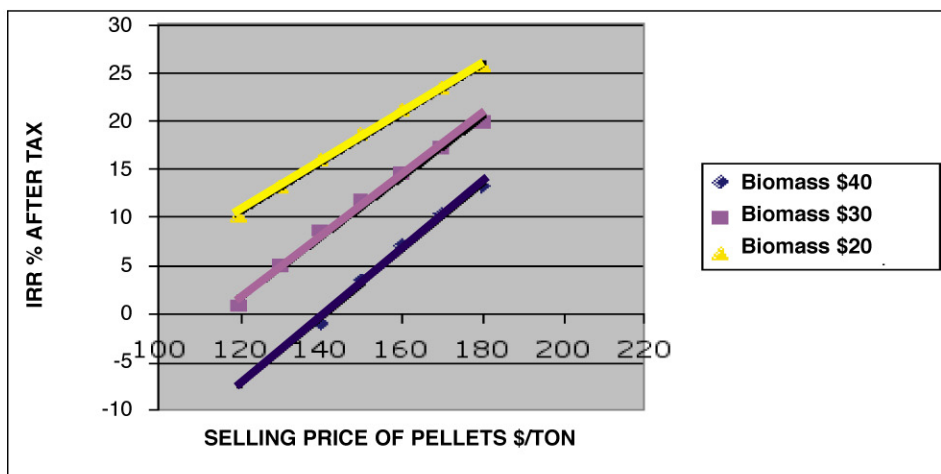
Scaling up to a 12ton/hr plant in two stages

An alternative business model would be to start operations with a 7 ton/hr plant and then once the business is established and markets are developed to add an additional 5 ton/hr capacity for a total of 12 tons/hr. The assumed model has the second phase occurring after year three of operation. To properly account for the time value of money, the

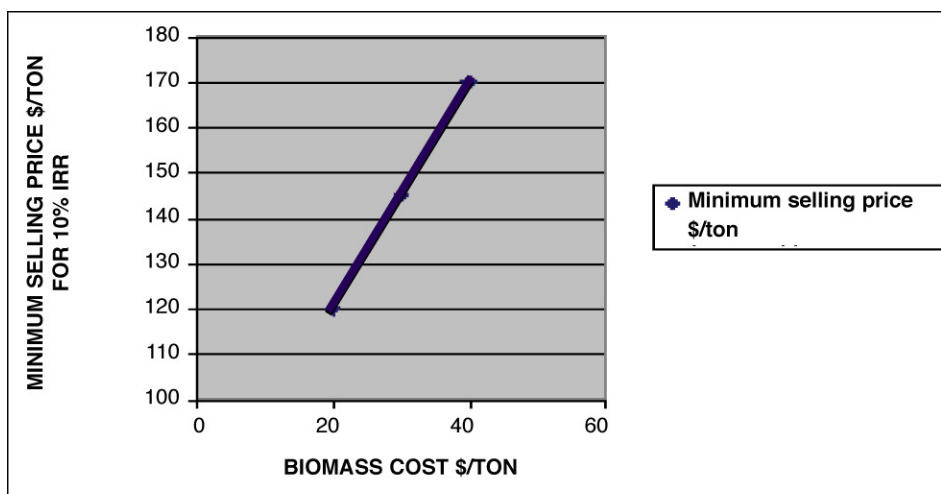
incremental capital required after year three was discounted back to today's dollars to accurately reflect the cash flow, IRR and NPV. The adjusted total capital for a two-phase 12 ton/hr plant is then \$20.7 MM.

Economic model parameters for a 2 phase, 12 ton/hr pellet plant

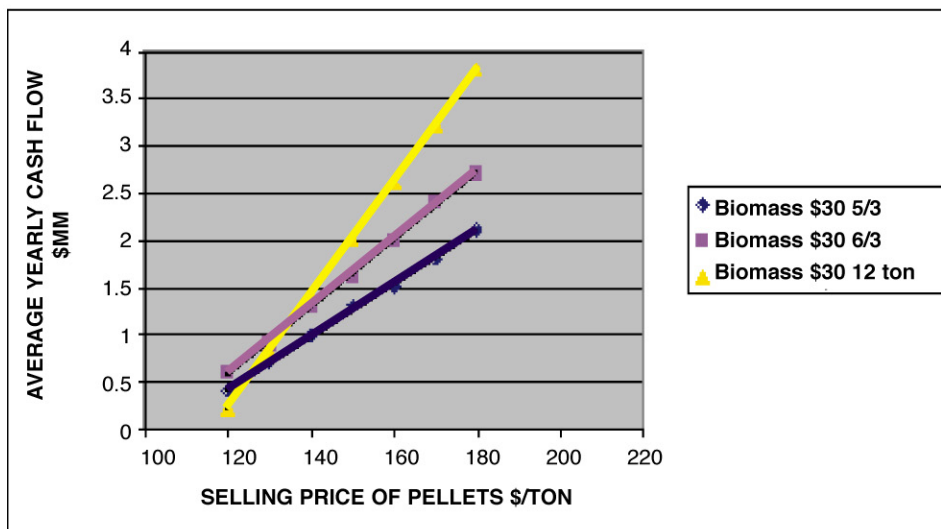
- ▶ Capital = \$20.7 MM in two phases with \$12.1 MM in phase one
- ▶ Yearly payroll after year 3 = \$1.2 MM
- ▶ Plant capacity = 84,000 tons/year at 6% moisture



▲ Figure 5.25. IRR vs. pellet selling price for various biomass costs for 12 ton/hr, 2-phase plant model.



▲ Figure 5.26. Minimum selling price to achieve 10% IRR vs. biomass cost for 12 ton/hr plant.



▲ Figure 5.27. Yearly Cash Flow (after tax) vs. selling price of pellets and biomass cost for three business models

- ▶ Startup costs same as 7 ton/yr. model
- ▶ 5 days per week, 3 shifts per day.

The results of the sensitivity analysis for selling price and biomass cost are shown in figures 5.25 and 5.26.

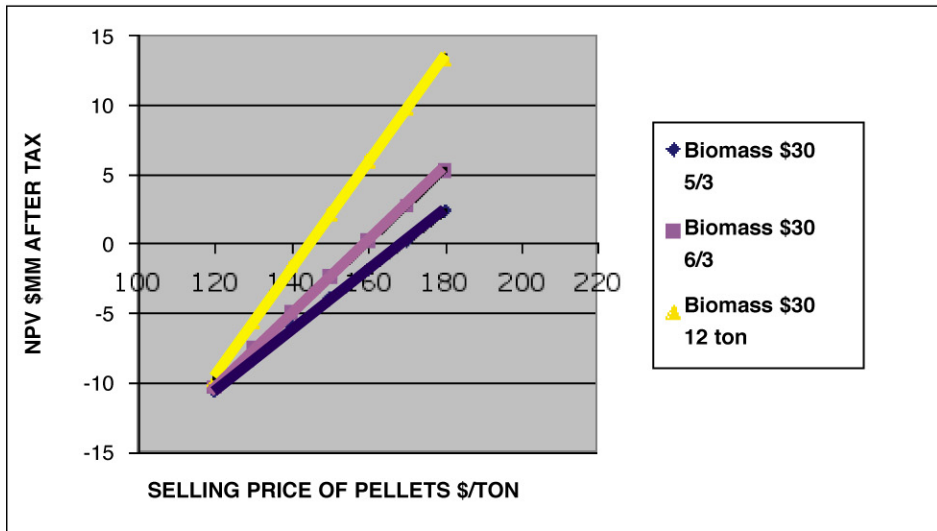
The economies of scale are apparent with the larger plant. A 10% IRR can be achieved even with biomass cost of \$40/ton if the pellet selling price is \$170/ton or greater. Conversely, the plant would be competitive at \$145/ton with biomass costs of \$30/ton.

Cash flow and NPV

From an operational standpoint it is useful to look at average yearly cash flow to assess the financial robustness of a manufacturing enterprise. Figure 5.27 shows the yearly cash flow vs. selling price for various biomass costs for the three business models.

As expected the average yearly after tax cash flow increases as plant output or capacity increases. Note that the 12 ton/hr line intersects the 7 ton/hr lines for pellet selling prices below \$140/ton. This is because the cash flow for the two phase 12 ton/hr plant is delayed from reaching a steady level due to the addition of phase 2 in the 4th year of operation. This is mitigated if the pellet selling price is above \$140/ton. Cash flow is not the best quantitative measure of the relative worth of competing models. It is better to compare the NPV of the various options as in figure 5.28.

It is clear that the 12 ton, two phase option offers the greatest return. A positive NPV means that the model is returning in excess of 10% after taxes. For example, at a selling price of



▲ **Figure 5.28. Net Present Value (NPV) at 10% hurdle rate (after tax) vs. pellet selling price for three business models**

\$170/ton all the models return at least 10% after taxes. However, the 12 ton plant has a NPV of \$9.6MM vs. a NPV of \$2.7MM for the 7 ton, 6/3 model. Conversely, for a pellet selling price above \$170 all the models have a positive NPV.

Biomass Cost

Pellet selling price is market driven and as such is difficult to control. Biomass cost is a variable that has a significant impact on financial performance and while it cannot be controlled it can be managed. The range of green wood (50% moisture) prices of \$40 to \$20/ton used in the sensitivity analysis spans a range of sawdust (15% moisture) prices from \$23.50/ton to \$11.76/ton. A combination of green wood, sawdust and waste wood to yield a weighted average of \$30/ton on a *green* wood basis would provide a safe haven. As fuel prices move upward again, as they inevitably will, the cost of biomass will rise. However, the selling price of wood pellets will rise as well which will mitigate the increasing biomass costs to a certain extent. The exact relationship is of course not known

except qualitatively.

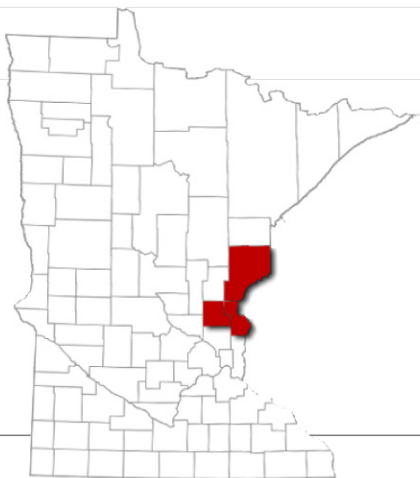
An Implementation Plan

- ▶ Develop relationships with sawmills and other manufacturers that can provide waste wood. Secure long-term contracts with local landowners, state and county entities and loggers for green wood.
- ▶ Identify and secure contracts with large users such as utilities, casinos, schools, government buildings and the like to develop a fixed product base.
- ▶ Market pellets to area dealers and try to establish a relationship with pellet stove manufacturers.
- ▶ Locate plant as close as possible to rail spur that serves Duluth to be able to participate in export of pellets to Europe.
- ▶ Start with a 7 ton/hr plant on either a 5/3 or 6/3 schedule depending on sales.
- ▶ Phase into a 12 ton/hr. plant as the market dictates.
- ▶ Longer term, develop a pellet from agricultural residues, brush and prairie grasses that can be blended with or substitute for wood to reduce costs and provide a custom pellet for large scale users.

Conclusions

A CIP pellet mill could be a successful enterprise that meets several needs including:

- ▶ Pellet mill yearly payroll between \$930,000 and \$1,200,00
- ▶ A step toward energy self-sufficiency with renewable resources
- ▶ Significant cost savings opportunity for local potential large scale users and individual home owners
- ▶ Employment opportunity for loggers
- ▶ Environmental improvements due to reduction of net carbon dioxide emissions. ■



CONCLUSIONS & RECOMMENDATIONS

A Path Forward

The Chisago, Pine and Isanti counties region (CIP) has a supply of renewable biomass that can be developed and further expanded sustainably to provide bioenergy and related jobs now and into the future while contributing to the energy independence of the nation and reduction of green house gas emissions. The path forward is defined by three major goals;

Goal 1, long term: The ultimate target is a renewable energy facility to convert the region's cellulosic biomass into environmentally sustainable, carbon-neutral liquid transportation fuels.

Goal 2, intermediate term: The grasslands in the region are not adequate to supply a commercial size conversion plant. Furthermore, there is not an adequate supply of diverse prairie grass seed to seed the region in high productivity, low input grasslands. CIP can begin a concentrated seed development project utilizing the Wild River State Park seed bank and supplementing with other sources of mixed prairie seed to establish 16,000 acres of diverse low input prairie within 10 years. This would form the basis for more extensive plantings to support future conversion plants.

Goal 3, near term: Investing in a wood-pellet plant can establish the initial biofuels manufacturing infrastructure with a yearly payroll in excess of \$1 million.

This three-phase economic development of the region's supply of bioenergy will improve the environment for wildlife and humans alike and provide economic stimulus to the CIP region while increasing the energy self-sufficiency of the area.

Biomass Supply

► The East Central region could support the production of 126 million gallons per year of ethanol, based on current conversion platform technologies, if all eligible acreage were producing biomass at sustainable levels. However, making this economically profitable is difficult at present.

► At sustainable harvest levels, a single 50-million gallon per year plant converting prairie grass to ethanol requires biomass from about 355,000 acres in this region.

► The cost of biomass is the dominant factor in determining the economic viability of biofuel conversion platforms.

► Biomass sugar composition data obtained by analysis of field samples taken in the East Central region can be combined with DOE yield models to predict ethanol yields for biomass actually growing in the region.

► Supply curve models developed in the project estimate the delivered cost for various biomass feedstocks by combining production, harvest, and trans-

portation costs.

► There is a limited amount of native grassland available in the East Central region. The Wild River State Park has areas of diverse restored native prairies that could be used to supply local seed, but is not sufficient to supply all the material needed for future bioenergy plantings. Land presently idle in the region that could be available for seed and grassland bioenergy production is about 16,000 acres. If enough native seed were gathered from available sources and used to initially seed 160 acres, a bootstrapping approach could be implemented to result in 16,000 acres seeded within 10 years.

Conclusions for liquid fuels from cellulosic biomass

► Ethanol should be viewed as a transition biofuel. Ultimately direct synthesis of gasoline, diesel fuels, and aviation fuels based on cellulosic biomass should prevail.

► Ethanol from cellulosic biomass with current technologies is not presently ready for commercialization.

► Significant technological discoveries and developments are required to make liquid phase fermentation based cellulosic ethanol conversion platforms profitable.

CONCLUSIONS

► Regardless of promised potential technical improvements, the capital cost will still be significantly higher than for corn ethanol plants of similar capacity.

► Under best -case scenarios, the biochemical platform is dependent on government subsidies to be profitable. The profit presently derives largely from the subsidies.

► Ethanol can be more economically produced by gasification of biomass and subsequent catalytic conversion to mixed alcohols. A small scale facility (20MGY) is currently under construction.

► Syngas catalytic conversion to gasoline appears to offer the best potential for conversion of cellulosic biomass to liquid fuels that are compatible with current usage and distribution patterns. This existing technology was applied commercially in New Zealand during the energy crisis of the 1980s.

► Syngas platforms will become economically and strategically compelling when 1) crude oil prices get high enough (gasoline rack price of \$1.70/ retail of \$2.55/gal or higher), and 2) foreign oil independence and reduction of carbon dioxide emissions become national priorities.

► Regardless of which platforms prevail commercially, the availability of sustainable renewable biomass must be increased dramatically to supply the needs of conversion platforms.

Recommendations

1. A project should be initiated to supplement the seed bank at Wild River State park as a source for seeding prairie grass in the CIP

region. Land presently idle in the region that could be available for seed and grass-land bioenergy production is about 16,000 acres. If enough native seed were gathered from available sources and used to initially seed 160 acres, a bootstrapping approach could be implemented to result in 16,000 acres seeded within 10 years.

2. A pellet mill in the CIP region could be a successful enterprise that meets several needs, including:

► Pellet mill yearly payroll between \$930,000 and \$1,200,00

► A step toward energy self-sufficiency with renewable resources
* Significant cost savings opportunity for local potential large scale users and individual home owners

► Employment opportunity for loggers

► Environmental improvements due to reduction of net carbon dioxide emissions

An Implementation Plan

► Develop relationships with sawmills and other manufacturers that can provide waste wood. Secure long-term contracts with local landowners, state and county entities and loggers for green wood.

► Identify and secure contracts with large users such as utilities, casinos, schools, government buildings and the like to develop a fixed product base.

► Market pellets to area dealers and try to establish a relationship with pellet stove manufacturers.

► Locate plant as close as possible to rail spur that serves Duluth to be able to participate in export of pellets to Europe.

► Start with a 7 ton/hr plant on either a 5/3 or 6/3 schedule depending on sales.

► Phase into a 12 ton/hr. plant as the market dictates.

► Longer term, develop a pellet from agricultural residues, brush and prairie grasses that can be blended with or substitute for wood to reduce costs and provide a custom pellet for large scale users. ■

GLOSSARY OF TERMS AND ACRONYMS

A

- ▶ **Aden Model.** An energy production model developed at NREL.
- ▶ **amylase.** An enzyme that converts starches to sugars.
- ▶ **annual.** A plant the lives one year only, reestablishing the next year from seed.
- ▶ **arabinose.** A form of sugar.
- ▶ **ArcGIS.** A commonly used GIS tool.
- ▶ **as-received.** Moisture content of 15% for grass or 50% for wood.
- ▶ **ash.** Solid material remaining after combustion.

B

- ▶ **big bluestem.** A tall warm season grass that is a main component of native prairie.
- ▶ **biochemical.** A chemical that is produced by living things.
- ▶ **biodiversity.** A measure of the number of different kinds of living forms occupying a region, habitat, ecosystem, or other unit on the Earth.
- ▶ **bioenergy.** Energy available from plants or other living things. Often used interchangeably with biofuel.
- ▶ **biofuel.** A fuel available from plants or other living things. Often used interchangeably with bioenergy.
- ▶ **biomass.** Material produced by living things, typically by plants.
- ▶ **board foot.** A volume equal to a board one foot square by

one inch thick.

- ▶ **bog.** An ecological community that arises when a wet area of land is isolated from nutrients flowing out of other ecological communities in the region.
 - ▶ **broadleaf.** A hardwood species, typically deciduous.
 - ▶ **BTU.** British Thermal Unit. A measure of energy. A single blue-tip match contains about one BTU of energy. Burning one BTU per second produces approximately one kilowatt of combined heat and power.
 - ▶ **brushland.** An ecosystem composed of short thin trees and brush.
 - ▶ **butane.** A fuel that evaporates at room temperatures but can easily be kept in liquid form. A component of LPG.
 - ▶ **butanol.** A form of alcohol.
- C
- ▶ **Ca.** Calcium.
 - ▶ **calorie.** A unit of energy equal to approximately four BTUs (large calorie) of 0.004 BTUs (small calorie).
 - ▶ **calorific.** Able to produce calories; energy containing. carbohydrate. A plant material that can be converted to biofuel. Sugars and starches are carbohydrates.
 - ▶ **carbon dioxide.** A major greenhouse gas. Abbreviated CO₂.
 - ▶ **carbon footprint.** How much greenhouse gas is emitted by all aspects of a process.

▶ **carbon monoxide.** A combustible gas. An incompletely burned form of carbon dioxide.

▶ **carbon negative.** A process that absorbs carbon dioxide from the air as it proceeds.

▶ **carbon neutral.** A process that does not add carbon dioxide to the air as it proceeds.

▶ **carbon sequestration.** Long-term storage of carbon to prevent it reaching the air as a greenhouse gas.

▶ **catalyst.** A chemical that helps convert one chemical into another without being substantially consumed in the process.

▶ **catalytic conversion.** Conversion of a substance such as biomass to another form with catalysts.

▶ **cell wall.** The outer portion of a plant cell. The main constituent of wood.

▶ **cellulose.** A substance in plant tissues, along with hemicellulose and lignin.

▶ **cellulosic ethanol.** Ethanol made from cellulose bearing crops, such as grass.

▶ **CHP.** Combined Heat and Power.

▶ **Cl.** Chlorine.

▶ **CO₂.** Carbon dioxide, a major greenhouse gas.

▶ **combined heat and power.** A process of combining the generation electricity with the generation of heat to get the greatest efficiency from a fuel-stuff.

► **conifer.** A softwood species, typically with needles and cones.

► **cool season grass.** A grass whose primary growing season is spring and fall. European grasses are typically cool season grasses.

► **corn stover.** Stover left after corn kernels have been harvested.

► **CPI.** Crop Productivity Index. This index ranges from 0 to 100, with 100 represent the most productive soils.

► **CRP.** Conservation Reserve Program.

► **C3.** A term associated with plant species that convert sunlight to living material in a specific way that benefits from higher levels of carbon dioxide in the air. Many imported European grasses are of this type.

► **C4.** A term associated with plant species that convert sunlight to living material in a specific way can tolerate lower levels of carbon dioxide in the air. Many native North American grasses are of this type.

D

► **DBF.** Database File. A particular format used in GIS applications.

► **DDG.** Dry Distillers Grain. The portion of biomass that microorganisms cannot convert to the desired product, such as ethanol.

► **deciduous.** Dropping leaves in the off-season. Most hardwood trees in the Upper Midwest are deciduous, but one softwood (the tamarack) is also.

► **dimethyl ether.** A fuel that is gas at room temperatures but

can easily be liquified under pressure. Potential substitute for diesel fuel.

► **distillation.** Removal of water by the addition of heat.

► **DME.** Dimethyl Ether.

► **DNR.** Department of Natural Resources.

► **DOT.** Department of Transportation.

E

► **ecology.** The branch of biology that studies the interactions—biological, physical, chemical, behavioral—among all the living forms in a region or on the planet.

► **ecosystem.** The ecological community together with its soils and waters, and also together with all the energy and nutrients that flow into it, out of it, and that cycle within it.

► **ECS.** Ecological Classification System. Used by MNDNR.

► **energy.** A capacity to generate power. Energy can be stored in many forms, as in biomass, oil, or batteries.

► **enzymatic hydrolysis.** Breaking apart water with the aid of enzymes.

► **enzyme.** A biochemical catalyst.

► **EPA.** Environmental Protection Agency.

► **ESRI.** Environmental Systems Research Institute. A corporation producing GIS software. Pronounced "Ez' ree."

► **ethanol.** A form of alcohol used as a transportation fuel.

► **exotic.** Not native to an area.

F

► **farm gate.** Ready to leave the farm for the power plant or other location.

► **feedstock.** Material used to supply energy to a power generation plant.

► **fen.** An ecological community that arises when a wet area of land is able to receive ample nutrients flowing out of other ecological communities in the region. When nutrients are available, marsh vegetation tends to crowd out bog plants.

► **fermentation.** Conversion of materials to alcohol by microorganisms such as yeast.

► **flora.** The vascular plants, mosses, and other non-animal species living in an area.

► **forb.** A non-woody species of vascular plant that is not in the grass family. Forbs typically die back to their roots in winter (perennials), or die completely and rely on seed for the next year's growth (annuals).

► **fossil fuel.** A fuel such as coal or oil that has been stored in the earth for thousands or millions of years.

G

► **galactose.** A form of sugar. GAP analysis. GIS data showing major land types.

► **gasification.** Conversion of a substance such as biomass to gaseous form, for example to syngas.

► **GIS.** Geographic Information System, a computer system used for managing and analysing analyzing maps.

► **glucose.** A form of sugar.

► **GPS.** Global Positioning System; a typically hand-held unit that reports positions on the Earth's surface, often presenting them in UTM coordinates.

► **grassland.** An ecosystem composed of grasses, flowers, and other non-woody plants.

H

► **hemicellulose.** A substance in plant tissues, along with cellulose and lignin.

► **herb.** A plant that is not woody; a grass, sedge, or forb. HerbaceousHerbaceous vegetation dies back to become litter in the fall.

► **herbaceous.** Non-woody plant material, such as grass.

► **HHV.** Higher Heating Value. A measure of energy content assuming that heat used to evaporate water contained in the material is recovered. See LHV.

► **high fertilization.** The process of adding substantial fertilizer, as in switch grass or fertilized prairies.

► **higher heating value.** (HHV). A measure of energy content assuming that heat used to evaporate water contained in the material is recovered. See lower heating value.

► **HPLC.** High Performance Liquid Chromatography. A technique for chemical analysis.

► **hybrid poplar.** A rapidly growing tree used for bioenergy.

► **hydrogen.** A combustible clean-burning gas, along with oxygen one of the two components of water.

► **hydrolysis.** A chemical process breaking off hydrogen from water molecules.

I

► **Indian grass.** A tall warm season grass that is a main component of native prairie.

► **indigenous.** In this report, used to refer to plants that have long lived in an area. Similar to native.

► **inorganic.** Related to non-living sources. Often refers to chemicals that do not contain carbon.

► **IRR.** Internal Rate of Return.

K

► **K.** Potassium.

► **kilowatt.** One thousand watts.

L

► **legume.** A group of plants capable of removing nitrogen from the air and converting to a form that can be used by plants.

► **LHV.** Lower Heating Value. A measure of energy content assuming that heat used to evaporate water contained in the material is not recovered. See HHV.

► **lignin.** A substance in plant tissues, along with hemicellulose and cellulose.

► **linear.** As used in this report, approximated by a straight line.

► **LLC.** Limited Liability Company.

► **low fertilization.** The process of adding minimal fertilizer, as in native prairies.

► **lower heating value.** A

measure of energy content assuming that heat used to evaporate water contained in the material is not recovered. See higher heating value.

► **LPG.** Liquefied Petroleum Gas. Includes mixtures of propane, and other fuels. macronutrients. A nutrient needed in large quantities for growth. mannose. A form of sugar. marsh. A wetland without trees. Typically marshes contain cattails, sedges, and some water-tolerant grasses.

M

► **MBF.** Million Board Feet. Equal to approximately 3000 cubic yards.

► **MCC.** Minnesota Conservation Corps.

► **megawatt.** One million watts.

► **methanol.** Wood alcohol. metric ton. Approximately 1.1 tons.

► **MGY.** Million Gallons per Year.

► **microorganism.** Microscopic forms of life, including bacteria and yeasts.

► **MJ.** Megajoule. A unit of energy equal to approximately 948 BTUs.

► **MM.** Abbreviation for million.

► **MMBTU.** One Million BTUs.

► **MN.** Minnesota.

► **MNDNR.** Minnesota DNR.

► **MNFRC.** Minnesota Forest Resource Council.

► **model.** A mathematical representation of a process or structure.

► **moisture content.** The amount of water absorbed by a material. Green wood has up to 50% or more moisture, air-dried wood or grass has typically 15% or less moisture. Oven-dried material has near 0% moisture.

► **molecular sieve.** A filter so fine that it can separate different types of molecules.

► **MSW.** Municipal Solid Waste.

► **MTBE.** Methyl Tertiary Butyl Ether. A fuel additive.

► **MTG.** Methanol to Gasoline.

N

► **N.** Nitrogen.

► **Na.** Sodium.

► **NAD.** A particular scaling for UTM.

► **NASS.** National Agricultural Statistics Service, part of the USDA.

► **native.** In this report, used to refer to plants that have long lived in an area. Similar to indigenous.

► **NCRS.** Natural Resources Conservation Service.

► **nitrogen fixation.** The process of converting the nitrogen in the air to a form usable by plants.

► **nitrogen.** An essential element of life. Nitrogen composes about 80% of the air.

► **NPV.** Net Present Value. The present value of net cash flows in the future minus the initial investment.

► **NREL.** National Renewable Energy Laboratory. Part of the USDA.

O

► **omnivorous.** Able to eat a variety of foods. When applied to an energy production facility, able to accept many feedstocks. organic. Derived from living organisms. Often refers to chemicals containing carbon.

P

► **P.** Phosphorus.

► **pellet.** A small cylindrical chunk of compressed fuel, typically made from wood or grass. Pellets are easily transported and burn relatively cleanly.

► **perennial.** A plant that lives for many years.

► **plant gate.** Delivered to the power plant.

► **platform.** As used in this report, a large-scale method of processing or converting biomass energy to usable forms.

► **polynomial.** As used in this report, approximated with a curve rather than a straight line.

► **PPI.** Producer Price Index.

► **prairie.** An ecosystem, once stretching west to the Rockies, containing hundreds of species of flowering forbs and grasses. Pure prairies contain no trees and their plant species live with much of their bodies underground in the form of roots and tubers.

► **productivity.** Ecological term for the amount of biomass produced. Above-ground biomass of interest for bioenergy.

► **propane.** A fuel that is gas at room temperatures but can easily be liquified under pressure. A component of LPG.

► **propanol.** A form of alcohol.

pulplog. A log that is intended to be ground in to pulp for paper or building materials.

R

► **regression.** The process of taking a set of measurements and converting them to a simple formula, either linear or polynomial.

► **restoration.** An effort to recover an ecological community that has been lost, usually due to human activities. Restoration typically involves seeding, transplanting, and sometimes prescribed treatments like burning.

► **riparian.** Bordering a stream or river, or related to a stream or river.

S

► **S.** Sulfur.

► **saccharification.** Conversion to sugars.

► **saprophytic.** Pertaining to a plant that does not make its own food. Typically such plants consume dead plant material in the soil.

► **savanna.** An ecosystem of prairie flora with scattered trees, typically fire-tolerant species like bur oak.

► **shortwood.** Sawlogs or pulplogs cut to standard length, typically slightly over eight feet long.

► **sawlog.** A log that is large enough and good enough to be cut into lumber.

► **silviculture.** The practice of growing trees.

► **slag.** A liquid mobile form of ash.

► **SNA.** Scientific and Natural Area.

► **SO₂.** Sulfur dioxide.

► **soil organic matter.** Material in the soil produced by plants and soil organisms.

► **spatial analysis.** Various mathematical and computer tools to analyze maps and other geographic object.

► **species.** A similar group of plants, animals, or other living things. Species are commonly defined as the largest group able to interbreed, but a complete definition is difficult.

► **spreadsheet model.** A model employing an array of numbers with formulas connecting them.

► **SQI.** Soil Quality Index. A number between -1 and 1, indicating loss or retention of organic matter.

► **SRWC.** Short Rotation Woody Crop. Hybrid poplar is an example.

► **SSURGO.** Soil Survey Geographic database. The most detailed level of digital soil mapping available from the NRCS.

► **standard deviation.** A statistical measure of how much variation exists in a set of measurements.

► **starch ethanol.** Ethanol made from starch-bearing crops, such as corn.

► **stover.** The stalks, leaves, and other residue left on the field after a crop has been harvested.

► **sugar ethanol.** Ethanol made from sugar-bearing crops, such

as cane.

► **super bug.** A hypothetical microorganism that can accomplish chemical conversion at little or no cost.

► **swamp.** A wetland with trees.

► **switch grass.** A species of North American prairie grass that can be cultivated as a crop.

► **syngas.** A combustible gas composed largely of hydrogen and carbon monoxide. Typically produced from biomass or other carbon-based substance.

T

► **T.** Ton. 2000 pounds of mass. Equal to approximately 0.9 metric tons.

► **therm.** A unit of energy equal to 100,000 BTUs.

► **thermochemical.** A chemical conversion that uses heat. USDA. United States Department of Agriculture.

U

► **USFWS.** United States Fish and Wildlife Service.

► **USGS.** United States Geological Survey.

► **UTM.** Universal Transverse Mercator; a set of coordinates for locating points on the earth, commonly used with GPS and GIS.

W

► **warm-season grass.** A grass whose primary growing season is summer. North American grasses are typically warm season grasses.

► **watt.** A measure of power.

750 watts is approximately a horsepower.

► **wetland.** An ecosystem with standing water or periodically wet.

► **windrow.** A row of hay or other biomass raked for drying.

► **WMA.** Wildlife Management Area.

► **woodland.** An ecosystem composed of trees and other compatible plants.

X

► **xylose.** A form of sugar. yellow-label. A process of tracking seeds or other plant material so that its origin is known.

Y

► **yield.** The amount of useful biomass that can be harvested. zeolite. A crystalline porous material used in processing materials.

Z

► **zero-moisture.** Oven dried to be essentially free of water. ZSM-5. A specific zeolite material.

SAMPLE SPREAD SHEET CALCULATION AND CAPITAL ESTIMATE
FOR NOMINAL 6 TON/HR. PELLET PLANT RUN ON A 6/3 BASIS

Parameters & Conditions

INPUTS:

6-3

W-E TONS WET BIOMASS REQ'D= 0
PURCHASED TONS WET BIOMASS REQ'D= 114,436
BIOMASS W-E COST/TON \$40
BIOMASS MARKET COST/TON \$40

PELLETS FOR SALE TONS:

W-E FOREST PELLET SALES TPY 50,736
PELLET MARKET SELLING PRICE= \$180
ELECTRICITY COST/KWH= \$0.06
PAYROLE \$1,116,000
KWH/YR REQ'D 11,466,805
MAINTENANCE 1% CAP \$120,967
10 YEAR CASH FLOW \$ 16,446,023
15 YEAR CASH FLOW \$ 27,708,161
CAPITAL \$12,096,652
NPV
IRR
TAXABLE=1 1

BUSINESS ASSUMPTIONS:

NO INCOME 1ST 2 MONTHS
START UP; 2 WKS MATERIAL/LABOR
WORKING CAPITAL 4 MO WAGE+BIOMASS+ELEC
PAYOFF ASAP
4 WKS INVENTORY ON SITE

Spread sheet –part 1 Years 1 through 4

| Year | | 1 | 2 | 3 | 4 |
|--------------------------------|-------------------|----------------|-------------|-------------|----------|
| Revenue | | | | | |
| W-E FOREST PELLET SALES | | \$ 7,610,400\$ | 9,346,180\$ | 9,564,881\$ | 9,788,69 |
| PUR BIOMASS PELLET SALES | | \$ - \$ | - \$ | - \$ | - |
| | | \$0 \$ | - \$ | - \$ | - |
| | | \$0 \$ | - \$ | - \$ | - |
| SUB TOTAL | | \$ 7,610,400\$ | 9,346,180\$ | 9,564,881\$ | 9,788,69 |
| COGS | | | | | |
| W-E BIOMASS COST | | \$ - \$ | - \$ | - \$ | - |
| PURCHASED BIOMASS COST | | \$ 4,577,421\$ | 4,684,532\$ | 4,794,150\$ | 4,906,33 |
| SUB TOTAL | | \$ 4,577,421\$ | 4,684,532\$ | 4,794,150\$ | 4,906,33 |
| Gross Margin | | \$ 3,032,979\$ | 4,661,648\$ | 4,770,730\$ | 4,882,36 |
| Expenses | | | | | |
| Wages and Salaries | | \$ 1,116,000\$ | 1,142,114\$ | 1,168,840\$ | 1,196,19 |
| maintenance expenses | | \$ 120,967\$ | 123,797\$ | 126,694\$ | 129,65 |
| DEPRECIATION | | \$ 8,064\$ | 8,064\$ | 8,064\$ | 8,06 |
| ELECTRICAL COST | | \$ 688,008\$ | 704,108\$ | 720,584\$ | 737,44 |
| START UP | | \$ 218,978 | | | |
| WORKING CAPITAL PAY BACK | 2,127,143\$ | 500,000\$ | 1,627,143 | | |
| EBIT | | | | | |
| PRINCIPLE AND Interest expense | | \$ - \$ | - \$ | - \$ | - |
| Profit before Tax | | \$ 380,962\$ | 1,056,421\$ | 2,746,548\$ | 2,811,00 |
| Taxes | | 133,337 | 369,747 | 961,292 | 983,85 |
| Loss Carry forward | | | | | |
| Net Income | | \$ 247,626\$ | 686,674\$ | 1,785,256\$ | 1,827,15 |
| Depreciation | \$ 12,096,652\$ | 8,064\$ | 8,064\$ | 8,064\$ | 8,06 |
| Capex | \$ 12,096,652 | | | | |
| FCF | \$ (14,223,795\$) | 255,690\$ | 694,738\$ | 1,793,321\$ | 1,835,21 |
| Terminal Value | \$ (14,223,795\$) | 255,690\$ | 694,738\$ | 1,793,321\$ | 1,835,21 |
| NPV 15 YR | \$ (1,071,329) | | | | |
| IRR 15 YR | 8.86% | | | | |

Spread sheet – part 2 years 4 through 9

| 4 | 5 | 6 | 7 | 8 | 9 |
|--------------|---------------|---------------|---------------|---------------|---------------|
| \$ 9,788,699 | \$ 10,017,754 | \$ 10,252,170 | \$ 10,492,071 | \$ 10,737,585 | \$ 10,988,841 |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ 9,788,699 | \$ 10,017,754 | \$ 10,252,170 | \$ 10,492,071 | \$ 10,737,585 | \$ 10,988,841 |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ 4,906,333 | \$ 5,021,142 | \$ 5,138,636 | \$ 5,258,880 | \$ 5,381,938 | \$ 5,507,870 |
| \$ 4,906,333 | \$ 5,021,142 | \$ 5,138,636 | \$ 5,258,880 | \$ 5,381,938 | \$ 5,507,870 |
| \$ 4,882,365 | \$ 4,996,613 | \$ 5,113,533 | \$ 5,233,190 | \$ 5,355,647 | \$ 5,480,961 |
| \$ 1,196,191 | \$ 1,224,182 | \$ 1,252,827 | \$ 1,282,144 | \$ 1,312,146 | \$ 1,342,851 |
| \$ 129,659 | \$ 132,693 | \$ 135,798 | \$ 138,975 | \$ 142,227 | \$ 145,551 |
| \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 |
| \$ 737,445 | \$ 754,702 | \$ 772,362 | \$ 790,435 | \$ 808,931 | \$ 827,881 |
| \$ 2,811,006 | \$ 2,876,972 | \$ 2,944,482 | \$ 3,013,572 | \$ 3,084,278 | \$ 3,156,631 |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ 2,811,006 | \$ 2,876,972 | \$ 2,944,482 | \$ 3,013,572 | \$ 3,084,278 | \$ 3,156,631 |
| 983,852 | 1,006,940 | 1,030,569 | 1,054,750 | 1,079,497 | 1,104,821 |
| \$ 1,827,154 | \$ 1,870,032 | \$ 1,913,913 | \$ 1,958,822 | \$ 2,004,781 | \$ 2,051,811 |
| \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 |
| \$ 1,835,218 | \$ 1,878,096 | \$ 1,921,978 | \$ 1,966,886 | \$ 2,012,845 | \$ 2,059,881 |
| \$ 1,835,218 | \$ 1,878,096 | \$ 1,921,978 | \$ 1,966,886 | \$ 2,012,845 | \$ 2,059,881 |

Spread sheet - part 3 years 9 through 15

| 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| \$ 10,988,845 | \$ 11,245,984 | \$ 11,509,140 | \$ 11,778,453 | \$ 12,054,069 | \$ 12,336,134 | \$ 12,624,800 |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ 10,988,845 | \$ 11,245,984 | \$ 11,509,140 | \$ 11,778,453 | \$ 12,054,069 | \$ 12,336,134 | \$ 12,624,800 |
| \$ - | \$ - | \$ - | \$ - | \$ - | \$ - | \$ - |
| \$ 5,507,876 | \$ 5,636,760 | \$ 5,768,660 | \$ 5,903,647 | \$ 6,041,792 | \$ 6,183,170 | \$ 6,327,850 |
| \$ 5,507,876 | \$ 5,636,760 | \$ 5,768,660 | \$ 5,903,647 | \$ 6,041,792 | \$ 6,183,170 | \$ 6,327,850 |
| \$ 5,480,969 | \$ 5,609,224 | \$ 5,740,479 | \$ 5,874,807 | \$ 6,012,277 | \$ 6,152,964 | \$ 6,296,940 |
| \$ 1,342,850 | \$ 1,374,273 | \$ 1,406,431 | \$ 1,439,341 | \$ 1,473,022 | \$ 1,507,490 | \$ 1,542,760 |
| \$ 145,555 | \$ 148,961 | \$ 152,447 | \$ 156,014 | \$ 159,665 | \$ 163,401 | \$ 167,225 |
| \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 |
| \$ 827,860 | \$ 847,232 | \$ 867,057 | \$ 887,346 | \$ 908,110 | \$ 929,360 | \$ 951,107 |
| \$ 3,156,639 | \$ 3,230,693 | \$ 3,306,480 | \$ 3,384,040 | \$ 3,463,416 | \$ 3,544,648 | \$ 3,627,780 |
| \$ - | \$ - | | | | | |
| \$ 3,156,639 | \$ 3,230,693 | \$ 3,306,480 | \$ 3,384,040 | \$ 3,463,416 | \$ 3,544,648 | \$ 3,627,780 |
| 1,104,824 | 1,130,743 | 1,157,268 | 1,184,414 | 1,212,195 | 1,240,627 | 1,269,720 |
| \$ 2,051,815 | \$ 2,099,950 | \$ 2,149,212 | \$ 2,199,626 | \$ 2,251,220 | \$ 2,304,021 | \$ 2,358,050 |
| \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 | \$ 8,064 |
| \$ 2,059,880 | \$ 2,108,015 | \$ 2,157,276 | \$ 2,207,691 | \$ 2,259,285 | \$ 2,312,086 | \$ 2,366,120 |
| \$ 2,059,880 | \$ 2,108,015 | \$ 2,157,276 | \$ 2,207,691 | \$ 2,259,285 | \$ 2,312,086 | \$ 2,366,120 |

Capital estimate parts 1 and 2

| | | | | STAFFING 3 SHIFTS |
|---------------------------------|---------------------|--------------------|------------------------------|----------------------|
| 1. SIZE REDUCTION/DRYING | | | | |
| | 6 MTPH | | | |
| LIFT TRUCK | \$40,000 | | | 3 |
| TUBGRINDER | \$30,000 | 100 | | 3 |
| SCREW CONVEYOR | \$10,000 | 10 | | |
| HAMMER MILL | \$160,000 | 200 | | |
| DUST COLL/VALVE | \$20,000 | 10 | | |
| BUCKET ELEVATOR | \$15,000 | 10 | | |
| SURGE HOPPER | \$5,000 | | | |
| METERING SCREW | \$10,000 | 10 | | |
| ROTARY DRYER | \$750,000 | | | 3 |
| BIOMASS BURNER | \$85,000 | | | |
| BUCKET ELEVATOR | \$15,000 | 10 | | |
| SUBTOTAL EQUIPMENT | \$1,140,000 | 350 | | 9 |
| INSTALLATION x2.25 | \$2,585,000 | | | |
| TOTAL CONSTRUCTION | \$3,705,000 | | | |
| ENGINEERING/ADMIN 20% | \$741,000 | | | |
| CONTINGENCY 18% | \$800,280 | | | |
| TOTAL UNIT OP COST | \$5,246,280 | | | |
| BURNER SIZE BTU/HR | 13,230 | | | |
| MOISTURE IN | 50% | | | |
| MOISTURE OUT | 10% | | | |
| PELLETING/BAGGING | | | | |
| | 6 MTPH | | | |
| TRACTOR/BUCKET | \$20,000 | | | 3 |
| METERING HOPPER/SCREW | \$15,000 | 10 | | |
| PELLET MILL | \$600,000 | 800 | | 3 |
| DUST COLLECTOR | \$20,000 | 10 | | |
| SCREW CONVEYOR | \$10,000 | 10 | | |
| SURGE HOPPER | \$5,000 | | | |
| SCREW CONVEYOR | \$10,000 | 10 | | |
| BAGGING SYSTEM | \$30,000 | 30 | | 3 |
| LIFT TRUCK | \$40,000 | | | 3 |
| SUBTOTAL EQUIPMENT | \$750,000 | 870 | | 12 |
| INSTALLATION x2.25 | \$1,687,500 | | | |
| TOTAL CONSTRUCTION | \$2,437,500 | | | |
| ENGINEERING/ADMIN 20% | \$487,500 | | | |
| CONTINGENCY 18% | \$526,500 | | | |
| TOTAL UNIT OP COST | \$3,451,500 | | | |
| 2. BULK STORAGE/LOADOUT | | | | |
| | 6 MTPH | | | |
| LOADING HOPPER/SCREW | 21,000 | 10 | | |
| DISTRIBUTION SCREW | 20,000 | 5 | | |
| 3 SLIDE GATES | 9,000 | | | |
| 3 HOPPER TANKS | 75,000 | | | |
| 3 SLIDE DIST GATES | 9,000 | | | |
| LOADOUT SCREW CONVEYOR | 21,000 | 10 | | |
| LOADOUT PAD | 24,000 | | | |
| SCALE | \$10,000 | | | |
| SUBTOTAL EQUIPMENT | \$189,000 | 25 | | 0 |
| INSTALLATION x2.0 | \$378,000 | | | |
| TOTAL CONSTRUCTION | \$567,000 | | | |
| ENGINEERING/ADMIN 20% | \$113,400 | | | |
| CONTINGENCY 18% | \$122,472 | | | |
| TOTAL UNIT OP COST | \$802,872 | | | |
| SQ FEET | 20,000 | | | |
| COST/SQ FT | \$75 | | | |
| BUILDING COST | \$1,500,000 | | | |
| INFRA STRUCTURE \$/SQ FT | \$25 | | | |
| INFRASTRUCTURE COST | \$500,000 | | | |
| SUBTOTAL BUILDING COST | \$2,000,000 | | | |
| ENGINEERING/ADMIN 10% | \$200,000 | | | |
| CONTINGENCY 18% | \$396,000 | | | |
| TOTAL BUILDING COST | \$2,596,000 | | | |
| TOTAL PROJECT | COST | +30% HP | STAFFING 3 SHIFTS | |
| SIZE REDUCTION/DRYING | \$5,246,280 | 455 | 9 | |
| PELLETING/BAGGING | \$3,451,500 | 1,131 | 12 | |
| BULK STORAGE/LOADOUT | \$802,872 | 33 | | |
| BUILDING | \$2,596,000 | 200 | 10 | |
| | \$12,096,652 | 1,819 | 31 | |
| KW | | 1,356 | | |

Capital estimate part 2

| <u>BULK STORAGE/LOADOUT</u> | 6 MTPH | STAFFING 3 SHIFTS | |
|------------------------------------|---------------------|------------------------------|------------------------------|
| LOADING HOPPER/SCREW | 21,000 | 10 | |
| DISTRIBUTION SCREW | 20,000 | 5 | |
| 3 SLIDE GATES | 9,000 | | |
| 3 HOPPER TANKS | 75,000 | | |
| 3 SLIDE DIST GATES | 9,000 | | |
| LOADOUT SCREW CONVEYOR | 21,000 | 10 | |
| LOADOUT PAD | 24,000 | | |
| SCALE | \$10,000 | | |
| SUBTOTAL EQUIPMENT | \$189,000 | 25 | 0 |
| INSTALLATION x2.0 | \$378,000 | | |
| TOTAL CONSTRUCTION | \$567,000 | | |
| ENGINEERING/ADMIN 20% | \$113,400 | | |
| CONTINGENCY 18% | \$122,472 | | |
| TOTAL UNIT OP COST | \$802,872 | | |
| | | | |
| SQ FEET | 20,000 | | |
| COST/SQ FT | \$75 | | |
| BUILDING COST | \$1,500,000 | | |
| INFRA STRUCTURE \$/SQ FT | \$25 | | |
| INFRASTRUCTURE COST | \$500,000 | | |
| SUBTOTAL BUILDING COST | \$2,000,000 | | |
| ENGINEERING/ADMIN 10% | \$200,000 | | |
| CONTINGENCY 18% | \$396,000 | | |
| TOTAL BUILDING COST | \$2,596,000 | | |
| | | | |
| <u>TOTAL PROJECT</u> | COST | +30% HP | STAFFING 3 SHIFTS |
| SIZE REDUCTION/DRYING | \$5,246,280 | 455 | 9 |
| PELLETING/BAGGING | \$3,451,500 | 1,131 | 12 |
| <u>BULK STORAGE/LOADOUT</u> | \$802,872 | 33 | |
| BUILDING | \$2,596,000 | 200 | 10 |
| | \$12,096,652 | 1,819 | 31 |
| KW | | 1,356 | |