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Project Title: Lowering the Cost of Bio-energy Feedstocks while Providing Environmental Services – A Win-Win Opportunity

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MILESTONE REPORT

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Executive Summary (Period between 10/23/2010 and 4/22/2011)

Project progress continues according to plan. We had a delay in the work on ash application but that has been resolved and that work is moving ahead. Research on moisture content of perennial grasses showed greater than 40% moisture content on 3 different harvest dates between September and March indicating a need for drying of the biomass irrespective of the harvest date. When analyzing dry matter yield across a similar range of harvest dates, there was very little difference in dry matter content indicating that waiting to harvest over the winter would have minimal impact on dry matter yield. Concentrations of minerals in the biomass declined over the same period. We have some preliminary results of the modeling work on watershed impacts of perennial biomass crops. Based on work done elsewhere in the region, prairie grass residue has the ability to reduce annual water flow by about 25% when compared to corn fields and that information has been incorporated into our models. Measuring the nutrients coming off of drained corn and soybeans and comparing that to water leaving a restored wetland shows significant mitigation of nitrate loading after the water moves through the wetland complex. Our models also indicate a decline in water yield from perennial crops with and without harvest when compared to corn/soybean systems. Over the last reporting period we prepared, and distributed a survey to 1,000 landowners in a 9 county fuelshed area for KODA Energy and the Madelia project. We had a 50% response rate and have started an initial analysis of that data. Initial results suggest that up to 18% of the landowners questioned about willingness to accept a net per acre loss in benefits would be willing to plant perennial crops even if the net benefit from those acres was less than what they are currently receiving. More detailed information on the results of the survey will be included in the Milestone 6 report.

The project goal is to develop an efficient system for the production, pre-processing and delivery of biomass feedstocks for energy production that minimizes feedstock cost for energy facilities while maximizing landowner income and the environmental benefits of biomass production.

The project objectives are:

- Establish, research cultural practices, and estimate costs and potential cost savings for the establishment, management, pre-processing and transport of perennial biomass feedstocks from field to energy facility.
- Estimate potential energy, wildlife, water quality, carbon and soil health benefits from targeted perennial biomass feedstock plantings.
- Value environmental benefits for potential payments to landowners who provide environmental commodities.
- Complete an integrated assessment of multiple ecological services markets currently being used; identify potential buyers of ecological services provided by perennial biomass energy crops; develop an integrated ecological services payment package.
- Develop a model for the production, pre-processing and delivery of perennial biomass feedstocks to energy facilities including a life-cycle assessment of the system from field to facility.

Technical Progress:

I. Biomass crop production field to farm gate

We are developing guidelines for production of biomass from native perennial crops. The biomass is intended for energy production. These research activities will help us understand issues in producing biomass crops on farm from planting through harvesting.

Experiment 1: Establishment strategies for weed control

Objectives: Weeds often provide excess competition with native grasses and prevent their establishment. Our goal is to develop new approaches for weed control in establishing native perennial grasses and grass-forb polycultures. Establishment treatments include spring oat, and barley companion crops, herbicides, and mowing for weed control.

Experimental design: Randomized complete block with three replications

Accomplishment: no new data to report from the 2010 seeding. We will repeat this trial in 2011. We will provide a complete summary of all years of the study in the next report.

Experiment 2: Optimum planting dates for native perennial crops

Objectives: There is debate regarding the best time to establish native perennial prairie plants. Some feel that winter and late spring overseeding is an effective and low cost approach. We determined the effect of planting date on the establishment of native perennial plants.

Experimental design: Randomized complete block with three replications

Accomplishment: We broadcast seeded a mixture of switchgrass, big bluestem and Indian grass with four native forbs and four native legumes on three dates: early December 2010 before snowfall; and March and June (to be completed) 2011. To provide variable amounts of cover, we also compared seeding into a tilled seedbed with seeding into a fall-seeded oat companion crop. The seeding rate of the native plants was 50 seeds per square foot. The plots were seeded on a silt loam soil at Rosemount.

There is no new information to report for this Experiment. Beginning on 1 December 2010, and March and June 2011, we are repeating this experiment at Rosemount and Waseca, Minnesota. A summary of the 2010-2011 results will be provided in the next report.

<u>Experiment 3:</u> Optimum harvest dates for native perennial biomass crops: (See Appendix A for more detail)

Native plants are typically harvested for biofuel after a killing frost in November, requiring long-term storage of the harvested biomass. With outside storage, plant biomass degrades and suffers from a loss of dry matter. Instead of storage, an option is to have multiple harvests of forage from the field.

Objectives: Determine the effect of harvest date on the yield, energy content, ash content, and persistence of native perennial grasses and grass-forb polycultures

Experimental design: Randomized complete block with 4 replications. We sampled plantings of switchgrass and native plant polycultures on four dates of harvest: September, December, March, May (before green-up). Samples were collected from four locations.

Accomplishment: Biomass samples have been collected for the September and December 2010 harvest dates, as well as for the March 2011 harvest date. Additional samples will be collected in May 2011. September and December harvests have been subjected to mineral and nutrient analysis and moisture content and yields of biomass have been calculated for September, December and March harvests (see appendix).

We found that moisture content of biomass was greater than 40% on all dates. Typically moistures of 20% are desirable for safe long-term storage. Drying of wet forage will require additional energy costs during processing.

We found that during the dormant season from December to March, biomass dry matter yield either did not change or declined somewhat depending on the location. This means that producers can leave biomass in the field with little concern about dry matter loss.

We found that the concentration of minerals declined somewhat from September to December as plants became dormant, we anticipate observing a further decline during overwintering from December to March (samples to be processed). It is likely that the decline in mineral concentrations is due to those minerals being transported into the root system as the plant goes dormant. This offers some advantages as a biomass feedstock as minerals in the biomass can lead to increased emissions into the atmosphere or may contribute to fouling during gasification or combustion. Since the research demonstrates limited degradation of the biomass plus a decline in mineral concentrations, there may be some advantages to a harvest during the dormant season. Nonetheless, it remains to be seen if these relationships continue over the life of the project.

<u>Experiment 4</u>: Fertilizer replacement value of biofuel ash: (See Appendix A for detail)
The combustion of herbaceous biofuels will generate a significant amount of ash that is often considered a waste product but that potentially could have value as a fertilizer. Recycling of this ash to the soil will be an environmentally sound practice that also provides a productive use of the ash generated by combustion.

Objective: The overall objective is to answer fundamental questions related to the agronomic use and potential environmental impacts of ash generated from combustion of herbaceous native perennial biomass at the Rahr Malting facilities.

<u>Accomplishment/update:</u>

We initiated activities to produce ash from combustion of native prairie grass hay. Ultimately, the ash will be used to conduct field studies to measure crop to use of ash nutrients as a fertilizer. Preliminary analysis of burning properties and elemental composition was conducted on two hay bales from prairies with varying botanical composition. These results are shown in the Appendix. Both hays had similar moisture (about 5%), energy content, and elemental content. They contain about 5% sulfur that can be an issue during combustion. Based on ash content of fertilizer nutrients such as K, P, Ca, and Mg, it appears that the ash will be important when used as a fertilizer.

We have transported ten 800 lb bales of prairie grass hay to the University of Minnesota Morris campus for incineration. Although a portion of these bales will be used for calibration of the incineration unit, we hope to generate about 150 lb of clean ash for use in field research in summer 2011.

II. Moving biomass from road/farm gate to facility

This activity will be undertaken by Koda Energy. Some of the work was initiated prior to the project start date as part of their commercial operations but they continue to evaluate other options for supplying biomass to their facility. Information from Koda Energy will be incorporated into the Life Cycle Assessment and as part of our supply chain analysis.

Koda continues to evaluate surge facilities options for the processing, drying and delivery of biomass. We have capital and operational cost estimates complete for such a facility. We are looking at locations in Scott, Hennepin, and LeSueur counties. Our partners are in the process of building an organic compost facility on their tribal lands for food and other agricultural material composting. This may be a natural fit to expand it to include Koda fuel storage, processing and delivery. This option is currently being researched by the Koda partners.

III. Measure and value environmental benefits

In this area we will measure and evaluate the specific impacts of biomass crops on the environment including: 1) changes in grassland songbird populations on areas planted and managed for biomass feedstocks; 2) changes in water quality parameters (turbidity, sediment, nitrogen and phosphorus concentrations); 3) register values reflected in emerging ecosystem markets for water quality and carbon and others as they emerge such as biodiversity; and 4) preparation of a life cycle assessment which allows us to estimate environmental impacts associated with the production, harvest and combustion of biomass crops including an evaluation of resource use and emissions as the crops are produced, transported and combusted.

A. Wildlife impacts

Overview of 2010-2011 Accomplishments

During this project reporting period, our project was in the winter season and, due to winter migrations, there are no songbirds to monitor.

Planned Activities for 2011

Songbird surveys will be initiated at the Shakopee plantings in the spring of 2011. We will conduct surveys on 20-acre (approx. 8 ha) plots. 50% harvest and block versus strip removals will be conducted to determine the impact of biomass harvest on songbird populations. Each plot will be surveyed twice using an area-based search method that covers the entire plot (Johnson and Igl 1995). Many birds will be detected primarily by their songs, but others may be detected by both sight and sound. Data from these plantings will be combined with the LCCMR data to test for overall effects of biomass removal on long-term dynamics of grassland bird communities.

B. Water quality assessment

Overview of 2010-2011 Accomplishments

Streamflow and water quality data collected from the Kittleson and SHEEK sub-watersheds of Elm Creek up to late summer of 2010 have been summarized up to August 2010. The flow data have been used to calibrate a revised version of the SWAT model that is capable of simulating the storage and interception losses of residue associated with prairie grasses. Based on previous studies, prairie grass residues interception can reduce annual flow by as much as 25% in contrast to corn fields. With the capability of better representing interception losses of prairie grass systems, we will be able to represent the changes in flow associated with different conversions from corn to prairie grasses over the landscape.

Water Quality Summaries from Monitoring:

Nitrate concentrations from tile drainage in corn-soybean fields (W2 and W4) sub-watershed ranged from 1.52 $mg{\cdot}L^{-1}$ to 23.3 $mg{\cdot}L^{-1}$ with early season values generally above 10 $mg{\cdot}L^{-1}$. During the drainage season, mean nitrate concentrations were 18.3 $mg{\cdot}L^{-1}$ and 20.1 $mg{\cdot}L^{-1}$, respectively, from drain tiles leaving W2 and W4, but during the growing (ET) season, concentrations were slightly lower, averaging 14.9 $mg{\cdot}L^{-1}$ and 17.3 $mg{\cdot}L^{-1}$ (Table 1).

Table 1. Nitrate mean (S.D.) concentrations for study years 2005 – 2010

Season	W2		W4		W5	S1	S2
	Surface	Tile	Surface	Tile		(2005-2008)	(2005-2008)
Runoff	12.1 (6.2)	18.7 (2.0)	15.6 (6.1)	20.1 (2.7)	3.3 (1.8)	0.3 (0.3)	4.4 (3.2)
ET	N.A.	14.9 (3.7)	N.A.	17.3 (4.0)	0.2 (0.5)	0.2 (0.8)	4.4 (1.5)

Samples taken from the perennial vegetation – wetland complexes (W5, S1 and S2) that receive water from corn-soybean fields (represented by W2 & W4 in Table 1) mitigate nitrate loading and export much lower nitrate concentrations to Elm Creek both during the pre-growing “drainage” season and the growing season (ET season in Table 1)..

Loadings of Total Suspended Solids (TSS), Nitrate (NO3), total phosphorus (TP) and orthophosphorus (OP) for 2009 – through august of 2010 are summarized for the spring – drainage season (Table 2) and the growing season (Table 3).

Table 2. Total Loads for Drainage Season (4/14 - 6/30) of 2009-2010

Site	Area ha	Volume m^3	TSS kg	NO3 kg	TP kg	OP kg
S1	563	50639	254.84	11.84	6.23	3.94
S2	1654	195593	751.40	1419.83	20.14	23.57
W3	290	88421	0.01	1725.25	0.35	4.59
W5	652	100588	978.72*	106.29	14.65	5.73
W7	164	49543	1.16	773.54	0.93	2.76

* Windy conditions in the shallow water body during sampling increased TSS.

Table 3. Total Loading for growing (ET) season (7/1 – 9/30) of 2009-2010.

Site	Area ha	Volume m^3	TSS kg	NO3 kg	TP kg	OP kg
S1	563	41373	94.27	9.04	10.25	7.95
S2	1654	247206	605.06	969.17	51.70	50.87
W3	290	51596	0.00	1057.14	0.06	2.60
W5	652	79420	1043.38*	66.50	36.22	24.72
W7	164	28855	52.16	500.25	0.84	1.72

* Windy conditions in the shallow water body during sampling increased TSS.

Simulating Conversions from Annual to Perennial (potential bioenergy) Crops

With the modified SWAT model the plan for the next 6 months is to examine potential hydrologic and water quality changes associated with conversions from corn-soybean crops to perennial bioenergy crops. GIS analysis on the entire Elm Creek watershed has been used to delineate potential sites that are deemed more suitable for perennial crops than annual crops, based on slope and proximity to water bodies. Beginning with the sub-watersheds that have been monitored over the past 5+ years, different scenarios of changes in cropping systems will be examined in terms of changes in water flow and water quality.

One scenario of converting corn-soybean fields to prairie grasses in the Kittleson subwatersheds has been developed using the calibrated SWAT model (Table 4). The model was calibrated for total water yield and surface runoff and tile flow for 2006-2009. The calibrated model was then run from 1995-2009. The prairie grasses reduced flows associated with corn crops under both a bioenergy harvesting scenario and an undisturbed prairie condition (Table 4). With the prairie grass - harvested scenario we simulated the effects based on 90% residue removal in contrast to the natural grass system in which there was 0% residue removal. Changes in annual flow, evapotranspiration (ET) and Q/P (the ratio of annual flow/annual precipitation) are illustrated in figure 1-3, respectively. Addition scenarios of perennial vegetation changes will be examined as well as larger scale bioenergy plantings in the SHEEK sub-watershed of Elm Creek.

Table 4: Mean Annual (Apr-Oct) Results Comparison of 15-yr Simulations

Scenario	**Precip (mm)**	**ET (mm)**	**Total Q (mm)**	**Surf Q (mm)**	**Tile Q (mm)**	**Base Q (mm)**	**Q/P (mm/mm)**
Corn/Soybean	613	536	116	26	86	4	0.19
Prairie conversion (90% harvest/10% residue)	613	549	95	18	74	3	0.15
Prairie conversion (0% harvest/100% residue)	613	605	47	8	37	2	0.08

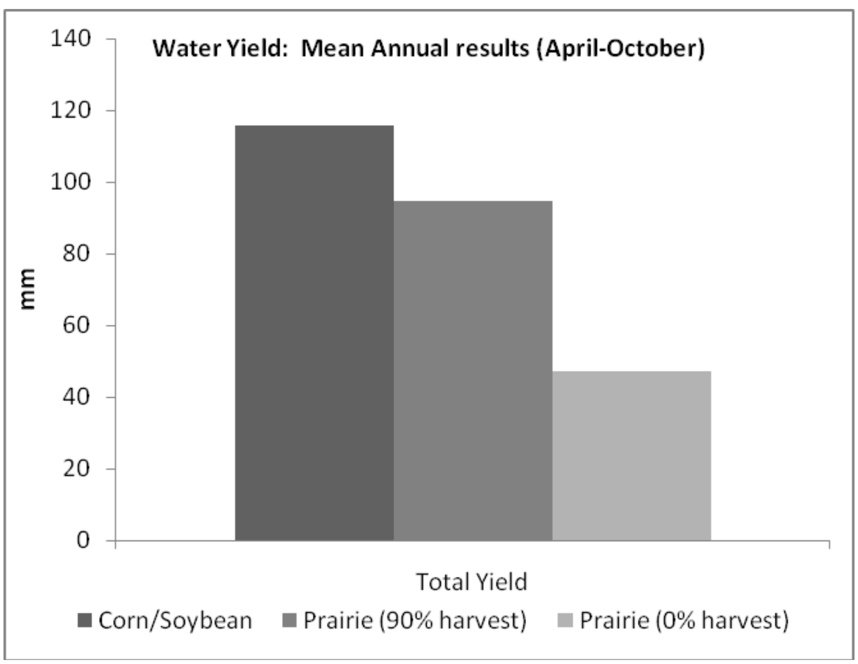

Figure 1. SWAT model simulations of differences in mean annual water yield for the Kittleson sub-watershed of Elm Creek.

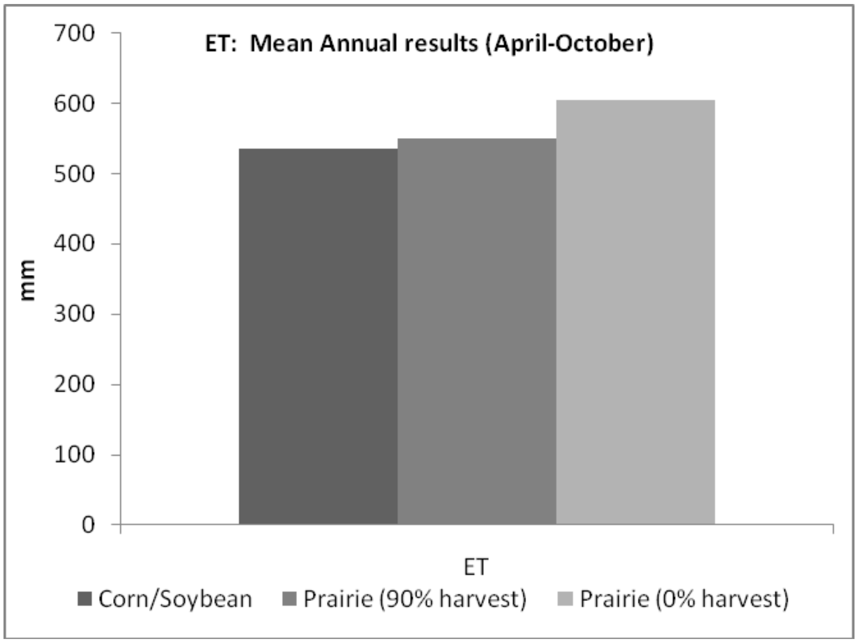

Figure 2. SWAT model simulations of evapotranspiration (ET) differences for the Kittleson sub-watershed of Elm Creek.

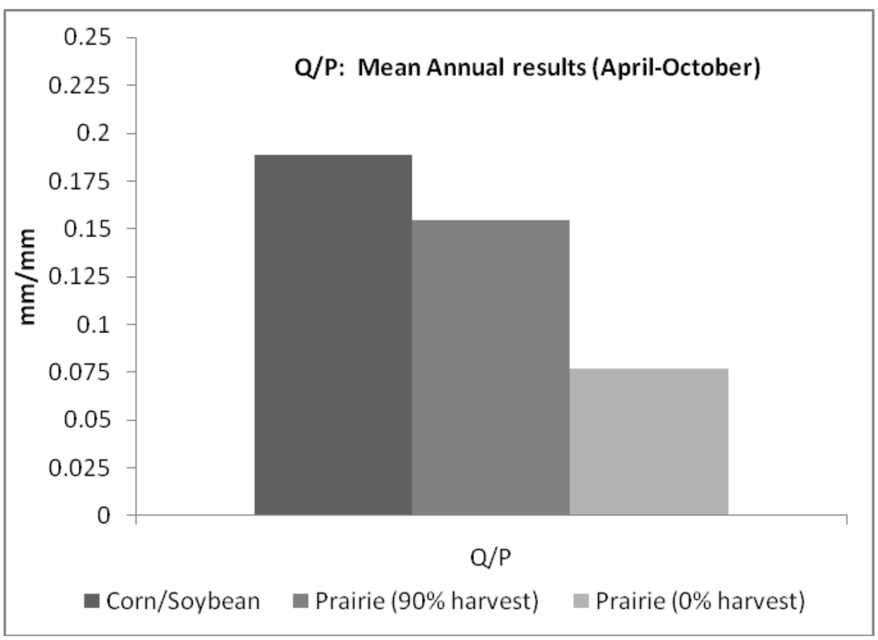

Figure 3. SWAT model simulations of differences in the ratio of mean annual water yield (Q) over mean annual precipitation (P) for the Kittleson sub-watershed of Elm Creek.

Planned Activities for 2011

Modifications have been made to the SWAT model so that it can better predict the hydrologic and water quality response of perennial bioenergy crops on Minnesota's agricultural landscape. The modified SWAT and a tier one approach will be used of estimate the changes in water flow, nitrate nitrogen and sediment associated with different percentages of perennial bioenergy crops (replacing existing corn-soybean crops) on watersheds of Elm Creek, a tributary of the Blue Earth River. The intent is to determine thresholds of change at different scales to estimate what might realistically be expected in areas that are better suited for perennial crops than current annual crops.

Using stream channel monitoring data and previously determined methods of assessing stream channel stability, an effort will be underway to develop a method of assessing potential for rehabilitation efforts in Elm Creek and Center Creek. Because the major source of sediment, associated phosphorus, and turbidity in these streams is derived from channel bank erosion, this work will complement the changes in watershed crop conditions as determined from (1). To achieve the maximum hydrologic and water quality benefits associated with bioenergy crops, both watershed and the riparian channel -floodplain system improvements will be needed. The channel assessment work also will complement the riparian buffer plantings that are part of a complementary research effort.

C. Integrated assessment of ecological service markets

Overview of 2010-2011 Accomplishments

The Ecological Services Team continues to meet as needed. To date the team has accomplished the following:

- IATP market assessment: IATP continues their work and will be working on identifying new markets and changes in existing markets.
- Rural Advantage has finished their work on ecosystem markets but continues to work on those issues as part of their ongoing work and contribute to this project.
- The University of Minnesota together with Rural Advantage prepared and sent out a survey to landowners in a 9 county area to identify constraints to adoption of perennial (grasses and woody species) biomass cropping systems. In this reporting period: 1) the survey was mailed out to 1,000 randomly selected landowners in the 9 county area; 2) follow up reminders and additional surveys were distributed; 3) we received a roughly 50% response rate (over 500 responses); 4) initial analysis of the data was undertaken.

Planned Activities for 2011

In the Milestone 6 reporting period, the two graduate students involved in the survey will be presenting preliminary results at seminars in the University as well as at National and International meetings over the summer.

We will continue to analyze the survey results and report on those findings. Final analysis of that data will be reported in the Milestone 6 report.

D. Life cycle assessment

Overview of 2010-2011 Accomplishments

As a proxy of further LCI updates, initial LCA module was developed. LCA team has constructed Life Cycle Inventory (LCI) of barley grain and forage, and switchgrass at farm stage and will add LCI of cultivating and harvesting oat grain and forage and Canada wildrye. Upstream productions of nitrogen, phosphate, potash fertilizer, atrazine, and energy (gasoline, diesel, propane, natural gas, electricity) were added to LCA module. Direct emissions of use of all the inputs will be added from other research groups. Transportation distance between feedstocks at farm to biomass power plant is assumed to be 50 miles (80 km). The LCI of includes manufacturing truck use in transportation and their energy use for the transportation to biomass electricity plant. Emissions data for bio-electricity conversion with Combined Heat and Power (CHP) will be provided by Koda Energy.

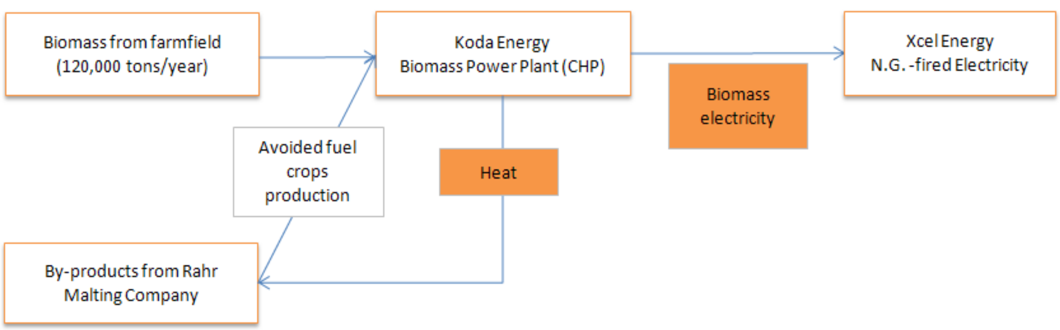

Figure1. Schematic Process Flow of Biomass Electricity at Koda Energy

Koda Energy receives 170,000 tons of fuel mix per year, which is mixture of barley grain and forage, oat grain and forage, Canada wild rye, and switchgrass. Of the total fuel mix, 120,000 tons is supplied by local agri-business, dried wood waste products, and dedicated energy crops and 50,000 tons by by-products in malting process at Rahr malting company.
Since the Koda Energy produces heat for Rahr Malting Company and electricity sold to Xcel Energy, the two products will displace the use of natural gas for electricity generation in Xcel Energy and the use of petroleum fuel for heat production in Rahr Malting Company. Thus, displacement method (system expansion) is being applied to assess avoided environmental impacts of biomass electricity as environmental benefits. The displacement methods will vary by allocation methods (based on energy content and market value of heat and electricity) to analyze environmental potent credits of Koda's biomass electricity.

Planned Activities for 2011

The displacement method is useful to determine environmental benefits of heat and electricity produced in the Koda Energy. The co-products in Koda Energy are heat and electricity sold to the Rahr Malting and Xcel Energy. Ash waste generated from the biomass combustion process at Koda Energy is sent back to farm and used for fertilizer replacement. Thus, the avoided fertilizer production will be accounted for.

Due to seasonal variation of feedstock availability and the fact that Koda Energy is not yet burning grasses but combinations of biomass, the current LCI for Koda Energy encompasses constant flow of biomass to their facility with a variety of sources of biomass. The current mix of biomass being used by Koda does not necessarily reflect the range of feedstocks contemplated in this project. Accordingly, the LCIs of farming switchgrass and the other five perennial grasses identified by our project are currently being modeled by quantifying resource and energy use based on information provided by the other teams through their data and test burns currently being undertaken. That information will be added into our current proxy LCA module.

After integration of all the full life cycle inventory data, initial Life Cycle Impact Assessment will be able to assess significance of environmental impacts of biomass electricity generation system by the type of bio fuels, by life cycle stages, and by category indicators, e.g. global warming, eutrophication, acidification, etc.

Data collection has continued and good progress has been made. There is still some data that is needed but that is being worked on. During the next milestone period our LCA team will meet with other project team members to fill in any missing information and start identifying scenarios that will be used for the final LCA analysis and report.

IV. Economic assessment of biomass production and delivery system

This research area looks at the financial and economic aspects of biomass production from the perspective of the landowner/farmer who may be interested in producing biomass feedstocks for the market and also the value of the environmental services (water quality, recreation, carbon) to society both qualitatively and quantitatively.

A. Cost Benefit Analysis – Plan activities and begin data collection

<u>Overview of 2010-2011 Accomplishments</u>

We have been able to aggregate data from primary and secondary sources to estimate costs of production and transport of biomass crops to a biomass using facility. We will be able to estimate costs and benefits from the production of the biomass crops as well as their use in two different types of facilities: 1) the KODA Energy facility in Shakopee; and 2) a portable pyrolysis unit compared to different scale-up options that would be available to individual producers on a farm scale in a co-op model or at a central unit that would collect and process biomass from many farms into a bio-oil.

In addition to our estimates of the costs of production and delivery of biomass crops, we now have estimates of the potential value of ecosystem services based on a review of relevant literature combined with measurements from our water projects (water quality improvements, air quality improvements and carbon benefits). As previously discussed, the impacts on songbirds will be available later in the project as additional data will be gathered from mature perennial plantings established by the project.

Appendix B contains a table of some of the values we are using for ecosystem services from perennial crops for the economic analysis that will be explained in more detail in the report that will accompany the Milestone 6 report.

Planned Activities for 2011

We will prepare our preliminary report of the economic analysis. The report will be prepared in a manner that will allow us to easily update it as new information on the impacts and their values become available. Some of that new data will come from the emerging markets for ecosystem services. We will continue to gather and incorporate new economic information as it becomes available. This is a rapidly developing area of research which will allow us to update our information and incorporate the most up to date information in our reports.

B. Valuation of ecological services

Overview of 2010-2011 Accomplishments

This will continue to be done in coordination with **IIIC** above. Results from **IIIC** will be used to help determine how the public values ecological services which will allow us to use those values for our analysis. In addition to the information gathered through the survey, we will be gathering data on the emerging markets for carbon and water quality credits. Linda Meschke is involved in a USDA Conservation Innovation Grant project which is studying payments for environmental services in the Minnesota River Basin and Dr. Bill Easter and Dr. Dean Current on our team continue to serve on the National Advisory Committee for that project which will provide another source of information for this work.

Planned Activities for 2011

We will continue gathering data on existing options for payments for environmental services as well as new initiatives. This information will be combined with the data generated through the survey instrument.

Project Status: The project continues to meet the timeline with some minor delays but with good progress in most areas.

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Appendix A – Detail for Objective 1, Experiments 3 and 4:

Experiment 3. Optimum harvest dates for native perennial biomass crops: Biomass moisture content and yields

Procedure Summary

Four replicate samples of a switchgrass monoculture and a native prairie polyculture were harvested at each of four sites on each harvest date. A 1 m^2 area was harvested for each sample and fresh weights were obtained in the field. The samples were then dried to a constant weight in a 140ºF oven and dry weights were obtained. Biomass moisture content and dry matter yield were then calculated.

Harvested biomass was also dried, ground and subject to analysis for mineral content (P, K, N, Ca, Mg). Nutrient analysis has been conducted on September and December biomass samples, while March and May samples have yet to be analyzed.

Results

Table 1 shows the average moisture content of harvested switchgrass and prairie polyculture biomass harvested on three dates at four Minnesota locations. In general, moisture content of biomass increased at each harvest date.

Table 1: Percent moisture of harvested biomass

	Location	September	December	March
Prairie mixture	Becker	48.4	58.2	61.6
	Rosemount	43.3	50.7	63.3
Switchgrass	Becker	44.6	56.6	54.9
	Rosemount	47.2	55.0	84.1

Table 2 shows the average biomass yields (tons per acre) of harvested switchgrass and prairie polyculture biomass harvested on three dates at four Minnesota locations. The Austin site exhibited greater native prairie biomass yields than Becker and Rosemount, while the Rosemount site exhibited greater switchgrass yields than the Waseca or Becker sites. On average, switchgrass was higher yielding than the native prairie mixture.

Table 2: Weed-free biomass yield (tons dry matter per acre)

		September	December	March
Prairie mixture	Becker	0.8	0.7	1
	Rosemount	2.2	1.6	1.7
Switchgrass	Becker	0.8	0.9	1.1
	Rosemount	4.3	5.5	4.5

Table 3 shows the average nutrient composition of prairie biomass harvested on two dates at two Minnesota locations. Results were averaged over locations because of a lack of location effects. In general, mineral concentrations decreased from the September harvest to the December harvest date, except for sodium, which remained the same over this period. Concentrations of metals increased as a portion of total dry weight (parts per million) from September to December.

Table 3: Prairie Biomass Nutrient Content

	September	December
%N	0.62	0.56
%P	0.11	0.06
%K	0.52	0.18
%S	0.06	0.04
%Ca	0.43	0.42
%Mg	0.12	0.10
%Na	0.01	0.01
Zn*	23.15	24.14
Fe*	114.18	175.82
Mn*	69.56	77.25
Cu*	8.29	9.75
B*	11.14	12.68

*parts per million

Experiment 4. Fertilizer replacement value of ash

Results are from a detailed analysis of energy and ash properties of samples from 2 native prairies (plot 2 and 20). Results for plot 2 and plot 20 were relatively similar. The information is important for characterizing use of native plant biomass for energy generation in combustion systems.

1. As-Received Moisture Content

Procedure Summary

A 10 gram sample was oven dried at 105° C for three hours. Sample was weighed pre- and post-test.

Results

As-received moisture content was approximately 4.3-6.8%. See Table below.

Table 4: Prairie Grass Moisture Content

Sample	Type	Moisture Content	Average
Plot 2	Oven Dried A	4.9%	**4.5%**
	Oven Dried B #1	4.3%	
	Oven Dried B #2	4.3%	
Plot 20	Oven Dried A	6.8%	**5.2%**
	Oven Dried B #1	4.4%	
	Oven Dried B #2	4.4%	

2. Thermogravimetric Analysis (TGA)

Procedure Summary

A 40 gram sample was weighed and placed in the TGA apparatus at 105° C. In each run the sample used was as-received. The sample was held constant at 105° C for approximately two hours to remove moisture. The temperature was then ramped up from 105° C to 750° C at approximately 5° C per minute and weight loss was measured. Nitrogen was purged into the system to reduce oxygen levels to nearly 0%. After two hours and fifteen minutes, the nitrogen was turned off and carbon dioxide was purged into the system. Off-gases were monitored as operational feedback. Thermocouple placement was in the center of sample during test.

Results

At a ramp rate of 5° C per minute, Figure 1 shows that 50% of the weight loss (from 90% to 40%) occurs between approximately 225° C and 380° C. Both Plot 2 and Plot 20 samples show that the weight loss curves were very similar, with Plot 20 run #2 being a bit higher temperatures for the same weight loss. The typical starting moisture for these samples was approximately 4%.

Table 5: Plot 2 and Plot 20 Weight Losses

	Plot 2 #1	Plot 2 #2	Plot 20 #1	Plot 20 #2	Average
Sample Moisture Content	4.39%	3.82%	4.00%	5.04%	**4.31%**
Sample Weight Loss in N_2	77.13%	72.94%	73.85%	74.84%	**74.69%**
Sample Weight Loss in CO_2	1.61%	1.78%	3.22%	2.56%	**2.29%**
Total Sample Weight Loss	78.74%	74.71%	77.07%	77.39%	**76.98%**

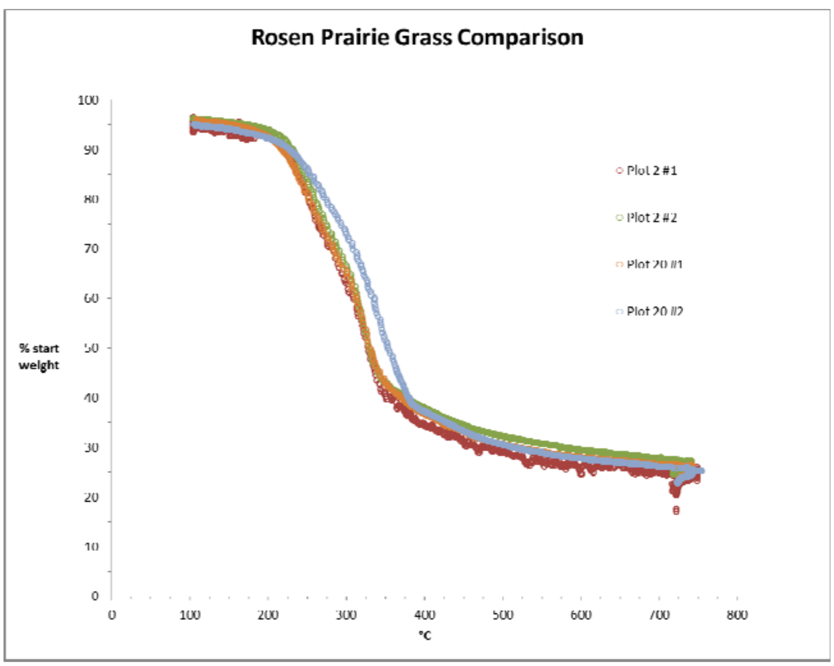

Figure 1: Prairie Grass TGA Weight Loss vs. Temperature

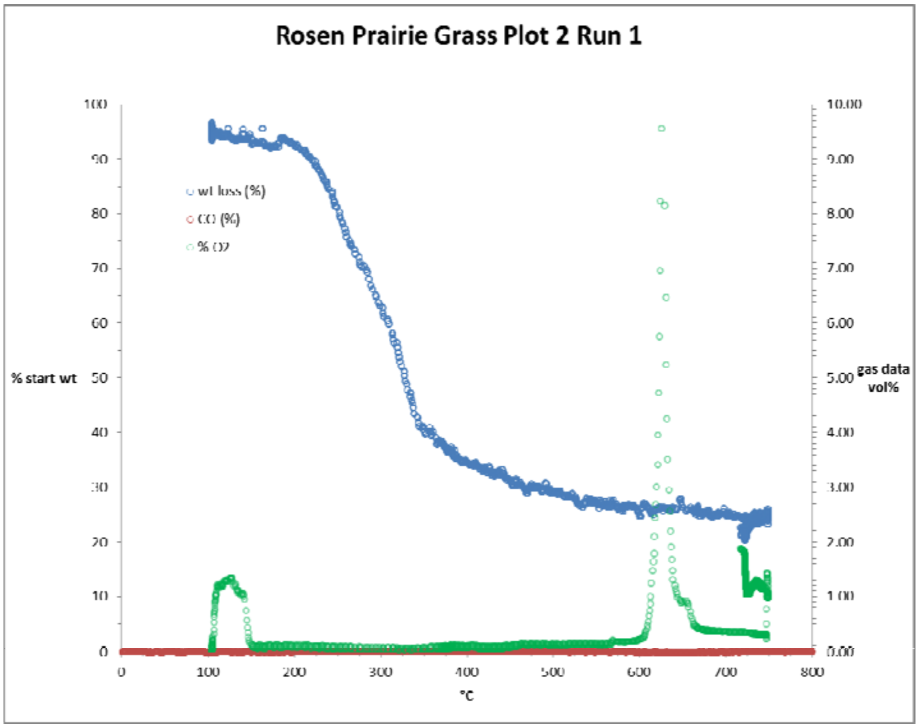

Figure 2: Plot 2 Run 1 TGA Data

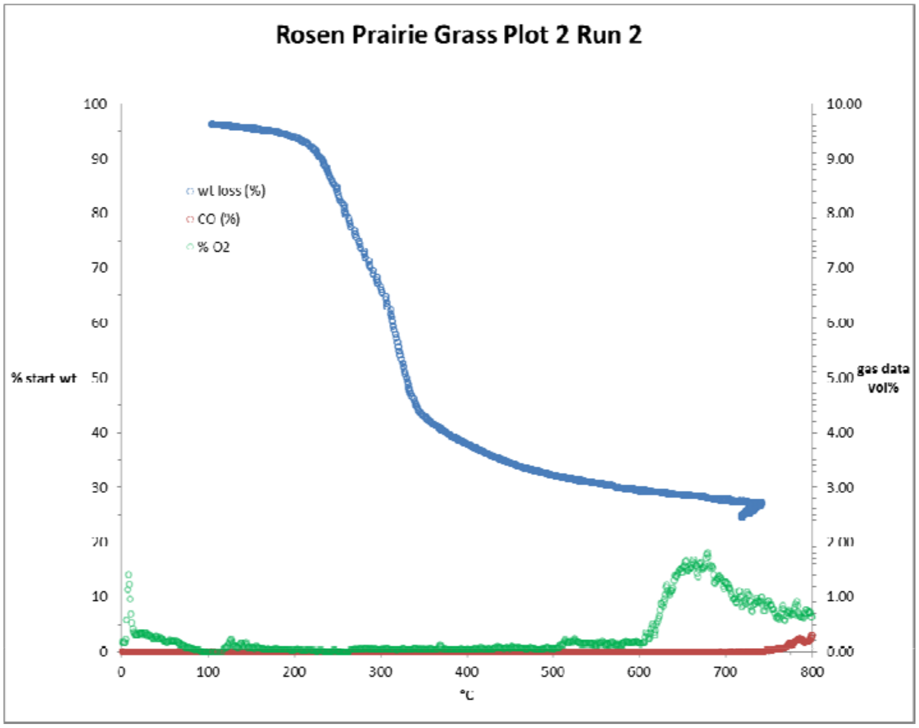

Figure 3: Plot 2 Run 2 TGA Data

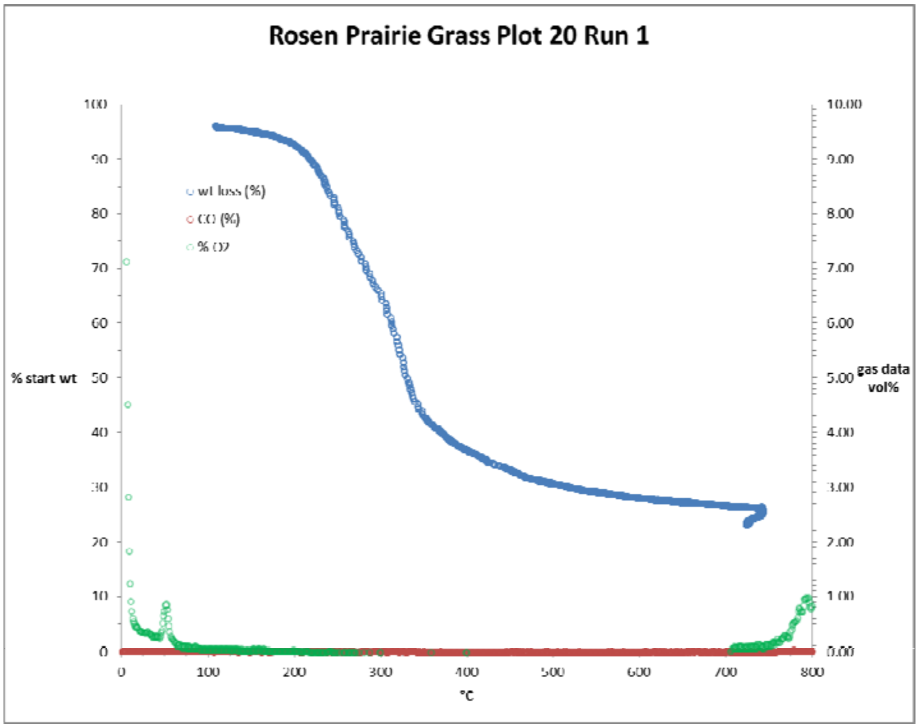

Figure 4: Plot 20 Run 1 TGA Data

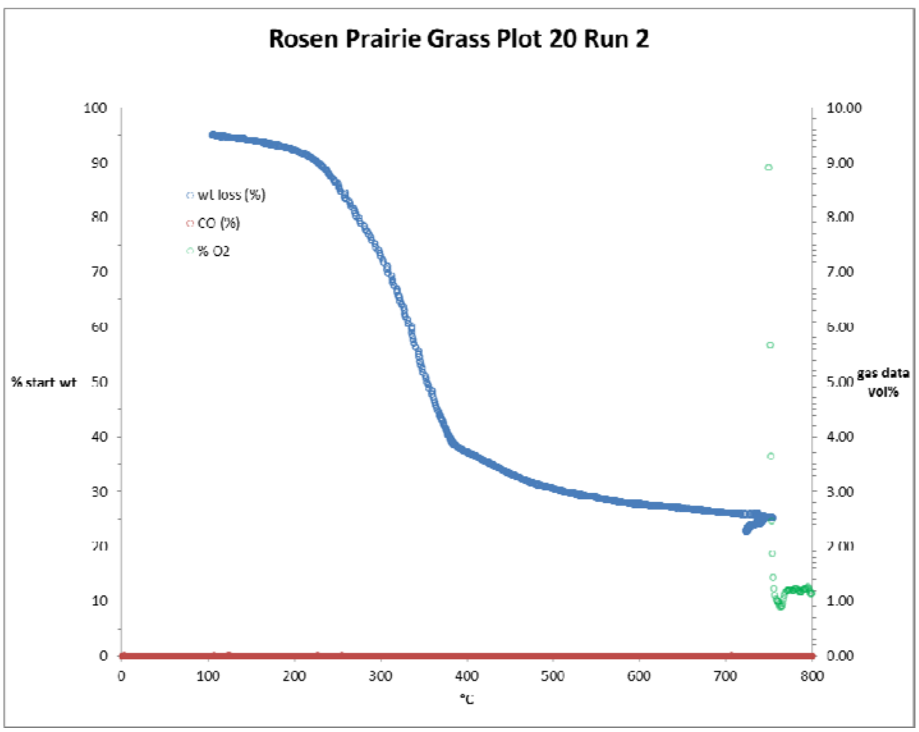

Figure 5: Plot 20 Run 2 TGA Data

3. Loss on Ignition (LOI)

Procedure Summary

A 1.0 gram sample was 200° C for two hours, weighed, and heated in an oven at 1,000° C for four hours. The remaining ash was then weighed.

Results

Both Plot 2 and Plot 20 contain approximately 5% ash.

Table 6: Prairie Grass Loss on Ignition Results

LOI	Plot 2	Plot 20	Average
Loss on Ignition	94.9%	94.2%	**94.6%**
Ash Content	5.1%	5.8%	**5.4%**

4. Carbon-Sulfur

Procedure Summary

A 1.0 gram raw sample was measured and run in the LECO Carbon-Sulfur 632 device after calibration with LECO standards.

Results

Plot 2 and Plot 20 both contain approximately 46% carbon and 5.5% sulfur.

Table 7: Prairie Grass Carbon-Sulfur Content

Carbon-Sulfur	Plot 2	Plot 20	Average
Carbon	46.3%	46.5%	**46.4%**
Sulfur	5.8%	5.2%	**5.5%**

5. Ash Analysis

Procedure Summary

Alumina and silica tests were run with non-ashed samples, prepped with sodium peroxide, and tested with 0.1 grams. Iron was run with a colorimetric titration procedure. The remaining test samples were ashed for 12 hours at 700° C and were wet prepped with hydrochloric acid, nitric acid, hydrofluoric acid, and finished in perchloric acid. Sodium, potassium, and phosphorous were tested in the inductively coupled plasma (ICP) mass spectrometer with 1.0 gram ash samples. Calcium and magnesium were tested with a 0.3 gram sample.

Results

Table 8 displays the major ash constituents from Plot 2 and Plot 20. Sodium, potassium, calcium, and magnesium are alkali and alkaline earth metals that typically have lower melting points. These components, along with chlorine and silica, can lead to slagging and corrosion in combustors and gasifiers.

Table 8: Prairie Grass Ash Chemistry

Ash Components	Plot 2		Plot 20	
	Ash Basis (%)	Total Basis (%)	Ash Basis (%)	Total Basis (%)
Estimated Ash Content	100.00	5.10	100.00	5.80
Na_2O	0.229	0.012	0.069	0.004
K_2O	6.191	0.313	6.074	0.352
P	1.176	0.060	1.114	0.065
CaO	9.416	0.476	8.955	0.519
MgO	3.189	0.161	3.658	0.212
Fe	1.78	0.09	0.17	0.01
Al_2O_3	5.34	0.27	0.17	0.01
SiO_2	66.60	3.37	68.79	3.99
Total	**93.92**	**4.75**	**89.01**	**5.16**

When comparing Tables 8 (native prarie) and 9 (for a standard corn stover and woodchip sample), both the prairie grass and corn stover have relatively high amounts of ash with silica representing the majority of the ash (approximately two-thirds).

Table 9: Corn Stover and Mixed Woodchip Ash Chemistry

Ash Components	Corn Stover		Mixed Woodchips	
	Ash Basis (%)	Total Basis (%)	Ash Basis (%)	Total Basis (%)
Estimated Ash Content	100.00	11.20	100.00	2.69
Na_2O	0.164	0.018	0.227	0.006
K_2O	0.524	0.059	18.020	0.485
P	0.029	0.003	1.270	0.034
CaO	0.840	0.094	44.190	1.190
MgO	0.403	0.045	6.000	0.162
Fe	N/A	N/A	N/A	N/A
Al_2O_3	18.57	2.08	0.87	0.02
SiO_2	66.97	7.50	7.76	0.21
Total	**87.50**	**9.80**	**78.34**	**2.11**

6. Calorimetry

Procedure Summary

Approximately a 0.5 gram sample was chopped and oven dried at 105° C for three hours and pressed into a disk at 12,500 psi. The sample was then inserted in an IKA C200 calorimeter to determine the energy content (in BTU/pound).

Results

Table 10 shows the energy content of Plot 2 and Plot 20. Both samples were approximately 7,600 BTU/lb (~17,700 kJ/kg).

Table 10: Prairie Grass Calorimetry

Calorimetry	Plot 2 (BTU/lb)	Plot 20 (BTU/lb)
Test 1	7,608	7,688
Test 2	7,604	7,612
Test 3	7,612	7,594
Test 4	N/A	7,625
Average	**7,608**	**7,631**

<u>Appendix B</u> – Initial estimates of ecosystem service benefits[1]

(Note: This is preliminary data and subject to change as better information becomes available)

Every acre planted with perennial crops provides ecosystem services, including improvements in water and air quality, avoided water usage, carbon storage, and potential recreational benefits. For each of five categories of environmental services, physical and economic data were estimated from published research. Physical data were estimated based on a "with-without CRP" scenario. It is an estimate of, for example, the water quality benefits of an acre on of CRP compared to a scenario without that acre enrolled in the CRP. This method was chosen because estimates of the environmental benefits of CRP can be found in published literature. Although harvest other than for personal use from CRP lands is prohibited, the environmental benefits of CRP lands can provide a good baseline estimate of the environmental benefits that would be provided by perennial feedstocks for the production of energy (Table 1).

Table 1. Baseline estimates of the environmental benefits of CRP lands.

	Physical Data			**Economic Data[a]**		
Parameter	**Value**	**Units**	**Source(s)**	**Value**	**Units**	**Source(s)**
Water Quality Benefits						
Avoided sediment loading	6.5	tons/ac/yr	FAPRI-UMC, 2007; Taff, 2011	8.27	$/ton	Ribaudo, 1989; Boody et al., 1995
Avoided N loading	20.7	lbs/ac/yr	FAPRI-UMC, 2007	0.89	$/lb	Kovacs et al.
Avoided P loading	5.4	lbs/ac/yr	FAPRI-UMC, 2007	27.52	$/lb	Kovacs et al.
Air Quality Benefits						
Avoided air pollution	6	tons/ac/yr	Minnesota Land Economics website, 2011	1.35	$/acre	Feather et al., 1996[b]
Carbon Benefits[c]						
Avoided carbon emissions	0.14	tons/ac	Lazarus et al., 2010	54.47	$/ton	Kovacs et al., 2010
Carbon sequestration	0.4	tons/ac	Boody et al., 2005; Kumar and Sokhansan, 2007	54.47	$/ton	Kovacs et al., 2010

a. All values have been converted to 2010 dollars.
b. The Feather et al., 1996 report does not specify the physical data, but instead reports benefits in economic terms only ($/acre). Numbers from the Feather et al., 1996 report are used in final estimates.
c. All carbon numbers here and throughout the report are carbon only, not carbon dioxide.

[1] This information was developed by Ann O'Neill, a graduate student working on the partner 319 project.

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