Feedstock Platform

Introduction

The size of the U.S. bioindustry will, to a large degree, be determined by the quantity and quality of biomass available. As the starting material in the biomass-to-biofuels supply chain, a sufficient and secure supply of affordable feedstocks is a critical step in accomplishing the Program goals. The Feedstock platform therefore relates strongly to all other facets of the program portfolio; it is, however, specifically linked to the Conversion platform as feedstock is the substrate for conversion technologies.

The Feedstock platform core R&D supports the first two elements of the biomass supply chain: feedstock production and feedstock logistics. Feedstock production includes all the steps required to sustainably produce biomass feedstocks to the point they are ready to be collected or harvested from the field or forest. The Program's feedstock production R&D is focused on selecting the best-suited feedstocks and solving specific feedstock production issues on a regional basis. The Program also partners with DOE Office of Science and USDA on advanced feedstock production R&D.

Feedstock logistics encompasses all the unit operations necessary to prepare and deliver biomass feedstocks to the biorefinery and to ensure that the delivered feedstock meets the specifications of the biorefinery conversion process. The Program's feedstock logistics R&D is focused on developing and optimizing cost-effective integrated systems for collecting, storing, preprocessing, and transporting a range of potential lignocellulosic feedstocks, including agricultural residues, forest resources and dedicated energy crops.

Platform Performance Goal

To develop technologies to sustainably provide a secure, reliable, and affordable cellulosic biomass supply for the U.S. bioindustry.

Objectives

- The feedstock production goal is to validate that a sustainable high-quality accessible feedstock supply of 130 million dry tons per year can be available by 2012, growing to 250 million dry tons per year by 2017. This goal is necessary to spatially quantify the accessible resource and validate the percentage of the resource that could be recovered cost effectively.
- The feedstock logistics goal is to reduce the feedstock logistics cost to $0.37 per gallon of ethanol (equivalent to approximately $33/dry ton in 2007$) by 2012, with further reduction to $0.33 per gallon of ethanol by 2017. Cost-saving and process-improving technologies will be developed within each stage of the feedstock supply chain. The logistics goal applies to the dry herbaceous, wet herbaceous and woody feedstock types.

FY 2007 Accomplishments

- Established the Regional Feedstock Partnership in all five regions of the U.S. through a series of workshops.
- Established separate teams within the Regional Feedstock Partnership to create, implement, and maintain a GIS-based resource assessment tool; conduct sustainable corn residue removal trials; and conduct energy crop trials.
- Completed regional feedstock supply curves, as well as an inventory of existing feedstock work in each region.
- Established a sustainability element to all feedstock production efforts.
- Completed a supply system design useful as a starting point for developing feedstock supply systems for pioneer biorefining facilities.
- Compared quantitative benefits of single pass harvesting with mow and rake harvesting.
- Completed preliminary rheological property data & analysis on archived samples for handling and transportation systems.

- Identified how preprocessing contributes to the uniform format necessary to hit 2012 targets.
- Identified three wet storage system designs that can potentially achieve cost targets: Wet-Dry Hybrid, Biological Preprocessing & Storage/Queuing, and Green Harvest/Wet.

Budget

The President's FY 2008 budget request includes increased funding for biomass feedstock R&D from $9,967,000 in 2007 to $10,000,000.

2008 Plans

- Establish industrial partnerships to address feedstock logistics.
- Continue to work with the Regional Feedstock Partnership teams to identify and develop available, cost-effective, and sustainable biomass feedstocks that can make a significant impact to the nation's biofuels production.
- Leverage Program deployment projects and/or state-funded efforts to conduct large crop demonstration projects that will accomplish the following:
  - Allow for equipment validation trials with manufacturers;
  - Address sustainability issues at a variety of scales;
  - Educate growers on viability of energy crops at a demonstration scale;
  - Help educate the grower community at a near-commercial scale; and
  - Allow for a real life test of providing feedstocks on a year-round basis to a conversion facility.
- Complete the first phase of the GIS-based resource assessment tool.

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Project Summaries

Feedstock Platform Support

Feedstock Regional Partnerships

Idaho National Laboratory

Principal Investigator:	Richard Hess	Funding Partners:	N/A
HQ Technology Manager:	John Ferrell	Sub-contractors:	N/A
PMC Project Officer:	Kevin Craig		

Goals and Objectives: Regional partnerships will enable development of more accurate cost supply information and improved communication with all elements and partners in the feedstock supply chain.

- Assist in the organization of the final three regional partnerships (Western, South
- Central, Northeastern) and work scope planning of all five regional partnerships
- Biomass Resource Tonnages and Cost quantified for 1, 5 and 60 B gal. ethanol (Supply demand and technology interactions validated and peer reviewed)

Project Description: The joint DOE/USDA billion ton study establishes the resource base and future potential for a large-scale biorefinery industry. The ethanol price target of $1.07/gallon by 2012 is based on a total biomass feedstock cost of $35/dry ton. This 2012 feedstock cost target can be subdivided into at $10/dry ton grower payment (stumpage fee for forest resources) to cover the biomass value and $25/dry ton for the feedstock supply system costs, which include harvest and collection, storage, preprocessing, and transportation and handling. It is estimated that from the 1.3 billion ton potential, as much as 130 million tons could be accessed for a grower payment at or near $10/dry ton. The expanding utilization of lignocellulosic biomass resources will create a demand for feedstocks, which will result in biorefineries paying more to access larger tonnages of more expensive resources (i.e., resources requiring >$10/dry ton grower payment). As the industry expands from grain ethanol to include cellulosic ethanol, it is expected that agriculture crop residues and forest logging residue resources will be the first to develop for biorefining purposes. Energy crops will develop and become integrated into the agricultural cropping systems as the biorefining industry matures and creates a demand for those resources. The increase in energy crop production will likely occur as land managers (i.e., farmers, plantation foresters, etc.) use these additional cropping options provided by a biomass energy market to maximize the productive capacity and economic returns of the land they manage. Collaborations with USDA and regional partners will become critical in developing sustainable biomass production and crop rotation strategies for both existing and new biomass resources.

Summary of Work to Date - Accomplishments (FY05-current): Organization of the regional partnerships and development of the collaborative scope of work between the DOE laboratories and regional partnership universities has been accomplished. The Southeastern and North Central regional partnership workshops were completed in May 10-12, 2006 and August 15-17, 2006 respectively. Of the three remaining regional meetings, the Western meeting will be held August 27-29, 2007, and the other two are targeting workshop dates for later this year. In addition, the Sun Grant regional partners completed a biomass related solicitation, and INL participated in the review of submitted proposals. As a matter of course, this review process identified numerous project opportunities for greater leveraging of DOE and other regional funding in the areas of resource assessment and resource development. This leveraging more effectively assists in accomplishing regional and national bioenergy goals.

Three additional key meetings between the Sun Grant Initiative leaders and DOE-OBP/Labs were held, one in October in St. Louis, MO, a second in December in Washington, DC and a third in February at ORNL for the initiation of the GIS resource assessment task with the regional partnerships. The outcome of these meetings was the ultimate agreement on the major scope of work tasks for the regional partnership. Work scope tasks included: 1) Resource Assessment; 2) Resource Development; and 3) Educations and Extension. The resource assessment task included development of GIS-base regional biomass supply curves, and completion of the regional road mapping workshops necessary to identify and develop regional biomass resources. The resource development task included inventorying existing and establishing new field trials for the development of sustainable agronomic cropping systems for crop residues and new energy crops, as well as, new biomass crop development. Finally, the education and extension task focused on enhancements to the bio-web as a mean to disseminate original research results, technical memos and resource assessment information development through the regional partnerships. INL and ORNL will continue working with each of the partnership groups in planning the workshops, as well as helping formulated the objectives and scope of each region's efforts that support DOE program objectives, specifically the FY08 milestones.

INL's accomplishments connecting supply systems to resource assessments, in conjunction with regional partners, have been two fold. First, efforts were initiated with Steve Fales (Iowa State University) and Wally Wilhelm (USDA-ARS, Lincoln, NE) to develop a white paper that assesses the status of cellulosic ethanol from the perspective of feedstock supply and critical issues associated with transitioning from the present day state to the future state of supply system envisioned in the billion ton study. This effort identifies critical issues with developing feedstock supplies that are cost-effective and sufficiently plentiful for the biofuel markets and at the same time sustainable. Feedstock value refers to the price that must be paid for biomass, standing or laying on the land, in order to purchase it from the producer (farmer or forester). While different feedstocks (i.e., corn stover, cereal grain straw, sorghum stover, switchgrass, prairie grass, logging residues, forest thinnings, etc.) have different median or average values, the price range for these different feedstocks can vary from less than $10/dry ton to $40/dry ton (or more in some cases). The specific reasons for this variability are as wide and diverse as the geographic regions and growers producing the biomass. However, the single largest variable affecting the feedstock value is tied to the tonnage demanded with respect to competing demands (competing demands include competing markets as well as soil/agronomic sustainability). ORNL (using POLYSYS) estimated that about 10% of the total 1.3 billion ton potential domestic biomass resource could be purchased at or below $10/dry ton. The analysis, as well as subsequent reviews from various parts of the U.S., demonstrated that the 10% resource availability was not uniform on a per acre basis nor across resource types; rather the 10% resource availability comes from the sum of all acres and biomass resources totaling the estimated 130 M dry tons (or 10% of 1.3 billion tons) that is accessible at or near the $10/dry ton price. This analysis is important in establishing the 2012 feedstock R&D and cost target goals for two reasons. First, based on the ethanol market demand estimates for cellulosic ethanol, the cellulosic biomass resource demand will not exceed 130 M dry tons until sometime after 2015. Thus, the $10/dry ton feedstock threshold value for an estimated 130 M dry tons is a practical feedstock cost estimate for the 2012 cost target. Second, the 130 M dry ton estimate includes all major feedstock types, so feedstock supply system technologies must be developed and validate for each of the major feedstock types. Additionally, by setting the biomass feedstock cost target at the entry point of the conversion process, all feedstock supply system unit operations are included in the Feedstock R&D scope. This also allows R&D technology development to be optimized across all feedstock supply business elements and unit operations. A draft paper discussing these issues is currently in review for publication as a Council for Agriculture Science and Technology assessment paper.

Schedule:

Project Initiation Date:	Sunday, October 01, 2006
Planned Completion Date:	Sunday, September 30, 2012

Feedstock Supply Chain Analysis

Idaho National Laboratory

Principal Investigator:	Richard Hess	Funding Partners:	ORNL
HQ Technology Manager:	Zia Haq	Sub-contractors:	N/A
PMC Project Officer:	Kevin Craig		

Goals and Objectives: The feedstock platform analysis effort will focus on studies to assess feedstock availability, cost (feedstock value or purchase price), and price (delivered to conversion process) for the 1 – 5 billion gallons of ethanol per year goal by 2017 and the 60 billion gallons of ethanol per year goal by 2030. The primary objective of analyses addressing the 2017 goal will be to concentrate on feedstock issues that ensure the near-term competitiveness of cellulosic ethanol. Analyses focusing on the 2030 goal will address the feedstock volumetric issues for longer-term cellulosic ethanol goals. These INL feedstock platform analysis studies will provide answers to the fundamental question for both the near-term and longer-term feedstock goals of, "What are the feedstock supply options and costs?" Other critical questions including, 1) What are the feedstocks? 2) What are the available feedstock tonnages and costs? and 3) What are the feedstock locations' opportunities / constraints? are questions that will be addressed through the regional partnerships tasks and by the ORNL analysis effort. Considering that this INL analysis task is part of a larger inter-laboratory and regional partnership effort, the collective intermediate target for answers to all four of these questions can succinctly be described as "demonstration of cellulosic biomass feedstock for all major feedstock types at pilot scale by 2012," with the analysis needs targeted to develop and validated the $35 feedstock supply system designs.

Project Description: As the deployment of cellulosic ethanol biorefineries approaches, one of the biggest unanswered set of questions is centered on feedstocks. The joint U.S. Department of Energy and U.S. Department of Agriculture billion ton study (Biomass as Feedstock, 2005) identified a domestic cellulosic feedstock resource potential sufficient to displace more than 30% of the 2004 U.S. finished motor gasoline demand. However, the questions of "How to cost effectively and sustainably get the biomass to the biorefinery?" and "How much biomass is available at what cost?" are significant looming challenges for the 2012 ethanol cost target of $1.07/gallon and the 2030 ethanol fuel target of 30% fuel displacement.

The 2030 goal to produce 60 billion gallons of ethanol will require the production of 40-45 billion gallons from cellulosic feedstocks (estimated 500 M dry tons of biomass), with the initial 15-20 billion gallons being produced from starch feedstock resources. While this ultimate goal of producing, supplying and converting 500 M dry tons of cellulosic biomass is important, it is useful to have an intermediate goal that 1) represents a realistic near-future biomass tonnage demand, 2) includes every major type of cellulosic feedstock, 3) provides feedstock at a price that the resulting ethanol product could be competitive in the near-future transportation fuels market, and 4) can be described and achieved with technology currently under development. Collectively, these four goals direct the path forward for the feedstock analysis.

Summary of Work to Date - Accomplishments (FY05-current): Biomass feedstock analyses have focused on support of the 2009 technology options milestone and tonnage targets for dry biomass systems, as well as defining supply system options for high moisture and woody biomass resources in support of the FY11 (woody) and FY12 (high moisture) technology options and tonnage targets. In addition to supply system options and cost analyses, GIS based feedstock location analyses conducted by ORNL are identifying feedstock production practices, availability constraints, local feedstock price ranges, and regional infrastructure options/constrains.

<u>1.6.1.2. A Feedstock Supply System Design</u> In FY06 a draft feedstock supply design for wheat and barley straw in a Pacific Northwest setting was completed. The model analyzed equipment, personnel, materials and facilities necessary to gather 800,000 tons of wheat and barley straw and deliver it in a preprocessed bulk format to a bioreactor. This model involved detailed investigations of: Costing Methodologies for Bulk Supply Systems, Straw Contracts and Supplies, Harvest and Collection of Harvest Data, Scheduling and

Dispatching, Bailing Operations, Roadsiding Bales, Quality Assurance, Inventory Mgt. and Field Storage, Grinding Operations, Transportation of Ground Feedstock, Weighing, Accounting and Unloading of Ground Feedstock, Plant Feedstock Storage, and In-Plant Transportation of Feedstock.

The FY06 design report content and requirements were evaluated for relevance to OBP programmatic interests as well as industry interest. Due to increasing interest in feedstock supply system issues, the scope of the design report was expanded to include a wet feedstock supply system design, and consider advanced designs beyond pioneer feedstock supply systems (i.e., uniform format commodity scale supply system). Prior to this, the scope of the feedstock design report was limited to the dry feedstock system. This decision has increased the scope of this report as well as the scope of the analysis efforts that support the development of this report.

As part of this expanded design scope, focused on the pioneer design case and understanding current practices, supply system options and processes that will affect feedstock costs and logistics as the cellulosic ethanol industry emerges has been conducted. An analysis of transportation cost factors was developed to show the significance of the fixed costs associated with transportation and to address the prevailing misunderstanding of transportation that overemphasizes the impact of transportation distance. The objective of this analysis was to quantify the relationship between the fixed costs associated with loading and unloading and variable costs, or mileage costs, which vary linearly with distance traveled. For example the fixed costs associated with loading and unloading the truck, totaling nearly $70 per load, exceed mileage costs out to about a 40 mile haul. In addition, the analysis compared the costs of various transportation methods including a self-propelled bale transporter, semi transport and rail transport. A self-propelled bale transporter is machine the can pick up bales in the field, transport them to the storage location and place them in a stack. This analysis shows the relative impact of the fixed and variable transportation costs on the economics of each of these transportation methods. The self-propelled transporter had the lowest fixed cost followed by semi hauling bulk feedstock and then semi hauling bales, with rail having the highest fixed cost. In comparison, the variable costs in this comparison is affected by the capacity of the transporter, so rail has the lowest variable cost and the Stinger has the highest variable cost, with semi variable costs in between. Accordingly, the self-propelled transporter is the most economical method of feedstock transportation for roadsiding up to five miles from the field. Semi transport then becomes most economical beyond five miles, with rail transport only being viable option for hauling bulk feedstock beyond about 180 miles.

Based on this transportation analysis, equations for self-propelled bale transport, semi transport of bale and bulk feedstock, as well as rail transport that include both the fixed cost and variable cost components were developed, and these equations were supplied to Steve Peterson to support the feedstock module of the Biomass Scenario Model. Additional analyses are ongoing to develop similar cost equations for the harvest and collection operations for feedstock in square bale, round bale and bulk format.

Work continues to develop an IBSAL interface for coupling to the INL spreadsheet model and performing sensitivity analyses of the INL designs. The IBSAL modules for each of the supply system unit operations have been developed, but additional work is necessary to directly couple IBSAL to the INL designs.

Out of these efforts a new draft Feedstock Design Report: the “Uniform Format Feedstock Supply System Design” report was completed. The purpose and objectives of this uniform format feedstock design document is threefold:

1) Provide (a) a supply system design basis that will be useful as a starting point for developing feedstock supply systems for pioneer biorefining facilities and (b) sufficient supply system attribute and modeling data to evaluate the efficacy of those designs.
2) Set forth the supply system design concepts for the “uniform format feedstock supply system,” which will allow for simplified and highly replicable supply system infrastructure and biorefinery conversion facility designs that can be rapidly and universally deployed to achieve the 20 in 10 Plan (Bush, 2007) and 30 x 30 Scenario (Foust et al., 2007) fuel displacement goals.
3) Present a uniform feedstock supply system design that can achieve the feedstock cost and quantity targets set forth in the biochemical (Aden et al., 2002) and thermochemical (Aden et al. 2007) conversion platform design documents.

1.6.1.2.B Corn Stover Removal Analysis In FY06, field research was performed to determine the impact of corn stover removal for a specific set of harvesting scenarios. Data collected from the research was analyzed and presented in a peer-reviewed publication that has been accepted for print. The conclusions from the research provide an initial look at the limiting factors that affect the environmental and economical impact of removing stover (referenced to the amounts identified in the "Billion Ton Study") for use in a biorefinery.

Methods for establishing sustainable biomass production solutions in response to the limiting agronomic factors were discussed with USDA. A method of establishing thresholds for each of the agronomic factors was considered as the basis for sustainable production solutions. This method has been used by other researchers to identify residue removal restrictions. However, it was determined that the interaction between these agronomic factors must be better understood in order to develop robust production solutions capable of addressing these issues. Therefore, it was decided to pursue additional limiting factor multivariant analysis as the basis for the production solutions developed by this task.

A draft corn stover analysis plan was developed that identifies the agronomic and soil management models and a proposed method of managing and structuring the flow of information for performing a multivariant analysis of the limiting agronomic factors (loss of soil organic carbon, increased soil erosion, increased nutrient leaching or run-off, loss of soil quality, reduced productivity, and environmental degradation) that were previously identified as potential constraints to crop residue removal. This analysis plan is currently submitted to the USDA for review and consensus on the methods.

1.6.1.2.C Woody Feedstock State of Technology The forest resources account for approximately one quarter of the estimated future biomass resources in the US in the Billion Ton Study, but a better understanding of the current technology is needed in preparation for future core R&D on woody feedstock supply. The United States contains large amounts of unused woody biomass with significant potential of becoming an important feedstock for the production of bioenergy, biofuels, and bio-based products. The potential to use these residues as a renewable source of energy, fuels, and chemicals and the recognized need to thin forests for wildfire mitigation, as prescribed by the Healthy Forest Restoration Act (2003), has established a national interest in recovering and utilizing these resources. This State of Technology will provide foundation knowledge in support of woody feedstock cost estimates needed for future logistical planning for forest residues and dedicated feedstock supply.

Woody supply systems in the U.S. are extremely variable. They are as hi-tech as helicopter logging and as low-tech as skidding with a horse. The approaches to obtaining forest biomass vary depending on: size and volume of area to be logged, topography, road availability, and types of wood to be harvested. Also local regulations pertaining to water shed protection and soil compaction may influence the approach.

Some of these unit operations are flexible and can feed into a variety of handling configurations, others necessitate specific machinery. Several forest harvest models have been developed and are available at various websites including the USDA site and sites maintained by individual universities. A list of these models include: The Auburn Harvesting Analyzer, the Sloan Logging Cost Calculator, and SIMYAR. In addition, the Forest Inventory and Analysis Data Center (FIA), operated by the USDA, has a tremendous quantity of data on timber inventories, harvests and technology.

The two largest end-users of forest products are the pulp and paper industry and lumber mills. These industries produce low value lignocellulosic waste streams. In the case of lumber production, this waste is primarily in the form of sawdust. The most prevalent process for paper production is the Kraft process which produces a waste stream called black liquor. Most Kraft pulp and paper mills burn the black liquor to produce steam and power for the process. Sawdust may be pelletized, burned, or composted. Both black liquor and sawdust could potentially be used in a thermochemical or biochemical plant.

Typical timber harvesting operations leave behind 20% to 30% of the harvestable biomass. This biomass is in the form of woody under story, limbs, leaves, and tree tops. Costs associated with gathering and transporting these materials often is higher than what an end user will pay. Sometimes the land owner will stipulate that the materials be removed for aesthetic reasons and to facilitate replanting. Spot markets for hog fuel (ground residues) exist in some areas of the country where direct-fired or co-fired power plants are present.

Forest products waste streams are often utilized for heat and power. In fact, a modern Kraft mill produces more energy than it consumes and sells electricity to the grid. Over 10% of logging residues are currently collected and burned in direct-fire or co-fire power plants. Any biofuels technology that seeks to utilize these feedstocks will compete for these materials.

Schedule:
Project Initiation Date: Saturday, October 01, 2005
Planned Completion Date: Sunday, September 30, 2012

Feedstock Platform Portfolio – Feedstock Supply & Sustainability

Feedstock Analysis

Bob Perlack, Oak Ridge National Laboratory

Principal Investigator:	Richard Hess	Funding Partners:	ORNL
HQ Technology Manager:	Zia Haq	Sub-contractors:	N/A
PMC Project Officer:	Kevin Craig		

Goals and Objectives: Expand BTV results to determine regional and local feedstock availability, cost and price, based on production goals of 1 BGY by 2015 and 60 BGY by 2030 (also consider production goals of 1, 5, 10, and 20 BGY of cellulosic ethanol by 2017). Develop a more comprehensive GIS-based data framework that addresses the prime question where feedstocks are located (current and potential) and at what cost.

Project Description: The results from the "Billion-Ton" biomass availability report will be expanded to determine regional and local feedstock availability, cost and price, based on production goals of 1 BGY by 2015 and 60 BGY by 2030. Included with this analysis will be a curve with crude oil price range, ethanol production, and delivered price range over time. This task will require cost modeling including updating existing cost of production models to answer some basic questions such as how much biomass is available, when, and with what level of development. These models will also require the development of new data, such as that on crop productivity (separate task) and feedstock values. This task will focus on the primary feedstocks – agricultural crop residues, forest residues, and perennial energy crops. Recommendations from the stage gate review will be addressed in this follow-up study.

To support the expansion and updating of the "Billion-Ton" report more comprehensive GIS-based methods are needed to identify and predict changes in the spatial and temporal distribution of biomass resources. To be comprehensive, these methods must rely on environmental sustainability data (e.g., temperature, humidity, rainfall, soil, nutrient values, etc.) and be capable of incorporating feedstock cost data and results of feedstock spatial analysis tools. Research outcomes include the identification of resource potential and availability at a fine-spatial scale and the examination and evaluation of environmental sustainability issues and how these issues affect feedstock availability and costs.

Summary of Work to Date - Accomplishments (FY05-current): Biomass has great potential to provide renewable energy for America's future. Biomass recently surpassed hydropower as the largest domestic source of renewable energy and currently provides over 3% of the total energy consumption in the United States. In addition to the many benefits common to any renewable energy use, biomass is particularly attractive, because it is the only current renewable source of liquid transportation fuel. This, of course, makes it an invaluable way to reduce oil imports — one of our most pressing energy needs. The U.S. Department of Energy and the U.S. Department of Agriculture are both strongly committed to expanding the role of biomass as an energy source. In particular, they support biomass fuels and products as a way to reduce need for oil and gas imports; to support the growth of agriculture, forestry, and rural economies; and to foster major new domestic industries — biorefineries — making a variety of fuels, chemicals, and other products.

A key question, however, is how large a role biomass could play. Assuming policy and conversion technology make biomass fuels and products economically viable, could the biorefinery industry be large enough to have a major impact on energy supply and oil imports? Any and all contributions are certainly needed, but would the biomass role be big enough to justify any needed infrastructure changes? Petroleum refineries, for example, are very large, capital-equipment-intensive operations. Would there be enough biomass feedstock available to warrant retooling some of those refineries to process biomass instead of or in addition to petroleum?

ORNL was asked to determine whether the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30% or more of the country's present petroleum consumption. This 30% goal was set by a joint advisory committee to the two departments as a vision for making a major contribution to energy needs. It would require approximately 1 billion dry tons of biomass feedstock per year.

The short answer to the question of whether that much biomass feedstock can be produced is yes. Looking at just forestland and agricultural land, the two largest potential biomass sources, ORNL found the potential exceeding 1.3 billion dry tons per year — enough to produce biofuels to meet more than one-third of the current demand for transportation fuels. This annual potential is based on a more than seven-fold increase in production from the amount of biomass currently consumed for bioenergy and biobased products. About 368 million dry tons of sustainably removable biomass could be produced on forestlands, and about 998 million dry tons could come from agricultural lands. In the context of the time required to scale-up to a large-scale biorefinery industry, the annual biomass potential of more than 1.3 billion dry tons can be produced with relatively modest changes in land use and agricultural and forestry practices.

Since publication of the Billion-Ton Vision report, efforts have focused on extending the results by disaggregating the resource potential to counties and pixels (1 km or 30 m), examining environmental sustainability (e.g., soil erosion and removal of crop residues) concerns and how these affect resource availability, and answering questions involving what feedstocks will be used, when will they be used, and what will be the costs.

Schedule:

Project Initiation Date:	Saturday, October 01, 2005
Planned Completion Date:	Friday, September 30, 2011

Regional Biomass Energy Feedstock Partnership

Terry Nipp, Sun Grant Association

Principal Investigator:	James Doolittle	Funding Partners:	Cornell University, Oklahoma State University, University of Tennessee, Oregon State University
HQ Technology Manager:	John Ferrell		
PMC Project Officer:	Kevin Craig		
		Sub-contractors:	N/A

Goals and Objectives: Regional partnerships will enable development of more accurate cost supply information and improved communication with all elements and partners in the feedstock supply chain.

- Assist in the organization of the final three regional partnerships (Western, South Central, Northeastern) and work scope planning of all five regional partnerships.
- Biomass Resource Tonnages and Cost quantified for 1, 5 and 60 B gal. ethanol (Supply demand and technology interactions validated and peer reviewed).

Project Description: The joint DOE/USDA billion ton study establishes the resource base and future potential for a large-scale biorefinery industry. The ethanol price target of $1.07/gallon by 2012 is based on a total biomass feedstock cost of $35/dry ton. This 2012 feedstock cost target can be subdivided into at $10/dry ton grower payment (stumpage fee for forest resources) to cover the biomass value and $25/dry ton for the feedstock supply system costs, which include harvest and collection, storage, preprocessing, and transportation and handling. It is estimated that from the 1.3 billion ton potential, as much as 130 million tons could be accessed for a grower payment at or near $10/dry ton. The expanding utilization of lignocellulosic biomass resources will create a demand for feedstocks, which will result in biorefineries paying more to access larger tonnages of more expensive resources (i.e., resources requiring >$10/dry ton grower payment). As the industry expands from grain ethanol to include cellulosic ethanol, it is expected that agricultural crop residues and forest logging residue resources will be the first to develop for biorefining purposes. Energy crops will develop and become integrated into the agricultural cropping systems as the biorefining industry matures and creates a demand for those resources. The increase in energy crop production will likely occur as land managers (i.e., farmers, plantation foresters, etc.) use these additional cropping options provided by a biomass energy market to maximize the productive capacity and economic returns of the land they manage. Collaborations with USDA and regional partners will become critical in developing sustainable biomass production and crop rotation strategies for both existing and new biomass resources. The Sun Grant Initiative, authorized under Section 9011 of the Farm Bill, encompasses all of the land grant universities in each State and U.S. territory into five bio-geographical regions, with its overall purpose to coordinate and support research and education programs on bioenergy and bio-product development. The Regional Biomass Energy Feedstock Partnership will utilize this unique regional land grant university network to develop a consortium that focuses on feedstock issues on a regional basis.

Summary of Work to Date - Accomplishments (FY07-current): Two of the regional meetings have been held and the architecture for the GIS database has been established.

Schedule:
Project Initiation Date: Monday, July 01, 2007
Planned Completion Date: Sunday, September 30, 2012

Mississippi State University Sustainable Energy Center

Michael Collins, Mississippi State University

Principal Investigator:	William D. Batchelor	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

Goals and Objectives:

- Characterize candidate bioenergy crops for Mississippi.
- Understand and reduce physiological and cell wall limitations to biomass production and conversion.
- Develop appropriate harvesting and processing technologies that increase biofuel production efficiency.

Project Description: The main goal of this project is to define which bioenergy crops may be useful in Mississippi by carrying out multiple field experiments around the state representing distinct physiographic regions, and to determine their yield potential using existing and project-developed best management practices. The same data will be useful in developing economical cropping systems for these species. Varietal studies are underway to determine which lignocellulosic and oilseed crops grow best in the different environments in Mississippi. The lignocellulosic varieties being studied include varieties of switchgrass (*Panicum virgatum*), such as 'Alamo', 'Cave-in-rock' and 'Kanlow' as well as several new switchgrass genotypes. The study also includes giant miscanthus (*Miscanthus floridulus*) and johnsongrass (*Sorghum halepense*). The oilseed species being tested are castor (*Ricinus communis*) varieties, such as 'Lynn' and 'Hale,' canola/ rapeseed (*Brassica napus*), flax (*Linum usitatissimum* L.), crambe (*Crambe abyssinica* Hochst.), indian mustard (*Brassica juncea*), hesperis (*Hesperis matronalis*), camelina (*Camelina sativa* L.), and sunflower (*Helianthus annus* L.). Cropping systems for several biomass crops are being studied to develop production systems that maximize yield while minimizing production costs and providing sustainability. Another key research goal is to discover growth and production limits of bioenergy crops under environmental and nutritional stresses. Also, the growth and development limitations of the crops under stressful conditions are being analyzed. In addition to the lignocellulosic and oilseed crop research, work has begun to define how much existing woody biomass inventories are available in Mississippi through the use of remote sensing technologies and other data acquisition tools. This information will then be used to complete an economic analysis of the use of woody biomass as a biofuel feedstock.

Researchers are also attempting to genetically modify plants to make conversion to biofuels easier and more efficient. For example, rice is being modified to lower the energy needed to breakdown the cell wall which makes sugars needed for biofuel production easier to obtain. Once this procedure is well understood for rice, it can be duplicated in a variety of other crops. Biological enzymes have also been identified that aid in the degeneration of the cell wall. Microorganisms have also been sought that are able to degrade plant cell walls which will lead to lower cost and more efficient conversion processes.

The processing technology being studied is pelletization which densifies biomass to decrease the cost of transportation to biofuel plants. Feedstocks such as switchgrass, giant miscanthus, elephantgrass, and wheat straw are being collected and pelletized to discover the best methods to densify different types of biomass. Analysis of the feedstocks and pellets will be completed to determine the chemical composition and physical characteristics.

Summary of Work to Date - Accomplishments (FY05-current): Multiple field experiments were established during 2005 using several candidate bioenergy species. Management variables evaluated in one or more of the locations include fertilizer and weed management, as well as seed production and germination as related to establishment. Effects of multiple harvests per season are also being evaluated. Alternating winter and summer crops for annual species is another research topic. For several of the studies involving switchgrass and other perennial grass, this first year was mainly used to establish productive stands of the perennial species. Switchgrass and other native warm season perennials are characterized by slow establishment so this represents typical responses. Thus, the yield data cannot yet be used to develop yield expectations for established stands of these crops. The study involving multiple harvest dates for switchgrass showed that biomass harvested in December was suitable for bioenergy use but not for livestock feeding. Dual-use stands may be possible for switchgrass since forage quality of multiple-harvested switchgrass was sufficient to support certain classes of beef cattle. The option for dual use of switchgrass could enhance the likelihood that farmers will establish this crop by spreading the risk associated with either market option alone. However, total biomass yield during the establishment year was greater in the plots harvested only in December, compared with the June and December regime. Seed yield was much greater for full-season switchgrass.

Preliminary (establishment year) results suggest that several of the new switchgrass breeding lines and ‘Alamo’ produced higher dry matter yields than other named cultivars. A study was underway to reduce seed dormancy in native grasses. Switchgrass was the most successful in dormancy reduction followed by indiangrass. The results from the weed management study were not conclusive because of the poor establishment due to the drought throughout the state. For oilseed crops, first-year data suggest that winter canola and winter mustard may be viable options for winter biodiesel crops for Mississippi.

Switchgrass and castor where subjected to multiple environmental stresses to determine effects on productivity. Various assessments were conducted to determine the effects of nitrogen deficiency. All growth and developmental rates declined with leaf N. The photosynthetic rate was more sensitive to leaf N followed by leaf and stem growth rates and leaf addition rates. Nitrogen deficiency decreased the absolute amounts of all plant component dry weights. Remote sensing algorithms were also compiled to aid in the observation of the plant growth and productivity.

In the forestry study, researchers collected data from forest inventories to develop a database that can be used to identify the amount of woody biomass available in the state by region. The types of biomass considered were logging residues, mill waste, thinned trees, and urban waste. Other capabilities are also being added to the database to allow the user to be able to identify locations that provide enough biomass for fuel production plants with a minimal amount of biomass transportation. The project’s first results indicate that Mississippi can yield up to 110 million gallons of ethanol per year, based on an estimated 4 million dry tons per year of biomass from logging residues, small diameter trees, urban waste, and mill residues.

Another objective of our work is to identify genes involved in modification of plant cell wall composition or susceptibility to degradation. Transformation of rice with WAX genes has progressed well. Transgenic calli have been obtained and moved to the plant regeneration stage. Transgenic seedlings for both genes were obtained. The WAX1 transgenic plants set seeds. Mass spectrometry of proteins from protoplasts and suspension cells are in progress. To study rice cell walls using a proteomic approach, we established the cell wall enzymatic removal system in both suspension cells and young seedlings of this species. We developed a vacuum infiltration method to improve enzyme access to the cell walls for large scale cell wall removal from seedlings of cereal crops. The two-dimension gel proteome map of the rice protoplasts was obtained. A large number of differentially regulated proteins after removal of cell wall were identified. Several microorganisms were isolated from fresh rice straw samples. Results suggest that a greater variety of microorganisms can be isolated using an incubation of cultures associated directly with the soil environment rather than utilizing traditional plating techniques.

Pelletization was studied as a method of feedstocks densification. Various feedstocks were collected and processed to produce pellets. The chemical and mechanical properties of the feedstocks before and after pelletization were compared to determine the effect of pelletization. During pellet making process it was found that steam conditioning the feedstocks prior to pelletization would aid in producing more uniform pellets. For this reason, researchers are engineering a mixing system to treat the biomass before pelletization. Results from the composition tests showed that the ash content and heat value of switchgrass pellets were similar to the ash content and heat value of raw switchgrass.

Schedule:
Project Initiation Date: June 1, 2006
Planned Completion Date: November 30, 2007

Switchgrass Demonstration Project

Burton English, University of Tennessee

Principal Investigator:	Burton C English	Funding Partners:	N/A
HQ Technology Manager:	Sam Tagore	Sub-contractors:	Lexington Logistics, Iowa State University - BECON Lab, Tennessee Agricultural Statistical Service, Southern Co
PMC Project Officer:	Kevin Craig		

Goals and Objectives: This year, the project will continue the experiments as designed at the Milan research and Education Center and the farmer production trials located in Henry and Benton Counties. Production for the 4th year at Milan and 3rd year on farm fields will be evaluated. Samples taken the last three years will be evaluated as to sugar and other nutrient content. Farmers will be interviewed as to potential problems that they experienced this past year. This past year has seen different climate then the other years. First, a freeze occurred in April resulting in new growth being knocked back. Then in May, June, and July rainfall has not been plentiful and the area has been declared a extreme drought area.

Four hundred bales of switchgrass were transported to Alabama Power and emissions tests were conducted with 240 of these bales used in the experiment. Four runs examining the emissions that occur from co-firing switchgrass with coal had the following characteristics:

1) First year harvest after frost - harvested in 2004,
2) First year harvest after frost - harvested in 2005,
3) Second year harvest before frost, and
4) Second year harvest after frost.

The emissions that occur under co-firing conditions were compared to 100% coal emissions. Samples of switchgrass harvested after frost had lower nitrogen content then the samples taken from bales before frost. Grass nitrogen content; however, did not appear to affect overall NOx emissions. CO emissions from grass harvested before frost were about the same as those resulting from grass harvested after frost. Unburned carbon was about the same when co-firing as compared to firing with coal alone. Proximate and ultimate analyses were conducted on the material prior to combustion.

Approximately one bale of switchgrass will be converted to bio oil at Iowa State University's BECON facility. The experimental design will be a complete block design considering 3 variables at 3 different sizes. The variables under examination include temperature, moisture content, and particle size. Samples will be sent back to UT for further analysis to be conducted next year. Information from the survey taken and summarized last year will be analyzed this year.

Project Description: This project is designed to evaluate the potential of producing switchgrass on commercial agricultural land and to utilize that switchgrass as an energy feedstock. The proposed project addresses three primary questions:

1) What incentives are required to induce producers to convert commercial cropland to switchgrass?
2) What impact would a mature switchgrass feedstock industry have on Tennessee's economy and the Nation's agricultural sector?
3) What is the potential of converting switchgrass to bio-oil for use as light-off fuel in a coal fired burner?

Schedule:

Project Initiation Date: September 01, 2004
Planned Completion Date: December 31, 2008

Alternate Fuel Source Study – An Energy Efficient and Environmentally-Friendly Approach

Ralph Zee, Auburn University

Principal Investigator:	Dr. Ralph H. Zee	Funding Partners:	N/A
HQ Technology Manager:	Neil Rossmeissl	Sub-contractors:	Lafarge North America
PMC Project Officer:	John Scahill		

Goals and Objectives: The overall objective of this project is for Auburn University and Lafarge North America to form a logical and synergistic partnership to develop a better fundamental understanding and to improve technologies with higher efficiency for the use of alternate fuel. This project has seven tasks as follows:

- Task A, the preliminary survey will determine the amount of alternate waste fuels available, their value as currently used, location, cost as a fuel, ease and cost of shipping, and the year-round availability, using a cement plant as a model.
- In Task B, two alternate fuel sources will be identified for evaluation and then tested to determine their effect on emissions, how they may affect the production operations of a cement production plant, and how they may affect the quality of the Portland cement.
- Task C involves coordinating with a cement industrial partner to use their cement kiln in the state of Alabama to conduct two cycles of test burn using two alternate fuel sources as identified in Task B. Results of the two test burns will be compared with standard operation to determine the feasibility of these alternate materials in terms of (1) energy, (2) cost, (3) emissions, and (4) product quality.
- Task D is devoted to the analyses of the results from the kiln operation and the quality of the cement and concrete produced.
- Task E is the development and testing of a cement burn simulator to enhance the confidence of the selection of alternate fuel based on scientifically obtained data.
- Task F involves the test burn of two additional alternate fuels and a synergistic burn in collaboration with Lafarge.
- Task G is a feasibility analysis of commercially available gasification technologies specifically applied to the cement kiln based on thermodynamic analysis.

Project Description: There are numerous industries that are energy intensive and can benefit from using alternate fuel sources. Cement is the most widely used manufactured material in the construction industry. Auburn University will focus their effort on the following five fundamental areas of research for use of alternate fuel sources in energy intensive operations:

1) a preliminary survey of available energy sources in a global manner, and the characteristics that each of these sources has in terms of burn efficiency and impact on the environment;
2) selection of two alternate sources of fuel for laboratory and field testing; and
3) testing of the burn characteristics in a cement production environment.
4) The development of a burn simulator to better understand the thermal process involved.
5) A feasibility study of the application of gasification technologies to the process.

Summary of Work to Date - Accomplishments (FY05-current): Task 1 was completed and it will be beneficial to other commercial processes that are highly energy intensive. Literature searches focused on the types of alternative fuels currently used in the cement industry around the world. Information was obtained on the effects of particular alternative fuels on the clinker/cement product and on cement plant emissions. Federal regulations involving use of waste fuels were examined. Information was also obtained about the trace elements likely to be found in alternative fuels, coal, and raw feeds, as well as the effects of various trace elements introduced into system at the feed or fuel stage on the kiln process, the clinker/cement product, and concrete made from the cement.

An emission monitoring system was installed and certified at the cement plant. An alternate fuel feed system was designed, constructed and is being installed. The delivery and installation of this extensive system was delayed. This system is essential for both alternate fuel test burns (coal+tire+plastics and coal+tire+broiler litter).

The sampling and analysis plans were developed to ensure that relevant and pertinent information about the effects of using alternative fuels in the cement manufacturing process will be obtained. Data were collected for the following two baseline burn conditions: (1) coal only as fuel, (2) coal+tires as fuel. The sample collection and testing was successfully executed in accordance with the test plan. In addition, the pre-burn sampling for all the alternative fuels was completed in December 2006.

Four test burns were completed, samples collected and analyzed. The four burns involved (1) coal only, (2) coal plus tire, (3) coal plus tire plus plastic, and (4) coal plus tire plus broiler litter.

Schedule:
Project Initiation Date: August 01, 2005
Planned Completion Date: December 31, 2007

Jefferson County Bio-Energy Initiative

Wade Yates, Jefferson County

Principal Investigator:	Wade Yates	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	CVL Consultants of Colorado Inc
PMC Project Officer:	John Scahill		

Goals and Objectives: The development of economically viable market outlets for biomass, encouraging the creation of new business and public-private sector partnerships, while simultaneously reducing the risk of catastrophic fires. Project focus is on the creation of a large centrally located biomass-processing site which will help reducing the supply uncertainty barrier to biomass utilization along the Front Range. Tasks: (A) Site selection and pre-application for development. (B) Property Survey. (C) Initiate formal re-zoning application (from Agricultural to Industrial). (D) Site development plan application and associated permits (County Planning and Zoning) (E) Site engineering, grading and drainage plan (F) Site Construction.

Project Description: The Jefferson County Bio-energy Initiative (JCBI) seeks to develop economically viable market outlets for forest thinning biomass through the creation of new businesses and public-private sector partnerships, while simultaneously reducing the risk of catastrophic fires and associated costs and damages. We have a strong interest in cooperating with the United States Forest Service (USFS) and private industry to help create the infrastructure that will reduce the barriers to new bio-energy markets due to logistical concerns over long-term forest biomass supply availability. We believe that the creation of a large central biomass-processing site will help reduce the costs and risks associated with supply uncertainty. The JCBI will operate as a cooperative between public and private sector entities, with Jefferson County acting as facilitator and not a competitor.

Summary of Work to Date - Accomplishments (FY05-current):

1) Site selection and pre-application for development. Three sites were selected based on their availability, ownership and current zoning. Ingress and egress eliminated two of the sites due to the fact truck traffic would be crossing HWY 285 and reconfiguring the roadway would cost more than the project funding would allow. The third site is simply too far from the source of material and would require a lease at a significant annual expense. The pre- application review process for the site has been completed with the Planning and Zoning Division of the County. The review response recommend re-zoning the project from a mixed status of light industrial and agricultural to one designation - Light Industrial.
2) Property Survey. A boundary survey of the site has been completed and ownership rights identified. Ownerships consist of Jefferson County, Jefferson County Open Space, Hayden Investment LLC, CDOT and Public Service Company of Colorado. The Board of County Commissioners visited the site location in order to familiarize themselves with any potential view-shed issues that may arise in the future since the project sits in what is considered the "Gateway to the Rockies". Open Space has approved a land swap with like property in the General Fund. This removes and restrictions and allow the property to be rezoned to support log storage.
3) Contract for Design Analysis and Engineering work necessary to prepare the site prior to actual construction. The County has successfully selected a contractor to through a competitive bid process to perform a phased site feasibility study.

Schedule:

Project Initiation Date: June 1, 2006
Planned Completion Date: December 31, 2008

Feedstock Platform Portfolio – Feedstock Logistics Core R&D

Feedstock Infrastructure Project

Corey Radtke, Idaho National Laboratory

Principal Investigator:	Corey Radtke; Chris Wright; Kevin Kenney	Funding Partners:	N/A
HQ Technology Manager:	Sam Tagore	Sub-contractors:	Antares, University of TN, Diamond Z, Diamondback Technology, Iowa State University, Vermeer
PMC Project Officer:	Kevin Craig		

Goals and Objectives: 1.3.1.1.A Sustainable Harvest and Collection The overall objective of this task is to develop cost effective and sustainable harvest technologies and practices through the development of advanced harvesting equipment and through the development of predictive models capable of identifying the impacts of agronomic and agribusiness practices on feedstock sustainability. As such, this task focuses on advanced engineering systems, sustainable practices and the relationship between the two. Biomass harvest systems must not be designed solely on cost and performance targets. Rather, the contracting interface and sustainability boundaries are also key parameters that must be included in the design of equipment and the development of harvesting practices. The contracting interface is important because it determines whether biomass is the primary crop or the secondary crop, and the harvesting system performance must reflect this hierarchy. Sustainability boundaries are important because it dictates the ultimate viability of equipment and the long-term success of harvesting practices. The specific objectives of this task are as follows:

- Identify the performance requirements and design specifications for advanced harvesting equipment capable of achieving the performance and cost targets that have been established based on feedstock supply analyses
- Develop analytical techniques and modeling tools needed to engineer advanced harvesting systems
- Identify the agronomic, environmental, social and political factors (i.e., sustainability factors) that impact sustainability
- Develop tools and models for predicting the potential consequences associated with resource shifts resulting from food and fuel demands within the United States, as well as mitigating actions to minimize these potential impacts.

1.3.1.1.B Biomass Preprocessing The main objective of this task is to reduce the cost of preprocessing within the dry feedstock supply system to $2.75/dry ton by increasing the efficiency and capacity of preprocessing equipment. With this said, specific objectives have been identified that will guide logical, and often fundamental research, that targets the necessary performance parameters underpinning efficiency and capacity improvements. These specific objectives include the following:

- Determine current hardware performance parameters for various biomass feedstocks as demonstrated by barley straw in FY05
- Define critical hardware parameters, design specifications, and instrumentation needed to develop a prototype research grinder capable of testing multiple feedstock types and varieties based on FY06 performance parameters
- Quantify preprocessing losses and if necessary mitigation strategies to minimize feedstock cost impacts and air quality issues
- Identify the performance parameters of a separation system that can be coupled to a preprocessing operation and take advantage of value-add fractions identified in FY06
- Understand preprocessing tissue deconstruction and its relationship to grinder configuration, tissue fractions, tissue moisture, and grinder capacity, in order to optimize grinder configurations for capacity, efficiency, and quality
- Apply the fundamental rheological properties of preprocessed feedstocks, including uniformity, compactability, and flowability, to the design, performance, and cost of the preprocessing operation

- Identify strategies to increase bulk densities of preprocessed feedstocks by coupling the understanding of biomass deconstruction and rheological properties with innovative bulk compaction methods
- Identify the drying capacity of full-scale grinding operations to determine its impact on biomass moisture content with respect to applied feedstock assembly system technologies and cost

<u>1.3.1.1.C Biomass Storage and Queuing</u> The objectives of this task are two-fold. First, the soluble sugars in wet stored biomass will be investigated. Because soluble sugars are largely lost in wet harvested biomass during transportation and storage, and because of the tremendous value of these sugars, recovering the value of soluble sugars is paramount for wet harvested biomass to become an economically viable feedstock. Second, there will likely be advantages in treating biomass with xylanase at key entry points in feedstock supply chains, is the objective of the secondary investigation.

The specific objectives for this task include the following:

- Test advanced wet storage scenarios, focusing on the dynamics of soluble sugars in biomass
- Determine soluble sugar conversion efficiencies
- Measure impacts on residual solid biomass
- Estimate impacts on the feedstock supply infrastructure
- Test the effects of using xylanase throughout the feedstock supply chain

1.3.1.1.D Biomass Transportation and Handling As evidenced by the focused efforts in the harvest and collection, preprocessing, and storage elements of the feedstock platform core R&D, a bulk feedstock supply system is both necessary and inevitable. Compared to the existing or “pioneer’ supply systems where feedstock is packaged into bales for transport and handling operations, a bulk feedstock supply system presents many challenges. The first of these challenges occurs at the instant the biomass is harvested. Rather than baling the residues, harvest and collection equipment is needed to collect, handle and transport the bulk biomass to a processing or storage location. Next, preprocessing equipment is needed that both grinds the bulk biomass to accomplish some level of size reduction, and fractionates the biomass into discrete product streams of bulk biomass that are sent to storage. While current methods of bulk storage included pile or bunker storage, bin or silo storage, and some form of packaged storage, such as silage tubes, the handling operations, methods and equipment vary widely. Finally, the bulk biomass is transported to the biorefinery, where again some form of short-term storage (referred to as queuing) is utilized prior to moving into the conversion process. All of these operations mentioned, involve different aspects of bulk biomass transportation and handling. Many of the issues affecting bulk feedstock supply system design are common among the different unit operations with regards to equipment function and design. Consequently, all of these bulk transportation and handling issues are collectively embodied in this task of feedstock platform core R&D. The specific objectives for this task include the following:

- Determine how biomass physical properties (particle size, moisture content, etc.), feedstock type, and environmental conditions (such as temperature and humidity) influence rheological properties.
- Investigate various compaction methods to control and improve biomass bulk densities that will lead to the design and construction of viable bench scale systems to optimize and guide the implementation of full-scale equipment into the feedstock assembly system. Perform an assessment of large scale systems in other industrial operations to determine potential alternate handling and transportation methods.
- Determine the relationship between rheological parameters and transportation and handling systems in order to optimize their capacities and efficiencies, thus decreasing the net cost of this unit operation.
- Quantify biomass losses with current transport and handling methods based on material balance calculations or initial/final weight measurements.

<u>1.3.1.1.E Woody Harvest, Handling, Preprocessing, and Storage</u> The objective of this task is to assess current woody feedstock supply systems and determine points of adoption and improvement for the emerging biorefinery industry for transportation fuels. This objective will rely on the fundamental assembly system features of the current pulp and paper industry and on other fundamental science and engineering R&D being performed within the Feedstock Infrastructure Project. The specific objectives for this task include the following:

- Assess the current woody biomass infrastructure and assembly system structure based on existing woody biomass industries
- Identify key unit operations and potential improvements within current woody biomass infrastructure that can be applied to a biorefinery industry
- Complete an initial assessment and measurement of currently available woody biomass rheological properties
- Apply woody biomass rheological data to harvesting, collecting, preprocessing, transporting, and handing requirements for a biorefinery supply system

Project Description: 1.3.1.1.A Sustainable Harvest and Collection INL analysis of agricultural residue feedstock supply system costs from various parts of the U.S., has shown that current feedstock costs for corn stover (dry) and milo stover (dry) exceed the $35 cost target by about $18 per ton and $17 per ton, respectively. A breakdown of these costs shows the harvest and collection element to be the most expensive of all the feedstock supply system elements, totaling 50% of the allowable $35 feedstock cost. Accordingly, this is a critical area of focus for feedstock research and development. The problem with current farming practices is that they are not designed for the large scale removal of crop residues, and consequently, current practices are too inefficient to achieve the cost goals of the biomass program. This is revealed by looking at the current technology which includes five separate unit operations for getting the crop residues from the field to storage. Incremental improvements (e.g., increased equipment capacities and efficiencies) to the harvest and collection processes will not achieve the level of cost reductions needed. Rather, significant technological advancements must occur that enable the elimination of entire unit operations within the harvest and collection processes. This task will focus on this issue through the design of single-pass harvester that enables the grain and residues to be collected together in a single-product stream in a single pass across the field. Accomplishing this could reduce the harvest and collection costs by as much as $14 per dry ton, thus achieving nearly 75% of the necessary feedstock cost reductions.

The prudent allocation of valuable and limited resources is fundamental to achieving a sustainable biomass harvest that supports both food and fuel goals. Resource allocation is a critical component of the sustainable harvest question. In agriculture, essential resources include: land, water, nutrients, seed crops, energy, labor, technology, residue, etc. These resources vary spatially and temporally as a result of natural processes, market shifts, and technological innovation. Properly balancing these resources to meet future demands requires that appropriate government policies integrate agricultural and forestry systems with both food and fuel production processes, consumer markets, and demands for other petro-chemical substitutions.

“Sustainability” describes an interdisciplinary process that integrates economic development, social values, and environmental health considerations. Sustainability strives to meet the needs of the present without compromising the ability of future generations to meet their own needs. Key to the sustainability concept is acknowledging that human beings, and their associated influences, are intimately linked to the natural environment.

This subtask will apply the principles of sustainability to define a framework of the projected impacts associated with the harvest of biomass for food and fuel. It will also define a set of sustainable harvest indicators with which to monitor the potential consequences of competing agricultural resource allocation scenarios.

Sustainable harvest indicators are metrics that delineate the potential consequences of resource allocation decisions. These proposed sustainable harvest indicators will incorporate into a dynamic framework the following factors:

- Economic – supply, demand, prices, employment, energy balance, capital and opportunity costs, tax supports and credits, etc.
- Environmental - land-use patterns, water resources, waste, pollution, climatic changes, etc.
- Social - political, community development, technological advancements, infrastructure demands, distribution systems, consumer values, patterns of consumption, etc.

These indicators will be useful gauges for monitoring the biomass strategy with regard to resource allocations, agricultural/forestry profitability, environmental quality, food and fuel sufficiency, and community viability.

Given that some implementation actions could result in negative performance it will be important for DOE/USDA to have the ability to identify these actions as soon as possible. This subtask will also use these indicators to identify mitigating actions that can be applied to minimize negative consequences associated with "less-than-sustainable" agricultural resource allocations. This systems-level interdisciplinary framework (resource allocations, sustainability indicators, consequences, mitigating actions) will be integrated with pertinent resource data and ongoing modeling efforts such as POLYSYS, GREET, Biomass Scenario Model, etc.

1.3.1.1.B Biomass Preprocessing Biomass preprocessing is a critical operation in the feedstock assembly system and the front-end of a biorefinery. Its purpose is to chop, grind, or otherwise format the biomass into a suitable feedstock for conversion to ethanol and other bioproducts. Without this operation, the natural size, bulk density, and flowability characteristics of harvested biomass would decrease the capacities and efficiencies of feedstock assembly unit operations and biorefinery conversion processes to the degree that programmatic cost targets could not be met. Thus, the preprocessing unit operation produces a bulk flowable material that 1) improves handling and conveying efficiencies throughout the feedstock assembly system and biorefinery 2) increases biomass surface areas for improved pretreatment efficiencies, 3) reduces particle sizes for improved feedstock uniformity and density, and 4) fractionates structural components for improved compositional quality. In addition, the preprocessing operation has the potential to change traditional methodologies for handling biomass that can lead to revolutionary improvements in the feedstock assembly system. For example, non-bale harvesting systems can be achieved by moving the preprocessing operation from the biorefinery to earlier stages in the feedstock assembly system where traditional bale handling equipment can be eliminated and conventional bulk solids handling and transport equipment can be utilized.

1.3.1.1.C Biomass Storage and Queuing A large portion of the agricultural residues in the US will be harvested while in a relatively wet state. For example when corn grain is harvested, corn stover is typically over 40% moisture. This moisture presents two major problems, one from the weight of the water and one from the microbial destabilization that the water provides. The weight of water increases the unit costs of the feedstock supply chain that scale with tonnage more than volume. For example, once trucks are grossed out in weight carrying biomass, additional water directly offsets the dry tonnage of biomass transported (i.e.: 50% moisture feedstock would require twice as many trucks as 0% moisture biomass). Further, water provides a microbial medium that can lead to biomass damage. This microbial susceptibility can be diminished by converting some of the available sugars in the biomass to organic acids, which in turn lower the pH and help stabilize the biomass (ensiling). However, to a biorefinery, these available sugars can be effectively lost in such a process, either by being metabolized (consumed) by the microbes, or contaminated with a stream of ethanol-fermentation inhibitors such as acetic acid and lactic acid. Further, for anaerobic storage of the biomass, air exclusion is necessary, which requires higher priced storage systems. And finally, wet biomass requires faster handling systems because of the microbial instability, which impacts the unit operations upstream and downstream of the stored biomass.

The problem is that the wet feedstock supply chain costs are likely too high to support a biorefinery, yet are necessary to access enough tonnage to significantly impact the petroleum displacement goals. The solutions for this problem are equally simple, but need to be linked together as part of an integrated feedstock supply chain coupled to a specific biorefinery operation to be valid. These solutions may include the careful manipulation of the soluble sugars and sugar-oligomers in biomass, to make a wet/dry hybrid feedstock assembly system.

1.3.1.1.D Biomass Transportation and Handling Handling and transportation systems represent a significant assembly system cost with little added value to the feedstock creating a barrier to utilizing certain feedstock resources and reaching the respective cost and tonnage targets. This task is focused on quantifying the physical and rheological properties (including bulk density) of low and high moisture herbaceous biomass as they relate to handling systems for optimizing handling and transportation capacities, efficiencies, and feedstock quality. Determining the feedstock rheological properties is important since it significantly impacts the design, function, and cost of preprocessing and other feedstock assembly system unit operations. The properties to be tested include: 1) uniformity, 2) compactability, and 3) flowability. These properties are a function of feedstock type, particle size, moisture content, consolidation pressures, time at rest and atmospheric conditions (e.g., temperature and humidity).

Advanced feedstock supply systems that will handle large tonnages of biomass over wide geographical areas will also rely heavily on the development of new handling methods and technologies that implement value-added preprocessing and merchandising of the raw feedstock material. Traditional biomass transportation systems, such as trucks, may not be economically possible because of the large transport distances, traffic congestion, or community opposition. Rail transport of biomass reduces the frequency of loads, but is often more expensive than truck because of infrastructure constraints and handling costs. Advanced transportation systems will likely incorporate technologies that not only provide infrastructure and operational cost savings but also incorporate in-transit value-add processes.

<u>1.3.1.1.E Woody Harvest, Handling, Preprocessing, and Storage</u> The United States contains large amounts of unused woody biomass with significant potential of becoming an important feedstock for the production of bioenergy. The potential to use these residues as a renewable source of energy, fuels, and chemicals and the recognized need to thin forests for wildfire mitigation, as prescribed by the Healthy Forest Restoration Act (2003), has established a national interest in recovering and utilizing these resources. Transportation costs and low conversion efficiencies are two factors that increase the costs of products produced from these materials. The infrastructure for woody biomass is well developed to support a number of existing markets (e.g., timber, pulp and paper, fuel wood and urban residues), and the supply systems vary widely with respect to equipment, products, land use, markets, and resource environment (policy, accessibility, slope, compaction, etc.) Therefore, the focus of this task is to assess the importance of material properties and their interactions with the current woody infrastructure and identify improvements that are needed in each of the fundamental components of the feedstock supply infrastructure (harvest and collection, storage, preprocessing, and transportation and handling) to meet the cost and supply targets of the DOE biomass program. It is anticipated the infrastructure requirements for woody biomass will be significantly different from typical agriculture-based feedstocks. Perhaps feedstock location provides the most complex and critical set of inputs into the analysis of woody feedstock supply analyses. There is also a pressing need to understand the natural variations in the chemical composition of woody biomass, and how harvesting methods may impact the quality of woody feedstocks.

Summary of Work to Date - Accomplishments (FY05-current):
<u>1.3.1.1.A Sustainable Harvest and Collection</u> A multi-year Sustainable Harvest and Collection Task (1.3.1.1. A) Plan was completed and submitted on December 15, 2007 The task is divided into two sub-tasks: (1) Integrated Conceptual Design of a Single-Pass Harvesting System (1.1.3.1.A.1) and (2) Sustainable Harvest for Food and Fuel (1.1.3.A.2). The plan describes the research objectives, technical approach, budget and schedule for producing a virtual prototype of a single pass harvesting system, including an integrated combine platform and a biomass separator. The plan also details the technical approach, budget, and schedule for developing a sustainable harvest indicators model, including economic, environmental and social aspects of biomass use, for application in making better-informed management and policy decisions.

The focus of FY-07 activities is to develop the performance requirements and design specifications that will serve as the basis of the single-pass harvester concept. Identifying performance requirements has involved the following activities:

- Evaluating the performance of existing multi-pass harvesting systems
- Evaluating the performance of other research or commercial whole-crop harvesting systems
- Evaluating integrated supply system processes to identify the impacts of harvester design parameters (such as feedstock format) on downstream operations
- Developing analytical methods for designing handling, separation and densification systems required in the harvester design.

A solid understanding of existing multi-pass harvesting systems is important to identify the deficiencies that necessitate change as well as the performance and logistical attributes that should not change with the advent of advanced harvesting systems. The performance of existing multi-pass harvesting systems is difficult to assess due the variability in equipment configuration, operator skill, field conditions, and a host of other factors. Consequently, the INL, in collaboration with an industrial partner, initiated a first-of-a-kind large scale field test program to quantify harvest, collection and transportation costs of herbaceous crop residues, related to the monitoring and evaluation of equipment performance over a range of field conditions, biomass yields, machine configurations, etc. This project will provide the baseline data necessary to evaluate machine performance parameters and associated feedstock harvest and collection costs that serve two main purposes. First, data collected from this project will serve as a baseline to which advanced harvesting systems will be compared. Second, this project will identify key performance parameters that will be used to evaluate the performance of advanced harvester systems.

A review of whole crop harvesting technologies and applications was conducted to help formulate the current concept based on successes and deficiencies of other design concepts. This review of past and current research and commercial whole crop harvesting systems helped to identify key design issues, approaches to address these issues and common barriers to achieving a successful design. Data compiled from this review will be used to benchmark parameters and to establish specifications in the conceptual design of the Single Pass Harvester System.

Residue handling, separation, densification and collection represent the main requirements of single-pass harvest. Many single-pass designs have basically side-stepped the engineering challenges associated with these processes. We are attempting to address these issues by understanding the role of fundamental material properties in the design of these systems. Accordingly, a study of biomass bulk flow properties was conducted to develop the analytical methods for designing harvester handling, separating and densification systems based on fundamental material properties. This is a unique approach to harvester design that may provide the breakthroughs that have eluded single-pass harvest designs to date. This study focused on identifying the bulk flow properties that relate to the performance and design of two key components of the harvester design: conveying and densification.

Test methods to quantitatively measure the bulk flow properties related to conveying and densification options are currently being developed. The challenge in developing these test methods is to evaluate the applicability of current test methods, which were designed for evaluating homogeneous powders and granulated materials, to heterogeneous materials of much large particle size and morphology. Successfully developing these test methods will provide the means to select among the process options and to design the process equipment based on the properties and behavior of the biomass.

<u>Subtask 1.1.3.1.A.2.</u> A literature review was conducted to identify and evaluate prevailing sustainability issues as well as existing resource data and component-level models that are considered relevant to the sustainable food and fuel harvest questions related to this subtask. Based on the literature review and expertise of INL researchers, a set of “Feedstock Supply System Sustainability Indicators” (see table below) was developed for potential use in measuring economic, environmental and social outcomes associated with grower’s allocation of resources. A preliminary regional sustainable harvest model was constructed using the agricultural sustainability indicators listed in the table below to evaluate the sustainability of regional and farm-level agronomic practices and cropping systems.

Feedstock Supply System Sustainability Indicators		
Category	**Indicators**	**Measures**
Agricultural	Food production	Grain yield Grain N content
	Raw materials production	Stover yield Stover N content
	Nutrient cycling	Post–harvest soil NO_3 Soil pH
	Greenhouse gas regulation	Soil organic C Pre–plant soil NO_3
	Water use efficiency	Agricultural units produced / water consumed
	Erosion	Off-site transport of soil Nutrient and soluble chemical loss
Waste Streams	Residues	Tons per acre Value per ton
	By-products	Cost of disposal for by-products per ton; Value per ton
Environmental Impacts	Occurrence of Invasive Species	Observed presence or absence of exotic species (plant, animal, microbial)
	Loss of wildlife habitat	Land Allocation of farm acreage {% cropland, % pasture, % CRP, % domestic (homes, roads), % water bodies, % undisturbed}
Socioeconomic	Producer health	Farmers with/without health insurance
	Producer preparation	Educational achievement of farm workers
	Farm Income	Farm Income (Farm Income + Supplemental Non-Farm Income)
	Producer persistence	Farmers with/without successor(s)
	Producer investment	Farm acreage owned by farmer
	Consumer prices	Food and beverage prices indexed against other CPI major groups

<u>1.3.1.1.B Biomass Preprocessing</u> The preprocessing unit operation has focused on grinding dry feedstocks of one type and variety. This focus provided an initial assessment of the grinding operation to be performed and has lead to the establishment of specific performance targets based on operational efficiency, machine capacity, and resulting feedstock quality. The data collected during FY04 full-scale preprocessing tests, encompassing machine cost and feedstock characteristic metrics (capacity, efficiency, bulk density, flowability, and fractional quality), have been implemented into integrated feedstock assembly system models and have been shown through cost and sensitivity analysis to be critical parameters in the techno-economics of the preprocessing unit operation. Current preprocessing tests are furthering the full-scale preprocessing work to include a wider variety of grinding parameters, biomass feedstocks and moistures. The scope of these new tests is incorporating more aggressive capacity, efficiency, and bulk density targets based on previous preprocessing results. These targets are guiding the work scope for the INL and their industrial partners. The preprocessing section of the draft feedstock assembly system design report for dry biomass feedstocks is based on the performance targets for efficiency, capacity, and feedstock quality as determined by the core R&D efforts of this preprocessing task. The final feedstock assembly system design will identify a clear path to demonstrate and validate the preprocessing unit operation by FY09.

<u>1.3.1.1.C Biomass Storage and Queuing</u> The key attributes of storage systems are the overall cost of the system and changes in biomass quality over the storage period. In FY 2006 we tested the quality changes of biomass in wet storage as well as dry storage.

The milestone targets and the accomplishments of this year for mechanical preprocessing are as follows:

FY06 dry storage loss target = **<5%** → FY06 accomplishment = **0.85%**
FY06 cost target = **<$1.75/dry ton** → FY06 accomplishment = **$1.18/dry ton**

Meeting these goals was largely done by selecting a geographic region which is optimal for dry storage. Southeast Idaho was used as the location to evaluate the effects of storage types and conditions on the final cost of lignocellulosic biomass at the throat of a reactor. The input data and set of assumptions come from the FY 2005 full-scale harvest and collection effort where bales, loafs, and a chopped pile were established for storage evaluation. The effects of the bale storage were evaluated using the INL feedstock assembly design spreadsheet (Dry_Bulk_Bale_Processing v7-05-06) developed in 6.2.3.5 HQ Analysis Coordination and Studies Support – INL. It should be noted that this version of the static spreadsheet model does not take into account losses outside of the storage unit operation such as preprocessing, transportation, and handling losses. The scenario was for; cereal straws, windrowed, made into 4x4x8ft bales, stored roadside without tarps, and ground with a mobile grinder, and transported by truck to a 3-day interim bin storage system before loading the biomass into a reactor. The other two storage methods (loafs and chopped piles) were also analyzed as a stand alone unit operation, as opposed to being integrated with the rest of the assembly system.

The effects of dry matter losses in wet storage were estimated in terms of the impact on the compositional quality of the biomass. A large portion of the dry matter losses come directly from the microbial utilization of soluble and structural sugars during wet storage, and this effect was found to be potentially large. For example, losing 5% of the dry matter, if coming directly at the expense of sugars, would lower the feedstock allowable purchase price by about $8/ton. In our optimized system, where corn stover was stored 12 months in an ensiled system, there was no dry matter loss found. However, bunker losses appear large in the Harlan Iowa (B/MAP) project, while bag-type systems (bale wrap, silo tube) reportedly have around 5% dry matter losses.

Feedstock Infrastructure Subtask (1.3.1.1.C.1)
Target Milestone: Complete a core R&D engineering design and techno-economic assessment of an integrated wet storage - biomass field pre-processing assembly system with a pretreatment process that could potentially be scaled up to produce feedstocks to achieve a reduction to $35 per ton by 2012 from $53 per ton as of 2003.

Lignocellulosic biomass which is harvested relatively dry and supports a fully dry feedstock supply chain is slated to support the pioneer biorefineries. However, wet harvested biomass is projected to become a major portion of the available tonnage in order to meet ethanol production goals in 2012 and beyond. In order to understand the storage of wet harvested biomass, an iterative approach was taken, between engineered systems (modeling) and potential responses (field and lab work) of the feedstock during storage.

We analyzed potential pathways for the feedstock supply chain, binned these into three major supply chain operations (dry, wet/dry hybrids, and wet), and performed cost analyses for the respective storage operations. Dry assembly pathways are appropriate for relatively dry harvested crops. Wet/dry hybrid assembly pathways begin with wet harvested biomass and include drying within the supply chain. Wet assembly pathways include long term wet storage and retaining biomass moisture throughout the feedstock supply chain.

To analyze the feedstock assembly pathways mentioned above, the following key parameters were needed: A) the value of soluble sugars in the feedstock, B) potential storage options and their respective costs for wet-stored biomass, C) costs for drying of biomass and potential capture of a value-added product (ethanol) to support wet/dry hybrid assembly pathways, D) the composition of wet-stored biomass and the quality (in terms of structural sugars) of the biomass in relation to biological dry matter loss (DML), D) the stability of ethanol produced in solid-state fermentation, and E) the potential cost-offset for biomass containing ethanol.

The soluble sugars in biomass feedstocks represent significant fractions of the overall chemical composition. For example, corn stover is composed of about 6 to 12% (w/w) soluble sugars, while in switchgrass soluble sugars reportedly range from about 4 to 16%. These soluble sugars constitute a significant component of the overall feedstock value. Given that high quality corn stover contains 65% structural sugars, the soluble sugar fraction ranges from 8.4 to 15.6% of the total sugar content. These soluble sugars make up 14.6 to 25.5% of the C-6 sugars in corn stover. The values of the soluble sugars may be estimated to range from $4.01 to $13.20/dry ton for switchgrass and $5.48 to $10.20/dry ton for corn stover, assuming that the soluble sugars in biomass are at least as valuable as structural sugars in biomass. However, this resource value is often not recovered because the soluble sugars in the feedstocks are typically degraded by microbial activities promoted by prolonged contact with moisture during storage.

One way to capture the value of soluble sugars is to simply ferment them to a product, ethanol for example, within the biomass in storage or in a queuing system. However, capture of ethanol (or any chemical that may be captured by volatilization) would involve drying the biomass, which could be a synergistic cost impact because of the lower transportation and handling costs of dry biomass. To obtain relevant biomass drying costs, a subcontract was placed with a commercial food and chemical process equipment manufacturing firm, with specific details to model the complete greenfield cost of supplying commercial drying systems to support 0.3, 0.8, and 5M dry tons/year biomass supply over moisture ranges from 40 to 60% w.b. This was necessary to support the wet/dry hybrid pathways where drying is needed at the commercial scale.

The costs of wet stored systems (bunker, bale wrap, drive-over pile, vertical storage structure) ranged from 13 to 31$/DMT, assuming no dry matter losses. Using published mechanical dry matter losses, the final costs ranged from 16 to 34$/DMT.

The amount of dry matter loss in storage from microbial and metabolic activity is a function of storage method and environmental factors that determine water activity in the stored material. Part of storage strategy in wet feedstocks is preservation; due to high water activity, some dry matter will be consumed. Traditional preservation for wet livestock feed is a mixed acid fermentation which stops plant metabolism and eliminates most microbial activity. Although investment cost would be greater for storage systems engineered to produce ethanol fermentation, such a system could accomplish the same reduction in activity as traditional ensiling and offer the added advantage of producing recoverable ethanol. Our model suggests such systems could result in storage costs competitive with dry storage, and they would produce a dried and compacted product that would reduce transportation costs. Depending on feedstock type and condition, an ethanol capture wet storage system could even result in a net profit out of storage.

Laboratory studies were conducted to investigate A) the stability of ethanol produced in solid state fermentation of corn stover, and B) the compositional impacts on the residual solid biomass. Although ethanol production was used as a model fermentation product, the data generated allows inference into other in-storage pathways which would use soluble sugars for conversion into value-added chemicals. In two cuts of corn stover, ethanol could be produced in storage ranging from zero to about 4% (wt/dry-wt biomass). Furthermore, these results show that the ethanol is relatively stable out to 90 days of storage, which may support several supply chain options.

<u>Feedstock Supply Chain Preprocessing Using Endoxylanases Subtask (1.3.1.1.C.3)</u> The purpose of this task is to examine the effects of using endo-1,4-beta xylanases at various stages within the feedstock supply chain on the preprocessing and downstream processing of corn stover and other lignocellulosic agricultural residues. Examples of such effects include potential improvements in the energy usage during preprocessing steps such as grinding and densification, and the reduction of required pretreatment severity without producing significant soluble oligomers.

An experimental plan was developed to assess the enzymatic activity of commercial endoxylanases on pre-purified arabinoxylan and selected cellulosic biomass samples at low water activities. Results obtained using wheat arabinoxylan will be used to determine enzyme activity/water activity relationships, which will then be combined with water activity/water content relationships for various lignocellulosic substrates to define the water content ranges that support enzymatic activity in the field. Rates of reaction will be measured over time at various fixed water activities. Methods developed for the pre-purified arabinoxylan will be applied to lignocellulosic biomass sources including corn stover, wheat straw, and switchgrass.

Initial method validation tests using wheat arabinoxylan indicate that enzyme activity is observed in under one week at an aw of 1.0 when water is transferred through the vapor phase to freeze-dried samples. Tests underway at aw ranging from 0.19 - 0.80 (4 - 21% moisture on a dry basis) will determine the minimum water activity necessary to support enzyme activity for selected commercial endoxylanases for use in dry storage systems.

1.3.1.1.D Biomass Transportation and Handling The barriers associated with transportation and handling costs in the feedstock assembly system have primarily been addressed by increasing feedstock bulk densities through a reduction of particle sizes during the preprocessing operation. Established particle size versus bulk density relationships in previous preprocessing R&D has shown that there is a point of diminishing returns where the cost of grinding to smaller particle sizes exceeds the bulk density gains achieved in transportation and handling. The purpose of this dedicated transportation and handling task is to investigate the effects of biomass rheological properties on advanced bulk systems as they are directly implemented into transportation and handling equipment, and not necessarily tied to the preprocessing operation.

A detailed multi-year task plan has been developed. The work expands upon previous work conducted by the INL Harvesting and Preprocessing Feedstock Tasks and is directed at developing techniques, and ultimately engineered systems, that will increase the bulk density of biomass materials transported in various feedstock conveying operations. The techniques will exploit fundamental rheological properties of the feed-stocks and range from mechanical compaction to two-phase flow systems. The initial step in this development effort is to design and conduct testing that will allow a detailed characterization of materials properties of various feedstocks under conditions that are representative of field, process, and storage environments. Properties of interest include particle size distribution, bulk density, compressibility, unconfined yield strength, permeability, internal and surface friction, elastic spring back, shear strength, and viscosity. Combinations of these properties allow the flow of materials to be defined and predicted when bulk feedstocks are fed, mixed, compacted, stored, or conveyed. Consequently, they are also critical for the design and optimization of transportation and handling systems for diverse feedstock unit operations.

Laboratory testing protocols for producing biomass flow property databases have been developed, and components and instrumentation for conducting the benchscale testing have been identified and procured. Since commercial rheological testers are typically designed for use with fine powders; and consequently, do not accommodate particulate that is greater than ¼ inch in diameter, the project has designed versions of these measurement systems for characterizing larger feedstock particles. Systems include compaction and shear cells that can be scaled for various material sizes, integrated with commercial load frames, and operated over a range of consolidation pressures. These cells will be used to determine compressibility, unconfined yield strength, permeability, and spring back for various feedstocks as a function of grind size and uniformity, moisture content, and degree of compaction. These properties can, in turn, be related to flowability of the material within storage bins, hoppers, augers, and other conveying systems.

A one cubic meter volume test hopper has been designed and fabricated that will allow feedstock flow to be observed as a function of various surface liner materials over hopper wall angles that can be varied from 0 to 60 degrees and outlet diameters that can be varied from a few entimeters to one meter. The test hopper will allow the visualization of flow properties, determine a material's tendency to arch or rat-hole, and measure frictional properties. Hopper tests will also be used to validate observations from testing conducted at smaller scales.

Bench scale testing of selected feedstock materials, including samples of wheat straw, corn stover, and switchgrass, has been conducted at the smaller particulate sizes (E Milestone). These initial tests serve as a baseline and allow the measurement protocols to be validated using commercial systems. The feedstocks were first ground into 1/4 inch minus (6.25 mm) fractions. The 1/4 inch minus fractions were then further processed to a size of approximately 1/12 inch minus (2 mm). The two size fractions were then adjusted in moisture content from the dry (<8%) condition to 45%. The parameters measured included bin density, feed density, permeability, spring back, compressibility, relaxation, unconfined yield strength, and frictional properties. The data collection procedures were based upon techniques developed for the flow classification system developed by J. R. Johanson. The classification scheme allows the fundamental rheological parameters listed above to be translated into index values that are predictors of material flow through systems of a particular geometry. The rheological testing is being expanded to larger size fraction feedstocks currently being collected in conjunction with the INL's harvesting and preprocessing activities.

A literature and vendor survey of high density bulk and slurry pipeline technologies has been completed. The survey examined the parameters needed to design, develop, and evaluate the cost-benefits of the use of these systems for the delivery of feedstocks to ethanol production plants. The availability of existing data on the flow properties of various feedstock materials that could be used in the development of advanced conveying systems was also assessed.

Based upon the experiences in mining industry, the survey indicated that pipeline transportation of materials may be cost-effective when there are: (a) high annual volumes of materials to be shipped; (b) long distances to be traversed; (c) travel through difficult terrain; (d) high anticipated rates of inflation; (d) low real interest rates; (e) large, closely-spaced material resources to feed into the system; (e) availability of sufficient water at low delivered costs; (f) limited, or circuitous, rail routes or inefficient rail operations; and (g) low cost of electric power relative to that of diesel fuel for railroad locomotives. Throughputs of at least one million tons per year are generally required to make transport using a new slurry line competitive with other modes of transportation. In addition, for pipelines that require slurry preparation and separation facilities, a distance of 50-100 miles is often necessary to spread the costs.

The search also found little data on the rheological properties of herbaceous feedstocks that could be used in the design and optimization of long distance slurry pipelines or shorter pneumatic conveying systems that could serve as feeder lines to ethanol production plants. The transport of biomass in water-based slurries presents a number of challenges not found in the minerals industries. In particular, the material is more susceptible to physical; and potentially, chemical/biological damage than minerals. The design of laboratory scale testing and evaluation systems are being investigated to address these data gaps and allow a more detailed assessment of these technologies.

<u>1.3.1.1.E Woody Harvest, Handling, Preprocessing, and Storage</u> Completion of E Level Milestone 1.3.1.1.E.ML.1 "Initial assessment of woody biomass industrial linkages to lignocellulosic fuel production and verification of near infrared (NIR) and other analytical tools for rapid characterization" was completed June 29, 2007. INL traveled to North Carolina State University (NCSU) and met with Steve Kelley to finalize project details and tour the university facilities. Meetings were held with local loggers and timber contractors to discuss current logging practices and availability of forest residues. Sample gathering and NIR scanning is continuing at various sites in North Carolina. Idaho loggers have been contacted and sampling in northern Utah is planned. Meetings with representatives from the Idaho Department of Lands and the Caribou National Forest are also scheduled to take place.

NIR: Preliminary data show a high degree of correlation between NIR spectra and wood chemical constituents that are important to biofuels platforms. This suggests that there is a high probability of successfully creating predictive models utilizing NIR data, however, this data also suggests that separate NIR calibrations for hardwood and softwood will be necessary.

Woody Biomass Industrial Linkages: The two largest endusers of forest products are the pulp and paper industry and lumber mills. These industries produce low value lignocellulosic by-products. In the case of lumber production, this material is primarily in the form of sawdust. The most prevalent process for paper production is the Kraft process which produces a by-product called black liquor which is high in lignin and about 60% organic matter. Residues from timber harvest make up 20% to 30% of the total biomass available. These three sources represent the majority of under-utilized lignocellulosic material.

Pulp and Paper: The U.S. pulp and paper industry consumes approximately 12% of all energy used in the manufacturing sector of the economy. Most Kraft pulp and paper mills burn black liquor to produce steam and power for the plant and to regenerate the chemicals used in the pulping process. Black liquor is the single largest source of bioenergy in the U. S. Older plants use relatively inefficient boilers and must augment this power with energy from outside sources. Newer plants can produce enough energy to sustain operations and may even produce surplus electricity. Utilizing black liquor from these plants to produce a liquid biofuel will directly compete with the energy needs of the plant. In order to compete with the existing technologies utilizing this energy source, a new process would need to be efficient enough to provide power to the mill and have a marketable surplus. Additionally, recovery of the pulping chemicals must be part of the over all design. A gasification system that produces steam and syngas to run a turbine to produce electricity for the plant with enough excess to produce fuels via Fischer-Troph may be feasible, however, it maybe difficult to economically compete with electricity production given that electrical power must be part of the design.

Sawmill: Modern sawmills utilize waste wood scraps and sawdust to generate electricity for there own needs similar to the pulp and paper industry. These mills produce a 10 % to 30% excess of electricity. Other uses for sawdust and woody scrap material are pelletization, composting, and incorporation into composite materials. As with black liquor, a biofuels process would have to compete with the current uses of these materials.

Forest residues: Typical timber harvesting operations leave behind 20% to 30% of the harvestable biomass (woody residue) which represents from 71 to 100 million metric tons. This biomass is in the form of woody under story, limbs, leaves, and tree tops. Costs associated with gathering and transporting these materials is often higher than what an end user will pay. Sometimes the land owner will stipulate that the materials be removed for aesthetic reasons and to facilitate replanting. Spot markets for hog fuel exist in some areas of the country where direct-fired or co-fired power plants are present. Forest residues represent a large lignocellulosic energy source that is largely under utilized due to difficulties in obtaining, handling and delivering these materials cost effectively. Current estimates put delivery costs at between $30 and $80 dollars a dry ton with this cost largely impacted by transportation costs. However, optimization of the unit processes associated with forest residues may lower the delivered cost substantially and these materials may represent the best opportunity to provide lignocellulosic feedstock at the scale necessary to be of national significance.

Schedule:

Project Initiation Date: September 01, 2000
Planned Completion Date: September 30, 2012

Feedstock Platform Portfolio – Feedstock Systems Integration

Supply System Logistics

Shahab Sokhansanj, Oak Ridge National Laboratory

Principal Investigator:	Shahab Sokhansanj Anthony Turhollow; Robert Perlack; Mark Downing	Funding Partners:	Natural Sciences and Engineering Research Council of Canada, USDA
HQ Technology Manager:	Sam Tagore	Sub-contractors:	University of British Columbia
PMC Project Officer:	Kevin Craig		

Goals and Objectives:

The Project Goal: The goal of Supply Systems Logistics is to accelerate the development and validation of optimum biomass delivery options that would reduce the cost of producing biofuels from cellulosic biomass to levels competitive with competing fuels.

Objectives and scope: This task develops validated models of integrated collection, preprocessing, storage, and transport systems with capabilities to:

- develop an accurate account of regional biomass availability based on harvest time-moisture content (wet and dry) of biomass;
- develop reliable cost estimates for producing and delivering biomass feedstock to biorefineries – from farm to the throat of biorefineries;
- conduct optimizations to search for minimum supply options with respect to regional biomass availability, biomass quality, and timeliness of deliveries;
- conduct risk and sensitivity analysis on costs, energy inputs, and environmental implications of innovative biomass supply options;
- integrate biomass supply with conversion and biofuel distribution operations for life cycle costing; and
- develop strategies for siting pre processing depots and organizing regional and national supply networks to ensure year round availability of feedstock supply to bio refineries.

Project Description: Two underlining goals drive this task: (1) provide an accurate account of engineering requirements and infrastructure for on-time delivery of biomass to a biorefinery, and (2) conduct risk analysis on cost variations due to inherent biomass availability and quality. The goals of this task are realized by simulating and validating individual unit operations and integrating these operations across the entire supply chain. The simulation model employed is continuously verified using experimental and commercial field data as these become available. When executed, the model optimizes every operation along the biomass supply chain with respect to cost, quality and quantity. The verified model results are used for strategic analysis in support of the pretreatment and sugar platform, the thermochemical platform, and in support of program analysis and management.

The efforts in this task uses field data from integrated biorefinery partners– the Chariton Valley Switchgrass project, the Imperial Nebraska wet storage project, and the Iowa State Integrated Corn Stover Harvest project. The data also comes from core R&D research supported by OBP and USDA as well as university based research. The model also integrates the supply chain with the conversion processes to search for minimum cost biofuel and/or bioproduct.

Other industries have developed some very sophisticated engineering tools to make their industries competitive. The DOE biomass supply logistics model is equally robust in simulating supply operations subject to regional crops and bio-ecological constraints. The model reduces potential risks associated with on-time biomass availability, cost, and quality

Summary of Work to Date - Accomplishments (FY05-current): Activities in Biomass Supply Logistics is divided into two broad spectrum: (1) modeling and simulation, (2) field and laboratory experiments in support of the modeling effort. The followings are samples of modeling and experimental efforts since 2005.

Modeling: Development of the IBSAL: The IBSAL model is a simulation of a biomass supply chain. It consists of a network of operational modules and connectors threading the modules into a complete supply chain. Each module is a mathematical simulation of a process. The process modules are drying, wetting, and biochemical reactions that may lead to dry matter changes in biomass during harvest and subsequent handlings. The model is written in an object oriented high-level simulation language EXTEND[T] (www.imaginethatinc.com). The supply chain is divided in two activities: (1) Collecting and storing the biomass at the collection sites and (2) preprocessing and transporting biomass from collection sites to a biorefinery. The collection processes start immediately following the grain harvest or wilting of the grass (switchgrass) in the field. The model execution is fast and usually does not take more than 30 seconds to complete a run. The model is highly interactive allowing changes in input and output as the program executes.

The peer review and publication of the IBSAL model constituted a major milestone for the feedstock platform to meet the stage gate review of the platform.

Reference: Sokhansanj, S., A. Kumar, and A.F. Turhollow. 2006. Development and implementation of integrated biomass supply analysis and logistics (IBSAL) model, *Biomass and Bioenergy*, 30(2006):838-847.

Large scale wet stover storage and supply: Based on experience with successfully storing water-saturated large piles of bagasse for the pulping industry, Atchison and Hettenhaus (2003) proposed that such a system can also be applied to corn stover. Regardless of the technical feasibility of this system, in this article we estimate the cost of harvesting corn stover in a single pass with corn grain, delivering the chopped biomass to a storage pile, storing the stover in a wet form in a large pile at 75% moisture in a 211,700-dry Mg facility within a radius of 24 km from the field, and transporting the stover 64 km to a biorefinery. Field-ground corn stover can be delivered to a biorefinery by rail for $55 to $61/dry Mg. Truck transport is more expensive, $71 to $77/dry Mg. To achieve a minimum cost in the system proposed by Atchison and Hettenhaus, it is necessary to field densify stover to 74 dry kg/m^3, without losing combine field efficiency, have a large storage pile to spread fixed costs of storage over enough biomass, and use rail transportation. Compared to storage in an on-farm bunker silo at $60/dry Mg, there are limited circumstances in which large pile storage has a cost advantage.

Reference: Turhollow, A.F. S. Sokhansanj. 2007. Costs of harvesting, storing in a large pile, and transporting corn stover in a wet form. Manuscript number pm 5511; Approved for publication in Applied Engineering in Agriculture.

Ranking of biomass collection and feedstock supply chains: A recent published journal article ranks various biomass collection and feedstock supply options for the biofuels. The study details multi-criteria assessment methodology (PROMETHEE) that integrates economic, social, environmental and technical factors in order to rank alternatives for biomass collection and transportations systems. ORNL's IBSAL (Integrated Biomass Supply Analysis & Logistics) is used to calculate costs, energy input and emissions. Ranking of biomass collection systems is based on cost of delivered biomass, quality of biomass supplied, emissions during collection, energy input to the chain operations and maturity of supply system technologies. The assessment methodology is used to evaluate alternatives for collecting 1.8 million dry tonne per year - based on assumptions made on performance of various assemblies of biomass collection systems. A proposed collection option using loafer/stacker was shown to be the best option followed by ensiling and baling. Ranking of biomass transport systems is based on cost of biomass transport, emissions during transport, traffic congestion and maturity of different technologies. At a capacity of 4 million dry tonne per year, rail transport was shown to be the best option, followed by truck transport and pipeline transport, respectively. These rankings depend highly on assumed maturity of technologies and scale of utilization. These may change if technology such as loafing or ensiling (wet storage) methods are proved to be infeasible for large scale collection systems.

Reference: Kumar, A. S. Sokhansanj, and P.C. Flynn. 2006. Development of a Multi-Criteria Assessment Model for Ranking Biomass Feedstock Collection and Transportation Systems. Applied Biochemistry and Biotechnology 129-132:71-87.

Collaborative Project: The University of Tennessee, Oak Ridge National Laboratory, First American Scientific Company, University of British Columbia: The project funded through the USDA/DOE - 2004 solicitation is targeted to address biomass size reduction (chopping, grinding) and dry separation of biomass components. First year objectives investigated biomass ultimate failure stress/ energy/ physical properties to understand current equipment to identify grinder and separating actions for in-depth evaluation. Assessment tools were developed and include rapid imaging for sizing large, non-uniform particles, FT-NIR for rapid chemical analyses and wet chemical protocols to evaluate targets and separated biomass. Biomass "models" were selected as follows: corn stover, switchgrass, rice straw, hickory wood, and bagasse. Project original goal was 15% grinding savings, and is now projected to reduce typical grinding cost $3 to $4 per dry ton (about 1/4 of current costs) based current understanding of pre- and post-grinding literature data. Multiple stage grinding may be most appropriate to maximize efficiency. Size reduction technologies for further research were identified for 2nd year instrumented testing as follows: hammer mill, knife mill, disk mill, and variable-spacing linear knife grid. The project team had two recent meetings to evaluate the mid-term progress. In May, the University of Tennessee team and a USDA peer review team conducted a joint review of the project milestones. In late June, Dr. Womac (PI- University of Tennessee) traveled to Vancouver, BC where he reviewed the progress with the industrial research partner Dr. Narayan (First American Scientific Corporation), and the University of British Columbia research team. The project is progressing towards its third and final year when a pilot scale size reduction equipment will be demonstrated and a complete business plan around biomass pre processing (size reduction and fractionation) will be developed.

Reference: Womac, A.R. C. Igathinathane, P. Miu, S. Sokhansanj, S. Narayan. 2007. Biomass Pre-Processing Size Reduction with Instrumented Mills. ASABE paper 076046. Presented at the International Meeting of the ASABE, Minneapolis, MN July 17-20, 2007.

Large Scale Switchgrass supply for biofuels: Switchgrass (Panicum virgatum L.) is a promising cellulosic biomass feedstock for biorefineries and biofuel production. This paper reviews current and future potential technologies for production, harvest, storage, and transportation of switchgrass. Our analysis indicates that for a yield of 10 Mg ha^{-1}, the current cost of producing switchgrass (after establishment) is about $41.50 Mg^{-1}. The costs may be reduced to about half this if the yield is increased to 30 Mg ha^{-1} through genetic improvement, intensive crop management, and/or optimized inputs. At a yield of 10 Mg ha^{-1}, we estimate that harvesting costs range from $23.72 Mg^{-1} for current baling technology to less than $16 Mg^{-1} when using a loafing collection system. At yields of 20 and 30 Mg ha^{-1} with an improved loafing system, harvesting costs are even lower at $12.75 Mg^{-1} and $9.59 Mg^{-1}, respectively. Transport costs vary depending upon yield and fraction of land under switchgrass, bulk density of biomass, and total annual demand of a biorefinery. For a 2000 Mg d^{-1} plant and an annual yield of 10 Mg ha^{-1}, the transport cost is an estimated $15.42 Mg^{-1}, assuming 25% of the land is under switchgrass production. Total delivered cost of switchgrass using current baling technology is $80.64 Mg^{-1}, requiring an energy input of 8.5% of the feedstock higher heating value (HHV).

With mature technology, e.g. a large loaf collection system, the total delivered cost is reduced to about $71.16 Mg^{-1} with 7.8% of the feedstock HHV required as input. Further cost reduction can be achieved by combining mature technology with increased crop productivity. Delivered cost and energy input do not vary significantly as biorefinery capacity increases from 2000 Mg d^{-1} to 5000 Mg d^{-1} because the cost of increased distance to access a larger volume feedstock offsets the gains in increased biorefinery capacity. The paper outlines possible scenarios for the expansion of switchgrass handling to 30 Tg (million Mg) in 2015 and 100 Tg in 2030 based on predicted growth of the biorefinery industry in the U.S. The value of switchgrass collection operations is estimated at more than $0.6 billion in 2015 and more than $2.1 billion in 2030. The estimated value of post-harvest operations is $0.6 - $2.0 billion in 2015, and $2.0 - $6.5 billion in 2030, depending on the degree of preprocessing. The need for power equipment (tractors) will increase from 100 MW in 2015 to 666 MW in 2030, with corresponding annual values of $150 and $520 million, respectively.

Reference: Sokhansanj, S. S. Mani, A.F. Turhollow, A. Kumar, D. Bransby, L. Lynd, M. Laser. 2007. Large scale production, harvest and transport of switchgrass (Panicum virgatum L.) - current technology and visioning a mature technology. Submitted to Biomass & Bioenergy Journal.

Research progress on biomass densification: Bulkiness of crop residues and grasses is a major technical barrier against the biomass as a convenient feedstock for fuels and chemicals. Processing biomass into dense granules increases the bulk density of a group of loose biomass particles pressed into a small volume (granule). Dense granules have low moisture content (about 8% wet basis) for safe storage, a high bulk density (more than 600 kg m-3 almost 10 times when loose) for efficient transport and flowability for easy handling. The objective of this research is to determine the optimum size of particles from biomass grasses and residues and the best combination of densification parameters that would produce durable granules. Ground biomass (wheat straw, barley straw, corn stover, switchgrass) passed through three screen sizes (3.2, 1.6 and 0.8 mm) were compressed under five levels of compressive forces (1000 to 4500 N) and at two levels of moisture contents (12% and 15%) to establish compression and relaxation data. In general, smaller particle size, low moisture content, and higher pressures significantly increased the density of biomass granules. Corn stover required the least pressure while barley straw needed the most for the same granule density. Barley straw granules showed the most rigidity among the four biomass species tested. Wheat straw and switchgrass were similar in their response to particle size, moisture content, and compressive forces.

Reference: Mani, S., L.G. Tabil, and S. Sokhansanj. 2006. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets. Biomass & Bioenergy 30(2006):648-654.

Schedule:
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Planned Completion Date: September 30, 2011