LOGISTICS TEAM

INTERAGENCY FEEDSTOCK LOGISTICS AND BIOFUELS DISTRIBUTION WORKING GROUP

Biomass Feedstocks Logistics Research, Development, Deployment, and Demonstration Programs in the Federal Government—Review and Recommendations for Coordination and Collaboration

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CONTENTS

1.0 SUMMARY 3
2.0 INTRODUCTION 3
3.0 BACKGROUND 4
3.1 Biomass R&D Board 4
3.2 Logistics Issues 4
4.0 APPROACH 5
4.1 Definition 5
4.2 Inventory 5
4.3 Scope 5
5.0 DESCRIPTION OF PROGRAMS 6
5.1 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Bioenergy Technologies Office 6
5.1.1 BETO Logistics FOAs 7
5.1.2 Sun Grant Initiative Regional Biomass Feedstock Partnership 7
5.1.3 BETO Logistic CDPs 7
5.1.4 SBIR/STTR 8
5.1.5 Outputs 9
5.2 National Laboratories, U.S. Department of Energy 10
5.2.1 Idaho National Laboratory (INL) 10
5.2.2 Oak Ridge National Laboratory (ORNL) 11
5.3 USDA 12
5.3.1 Regional Biomass Centers 12
5.3.2 Agricultural Research Service (ARS) 13
5.3.3 National Institute of Food and Agriculture (NIFA) 18
5.3.4 U.S. Forest Service (FS) 19
5.4 USDA/DOE Joint Solicitation 23
5.5 Sun Grant Initiative 23
5.6 U.S. Department of Energy, Office of Science 24
5.6.1 U.S. Department of Energy, Office of Science, Great Lakes Bioenergy Research Center 24
6.0 SUMMARY 24
7.0 RECOMMENDATIONS 26
8.0 REFERENCES 27

1.0 SUMMARY

The commercialization of biofuels will require prices that are competitive at the pump with other fuel options. One way to reduce biofuels cost is to improve the efficiency and cost of feedstock logistics systems. Several federal agencies have research, development, demonstration, and deployment (RDD&D) programs or activities that are addressing the challenge of improving biomass logistics. The U.S. Departments of Agriculture (USDA) and Energy (DOE) are leading agencies for logistics RDD&D. This report provides an overview of these programs and information about some of the past or ongoing activities.

Most logistics RDD&D efforts are part of a program that has a broader mission and a wider range of goals and activities. Of these programs within DOE, most are either part of the Bioenergy Technologies Office (BETO), the Office of Science, or the Advanced Research Projects Agency–Energy (ARPA-E). USDA has programs in several agencies, but most efforts are in Agricultural Research Service (ARS) and the Forest Service (FS).

The RDD&D is completed through various approaches and varies by organization. Primary approaches include research centers or units, grants to other organizations, national laboratories, and formal/informal partnerships. The programs reflect the complexity of logistics and include a wide array of activities and approaches involving biology, ecology, engineering, economics, and other disciplines.

A general assessment concludes that these federal programs are addressing the following barriers to low-cost logistical systems: (1) the inherent low bulk density and energy content, and high moisture of raw feedstocks, (2) equipment inefficiencies, and (3) high transport costs. Significant progress and major accomplishments have been made, but more effort is still needed. Recommendations to facilitate additional RDD&D and improve coordination are provided.

2.0 INTRODUCTION

An expanding biofuels industry offers many potential benefits, including reduced dependence on foreign oil, economic growth and job creation, as well as environmental benefits, including greenhouse gas reduction. The extent to which the biofuels industry expands will largely depend on reducing the cost of biofuels relative to that of conventional fuels, such as through subsidies or through reducing the cost of production. Much research is focused on the latter, aimed at reducing costs at various parts in the supply chain. Examples include genetic research aimed at developing new biomass varieties, increasing conversion yields, and reducing logistics costs.

Biomass feedstock logistics includes all processes, from removing the biomass from the point of production through to feeding the material into the conversion reactor at the biorefinery. Specific logistics operations include biomass harvest, collection, preprocessing (including densification), storage, and transportation.

Efficient biomass supply systems have been developed for handling agricultural commodity crops and forest materials; however, they were designed for transport over short distances and limited storage periods, and do not address quality challenges as is required by biorefineries. Logistics technologies and systems are being developed specifically for the bioenergy industry, but such systems fall short in the sustainable, economic delivery of an on-spec feedstock in the quantities needed to support an expanding bioenergy industry. Improving feedstock logistics through research and development, and accelerated deployment of new systems and technologies are crucial to reducing biofuels production cost.

Although variable, feedstock logistics costs can account for 35–65% of the total production costs of lignocellulosic ethanol (Fales et al. 2007), and logistics costs for corn grain contribute roughly 7–19% of the total cost of producing fuel ethanol (Shapouri and Gallagher 2002; Duffy and Smith 2008; Rapier 2008). An analysis of five different feedstocks showed that 20%–50% of the delivered costs was transportation and handling (Browne et al. 1998). High logistics costs are a barrier to biofuels becoming cost competitive with fossil fuels, preventing the United States from achieving energy security goals for domestic production of renewable energy. Therefore, there is a need to improve logistics efficiency and economics for lignocellulosic feedstocks.

Many federal agencies are involved in reducing feedstock logistics cost by funding science and engineering work, aimed at identifying and addressing barriers to efficient systems. Although some of these efforts have logistics as their main focus, for many, if not most, feedstock

logistics efforts are secondary. Feedstock logistics work sponsored by the U.S. government includes RDD&D. Examples include energy crop establishment and cultivation, measurement and characterization techniques, planning and modeling, informatics, techno-economic analysis, business management, and modeling. This paper identifies RDD&D programs within the U.S. government involved with biomass feedstock logistics. The purpose of the paper is to provide a brief description of these programs, summarize ongoing activities across the federal government, make a general assessment of federal efforts, and make recommendations for improving coordination.

3.0 BACKGROUND

3.1 Biomass R&D Board

The Biomass Research and Development Act of 2000[1] established the Biomass Research and Development (R&D) Board "to coordinate programs within and among departments and agencies of the federal government for the purpose of promoting the use of bio-based industrial products" (defined as fuels, chemicals, building materials, or electric power or heat from biomass in Sec. 303 (2)). The original act has been amended several times, with the latest being part of the Food, Conservation, and Energy Act of 2008.[2] The general role of the Board has remained unchanged.

The Biomass R&D Board chartered the Feedstock Logistics and Biofuels Distribution Working Group[3] to enhance collaboration among federal agencies involved in improving production and delivery systems for biofuels and other bioproducts. The goal of the working group is to overcome technical challenges to systems integration, scalability, and deployment. The group also evaluates storage and transportation options and trade-offs for both upstream logistics and downstream fuel distribution and end-use requirements. This effort is separated into "feedstocks" and "distribution" teams to better manage the tasks. The feedstocks team (Logistics Team) is addressing collaboration and coordination of RDD&D activities to help reduce the costs of feedstocks and ensure sustainability.

Before the creation of the Board and the Logistics Team, coordination and collaboration across federal agencies in improving biomass feedstock logistics were *ad hoc*. Information exchanges were mostly limited to scientific and technical conferences, or through published sources.

3.2 Logistics Issues

Biomass feedstock logistics, like other agricultural and forestry logistics systems, involve a myriad of combinations of feedstock types and associated systems. Different feedstocks require different systems due to inherent differences in biomass type, such as a tree vs. a standing crop. However, feedstock type and associated supply logistics systems also vary greatly across the country because of such factors as weather, soil and terrain, culture, scale, haul distance, and markets. The complexity of products, techniques, equipment, and systems results in the need for multiple solutions to common barriers.

Initial tasks of the Logistics Team were to (1) conduct a review of current logistical systems and (2) make recommendations for research and commercialization.[4] The report concludes that machines and systems exist that are capable of performing each biomass supply chain operation, but the technology is not designed for the scale and efficiency required. The report also mentioned challenges associated with inconsistent and low-quality feedstocks. Therefore, the costs of supplying biomass using currently available technologies are too high for market acceptance of biofuels. The reduction of logistics costs is essential to create an economical, sustainable biofuels industry.

The report identified several feedstock considerations that are barriers to commercialization of biofuels:

1. ***Biomass from agricultural and forest resources have low bulk and energy densities.*** The low densities of these feedstocks make transport, handling, and storage inefficient. Low cost densification and other preprocessing technologies are needed to achieve higher bulk and/or energy densities for transportation, storage, and other logistics operations.

[1] See Sec. 305 (a). Public Law 106-224, Title III, Sec. 305, http://www.gpo.gov/fdsys/pkg/PLAW-106publ224/pdf/PLAW-106publ224.pdf.
[2] Section 9008, Public Law 110-234. http://www.gpo.gov/fdsys/pkg/PLAW-110publ234/pdf/PLAW-110publ234.pdf
[3] http://biomassboard.gov/board/working_groups.html
[4] Biofuel Feedstock Logistics: Recommendations for Research and Commercialization, www.biomassboard.gov/board/working_groups.html

2. ***The moisture content of biomass at the time of harvest—whether agricultural, silvicultural/woody, or algal—make it conducive to rotting, leading to quality degradation, material loss, and safety concerns such as fires.*** High moisture content can cause aerobic instability during storage and reduce the efficiency of transportation and preprocessing operations. Strategies and equipment are needed to deal with high-moisture biomass.

3. ***Currently, feedstock logistics equipment is inefficient.*** Existing equipment has insufficient capacity to efficiently and economically harvest, store, and deliver feedstocks for biofuels, and it does not address various quality considerations that are critical to conversion processes. Industry collaboration is needed for the development of innovative equipment and systems designed specifically for lignocellulosic feedstock. New methods of integrating system components are also needed to increase efficiency and reduce costs.

4. ***Biomass quality is variable and inconsistent within a given species and between different species.*** Biomass attributes vary with feedstock source and season, resulting in inefficiencies in handling and conversion systems. There is a need to develop logistics operations that maximize uniformity and consistency of delivered feedstock attributes. Quality standards are needed for delivered feedstocks, as is instrumentation to determine feedstock quality quickly at the point of sale.

5. ***Transportation could potentially overburden transportation networks.*** Trucking is commonly used for biomass transportation, which is not only costly over long distances, but it is often damaging to roadways and leads to increased traffic. Therefore, it can be socially undesirable. Research is needed to understand how trucking regulations impact payload limits, reduce costs, and reduce traffic impacts, as well as to explore opportunities to use other transport modes, such as rail. Innovative transportation solutions such as improved containers and lighter vehicles could also reduce cost.

4.0 APPROACH

4.1 Definition

This report focuses on feedstock logistics work funded but the U.S. government. For the purpose of this report, biomass feedstock logistics refers to all operations that occur after the biomass is produced and is standing in a field or forest ready for harvest and before it is introduced into the conversion facility in-feed system (also referred to as the "reactor throat"). The goal of this effort was to be more inclusive and to garner more information about on-going federal activities concerned with biomass inventory, resource assessments, monitoring, production, harvest and collection, transport, storage, preprocessing, feedstock characterization, etc.

4.2 Inventory

The Logistics Team of the Interagency Working Group conducted an inventory[5] of logistics projects in the federal government, primarily in DOE and USDA. The inventory, although just a snapshot of activities within the federal programs, provided some important information as to the level and types of activities at the federal agencies. The information is useful in understanding how some of the barriers identified above are being addressed.

4.3 Scope

Although the development of viable feedstock logistics systems will require combined public and private efforts, there is a significant role for the federal government. Several federal government research programs and activities are contributing to reducing and eliminating the identified barriers. The following list, although not exhaustive, provides some examples:

- The Biomass R&D Board sponsors the Interagency Feedstock Logistics and Biofuels Distribution Working Group, in which DOE, the U.S. Department of Transportation (DOT), the U.S. Department of the Interior, and USDA participate.
- The Board also sponsors the Algae Interagency Working Group (includes logistics), in which several agencies participate.
- DOE's ARPA-E sponsors logistics R&D.

[5] Inventory of Biomass Feedstock Programs & Activities in the Federal Government, http://www.biomassboard.gov/board/feedstock_inventory.html

- DOE's BETO and USDA's National Institute on Food and Agriculture (NIFA) sponsor joint funding solicitations under the Biomass Research and Development Initiative (BRDI).
- DOE's Office of Science supports advanced feedstock development RD&D via the Joint Genome Institute under the Genomes-to-Life Program.
- DOE's Office of Science supports three bioenergy research centers, which include limited feedstock research.
- DOE's Office of Science supports Energy Frontier Science Centers (EFRC), which include the genetic improvement of feedstock plant material.
- USDA's Agricultural and Food Research Initiative (AFRI) supports regional bioenergy coordinated agricultural projects (CAPs).
- USDA's ARS and FS support Regional Biomass Research Centers.
- USDA's ARS sponsors National Programs #213 ("Bioenergy") and #301 ("Plant Genetic Resources, Genomics and Genetic Improvement").

In addition to the efforts listed above, there are many excellent research and development activities on-going outside the federal government at universities and in the industry. In fact, most of the federally funded logistics R&D is either directly through or in collaboration with outside cooperators, including universities. Commercialization and deployment are primarily through manufacturers and end-users.

5.0 DESCRIPTION OF PROGRAMS

Several federal programs involved in biomass feedstocks logistics research, development, and demonstration are summarized below.

5.1 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Bioenergy Technologies Office

The Bioenergy Technologies Office (BETO) supports research, development, and demonstration (RD&D) aimed at reducing logistics cost, conducted through the Feedstock Supply and Logistics Program within BETO. Research efforts are supported through grants, partnerships, and national laboratories contracts. BETO's feedstock logistics RD&D is focused on developing and optimizing cost-effective, integrated systems for harvest, collection, storage, preprocessing, and transportation of a range of feedstocks, including agricultural residues, forest resources, and dedicated energy crops.[6] Logistics are broadly broken down into four categories:

1. harvest and collection
2. preprocessing
3. storage and queuing
4. handling and transportation.

Project needs are developed through a combination of strategic and tactical planning processes. One important tool is a request for information (RFI), in which the public provides comments on a specific topic. Two other tools are biennial program reviews,[7] multi-year program plans (MYPPs),[8] and the annual *Biomass* conferences.[9] Peer reviews allow experts from academia and industry to assess the overall program and individual platforms in their ability to set and meet goals, and provide input on future direction. MYPPs are public documents that enable both internally funded researchers (such as those at national labs) and external groups to link their activities to work on-going and planned at BETO. The MYPP helps identify clear linkages between key program activities and progress toward identified goals. Annual *Biomass* conferences bring together stakeholders to give them opportunities to present current work and new ideas, as well as to network with colleagues.

Research is funded to help meet BETO goals. The following are mechanisms for selecting collaborators to completing projects:

1. Annual programs of work with national laboratories and other entities using competitive selection processes
2. Funding opportunity announcements (FOAs), which are also awarded through a competitive process
3. Congressionally directed projects (CDPs), through which new projects have not been funded since 2010.

Annual programs of work are developed for each project, whereas FOAs are program priorities and are dependent on available funding. CDPs may be included in annual appropriations. Annual Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) competitive grants are other funding mechanisms.

[6] Note that BETO also funds research in algae.
[7] https://www2.eere.energy.gov/biomass/peer_review2013/Portal/
[8] http://www.energy.gov/eere/bioenergy/downloads/bioenergy-technologies-office-multi-year-program-plan-july-2014-update
[9] http://www.energy.gov/eere/bioenergy/biomass-2014-growing-future-bioeconomy

5.1.1 BETO Logistics FOAs

A major component of BETO's logistics efforts is through FOAs. A FOA sponsored in 2009[10] provided funding from 2010–2014 for feedstock logistics industrial partnerships, referred to as the "high-tonnage projects." The purpose of the FOA was to design and demonstrate a system for harvesting, collecting, preprocessing, transporting, and storing sustainably produced feedstocks to support the expansion of the biofuels industry. The awardees[11] have made significant progress in the development of an industrial-scale handling system capable of supplying high-impact feedstocks,[12] and in addressing logistics challenges from harvest through to in-feed into the conversion reactor at the biorefinery. Although substantial progress has been made, logistics challenges remain.

A 2013 FOA[13] focused on developing new logistics strategies and technologies that address key challenges in large-scale biomass feedstock logistics, such as total logistics-associated cost, format and quality variability, storage stability, bulk and energy density, handling characteristics, and variable conversion performance. FDC Enterprises, the sole awardee from this FOA, seeks to reduce the number of process steps in the supply chain for both round and square bales, thereby reducing the manpower and equipment required to efficiently harvest, collect, transport, and process high-impact biomass feedstocks into end-use fuels. This work will include development of new equipment and conveyor designs, advanced process automation and controls, and improved milling equipment optimized for herbaceous biomass. In addition, this project will emphasize feedstock quality monitoring throughout the supply chain using advanced technologies to lower feedstock sampling costs and incorporating real-time analysis for important parameters such as biomass moisture and ash content. The culmination of this work is expected to help BETO achieve its 2017 goal, which is an nth-plant-modeled biofuels production cost of $3/gasoline gallon equivalent. The feedstocks contribution to this goal is to validate efficient, low cost, and sustainable feedstock supply and logistics systems that can deliver feedstock to the conversion reactor throat at required conversion process in-feed specifications, at or below $80/dry ton ($2011) by 2017 (including grower payment/stumpage fee). This project is expected to end in 2016.

5.1.2 Sun Grant Initiative Regional Biomass Feedstock Partnership[14]

The Regional Feedstock Partnership is funded through BETO with the goal of addressing barriers associated with the development of a sustainable and predictable supply of biomass feedstocks. The Partnership's primary focus has been quantifying growth and yield for selected energy crop species across the United States and mapping the results.[15] The associated yield work is important to improving logistical systems for biomass feedstocks.

5.1.3 BETO Logistic CDPs

CDPs are designations by Congress to work with a specific entity, such as a university, to accomplish a particular project. While several of these projects remain on-going, this mechanism has significantly lessened since fiscal year (FY) 2010. Although CDPs cover a range of topics, a few focus on feedstocks logistics or have logistics as a component (see the inventory for project examples). Some of the currently funded CDPs[16] addressing logistics include the following:

- ***Improving Biomass Yield of Energy Crops***
  - St. Joseph's University Institute for Environmental Stewardship: This project is examining the physiological, morphological, and reproductive responses of *Panicum virgatum* (switchgrass) cultivars identified as potential biofuels-producing cultivars as well as naturally occurring varieties of switchgrass to projected changes in climate for the central portion of the United States.

[10] http://energy.gov/articles/doe-selects-biofuels-projects-receive-21-million-funding
[11] http://energy.gov/articles/doe-selects-biofuels-projects-receive-21-million-funding
[12] The FOA defined "high-impact feedstocks" as feedstocks that are domestically available and have the agronomically and ecologically sustainable ultimate availability potential of at least 50 million dry metric tonnes of lignocellulosic biomass per year. Multiple feedstocks may be combined to satisfy this requirement if the proposed conversion technology is shown to be capable of converting each of the feedstocks that constitute the 50 million dry metric tonnes per year. Alternately, the feedstock must be domestically available and have the agronomically and ecologically sustainable ultimate availability potential to produce at least 1 billion gallons per year of an acceptable biofuel.
[13] https://www1.eere.energy.gov/financing/solicitations_detail.html?sol_id=570
[14] http://www.sungrant.org/Feedstock+Partnerships
[15] https://www.bioenergykdf.net/content/maps-productivity-potential-bioenergy-crops-sun-grant-regional-feedstock-partnership
[16] https://www.eere-pmc.energy.gov/CDPRecipients.aspx

- University of Rhode Island: Rapid genetic improvement of the most promising perennial grass feedstocks, such as switchgrass and Miscanthus (which are not highly domesticated) was produced using molecular-assisted breeding methods. In addition, biofuel-specific traits can be engineered to increase fuel production per acre, such as production of glycosyl hydrolases, biopolymers, altered sugar, low starch or low lignocellulose fibers, cell wall biosynthesis proteins for increased cellulose, and decreased lignin. The overarching mission of this project is to improve and allow production of switchgrass for biofuels regardless of downstream processing technologies through the development of hybrid plants and gene confinement strategies relevant to commercialization.
- University of Hawaii: This project is examining production of four energy crops (napier grass, sweet sorghum, energy cane, and sugar cane) at three elevations and three irrigation levels and will complete feedstock characterization for assessing success of subsequent conversion via biochemical or thermochemical means.
- University of Connecticut: This project is identifying poplar varieties for field evaluation and demonstration followed by characterization of genetically improved poplar with enhanced growth rate and altered wood chemical compositions. Subsequent tasks included development of a method for genomics-guided mutation breeding of poplar for bioenergy applications as well as preparation and characterization of heterogeneous catalysts for biomass conversion.

- ***Resource Assessment and Feedstock Logistics***
  - Oklahoma State University: This project facilitates the development of biofuel production from regionally available feedstocks, particularly switchgrass. Project activities are concentrated in five major areas:
    (1) The first component focuses on demonstrating the supply of feedstocks by modeling the yield and cost of production of dedicated energy crops at the county level.
    (2) The second component of the project involves modeling the harvesting, transportation, and storage of biofuel feedstocks.
    (3) The third component models alternative conversion processes.
    (4) The fourth component of the project involves the development of a comprehensive biofuel supply chain model that incorporates feedstock production, feedstock logistics, biofuel production, and distribution.

    The supply chain model identifies the optimal type, size, and location of biofuel refineries. The final phase of the project involves the development of a community economic impact model.

- ***Biopower Applications***
  - Laurentian Bio-Energy Project: The project is primarily intended to determine and make the necessary modifications to existing coal-fired boilers in order for them to burn biomass fuel—specifically, wood chips. It involves engineering, design, equipment modification, and permitting. A secondary aspect of the grant involves the study of the economic feasibility of processes, which, while providing fuel for energy production, also improve timber stand growth for the pulp and paper industries. A final aspect of the grant is to facilitate a re-assessment of biomass availability in light of increased resource pressure.

- ***Sustainability***
  - University of Nebraska–Lincoln: A second-generation biofuel industry is developing the use of maize residue for cellulosic ethanol, which is the most cost effective and abundant cellulosic feedstock in the central United States for the foreseeable future. A number of commercial-scale facilities under construction will use maize residue as the primary feedstock. This project focused on determining the impact of maize residue removal on (a) carbon sequestration, (b) water use efficiency, and (c) life cycle analysis of total greenhouse gas (GHG) emissions. This information will be entered into a model to predictt whether second-generation biofuel producers using maize residue feedstock meet GHG emissions thresholds specified in the 2007 Energy Independence and Security Act.

5.1.4 SBIR/STTR

The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)[17] programs in the DOE Office of Energy Efficiency and Renewable Energy (EERE) are designed to stimulate technological innovation by small advanced technology firms and provide new, cost-effective scientific and engineering solutions to challenging problems. The SBIR and STTR programs are one of EERE's best sources of risk capital for small businesses that are developing promising new technologies. Some examples for feedstock logistics are shown in Table 1.

[17] http://www.sbir.gov/

Table 1. FY13 SBIR Phase I Grantees for Feedstock Logistics.

Company	Project Title	Project Summary
Carbo Analytics, LLC	Simple & Rapid Determination of Total Accessible C5 & C6 Content of Biomass Samples	Variability in the sugar content of biomass raw materials can be the difference between a profitable and unprofitable biorefinery. Carbo Analytics proposes to create a simple, fast instrument for measuring fermentable sugar content for today's biorefineries as well as tomorrow's biomass supply chain.
Forest Concepts, LLC	Low-Energy Rotary Shear for Sub-Millimeter Particle Production	Advanced rotary shear technologies from this project will dramatically reduce biofuels conversion systems costs through lower total capital costs, lower process energy consumption, and increased biofuels yields, bringing the nation towards import oil independence.
Hydrogy LLC	Forest Understory Energy Logistics (FUEL) A Woody Biomass Energy Intensification System	A hybrid torrefaction process is proposed to convert the forest understory to a universal fuel with desirable properties. This woody biomass intensification approach facilitates Forest Understory Energy Logistics (FUEL) from the grass root of the supply chain for a wide range of biomass energy applications. The goal of this project is to design, construct, and test a bench-scale FUEL system that is effective, robust, and scalable for practical applications.
SABIA, Inc.	On-Line Analysis for Enabling Effective Production and Usage of Biomass Fuels	This project will develop an analyzer that is specifically suited for use with biomass and combinations of biomass and other fuels. The analyzer will measure material density, the percentage of moisture, the percentage of the elements (hydrogen, oxygen, carbon, and nitrogen, and ash elements, such as, iron, aluminum, silicon, calcium, etc.), and it will calculate calorific value of the material being analyzed.

5.1.5 Outputs

The BETO feedstock logistics-related outputs to date can be grouped into three categories:

1. Technology and feedstock logistical systems development
2. Systems models and economics
3. Information and deployment

Idaho National Laboratory (INL) leads feedstock logistics systems development and works with Oak Ridge National Laboratory (ORNL) to provide engineering information on system function, cost, and performance. A significant output has been the development and demonstration of the uniform-format feedstock supply system concept. A recent output has been the development of the Feedstock Process Demonstration Unit (PDU) to test alternative biomass processing options. More detail is available in Section 5.2.1.

BETO has made advances in systems logistics modeling, such as Integrated Biomass Supply Analysis & Logistics (IBSAL)[18] and the Biomass Logistics Model (BLM)[19]—both simulation models. The Western Governors' Association provided national siting model information on biomass supply and potential biorefinery sites using transportation attributes (Parker et al. 2011). This project has concluded, but it is an example of a resource model. The National Bioenergy Routing Model at ORNL provides user-interface basic routing information for transporting biomass and bioenergy products. ORNL developed a prototype optimization model—Biofuel Infrastructure, Logistics, and Transportation (BILT)[20]—capable of specifying infrastructure for the entire supply chain, including selection of biomass, transport mode, location and capacity of preprocessing and refinery facilities and distribution.

[18] http://biomass.ubc.ca/software/
[19] Jacobson, J.J.; Searcy, E.M. (2010). Uniform-Format Feedstock Supply System Design for Woody Biomass. Presented at the Spring Conference of the AIChe, Orlando, Florida.
[20] https://bioenergykdf.net/models/bilt-model

Another effort has been managing and, when practical, improving feedstock quality throughout the supply chain. A library repository is being developed for feedstock physical and chemical properties. The Biomass R&D Resource Library,[21] developed within INL's Bioenergy Program, provides a robust mechanism to store, track, and retrieve various biomass feedstock materials for research and demonstration purposes. Some features of the library include the physical storage of feedstock materials and the archive database system (including a bar-coding and sample hierarchy). The Bioenergy Knowledge Discovery Framework (KDF)[22] provides web-based data and tools to synthesize, analyze, and visualize vast amounts of information. This GIS-based framework is useful for analyzing all aspect of the biomass supply/use chain. The Bioenergy Feedstock Information Network[23] at ORNL is an example of an outlet of feedstock logistical information.

An update to the *Billion-Ton Study* was released in 2011 and includes information on feedstock availability.[24] A supplemental study has been completed on the availability of algae as a bioenergy feedstock.[25]

A recent deployment activity example was the 2011 "Biomass Preconversion, Formulation, and Densification Workshop"[26] to discuss and demonstrate options for feedstock handling efficiency. Other deployment activities such as demonstrations are incorporated into FOA projects.

5.2 National Laboratories, U.S. Department of Energy

5.2.1 Idaho National Laboratory (INL)

INL's Bioenergy Program research takes an engineering approach to reducing feedstock logistics costs, iterating between analysis, field work, and lab work. This work has focused on addressing barriers to sustainable and economic feedstock delivery that have been identified by rigorous sensitivity analyses.

The INL Bioenergy Program manages the newly designated DOE-EERE Biomass Feedstock National Users Facility (BFNUF), which is located in the INL Energy Systems Laboratory (ESL) in Idaho Falls, Idaho. BFNUF serves as a national research resource for bio-industry developers, ranging from federally sponsored research programs to industry and academia, providing single-point access to state-of-the-art equipment, expertise, feedstock, and data. Facilities include pilot-and bench-scale preprocessing units for biomass drying, size and ash reduction, and blending and densification, as well as laboratories for physical and chemical analyses of biomass and engineered feedstocks.

BFNUF is home to the DOE-sponsored feedstock PDU, which is located in a 27,000-sq ft^2 high-bay at ESL. Most PDU projects involve sourcing biomass, preprocessing, and shipping the preprocessed feedstocks to project participants and customers. Other supporting capabilities are available at INL to enhance the user facility model. The PDU is operated in concert with the Biomass R&D Resource Library, which provides a robust mechanism to store, track, and retrieve various feedstocks for research and demonstration purposes. The library is comprised of the physical storage of feedstock materials, the archive database system, and leverages the extensive analytical capabilities at INL. The library allows subsequent quality analyses to be tracked back to the original sample such that one could explain the impact of initial biomass quality on various conversion processes.

Examples of Idaho National Laboratory logistics RDD&D areas include the following:

- Feedstock engineering
  - Harvest, collection, and storage
  - Preprocessing, including size reduction, drying, and densification, as well as blending and formulation
  - Transport and handling.
- Analysis (including using the BLM to model logistics cost and modeling advanced concepts)
  - Collaboration with other national labs to model sustainability criteria.

[21] https://bioenergy.inl.gov/Home/Login.aspx?ReturnUrl=%2f
[22] https://www.bioenergykdf.net/
[23] https://bioenergy.ornl.gov/
[24] https://bioenergy.energy.gov/pdfs/billion_ton_update.pdf
[25] Wigmosta, M. S.; Coleman, A.M.; Skaggs, R.J.; Huesemann, M.H.; Lane, L.J. (2011). National microalgae biofuel production potential and resource demand, *Water Resour. Res.*, 47, W00H04, doi:10.1029/2010WR009966.
[26] https://inlportal.inl.gov/portal/server.pt/community/bioenergy/421/densification%
[27] https://inlportal.inl.gov/portal/server.pt/community/bioenergy/421/densification_workshop/10352

- PDU development and design (which address scale-up, and involve collaboration with industry) and capital procurement.
- Quality characterization (using INL's extensive chemistry equipment and other quality analysis tools)
  - Biomass R&D Resource Library, including data from the Regional Feedstock partnership.
- International projects focused on integrated supply system logistics and bi-national trade analysis, such as with Europe, and through the International Energy Agency.

5.2.1.1 Outputs

5.2.1.1.1 High-Yield Scenario Workshop

The High-Yield Scenario workshop series[27] was sponsored by BETO to identify and discuss the challenges associated with substantially increasing production of lignocellulosic biomass resources—such as agricultural residues (in particular, corn stover) and herbaceous and woody energy crops—to sustainably supply feedstock for biorefineries. Respected experts in diverse segments of industry, academia, and government were selected as workshop participants. Individual workshops were held in St. Louis, Missouri, on December 3, 2009, and in Chicago, Illinois, on December 10 and 11, 2009.

5.2.1.1.2 Designing Biomass Commodity Feedstock Supply Systems—A Uniform-Format Feedstock Supply System to Produce 60 Billion Gallons of Fuel by 2030

Raw, field-run biomass does not meet biorefinery specifications. At minimum, the biomass will need to be size reduced, but may also require additional preprocessing such as drying or quality control processes, such as ash reduction. A vision INL has proposed is transforming raw, field-run biomass that does not meet biorefinery requirements, into a commodity, analogous to the grain industry. The commodity vision is termed the "Advanced Uniform-Format Feedstock supply system" concept, or more simply, the "Advanced System," and draws in presently inaccessible and/or underused resources via local biomass preprocessing depots that format biomass into stable, bulk, densified, and flowable feedstocks for production of biofuels, biopower, and other bioproducts. The formatted feedstocks are transported to biorefineries or a network of supply terminals where the material can be blended to consistent specifications required by biorefiners (note that specification change depends upon the conversion process). The intent of the Advanced System is to enable the United States to meet biofuels cost, quality, and volume targets.

The Advanced System incorporates design improvements as technologies emerge and the industry expands, providing feedstock supply system designs that couple to and build from current systems. These advanced systems address barriers that have been identified by rigorous sensitivity analyses as having the greatest impact on supply system efficiencies and costs. Implementing a commodity-based feedstock supply system not only reduces risk to the biorefinery and producer, but also promotes cropping options beyond local markets (Hess et al. 2009).

The Uniform-Format System consists of distributed biomass preprocessing depots that can be adapted to the diversity of feedstocks, producing a feedstock that is consistent and infrastructure-compatible with existing grain handling equipment and systems. The depots would be located near the field or forest, and would transform diverse biomass feedstocks into uniform-format products that enable commodity-scale distribution and use. The depot is one element of Advanced Systems; research continues on other components including blending and formulation, high-moisture densification processes, and novel stabilization techniques. INL has published several reports and documents on the commodity system.[28]

5.2.2 Oak Ridge National Laboratory (ORNL)

The goal of this program is to incorporate science, engineering, and economic fundamentals to develop mathematical models and to analyze advanced biomass processing technologies and supply scenarios in support of a commercial bioenergy industry.

ORNL conducts biomass resource assessments, applying various datasets to estimate volumes of biomass available in the future, as well as its location and projected price. The projections are published annually, and are also incorporated into the Bioenergy KDF. The *U.S. Billion-Ton Update*[29] also incorporated data from these analyses. ORNL developed IBSAL, which includes equations and algorithms for logistics operations (e.g., harvesting, storage, transportation, processing). These equations and algorithms are incorporated into system simulations and used to design sustainable feedstock supply systems and

[27] https://inlportal.inl.gov/portal/server.pt/community/bioenergy/421/high_yield_scenario/8985
[28] https://inlportal.inl.gov/portal/server.pt?open=512&objID=421&PageID=5806&cached=true&mode=2&userID=1829
[29] https://bioenergykdf.net/content/billiontonupdate

help achieve BETO feedstock cost targets. ORNL also conducts various sustainability work, such as sustainable landscape design.

5.2.2.1 Major Project Areas

5.2.2.1.1 Bioenergy Feedstock Supply System Modeling

The goal of Bioenergy Feedstock Supply System Modeling is to develop mathematical models to simulate current and advanced unit operations and changes in biomass that occur along the supply chain:

- Developing feedstock supply curves and associated prices, which are critical to estimating biomass grower payment, as well as the volume of biomass available at that price. Total delivered feedstock cost includes both grower payment and logistics cost. Therefore, determining the cost to deliver feedstock to the biorefinery requires understanding both components.
- Calibrate mathematical models with field and/or lab data. The following are examples:
  - Controlled environment drying experiments for calibration of field drying models for switchgrass, miscanthus, and energy sorghum.
  - Wood chip storage (logging residue)—moisture impacts on degradation/quality relationships, self-heating, dry matter loss.
  - Size-reduction experiments to correlate particle size and power requirements.
- Spatial analysis using future feedstock availability projections and actual road, rail, and barge networks to estimate transportation distance from the field to the depot or biorefininery.
- Simulation of DOE-funded logistics demonstration projects to estimate cost improvements of improved technologies.
- Develop partnerships with academia and industry for sharing data and algorithms
  - Engage feedstock logistics modelers at technical and professional meetings.
- Estimate feedstock logistics cost using Biomass Logistics Model. These logistics estimates are combined with estimated grower payment for gauge progress towards feedstock cost targets.
- Work with INL to incorporate new models into the Biomass Logistics Model.

5.2.2.1.2 Advanced Biomass Processing

The goal is to develop and analyze advanced designs to transform bulky, unstable cellulosic feedstock into a free-flowing granular format or to stable packages for ease of handling and efficient transport, storage, and conversion. Examples of activities include:

- Testing thermal and steam treatments to improve properties of biomass pellets.
- Measuring effects of thermal and steam treatments on bulk density, heat value, durability, and hydrophobicity of pellets.

5.2.2.2 Significant Products

ORNL has several significant logistics-related projects. Examples include the following:

- IBSAL—simulation tool for estimating costs and emissions from feedstock supply chains.
- Bioenergy KDF—access to literature and supply information
- Simulation analysis of field projects to validate cost improvements of new and improved technologies
- Experimental chamber for measuring emissions from stored bulk biomass (e.g., pellets, wood chips)
- Experimental data on impacts of torrefaction and pelleting process parameters and grinding performance for various biomass types
- Equations/algorithms for dry matter losses in field and during storage, moisture changes during field drying, and impacts of weather and equipment delays
- Partnerships with universities and companies for sharing models and logistics data.

5.3 USDA

5.3.1 Regional Biomass Centers[30]

ARS and FS R&D jointly established the Regional Biomass Centers. The President's Biofuels Interagency Working Group report, *Growing America's Fuel*, called for the establishment of five USDA regional Biomass Research Centers for the development of non-food biomass feed stocks. These regional centers—involving collaboration between ARS and USFS—focus, accelerate, and coordinate the science and technology needed to incorporate feed stock production into existing agricultural and forest based systems.

[30] http://www.ars.usda.gov/research/projects/projects.htm?accn_no=420471

The centers assist rural development officials in the development and construction of biorefineries. The lead personnel at the centers draw on the expertise of the entire USDA team including, but not limited to, rural development coordinators, Farm Service personnel, Natural Resources Conservation Service officials, Forest Service experts, and extension service specialists.

The centers are in the regions of the country at the following locations:

1. The Northeast Center is located in Madison, Wisconsin, led by the Forest Service.
2. The Central East Center is located in Lincoln, Nebraska, led by ARS.
3. The Southeast Center is located in Boonesville, Arkansas, and in Tifton, Georgia, led by ARS; and in Auburn, Alabama, led by FS.
4. The Western Center is located in Maricopa, Arizona.
5. The Northwestern Center is located in Pullman, Washington, led by ARS, and in Corvallis, OR, led by FS.

5.3.2 Agricultural Research Service (ARS)

The ARS Bioenergy Research Program[31] generates scientific and technological knowledge to help attain federal targets for renewable fuel production through both the sustainable harvesting of crop residues and sustainable production of herbaceous energy crops, and by the conversion of these feedstocks into marketable fuels and value-added co-products. The ARS Bioenergy Program has coordinated efforts in three areas:
(1) feedstock development, (2) sustainable feedstock production systems, and (3) biorefining. Through these three components, the program ensures that bioenergy production is integrated into existing agriculture in ways that

- Provide consistent, attractive returns to producers
- Minimize adverse impacts on existing markets for food, feed, and fiber
- Demonstrate good stewardship of soil, water, and air resources.

ARS places a high priority on partnering with stakeholders in the entire bioenergy value-added chain (i.e., feedstock production, harvesting, collection, transportation, storage, fractionation, preprocessing, biorefining, and product marketing) so as to maximize the chances that ARS research will generate the widest impact, in the shortest possible timeframe, with the lowest investment cost.

5.3.2.1 National Program 213—Bioenergy[32]

This program component enabled new optimal practices and systems that maximized the sustainable yield of high-quality bioenergy feedstocks. This program has been superseded by National Program 307, and there are no current projects.

5.3.2.2 National Program 307—Bioenergy and Energy Alternatives[33]

ARS bioenergy research both pursues opportunities and overcomes problems associated with bioenergy production, while maximizing the net impact from ARS research. The growth and long-term viability of bioenergy production are impeded by a number of technical and commercial barriers. ARS addresses technical barriers by leveraging its strengths and unique capabilities to (1) pursue technical barriers that can be overcome by ARS resources and (2) provide substantial and unique contributions towards the nation's bioenergy goals. The following are Program 307 accomplishments for 1999–2006:[34]

- ***Demonstrated modeling approach to minimize feedstock transportation***
  The low-bulk density characteristics of lignocellulosic biomass increase the cost of transportation, which drives biorefineries to site the facility near the feedstock resource, limiting transportation distance. ARS developed a fuel shed modeling approach that predicts crop yields by soil type to evaluate placement of biomass plantings to minimize transportation distance and maximize net energy yield within a fuel shed (Russelle et al. 2006).
- ***Determined amount of available straw for biomass in Northwest***
  ARS scientists quantified the amount of total straw produced on a county-by-county basis in Idaho, Oregon, and Washington, and calculated the amount of straw (also on a county-by-county basis) that should be returned to the soil for conservation purposes. This accomplishment permitted calculation of the

[31] http://www.ars.usda.gov/main/site_main.htm?modecode=36-20-61-00
[32] http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=213
[33] http://www.ars.usda.gov/research/programs/programs.htm?np_code=307
[34] http://www.ars.usda.gov/SP2UserFiles/Program/307/NP307AccomplishmentReportFinal-web.pdf

amount of straw potentially available in the region as a biofuel feedstock. These data provided the basis for preparation and submission of a peer-reviewed manuscript.

- ***Determined the economic production and cost feasibility of perennial herbaceous energy crops***
  Switchgrass was planted and managed as a bioenergy crop for 5 years (2000–2005) in fields on 10 farms in Nebraska, South Dakota, and North Dakota with cooperating farmers to determine economic costs of production. Primary production factors that affected feedstock costs were stand establishment (which affected first and second year yields), fertilization and harvest management (which affected post-establishment yields), and available precipitation (which affected both establishment and yields). All factors except for precipitation can be significantly improved by management. The study demonstrated that additional improvements in biomass yield and in reduction of biomass costs per ton can be achieved with improved cultivars, seed quality, and management practices. This research was conducted in cooperation with a University of Nebraska agricultural economist. ARS resumed the work in 2006, with a research emphasis toward perennial cellulosic energy crops such as switchgrass.
- ***Developed technology for biomass handling, storage, and transportation systems***
  USDA ARS research activities under Feedstock Logistics are focused on assessing the effects of harvest time and procedure, on-site biomass pretreatment, and alternative uses on biomass handling and effects on storage and transport. Research has shown that harvesting corn stover high in moisture (~ 40 %) and storing the stover in plastic film under non-ensiling conditions economized field operations, increased the rate and efficiency of harvesting, and reduced storage losses of dry matter percentage.

5.3.2.3 Estimated Sustainability of Corn Stover Removal for Biomass Ethanol Production in Selected Corn Belt Sites[35]

This was a project that was in effect October 2006 to September 2010. The objectives were (1) to develop a summary of published and unpublished data on the impact of corn residue (stover) removal on future crop yield and soil quality and (2) to define and establish field experiment (specific to candidate locations for biomass ethanol plants) to assessing the impact of corn residue removal on future crop yield and soil quality.

Approach for Objective 1: ARS and INL were to jointly prepare and publish an assessment of the impact of corn stover removal on future soil quality (SOC content and soil function) and crop productivity by summarizing literature and conducting new analysis of previously reported data and unpublished data from ARS experiments. These experiments were conducted in the Corn Belt in areas identified by DOE as likely locations for the first biomass ethanol production facilities (biorefineries).

Approach for Objective 2: Plan, design, and implement long-term experiments to verify the analyses conducted and reported under Objective 1. These studies were composed of new experiments or modified existing experiments, depending on location, factors under investigation, and historical and current data collection schedules and procedures.

5.3.2.4 Other Related Units

Several ARS laboratories are involved in feedstock logistics research.

1. **Location:** Ames, Iowa

   Unit: Soil, Water, and Air Resources Research Unit; and Agroecosystem Research Unit

   Projects:

   A. **Project Title:** Soil Management for Enhanced Agricultural Productivity

      Project Objective: Develop sustainable biofuel feedstock production systems and an analysis framework capable of multi-variant agricultural residue harvest assessment.

      Project Approach: Several field studies affiliated with the ARS Renewable Energy Assessment Project (REAP) are being conducted to quantify effects of various stover harvest strategies on long-term grain and stover production and effects on soil quality indicators. In collaboration with scientists from INL, under a non-funded cooperative agreement (3625-12000-013-05N), a framework has been assembled using the field data and accepted, peer reviewed environmental process models addressing six primary limiting factors that have been identified

[35] http://www.ars.usda.gov/research/projects/projects.htm?accn_no=410168

as potential constraints for sustainable feedstock production.

The limiting factors are the following: (1) soil erosion, (2) soil organic matter, (3) management of plant nutrients, (4) soil compaction, (5) soil water and temperature, and (6) environmental degradation. Each limiting factor must be balanced against the economic drivers essential for developing viable biofuel industries based on agricultural crop residues to make sustainable residue harvest decisions. One key implementation of the analysis framework (e.g., the Residue Tool) has been performing regional and national-scale sustainable agricultural residue analysis. The residue tool has been used to support the DOE-sponsored update to the *U.S. Billion-Ton Study* through the generation of a national residue availability dataset. REAP tillage and stover harvest impact studies at the regional scale are being conducted to provide additional calibration data for the residue tool. The tool has also been used to study the impact of sub-field scale variability in crop yield, surface topography, and soil characteristics on sustainable residue availability. It is currently being made available for beta testing by the Natural Resources Conservation Service, crop consultant and other potential stakeholders.

2. **Location:** Booneville, Arkansas

Unit: Dale Bumpers Small Farms Research Center

A. **Project Title:** Bioenergy Potential for Small Farms

Project Objective: (1) Develop flexible production systems that are able to produce bioenergy crops while providing alternative opportunities for small farms, such as cattle, goat, and sheep production. (2) Develop agroforestry systems that include annual, perennial, and woody crops that can be used for bioenergy production and which could potentially be harvested year-round.

Project Approach: Flexible production systems are being researched to identify crops that would most easily fit within a production system to continuously produce biomass while minimizing biomass storage and associated costs. These production systems would be designed to produce either an annual or perennial crop during summer months that could be harvested in late summer or early fall. A winter cover crop would then be established that could be harvested the following spring. During the winter months, short-rotation woody crops could be harvested. The perennial crops under consideration are switchgrass and miscanthus, while annual crops under consideration include sorghum and sorghum-sudan. Research has been conducted with the assistance of AGCO/Hesston, which has provided planting and harvesting equipment. This equipment has been optimized to assist with harvesting downed bioenergy crops and to quickly dry crops that contain large amounts of moisture when harvested. A round hay baler was developed and tested as part of the agreement with AGCO to enable site-specific harvesting information to be obtained from bioenergy crops. Successful development of integrated bioenergy cropping systems that support small farms will enable this very large segment of American agriculture to improve productivity, efficiency, sustainability, and rural economies.

3. **Location:** Corvallis, Oregon

Unit: Forage Seed and Cereal Research Unit

A. **Project Title:** On-Farm Evaluation of Thermochemical Conversion of Kentucky Bluegrass Straw to Energy

Project Objective: The objective of this cooperative research project is to develop an integrated system for on-farm energy production from straw residues generated during grass seed production. Developing this system includes the test of a farm-scale gasification reactor suitable for burning grass seed straw to produce high-quality syngas. This syngas could then be used to generate electricity and other value-added bio-based products to increase on-farm income. Using the seed production cropping system and a test gasification reactor platform, we will determine the most economic technical paths to overcome agronomic, microbiological, and physical chemical limitations to on-farm production of energy and other bio-based products.

Project Approach: An integrated system for harvest, collection, storage, and transport of straw to a farm-scale gasification reactor will be evaluated for

concept and related technologies of on-farm energy production from Kentucky bluegrass straw. The goal will be to develop an economical and integrated system that will result in the conversion of straw into a high-quality syngas. Chemical characterization of straw produced from diverse grass and cereal production systems have been performed to evaluate their relative suitability as feedstock for thermochemical conversion and to provide a baseline for estimating storage-related quality changes. A system for collecting non-densified straw has been developed, which minimizes energy and labor inputs involved in delivery of straw to the biorefinery. The system also conducts field trials to quantify the impact of tillage practices in perennial grass production systems on seed and biomass production along with soil and water quality. This research has been extended to incorporate screening residues that result from seed and grain cleaning as feedstock for on-site thermochemical approaches to electricity production to reduce the input costs associated with providing high-quality seed and grain and to insulate these producers against future increases in the cost of power.

4. **Location:** Lincoln, Nebraska

Research Unit: Grain, Forage, and Bioenergy Research Unit; Agroecosystem Management Research Unit

A. **Project Title:** Genetic, morphologic and storage effects on switchgrass feedstock logistics

Project Objective: Determine the effects of pre- and post-harvest management practices on switchgrass feedstock production economics and bioenergy conversion efficiency.

Project Approach: In 2006, a 23 ha (57 acre) field was planted with switchgrass near Mead, Nebraska, to evaluate harvesting and storage methods. Several baling methods were compared and stored on concrete pads, with various levels of weather protection. Storage losses and changes in biomass quality are being determined for harvest date, storage method, storage location, and time in storage. These data have been used to quantify switchgrass storage losses over time by storage method to determine how much additional feedstock must be grown at the regional scale to account for feedstock losses. This information was used to support the *U.S. Billion-Ton Update*.

5. **Location:** Lubbock, Texas

Research Unit: Cotton Production and Processing Unit

Projects:

A. **Project Title:** Densification of Herbaceous Bioenergy Feedstocks for Transportation and Handling

Project Objective: Evaluate various biomass feedstocks for the most cost-effective means of processing, densification, transportation, and storage.

Project Approach: This is a collaborative project with Oklahoma State University intended to minimize the impact of the distance between the end-user and the farm. We plan to evaluate energy usage when processing different biomass feedstocks using select processes to enhance handling, transportation, and storage. An expected outcome of this study is a better understanding of the energy cost associated with processing of select types of biomass for long-term storage.

B. **Project Title:** Microwave moisture imaging of densified biomass feedstocks for quality preservation and storage

Project Objective: To develop a reliable microwave moisture imaging system that is able to map moisture inside densified biomass bales in the range of 10–40% moisture content.

Project Approach: A cooperative research and development agreement (CRADA) is being developed with DOE to map moisture in biomass bales to determine the impact of localized, internal, high-moisture regions on the quality of the biomass for use in ethanol feedstocks. The expected outcomes of this research are (1) better understanding of the impact moisture has on feedstock viability for use in cellulosic ethanol, (2) better understanding of moisture migration within bales during long-term storage under field conditions, and (3) a low-cost, non-invasive, sensor for determining internal bale moisture.

6. **Location:** Madison, Wisconsin

   Unit: Cell Wall Biology and Utilization Research Unit

   Projects:

   A. **Project Title:** Value-Added Products from Forages and Biomass Energy Crops

      Project Objective: Develop harvesting, fractionation, and storage processes for forages and bioenergy crops that are economical and that retain product quality.

      Project Approach: New harvesting strategies will be developed that economically separate forages and bioenergy crops into higher- and lower-value fractions. An example includes harvest fractionation of alfalfa into leaves and stems, with leaves used for animal feed and stems used for ethanol production. New storage and pre-processing technologies will be developed to increase their ferment ability, and thus their saleable value. Farm-scale economics of new harvest and pre-processing technologies will be assessed.

   B. **Project Title:** Cost, crop quality, and energetic considerations for crop merging

      Project Objective: Successful completion of this project will include meeting the following objectives: (1) Measuring the relative importance of crop moisture and cutting height on incorporation of ash into the consolidated windrow, (2) measuring the importance of crop moisture on the impact of leaf loss, and (3) survey leaf loss, ash and machine set-up in a production setting.

      Project Approach: Field efficiency, leaf loss, and the efficacy of a tine pickup merger to incorporate ash (soil) into windrows will be investigated by on-farm observation and through a controlled experiment. A factorial experiment will be conducted at the U.S. Dairy Forage Research Center Farm to better understand how cutting height and machine adjustment influence the incorporation of ash into windrows. Concurrent with the factorial study, merging productivity will be observed at four local farms. Typical cutting heights, machine settings, and merged crop moisture will also be observed. Additionally, tractor performance (e.g., fuel use) and spatial data will also be collected if compatible tractors are used for the merging process. Productivity will be assessed by monitoring the merger's speed, turning time and downtime due to maintenance, plugging and/or failure. This approach will provide the data necessary to model field capacity of the merger. Finally, assessment of crop moisture, soil moisture and texture, and ash inclusion will be conducted.

   C. **Project Title:** Economics and energy use of corn stover harvest and storage systems.

      Project Objective: Determine the production costs of current and novel systems for corn stover harvest and on-farm storage.

      Project Approach: A spreadsheet model will be developed to estimate production costs and fuel use for corn stover harvest systems, including three pass and two pass with baling and chopping, and single pass. The systems represent currently available and novel technology still in development. A spreadsheet model developed at the University of Wisconsin will be utilized to estimate on-farm stover storage costs for outdoor and indoor dry bales, outdoor wrapped bales, and chopped stover in bags, bunks, or piles. A comparison will be developed between systems to determine advantages and disadvantages of each.

7. **Location:** Pendleton, Oregon

   Unit: Soil and Water Conservation Research Unit

   Projects:

   A. **Project Title:** On-Combine Measurement and Mapping of Straw Yield

      Project Objective: Assess the quantity of wheat residue at site-specific field locations across farm fields.

      Project Approach: A straw production model will be developed from the results of a three-year field experiment with six cultivars of spring wheat grown in factorial combination with five nitrogen levels and three water regimes. Information collected will include grain and straw yield, crop height, and grain protein concentration. Linear regression will be used to develop straw yield prediction equations, and will be evaluated by comparing model predictions

against actual estimates obtained from farm fields. Plots for measuring grain yield, grain protein, and straw yield will be identified in each field for validation of the straw production model. On-combine measurements of grain yield and grain protein will be obtained using a combine harvester equipped with a mass flow yield monitor and inline optical spectrometer.

5.3.3 National Institute of Food and Agriculture (NIFA)[36]

NIFA is an agency within the USDA. Congress created NIFA through the Food, Conservation, and Energy Act of 2008. NIFA replaced the former Cooperative State Research, Education, and Extension Service (CSREES), which had been in existence since 1994. NIFA administers federal appropriations through the three basic funding mechanisms. BRDI is another source of NIFA funding (joint with DOE) for work relevant to the Sustainable Bioenergy Challenge Area. See section 5.4 for further details about the BRDI program.

5.3.3.1 Competitive Grants

NIFA awards competitive grants for fundamental and applied research, extension, and higher education activities, as well as for projects that integrate research, education and extension functions. Eligibility, administrative rules, and procedures vary for each specific program according to authorizing statutes.

5.3.3.1.1 Agriculture and Food Research Initiative (AFRI)[37]

AFRI provides competitive grants for fundamental and applied research, extension, and education to address food and agricultural sciences. Awards may be made to the following eligible entities: state agricultural experiment stations, colleges and universities, university research foundations, other research institutions and organizations, federal agencies, national laboratories, private organizations or corporations, individuals, or any group consisting of two or more of the aforementioned entities.

Although no new coordinated agricultural project (CAP) awards will be made in FY 2014, the NIFA Sustainable Bioenergy Program will support ongoing investments in bioenergy. Funding will support 5 regional projects with activities in 22 states involving 32 universities plus 9 federal and eight industrial partners. These regional projects link research for sustainable biomass production, logistics of handling feedstocks for biofuels, and education programs to create the needed skilled workforce. Funding also will go to on-going targeted research on enhanced value co-products, crop protection, land-use changes resulting from feedstock production and conversion, implications of the development of bioenergy delivery systems on water, and identification of socioeconomic impacts of biofuels in rural communities in order to enhance sustainable rural economies.

5.3.3.1.1.1 Regional Approaches to Sustainable Bioenergy Systems Program

This program funds Regional Bioenergy Coordinated Agricultural Project (CAPs) that integrate research and development, education (workforce development) and extension/outreach/technology transfer focusing on five groups of dedicated energy feedstocks: (1) energycane, (2) perennial grasses, (3) sorghum, (4) woody biomass, and (5) oil crops (oilseeds and algae). These crops will serve as feedstocks for the production of advanced non-ethanol, infrastructure-compatible fuels and biobased products through a systems-oriented approach that links feedstock development, production, logistics, conversion, and markets. As such, projects are transdisciplinary and integrate genetic crop development; sustainable agronomic and silvicultural practices; pest and beneficial species management; coordinated energy-efficient logistics; flexible and scalable sustainable conversion and refining technologies; marketing and distribution systems; and environmental, economic, and social prosperity for rural communities. Data-acquisition systems, modeling, and decision-making tools are developed to evaluate social, economic, and environmental impacts and to optimize system planning and implementation that help to achieve desired outcomes. Innovative projects will support workforce development needs and the dissemination of information to producers, processors, decision and policy makers, and consumers through Cooperative Extension and other outreach and technology transfer mechanisms.

5.3.3.1.2 SBIR[38]

The USDA SBIR program office directs all activities required under the SBIR law and executes the policy established by the Small Business Administration. The SBIR program at USDA is administered exclusively by NIFA, and program awards are based on the scientific and technical merit of investigator initiated ideas. The SBIR Program does not make loans and does not award grants for the purpose of helping a business to get established.

[36] http://www.csrees.usda.gov/about/background.html
[37] http://www.nifa.usda.gov/funding/rfas/afri_sustain_bio.html
[38] http://www.nifa.usda.gov/funding/rfas/sbir_rfa.html

5.3.3.1.2.1 SBIR: Plant Production and Protection—Engineering

Plant Production and Protection—Engineering is one of 10 topic areas in the USDA SBIR program. This topic area supports research and development of products, process, and services that take an engineering approach to addressing issues in agronomic and horticultural crop production and protection from pests and disease.

There are about six phase I projects funded each year in this topic area. Some of the projects include aspects of logistics, with projects including harvesting of camelina and canola for biodiesel and developing agronomic practices for pennycress oilseed production for conversion to biodiesel.

5.3.3.2 Formula Grants

NIFA provides funds for research and extension to land-grant institutions (1862, 1890, and 1994 institutions), schools of forestry, and schools of veterinary medicine through several formula program authorities. The funding provided to each institution is determined by formulas that are often statutorily defined. Local or regional university leaders decide which specific projects will be supported.

There are many bioenergy projects completed and underway at the various land grant institutions. The following are examples of projects that have a strong element of logistics:

- Modeling of logistics scenarios to reduce costs for switchgrass management (Nebraska)
- Logistics strategies for algae (Texas)
- Small-scale harvesting system for short rotation willow crops (New York)
- Use-processing technologies such as thermochemical or fermentation to reduce the logistics costs for low-density cellulosic biomass (Iowa)
- Sustainable feedstock production systems to support biorefinery industries (Oklahoma)
- Enhanced performance of agricultural biomass supply chains at the logistics system level (Texas)
- Logistics to optimize delivery of round bales to biorefinery (Virginia)

5.3.3.3 Non-Competitive Grant Programs

Some projects are directed by Congress to specifically support a designated institution or set of institutions for particular research, education, or extension topics of importance to a state or region. These projects are supported through Special Research Grants or Direct Federal Administration Research or Education Grants.

There have been several special grants designated by Congress that address generating energy from agricultural sources; however, very few of these projects focus on logistics issues related to energy from biomass sources. The following are examples of projects that broadly address biomass and include some aspects of logistics (harvest, collection, pre-processing, storage and transportation):

- Food and Fuel Initiative, Iowa
- Advancement of forest biorefineries, Tennessee
- Arkansas Forest Resources Center, Arkansas
- Biomass based energy research, Mississippi
- Bioprocessing for utilization of agricultural resources, Michigan
- Bio Century Research Farm, Iowa
- Midwest Center for Bioenergy Grasses, Indiana
- Bio-based energy research, Mississippi/Oklahoma

5.3.3.4 Sun Grant Program

NIFA and its Land Grant University partners participate in and support the Sun Grant Research Program, which is also supported by DOT and is supported by DOE through the Sun Grant Regional Partnership. See section 5.5 for additional information.

5.3.4 U.S. Forest Service (FS)

5.3.4.1 Research & Development[39]

FS R&D has a long history in bioenergy and biobased products. Since the 1970s, significant accomplishments have been made in harvesting, genetics, silviculture, and conversion processes related to energy. FS funds scientist and collaborating partners in a broad research program, developing the science and technology to sustainably produce forest feedstocks and significant amounts of biofuels and biobased products from forest resources. Examples of research areas include developing sustainable management and harvest/

[39] http://www.fs.fed.us/research/

recovery systems for alternative resources; improving conversion and biorefinery technologies for cost, energy, and environmental efficiencies; developing innovative uses for wood and wood components; and improving the cost competitiveness of wood for energy. FS R&D coordinates with other FS deputy areas and actively partners with USDA agencies, other federal departments and agencies, universities, nongovernmental groups, and industry. FS R&D supports related work through Agenda 2020 and represents the United States on the International Energy Agency Task 42 for biomass energy.

The "Forest Service Research and Development Bioenergy and Biobased Products Strategic Direction 2009–2014"[40] provides some logistics-related goals:

- Improved harvest, collection, handling, and transportation systems for woody biomass.
- Cost and equipment information and options for field processing to improve efficiency and mitigate impacts.
- Strategies to integrate forest systems into agricultural landscapes to provide services and income.
- Sustainable management and utilization systems that integrate bioenergy feedstock production with biomass and residue management, forest health and fuels reduction treatments, and production forestry.
- Logistics and decision support tools to reduce costs of treatments involving biomass removal and improve harvest and transport efficiency.

The FS R&D program is partnering with ARS in a coordinated Regional Bioenergy Research program. There are five regional centers with FS R&D teams working in each (see Section 5.3.1). The overall research program includes a broad range of biomass topics, and several regional centers have specific work related to feedstock logistics.

5.3.4.2 The Southern Regional Center

The Southern Regional Center's logistics work is primarily in the Forest Operations Unit of the Southern Research Station (SRS).[41] SRS has been involved in biomass-related research since the late 1970s. The primary focus of research is the physical operation in the forest that results in establishment, harvesting, or recovery of woody biomass. Using an integrated systems approach, studies include multiple factors including productivity, cost, performance, and ecological effects. Past work has examined biomass baling and bundling technology, thinning, chipping and grinding operations, and alternative transportation formats.

Current projects include the following:

1. Development of a new feedstock system for high-production harvesting of young southern pine plantations.
2. Evaluation of alternative harvesting technology for short rotation wood crop hardwood plantations in the lower Mississippi Alluvial Valley.
3. Comparison of alternative harvesting technologies for pinyon-juniper treatment in the Western United States.
4. Assessment of fuel consumption and life cycle inputs for woody biomass harvesting systems.
5. Quantifying field collection efficiency (residue recovery rate).

5.3.4.3 Tennessee Partnership

SRS also has cooperative work at the University of Tennessee developing biomass availability and biorefinery siting tools (BIOSAT). In 2004, the FS, SRS, and The University of Tennessee established a partnership to link high-performing graduate students working toward degrees in bio-based research with strengths of the land-grant universities, industry, and the FS. In 2007, the partnership refocused the research objectives to meet demands for logistics and decision support tools for a changing biomass and bioenergy industry. The partnership is building modern tools that exploit the potential of today's information technologies and works to acquire the necessary data to make them useful. As such, the alliance is building dynamic and durable decision support tools that simplify the process of acquiring answers to complex questions and improve public understanding of global energy influences on the agricultural, range, and forest sectors and their continued productive management and use. Other benefits include identification of opportunity zones and site selection for bioenergy facilities, improving harvest and transport logistical efficiency, and improving sub-county landscape characterization.

The landscape-scale modeling program recognizes that biomass availability is a national issue, and that concerns around sustainability—economic, environmental, and social—are central considerations. The partnership is

[40] http://www.fs.fed.us/research/pdf/RD_Bioenergy_Strategy_March_2010.pdf
[41] http://www.srs.fs.usda.gov/forestops/

deploying technological advances that capture both socio-economic and biophysical drivers as well as the place-based, human-environment conditions that impact land-use and land-cover change.

The goal is to improve information and tools for decision making and policy analysis. The research mission is to examine and deliver baseline science with greater precision to better serve local publics in meeting education and service goals with limited resources.

The cooperative relationship has yielded a number of research accomplishments of regional and national note. The partnership accomplishments illustrate the scope of the effort that is underway and underscores the commitment by the research alliance. It also demonstrates the value of collaboration to blur the lines of traditional towers by sharing and leveraging financial resources, research skills, knowledge, and facilities.

5.3.4.4 Research Projects

Project Title: Biomass and Bioenergy Graduate Education and Research Initiative (2004–2008)
Project Objectives: Link high-performing graduate students with strong science and math skills with the research strengths of the land-grant universities, industry, and the Forest Service to increase educational exposure, cross institutional diversity, and research capacity in biomass, bioenergy, and logistics research.

Project Title: Biomass Site Assessment Tools (BioSAT) (2007)
Project Objectives: Create web-accessible model to evaluate agricultural, range, and forest locations for sustainable biomass facilities and a dynamic and durable data delivery system to compare, map, and display a variety of data and information by zip-code within the 33 eastern states. BioSAT estimates the total costs, average total costs, and marginal cost ($/dry ton) of biomass by Zip Code Tabulation Areas (ZCTAs). The cost of the resource, harvesting, and transportation) are included in the estimate.

Project Title: Regional Comparative Advantage for Woody Biofuels Production (2007)
Project Objectives: : Develop woody biomass feedstock cost projections for woods and process residue, and create biomass transportation and logistics cost model.

Project Title: Developing a POLYSYS Forest Sector Module—Demand Side (2007)
Project Objectives: Use Global Forest Products Model to develop protocols to incorporate demand considerations into projections of biomass cost provided by POLYSYS model.

Project Title: Developing a POLYSYS Forest Sector Module—Supply Side (2007)
Project Objectives: Establish a forest supply side module that is integrated with the existing POLYSYS model framework for initial evaluation of biomass land-use changes.

Project Title: Wood-Based Bioenergy Biofuels Technologies and Industries in North America (2008)
Project Objectives: Improve logistics by building a spatial industrial wood to energy user's online database; provide a state-of-the science report for current wood conversion technologies, pathways, and market sustainability.

Project Title: Landscape Flexibility and Biomass Access (2010)
Project Objectives: Develop a sub-county spatially-defined comparison of dominate environmental, economic, and societal factors impacting landscape flexibility, logistics and biomass access.

Project Title: Spatial Products to Identify Potential Sites for Short Rotation Woody Crops (2011)
Project Objectives: Develop an economic and biophysical decision support tool useful for assessing spatially-explicit short-rotation woody crop (SRWC) production metrics and logistics in conjunction with likely conversion locations.

Project Title: Bayesian Probabilities of Risk and Cost for Defining Optimal Short Rotation Woody Crops Sites in the Southeastern United States (2011)
Project Objectives: Develop GIS data layers of key spatial metrics that influence the siting of SRWC locations using Bayesian spatial logistic regression model with the BioSAT model.

Project Title: Modeling the Impact of the Emerging Bio-Economy on Transportation Network Flows with Simulation and Bayesian Inference (2011)
Project Objectives: Identify regions in the southeastern United States that have high potential for emerging bio-economy in the presence of high transportation flow using Bayesian inference with the BioSAT model.

[46] http://www.fs.fed.us/research/publications/RD_Research_Highlights-2010.pdf

Project Title: Southeastern Partnership for Integrated Biomass Supply Systems (IBSS) (2012)
Project Objectives: Decision Models—IBSS is a collaboration of several universities, government agencies and industry partners who will work on all aspects of the biofuels pipeline between the biomass feedstock and where the biofuels are produced. This project will enhance and more tightly integrate harvesting, logistics, cost and spatial logistics models to provide comprehensive data.

5.3.4.5 Northern Regional Center[42]

The Northern Regional Center includes work at the Forest Products Laboratory and other units:

1. Forest Products Laboratory: During manufacturing of renewable materials such as wood products, woody biomass is often burned for energy. In this project, Forest Products Laboratory scientists used life-cycle assessment (LCA) to evaluate the extent of offsetting demand for fossil fuels by burning woody biomass for energy. Life-cycle inventory (LCI), a major component of LCA, tracks all material and energy inputs and outputs flowing into and out of a system boundary. For a "cradle-to-gate" LCI, the product is tracked from the forest (a tree) to the final product leaving the gate of a manufacturing facility. This LCI project examined a number of wood products made in the United States, such as softwood lumber, hardwood lumber, and solid hardwood flooring. Results showed that burning woody biomass for energy during manufacturing for all these wood products greatly reduces environmental burdens by offsetting demand for fossil fuels. This project was part of a larger initiative conducted by the Consortium for Research on Renewable Industrial Materials (CORRIM), which includes 15 research institutions and focuses on the effects of producing and using renewable materials.
2. The Northwestern Center (including logistics work at the Rocky Mountain and PNW Research Stations): Removing accumulations of woody biomass from the forest reduces fire fuel and provides wood for energy production. Is the value of the biomass high enough to cover the cost of removing it? Forest managers can now use a computer spreadsheet tool to find out. The Western Biomass Tool estimates the costs of harvesting, chipping, and transporting biomass. The Western Biomass Tool can also be used to calculate the cost of removal purely as a fuel-management measure. Both applications are valuable to managers who need to understand the economic viability of their proposed management activities. Funded through the FS National Fire Plan, development of the tool was a collaborative effort by FS researchers and the University of Idaho.

5.3.4.6 Biomass R&D Grants

The FS R&D Washington Office has supported an internal biomass research grant program for several years. Projects are competitively selected. The most recent round funded in FY11 included support for projects including, development of a biomass accessibility index, development of SRWC harvesting technology and an economic model, evaluation of feasibility of mobile fast pyrolysis, and development of pinyon-juniper harvest and utilization technology.

5.3.4.7 Woody Biomass Utilization Grants—State & Private Forestry[43]

Submission of an application is required for a grant of up to $250,000 for wood energy projects that require engineering services. These projects will use woody biomass material removed from forest restoration activities, such as wildfire hazardous fuel treatments, insect and disease mitigation, forest management due to catastrophic weather events, and/or thinning overstocked stands.

The woody biomass shall be used in a bioenergy facility that uses commercially proven technologies to produce thermal, electrical, or liquid/gaseous bioenergy. The funds from the Woody Biomass Utilization Grant program must be used to further the planning of such facilities by funding the engineering services necessary for final design and cost analysis.

[42] http://www.nrs.fs.fed.us/
[43] http://ucanr.edu/sites/WoodyBiomass/Grants_2/Woody_Biomass_Utilization_Grant

5.3.4.8 Technology and Development Centers

5.3.4.8.1 Missoula Technology Development Center[44]

The Missoula Technology Development Center has several roles, including the following:

- Interviews FS personnel to help identify forest management technology needs.
- Surveys commercial markets and tests promising products.
- Designs, builds, and tests prototype equipment.
- Cooperates with private industry to develop commercial sources.
- Maintains specifications and standards for fire and safety equipment.
- Disseminates publications, fabrication drawings, project films, and audiovisual programs.

5.3.4.8.2 San Dimas Technology and Development Center[45]

Program areas include fire and aviation, recreation, engineering, watershed, and timber. The Center uses multiple disciplinary teams to resolve technical issues for forest management

5.4 USDA/DOE Joint Solicitation[46]

BRDI is a joint effort between DOE and USDA to accelerate research and development in bioenergy research and biobased products. The grant program is open to higher education institutions, national laboratories, federal research agencies, state research agencies, private sector entities, non-profit organizations, and consortia of these types of entities. The proposals are competitively selected by the two departments and funded separately; only a few logistic projects have been selected over the tenure of the program.[47] Some projects announced in 2011 include the following:

- *University of Kansas Center for Research; Lawrence, Kansas.* The purpose of this project is to demonstrate a novel, sustainable technology at a pilot scale that produces diverse products, including advanced fuels, industrial chemicals, and chemical intermediates.
- *University of Kentucky; Lexington, Kentucky.* The purpose of this project is to improve the economics for biorefineries by using on-farm processing to convert biomass to a mixture of butanol, ethanol, acetone, and organic acids. The product can then be easily transported to a biorefinery for further processing. The project will integrate input from experts in a variety of disciplines, including plant and soil scientists, horticulturists, chemical engineers, and economists.
- *FS, Rocky Mountain Research Station; Missoula, Montana.* This project will develop an integrated approach to investigate biomass feedstock production, logistics, conversion, distribution, and end use centered on using advanced conversion technologies at existing forest industry facilities.

5.5 Sun Grant Initiative[48]

The Sun Grant Initiative is a national network of land-grant universities and federally funded laboratories working together to further establish a biobased economy.

These institutes are at the forefront of research and innovation involving bioenergy and biofuels production. They have the history, technology, and resources available to lead the nation towards a renewable, sustainable, domestic energy industry. Sun Grant Centers are also charged with reviving America's farming communities by placing an emphasis on rural economic development through the production of biobased renewable energy feedstocks.

Five land-grant universities serve as regional Sun Grant centers. The Sun Grant Regional Centers are north central, south central, south east, north east, and west. The Sun Grant Centers facilitate ongoing and proposed federally funded research, extension, and education programs in their respective regions to promote the development of biobased industries in rural communities. These regional centers are also charged with making significant advances in biobased industries while embracing the multistate, multi-function, multi-disciplinary integrated approach that is at the heart of the land-grant mission and methodology for developing science-based solutions to national challenges. Grant funding is provided by DOT, USDA, and DOE.

[44] http://www.fs.fed.us/eng/techdev/mtdc.htm
[45] http://www.fs.fed.us/eng/techdev/sdtdc.htm
[46] http://www.biomassboard.gov/initiative/initiative.html
[47] http://genomicscience.energy.gov/centers/glbrc.shtml#page=news
[48] http://www.sungrant.org/

5.6 U.S. Department of Energy, Office of Science

The Office of Science enables broad community access to general tools, including high-throughput genome sequencing and analysis capabilities at the Joint Genome Institute, analytical and characterization tools at the Environmental Molecular Sciences Laboratory, and structural characterization and crystallographic tools at the light source and neutron source facilities. The Office of Science supports fundamental research in the areas of feedstock improvement and molecular genetic analysis, including research supported by the Bioenergy Research Centers, the Energy Frontier Research Centers, and other solicited genomic science research conducted at universities and national laboratories. There is also a joint USDA-DOE plant feedstock genomics for bioenergy program that has supported fundamental research to develop molecular breeding approaches. These approaches improve feedstock characteristics and develop new bioenergy crops with related impacts on their handling and logistics.[49]

5.6.1 U.S. Department of Energy, Office of Science, Great Lakes Bioenergy Research Center

The Great Lake Bioenergy Research Center (GLBRC)[50] uses a basic science approach to make key discoveries and major advances that will lead to breakthrough technologies for eventual large-scale conversion of biomass into biofuels. The Center works closely with industry partners through technology-transfer mechanisms or collaboratively for commercialization of new technologies. GLBRC leadership is focusing on two key knowledge gaps: sustainable production of crops with desirable biofuel traits and efficient conversion of biomass into fuels and chemicals.

5.6.1.1 New Modeling Tool Combines Environmental and Economic Analysis of the Biorefinery in Agricultural Landscapes

Forecasting the risks and tradeoffs of the complete biofuel production chain requires the use of modeling tools such as the Biorefinery and Farm Integration Tool.[51] The model includes both crop and animal production. The model determines potential economic profitability as well as environmental impacts. Based on these projections, biofuels markets could improve farm economics and reduce emissions without additional clearing of lands for biofuels.[52]

6.0 SUMMARY

Biomass logistics are a critical part of the bioenergy production chain. Logistics costs depend on a variety of factors, such as region, biomass type, and biorefinery in-feed specification. The costs can be significant—up to, if not more than half the cost of delivered feedstock. Therefore, improving the logistics system efficiency and reducing the cost is very important to making bioenergy cost competitive with conventional fuels. Several federal agencies have RDD&D programs or activities that are addressing the challenge of improving biomass logistics. USDA and DOE are the agencies leading this effort.

The agencies are providing the science, technology, and support to improve biomass feedstocks logistics. The science spans many disciplines and includes some basic, but mostly applied activities as engineering and economics. Technology development is primarily through industrial cooperators that involve mostly field equipment and monitoring systems development. Finally, the agencies demonstrate both the science and technology breakthroughs to aid in application, but provide very limited direct financial support to the users through grants, loans, and other mechanisms.

The array of RDD&D programs within the U.S. government associated with improving biomass feedstock logistics is very diverse and widely distributed between the major departments. The logistics RDD&D is part of a program with a broader mission and with a wider range of goals and activities, but which encompasses logistics.

Most of the programs that are in DOE are part of BETO with two national laboratories and in the Office of Science and ARPA-E. USDA has programs in several agencies, but most efforts are in ARS and FS. A listing of programs identified is as follows:

- DOE's BETO
- INL
- ORNL
- DOE's Great Lakes Bioenergy Science Center

[49] http://genomicscience.energy.gov/centers/brcbrochure_hq.pdf
[50] http://genomicscience.energy.gov/centers/glbrc.shtml. Note that there are three bioenergy centers; however, GLBRC is the only one that works in logistics.
[51] http://onlinelibrary.wiley.com/doi/10.1111/j.1757-1707.2009.01027.x/abstract
[52] Sendich, E.D.; Dale, B.E. (2009). "Environmental and Economic Analysis of the Fully Integrated Biorefinery," *GCB Bioenergy* 1, 331–4.

- DOE's ARPA-E
- USDA's Regional Biomass Centers (ARS and FS)
- USDA's ARS
- USDA's NIFA
- USDA's FS

The RDD&D is completed through various approaches and varies by the organization. Some of the primary approaches included the following:

- Conducted internal to the organization
  - Research centers
  - Individual units
- Conducted external to the organization
  - Competitive grants
  - Non-competitive grants
  - National laboratories
  - Partnerships

The federal government has a very broad portfolio of programs involved with logistics RDD&D, reflecting that the complexity of logistics is being addressed from several angles. Also, the different departments and agencies have various missions and approaches, which results in the bracketing of efforts into other ongoing programs that have the expertise to address the barriers to biomass commercialization. A summary of the types of programs includes a wide array of different activities and approaches from molecular to landscape, involving biology, ecology, engineering, and economics, to name a few.

As part of the review, there was an effort to determine if the identified barriers to biomass commercialization were being addressed at the federal level. Below is a general assessment of the various programs working to overcome the barriers:

1. **Inherently low bulk density and energy content and high moisture in biomass produces poor quality feedstocks that result in higher costs across the supply chain.**
   - DOE's BETO uses funding opportunity announcements to fund projects that will help understand and reduce impacts of poor biomass quality through pretreatment and blending strategies.
   - DOE's BETO sponsors the Regional Feedstock Partnership to improve crop yields and reduce impacts on logistics.
   - DOE's BETO provides grants to understand plant composition impacts and technologies for rapid biomass quality assessments.
   - INL operates a process demonstration unit to work with industry, academia, and other partners to better understand and improve biomass preprocessing, handling, and quality control.
   - ORNL conducts strategic assessments of biomass quantity and quality.
   - ARS develops plant material and management systems to improved quality for selected energy crops.
   - ARS quantifies the impacts of storage on switchgrass quality.
2. **Inefficient conventional technology and harvest systems result in high logistics costs.**
   - INL conducts research to improve system function, cost, and performance.
   - INL models logistical systems to estimate costs and performance parameters, and to identify opportunities for improvement.
   - INL has developed a commodity concept for biomass feedstocks to reduce risk to the biorefiners, increase resources available for bioenergy production, and potentially improve efficiency.
   - ORNL models logistics operations to understand cost and identify opportunities for improvement.
   - ARS reduces production costs as part of supply chains for switchgrass.
   - ARS works to improve sustainability of operations.
   - BETO incorporates sustainable management practices into field operations.NIFA develops improved regional production and harvest systems.
   - NIFA uses various grant options to address various logistical barriers at different scales.
   - FS develops innovative harvest, handling, and transportation systems.
   - FS conducts life-cycle assessment to understand sustainability factors and potentially reduce systems impacts.
   - FS uses grants to assist in the deployment of new technologies.

3. **Low-capacity haul trucks and restricted transportation options limit haul distance and result in high costs.**
   - ORNL models improve our understanding of transportation routing of biomass.
   - ARS uses a fuel shed modeling approach to minimize transportation costs.
   - ARS reduces biomass handling, storage, and transport cost by managing characteristics through harvest timing and methods.
   - FS uses models to reduce transport cost and improve travel efficiency.
   - FS uses siting tools to improve transportation systems.

7.0 RECOMMENDATIONS

1. The Biomass Board and the Interagency Working Group provides an excellent opportunity for coordination among the federal agencies and should continue to explore opportunities for collaboration, such as workshops, meetings, joint reports, and jointly funding projects. An example of this would be to more closely share ongoing work and accomplishments at the scientist and field level.
2. Efforts should continue to ensure that federal logistics programs are complementary and non-duplicative. Efforts made by the various departments and agencies should be synergistic in overcoming logistical barriers.
3. A holistic approach is needed that links together agronomics, production, logistics, conversion, product distribution, and use. The biological, physical, and chemical sciences need to be integrated with engineering and technology developments.
4. The Working Group should use the 2010 Board Report to evaluate progress and assess changes to approaches and RDD&D emphasis to accelerate the development and deployment of new science and technology to overcome the barriers to biomass commercialization.

8.0 REFERENCES

Banerjee, A.; Noguer, J.L. (2007). Biofuels supply chain characterizations. Thesis: Degree of Master of Engineering in Logistics, Massachusetts Institute of Technology, Cambridge, MA. June 2007. 89 pages. http://dspace.mit.edu/handle/1721.1/40111

Biomass Research and Development Board. (2010). Biofuel Feedstock Logistics: Recommendations for Research and Commercialization—A Report by the Feedstock Logistics Interagency Working Group. November, 2010. 38 pages. http://www.biomassboard.gov/pdfs/biomass_logistics_2011_web.pdf

Browne, M.; Allen, J.; Hunter, A.; Boyd, J.; Palmer, H. (1998). Logistics management and costs of biomass fuel supply. International Journal Phys Distrib Logistics Manage, 28 (1998), pp. 463–477.

Department of Energy. (2014). Bioenergy Technologies Office Multi-Year Program Plan. Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office. July 2014. 214 pages. http://www.energy.gov/eere/bioenergy/downloads/bioenergy-technologies-office-multi-year-program-plan-july-2014-update

Fales, S.L.; Hess, J.R.; Wilhelm, W.W. (2007). Convergence of agriculture and energy: II. Producing cellulosic biomass for biofuels. Commentary QTA 2007-2. Council for Agricultural Science and Technology (CAST). Ames, Iowa.

Hess, J.R.; Kenney, K.; Ovard, L.; Searcy, E.; Wright, C. (2009). Uniform-Format Solid Feedstock Supply System: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass, INL/EXT-08-14752.

Kumar, P.K.; Ileleji, K.E. (2009). Techno-economic Analysis of the Transportation, Storage and Handling Requirements for Supplying Lignocellulosic Biomass Feedstocks for Ethanol Production. Paper No: 097427. 2009 ASABE Annual International Meeting, Reno, Nevada. June 21–24, 2009.

Parker N.; Hart, O.; Tittmann, P.; Jenkins, B. (2011). National biofuel supply analysis. Final report prepared for the Western Governors' Association, Contract 20113-03, University of California, Davis, California.

Russelle, M.P.; Birr, A.S.; Tiffany, D.G. (2006). Estimated net energy yields of biomass in a fuel shed. ASA-CSSA-SSSA Annual Meetings. Abstracts 167-2 (CDROM).

Suh, K.; Suh, S.; Walseth, B.; Bae, J.; Barker, R. (2010). Optimal Corn Stover Logistics for Biofuel Production: A Case in Minnesota. Transactions of the ASABE, Vol. 54(1): 229-238, November 2010. https://elibrary.asabe.org/abstract.asp?aid=36240&t=2&redir=&redirType=

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