WBS # **CID#**

Final Technical Report

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Project Title: Native Grass Utilization Project: Fuel Feedstocks
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Recipient: Great Plains Institute for Sustainable Development
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University of Minnesota – Morris
University of North Dakota – EERC
University of Minnesota – Humphrey Institute

Cost-Sharing Partners: South Dakota State University
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DOE Analysis: [This item to be filled out by DOE Project Officer or Project Monitor]
Progress in Past Quarter:

Executive Summary:

The world has changed dramatically since the start of this contract. We initiated this research to identify more sustainable opportunities for producing liquid fuels from plant material that also provide return to landowners and farmers in the more arid regions of the Midwest (western Minnesota and the Dakotas). Since that time no-till corn has moved corn production substantially west and corn ethanol has been expanding at an unprecedented rate. Meanwhile high gasoline prices and the search for fuel alternatives have focused the nation's attention on biofuels development – the limitations to corn-based ethanol, impacts on food prices, energy balance of corn-ethanol and the implications of corn expansion on conservation lands and wildlife.

The following report contributes to our knowledge of how to economically produce wildlife-friendly grass mixtures for future fuel feedstocks in the northern plains. It investigates northern-adapted cultivars; management and harvest regimes that are good for yields, soils and wildlife; comparative analysis of monocultures and simple mixtures of native grasses; economic implications of growing grasses for fuel feedstocks in specific locations in the northern plains; and conversion options for turning the grasses into useful chemicals and fuels. The core results of this study suggest the following:

- Native grasses, even simple grass mixtures, can be produced profitably in the northern plains as far west as the 100th meridian with yields ranging from 2 to 6 tons per acre.
- Northern adapted cultivars may yield less in good years, but have much greater long-term sustainable yield potential than higher-yielding southern varieties.
- Grasses require very little inputs and stop economically responding to N applications above 56kg/hectare.
- Harvesting after a killing frost may reduce the yield available in that given year but will increase overall yields averaged throughout multiple years.
- Harvesting after a killing frost or even in early spring reduces the level of ash and undesirable molecules like K which cause adverse reactions in pyrolysis processing. Grasses can be managed for biomass harvest and maintain or improve overall soil-health and carbon sequestration benefits of idled grassland
- The carbon sequestration activity of the grasses seems to follow the above ground health of the biomass. In other words plots where the above ground biomass is regularly removed can continue to sequester carbon at the rate of 2 tons/acre/year if the stand health is strong and yielding significant amounts of biomass.
- Managing grasses for feedstock quality in a biomass system requires some of the same management strategies as managing for wildlife benefit. We believe that biomass development can be done in such a way that also maximizes or improves upon conservation and other environmental goals (in some cases even when compared to idled land).
- Switchgrass and big bluestem work well together in simple mixture plots where big bluestem fills in around the switchgrass which alone grows in bunches and leaves patches of bare soil open and susceptible to erosion.
- Longer-term studies in the northern plains may also find that every other year harvest schemes produce as much biomass averaged over the years as annual harvests

- Grasses can be grown for between $23 and $54/ton in the northern plains at production rates between 3 and 5 tons/acre.
- Land costs, yields, and harvest frequency are the largest determining factors in the farm scale economics. Without any land rent offset or incentive for production, and with annual harvesting, grass production is likely to be around $35/ton in the northern plains (farm gate).
- Average transportation costs range from $3 to $10/ton delivered to the plant gate. Average distance from the plant is the biggest factor - $3/ton at 10 miles, $10/ton at 50 miles.
- There is a substantial penalty paid on a per unit of energy produced basis when one converts grasses to bio-oil, but the bio-oil can then compete in higher priced fuel markets whereas grasses alone compete directly with relatively cheap coal.
- Bio oil or modified bio-oil (without the HA or other chemical fraction) is a suitable fuel for boiler and combustion turbines that would otherwise use residual fuel oil or number 2 diesel.
- Ensyn has already commercialized the use of HA in smokey flavorants for the food industry but that market is rather small. HA, however, is also found to be a suitable replacement for the much larger US market for ethanolamines and ethalyne oxides that are used as dispersants.
- Unless crude oil prices rise, the highest and best use of grass based bio-oil is primarily as a direct fuel. As prices rise, HA, phenol and other chemical fractions may become more attractive
- Although we were able to create available glucose from the AHG fraction in the bio-oil it proved recalcitrant to fermentation by yeast. Although fermentation results were much more positive with wood based bio-oil sugars, ethanol does not appear to be a likely product from grass based bio-oil.
- A package of policy recommendations has been developed with roughly 75 key stakeholders from throughout the region that would support the transition to greater development of advanced biofuels and products in the region, as well as a strong role for native grass agriculture to support those industries.

Please see: *Roots of Change: Home Grown Energy: The Potential for Fuels, Chemicals and Power from Prairie Grass* and the accompanying website www.nativegrassenergy.org.

Comparison of Actual Accomplishments with Goals/Objectives of the Project:

The five major goals of the project as stated in the original Statement of Work are the following:

1. **To help coordinate regional research on biomass to liquid fuels production and provide overall project management.**
    a. Coordinating research between the agronomists, chemical engineers, economists and policy analysts proved to be one of the more interesting features of this project. While we facilitated the project to completion, we learned a great deal about interventions in the plant's lifecycle that could make them better suited for fuel production or wildlife and other revenue generating opportunities.
2. **To compare and characterize liquid fuels biomass production potential of switchgrass monocultures to native warm-season grass mixtures from western Minnesota to central North and South Dakota; and to identify most environmentally sustainable methods of production.**
    a. We successfully compared switchgrass monocultures to simple polycultures (2 and 3-way mixtures of big bluestem, switchgrass and indiangrass). While the switchgrass monocultures out-performed the mixtures in yield across the board, mixtures of big bluestem and switchgrass produced nearly as well. We also evaluated the impacts of the production system and harvesting on soils and wildlife. All of these results are detailed below in this report.
3. **To evaluate a fast-pyrolysis-based biorefinery concept for production of bio-fuels and chemicals from grasses indigenous to the Northern Plains.**
    a. We conducted three test runs of a fast-pyrolysis on a variety of grasses. After a very low-yielding first run, we made some changes to the feedstock (late harvest) to reduce the potassium content and ensured that the bio-oil product was cooled faster. This improved bio-oil yields substantially. While chemical product fractionation continues to look promising for HA and other chemicals, it proved very difficult to ferment the 6-carbon sugars from the bio-oil.
4. **To identify the region in the Northern Plains most ripe for profitable production of native grasses for use in cellulosic liquid fuels conversion.**
    a. Our research suggests that native grasses can be profitably grown for a bio-fuel feedstock up to the 100^{th} meridian or roughly west to the middle of the Dakotas. This depends on a variety of factors including yields, cost of land, harvest scheme and policy instruments that might help support the production of native grasses (all described in the economic analysis component below). In addition the research team outlined suggestions for best use of bio-oil in the near-term (the production of ethanol specifically was not among them in this case).
5. **To utilize the proposed research as a model for building consensus around policy and project measures that would enhance biomass – liquid fuels in particular – development in the region.**
    a. A comprehensive policy slate, vetted by well over 50 regional stakeholders, is attached to this report.

Summarized Project Activities/Report for Entire Contract Period

Objective 1: Project Management

General Management: GPI's core responsibilities under project management were to ensure that the reporting, financials and scheduled delivery of outputs for the project were in order. GPI also managed overall project direction and regular communication between project partners so as to cross fertilize ideas between grass production and management, processing and economic analysis.

The first year's work was dedicated to setting up working relationships, contracts, invoicing routines, partner agreements, cost-share requirements, timelines and overarching work schedules. After a change of leadership at the University of Minnesota's Humphrey Institute of Public Affairs, GPI staff negotiated new terms on which the U of M would play a role in the economic analysis components of the project. Eventually Vern Ruttan volunteered to lead a team of graduate students to determine the farm scale economics of a variety of switchgrass and mixed grass production scenarios in the region. Ethanol industry expert Doug Tiffany also joined the team to help with the processing economics based on the pyrolysis approach outlined by the project team.

Later GPI staff worked to convene regular meetings of the project team to identify progress, opportunities and areas of concern with each respective component of the research. This included regular conference calls and site visits. In person meetings proved to be vital to all aspects of the project as it was only in those meetings that the relationships between agronomy and harvest management and the processing of the biomass feedstock were discussed in detail.

The project team, for example, traveled to Ottawa to meet with Ensyn staff and engineers and tour the newly constructed bio-oil plant. We were able to see first-hand the commercial and lab-scale equipment as well as the primary end-product platforms.

The delegation included partner researchers from all of the major project partner institutions and was a highly productive visit. GPI staff spent considerable time with EERC, Ensyn and SDSU partners trying to determine reasons for the low initial yields of biomass with the first run. Two key problems were identified in this meeting as well as possible solutions. The first was that Ensyn used a remote water quench in the lab scale unit whereas they regularly used a direct (cold product) quench in their commercial unit. The latter offers a much more efficient quench whereas project partners hypothesized that the remote quench cooled more slowly allowing for further and undesirable breakdown of the molecules.

Secondly we noted that the ash (particularly K) concentrations were significantly higher than that of the wood projects Ensyn's technology had been built upon. Potassium is known to cause undesirable catalytic reactions in the reaction chamber so partners spent considerable time discussing the possibilities to reduce K concentrations in the feedstock prior to entering the reaction chamber. The results of such discussions highlighted for us just how important regular communication between the chemical engineers and the agronomists was. Many aspects of harvest management were thought to have bearing on K concentrations in the harvested feedstock. Time of harvest had dramatic impact on the K concentrations in post-frost harvests were lower and were even lower yet in those grasses left standing over winter and into the early spring (apparently additional moisture and thaw allowed leaching of additional minerals.

Modifications were made to allow for a faster (direct) quench on the processing side. Additionally SDSU promised to deliver later year harvested grasses in the hopes that they would have significantly reduced ash and potassium fractions. This did, in fact, turn out to be the case and the second and third bio-oil processing runs produced substantially improved yields.

Staffing Changes:
Tragically the EERC staff person with expertise in anhydroglucose fermentation committed suicide during the tenure of this project, leaving EERC unable to do the fermentation testing of their bio-oil samples. After it became clear that EERC would not be able to complete this portion of the work-plan, GPI worked with the University of Minnesota's Mark Von Keitz to analyze the fermentability of the bio-oil sugars.

Regular DOE Stage Gate and Other Reviews:

- November 2004: Minneapolis Review by Andy Trenka
- 2005: Washington DC: USDA/DOE Feedstock Stage Gate Review
- 2005: Washington DC: USDA/DOE Processing Stage Gate Review

Delivery of Results and Final Reporting Requirements: GPI worked with partner organizations to finalize reports and outreach materials based on this research.

Additional Funding: In addition to the cost-share funding provided by all project partners, GPI worked to raise additional funding to dovetail or directly match Department of Energy Funding. On the policy side, the Great Plains Institute secured Energy Foundation funding to expand on policy research and recommendations developed as part this project. The Energy Foundation recently decided to expand funding for 2007 to allow GPI to build on their DOE-funded research with the creation of a Midwestern network of 12 State Departments of Agriculture, Land Grant Experiment Stations, and Extension with a funding match provided by all of the member institutions.

GPI also worked with project partners on several other competitive proposals that would extend the course of this study (knowing longer-term research was needed) but was unsuccessful to date. Attempts included proposals responding to at least two USDA/DOE requests for proposals, the Xcel Renewable Development Fund and the Minnesota Legislative Commission on Natural Resources.

Objective 2: Agronomic Best Management Practices and Fuel Feedstock Characterization

SUMMARY:

Biomass Production- best management practices and cultivars: SDSU compared biomass production potential of switchgrass monocultures to native warm season grass mixtures (switchgrass, indiangrass, and big bluestem) across an east-west and north-south environmental gradient. The study included determining the best management practices, best cultivars for the northern plains, region-specific production potential, and optimal planting and harvesting dates. Establishment time, stand density, and production yields were the criteria used to identify the best management practices. Several key findings include:

1. Big bluestem has an ability to fill areas perhaps underutilized by other species.
2. Switchgrass monocultures produced the greatest biomass followed by mixtures containing switchgrass.
3. Indiangrass, alone or in mixtures, tended to produce the lowest biomass.
4. The highest biomass yield for four locations ranged from 5.0 to 12.4 Mg ha^{-1}.
5. With average yields of 3-10 Mg ha^{-1} across an environmental gradient in the northern Great Plains, dedicated biomass crops such as switchgrass and big bluestem may be a viable option in the region.
6. This research has demonstrated that while initial results suggest slight yield reductions, there are also important benefits of grass mixtures in biomass production. Combining big bluestem with switchgrass, while resulting in slightly lower total yields, helps to improve soil cover and provides a more diverse habitat for wildlife. Long-term research is required to better understand the relative balance and persistence of individual species within a mixture over time.

Suitable Cultivars for the Northern Plains: The project team worked to determine switchgrass cultivars most suitable for sustainable biomass production in northeastern South Dakota. During early July 1999, biomass trials composed of eight cultivars were planted in to conventionally tilled seedbeds at Bristol and South Shore in SD.

1. Identified three cultivars of switchgrass (i.e., Dacotah, Forestburg, and Sunburst) that are highly suitable for long-term sustainable production of biomass in the eastern Dakotas.
2. Determined that high-biomass yield-potential cultivars with southern origins (e.g., Cave-In-Rock, Shawnee) may produce high yields in good years or early in the stand's life but eventually suffer severe decline in stand and productivity.
3. Harvesting after a killing frost helps insure stand persistence and sustainable biomass production for adapted cultivars, but does not protect non-adapted cultivars, such as Cave-In-Rock, from winter injury and stand deterioration.
4. Detected a range exceeding 3.5 Mg ha^{-1} between existing high- and low-yielding families averaged across 4 production years.
5. Development of new cultivars from within-adapted-cultivar selection could increase sustainable biomass production in the eastern Dakotas by up to 30% and income by $150 per hectare compared with presently available adapted cultivars. This is based on the difference between average annual biomass production of the selected families and that of the source population mean and a farm-gate price of $55 Mg^{-1}.

Interaction of Precipitation, Harvest and Yield: The objectives of this task were to determine patterns of biomass accumulation and optimum harvest times for an early maturing cultivar, Dacotah and a later maturing cultivar, Cave-In-Rock in central South Dakota, and if variation in patterns of biomass accumulation were associated with variation in patterns of precipitation.

1. Determined that switchgrass can be grown for bioenergy feedstock production 250 km west of the tallgrass prairie region in temperate steppe in central South Dakota, but biomass yields may vary more than 5-fold between consecutive years due to variation in pattern and amount of precipitation.
2. Concluded that variation in peak standing crop in response to variation in precipitation during July-September will determine the optimal harvest time from August to September.
3. Determined that biomass production from over-wintered stands harvested in March was 85% to 99% of biomass production of stands harvested at the end of the previous growing season, suggesting stands could be stockpiled over winter for conservation (e.g., snow catch) and wildlife habitat without significant loss in biomass
4. Determined that biomass production during a drought cycle will be a function of the amount of precipitation received during April and May of the current growing season.
5. Harvesting early-maturing cultivars of switchgrass during August in central South Dakota will result in up to 40% more biomass compared with harvesting after a killing frost (recommended for sustainable biomass production of adapted cultivars in northeastern South Dakota).
6. Switchgrass will produce appreciable amounts of biomass (at least 2 Mg ha^{-1}) without inputs during drought years in central South Dakota when annual crops fail.
7. Switchgrass is a highly flexible crop (can be utilized for biomass, forage, or seed) that will protect the soil from erosion, maintain or increase soil carbon, reduce pesticide and fertilizer inputs, and provide wildlife habitat in a cropping sequence in central South Dakota.

Biomass Production and the Conservation Reserve Program Lands: SDSU evaluated various agronomic practices on marginal farmland and grassland when used for biomass production. The team evaluated the value of various types of CRP land for potential biomass production and identified management practices that optimize biomass production on CRP land. Three monoculture switchgrass sites (Moody Co., Gregory Co., and Marshall Co.) and two warm-season grasses mixture sites (Gregory Co.) were selected in South Dakota. Biomass was harvested from 2001 through 2004. The effects of N fertilization, harvest timing, and harvest frequency were determined on biomass yield.

1. Switchgrass CRP lands have potential for biomass production with appropriate agronomic practices in the northern Great Plains.
    - Optimum N application rate was 56 kg N ha^{-1} (~ 50 Ib N $acre^{-1}$).
    - Switchgrass produced the greatest biomass averaged across multiple years when harvested every year after killing frost.
2. Proper harvest management for switchgrass is critical for long-term sustainable production.
    - Annual harvests after a killing frost in the fall has not decreased stand persistence over 4 yr. and is the best option for long-term sustainable biomass production.

- Alternate year harvests may work in certain situations where an early summer harvest is desired.

3. Because ash content was lower, biomass quality as a fuel feedstock increased when switchgrass was harvested after a killing frost.

Soil Quality and Carbon Sequestration (newly established grasses): SDSU evaluated changes in overall soil health and carbon storage on marginal farmland and grassland when used for biomass production. Shifts in soil quality and soil carbon storage due to biomass production practices were determined from differences in the measurement parameters before and after the agronomic treatments

1. Soil organic carbon storage was not significantly changed within the three years of biomass production studied using perennial grasses.
2. Soil structure can be quickly improved with grass establishment.
3. Two years of biomass removal reduced the level of nitrogen in the soil profile, therefore additional nitrogen may be needed for biomass production.
4. Establishment of perennial grass land for biomass production
   - Has the potential to increase soil C sequestration over time.
   - Improves soil quality through reduced tillage and root activity of perennial grasses
5. Suggestion for the future research:
   The major source of carbon sequestration is root biomass of perennial grass in land managed for biomass production. However, root biomass production of new or young perennial grass may not contribute to carbon storage in the first short period. Therefore, to evaluate carbon sequestration of perennial grass in the short-term, quantification of root biomass will be necessary in future research.

Soil Quality and Carbon Sequestration (mature grasses): This study was conducted on land enrolled in CRP and on land similar to CRP to evaluate the effects of various agronomic practices for biomass production on changes in soil quality and carbon storage.
Three monoculture switchgrass sites (Moody Co, Gregory Co, and Marshall Co, SD) and two warm-season grasses mixture sites (Gregory Co, SD) were selected in South Dakota.
Baseline soil samples were collected to depth of 120 cm from each research site before the agronomic treatments were initiated in 2001. Post-treatment soil samples were analyzed for soil pH, field moisture content, bulk density, total C and N, inorganic C, SOC, and aggregate stability. Changes in soil quality and soil carbon storage, caused by biomass production practices, were determined from differences in the measurement parameters before and after the agronomic treatments.

1. After four years biomass production changes in soil carbon in switchgrass CPR land varied with locations.
   - Soil carbon increased in the site (Moody County), which had relatively high biomass yield and stand persistence. The carbon sequestration rate was approximately 4 Mg C ha^{-1} yr^{-1}.
   - Soil carbon decreased in sites (Gregory and Marshall Counties), which had lower biomass yield and poor stand persistence.
   - These variations may be related to switchgrass persistence and response to growing environment such as precipitation and temperature.
2. CRP land managed for biomass production has the potential for carbon sequestration when biomass production is maximized and stand persistence is maintained.

- To ensure biomass production, a nitrogen application of 56 kg N ha^{-1} is necessary.
- Switchgrass and warm-season grasses strongly responded to harvest management and precipitation. Summer harvest severely reduced stand persistence and we believe this affected the above and under ground biomass production.
- Harvesting after a killing frost is recommended for stand persistence.

3. Soil quality can be maintained with proper management when CRP lands are used for biomass production.
4. Development of appropriate agronomic management practices for biomass production in CRP lands will:
   - Increase biomass production and maintain stand persistence
   - Maintain soil quality from previous CRP management
   - Increase or maintain soil carbon storage

Avian diversity: SDSU evaluated and compared the effect of switchgrass monocultures and warm-season grass mixtures on avian biodiversity or species richness. We evaluated the relationship between plant species diversity and avian community structure in 5 grassland types (switchgrass and intermediate wheatgrass monocultures, warm and cool season polycultures, and native sod prairies). Birds and vegetation were surveyed on 86 grassland sites in eastern South Dakota and western Minnesota, USA, during the breeding seasons, 2002-2004. Bird species occurrence and density were calculated from 2-ha fixed-width belt transect surveys. Plant species diversity, height-density readings, litter depth, and grass, forb and woody vegetation heights were recorded to evaluate vegetative structure.

1. Litter depths and mean tallest grass heights were higher in polycultures than in monoculture stands.
2. Grasslands with greater plant diversity had higher avian richness and occurrence and/or density of several species.
3. We recommend that a high diversity of plant species should be incorporated into sown grassland mixtures to benefit the majority of grassland birds.
4. In this study, grasses sown to native warm season mixes provided more habitat for grassland birds than either monotypes or cool season mixes.
5. Harvesting grasslands resulted in decreased height density and litter. As a result, Sedge Wrens and Clay-colored Sparrows were not present in mowed grasslands. Red-winged Blackbird and Common Yellowthroat densities were significantly higher in mowed grasslands. Individual species densities for all other species were not significantly different between mowed and unmowed grasslands. However, low sample size may have contributed to the nonsignificance. Overall grassland bird species richness did not differ between mowed and unmowed grasslands.
6. To attract the most grassland bird species to a specific grassland, recommendations would include mowing half and leaving the rest idle. Mowing should not occur during the breeding season, April 15-August 1.
7. Recommendation for future studies: Nesting studies comparing different mowing practices (i.e., whole field, ½ field, every other year, etc.) and polycultures and monocultures would further elucidate the quality of grassland bird habitat present in grasslands used for biomass.

For More Detail: See SDSU final report from early reporting period (or on www.nativegrassenergy.org).

Objective 3: Fuel Processing

Summary: EERC and Ensyn Renewables evaluated three prairie grass materials as fast-pyrolysis biorefinery (FPB) feedstocks using the laboratory-scale Ensyn Rapid Thermal Process™ (RTP) system (a system which had been developed for woody biomass). The project goal was to investigate utilization of the Ensyn fast-pyrolysis process for conversion of prairie grass to bio-oil containing commercially significant amounts of anhydrosugars (AHS) and hydroxyacetaldehyde (HA), which have value as a fermentation process feedstock and chemical intermediate, respectively.

The initial pyrolysis feedstock was a mixed-grass sample harvested near Morris, Minnesota, in November. The sample had a potassium content of about 1.3%. Because of its high catalytic activity, high levels of potassium in biomass pyrolysis feedstocks is generally regarded as undesirable because of an increased potential for pyrolysis-zone potassium-catalyzed degradation of AHS, HA, and other bio-oil constituents. Two pyrolysis tests conducted with the Morris sample gave less than 2% yields of anhydroglucose (AHG) and HA. AHG is the major constituent of the bio-oil-contained 6-carbon AHS that can be hydrolyzed to glucose and other fermentable sugars via an EERC-developed solid acid-catalyzed process. Based on HA and AHG yields from prior Ensyn processing of wood feedstocks with negligible potassium content, it appeared that the low HA and AHG yields from the Morris grass may have been a result of high potassium content.

At a meeting with both the agronomists and chemical engineers, we discussed possible options for reducing the ash and potassium content in the feedstock. We knew that ash and protein levels were reduced in late fall harvests compared with those harvested at anthesis and assumed that even later year harvests may bring down levels even further. At this point we delayed further processing until a spring sample could be collected.

In addition the lab scale testing unit was using a non-surface quench whereas the commercial units quenched directly with cold product. The project team thought this difference may be responsible for additional degredation in the reaction chamber and decided to use a surface water quench in later trials.

South Dakota-grown, April-harvested switchgrass and big bluestem grass samples were evaluated as FPB feedstocks. Overall potassium content in the April-harvested switchgrass and big bluestem materials was 0.22% and 0.15%, respectively, several times reduced from the late fall harvest. In processing both spring-harvested grasses, a pyrolysis temperature of 500°–510°C was utilized, with the objective of maximizing both overall bio-oil yield and HA and AHS yields. Bio-oil yields from the switchgrass and big bluestem feedstocks were 68% and 71%, respectively. Analysis of the switchgrass bio-oil gave HA and AHG concentrations of 8% and 5%, respectively, which translated to overall moisture- and ash-free (MAF) yields of 5% and 4%. Analysis of the big bluestem bio-oil gave surprisingly positive HA and AHG concentrations of 13% and 9%, respectively, which translated to overall MAF yields of 9% and 6%. Based on Ensyn experience in laboratory- and commercial-scale process optimization with hardwood feedstocks, it is likely that HA and AHG yields from grasses could be increased significantly with further optimization of process design and pyrolysis and product condensation conditions.

Water-soluble fractions of the bio-oils generated from the April-harvested grasses were vacuum-distilled to remove HA and other potential fermentation-inhibiting species, and the distillation residuals were subjected to an EERC-developed solid acid-catalyzed hydrolysis process for conversion of AHS to glucose and other yeast-fermentable 6-carbon sugars. Although 99% AHS-to-glucose conversions were achieved, yeast growth levels were low, likely due to the presence of catechols and other yeast-inhibiting species. Several solvent and sorbent extraction procedures were employed to effect inhibitor removal, but none of the limited number of experimental procedures tested was successful in generating a yeast-friendly fermentation feedstock. Further analysis of the AHS fraction is required to enable definitive identification of the fermentation-inhibiting species.

Although attempts to sustain yeast growth in grass-derived bio-oil hydrolyzates were unsuccessful, success was achieved in fermenting a hydrolyzate from a wood-derived bio-oil generated at a commercial Ensyn pyrolysis plant. The successful achievement of fermentation is significant because it supports the concept of an FPB with ethanol as a major product. More research is required to improve the fermentability of wood-derived bio-oil hydrolyzate and to establish whether its fermentability is due to the chemistry of wood-versus-grass pyrolysis feedstock, the pyrolysis process conditions existent in the commercial- versus lab-scale reactor system, or a combination of these two variables.

For More Detail: See EERC final report from earlier reporting period (or on www.nativegrassenergy.org)

Objective 4: Economic Analysis

Summary: The Great Plains Institute partnered with the Department of Applied Economics and the Initiative for Renewable Energy and the Environment at the University of Minnesota to analyze both the farm scale economics and overall process economics of producing bio-oil from native grasses. This research integrates findings from all aspects of this research, including best management practices, feedstock characterization, and fuel processing.

Doug Tiffany and Vern Ruttan, known for their practical and academic leadership in biofuels respectively, began this work by leading a capstone graduate course based on our agronomic research. The team developed models to assess the price needed to cover the farm costs of producing grasses under a variety of different scenarios (including scenarios like a 50 percent harvest that would help accommodate wildlife driven goals); the impacts of policy tools on total costs; land needed to support a variety of plant sizes in the northern plains; and the average transportation costs associated with different scenarios.

Key Findings:

- Grasses can be produced in the northern plains where averaged yields of 3 to 5 tons per acre can be produced in the range of $23 to $54/ton at the farm gate (includes harvesting and collection costs).
- Land rents and biomass yields are the biggest determining factors in the system which requires little in the way of other inputs. That said lower yielding areas of the northern plains are competitive because land rents are so low.
- A full or partial land rent offset payment, modeled after the Conservation Reserve Program, could bring the costs per ton down as low as $23/ton at the farm gate.
- Average transportation costs range from $3 to $10/ton delivered to the plant gate. Average distance from the plant is the biggest factor - $3/ton at 10 miles, $10/ton at 50 miles.
- It is possible to obtain enough grass biomass from existing CRP lands within a 50 mile radius to supply a large plant in certain parts of the northern plains. In other words it should be possible to produce between 400,000 and 800,000 tons of grass biomass from existing grasslands within a 50 mile radius of a given plant. The lower amount assumes only 2 tons/acre and the upper 4 tons/acre on existing CRP plots. A 60 million gallon a year cellulosic ethanol plant would require about 800,000/tons of grass a year.
- Future carbon payments, revenue from wildlife habitat and possible sale of seed will only increase the landowner profits. Grasses are currently recognized as sequestering 0.75/tons per acre on the Chicago Climate Exchange where our research suggested that well-managed grasses could easily sequester well over double that amount on an annual basis even with regular removal of the above-ground biomass. Today, using the Chicago Climate Exchange assumption, this would only amount to a couple dollars/acre given the low carbon prices in a voluntary market but may well be a more significant revenue stream in the near future.

Later Doug Tiffany developed an integrated bio-refinery model. This spreadsheet-based tool expanded on previous efforts that merely model the costs of producing raw bio-oil as a liquid fuel for heating or power production. This tool considered a business model for producing anhydrosugars for ethanol processing and bulk chemicals such as hydroxyacetaldehyde (HA) and resins. The model viewed bio-oil as a chemical feedstock in addition to being a liquid fuel.

Key Findings:

- Turning switchgrass into bio-oil costs four times as much as using switchgrass directly on a per unit of energy produced basis.
- Where switchgrass alone would have to compete with coal (at roughly half the price) in a simple combustion unit, it can compete with higher priced fuels. Bio-oil is cost competitive with residual fuel oil and is considerably cheaper than Number 2 fuel oil (diesel fuel). This assumes crude oil costs of equal or above $60/barrel and biomass feedstock costs of $40/ton delivered.
- These results are without capturing value from other chemical products from the processing stream – something that is the primary income generator for currently commercial facilities.
- Potassium levels are higher in herbaceous species than woody species which can cause significant degradation of HA and AHG, the most valuable constituents of bio-oil, in the reaction chamber. This can be mitigated by early spring harvest and the processing yield increases seem to more than make up for the biomass yield losses by allowing the stand to rest in the field longer.
- Technical problems fermenting the bio-oil sugars suggest that chemical products like HA, rather than higher alcohols like ethanol, will be the near term profitable co-product.
- Ensyn currently extracts Hydroxyacetaldehyde (HA) from wood-based bio-oil and processes it into a charcoal flavorent for the food market. Tiffany and his co-authors were uncertain how wide this market is beyond current sales but thought HA could also replace ethanolamines or ethylene oxides which are used as dispersing agents. The size of this market is well over a billion pounds per year in the United States and prices range from $0.56 to $0.67 per pound.
- Phenols can also be created from the bio-oil resins and used in such things as fiberboard. Here too prices are highly correlated with crude oil prices and ranged in recent years from $0.45 to $0.68/per pound.
- Increasing crude oil prices will make chemical extractions from the bio-oil more favorable, whereas current prices suggest the bio-oil will more likely be used as a direct fuel. In either case the bio-oil or modified bio-oil (without chemicals like HA) should be a satisfactory fuel for boilers and combustion turbines for producing electricity.

Mr. Tiffany released this paper summarizing this economic analysis as a departmental paper through the Department of Applied Economics. This work has been supported by the Initiative on Renewable Energy and the Environment at the University of Minnesota, in addition to the Department of Energy Sponsorship through the Great Plains Institute.

For More Detail: See University of Minnesota Department of Applied Economics paper from early reporting period (or on www.nativegrassenergy.org).

Objective 5: Policy Options

Summary – GPI was tasked with distilling the results of research by the other project partners into policy options and strategy leading to commercialization of biorefinery models in the northern Great Plains region (particularly those that could use native grass biomass). The Great Plains Institute staff worked carefully with a variety of stakeholder groups to learn from the various elements of this research and to build consensus around biomass policies for the northern plains.

When this project was launched there was very little agreement on biomass objectives. While there were successful policy lessons in corn ethanol and soy diesel, particularly in Minnesota and Iowa, there were very few successful examples of broader biomass policy. In fact policy makers in Minnesota had been wrestling with a biomass mandate which had (at the time of this project's launch) yielded very few viable biomass projects and an inability to fill the mandate. This was, of course, focused on bio-based electricity projects that were invariably three to four times more expensive than our region's other generation options. Because of the troubled biomass policies in Minnesota, it was hard initially to get stakeholders to focus on future biomass policy packages. Perhaps this was also true in part because the push to develop affordable wind resources in the region was consuming the vast majority of human and institutional resources available for renewable energy development.

Since that time, however, a combination of outside events and several years' stewardship of the biomass conversation in the region has yielded a vastly different political environment for biomass policy than from where we began this work. Through this research project, GPI led stakeholders toward consensus agreement on state policy tools that would essentially enable the whole value chain of biomass development in the northern plains (more on this below). GPI also worked carefully with a variety of stakeholders to consider federal tools that would help encourage greater (and low risk) adoption of grass agriculture by landowners. While we did not actively promote policy implementation with legislators under this grant, we feel very confident that a variety of our stakeholders are working to implement elements of the biomass policy agenda in the upcoming legislative sessions.

The Great Plains Institute was able to dovetail its Department of Energy funding with a strategic investment from the Energy Foundation that was solely focused on policy development for advanced biofuels.

Policy analysis

GPI staff began the policy work as part of a comprehensive energy project called Powering the Plains (PTP). The goal of the initiative was to refocus the regional climate change conversation from one of net costs to the region to one of opportunities. PTP participants (see attached stakeholder list) were charged with the ambitious task of laying out a profitable path forward for the region that also mitigated the risks of climate change. The fact that this project was comprehensive and long-term in scope allowed otherwise dismissed early discussions about bio-energy development to take place.

An early (foundation funded) delegation to northern Europe and Iceland with PTP stakeholders in fall 2003 stimulated valuable new thinking on bioenergy development. The group heard from policy makers in Holland who were planning 50 years out, investing in several promising biomass technology pathways knowing some would work and others would not, and were planning for large scale importation of densified biomass to fill their goal of 30% of their energy use coming from biomass. In Denmark the group saw new ownership and operation bioenergy models where Dansk Biomass owned and operated equipment for large-scale regional local ownership projects, thereby dismissing the idea that locally owned projects must be small in scale. Participants were also impressed with use of biomass in residential heating and with the sheer scale of biomass utilization in Denmark. In combination these findings helped reinvigorate biomass policy discussions within PTP (this allowed us to maintain productive biomass policy discussions while the core research under this project got underway).

Between the work in PTP* and a work group later developed to focus exclusively on biomass policy (Biomass Working Group), roughly 70 regional stakeholders have contributed to the policy recommendations included here (see attachment: Biomass Working Group Policy Menu); an Energy Transition Roadmap should be available later this spring. The stakeholders agreeing on the set of policy objectives include investor-owned utilities, rural electric cooperatives, farm service agencies, environmental and sustainable agriculture non-profits, state government agency representatives, industry, research and academic institutions and elected officials (see attached GPI stakeholder lists).

The consensus policy recommendations based on this work and research includes everything from incentives for carbon sequestration and creating a native grass biomass supply; from state procurement of bio-based products and transportation fuels; and from research on feedstock development to storage and logistics. In short, it covers nearly the whole value chain involved in producing bio-fuels and products from farm to fuel tank. While these are described in more detail in the attached BWG State Policy Menu, the following is a summary of their consensus ideas:

1. Support demonstration and commercialization of advanced biomass technologies by:
    a. Providing capital through cost share, loan guarantees, revolving loan funds and bonds;
    b. Production and purchase incentives for bio-based energy production;
    c. Reduction of regulatory barriers through streamlining and new permitting rules and other procedures for emerging technologies; and
    d. Supporting local ownership while recognizing the role that outside investment will play in the industry.
2. Develop a perennial biomass supply through a range of incentives and programs.
3. Establish bio-based product procurement rules in each state and province of the region that are consistent across the region.
4. Implement policies that help increase the penetration of biofuels in the marketplace such as renewable fuels standards (including for cellulosic biofuels), promotion of biofuel powered vehicles, state purchasing and retail tax incentives.

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* Previous quarterly reports have also included copies of earlier PTP agreements on such things as carbon sequestration rules and guidelines as well as principles for biomass development in the region. The Biomass Policy Menu and the Biomass Roadmap Chapter represent the more current results of this work.

5. Provide technical assistance and support through state and provincial funding of front-end engineering and design studies, business planning and assistance, and expansion of technical assistance capabilities and services.
6. Help the industry overcome the difficulties with feedstock logistics by funding necessary assessments and research, using public university and state resources to provide technical assistance, providing financial incentives for the equipment to manage and harvest biomass crops, and leading energy crop pilot projects.
7. Support basic and applied research on crops and conversion technologies.
8. Expand state/provincial workforce development programs and cooperation with the private sector to ensure a new generation of trained personnel to build and operate the new bio-economy.
9. Increase public education about the bio-economy through schools, government agencies and private organizations.
10. Establish a regional entity to foster collaboration among state departments of agriculture, land grant universities and extension systems to advance bio-economy goals, policies and initiatives.
11. Facilitate the trading of carbon and water credits associated with biomass production.

The PTP biomass roadmap chapter (available on request) included most of these recommendations as part of a larger and more comprehensive energy vision for the region over the next 50 years. The PTP roadmap in its full form represents 4 years of serious debate and clear decision on the consensus recommendations. It is also a document that has been requested by the International Legislators Forum, a regional group of bi-partisan state legislators. In both cases the level of investment by stakeholder parties will be evident in the implementation phases.

Lastly GPI has worked with wildlife and conservation interests on identifying the critical components of a feedstock incentive system that would support landowner transition to perennial grasses that also enhances conservation benefits. The results of this work have provided timely background to the federal farm bill discussions.

Major Stakeholder Groups Behind the Policy Analysis

Stakeholder networks:

- **Biomass Working Group (BWG):** The Institute created and facilitated a multi-state working group of more than 50 knowledgeable stakeholders committed to the commercialization of advanced and cellulosic bio-energy technologies and the development of cellulosic biomass as a value-added product for agriculture. The BWG is a committed group of individuals from agriculture, state government, industry, environmental groups, and legislators from Iowa, Minnesota, North Dakota, South Dakota, Wisconsin;
- **The North Central Bio-economy Consortium (NCBEC):** A key recommendation from the Biomass Working Group was the creation of a regional partnership to share information, coordinate research, develop regional projects, coordinate regional policy

efforts, and work to increase the overall amount of federal funding available for bio-energy projects. Great Plains Institute staff proposed this concept, among others, to the Midwest Association of State Departments of Agriculture at their July 2006 meeting in Madison, WI. Following the agreement of that organization and months of preparation, a 12-state partnership of the MASDA Ag. Departments and the corresponding 12 Land Grant Experiment Stations, and Cooperative Extension Services was announced April 20, 2007 (See more information at www.ncbioconsortium.org)

- **Powering the Plains (PTP)** Policy recommendations from the BWG were presented to the Powering the Plains stakeholders and eventually adopted as part of their Energy Transition Roadmap – scheduled for release June 2007. This will enable the biomass policy menu to 'live on' beyond the current grant and current legislative sessions.
- **Legislators Forum:** Powering the Plains presented recommendations on cellulosic biofuels as part of a presentation on a variety of low-carbon energy options for the northern plains. The Legislators Forum issued a resolution requesting more information on cellulosic biofuels as a strategy for the transportation sector, which GPI staff are working on for a presentation to the 7th Annual Legislators Forum in Pierre, SD in May 2007.

Policy Development

While GPI works to identify common opportunities and build consensus among diverse groups on how to best advance cellulosic technologies in our region, we leave it up to the individual stakeholders in our processes to decide which policy instruments seem the best fit for their jurisdiction. In this case, stakeholders worked independently to implement some of the general policies in several states in our region. Policy efforts, of course, had varying degrees of success from state to state, and some legislative sessions are still on-going, but the efforts outlined below reflect where states in the region may be headed with regard to advanced biofuels development:

- **North Dakota:**

BWG stakeholders in North Dakota shared the BWG policy menu with members of the North Dakota Renewable Energy Partnership and the North Dakota Biomass Taskforce, and members of those groups worked to develop legislation. Governor Hoeven signed a series of energy-related bills on April 27, 2007; including the following:

  - 1515: Provides technical assistance and financial support for producers developing a cellulosic biomass feedstock supply for energy uses;
  - 1483: Authorizes the development of a preferential procurement program for bio-based products.

- **South Dakota:**

Stakeholders in South Dakota determined that the best course of action was to introduce a resolution containing many elements of an advanced biofuels agenda as a way to better educate legislators about advanced bioenergy technologies and to pave the way for future legislative action in future sessions. Senate Concurrent Resolution 8 "Establishing South Dakota's commitment to the development of the bio-economy", was introduced February 22, 2007, passed 34 to 0 in the Senate on February 23, 2007, and passed the House of Representatives 66 to 4 on February 27, 2007.

- **Minnesota:**

With help from several of the institutions participating in the Biomass Working Group, several promising policy instruments were highlighted in the 2007 legislative session. Below is a list of the initiatives recommended that reflect the policy analysis done by the biomass working group:

1. Incentives for cellulosic bioenergy on a $/mmbtu basis or in the form of grants or loan guarantees,
2. Renewal of the 20 cent/gal. producer payment applied now only to cellulosic liquid fuels,
3. Funding for technical assistance for new projects, and
4. The creation of a land rental payment program to create a supply of perennial grass biomass for energy projects.

While all four elements looked promising this session, the last was written to instruct the DNR to design and make recommendations for the development of such a program rather than implementing it at the outset.

Disseminating research results:

Key Stakeholders: The Great Plains Institute staff members have worked to integrate the results of this research into regular stakeholder working group decisions which are represented primarily in the attached documents and largely described above. The two Biomass Working Group meetings described below represent the 'summit' style meetings described in the statement of work where high level stakeholders were invited to an outcome oriented meeting.

Other Invested Parties (Conservation Interests): GPI has very deliberately given presentations and regular updates on our research findings to wildlife and conservation groups who have substantial influence in federal farm policy conservation programs. Some of our core agronomic research focused on lands currently in CRP holdings and suggest that proper management under a biomass harvest regime could maintain or improve soil and wildlife benefits of CRP. We wanted to engage the wildlife and conservation groups in this discussion and did so by reaching out to Ducks Unlimited, Pheasants Forever, The Izaak Walton League of America, The Nature Conservancy and others on a regular basis. While these groups are agreed on the benefits of native grass agriculture to their broader goals, we could not reach full agreement on whether harvest should be allowed on program land. We did reach agreement that a pilot scale program that paralleled the previous CRP pilots for bio-energy would be desirable or acceptable for grass based fuels demonstrations.

Despite making only modest progress on policy recommendations within the conservation community, our discussions helped advanced these institutions' thinking about the active role they should/could play in biofuels development. This is a constructive outcome as many had remained relatively agnostic about corn ethanol until recently as corn prices begin to severely threaten conservation lands. Rather than being wholly dismissive of biofuels development, these agencies now have an informed and positive message about biofuels development that helps conservation goals. While certain organizations were already further along this path (Pheasants Forever), GPI played a significant role in helping advance the thinking with the great plains regional offices for the other organizations.

General Audiences: GPI wrote and published a document akin to an executive summary of the research results described in this report. We also developed a website, www.nativegrassenergy.org, which houses this report alongside peer-reviewed journal articles and other background data on the research itself. The hard copy of the report is being mailed out to 500 key stakeholders in government agencies, biomass industries, wildlife and conservation organizations, policy making bodies and media institutions. The report is designed to draw interest from a wider audience, while the text gives enough detail hopefully move the policy conversation forward. This report is included in the attachments.

Other Outreach:
Meetings Focused on Research Results:

- November 28, 2006: Meeting with Ducks Unlimited Staff, Bismarck, ND
- November 20, 2006: Meeting with Western Governors Association-funded North Dakota Biomass Taskforce, North Dakota Farmers Union, Jamestown, North Dakota
- July 2006: Biomass Working Group in person meeting in Ames, IA. This meeting led to the biomass policy menu for the region representing the agreement of roughly 50 regional stakeholders interested in biomass development.
- April 24, 2006: Finding Common Ground for Conservation and Bioenergy – Organized by Great Plains Institute and Windward Consulting – Farmers Union National Headquarters, Washington DC
- 2005-2006: Regular Biomass Working Group Conference Calls to develop key policy ideas for consensus agreement within working group
- August 4th and 5th 2005: Biomass Working Group Meeting hosted by Iowa Farm Bureau in Des Moines, IA. Presentations by Vance Owens, Dokyoung Lee and Brendan Jordan focused discussion on future policy development on core elements of this research.
- December 2004: Project team went on a fact finding delegation to Ottawa and visited with both Iogen and Ensyn.
- April 22, 2004: Brookings, SD. Powering the Plains educational session devoted to the intermediate results of this research.

SDSU Presentions

1. D.K. Lee. 2004. Soil respiration and carbon sequestration in switchgrass land managed for biomass production. Mankato State University, January, 2004. Mankato, MN
2. A. Boe, D.K. Lee, V. Owens, D. Beck, R.M. Zamy, D. Gustafson,Y. Jin, and J. Roitsch. 2003. Genetic, environmental, and management effects on growth and persistence of switchgrass in South Dakota. Soil and Water Conservation Society North Dakota Chapter Annual Meeting, December 2003. Bismarck, ND.
3. V.N. Owens, V. Olson, and D.K. Lee. 2003. Switchgrass harvest management in South Dakota. Soil and Water Conservation Society North Dakota Chapter Annual Meeting, December 2003. Bismarck, ND.
4. D.K. Lee, J.J. Doolittle, V. Owens, and A. Boe. 2003. Carbon sequestration and soil respiration in switchgrass land managed for biomass production. Soil and Water Conservation Society North Dakota Chapter Annual Meeting, December 2003. Bismarck, ND.
5. D.K. Lee. 2003. Soil respiration in switchgrass land managed for biomass production. South Dakota Professional Soil Scientist Association Annual Meeting, March 2003. Huron, SD.
6. A. Boe and D.K. Lee. 2004. Patterns of biomass accumulation in switchgrass under drought stress. ASA Annual Meeting, October 30-November 3, 2004. Seattle, WA.
7. D.K. Lee, V.N. Owens, V.R. Mulkey. Switchgrass yield, quality, and persistence in a bioenergy management system. ASA Annual Meeting, October 31- November 4, 2004. Seattle, WA.
8. J.J. Doolittle and D.K. Lee. 2004. Carbon dioxide flux and microbial activity in grassland after manure and ammonium nitrate application. ASA Annual Meeting, October 30-November 3, 2004. Seattle, WA.
9. D.K. Lee and V.N. Owens. 2004. Switchgrass yield and persistence in a bioenergy management system. ASA Annual Meeting, October 30-November 3, 2004. Seattle, WA.

10. D.K. Lee, J.J. Doolittle, V.N. Owens, A. Boe, T.E. Schumacher, and D.D. Malo. 2004 Switchgrass management for biomass production, carbon sequestration, and soil conservation. Soil and Water Conservation Society Annual Meeting, July 2004. St. Paul, MN.
11. D.K. Lee, J.J. Doolittle, T.E. Schumacher, and B.H. Bleakley. 2003. Carbon mineralization affected by nitrogen and manure application. ASA Annual meeting, Nov. 2-6, 2003 Denver, CO.
12. A. Boe and D.K. Lee. 2003. Patterns of Biomass Accumulation in Switchgrass Under Drought Stress. ASA Annual Meeting, November 2-6, 2003. Denver, CO.
13. S.H. Lee, J.J. Doolittle, D.K. Lee, D.D. Malo, V.N. Owens. 2003. Soil Respiration in Switchgrass Land Managed for Biomass Production. ASA Annual Meeting, November 2-6. 2003. Denver, CO.
14. Lee, S.H., J.J. Doolittle, D.K. Lee, D.D. Malo, and V.N. Owens. 2003. Soil respiration in switchgrass land managed for biomass production. ASA Annual meeting, Nov. 2-6, 2003 Denver, CO.
15. A. Boe and R. Bortnem. 2003. Development of the proaxis of switchgrass. ASA Annual meeting, Nov. 2-6, 2003 Denver, CO.
16. V.R. Mulkey and V.N. Owens. 2003. Management of CRP grasslands for biomass energy production. ASA-CSSA-SSSA Annual meeting, Nov. 2-6, 2003 Denver, CO.
17. M. Zamy and A. Boe. 2003. Tiller origin and development in switchgrass. ASA Annual meeting, Nov. 2-6, 2003 Denver, CO.
18. M.M. Mills, Bakker, and K.F. Higgins. The effect of plant species diversity on the occurrence and density of prairie birds. Fall meeting of the South Dakota Ornithologists'Union, October 10-12 Madison, SD,
19. A. Boe and R. Borthem .2002. The Proaxis of Switchgrass. ASA Annual Meeting, November 10-14, 2002 Indianapolis, IN.
20. R.M. Zamy and A. Boe. 2002. Environmental and Genetic Impacts on Growth Stage Variation in Switchgrass. ASA Annual Meeting, November 10-14, 2002. Indianapolis, IN.
21. J.H. Lee, J.J. Doolittle, D.D. Malo, V.N. Owens, T.E. Schumacher, D.K. Lee. 2002. Soil Respiration in Switchgrass Land Managed for Biomass Production. ASA Annual Meeting, November 10-14, 2002. Indianapolis, IN.
22. D.K. Lee, J.J. Doolittle, D.D. Malo, J.H. Lee, B.H. Bleakley. 2002. In-situ C02 Evolution and Soil Organic C Pools in Switchgrass Land Managed for Biomass Production. ASA Annual Meeting, November 10-14, 2002. Indianapolis, IN.
23. A. Boe and P.J. Loewe. 2001. Phytometric Analysis of Biomass Production in Switchgrass. ASA Annual Meeting, October 21-25, 2001. Charlotte, NC.
24. J.J. Doolittle, J.H. Lee, D.K. Lee, V.N. Owens, D.C. Otto, D.D. Malo, T.E. Schumacher. 2001. Evaluation of Soil Carbon and Physical Properties in Switchgrass Land. ASA Annual Meeting, October 21-25, 2001. Charlotte, NC.
25. D.K. Lee, J.H. Lee, J.J. Doolittle, D.L. Otto, V.N. Owens. 2001. Fertilization Effects on Seasonal C and D Dynamics Under CRP Land Managed for Biomass Production. ASA Annual Meeting, October 21-25, 2001. Charlotte, NC.

GPI Presentations or Poster Sessions:

- (GPI staff continues to regular invited presentations based on this research beyond the scope of this grant's timeline).
- December 8, 2006: National Caucus of Environmental Legislators – Midwest/Great Lakes Forum, Washington, DC.
- December 1, 2006: Pheasants Forever Annual Staff Meeting, St. Paul, MN
- December 2006: Presentation to Ducks Unlimited Great Plains regional staff in Bismarck North Dakota.
- November 1-3, 2006: Meeting of the Central US Region Nature Conservancy Trustees, 3 presentations.
- July 21, 2006: Midwest Association of State Departments of Agriculture, Annual Meeting, Madison, Wisconsin
- March 22, 2006: Midwest Association of State Departments of Agriculture – Terrestrial Sequestration Forum, Madison, Wisconsin
- March 16, 2006: Iowa Green Lands Blue Waters, Des Moines, Iowa
- February 21, 2006: Iowa Business Council – Biomass Working Group, Newton, Iowa
- January 17-18 2006: Marketplace for Entrepreneurs in Fargo, North Dakota
- December 2005: Poster session at DOE processing stage gate review. Washington DC.
- December, 2005: Presentations by project team members to McKnight Foundation symposium on sustainable biomass production and use.
- November 29, 2005: Initiative on Renewable Energy and the Environment poster session at the University of Minnesota
- March, 2005: Presentation at USDA and DOE joint biomass feedstock stage gate review. Washington DC.
- April 2004, Brookings South Dakota: Joint presentation from project team to Powering the Plains stakeholders at quarterly meeting.
- November 2003: Presentation to Annual Biocycle Conference Minneapolis, Minnesota.

List of refereed journal publications

1. Lee, D.K. and A. Boe. 2005. Biomass production of switchgrass in Central South Dakota. Crop Science (in press).
2. Lee, D.K. and J.J. Doolittle. 2005. Soil Carbon Dioxide Flux and Organic Carbon in Grassland after Manure and Ammonium Nitrate Application. Korean Soc. Agri. Environ. J. (in press).
3. V.R. Mulkey, V.N. Owens, and D.K. Lee. 2005. Management of switchgrass-dominated Conservation Reserve Program lands for biomass production in South Dakota. Crop Science (in press).
4. Lee, J.H., D.K. Lee, J.J. Doolittle, and D.D. Malo. 2005. Influence of drying conditions on quantifying soil organic components. Soil Science and Plant Nutrition, Japan (submitted).

GPI Publication on Project Results:
Home Grown Energy Security, The Potential for Fuels, Power and Product from Native Grasses. Available at www.nativegrassenergy.org

Websites Devoted to Project Results:
www.nativegrassenergy.org

Networks or Collaborations Fostered:
The Biomass Working Group was initiated under this award contract but will continue into the future with Energy Foundation funding. In addition a network called the North Central Bioeconomy Consortium (NCBEC) was developed as an outgrowth of the Biomass Working Group. The Consortium brings together 12 state directors (or secretaries) of the state departments of agriculture, state experiment stations and state agricultural extension offices with an aim advancing the next generation of biofuels and products in the region.

Technologies/Techniques:
All techniques utilized were described in the technical pieces of this final report.

Inventions/Patent Applications, licensing agreements:
Described in Patent Certification Forms supplied by GPI, SDSU and EERC.

Other Products:
None

Attachments:

1. Published executive summary of report findings
2. GPI stakeholders working on policy related to this research
3. BWG Biomass Policy Menu

Documents attached during an earlier reporting period:

1. All are also available on www.nativegrassenergy.org)
2. SDSU final report
3. EERC final report
4. University of Minnesota Applied Economics Paper

Great Plains Institute
Working on tomorrow's solutions with today's leaders

State Policies for Promoting the Next Generation of Biomass Technologies

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Background

These policies have been formulated through the discussions of the **Biomass Working Group**, a stakeholder group that includes agriculture, industry, environment, academic, and government participation from Iowa, Minnesota, North Dakota, South Dakota, Wisconsin, and important national organizations. The Biomass Working Group is an ad hoc organization that does not require full endorsement of a specific policy platform. Because some individuals and organizations included here do not lobby, this menu does not imply endorsement by all of the groups on the list. The proposals listed here are intended to provide a starting point for developing detailed state specific policy proposals. Biomass Working Group members and others interested in advancing the next generation of cellulosic and advanced energy technologies are invited to adopt and develop ideas and proposals for specific state policy initiatives that are tailored to the political and economic context of individual states.

Endorsement - After development by the Biomass Working Group, this policy menu was adopted by the **Powering the Plains** working group, a multi-stakeholder group representing electric utilities, agriculture groups, environmental groups, public utility commissioners, and other government agency representatives from the upper midwest. Powering the Plains is working to develop a long-term energy "roadmap" for transitioning to a reduced carbon energy system.

Goals of This Policy Menu

- Promote the next generation of advanced biomass technologies to utilize ligno-cellulosic biomass and manure to replace liquid fuels, natural gas, heat, electricity, and other high-value products and to promote new products from the conventional biofuels industry.
- Reduce the carbon and water-use intensity of biomass production and conversion, promote biomass crops that improve soil and water quality and wildlife habitat.

The Menu

1. Demonstration and Commercialization of Advanced Biomass Technologies

The most important step in taking advantage of cellulosic ethanol and other advanced biomass technologies is making those technologies commercial. Many technologies are near commercialization, but too high risk for the investment community. State policies could help mitigate risk and bring the next generation of advanced biofuels to market. Long-term support for projects should be encouraged until projects are profitable on their own. Incentives should be sun-setted when no longer needed.

Qualifying projects: In seeking to assist in the commercialization of advanced biomass technologies, governments should be careful not to provide incentives to projects that are already operating on a commercial basis. Governments should provide funding or incentives to projects meeting the following criteria:

- Projects using advanced technologies and practices that are not already commercial technologies or well-established practices. Projects would include commercial scale ups of qualifying technologies.
- Projects using ligno-cellulosic biomass in novel ways to produce energy in any form – liquid fuels, gas, heat, or electricity – or new biobased products, or
- Projects that expand the range of valued added products from conventional biofuels facilities, including producing new types of fuels in conventional biofuel plants, or
- Projects that otherwise seek to demonstrate or commercialize a new use of any biomass material to produce energy or high value products.
- Where possible, public financing should go into projects that have a local ownership stake, and include some promise of local hire, prevailing wage standards, and a commitment to worker training.
- Where possible, support existing projects and technologies that help demonstrate the development and sustainability of biomass feedstock supply.

Recommendations:

1A. Capital - State governments and local economic development agencies should provide assistance in the form of capital cost share, loan guarantees, revolving loan funds, and Industrial Development Bonds to projects qualifying as advanced biomass technologies.

- State governments should not provide all project funding, assuring that investors share the risk.

- Government spending should favor projects with at least part ownership by agricultural producers and local investors, without excluding or discouraging outside investment.
- This could be structured as a revolving fund or multi-year production incentive.
- Industrial Development Bonds could also be granted for projects meeting advanced biomass technology project criteria.

1B. Subordinated Debt - Governments should offer subordinated debt for advanced biomass projectsin order to encourage investment in higher risk projects and enhance equity risk reward equations.

1C. Incentives - States should provide incentives for the production or purchase of energy from biomass by all consumers, or for the production or purchase of cellulosic biomass by various energy users.

- In many cases state incentives already exist that could be extended to energy from biomass.
- States should consider expanding any corn ethanol incentives to cellulosic ethanol.
- Incentives should be applied broadly to promote the use of cellulosic biomass to replace liquid fuels, natural gas, heat, and electricity.
- Existing tax exemptions for manufacturers' energy bills should be tied specifically to use of biomass.

1D. Regulatory barriers: New technologies can deliver environmental benefits, but often do not fit neatly into regulatory categories. Many demonstration projects have been delayed by regulatory agencies lack of familiarity with new technologies, fuels and production systems.

- States should develop permitting rules for emerging technologies.
    - Permitting authorities should be educated about types of projects, including obtaining and standardizing data.
- States should find ways to exempt or streamline novel demonstration projects from the conventional regulatory process to allow experimentation, without creating a dangerous precedent.
    - In order to avoid a dangerous precedent, only qualifying demonstration projects should receive exemptions.
    - State regulatory agencies should be given the authority to grant or deny such exemptions.
    - States may want to structure regulatory exemptions as limited-time grace periods to get projects started. They may also only allow exceptions for projects below a certain size.
- As some biomass projects will have an electricity component, the Power Purchase Agreement process should be made more consistent and transparent.

- States should promote innovative environmental control strategies that improve the overall environmental characteristics of the plant - including energy, fossil, and materials balance.
- Policy-makers should seek to create regional consistency in the regulation of advanced biofuels facilities.

1E. Local Ownership - Recognizing that outside money will play a role in the development of a new generation of advanced biomass technologies, efforts should be made to ensure that significant benefits of these facilities accrue to the communities containing them.

- Governments should provide loans for equity capital.
- Allow coops, municipal utilities, and other local and community-owned entities to have bonding authority to fund biomass projects.
- Public investments should include a preference for the highest level of local ownership practicable.
- States should develop structures that make it easier to have a lot of small investors.
    - Regulatory costs associated with securities filing are difficult for small projects.

2. Developing a Perennial Crops Biomass Supply:

Of all potential sources of cellulosic biomass, perennial crops such as switchgrass and other native grass mixtures as well as short rotation woody crops such as hybrid poplar and willow represent the biggest opportunity to improve soil, water, wildlife and agricultural energy efficiency benefits while generating a potentially significant biomass resource. Because of the synergies between farm economics, biofuel production and environmental objectives, any biofuels policy should encourage the development of a perennial biomass supply.

Recommendations:

- States should provide producer incentives for the production of perennial energy crops.
- Many states already have programs that pay landowners for planting perennial grasses for water quality and wildlife purposes. Production of perennial biomass for biofuels should be another goal of those programs so long as it doesn't take away from other program objectives.

- Energy Crops acreage should be recruited based on proximity to a proposed or existing plant designed to use ligno-cellulosic biomass, and not simply assigned at random.
- Perennial biomass demonstration projects should be accompanied by research evaluating the impact of these projects on farmer income, wildlife, soil, water, and greenhouse gas emissions. Projects should seek to maximize benefits in these areas.
- States should create programs to offer crop insurance to producers that want to grow perennial energy crops that are not covered by current crop insurance programs.
- State governments should use their boilers to provide small-scale local energy crop demonstration projects.
- State governments should lead collaborative efforts to develop and implement energy crop demonstration programs.

3. Bio-based Product Procurement

As part of the 2002 Farm Security and Rural Investment Act, the USDA was required to create a comprehensive program for designating bio-based products. In addition to creating a list of products, federal agencies are required to purchase bio-based product provided that they are available and near cost-competitive with their fossil-based equivalent. This program can play a crucial role in raising awareness about, and developing markets for new bio-based products. High value non-energy products can play a key role in improving the profitability of plants producing bio-fuel – just as sales of bulk chemicals improve the profitability of oil refineries.

Recommendations:

- States should adopt bio-based product procurement rules at the state level. They may decide to simply adopt the federal rules and the federal list of bio-based products.
- As with the federal rules, state agencies should be required to procure bio-based products provided that:
    - They are available
    - They are near cost-competitive relative to the fossil-based equivalent
- Whatever rules are adopted, they should be consistent throughout the region.
- States should expand the program further by creating a regional certification program and promoting it through education and through incentives for participation by businesses.
- States should consider joint procurement with other states using shared standards to increase their market power.

4. Bringing Biofuels to Market

Recommendations:

- Promote renewable fuels standards and consider inclusion of specific carve-outs for advanced and cellulosic biofuels.
- States should promote development and production of highly efficient bio-fuel-powered vehicles.
- States should create market pull by expanding state government use of biofuels, including: directing agencies to purchase high blend biofuels, such as E-85 and B-20 where available and appropriate; creating interagency strategies to educate fleet managers and drivers about the goals, options and priorities pertaining to biofuel use and establish biofuels goals and measures for state agencies; and develop and fund investment plans for appropriate state fleet infrastructure (ie. E-85 and B-20 tanks where fleets have dedicated fueling stations).
- States should consider retail tax incentives that encourage retailers to sell biofuels and bio-based products.
- States should provide incentives or standards that increase the number of gas stations selling biofuels, particularly high blends such as E85 and B20.
- States should consider joint procurement of high-efficiency flex-fuel vehicles and biofuels distribution infrastructure.

5. Technical Assistance

Adopting new technologies will be challenging. States can assist in many ways.

Recommendations:

- States should provide funding for Front End Engineering and Design (FEED) studies, and other feasibility studies for advanced and cellulosic projects.
- States should provide business planning assistance and mentoring
- There should be an expansion of technical assistance capabilities and funding in the following areas at the state and regional level, including: Cooperative Development Centers, State Departments of Agriculture, Universities – including Extension, RC&Ds and State Energy Offices.

6. Overcoming the Difficulty of Feedstock Logistics

Although there is an enormous potential supply of biomass in the Midwest, there will be tremendous challenges in growing, harvesting, collecting, transporting, storing, and processing it. Overcoming logistical challenges will be a precursor to the development of a prosperous bioeconomy. As we move forward, both producers and commercial and custom harvesters will need to develop experience in developing a feedstock supply.

Recommendations:

- Extension Service, RC&Ds, Soil and Water Conservation Districts, and Agronomic Coops should provide technical assistance for feedstock logistics.
- States should provide dedicated funding to demonstration projects as they seek to develop a sustainable biomass supply, including providing funding and assistance to local governments and communities that want to do a biomass resource assessment.
- States should provide incentives (grants, tax exemptions, low interest loans) for specialized, dedicated equipment for biomass crops.
- States should fund research evaluating the sustainability of crop and forestry residue removal, and developing Best Management Practices for sustainable residue removal.
- States should fund applied research on feedstock logistics from field to plant in order to develop more efficient methods.
- States should lead energy crop pilot projects using existing boilers to build practical, on-the-ground experience using local energy crops.

7. Basic and Applied Research on Crops and Conversion Technologies

Although there are currently technologies that are near commercialization or already commercial, and appropriate biomass crops that could be better utilized, we have only caught a glimpse of the bioeconomy’s potential to deliver energy, products, and various ecosystem services. Although we have knowledge for some biomass crops, there is a lot of research that needs to be done.

Recommendations:

- State universities should form interdisciplinary centers on the bioeconomy, and develop strategic plans to target university resources to this challenge.
- States should fund basic and applied research on biomass crops, breeding, agronomy, cropping systems, germplasm development, and conversion technologies.
- States should fund research on advanced cropping systems – including native grass mixtures - and long-term studies on the impact of biomass crops on soil, water quality, and wildlife. Studies should also evaluate the long term impact of crop and forestry residue removal on soil, water quality, and wildlife
- Studies should evaluate the appropriateness of feedstocks for various climates, soil types, and inputs.
- States should support lifecycle assessments of various technology and product options.

8. Workforce Development

A new generation of workers must be trained to build and operate the new bioeconomy. This will require new skilled workers in nearly every imaginable field being engaged in this challenge.

Recommendations:

- States should create workforce development programs that create collaboration between industry, state government, and educational institutions. Target state subsidies and incentives to companies dedicated to participation in these programs.
- State Universities, Technical and Community Colleges, High Schools, and other Secondary and Post-Secondary institutions should evaluation their curriculum and make and implement recommendations for incorporating the bioeconomy into their curricula.
- Extension, Resource Conservation and Development Districts, agronomic coops, soil and water conservation districts, agribusiness providers and other institutions will have a particularly important role in providing information and training to the agricultural industry interesting in producing, selling, and marketing bioenergy crops.
- Local financial institutions should be educated about potential biomass technologies.

9. Public Education

The public should be educated about benefits and realities of the bioeconomy.

Recommendations:

- Grants should be made available to allow organizations to do public education, and promote state goals with respect to bioeconomy development.
- Extension, youth programs like 4H and FFA, primary and secondary institutions, and other state institutions should provide education about the bioeconomy.

10. Regional Recommendations

Many of the recommendations included here should be done regionally to ensure a level playing field for business throughout the region, and to learn from the successes and mistakes of others.

Recommendations:

- Departments of Agriculture and Land Grant Institutions should establish a vehicle for collaborating on Bioeconomy goals throughout the Midwest.
- There should be a regional catalog of what resources are available for those interested in beginning projects (including from Extension, federal laboratories, Departments of Agriculture, private industry, utilities, RC&Ds, and international sources of information).
- Regional governments and institutions should collaborate to develop consistent regional "asks" for federal policy and funding.
- Regional regulators (including Departments of Natural Resources, Pollution Control Agencies) need a learning venue for discussion of innovative models and regulatory needs.

11. Renewable Energy, Greenhouse Gas and Water Credit Trading

There are opportunities to create increased income through the sale of renewable energy, carbon and water credits, and biofuels production and use has the potential for significant reductions in regional greenhouse gas emissions and improvement in water quality.

Recommendations:

- No policies recommended in this document should prevent landowners from selling permits or credits for legitimate, demonstrated sequestration of carbon in soils, for improvement in water quality or for production of renewable energy.
- States should facilitate the trading of renewable energy, carbon and water credits.
- There should be a regional program to evaluate the potential for agricultural and forestry carbon sequestration, and for water quality improvement from the production of biomass and biofuels.
- There should be carbon and water credit registry systems similar to the soon-to-be adopted Midwest Renewable Energy Tracking System (MRETS).
- The region should strive for continuous reductions in the greenhouse gas and water use profile of biofuels.
- Research should be performed to better understand the water and greenhouse gas impact of various biofuels technologies, and biomass crop production systems.

The Biomass Working Group

Who we are:

The Biomass Working Group is an ad hoc group that includes leaders from agriculture, environmental organizations, industry, state goverment, and the legislature. While the group has strongest participation in the Upper Midwest region - including Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin - it also includes leading national and international organizations.

Rationale:

The Upper Midwest region is well-positioned to take a leadership role in promoting the next generation of biomass technologies.

- **National Leadership:** We enjoy national recognition for our development of a mature industry in corn ethanol and for laying the foundations for a biodiesel industry.
- **Research strength:** Our universities are leaders in developing new ideas for the utilization of biomass for fuels, chemicals, and products.
- **Industry Leaders:** We already have successful bio-based industries, including the forest products industry and agricultural industries. Many companies are advancing the next generation of biomass technologies and processes.
- **Abundant Biomass:** Our fields and forests produce abundant biomass, and new management techniques will allow us to produce much more.
- **Multiple Benefits:** The bio-economy, if implemented strategically, can boost farm income, benefit wildlife, improve water quality and soil health, and help to mitigate global warming.
- **Independance from Foreign Oil:** Finally, our region can potentially offer energy and products that are cost-competitive with increasingly expense petroleum-based alternatives. We can offer part of a national solution to becoming independant of imported oil.

Goals of the Biomass Working Group:

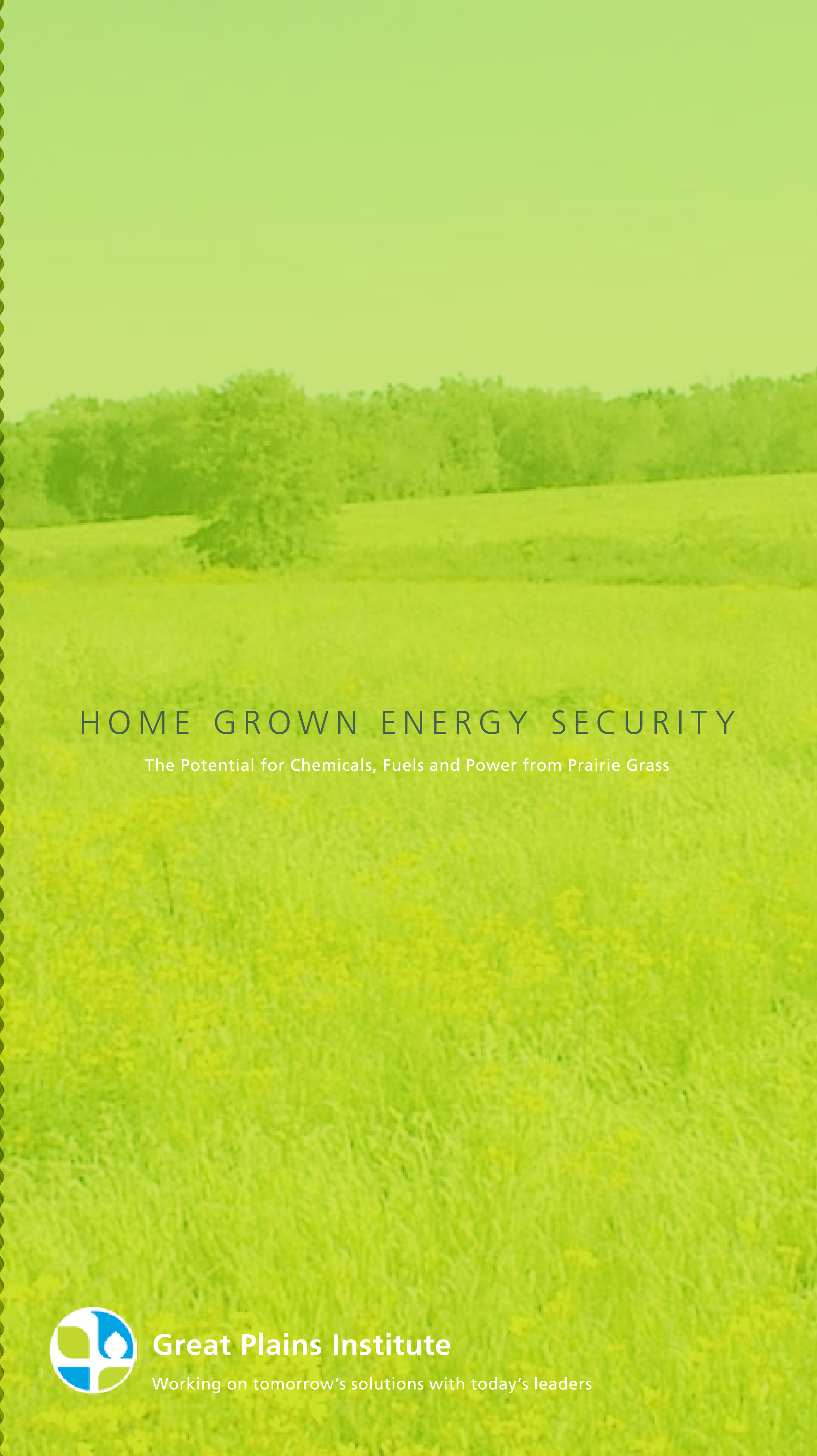
- **Promote the development of the next generation of biomass technologies, including:**
  - Cellulosic ethanol and other cellulosic liquid fuel
  - The use of cellulosic biomass to replace natural gas, heat, electricity, and any other products currently produced from fossil fuels.
  - Technologies and processes for producing new value-added products from existing biofuel facilities and manure digesters.
  - Manure digestors.

- **Make progress on other important goals, including:**
    - Reducing the carbon intensity of biomass production and conversion,
    - Improving energy security and addressing climate change by replacing fossil fuels with biomass,
    - Making improvements in water quality, wildlife habitat and soil quality, and
    - Promoting economic development through local ownership of projects and local production of biomass feedstocks.
- **Promote regional collaboration around policy and research**
- **Leverage awareness-raising opportunities**

Participants in the Biomass Working Group:

- **John Baumgartner** Baumgartner Environics
- **Gretchen Bonfert** McKnight Foundation
- **David Boulard** Ensyn
- **Michael Bowman** 25x25
- **Robert Brown** Iowa State University
- **Jim Burg** Retired Public Utilities Commissioner
- **Kim Christianson** North Dakota Department of Commerce
- **Jim Cooper** Prairie Rivers of Iowa RC&D
- **Ronald Cox** Center for Industrial Research and Service, Iowa State University
- **Dean Current** Center for Integrated Natural Resources and Agriculture Management, University of Minnesota
- **Dave DeGeus** The Nature Conservancy
- **Chris Deisinger** Energy Foundation/ Union of Concerned Scientists
- **Steve Devlin** Center for Industrial Research and Service, Iowa State University
- **Jill Euken** Iowa State University Extension
- **Patrick Girouard** Iogen
- **Kate Gordon** Center on Wisconsin Strategy
- **Nathanael Greene** Natural Resources Defense Council
- **Mindi Grieve** North Dakota Farmers Union
- **Robert Gronski** National Catholic Rural Life
- **Ralph Groschen** MN Department of Agriculture
- **Chad Hart** CARD, Iowa State University
- **Ken Hellevang** North Dakota State University Extension
- **Jennifer Hermans** GDS Associates
- **Jack Huggins** The Nature Conservancy/ethanol plant board member
- **Michael Jerstad** PraireGold Venture Partners
- **Stanley Johnson** University of Nevada - Reno
- **Dennis Keeney** Institute for Agriculture and Trade Policy

- **Jim Kleinschmidt** Institute for Agriculture and Trade Policy
- **Arnold Kruse** North Dakota Natural Resources Trust
- **Charles Kubert** Environmental Law and Policy Center
- **Patrice Lahlum** North Dakota Department of Agriculture
- **Ben Larson** Union of Concerned Scientists
- **Rich Leopold** Iowa Environmental Council
- **Mark Lindquist** MN Project/Midwest AgEnergy Network
- **Deron Lovaas** Natural Resources Defense Council
- **Scott McLeod** Ducks Unlimited
- **Russ Meier** ePowerSynergies
- **Dave Miller** Iowa Farm Bureau
- **Jeff Moore** Virent
- **Bob Mulqueen** Iowa Environmental Council
- **Jeri Neal** Leopold Center for Sustainable Development
- **Katie Nekola** Clean Wisconsin
- **Jon Nelson** North Dakota State Senator
- **Andy Olsen** Environmental Law and Policy Center
- **Ben Paulos** Energy Foundation
- **Gary Radloff** WI Department of Agriculture, Trade, and Consumer Protection
- **Norman Reese** Frontline Bioenergy
- **Keith Reopelle** Clean Wisconsin
- **Todd Reubold** Initiative for Renewable Energy and the Environment (IREE), University of Minnesota
- **Preston Schutt** CleanTech Partners
- **John Sellers** Producer/Chariton Valley Biomass Project/Leopold Center for Sustainable Development
- **Robin Shepard** University of Wisconsin Extension
- **Jerod Smeenk** Frontline Bioenergy
- **Doug Sombke** South Dakota Farmers Union
- **Ray Sowers** South Dakota Department of Agriculture
- **Paul Symens** Producer/Coop Board/Retired State Senator
- **Sean Weitner** Energy Center of Wisconsin
- **Carol Werner** Environmental and Energy Study Institute
- **Jack Werner** New Uses Council
- **Jetta Wong** Environmental and Energy Study Institute
- **Ed Woolsey** Iowa RENEW



ROOTS OF CHANGE

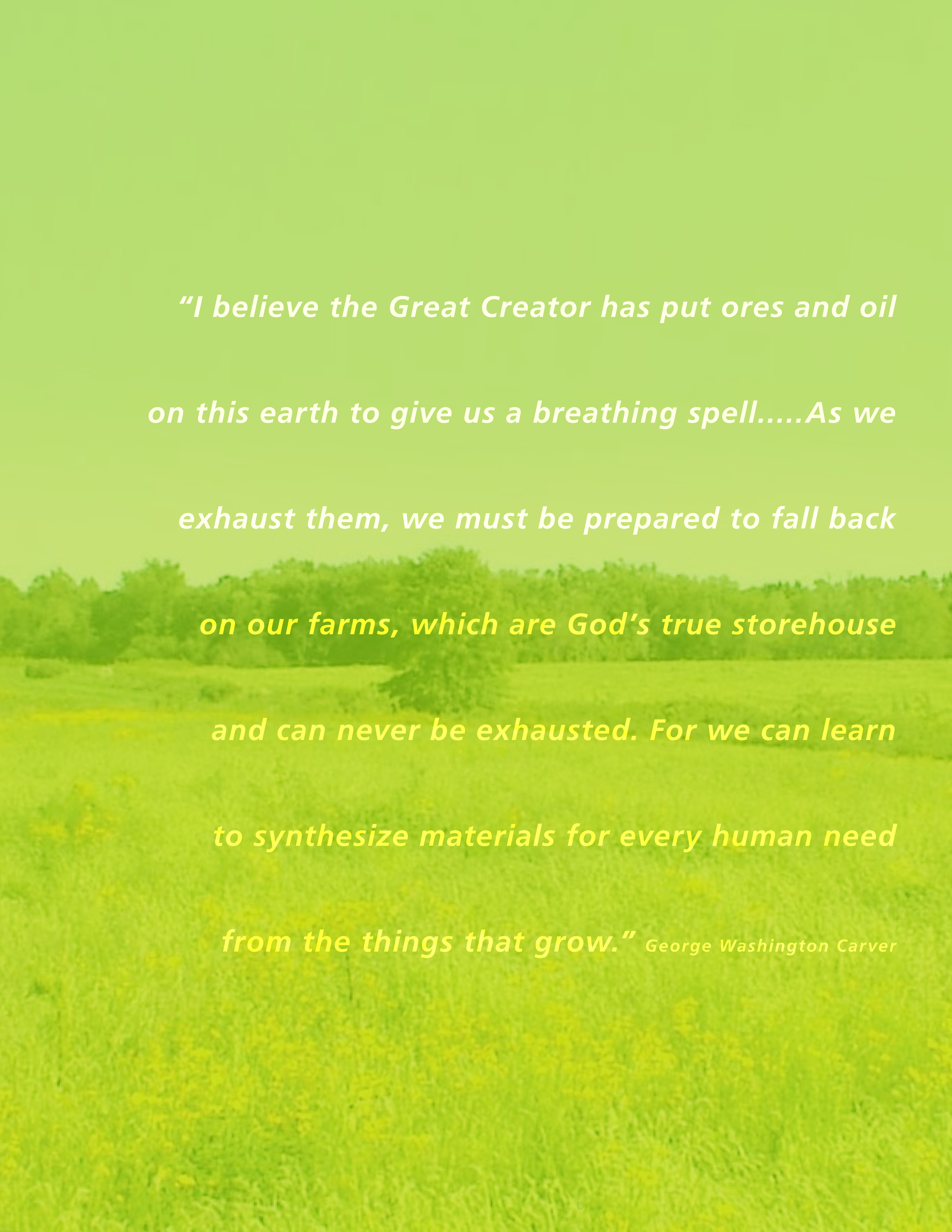
HOME GROWN ENERGY SECURITY

The Potential for Chemicals, Fuels and Power from Prairie Grass

Spring 2007

Great Plains Institute

Working on tomorrow's solutions with today's leaders



"I believe the Great Creator has put ores and oil on this earth to give us a breathing spell.....As we exhaust them, we must be prepared to fall back on our farms, which are God's true storehouse and can never be exhausted. For we can learn to synthesize materials for every human need from the things that grow." *George Washington Carver*

‘grassoline’ from native prairie plants?

The research outlined in this report suggests that sustainably-produced biomass — particularly native prairie grasses well-adapted to the Great Plains — can make a significant contribution to our country’s energy and material needs.

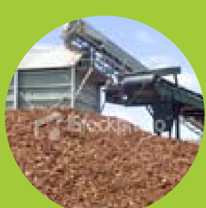
>>

TYPES OF BIOMASS

ENERGY CROPS

FOREST PRODUCTS

CROP RESIDUE



FORESTRY RESIDUE

SOLID WASTE

>> George Washington Carver, famous for inventing new products from plants most notably from the peanut, began investigating the usefulness of legumes as a way to replenish the South's depleted soils from decades of intensive cotton farming. His findings — that plants could serve multiple ends from soil building to the manufacture of chemicals and products — is as salient today as it was years ago.

We have some serious current problems in need of such solutions; actually several that are intertwined. First, the U.S. currently imports nearly two thirds of its oil, much of it from Canada today, but increasingly from the Middle East and other unstable parts of the world. This dependence is projected to grow to 70 percent within two decades.

According to the U.S. Energy Information Administration, global growth in oil demand is expected to increase 68 percent by 2030, from 80 million barrels a day in 2003 to 118 million barrels per day in 2030 (largely because of surging demand in China and India). Fully one-half of this growth will occur in the transportation sector and nearly another forty percent in chemicals to be used in the industrial sector.

In the U.S., the transportation system is roughly 96 percent reliant on fuels from oil. The combination of U.S. oil dependence and global growth in demand highlights the critical importance of accelerating the commercialization of competitive alternatives to petroleum that can deliver transportation fuels and chemical feedstocks. Biomass can deliver both.

The second key problem facing the U.S., and its fellow nations, is the enormity of the carbon dioxide (CO_2) reduction challenge. Carbon dioxide is the principle greenhouse gas causing global warming. The worldwide scientific consensus is that we must reduce CO_2 emissions by 50-80 percent (below 1990 levels) over the next 50-100 years in order to avoid the worst effects of climate change. Although the time-frame may seem long, we also need to keep in mind that much of the energy infrastructure we build today has a similar lifespan and the CO_2 emitted from such facilities will last a century or more in our atmosphere.

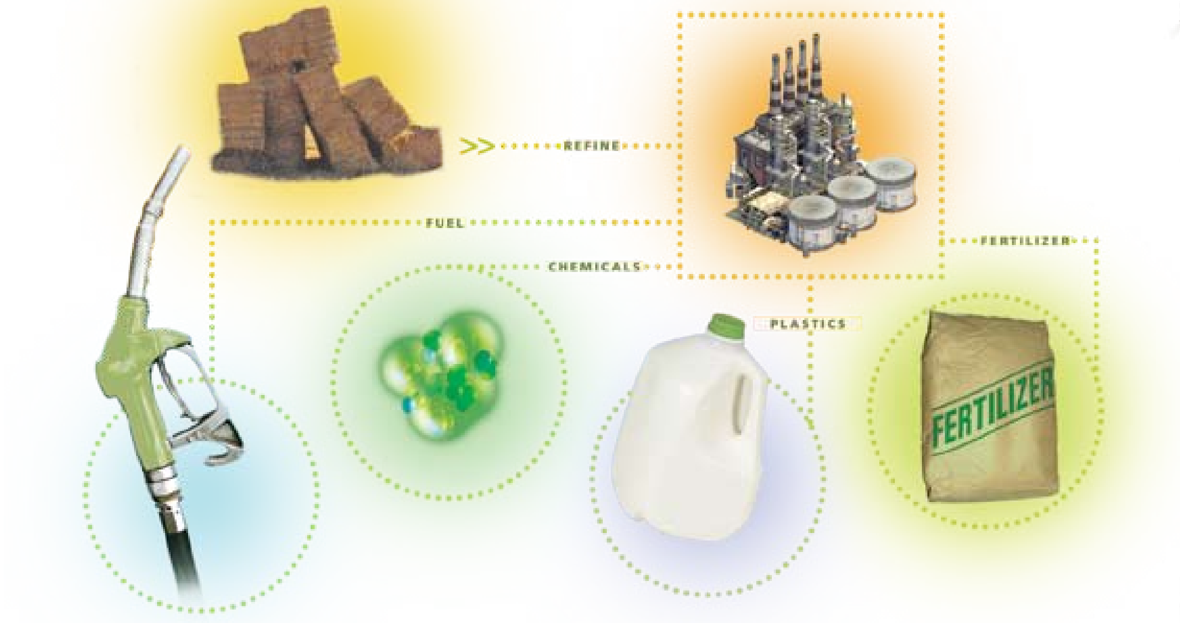
Of the projected global increase in oil use in the reference case over the 2003 to 2030 period, one-half occurs in the transportation sector.

The industrial sector accounts for a 39-percent share of the projected increase in world oil consumption, mostly for chemical and petrochemical processes.

The third key energy challenge is finding the resources that will help solve our energy security and climate problems without exchanging them for new problems. The resources and practices brought into this equation will necessarily have to be practical, sustainable and economically viable over time.

The story that the research findings summarized in this report tell is that biomass — native grasses in particular — can and must be part of the nation's multi-pronged approach to achieving energy security and a stable climate. Native grasses are the quintessential 'home-grown' resource, are as good or better than nearly any other biomass resource in offsetting CO_2 emissions and bring with them a suite of ancillary environmental benefits to boot.

Nearly a century after Carver convinced the country that peanuts, soybeans and other legumes could be the base for great American innovation, leaders have been raising the profile of another obscure plant: switchgrass. The grass which once quietly covered our nation's great plains was thrust into the national spotlight in President Bush's 2006



Native grasses could eventually serve as the raw material for "biorefineries" that, like petroleum refineries today, produce a range of energy products and materials.

State of the Union address where for the first time a U.S. President uttered the name of a humble prairie grass in a major address. In the wake of that speech, the word "switchgrass" hung on lips of many confused people. Across the country, entrepreneurs and others ran for their dictionaries. What is switchgrass, and why is the President offering it up as one solution to our nation's energy woes?

Until now, the modern world has come to rely on oil and other fossil fuels as the chemical "toolkit" for producing most of our energy and a vast array of goods. At their simplest, these fossil fuels are very old, fossilized plant matter. They formed from the remains of plants and animals deposited millions of years ago. Once buried, compressed and heated by geologic processes, this plant matter changed physically and chemically to yield today's carbon-based oil, coal and natural gas. Today, policymakers, entrepreneurs and researchers alike are looking to above-ground plants as a renewable, potentially CO_2-neutral (or even CO_2-reducing) alternative.

The President put switchgrass on the national agenda because it and other native grasses offer great promise as cost-effective replacements for natural gas, petroleum, and even coal under some circumstances. These grasses can eventually provide all of the high-value chemicals we now get from oil. Thus, native grasses could eventually serve as the raw material for "biorefineries" that, like petroleum refineries today, produce a range of energy products and materials.

While replacing imported oil with homegrown grasses is a tantalizing prospect, scientists and others are only beginning to understand what native grass agriculture can and cannot deliver.

ROOTS OF CHANGE

Many of the benefits of perennial native grasses derive from the deep, extensive root systems they use to adjust to environmental conditions.

native perennial grasses as an energy crop have the potential to reconcile farmers' profits with environmental benefits in unprecedented ways

National Context

The Department of Energy released a study in 2005 commonly referred to as the 'Billion Ton Study'. In short, the study estimates that U.S. agriculture and forestry could produce 1.3 billion tons of plant material – or biomass – for our energy needs, without significantly compromising allocation of agricultural uses to other important uses such as food.

While this estimate included products like corn grain, which is currently being used to produce ethanol, the vast majority of resources identified were cellulosic materials: agricultural residues; forestry and mill residues; and so-called dedicated energy crops like hybrid poplar and switchgrass. Because the next generation of biofuels technologies will be able to transform not only the sugar-rich grains, but virtually any product of photosynthesis into fuels, biomass once thought able to displace only a minimal amount of our petroleum needs is now anticipated to replace more than one third of current U.S. petroleum consumption. Of the plant resources identified, perennial crops provided roughly a third of the total and has been the focus of this 4-year research project investigating the practical use of switchgrass and other perennial grasses as sources of energy, fuels, and chemicals.

A perennial species grows year after year without replanting. The perennial grasses we discuss at length here — namely switchgrass, indiangrass and big bluestem — were once dominant species across the country's tall grass prairie. Many of the benefits of perennial native grasses derive from the deep, extensive root systems they use to adjust to environmental conditions. In the event of a prairie fire or with the onset of winter, they respond by forcing important nutrients into the crown of the plant, only to come back later with greater fervor. Their root systems help hold the soil in place, even during harsh winds, droughts and intense flooding common to the northern plains. These same root systems prevent erosion and run-off, improve soil health, and remove CO_2 from the air. These attributes not only mean that native perennial grasses will survive longer than others through the dramatic weather variations common to the northern Great Plains, but that they are able to do so with minimal additions of fertilizer, pesticides and other inputs. The grasses also create important habitat for birds and animals looking for shelter, particularly if several species are grown together on the same land in mixtures rather than in single-species monocultures.

Because of these characteristics, native perennial grasses as an energy crop have the potential to reconcile farmers' profits with environmental benefits in unprecedented ways. Farmers will be compensated for selling a native grass crop, while they deliver multiple benefits to society – soil health, climate change mitigation, water quality, and wildlife conservation. Because native grasses require little in the way of expensive inputs, such as fertilizers and pesticides, they will also require lower regular yearly expenditures than annual crops grown in the same location.

Unique Research Approach

The Great Plains Institute (GPI) coordinated this multi-year research project for the U.S. Department of Energy, partnering with several key research institutions in the region *(see list of partners on the back cover)*. The project had three major components, each summarized in this report:

1. Assessing production of the grasses in the region;
2. Converting grass hay into useful fuels and products, and
3. Evaluating the economics of all aspects of the process

Although others are studying native grass energy, this research is unique in several respects. For example, it:

- Evaluates the use of economically-harvestable mixtures of grass species rather than just switchgrass monocultures. In-depth analysis documented many benefits of this approach, including better soil health, erosion prevention, and improved wildlife habitat.
- Investigates cultivars of native grasses specially adapted for the northern plains, rather than high-yielding cultivars better adapted for southern climates.
- Reveals practical strategies for transitioning to grass agriculture that would be relatively easy and economical for farmers to adopt.
- Brought together chemical engineers, soil scientists, agronomists, plant breeders, economists and policy analysts to identify interventions in the plant's lifecycle that could make them better-suited to fuel production.
- Evaluates the pyrolysis of various grasses. Pyrolysis uses heat to convert biomass into a mixture of gases, char and a liquid called "bio oil," a complex mixture of chemicals analogous to petroleum crude oil.

The following pages describe the scope and results of this analysis in broad terms. More detailed methodology, analytical results and research partner contacts can be found on our companion website: www.nativegrassenergy.org

growing the grasses: building on nature's r&d **Emerging biofuels technologies have dramatic implications for agriculture. While centuries of farming has revolved around producing, harvesting, transporting, selling and processing the seed or fruit of most plants — as is still the case in making corn ethanol and soy diesel — a new era of farming will profit as much or more from harvesting the rest of the plant, while leaving enough on the ground for soil health.**

Where we have spent the last century dramatically improving the durability and yield of corn, for example, nature has spent thousands of years honing the viability of specific species of plants for different regions and ecosystems. Because fuel processing technology is now able to accommodate a wider variety of plant material, society has become better equipped to take advantage of nature's storehouse of highly evolved plants.

The result is that landowners will soon be able to make growing decisions based on what the specific conditions of their land can best support, and on which plant species can optimize their land's commercial, recreational and ecological potential. This invites and allows for a broader and more holistic calculation than simply determining which few commodity crops are likely to fetch the highest price. In the northern plains, this may lead producers to convert underperforming acres now dedicated to commodity crops to growing the very native grasses that once covered the landscape. These grasses have always had enormous ecological value; now, their commercial value will increase as technology advances to the point where industry begins using virtually any product of photosynthesis in the energy and materials economy.

Testing the Northern Plains' Potential

Much of the original research on perennial energy crops has been carried out in the South, with its much longer growing seasons and different soils and precipitation. By contrast, there has been relatively less research and field trials in the Northern Plains to test how energy crops might fair in northern climates. While perennial energy crops seemed promising, there were many unanswered questions.

To get answers, the Great Plains Institute and its partners, primarily South Dakota State University, developed a set of tests that looked at:

1. The environmental impacts of growing and harvesting perennials;
2. Comparisons of higher-yielding cultivars of switchgrass with northern-adapted cultivars;
3. Differences in yield between native warm season grass monocultures and mixtures; and,
4. Best practices for sustainable, long-term management of grass stands.

Adapted Cultivars:
Benefits of plants native to the Northern Plains

The strains of switchgrass most frequently studied and tested for biomass development are primarily southern varieties like Alamo, Shawnee and Cave-in-Rock. These exhibit very high yields in longer growing seasons with significant spring precipitation. This research has found that the colder, harsher climate of the northern plains, combined with a shorter growing season and drier conditions diminishes the grower's ability to sustain southern cultivars over time while obtaining significant yields.

South Dakota State University plant breeder Arvid Boe and his research team have been developing northern-adapted cultivars that will be hardier, produce higher yields and provide better quality feedstocks for energy production in the Northern Plains. To accomplish this, scientists conducted trials of eight cultivars in the eastern Dakotas. The origins of these cultivars ranged from southern Illinois (Cave-in-Rock) to southeastern North Dakota (Dakotah). Three of these proved highly suitable for long-term sustainable biomass production in the eastern Dakotas: Dacotah, Forestburg and Sunburst.

Northern-adapted cultivars were better able to withstand drought conditions, in addition, switchgrass produced appreciable amounts of biomass (at least 1 ton/acre) without inputs during a drought that caused annual crops to fail.

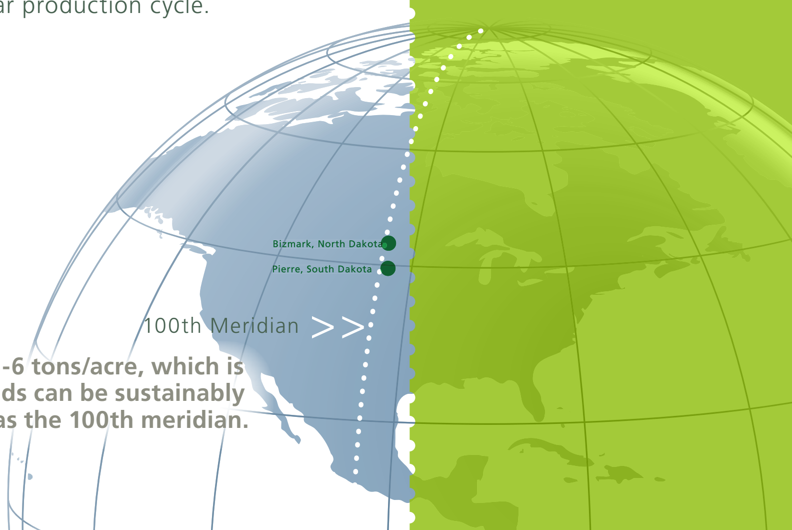
While southern cultivars have longer growing seasons and tend to out-produce the northern varieties in good years, many of the trial plots with southern cultivars were substantially diminished by the third year. The intense drought of 2002, for example, severely curbed stands in that year. The northern-adapted cultivars rebounded back to normal biomass production in the subsequent year while southern varieties did not. Southern cultivars also suffered further winter injury and deterioration than the northern counterparts.

With good management, northern-adapted strains of switchgrass should survive for at least 30 years or longer. Seeding and stand establishment constitutes the most costly part of the perennial grass system, making stand longevity key to the economic success of such a system. To put this in a farm-scale economic context, Arvid Boe and his colleagues at SDSU assert that using native-adapted cultivars, that have a higher probability of long-term survival, could reduce the costs of establishment (seed, fuel and labor) by at least two-thirds over a 10 to 15-year production cycle.

Northern Plains Strategic Advantages

The Northern Plains has key advantages favoring perennial energy crop production, including switchgrass, such as:

- Good growing conditions for certain native grasses well adapted to this region;
- Lots of acreage considered "marginal" for conventional crops yet ideal for native grasses, and lots of idle acres, which could both ease the transition to grass farming;
- Lower-cost agricultural land that is well suited to native grass crops;
- Significant economic potential for birding and hunting, both of which are enhanced with native grass production;
- The potential to sell "carbon credits" based on the ability of native grasses to remove CO_2 from the air during their growth and store carbon in the soil.



Biomass yields in the region can easily range from 2.5-6 tons/acre, which is economically viable given the low cost of land. These yields can be sustainably produced in the northern U.S. plains as far west as the 100th meridian.

BIOM

SUSTAINABLE
THE GREA

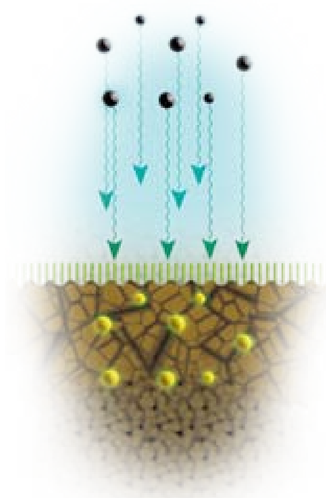
Resilience: Because of their robust root system, native grasses are well suited to marginal land and harsh climates where traditional row crops have been under-performing. Grasses also require fewer fertilizer or chemical inputs.

Minimizing Risk: The ability of grasses to withstand harsh weather conditions common in the northern plains, like drought and early or late freezing, means that having some land in grasses could mitigate the landowner's risk in years with significant conventional crop failure.

Multiple Revenue Streams for Landowner: The production of native grasses could yield multiple revenue streams for a producer, including the sale of biomass, and carbon credits, hunting, birding and other recreation opportunities, and perhaps the eventual sale of the grass seed.

Ongoing Revenue from Biomass: With yields between 3 and 5 tons per acre in marginal areas of the northern plains, a producer could cover costs by selling the grass hay for roughly $25-50/ton at the farm gate. If well managed, those same grasses could continue producing for decades or virtually indefinitely even with regular harvest.

Revenue from Habitat Development: Birding has become among the most important past times and income generators for the northern plains, particularly in North Dakota. The number and diversity of songbirds increases significantly by switching to native grasses and increases steadily as the grass mixture becomes more diverse.



Scrubbing Carbon out of the Atmosphere: Perennial grasses, even well managed monocultures, are good at pulling carbon dioxide out of the air and storing it underground. The amount of carbon sequestered underground seems to be highly correlated with the health of the biomass stand above ground. Grasses can easily sequester 2 tons of CO_2 an acre per year even in marginal soils and with regular harvest of the biomass.

MASS

ENERGY FROM
AT PLAINS

Reducing Tension Between Food and Fuel: Grasses can be grown on land less suitable for other agricultural products, even alongside traditional food crops, reducing the tension between using land for fuel or food.

Soil and Water Health: Grasses' extensive root systems improve overall soil health and water retention, dramatically reducing run off and thereby improving local waterways.

From Biomass to Bio-oil: By converting grass hay into a bio-oil, biomass can provide something akin to crude oil. And as with crude oil, bio-oil can be converted into a variety of fuels and products that are already widely used across our economy. Converting biomass into fuels and chemicals we already use may also take advantage of existing costly infrastructure.

Flexible inputs and outputs: Thermo-chemical processing of biomass, like pyrolysis or gasification, can process a wide variety of biomass feedstocks into a wide variety of valuable outputs like fuels, industrial chemicals, solvents, and plastics.

Keeping Energy Dollars Local: States in the northern plains spend billions on energy imports annually. Locally produced grass-based fuels may be among the best opportunities to keep some of those dollars in the local economy.

Improved Energy Security: Grass-based fuels could greatly enhance our energy security. The lower the total petroleum inputs to a biofuels system, the better suited the fuel is to displace oil. Grasses require among the least petroleum inputs of any dedicated energy crop.

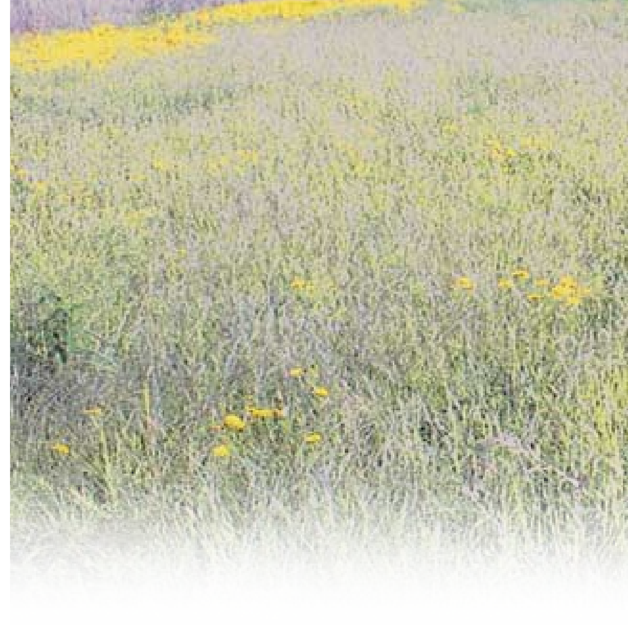
We are only beginning to understand the potential of native grass farming

When one considers that agronomists, plant breeders and biotechnologists have improved corn yields eight-fold over the past several decades, the past few years' of research on switchgrass pales by comparison. We are just starting to understand how these plants function in different conditions and the traits responsible for drought and disease resilience, traits which will be the most critical in selecting for long-term yields.

Arvid Boe and his colleagues, for example, noticed that there was a range of nearly two tons per acre per year between high and low-yielding families, averaged across four years of trials. This significant variation suggests that continued selection within already available cultivars could improve sustainable biomass yields by at least 30 percent. Others are advancing the science on hybrid and bio-engineered varieties that promise far greater annual yield increases.

The observed frequency and density of songbirds increased steadily along a spectrum of plots, from monoculture commodities and warm season grasses to mixed grass stands, where the greatest number and frequency were found.

Research on other perennial grasses, like big bluestem, is even more nascent. While plant breeders have researched the use of big bluestem as a forage crop, the desirable characteristics for forage (small, tender and protein-rich shoots with lots of tillers) are nearly opposite to those for energy feedstocks (large, woody stands with low protein). Even though the big bluestem strains used in our research were developed primarily for forage use, they turned out to have favorable characteristics for fuel processing (discussed later in this report). For example, hay from the big bluestem fields produced more cellulose (or plant fiber) than hemi-cellulose (a sugar that is more difficult to process), and left behind relatively little ash, too much of which can complicate processing. This suggests that big bluestem, while rarely identified as a potential biomass feedstock, may have some natural advantages as a fuel feedstock, especially with further breeding development.



Mixtures vs monocultures

In an attempt to focus national research on native grasses, Oak Ridge National Lab decided in the 1990s that switchgrass would be the best test-case energy crop because of its durability and wide natural habitat (ranging throughout the plains of Canada to Mexico). This focused limited resources to learning a great deal about this one species. While agronomists and plant breeders have since analyzed switchgrass grown primarily as a single species crop, it may now be preferable to build on that knowledge base by learning how to manage it in combination with other grasses, mimicking how it once behaved in native tall grass prairie.

Here again the flexibility of new processing technologies allows scientists and farmers to think beyond traditional agricultural models. Monocultures make sense for very specific commodity markets, but may not be the perfect or only model for serving a fuel feedstock system based on grasses.

Switchgrass tends to grow in bunches, leaving bare ground around the plant that is susceptible to soil erosion when it rains. This so-called "channeling" effect in the soil around the plant can be muted or even eliminated by combining switchgrass plantings with big bluestem and other prairie grasses that fill in those bare spots. Our research to date suggests that big bluestem, in particular, complements switchgrass well and helps with soil retention and quality.

Simple mixtures can produce yields comparable to monocultures

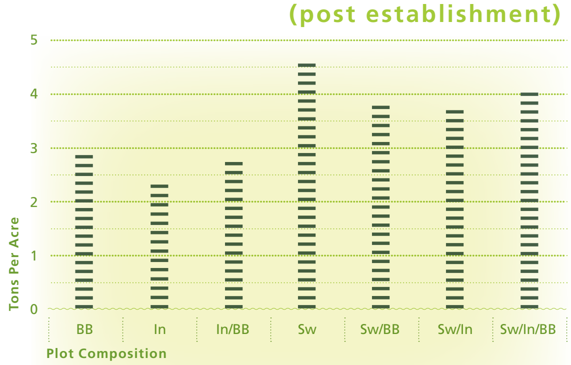
Mixtures of grasses also clearly improve wildlife habitat. Between 2002 and 2004, wildlife biologists studied plant species diversity and its bearing on songbird quantity and diversity on 86 grassland sites from eastern South Dakota to western Minnesota. Both the number and variety of songbirds increased as the diversity of plants increased.

Grass mixtures appear to deliver better ground cover, wildlife habitat, erosion control and water quality. What is less well-known is the impact that harvesting them may have on these benefits, and what sort of yields growers can expect from mixtures. To get answers, researchers established a series of comparative plots across a north-south, east-west grid from western Minnesota into the Dakotas. Plots included monocultures of switchgrass, big bluestem and indiangrass, as well as two and three-way mixtures of those species. All three warm season grasses were selected because of their relative prominence in the native prairie of the northern plains and in the hope that early trials would show that mixtures could eventually prove competitive with monocultures in the region.

While switchgrass monocultures provided the greatest averaged biomass yields in our tests, two-way mixtures of switchgrass and big bluestem were very close. The plots including switchgrass and indiangrass also produced yields at similar levels, but plot composition by the end of 2004 was almost uniformly switchgrass. Although indiangrass proved hard to maintain in simple mixtures, big bluestem and switchgrass complemented each other well. In the first establishment year, switchgrass was the dominant species and in later years big bluestem became more dominant at two of three sites. Although longer-term trials are needed, it seems that both species can be managed together and kept in relative balance overtime. Furthermore, it appears that the two grasses might complement each other by withstanding weather conditions differently, ensuring that if conditions proved poor for switchgrass one year, big bluestem might fare better and vice versa.

The fact that plots with switchgrass had the highest yields is not surprising given that switchgrass has been the nearly exclusive focus of energy crop breeding programs. And as noted earlier, the limited breeding work on the other grasses has focused on forage development. In short, we find these early trials especially promising given that we are at the very front end of breeding work on the various grasses, and only starting to know how to manage large tracts of mixtures for high yields.

AVERAGE GRASS YIELDS
(post establishment)



While switchgrass remained the highest yielding crop, mixtures with switchgrass and big bluestem performed nearly as well.

Best practices for management of native grass stands, in order to both ensure long-term survival of the stand and provide benefits for soil carbon, erosion protection, and wildlife, include the following:

- Harvesting outside the primary nesting season both ensures long-term survival of the stand and does not interfere with nesting birds. It also lowers ash content, which is favorable for processing.
- Harvesting every other year, or no more than half of a stand of grass every year, can ensure habitat protection for birds that prefer undisturbed grass. Ash content is also decreased by every other year harvest.
- Harvesting at anthesis (approximately July) is generally not advised, as it can decrease the longevity of the stand, it results in high ash content, and can interfere with nesting birds.
- Harvesting in the spring may help some bird species by leaving overwinter cover, and does not seriously impact yields.

cutting the grass

Can a harvesting system provide other benefits? Rising oil prices and new federal mandates for biofuels have spurred discussion about how much land, in which locations, might be converted to perennial production of biomass. Primary options include transitioning some targeted lands from commodity crops, pastureland, or idled land much of which is now under the federal Conservation Reserve Program (CRP).

Of the three, much attention has been focused on the CRP because land enrolled in this program is out of production, and thousands of acres will soon be dropped from the program unless farmers renew their contracts with the federal government. Many are unlikely to renew unless they see an economic benefit in doing so, an increasingly uncertain outcome as the ethanol boom pushes corn prices up to tantalizingly high levels.

The prospect of using CRP lands for energy production, however, poses many serious questions. Although some parcels of CRP land are managed better than others, the program as a whole is largely thought to be a success in terms of improving soil health, reducing erosion and providing wildlife habitat. While there is much more to be answered, we posed the following thought experiment through our research: what impacts would more active management and harvesting of CRP grasslands have on soils and wildlife?

Impacts on wildlife

The wildlife benefits of CRP are among those most discussed and most loved by different interests from wildlife and conservation enthusiasts to hunters and sportsmen. Naturally interested parties have expressed strong concern over the impacts of harvesting CRP lands on the wildlife habitat that has been built through the program. While this research cannot provide definitive answers to the very appropriate concerns of such groups, it can help inform future research needs and point to best management strategies that help marry ecological and wildlife goals with our nation’s energy security interests.

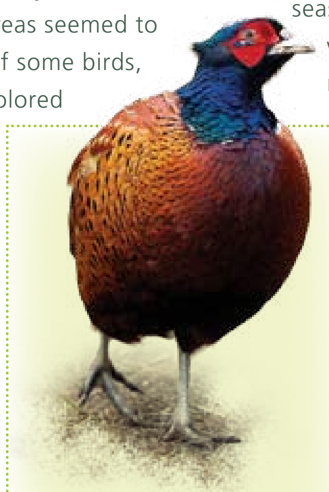
To begin to get an understanding of the impacts of a harvest system on wildlife, we chose to monitor songbird frequency and density because songbirds are reasonably good indicators of overall ecological health and biodiversity. The results clearly highlighted that songbird quantity and diversity of species was highly correlated with plant diversity, with the greatest number and species richness in native warm season grass mixtures.

It would likely follow that the conversion of diverse grasslands to monoculture grasses or, more strikingly, other crops would likely reduce the songbird diversity and density in those lands. Were acres dominated by non-natives or a single species to be converted, the effect of managing for perennial biofuels feedstocks could be the reverse.

In addition to the composition of species, decisions about harvesting impact habitat quality. Harvesting grasslands decreases the height density and litter, or loosely available habitat, for the harvested period. Various songbird species respond differently to harvesting. While the mowed areas seemed to negatively affect the presence of some birds, notably Sedgewrens and Clay-colored Sparrows, other birds like red-winged blackbirds and common Yellowthroat, were found in greater frequency in the mowed areas. Of the eight song-bird species studied, the individual species densities for all other species were not significantly higher in unmowed versus mowed grasslands.

Not only is the simple practice of harvesting important to bird habitat, so too is harvest timing and frequency. While many express concern that harvesting not take place during primary nesting season (typically between April and late-August in the northern plains), the nesting season differs considerably between species and in different regions of the country. The question then becomes: how flexible is the end use of the harvested product to other priority considerations like ensuring adequate cover during a certain species' nesting period?

While there are a variety of processing techniques to consider, we focused on a particularly sensitive thermo-chemical approach called pyrolysis where the composition of the feedstock can dramatically change the fuel and product yields of the process. We found that the most desirable feedstocks for processing were those that had not only been left well through the primary nesting seasons, but had also been overwintered in the field. As the grasses sat in the field providing winter cover for birds and animals, winter snows leached undesirable chemical constituents from the stalks and stems of the plant leaving a more concentrated and valuable biomass feedstock in early spring. And while there were some yield losses, the losses were made up for in process improvements. Perhaps even more telling was that in plots where the harvesting was done before a killing frost, or closer to nesting season, the long-term stand persistence was considerably diminished. These results suggest that managing grassland harvest to protect bird habitat may conveniently also yield the best long-term fuel production results.



Harvesting of grasses can be done in such a way that the environmental benefits of native grasses – including wildlife habitat benefits – are not diminished. Habitat-compatible methods found to provide economically viable yields included post-growing-season harvest of grasses, as well as biennial harvests.

Similarly harvesting practices can be honed to meet joint goals of providing sufficient habitat for wildlife while encouraging long-term grass stand yields. According to Ken Higgens, the wildlife biologist who conducted the bird studies included in this report, the best way to attract the greatest number and diversity of birds while harvesting for biomass will be to only harvest fifty percent of any given plot of land and alternate every year. Vance Owens, lead agronomist on the project, also explains that those plots where his team harvested every other year were the healthiest and showed the best signs of long-term stand persistence. While further study is certainly needed, it may also be that in northern climates alternate year harvests can produce nearly competitive yields in aggregate when compared to annual harvest systems. This may be a unique characteristic of northern climates where the growing season is quite short and should be studied over a longer period of time. Here too the practices that are best for wildlife production might also be best for long-term stand health and biofuels yields.

Impact on soils and carbon sequestration

Another concern is the impact regular removal of the soil-replenishing organic material might have on soil health and carbon uptake. Jim Doolittle and Dokyoung Lee at SDSU have been studying the impact of soil health and carbon uptake on unharvested CRP lands for over a decade. On those same plots of land, the two soil scientists studied the effects of actively managing and harvesting the grasses. After four years, total soil health and carbon sequestration seemed to correlate with the productivity of a given stand of grass. Where the above ground biomass yields were the healthiest, so too were the results underground. In plots where the biomass yields were high and stand persistence strong, the carbon sequestration rate was roughly 4 Mg C ha-1 yr-1, even with regular biomass removal. This is nearly 2 tons/acre/year, or more than double the rate recognized for grasslands in the region.

In sites with relatively lower yields, such as those where agronomists found that too early harvests negatively impacted stand health, soil health and carbon decreased somewhat. In short, practices that improve the above-ground biomass are likely to maintain or increase soil carbon and health, whereas practices that curb above ground biomass overtime will likely diminish soil quality when compared to unharvested acres.

processing biomass

producing products: the role of technology on the landscape

Researchers all over the world, including in the US Departments of Agriculture and Energy, US companies, and industry are working to develop and improve various processes for transforming biomass into value-added products – including biofuels. While there are too many processes to go into detail, they tend to share a common feature. Whether they use enzymes, strong acid or base, or heat and pressure, these processes all tend to break down the complex molecules in biomass into smaller components that can be re-constructed into useful compounds.

Pyrolysis, the technological focus of this study, exposes biomass to heat in the absence of oxygen, along with physical agitation (e.g. blasting the feedstock with hot sand), all within about a second. The biomass vaporizes, and then the vapors are rapidly cooled, or quenched. The resulting dark brown liquid contains a mixture of different chemicals. Often called bio-oil or bio-crude, this liquid resembles conventional crude oil. Yet, bio-oil differs from petroleum crude in some important ways. Unlike petroleum, bio-oil mixes with water. Unlike ethanol and biodiesel, it cannot be blended with petroleum-based fuels. Bio-oil is heavily oxygenated, making it much lower in energy density than petroleum fuels. For example, bio-oil has about half the heating value of residual and distillate oils, which may result in increased costs for transportation and storage.

Various chemicals can be refined out of bio-oil, and it can be used as a low-grade fuel oil. A charcoal-like product called bio-char emerges from the process and can be used as a soil enhancement. Pyrolysis also produces other combustible gases that may have value, if only to provide energy for the pyrolysis process itself.

Bio-oil is used in power generation by several companies and electric utilities in North America and Europe. It has been tested by the Canadian company Dynamotive as a liquid fuel in diesel engines and gas turbines to deliver high-efficiency peaking power to the grid. Another major North American company, Ensyn Renewables (a partner on this research), uses bio-oil primarily for manufacturing various chemical products and for generating energy as a secondary product using relatively conventional boiler technology.

As the technology improves, the potential uses for bio-oil will increase. Potential high-value chemicals derived from bio-oil are likely to include polyphenols for the manufacture of phenol-formaldehyde resins commonly used in fiberboard, calcium and/or magnesium acetate for biodegradable de-icers, levoglucosan and other anhydrosugars for ethanol production, and food flavorings. Ensyn corporation, and their partner Red Arrow, already supply hydroxyacetaldehyde from bio-oil as a smoky food flavoring. According to David Boulard, vice president of Ensyn, the company has also developed and tested a natural resin product from the polyphenol fraction. High value products can increase the revenue for a bio-oil producer and still leave behind residual bio-oil for energy production.

Bio-oil produced from pyrolysis of biomass presents several key challenges that must be managed whether one uses the bio-oil as a feedstock for chemical production or as a fuel. These challenges have been the subject of past research efforts and will likely receive substantial attention by chemical engineers in the future. First, bio-oil is chemically unstable, and can continue to react in storage. This can be dealt with by mixing it with methanol or ethanol. Bio-oil is acidic, and must be stored and processed with stainless steel, polypropylene, or other resistant materials. Bio-oil can gain viscosity in storage, and may need to be heated before use as a fuel.

Challenges notwithstanding, bio-oil has advantages over a raw bale of switchgrass. For example it can be transported more cheaply and easily because of its higher density and liquid form; and it can be processed into chemicals and fuels that have a higher value than raw switchgrass. It is also a relatively simple technology that can be economical at smaller scales.

Hoping to better understand these advantages and begin addressing the challenges, the Great Plains Institute commissioned an evaluation of bio-oil's potential. The research was performed by Ensyn Renewables and the University of North Dakota's Energy and Environmental Research Center. Several key findings emerged from that research:

- Bio-oil can be produced from various native grass species, including switchgrass and big bluestem. It is possible to achieve yields as high as 71 percent, similar to those achieved with wood.
- Different grass species produce bio-oil with different characteristics. For example, one high value chemical was twice as abundant in big bluestem bio-oil as in switchgrass bio-oil. Other chemicals were more abundant in switchgrass. This suggests that research should be conducted on a variety of grass species or mixtures of grass species.
- The highest bio-oil yields are achieved with grasses that are low in potassium. Grasses have lower potassium levels when harvested in the spring, winter or fall because grasses pull nutrients into their roots outside of the growing season, and minerals leach out of the grass over the winter. Harvesting outside of the growing season also helps ensure habitat for nesting birds and long-term survival of perennial grass stands. This finding supports an exciting synergy between industrial processing, native grass harvest, and habitat conservation and biodiversity.
- Impurities in the sugars prevented good fermentation with grass-derived bio-oil, but fermentation was possible with bio-oil derived from wood. One component of bio-oil is a type of sugar called anhydrosugar. Although a technique was developed to extract these from bio-oil, and to convert them to fermentable sugars, the researchers were unable to sufficiently purify the sugars from grass-based bio-oil.

COMPARATIVE FUEL PRICES

Energy Source		Theoretical Price	Average 2005 Electric Utility Price ($/MMBTU)	Average 2005 Price All Sectors ($/MMBTU)
Switchgrass[1]		$2.50		
Comparable Fuels	Coal		$1.52	
	Petcoke		$1.10	
Switchgrass Bio-oil[2]		$8.60		
Comparable Fuels	No 2. Fuel Oil		$11.30	$12.74
	Residual Fuel Oil		$6.57	$7.53

[1] Assumes $40/ton Switchgrass
[2] Assumes $40/ton Switchgrass, 20 ton per hour plant
** Source: Doug Tiffany, University of Minnesota*

Processing descriptions:

Enzymatic Hydrolysis and Fermentation

A tailored cocktail of enzymes help breakdown cell wall structure and produce sugars available for yeast fermentation into bio-ethanol.

Thermo-Chemical

Cellulosic biomass is fed into a reaction chamber which uses a combination of heat and pressure to break down cell structure.

Biomass gasification, using high temperature and pressure yields a gas similar to natural gas and composed primarily of CO and H2. This gas can be cleaned and used as a substitute for natural gas or it can be converted into an array of biofuels including alcohols, dimethylether, fisher tropsch liquids or hydrogen.

Fast Pyrolysis, a similar but lower temperature and pressure system, uses the heat and pressure to partially break down cell structure. The material is quickly cooled with a fast quench and the resulting products include a bio-oil, gases and a bio-char (that can be used as a soil enhancement). The bio-oil is analogous to crude oil and can be further processed or refined into a variety of liquid fuels and industrial chemicals.

evaluating the economics of fuels, chemicals and power from native grasses

In the third and final component of the research, the University of Minnesota's Douglas Tiffany and Vernon Ruttan led a team of graduate students to investigate the costs involved in growing, transporting, storing, and processing native grasses to produce useful products – particularly energy products. This analysis aimed to determine whether a native grass-based industry can be economically viable for farmers, industry, and consumers. The answer seems to be yes. Native grasses can be grown in the Northern Plains at reasonable cost with reasonable returns to producers. Native prairie grasses can be cost-effectively transported in sufficient volumes to support large industrial plants. At least one process – pyrolysis – can convert native grasses to several marketable products at competitive costs.

The research team calculated grass production costs based on interviews with producers, data provided by the agronomists involved in this research and studies of the literature. Native grass crops can be produced for between $25-50/ton, depending on a variety of factors *(see table to the right)*. This assumes one establishment period and determining factors include land cost and yield of grass on an acre of land. The research evaluated different Northern Plains counties with varying yield capability and land costs — Lincoln County, MN; Marshall County, SD; and Eddy County, ND — in order to get a representative sample of lands and cost factors.

A transportation model was devised to determine whether large quantities of grass could be brought to a plant using only land enrolled in CRP. A site in eastern North Dakota was selected for its proximity to abundant acreage enrolled in the program. Only acres within 50 miles of the plant were considered. Acreages designated with high priority for wildlife or wetlands conservation were excluded from the analysis.

This analysis reveals that it is possible to obtain between 400,000 to 800,000 tons of native grass biomass within a 50 mile radius of a plant in eastern North Dakota ND (and in many similar areas). To add context, 800,000 tons per year would supply approximately a 60 million gallon per year cellulosic ethanol plant, a scale comparable to many corn ethanol plants being built today. On average, transportation will cost less than $10/ton. The further you go from the plant, the higher the cost of gathering enough biomass for a large-scale facility.

The researchers also evaluated the economics of pyrolysis processing. Turning switchgrass into bio-oil (via pyrolysis) costs four times as much as using the switchgrass directly on a per-unit-of-energy-produced basis. Why pay this penalty? Because it also raises the value of the raw material by allowing it to compete in other markets *(see table on page 15)*. Baled switchgrass can only compete with coal, and not very well at nearly twice the cost per unit of energy. Bio-oil, on the other hand, is nearly cost-competitive with residual fuel oil, and is considerably cheaper than No. 2 fuel oil (diesel fuel). And this is without the benefits of large-scale processing that also yields chemicals of even more value than any of the energy products. The production of high-value chemicals will improve the economics of bio-oil further, which is why companies like Ensyn Renewables began their business by producing and selling chemicals rather then energy.

TOTAL COST PER TON

Scenario	**Lincoln, MN**	**Marshall, SD**	**Eddy, ND**
Scenario t/acre	5	4	3
A, no land rent	$22.56	$23.92	$24.43
B, no and rent	$27.45	$29.52	$29.43
A, reduced	$25.79	$26.94	$27.20
B, reduced	$30.69	$32.54	$32.20
B, full rent harvest year	$40.39	$41.59	$40.52
A, full land rent	$35.49	$35.99	$35.52
B, full land rent	$53.32	$53.66	$51.61

A = annual harvest B= biannual harvest

In Summary:

Native grass agriculture can make a significant contribution to at least four pressing national issues: the nation's dependence on oil in the transportation sector; worldwide growth in the demand and competition for that oil; the need for low or zero-carbon energy production that does not worsen global warming; and the need to diversify and reinvigorate rural economies. On this latter point, native grass production could mean increased farm income through the sale of native grass hay, the creation of millions of acres of improved wildlife habitat and the recreation and tourism opportunities that brings, not to mention the potential for future carbon sequestration payments.

In addition, native grass agriculture promises landscape-level benefits in water quality, soil health and biodiversity. It is sustainable development in the truest sense because it allows agricultural producers to improve their economic prospects while actually enhancing natural resources and amenities for society as a whole.

For More Information about this Report:

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About the Great Plains Institute:

The Great Plains Institute is a regional non-profit organization that brings together key public and private leaders from across the region to identify policies, projects and research that will accelerate the transition to a renewable and carbon-neutral energy system by mid-century.

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