# Roadmap

## *for Agricultural Biomass Feedstock Supply in the United States*

November 2003

Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

U.S. Department of Energy
Energy Efficiency
and Renewable Energy

# *Roadmap*

## for Agricultural Biomass Feedstock Supply in the United States

This Biomass Roadmap was sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Biomass Program.

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PN03-0333-02

# *Executive Summary*

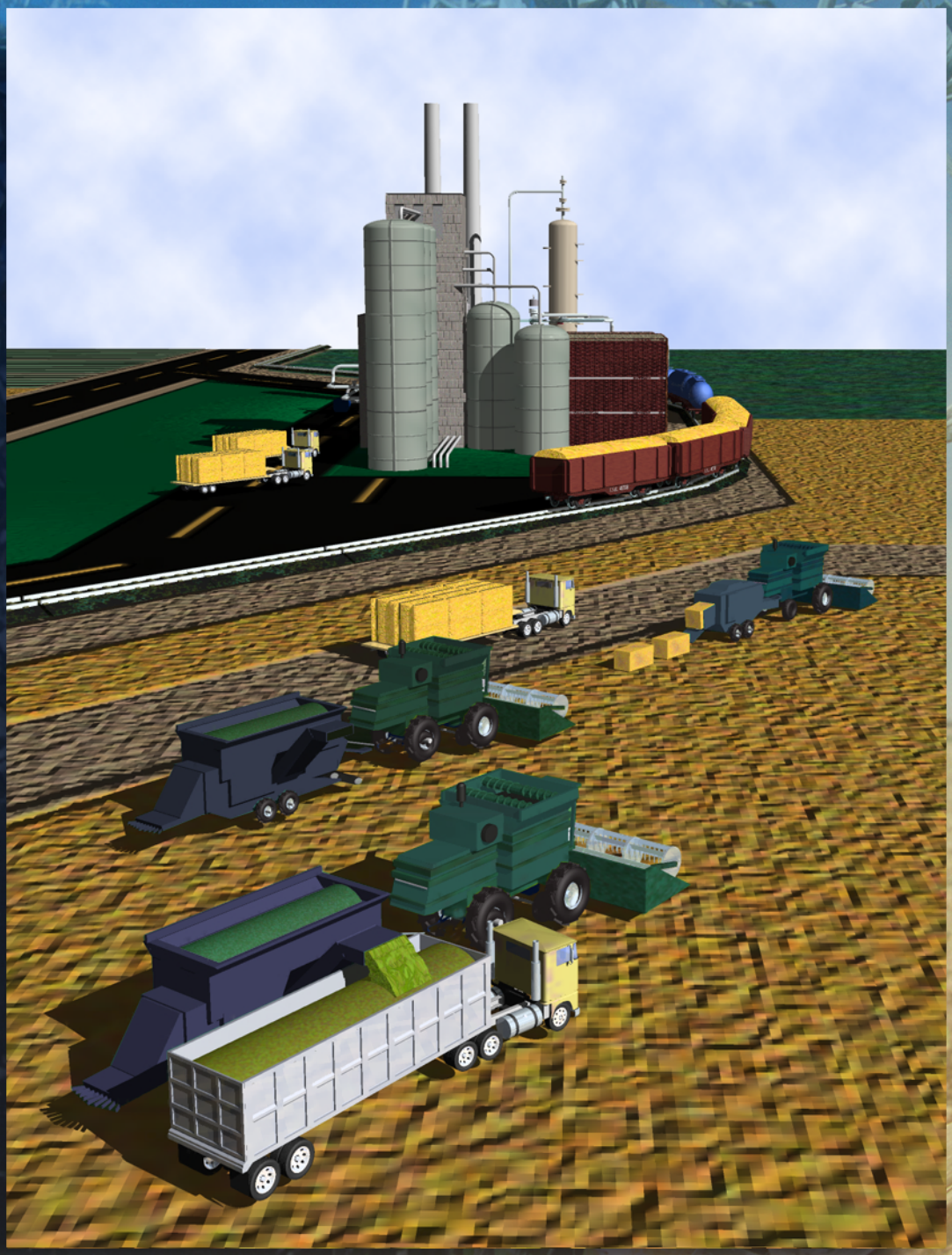
The Biomass Research and Development Technical Advisory Committee established a goal that biomass will supply 5% of the nation's power, 20% of its transportation fuels, and 25% of its chemicals by 2030. These combined goals are approximately equivalent to 30% of the country's current petroleum consumption. The benefits of a robust biorefinery industry supplying this amount of domestically produced power, fuels, and products are considerable, including decreased demand for imported oil, revenue to the depressed agricultural industry, and revitalized rural economies. A consistent supply of high-quality, low-cost feedstock is vital to achieving this goal. This biomass roadmap defines the research and development (R&D) path to supplying the feedstock needs of the biorefinery and to achieving the important national goals set for biomass.

To meet these goals, the biorefinery industry must be more sustainable than the systems it will replace. Sustainability hinges on the economic profitability of all participants, on environmental impact of every step in the process, and on social impact of the product and its production. In early 2003, a series of colloquies were held to define and prioritize the R&D needs for supplying feedstock to the biorefinery in a sustainable manner. These colloquies involved participants and stakeholders in the feedstock supply chain, including growers, transporters, equipment manufacturers, and processors as well as environmental groups and others with a vested interest in ensuring the sustainability of the biorefinery. From this series of colloquies, four high-level strategic goals were set for the feedstock area:

- Biomass Availability – By 2030, 1 billion dry tons of lignocellulosic feedstock is needed annually to achieve the power, fuel, and chemical production goals set by the Biomass Research and Development Technology Advisory Production Committee
- Sustainability – Production and use of the 1 billion dry tons annually must be accomplished in a sustainable manner
- Feedstock Infrastructure – An integrated feedstock supply system must be developed and implemented that can serve the feedstock needs of the biorefinery at the cost, quality, and consistency of the set targets
- System Profitability – Economic profitability and sustainability need to be ensured for all required participants in the feedstock supply system.

For each step in the biomass supply process—production, harvesting and collection, storage, preprocessing, system integration, and transportation—this roadmap addresses the current technical situations, performance targets, technical barriers, R&D needs, and R&D priorities to overcome technical barriers and achieve performance targets. Crop residue biomass is an attractive starting feedstock, which shows the best near-term promise as a biorefinery feedstock. Because crop residue is a by-product of grain production, it is an abundant, underutilized, and low cost biomass resource. Corn stover and cereal straw are the two most abundant crop residues available in the United States. Therefore, this roadmap focuses primarily on the R&D needed for using these biomass sources as viable biorefinery feedstocks. However, achieving the goal of 1 billion dry tons of lignocellulosic feedstock will require the use of other biomass sources such as dedicated energy crops. In the long term, the R&D needs identified in this roadmap will need to accommodate these other sources of biomass as well.

# 1. Background and Overview



# 1. Background and Overview

Biomass is a sustainable feedstock for energy products that could potentially enrich the future of the United States and the world. This roadmap focuses on the feedstock supply of lignocellulosic biomass, such as corn stover, straw, and wood, that can be converted into energy products (i.e., fuels, chemicals, and power) through sugar or syngas platforms. Lignocellulosic biomass is the nonstarch, fibrous part of plant material that is inherently moist and lightweight. The sugar platform hydrolyzes biomass into its component sugar molecules and then ferments the sugars into energy products; the syngas platform breaks down biomass into carbon, hydrogen, and oxygen elements and then uses basic chemistry to synthesize these elements into energy products.

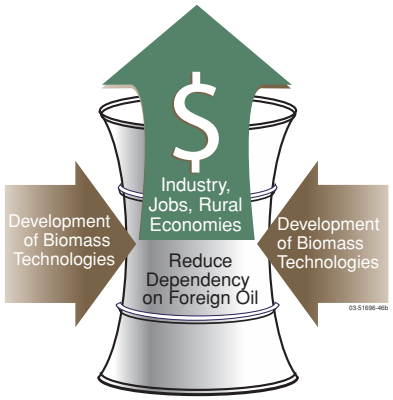



**Figure 1.1. Benefits from an increased biomass industry will enrich the future of the United States and the world.**

Although some biorefinery processes, such as paper and corn mills, already use biomass rather than petroleum feedstocks, there is currently no guarantee that they will maintain sustainability or benefit all stakeholders. Yet, if sustainability issues are addressed, the benefits of collecting, storing, and transporting biomass to processing facilities, as well as of using biorefinery co-products such as feeds and fertilizers in the agricultural system, will have positive economic, environmental, and social impacts. These benefits will include a decreased demand for imported oil, additional revenue for the depressed agricultural industry, new jobs, and revitalized rural economies (see Figure 1.1).

## What is a biorefinery?

A biorefinery processes biomass into value-added product streams. These can range from biomaterials to fuels such as ethanol and fuel gases, or key intermediates for the production of chemicals and other materials. Biorefineries are based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

In order for a lignocellulosic biomass refining industry to be successful, the biorefinery and the associated feedstock supply system must be more sustainable than the fossil fuel-based energy system it is replacing. Such sustainability consists of three components:

- Economic viability for all participants in the value chain
- Acceptable environmental impact of the biomass feedstock system
- Positive social impact of the biomass production and products.

The purposes of this roadmap are to define an R&D path forward and to express the methods and infrastructure necessary to supply agricultural

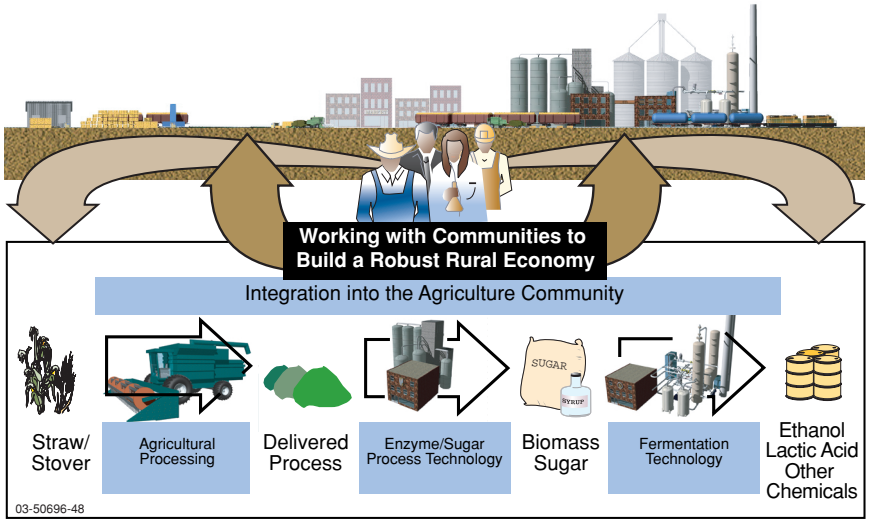



**Figure 1.2. Stakeholder involvement ensures successful integration of sustainable feedstock supply technologies and systems into rural communities.**

lignocellulosic feedstocks to biorefineries for producing biobased fuels, power, and products. This document is designed to build upon groundwork laid in the "Vision for Bioenergy and Biobased Products in the United States" in the "Roadmap for Biomass Technologies in the United States," which were prepared for the U.S. Department of Energy (DOE) by the Biomass Research and Development Technical Advisory Committee (TAC). The R&D needs and priorities discussed in this document represent the collective input of stakeholders directly involved in the agricultural feedstock value chain, including growers, equipment suppliers, transporters, and processors, as well as input from indirectly involved stakeholders including public R&D organizations, universities, educators, traditional agricultural industry sectors, environmental advocacy groups, states, and rural communities. As these stakeholders become more involved, the benefits to everyone will increase (see Figure 1.2).

## *1.1 Stakeholder Involvement and Benefit*

In early 2003, a series of colloquies and workshops were held to involve all stakeholders in outlining and defining R&D needs and directions for lignocellulosic feedstock supply. The colloquies focused primarily on corn and cereal straw crop residues, recognizing that the resultant biomass supply technologies and infrastructure must ultimately accommodate energy crops and other sources of biomass. The input provided by the many different perspectives has been combined and prioritized in this roadmap according to the highest impact on the sustainable, cost-effective supply of biomass feedstock and on the biorefining industry.

The continued involvement of and benefit to all stakeholder groups in this system are critical to the success of the R&D outlined in this roadmap. Growers and processors are a vital part of the feedstock supply system and will ultimately be responsible for its sustainable economic and environmental operation. Their investments in the R&D outlined in this roadmap will directly impact technology development and product lines, while the commercial technology products and systems produced will ultimately be purchased and used by these same stakeholders. Equipment manufacturers are arguably equal in importance to the growers and processors, since they are the group that will actually integrate the technologies and build the commercial biomass feedstock system to be operated by grower and processor groups. Due to the high level of uncertainty and risk in developing this new biorefining industry, industry access to and partnerships

with DOE national laboratories, U.S. Department of Agriculture (USDA) laboratories, and universities will be essential for solving the technical gaps and for understanding the sustainability issues of greatest concern. These public R&D groups will also prove useful in bringing nontraditional expertise from other industry sectors, thereby providing new approaches and solutions to seemingly insurmountable problems.

Transportation and feedstock guarantees are critical issues for the biomass processing industry. Therefore, involving the transportation and brokering industry that traditionally deals with forage and other large volume/tonnage agriculture commodities is necessary. In addition, transportation equipment, laws, and infrastructure are likely the least-flexible components of the feedstock system, so involving this group while defining requirements and influencing rule and policy changes will greatly affect technology selections throughout the feedstock supply system. Finally, the states/communities and nongovernmental organizations represent the people and environmental resources that will be most affected by this new biomass refining system. While these groups are not responsible for building this feedstock system, their support of the technological, environmental, and business solutions is essential for success. As such, environmental sustainability and economic profitability are key measures of performance throughout this document.

### U.S. Bioenergy and Bioproducts Vision Goal

- **Biopower** – Biomass consumption in the industrial sector will increase at an annual rate of two percent through 2030, increasing from 2.7 quads in 2001 to 3.2 quads in 2010, 3.9 quads in 2020, and 4.8 quads in 2030. Moreover, biomass consumption in electric utilities will double every 10 years through 2030. Combined, biopower will meet four percent of total industrial and electrical generator energy demand in 2010 and five percent in 2020.
- **Biobased Transportation Fuels** – Transportation fuels from biomass will increase significantly from 0.5 percent of U.S. transportation fuel consumption in 2001 (0.147 quads) to four percent of transportation fuels consumption in 2010 (1.3 quads), 10 percent in 2020 (4.0 quads), and 20 percent in 2030.
- **Biobased Products** – Production of chemicals and materials from biobased products will increase substantially from approximately 12.5 billion pounds, or five percent of the current production of target U.S. chemical commodities in 2001, to 12 percent in 2010, 18 percent in 2020, and 25 percent in 2030.

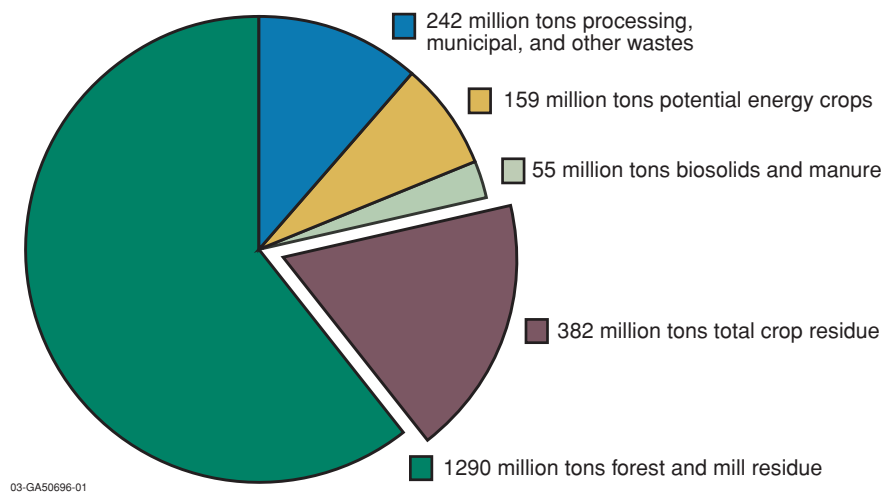
**"Vision for Bioenergy and Biobased Products in the United States," Oct 2002, http://www.bioproducts-bioenergy.gov/pdfs/BioVision_03_Web.pdf**

## *1.2 U.S. Bioenergy Vision and Feedstock Supply*

The "Vision for Bioenergy and Biobased Products in the United States" establishes the goal that by 2030 biomass will supply 5% of the nation's power, 20% of its transportation fuels, and 25% of its chemicals. These combined goals are approximately equivalent to 30% of the country's current petroleum consumption.

From a feedstock supply perspective, it is important to determine how much biomass is needed to meet the 2030 goals. Considering average conversions of standard lignocellulosic biomass, 1 billion dry tons of lignocellulosic feedstock is required annually to supply the projected biobased industry in 2030. It is estimated that roughly 2 billion dry tons of biomass is potentially available in the U.S. in the form of crop, forest and mill residues, and livestock and municipal wastes (see Figure 1.3). Forest residues produced from traditional forest product industries have and will continue to be about 200 million dry tons of forest residue biomass per year. This biomass resource is the primary source of bioenergy today. Significant additional forest supplies could result from thinning forests for fire hazard reduction. Though forest residues represent the largest total volume, sustainability and economic concerns (i.e., harvesting, endangering species, and disturbing public lands) call into question the reliability of these residues in the near term for further large-scale development. As a result, crop residues are the most likely high-volume lignocellulosic feedstocks to be available as a new large-scale biomass source for development in the near term. A portion of these crop residue biomass resources will provide sufficient feedstock to expand the biorefining industry,

achieve the bioenergy vision's 2010 goals, and, to a great extent, achieve the 2020 goals. With an established and profitable feedstock infrastructure and biorefining industry, existing biomass resources can be used more effectively, and dedicated crops (i.e., switchgrass and fast growing trees) can be developed and established, all of which will be required to satisfy the 1 billion dry ton feedstock target by 2030.




**Potential biomass generation in the U.S.**
Data From: Arthur D. Little. 2001. Aggressive Growth in the Use of Bioderived Energy and Production in the United States by 2010: Data Volume Reference 71038 Oct 2001. pages 103-144.

**Figure 1.3. Of the estimated 382 million tons of crop residues, 150 million tons could be collected with development of feedstock supply infrastructure technologies that address environmental and economic sustainability concerns.**

Since the initial focus is on using stover and straw to achieve the near-term bioenergy vision objectives (see Figure 1.4), this roadmap primarily addresses efficiently and cost-effectively harvesting, collecting, storing, preprocessing, and transporting these crop residues, with minimal or positive crop production impacts. However, fundamental infrastructure solutions must be applicable to all or multiple biomass feedstocks.

Several challenges must be addressed while establishing such a large feedstock infrastructure. For example, no single agriculture or forest product commodity even approaches the 1 billion dry ton scale. The corn grain crop, which is one of the largest U.S. commodities, makes up only about 280 million dry tons per year. On a tonnage basis, the proposed biorefining industry would be 3.5 times larger than the U.S. corn industry. This underscores the critical importance of a feedstock supply infrastructure to the emerging biofuels and bioproducts industry. While improvements in processing technology and the development of new and innovative chemicals and products from biomass will undoubtedly advance the biobased industry toward the vision goals, the lack of a large-scale guaranteed supply of feedstock could limit the biobased industry to niche markets.

**Figure 1.4. Initial focus is on using stover and straw.**

Several general priority R&D areas for feedstock production are outlined in the "Roadmap for Biomass Technologies in the United States." These include:

- "Biotechnology, genetics and plant physiology for improved feedstocks
- "Optimize agronomic practices, including land use availability and soil sustainability
- "Optimize logistics for collecting, storing and combining (i.e., blending) feedstocks."

This feedstock roadmap builds primarily upon the biomass technologies roadmap by expanding the priority R&D area of "feedstock handling" into a technical R&D roadmap of far greater detail that can be used as a guide for developing biorefinery feedstock supply technologies for the future.

## *1.3 Strategic Goals and Associated Industry Performance Targets*

The overarching goal of this roadmap is to achieve a $30/dry ton cost of feedstock delivered to a biorefinery at the prescribed megaton scale. This feedstock cost supports producing lignocellulosic sugars at about $.07/lb, the production price needed to be economically competitive with sugars produced from starch grain or other starch-based sources. Determining an accurate current cost for feedstocks is difficult because existing biomass markets are not at the scale of the biorefinery. In addition, for any given geographic area, the amount and quality of feedstock biomass economically available for a biorefinery varies depending on annual growing conditions, the amount that needs to be left in the field for sustainability and other purposes, the efficiency of harvest, the transportation infrastructure, and postharvest losses associated with storing and handling.

Current estimates for the delivered cost of biomass feedstocks at the scale of the biorefinery, factoring in all these variables, are approximately $50–$55/dry ton, which includes a modest $10/dry ton return to the biomass producer. Figure 1.5 shows how the research and technology development outlined in this roadmap lays out a viable path for reducing this cost to the target $30/dry ton.

The strategic goals of this roadmap are aligned into four categories that address separate, but interconnected requirements of the feedstock supply chain:

- Biomass availability
- Sustainability

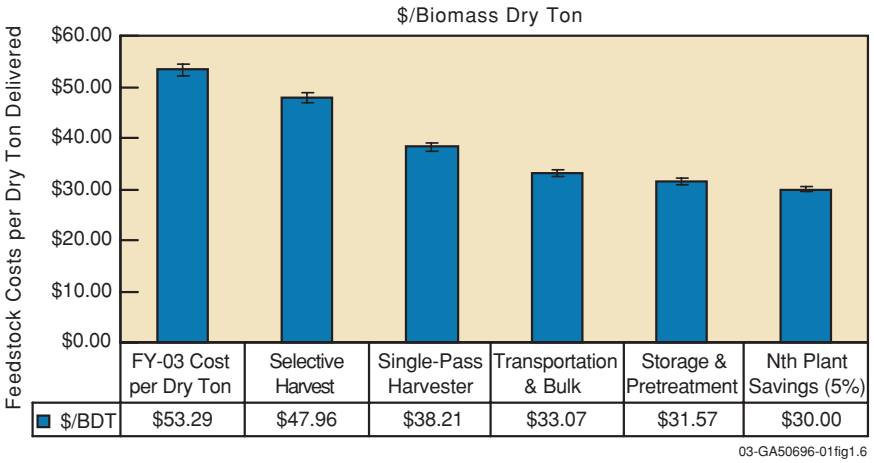



**Figure 1.5. Research and technology development pathway toward achieving feedstock price target.**

**Strategic Goals (SG):** The intermediate goals that lead to achieving the overarching goal of $30/dry tons of biomass.
**Performance Targets (PT):** The steps that lead to achieving goals.
**Technical Barriers (TB):** Issues that inhibit achieving performance targets and therefore strategic goals.
**R&D Needed (RD):** R&D that will help overcome technical barriers, achieve performance targets, and reach strategic goals.

| | |
|---|---|
| **Stakeholder Needs Statements (SN)** | • Sustainable harvest<br>• Low cost harvest<br>• Economically sustainable |
| **Strategic Goals (SG)** | • 30% of U.S. fuel supply<br>• 1 billion tons/year<br>• $30 ton |
| **Performance Targets (PT)** | • 150 million tons/year crop residue<br>• Selective biomass harvest<br>• 50% cost reduction |
| **Technical Barriers (TB)** | • Incapable of selective harvest/megaton-scale operation<br>• Multiple passes required<br>• Baling is expensive |
| **R&D Needs (RD)** | • Selective harvest<br>• Single pass<br>• Bulk collection and handling |
| **Technical Elements (TE)** | • Biomechanical properties<br>• Mechanical fractionation<br>• Air separation |

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**R&D Traceability**
**R&D needs were derived from the stakeholder need statements (refer to the appendixes for complete listings of the stakeholder need statements), and these R&D needs were prioritized according to their respective importance for addressing technical barriers and achieving performance targets necessary to accomplish DOE Office of Biomass and Industry Strategic Goals. Technical Elements, which represent a nonexclusive list of projects required to develop R&D solutions, are inherently linked such that every R&D project contributes to overcoming technical barriers and achieving overall program performance targets for accomplishing strategic goals and solving specific stakeholder needs. This chart uses harvesting details as an example.**

**Table 1.1. Alignment of strategic goals with industry-wide performance targets.**

| Strategic Goals | Industrywide Performance Targets |
|---|---|
| SG1<br>Biomass Availability | SG1.1 Accelerate annual development of 1 billion tons of available lignocellulosic biomass resources for fuels and chemicals by:<br>• Developing technologies and systems to begin and then increase sustainable utilization of crop residue biomass resources to work toward meeting the 2010 vision goals for bioenergy and bioproduct<br>• Expanding the diversity of available and potential biomass resources including processing wastes, forest resources, energy crops, etc., to meet 2020 and 2030 vision goals.<br>SG1.2 Create the technologies and systems that allow the widespread production and supply of biomass feedstock and resources to reduce the risk of reliance on single or few contract feedstock suppliers. |
| SG2<br>Sustainability | SG2.1 Minimize net impact of biomass production and utilization on the environment.<br>SG2.2 Enhance environmental resources and the productive capacity of the enterprise-level production system for different climates and cropping systems.<br>SG2.3 Improve net energy balance of biomass production, harvesting, collection, and handling. |
| SG3<br>Feedstock Infrastructure | SG3.1 Increase efficiency of utilizing standard transportation equipment and infrastructure with respect to safety per local laws and labor agreements.<br>SG3.2 Define and achieve feedstock composition and quality throughout the system.<br>SG3.3 Demonstrate cost-effective storage systems for megaton quantities of wet and dry biomass.<br>SG3.4 Minimize required farm-level capital investments and enterprise impacts of harvest and collection systems.<br>SG3.5 Increase biomass value with every process step of the feedstock chain. |
| SG4<br>System Profitability | SG4.1 Define life-cycle value of crop residue to the production enterprise.<br>SG4.2 Improve overall system efficiency and profitability by integrating value-add processes throughout the feedstock system.<br>SG4.3 Improve enterprise-level economics for sustainable technologies and practices to reduce or eliminate the need for subsidies and/or incentive payments. |

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- Infrastructure
- System profitability.

Developments in these categories are necessary in each step of the feedstock supply chain to develop a feedstock supply infrastructure that can handle 1 billion dry tons annually by 2030, while producing a profit for each party involved in the supply chain from grower to processor. The strategic goal categories, with their associated industrywide performance targets, are shown in Table 1.1.

## *1.4 Roadmap Organization and Top Priority R&D Needs*

Although conversion and product use technologies are not included in this roadmap, processing technologies represent the bulk of the technical performance characteristics of a biomass feedstock. Growers that produce grain and/or dedicated energy crops will be the primary biomass feedstock suppliers of crop residues. Thus, growers and processors form the backbone of the industry and are primarily responsible for adopting the technologies and practices that will contribute to achieving long-term industry goals. The remaining stakeholders will provide technologies, services, and support to the feedstock supply operation.

This roadmap is organized by supply system industry segment and the primary grower-oriented feedstock production and supply steps (see Figure 1.6). It presents detailed performance targets, technical barriers, R&D needs, and R&D priorities for each feedstock production and supply industry segment including:

- Production
- Harvest and collection
- Storage
- Preprocessing
- System integration
- Transportation.

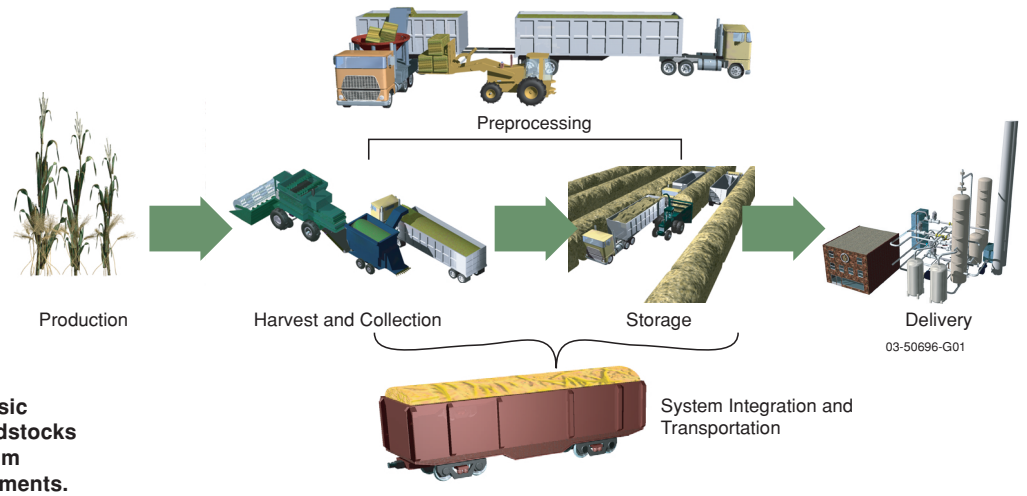


**Figure 1.6. Lignocellulosic biomass feedstocks supply system industry segments.**

The areas of R&D needed within each of these feedstock production and supply industry segments are shown in Table 1.2. These R&D areas represent technological needs that offer significant opportunity for the industry to develop an adequate and reliable biomass supply, ensure that the natural resource base can sustainably support the intensified production demands, develop the infrastructure for a large-scale biomass industry, and ensure the economic viability of the industry at both the individual enterprise level and the national and global scale.

## *1.5 Key Partners for Feedstock Goals Include USDA and DOE*

The U.S. stands to reap significant benefits from a robust biorefinery industry that can convert abundant crop residue and other biomass sources to domesti-

| Feed Stock Industry Segments | Areas of R&D |
|---|---|
| Production | • Resource assessment<br>• Sustainability/agronomics<br>• Plant science/agronomics |
| Harvesting and Collection | • Selective harvest for sustainability<br>• Single-pass harvesting and collection<br>• Bulk harvesting and collection |
| Storage | • Feedstock quality and monitoring<br>• Dry storage systems<br>• Wet storage systems |
| Preprocessing | • Biomass material properties<br>• Biomass physical state alteration<br>• Biomass bulk material handling |
| Systems Integration | • Subsystem specifications<br>• Overall integration<br>• Market and policy |
| Transportation | • Integrated systems for the utilization of existing infrastructure |

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**Table 1.2. Key areas of R&D needed for feedstock production and supply.**

cally produced fuels and products, benefits such as a decreased demand for imported oil, additional revenue for the depressed agricultural industry, new jobs, and revitalized rural economies. A cost-effective, sustainable harvest and collection of crop residue biomass is critical to the success of this industry. However, as with any new industry, a few issues need to be addressed, such as a biobased industry will require new infrastructure from stakeholders that may not want to build new infrastructure without an existing market; processors want a guaranteed supply of low-cost, high-quality biomass over the long-term before committing to build a biorefinery; and similarly, growers and equipment manufacturers want a reliable market and dependable prices prior to investing in producing the required quantities of biomass feedstock.

Plant sciences and agronomy are key R&D elements required for achieving the 1 billion dry ton target. The expertise of the USDA in production, agronomy, and plant sciences is essential for achieving biomass feedstock supply goals. In addition, the biomass technologies roadmap and this roadmap identify a need for DOE in industrial science and engineering to solve many feedstock infrastructure issues that directly affect supply, sustainability, and profitability (see Figure 1.7). USDA and DOE will need to interface with each other to achieve the 1 billion dry ton goal.

DOE's participation and support of the R&D needs identified in this roadmap are crucial in allowing the biorefinery concept to move forward and realize potential benefits. Continued sponsorship will enable research to develop and demonstrate the necessary biomass harvest and collection technologies and methods. DOE leadership and resources are also needed in sponsoring public/private partnerships of growers and equipment manufacturers working in tandem with the processors to commercialize and implement the necessary harvesting and collection technologies and methods to meet the biorefinery industry needs.

Although the collective benefits to the nation as a whole are considerable, the benefit to any individual grower or equipment manufacturer does not justify the resources and risk required. As such, DOE's sponsorship of public/private partnerships is absolutely critical. Investments in cost-shared partnerships and research at the national laboratories, USDA laboratories, and universities are necessary to develop the science and technology base as well as to address important knowledge gaps.

*DOE resource assessments confirm sufficient biomass for the first 30 to 150 plants (i.e., about 150 million tons).*

*The infrastructure needs the ability to deliver biomass to the biorefinery at the $30 price target.*

**Figure 1.7. The Bioenergy Vision 2010 milestone will primarily be achieved by the application of DOE industrial science and engineering to solve infrastructure development issues related to the utilization of readily available crop residues and other forms of biomass.**

# 2. Production

# 2. Production

Sustainability is a requirement for all new biobased technologies. Environmental sustainability is generally not a significant issue when using processing wastes like corn fiber, rice hulls, or sugar cane bagasse, materials that have already been removed from farm fields and often represent a disposal problem for food processors. For this reason, these materials may be the preferred feedstocks used in the first biorefineries. Feedstock sustainability is a factor, however, for all feedstock supply systems that involve producing biomass crops or collecting agricultural or forestry residues.

This section focuses on research priorities for meeting the near-term needs of deploying early technology. These R&D activities address technical barriers related to resource assessment and sustainability. This roadmap also summarizes recommendations for long-range research in plant sciences, agronomics, and sustainability, especially those identified in the Roadmap for Biomass Technologies in the United States. It assumes that the detailed planning for such research will be carried out in the relevant basic plant sciences research programs of the DOE Office of Science and USDA and in the applied plant and soil sciences R&D programs of the USDA (see Figure 2.1).

**Figure 2.1. Long-range research is needed in plant sciences to improve biomass quality and quantity.**

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## 2.1 Current Technical Situation

Biomass now contributes about 200 million dry tons annually to the nation's energy supply, primarily from wood residues. Increasing the annual contribution to 1 billion dry tons will require new biomass supplies and new uses for existing biomass resources. Industries that already have biomass supply infrastructures – such as wet and dry corn mills and pulp and paper mills – can reduce the need for new feedstock sources by more fully using all components of their existing feedstocks. New biorefineries, however, need new region-specific feedstocks and supply systems to ensure reliable supplies of high-quality, low-cost biomass. The major existing and potential biomass resources have been estimated at national, state, and sometimes county levels. Estimates from the various studies, however, are difficult to compare and combine because of embedded differences in geographic coverage, timeframe, costing methodology, and assumptions about availability and competing uses.

**Forest and industrial wood residues**, including logging residues, bark, other mill residues, and spent pulping liquors, are the source of most biomass energy consumed today. The forest products industry has a harvesting and processing infrastructure for wood, and continually seeks higher-value uses for mill residues. Residue availability is determined by production levels of wood products and by the economics of alternative uses. Under certain ecological, financial, and policy conditions, the supply of forest harvesting residues could be increased. Thinning forests to reduce fire hazards, a potentially significant new source of biomass,

is the subject of major environmental and cost studies by the U.S. Forest Service (see Figure 2.2).

**Urban wood residues** from tree trimmings, construction, and demolition make a small contribution to biomass energy today. These resources tend to be used where disposal fees are high. Other urban wastes sometimes considered for bioenergy include grass clippings and newspapers. Alternate markets for these include mulches and paper recycling.

**Other industry residues** include the by-products of grain and food processing industries. These resources are small in total amount but are already collected and potentially readily available. Issues include the proprietary nature of the resource information, and possible competition from other new uses for the same resources.

**Figure 2.2. Biomass can be obtained from natural, residential, commercial, and industrial sources.**

**Agricultural residues** is the largest available lignocellulosic biorefinery feedstock resource. Current production is concentrated where grain is grown, in the Midwest and Great Plains. Researchers have concluded that, within limits, residue removal can be sustainable and crop residues could be an additional revenue source for farmers. Ongoing research is needed in identifying conditions under which residues can be removed without increasing erosion or reducing soil productivity. The research results still need to be applied to the development of decision-making tools for on-farm application. The task of developing new harvest equipment capable of removing specific components of residue creates a need to understand the implications of differential residue removal on erosion, carbon, and nutrient cycling.

**Dedicated biomass crops** include grasses and short-rotation trees. Grasses are widely planted for forage and conservation purposes. New varieties that produce sustained high biomass yields with relatively low nutrient inputs have already been developed. The deep roots, perennial nature, and high nutrient-use efficiencies of some warm-season grasses increase the probability of dependable yields. Short-rotation tree crops are being used commercially for fiber and in a few locations as dedicated biomass crops for bioenergy demonstration projects. New varieties and culture techniques offer the capability for high-yield, sustainable production systems similar to grasses. The ongoing genetic sequencing of poplars is making available information and tools to design woody crops with desired feedstock characteristics.

## 2.2 Performance Targets

Targets for production research and analysis activities that can contribute to achieving the overall biomass feedstock industry goals and performance targets described earlier in this roadmap are grouped into three areas in Table 2.1. The first area, biomass availability, includes defining and documenting feasible scenarios for the development of feedstock resources. The targets specify resource levels that can support the expansion of biobased industries at rates that meet the targets defined in the "Vision for Bioenergy and Biobased Products in the United States" through the year 2030. The second area, sustainability, addresses short-term targets that will facilitate the translation of research data into decision-making tools for on-farm use by producers, and longer-term targets that assess the regional- and watershed-level effects of biomass production on water quality and water use. The third area, profitability, includes targets that integrate feedstock production and conversion technologies to improve overall system efficiencies.

**Table 2.1. Production performance targets.**

| | |
|---|---|
| PT1 Biomass Availability | PT1.1 By 2005, resource data with national coverage for all significant biomass resources is up-to-date, documented, and readily accessible via the Internet.<br>PT1.2 By 2010, production systems are defined and demonstrated for the sustainable collection of 100M dry tons/year of crop residues.<br>PT1.3 By 2020, production systems are defined and demonstrated for the sustainable collection of 600M dry tons of biomass feedstocks.<br>PT1.4 By 2030, production systems are defined and demonstrated for the sustainable collection of 1B tons/year of biomass feedstocks |
| PT2 Sustainability | PT2.1 By 2010, sustainable practices and management decision tools for collecting crop residues are defined for multiple regions.<br>PT2.2 By 2010, the regional environmental benefits of biomass production have been identified and quantified.<br>PT2.3 By 2010, environmentally sustainable production systems and management decision support tools are developed for dedicated biomass crops, and the information is made available for farmer/industry use.<br>PT2.4 By 2020, new crops are significantly more efficient (i.e., higher grain and/or biomass yields per land, water, and nutrient use) per unit of input. |
| PT3 System Profitability | PT3.1 Improved feedstock quality reduces processing costs.<br>PT3.2 Genetically improved and environmentally acceptable feedstocks increase the dollar value of biobased products.<br>PT3.3 Reliable feedstock supply data reduce the costs and risks in locating sites for biorefineries. |

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## 2.3 Technical Barriers

The biomass production area covers the R&D activities related to the sustainable production of biomass for bioenergy and bioproducts. The technical barriers addressed by this work are grouped into three areas:

- Resource availability
- Sustainability and agronomics
- System profitability.

Crop residues appear to be the lowest-cost feedstock option for the initial development of biorefineries. In the longer term, biomass supplies can be increased by using other sources, including municipal wastes, forest residues, and energy crops. Estimates of current and potential future feedstock resources provide support for a variety of policy and industrial development activities. Feedstock supply data (current and projected) are important in shaping the design of competitive biorefineries and in formulating the strategy needed for supplying an industry capable of reducing our dependence on foreign oil.

Producers approach collecting, or not collecting, crop residues as a business decision. The technical barriers associated with making such decisions include incomplete information on the costs and benefits of adding residue collection to their crop management systems. Costs related to crop production include issues also related to sustainability, especially the near- and long-term effects on soil quality and crop productivity.

In the long term, plant sciences research can increase the profitability of biorefineries by producing biomass resources that are more uniform, produce higher product yields, and/or cost less than the current process. In general, increasing yields and increasing the efficiency of using inputs are effective ways of reducing the costs of producing biomass that can be applied to any crop. For maximum impact, it is likely that research to change the chemical composition or physical form of the biomass will be designed to improve feedstocks for specific conversion processes.

Major technical, institutional, and policy barriers that are drivers for production research and analysis are summarized in Table 2.2. These barriers are currently limiting efforts in achieving the performance targets listed in the previous section.

## 2.4 Research and Development Needs

The R&D needed to achieve the performance targets can be organized into three major areas:

- Biomass supply forecasts and analysis
- Sustainability and agronomics
- Basic plant sciences (i.e., genomics and plant physiology).

### Biomass Supply Forecasts

Biomass supply forecasts comprised developing projections for the prices and quantities of biomass resources available to support biorefineries. Activities will involve developing and applying modeling tools that integrate available resource databases from USDA with new data from plant sciences, sustainability, and

**Table 2.2. Production technical barriers.**

| | Performance Targets Addressed |
|---|---|
| **TB1 Resource Availability** | |
| TB1.1 There are no periodic national surveys of lignocellulosic biomass production, and current estimates of feedstock resources are limited in scope and do not consider how major technological advances in production technologies will impact biomass availability. | PT1.1, PT1.2, PT1.3, PT1.4, PT3.3 |
| TB1.2 Uncertainty about the amount, price, quality, and year-round reliability of feedstock resources is a barrier to stimulating bioindustry development. | PT1.1, PT1.2, PT1.3, PT1.4, PT3.3 |
| TB1.3 Existing data on the environmental effects of feedstock production are not adequate to support life-cycle analysis of bioenergy systems. | PT1.1, PT2.1, PT2.2, PT2.3, PT2.4 |
| TB1.4 The production of biomass feedstocks will ultimately be limited by competition for finite land and water resources. | PT2.3, PT2.4 |
| TB1.5 Physical and chemical characteristics of feedstocks vary by source, year, and season, increasing processing costs. | PT1.1, PT2.2, PT2.4, PT3.2 |
| TB1.6 There is inadequate information on plant biochemistry as well as inadequate genomic and metabolic data on many potential biomass crops. | PT3.1, PT3.2 |
| **TB2 Sustainability** | |
| TB2.1 Farmers are concerned about long-term effects on soil and crop productivity, return on investment when collecting residues, and lack of data and tools to support on-farm decisions about residue collection. Research has not addressed the potential differences between returning whole-crop residues and specific fractions of crop residues. | PT1.2, PT2.1, PT2.2 |
| TB2.2 The regional- and/or watershed-level effects of biomass feedstock production on water flows, water quality, biodiversity, and crop productivity have not been addressed. | PT2.2, PT2.3, PT2.4 |
| TB2.3 Genetic modification of dedicated crops for improved characteristics may create risks to native populations of related species. | PT3.2 |
| **TB3 System Profitability** | |
| TB3.1 System profitability is highly sensitive to crop inputs and yields, residue collection rates, and effects on other farming operations. | PT2.1, PT2.4, PT3.2 |
| TB3.2 Genetic modification of commodity crops to improve residue characteristics may affect grain values. | PT2.4, PT3.2 |

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agronomic research (see Table 2.3). Applications include projecting biomass costs and supplies, defining delivered costs and relating them to the size of the biomass-using facility, and providing input data for life-cycle assessments. The resource forecasts inform the energy projection, policy and planning, and results reporting activities of DOE. They also support industries and other organizations directly involved in the development of biorefineries. Because biomass supplies and competing uses change with time, and availability and costs change as collection and transportation technologies advance, this area includes periodic updates of all feedstock types. In addition, since existing resource data are frequently requested for a range of uses, this will also include making resource forecasts and projections accessible in an efficient, Web-based format.

### *Sustainability and Agronomics*

Although it is assumed that USDA and universities will be performing the research and developing the detailed R&D priorities and technical elements, the R&D needs identified in the colloquies and workshops for the sustainability and agronomics area are described in Table 2.3. Coordination between research on harvest technologies and agronomics and sustainability will be important, especially for systems that collect and return specific residue fractions. There is no information on the effects of new in-field fractionation technologies on soils, though changing the average physical and chemical characteristics of collected biomass will also change the characteristics of the returned biomass, which can be expected to have some effect on soil processes and crop production. For all harvesting systems, cost is closely correlated to the amount of biomass collected per acre of land, making assumptions about sustainable collection rates critical to feedstock cost as new technologies allow greater control over residue removal and return.

### *Plant Sciences*

Plant sciences research is a long-term effort that can potentially make significant contributions to the overall efficiencies of advanced biorefineries and to the suite of bioproducts they produce. It is assumed that the USDA and the DOE's Office of Science will perform the basic plant sciences research needed to support biorefinery development. Table 2.3 lists the major R&D needs in the area of plant sciences, specifically those identified in the "Roadmap for Biomass Technologies in the United States." However, it is assumed that detailed R&D plans will be developed by the organizations supporting the research, and plant sciences R&D, like sustainability R&D, are not included in later sections of this document.

## *2.5 Research and Development Priorities*

Research needs were selected as top-priority needs based on their relevance to the DOE Office of Biomass goals. Table 2.4 details key technical elements for the biomass supply forecast and analysis activity. They are:

- Develop forecasts of biomass supplies
- Maintain a Web-based biomass resource database
- Detail a long-term vision for developing biomass supplies
- Support total system techno-economic and life-cycle analysis.

**Table 2.3. Production R&D needs.**

| Priority | Term of Impact | R&D Need | Technical Barriers Addressed |
|---|---|---|---|
| **RD1 Resource Assessment** | | | |
| Top | N | RD1.1 Develop biomass supply forecasts and perform analysis activities in support of life-cycle assessment, techno-economic analysis, and defining the steps necessary to produce 1B tons/year of biomass in a sustainable manner. | TB1.3 |
| High | N | RD1.2 Develop biomass feedstocks supply data relevant to diverse user needs. | TB1.2, TB1.5 |
| **RD2 Sustainability/Agronomics** | | | |
| Top | N | RD2.1 Develop data on carbon and nutrient flows in biomass feedstock production to support life-cycle assessment, establish requirements for system sustainability, and support development of on-farm decision-making tools. | TB2.1 |
| Top | N | RD2.2 Develop data on the effects of fractionating biomass feedstocks at harvest to support life-cycle analysis and equipment development, and to establish requirements for system sustainability. | TB1.3, TB2.1 |
| High | M | RD2.3 Develop data and information on the effects of biomass feedstock production on water quality and water use, including landscape and watershed-scale studies, to support life-cycle analysis and to establish requirements for system sustainability. | TB1.3, TB2.2 |
| Medium | M | RD2.4 Quantify other environmental debits and credits of biomass production as needed for life-cycle assessment- | TB1.3 |
| **RD3 Plant Science/Agronomics** | | | |
| Top | L | RD3.1 Develop plant varieties and optimize associated agronomic practices for sustainable biomass feedstock production. | TB3.1, TB3.2 |
| High | L | RD3.2 Improve the technical understanding of plant biochemistry and enzymes and develop the ability to engineer enzymes within desired crops. | TB2.3, TB3.2 |
| Medium | L | RD3.3 Develop the chemical and chemical/biological pathways necessary to improve the energy density and chemical characteristics of delivered feedstocks for efficient storage and processing. | TB2.3 |

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Term of Impact = N: Near-term (within 3 years) M: Mid-term (within 10 years) L: Long-term (>10 years)

Table 2.4 also provides additional details on the risks, payoffs, and expected timeframes for results from R&D on each of the high-priority areas for biomass supply forecasts and analysis. Top research needs in sustainability and plant sciences areas are listed in the Table 2.4. For plant sciences, these research areas are outside the current scope of the DOE program, and it is assumed that the key technical elements associated with them will be defined by the organizations or agencies performing the research.

**Table 2.4. Production R&D priorities.**

| | |
|---|---|
| R&D Priority – RD1.1 | Develop biomass supply forecasts and perform analysis activities in support of life-cycle assessment, techno-economic analysis, and defining the steps necessary to produce 1B tons/year of biomass in a sustainable manner. |
| **Key Technical Elements** | **TE1** Develop documented forecasts of biomass supplies from current crops and from potential feedstock production systems, including costs, quantities, and locations.<br>**TE2** Develop and maintain a documented, Web-based resource database.<br>**TE3** Produce a journal paper describing a vision for how biomass resources can be developed to supply 1B tons/year of biomass on a sustainable basis.<br>**TE4** Support total system techno-economic analysis led by conversion researchers and developers.<br>**TE5** Support total system life-cycle assessments with feedstock production data. |
| Technical Barriers Addressed | TB1.1, TB1.2, TB1.3 |
| Performance Targets Addressed | PT1.1,PT1.2, PT1.3, PT1.4, PT2.1, PT2.2, PT2.3, PT2.4, PT3.3 |
| Risk | Low – The risk is low because the necessary background data are available, and similar analyses have been performed successfully in the past |
| Benefit to Strategic Goals | • Increase in credibility of resource estimates.<br>• High-quality information on quantity, price, location, and quality of biomass residues important to near-term bioenergy implementation.<br>• Development of a methodology that can be easily used to update estimates.<br>• Good feedstock supply curve estimates could help DOE and USDA establish priorities for type and locations for cooperation on relevant projects or research.<br>• Development of a common vision on resource availability. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN1.1, SN1.5, SN1.10, SN1.13, SN11.14, SN12.2, SN13.3, SN13.5, SN18.5, SN19.1, SN19.4 |

| | |
|---|---|
| R&D Priority – RD2.1 | Develop data on carbon and nutrient flows in biomass feedstock production to support life-cycle assessment, establish requirements for system sustainability, and support development of on-farm decision-making tools. |
| **Key Technical Elements** | **This research is outside the scope of DOE's OBP.** It is assumed that the programs within USDA or other DOE offices responsible for performing the research will develop the key technical elements. |
| Technical Barriers Addressed | TB1.3, TB1.4, TB2.1 |
| Performance Targets Addressed | PT1.1, PT1.2, PT2.1, PT2.2, PT2.3, PT2.4 |
| Risk | Medium – The technical risk is moderate because information will be required before long-term studies can be completed. The technical risk increases with the degree of extrapolation over space and time. |
| Benefit to Strategic Goals | • Documented data inputs for quantification of life-cycle benefits of biobased systems.<br>• Increased public support for biobased energy systems.<br>• Increase in types and amounts of biomass feedstocks generally accepted as sustainable or "green." |

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| | |
|---|---|
| Term of Impact | Near-term – Results from existing DOE-USDA studies on corn residue. New studies will yield mid- and long-term results. |
| Stakeholder Needs Addressed | SN1.8, SN2.6, SN11.14, SN13.2, SN13.6, SN13.7, SN14.5, SN16.3, SN16.9, |

| | |
|---|---|
| R&D Priority – RD2.2 | Develop data on the agronomic effects of fractionating biomass feedstocks at harvest to support life-cycle analysis and equipment development, and to establish soil sustainability requirements. |
| **Key Technical Elements** | **This research is outside the scope of DOE's OBP**. It is assumed that the programs within USDA or other DOE offices responsible for performing the research will develop the key technical elements. |
| Technical Barriers Addressed | TB1.3, TB2.1 |
| Performance Targets Addressed | PT1.1, PT1.2, PT2.3, PT2.4 |
| Risk | Low - The technical risk in this research is low, except when short-term and site-specific results must be extrapolated to long-term effects and to different sites. |
| Benefit to Strategic Goals | • More efficient harvesting systems that improve soil quality and ensure sustainability.<br>• Documented data inputs for quantification of life-cycle benefits of biobased systems. |
| Term of Impact | Near-term - Pilot plot-scale can begin immediately. Field-scale tests would be coordinated with schedule for equipment trials. |
| Stakeholder Needs Addressed | SN1.8, SN2.1, SN2.2, SN2.3, SN2.4, SN2.5, SN2.6, SN2.7, SN2.9, SN2.11, SN2.13, SN2.14, SN2.15, SN2.16, SN2.17, SN2.18, SN2.19, SN11.5, SN14.5, SN16.3, SN16.9, SN18.2, SN19.3 |

| | |
|---|---|
| R&D Priority – RD3.1 | Develop plant varieties and optimize associated agronomic practices for sustainable biomass feedstock production. |
| **Key Technical Elements** | **This research is outside the scope of DOE's OBP.** It is assumed that the programs within USDA or other DOE offices responsible for performing the research will develop the key technical elements. |
| Technical Barriers Addressed | TB1.4, TB1.5, TB3.1, TB3.2 |
| Performance Targets Addressed | PT1.1, PT2.1, PT2.2, PT2.3, PT2.4, PT3.2 |
| Risk | Medium-High – The greatest risk comes from the fact that the research is outside the DOE scope, and therefore outside DOE's control. |
| Benefit to Strategic Goals | • By increasing the amount of biomass produced per unit area, and reducing the inputs required, this research increases the potential energy, economic, and environmental benefits of bioenergy and biobased products. |
| Term of Impact | Long-term |
| Stakeholder Needs Addressed | SN2.20, SN11.14, SN12.4, SN12.5, SN17.1, SN17.2, SN17.3, SN17.4, SN19.2, SN19.5 |

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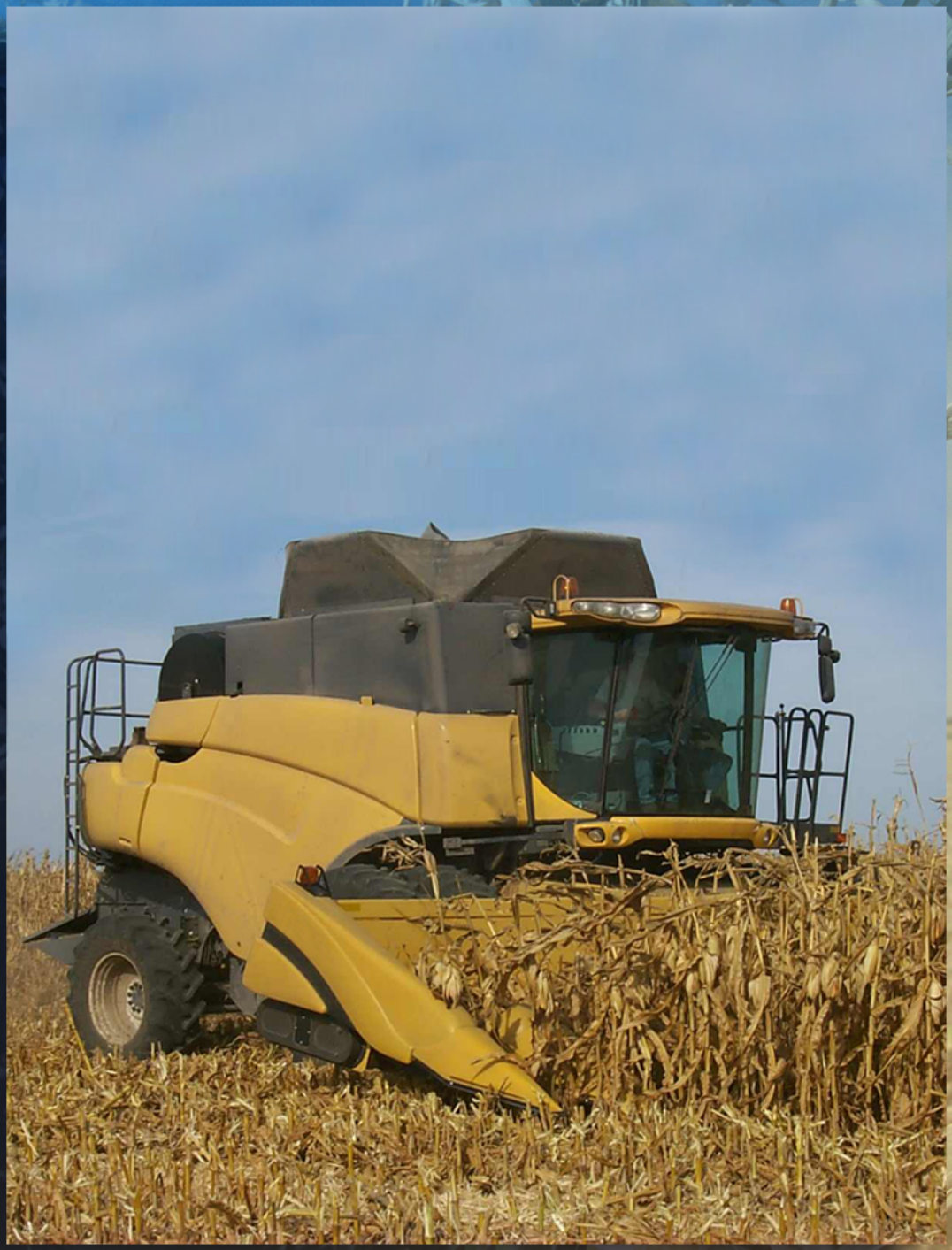
# 3. Harvesting and Collection



# 3. Harvesting and Collection

Harvesting and collection technologies are the first step in the feedstock infrastructure process. The primary goal is to harvest, collect, and remove the biomass from the field in a sustainable, cost-effective manner.

Harvesting and collection must be considered in the context of the overall feedstock supply infrastructure. For instance, harvesting and collection methods and technologies have significant impacts on storage, transportation, and preprocessing. Additionally, sustainability concerns such as soil compaction as well as portions of the biomass left in the field for erosion control must be considered and addressed.

Currently, agricultural crops such as corn, wheat, and barley are grown for grain, thus harvest and collection technologies have been developed and optimized for grain harvest. Both the infrastructure and grower familiarity exist with equipment such as combines, grain carts, and grain trucks. Therefore, in order to meet the biomass price targets of the biorefinery, biomass harvesting and collection technologies must be compatible with existing harvest equipment and technologies.

## 3.1 Current Technical Situation

Currently, small amounts of the crop residues corn stover and cereal straw are harvested, collected, and used in the livestock and dairy industries, as well as in some specialty applications such as hydromulch. The current harvest and collection method is a three- or four-step process (see Figure 3.1). First, a combine harvests the grain and discharges the biomass in a windrow behind the combine. Second, a baler towed by a tractor picks up the windrow, packages the biomass in a bale, and discharges the bale when baler capacity is reached (typically 1,000 to 1,300 dry lb for large balers). Third, a tractor picks up the bales and hauls them field side. For corn stover, intermediate steps are needed to mow and rake the stalks into a windrow prior to baling.

Crop residue biomass harvesting and collection in this manner is inadequate to meet the feedstock performance targets of the biorefinery for several reasons. Harvesting using this approach introduces a significant amount of dirt and rock contamination into the feedstock by dropping it on the ground before picking it back up. The multiple passes across the field in the current system add costs by

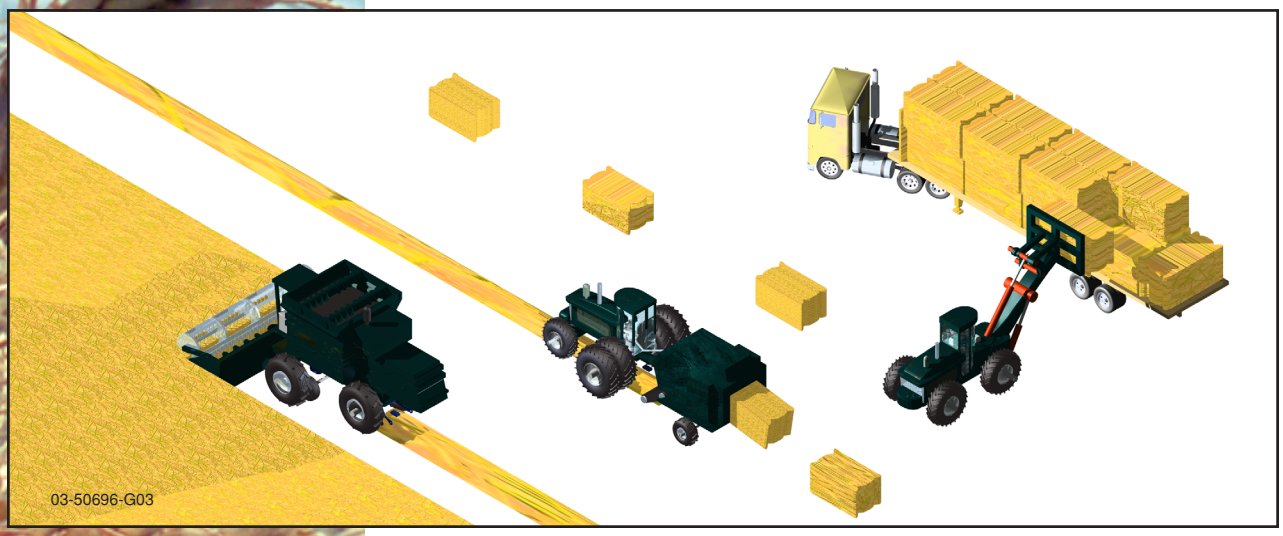



**Figure 3.1. Current biomass harvest technology.**

requiring additional dedicated equipment and labor and increase soil compaction, making minimum or no-till agronomic practices more difficult to implement when the biomass is harvested in this manner. Numerous studies have shown that minimum or no-till practices are highly desirable for maintaining soil carbon levels when crop residue biomass is harvested.

The continuous harvest of crop residue biomass to meet the needs of the biorefinery on the national and local scale will demand that sustainable biomass harvest technologies be developed and implemented. The goal of sustainable harvest for the biorefinery is to maximize the amount of residue that can be removed for use as biorefinery feedstocks while adhering to sustainability guidelines. Crop residue biomass, whether it be corn stover or cereal straw, is composed of many components such as stalks or stems, leaves, sheaths, husks, cobs, awns, and other minor components. Certain components of the biomass are more valuable than others when left on the field for sustainability and erosion concerns; this varies depending on climate, growing conditions, and the crop. Selective harvest technologies that have the ability to leave the components and amounts of the residue most desired for sustainability and erosion concerns while harvesting only the remaining portions of the residue, will be more sustainable than current approaches. Additionally, since selective harvest will maximize the sustainability benefits of what is left in the field, this approach holds the promise of maximizing the amount of residue that can be removed in a sustainable manner.

The development of a single-pass harvester capable of selective biomass harvest shows promise for meeting the availability, sustainability, quality, and price performance targets for biorefinery feedstocks. As shown in Figure 3.2, this equipment would selectively harvest specified components of the biomass to be used for biorefinery feedstocks in a single pass, simultaneously harvesting the biomass with the grain. This equipment could help address important sustainability needs by leaving the required percentages of biomass components required for soil health and erosion constraints. In addition, another potential benefit of single-pass biomass and grain harvest includes reduced soil compaction, which makes biomass harvest more compatible with minimum or no-till practices and with reduced costs and energy use.

Bales are also problematic for the biorefinery. Although bales are a well-developed technology that works well for the livestock industry, they are not well suited for the large-scale needs of the biorefinery. Bales are expensive to make, have low bulk density as compared with other dry industrial feedstocks, require separate power equipment such as loaders or forklifts to load and unload, and are difficult to handle at the large scale of the biorefinery. Bulk collection systems need to be designed and developed to overcome the limitations of the bale system at the large scale.

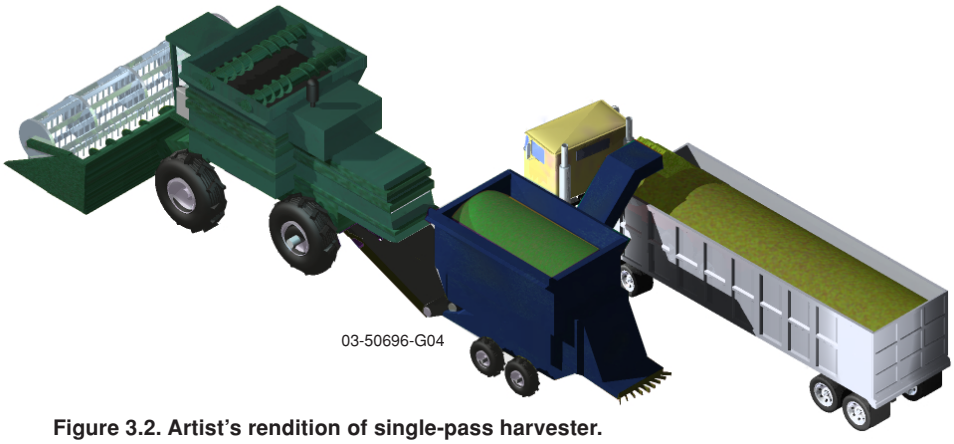



**Figure 3.2. Artist's rendition of single-pass harvester.**

## *3.2 Performance Targets*

The economics of the biorefinery present some significant challenges for feedstocks. The biomass must be plentiful on a nationwide basis, yet its availability must be concentrated on a local basis, since its low bulk density precludes transportation over large distances. It must be low cost, of consistent quality, and harvested and collected in a sustainable manner while being removed from the field in a short harvest window to not negatively impact other farming operations.

**Table 3.1. Harvesting and collection performance targets.**

| | |
|---|---|
| PT4 Biomass Availability | PT4.1 Technologies and methods are developed to harvest and collect 150M tons/year of crop residue biomass nationally with a 50% cost reduction when compared with current technologies.<br>PT4.2 Biomass harvest and collection technologies can handle bulk crop residue biomass at the megaton scale. |
| PT5 Sustainability | PT5.1 Selective biomass harvest systems are developed by 2010 that can be tailored to address site-specific sustainability and economic concerns.<br>PT5.2 Single-pass harvesting systems consume less fuel and reduce total energy demands of biomass harvest and collection by 33% over current multipass systems.<br>PT5.3 Single-pass, selective biomass harvesting systems reduce soil compaction and erosion associated with the biomass harvest by 50%, and these systems are compatible with no-till cropping systems by 2010. |
| PT6 Feedstock Infrastructure | PT6.1 Specialized equipment needed for optimized grain and biomass harvest systems are minimized as well as associated capital equipment costs (i.e., less machinery performs the grain and biomass harvest for 50% less cost than current harvest, mow, rake, and bale machinery processes).<br>PT6.2 Single-pass stover and straw harvest has no negative impact on the grain harvest.<br>PT6.3 Biomass selective harvest can be accomplished in a single pass over the field by 2010.<br>PT6.4 Biomass harvest equipment reduces soil and other contaminants by 90% or more by 2010.<br>PT6.5 By 2020, advances in single-pass harvester technology allow significant value-added on-harvester biomass feedstock preprocessing.<br>PT6.6 By 2020, single-pass grain/biomass harvesters can harvest grain and biomass from multiple crops.<br>PT6.7 Harvesting equipment must operate in an optimal mode for both biomass (<1% loss and soil contamination) and grain (<1% loss/damage). |
| PT7 System Profitability | PT7.1 Costs to harvest and collect the crop residue biomass are reduced by 50% over current technologies.<br>PT7.2 Biomass harvest and collection technologies and methods must be profitable for both the equipment manufacturer and the grower. |

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These objectives put considerable demands on biomass harvest and collection technologies and methods. Harvest and collection technologies must be able to handle biomass in large volumes at low cost, and the systems must have broad nationwide applicability but be readily adaptable to the needs of specific crops and areas. The performance targets for the harvesting and collection area that make these objectives achievable are presented in Table 3.1.

## *3.3 Technical Barriers*

Crop residue biomass is an attractive starting feedstock for the biorefinery because of its high availability and current underutilization. Additionally, since it is a byproduct of grain production, the grain crop covers primary production costs. However, many significant barriers exist that must be addressed. The technical barriers for harvest and collection are shown in Table 3.2 and are grouped into three technology areas:

- Sustainable biomass harvest
- Single-pass harvest
- Bulk harvesting and collection systems.

Although crop biomass harvesting and collection currently occurs on a limited basis, biomass harvesting and collection at the required scale, quality, and price targets, is a new endeavor for a national biorefinery industry. As with any new endeavor, significant challenges and opportunities exist. Achieving the performance targets for this area in the desired timeframe will require an accelerated R&D program. Feedstock costs and quality have a significant impact on the overall economics of the biorefinery. Meeting the $30/ton price target at the quality levels required by the biorefinery, while making this an economically sustainable venture for all parties involved in the feedstock supply chain, represents a significant challenge. Clearly there is a need for enabling research as well as public/private technology development and implementation partnerships to address these technical barrier areas and achieve the performance targets set for the harvesting and collection area.

## *3.4 Research and Development Needs*

To meet the performance targets set for the harvest and collection area, biomass harvest and collection equipment must address long-term sustainability issues associated with biomass harvest such as soil health and erosion concerns. The equipment must be robust and tailorable to specific crops and site-specific concerns. In addition, it must produce a clean, high-quality, consistent feedstock; have minimal impact on soil compaction; require low energy and labor inputs; and be affordable. To accomplish these significant performance targets within the desired time scale will require an accelerated research and technology development effort that involves research at national laboratories and universities and integrated demonstrations involving growers, equipment manufacturers, and processors. The R&D needed to achieve this can be organized into the same three areas:

- Sustainable biomass harvest
- Single-pass harvest
- Bulk harvesting and collection systems.

**Table 3.2. Harvesting and collection technical barriers.**

| | Performance Targets Addressed |
|---|---|
| **TB4 Selective Harvest for Sustainability** | |
| TB4.1 Current crop harvesting machinery is unable to selectively harvest desired components of biomass and address the soil carbon and erosion sustainability constraints. | PT5.1, PT6.2 |
| TB4.2 Lack of feedstock specifications and standards against which to engineer harvest equipment, technologies, and methods. | PT6.5 |
| TB4.3 Biomass variability places high demands and functional requirements on biomass harvesting equipment and is not currently addressed. | PT6.6 |
| TB4.4 Lack of methods to optimally control operational performance of multicomponent harvesting equipment. | PT6.7 |
| TB4.5 Site-specific quantifiable data are needed on the value of the residue left in the field for sustainability (i.e., impact to farming operations, yields, crop rotations) versus value to the grower as a biorefinery feedstock. | PT5.1, PT5.3 |
| TB4.6 Lack of data on how residue removal could potentially negatively or positively impact no-till operations in certain areas. | PT5.3 |
| **TB5 Single-Pass Harvest** | |
| TB5.1 Current biomass harvest methods require multiple passes across the field, which causes soil compaction and high fuel and labor usage. | PT5.2, PT5.3, PT6.3, PT7.2 |
| TB5.2 Current harvest and collection technologies and methods do not produce clean feedstock. The process of picking up the windrow behind the combine also picks up large amounts of dirt and rocks. | PT6.4 |
| TB5.3 Small margins allow for a minimal capital outlay from growers for new specialized equipment, which translates into very small margins for equipment manufacturers. | PT6.1, PT7.2 |
| TB5.4 Grain harvest occurs during a short window in which the additional complexity of the biomass harvest could have negative impacts. | PT6.2 |
| TB5.5 Site- or region-specific definitive data are needed on what percentages and portions of the biomass should be left on the field for soil health and erosion protection. | PT5.1, PT5.3 |
| TB5.6 Lack of data on soil compaction associated with biomass harvest and collection. | PT5.3 |
| **TB6 Bulk Harvesting and Collection Systems** | |
| TB6.1 Current crop residue biomass harvesting and collection technologies and methods are inadequate (i.e., not designed for handling many millions of tons) to meet the 150M-ton/year collection capability goal by 2010. | PT4.1, PT4.2 |
| TB6.2 Current biomass collection, handling, and transport methods, which are bale based, are primarily designed to meet the needs of the livestock and dairy industry and are inadequate to meet the large low-cost biomass needs of the biorefinery. | PT4.1, PT4.2, PT7.1 |
| TB6.3 Current methods of harvesting and collecting biomass are too costly. | PT7.1, PT7.2 |
| TB6.4 Biorefinery feedstock price targets combined with costs of current technologies and methods allow a very small margin for growers. | PT6.2, PT7.2 |

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## *Sustainable Biomass Harvest*

Maintaining soil carbon levels for soil health and reducing soil erosion losses from wind and/or rain dictate that certain percentages and components of the biomass are left on the field. The different percentages and components that must be left vary depending on soil type, climate, and agronomic practices. Biomass harvesting and collection technologies and methods are needed that can meet these sustainability requirements by selectively harvesting the portions and percentages of the biomass acceptable for removal. They must be adjustable to meet site-specific needs, able to handle different biomass and crop types, and be low cost. In addition, sustainable harvest equipment must be developed for a variety of crops and various moisture levels (see Table 3.3).

## *Single-Pass Harvest*

The sustainable selective biomass harvest systems must be capable of single-pass simultaneous harvest of the grain and biomass. Whether the grain and biomass are separated in the field or at field-side depends on the specific crop, moisture content, and end use. No till or minimum till practices can allow significantly higher amounts of biomass to be removed while still meeting soil carbon and erosion constraints. Single-pass biomass harvest systems can reduce soil compaction and make biomass harvest compatible with no or minimum till agronomic practices. Additionally, single-pass biomass harvest can reduce the cost of biomass harvest and facilitate achieving the biorefinery feedstock price targets. It is of utmost importance to the grower that these sustainable selective biomass harvest systems not have negative impact on other important farming operations (see Table 3.3).

## *Bulk Harvesting and Collection Systems*

Current bale-based systems for collecting and handling biomass have many significant drawbacks including low bulk density, high dirt and rock contamination, high unit cost, and significant handling and storage issues at the large scale. These issues combine to make it unlikely that biorefinery feedstock performance targets can be achieved with current bale-based systems. Fortunately, bulk collection and handling systems offer significant potential toward overcoming these limitations and achieving the biorefinery feedstock performance targets. A critical component to the viability of bulk systems is the ability to harvest, collect, and remove biomass from the field in a large-scale bulk mode. Research and technology development need to be conducted on developing bulk biomass harvesting and collection technologies and methods. Since there will most likely be a transition period from existing bale systems to the bulk systems, the newly developed bulk handling systems will need to be compatible with existing bale-based systems (see Table 3.3).

**Table 3.3. Harvesting and collecting R&D needs.**

| Priority | Term of Impact | R&D Need | Technical Barriers Addressed |
|---|---|---|---|
| **RD4 Selective Harvest for Sustainability** | | | |
| Top | M | RD4.1 Develop the biomass separation techniques necessary for development of a harvester capable of biomass selective harvest. | TB4.3, TB4.4, TB5.5 |
| High | N | RD4.2 Develop economic data/models to determine what separations should be done in the field versus at later stage handling steps to economically maximize biomass quality and optimize cropping system sustainability. | TB4.5, TB4.6, TB5.5 |
| High | M | RD4.3 Develop biomass quality assurance and quality control specifications for engineering requirements to guide in-field equipment designs. | TB4.2 |
| Medium | N | RD4.4 Develop autonomous intelligent control systems for multicomponent selective harvest equipment. | TB4.3, TB4.4 |
| Low | M | RD4.5 Develop in-field technologies that add value to the biomass crop and further improve system sustainability and economics. | TB4.1 |
| **RD5 Single-Pass Harvesting and Collection** | | | |
| Top | N | RD5.1 Develop biomass harvest and collection technology that simultaneously harvests the biomass with the grain in a single pass to minimize soil compaction, make biomass harvest compatible with no or minimum till agronomic practices, and minimize costs. | TB4.5, TB5.1, TB5.2, TB5.3, TB5.6, TB6.1 |
| High | M | RD5.2 Integrate biomass harvesting and collection equipment and methods with the entire farming operation to ensure economic sustainability. | TB4.5, TB5.4, TB6.4 |
| **RD6 Bulk Harvesting and Collection Systems** | | | |
| Top | N | RD6.1 Develop crop residue biomass bulk handling and feedstock infrastructure system, collection methods, equipment, and transport and operational scenarios that reduce equipment and operational costs by 50%. These systems should minimize dirt and rock contamination without negative impact on grain harvest or soil compaction. | TB4.1, TB5.2, TB5.3, TB6.1, TB6.2, TB6.3, TB6.4 |
| Medium | N | RD6.2 Develop bulk handling and collection technologies for the range of biomass variability that optimize the use of locally available transportation infrastructure. | TB4.3, TB6.1 |
| Low | M | RD6.3 Investigate innovative equipment designs such as vacuum pickup and biomass compaction following the combine or doing away with the combine entirely. | TB6.1 |

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Term of Impact = N: Near-term (within 3 years) M: Mid-term (within 10 years) L: Long-term (>10 years)

## *3.5 Research and Development Priorities*

Although all the R&D needs presented in Table 3.3 are important in achieving performance goals, three major needs have emerged as high priority for harvesting and collection (Table 3.4). Focusing resources and efforts in these areas will provide the most benefit toward achieving the performance targets set for this area. These three needs are:

- Develop the biomass mechanical fractionation and separation techniques necessary for development of a harvester capable of biomass selective harvest
- Develop biomass harvest and collection technology that simultaneously harvests the biomass with the grain in a single pass to minimize soil compaction to make biomass harvest compatible with no or minimum till agronomic practices, and to minimize costs
- Develop a feedstock infrastructure system capable of handling the biomass in a bulk mode with a goal of reducing equipment and operations costs by 50%, compared with conventional baling systems. This system should minimize dirt and rock contamination and have no negative impact on grain harvest or soil compaction.

**Table 3.4. Harvesting and collection R&D priorities.**

| | |
|---|---|
| R&D Priority – RD4.1 | Develop the biomass mechanical fractionation and separation techniques necessary for development of a harvester capable of biomass selective harvest. |
| **Key Technical Elements** | **TE6** Develop and evaluate biomass mechanical fractionation techniques.<br>**TE7** Develop and evaluate air stream separation of the different components of the biomass.<br>**TE8** Engineer mechanical fractionation and air stream separation for implementation on a harvester.<br>**TE9** Design, build, and evaluate prototype selective biomass harvesters. |
| Technical Barriers Addressed | TB4.1, TB4.2, TB4.3, TB4.4, TB5.5 |
| Performance Targets Addressed | PT5.1, PT5.3, PT6.2, PT6.5, PT6.6, PT6.7 |
| Risk | High – The risk is high because of the complexity of the several new techniques that must be developed. |
| Benefit to Strategic Goals | • Necessary for long-term sustainability.<br>• Increase amounts of biomass available in a sustainable manner.<br>• Increased yields.<br>• Higher-quality feedstocks. |
| Term of Impact | Mid-term |
| Stakeholder Needs Addressed | SN4.1, SN4.2, SN4.4, SN4.6, SN4.12, SN7.1, SN7.2, SN7.6, SN7.7, SN12.7, SN15.2, SN18.3 |

| | |
|---|---|
| R&D Priority – RD5.1 | Develop biomass harvest and collection technology that simultaneously harvests the biomass with the grain in a single pass to minimize soil compaction to make biomass harvest compatible with no or minimum till agronomic practices, and to minimize costs. |
| **Key Technical Elements** | **TE10** Develop single-pass concepts and perform conceptual evaluation.<br>**TE11** Define selective and bulk harvest interface requirements for single-pass harvest.<br>**TE12** Engineer, build, test, and optimize prototypes and document performance. |

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| | |
|---|---|
| Technical Barriers Addressed | TB4.5, TB5.1, TB5.2, TB5.3, TB5.6, TB6.1 |
| Performance Targets Addressed | PT4.1, PT4.2, PT5.1, PT5.2, PT5.3, PT6.1, PT6.3, PT6.4, PT7.2 |
| Risk | Medium to High – Many individual technologies for single-pass harvesting are available today, however, as more unit operations are combined into a single machine/operation, the complexity and cost of machinery dramatically increases. |
| Benefit to Strategic Goals | • Decreased cost of biomass harvest.<br>• Decreased soil compaction making biomass harvest compatible with no or minimum till agronomic practices.<br>• Decreased energy and labor demand. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN1.9, SN1.12, SN2.3, SN4.2, SN4.3, SN4.6, SN4.9, SN9.1, SN9.2, SN9.3, SN9.6, SN11.1, SN11.7, SN11.11, SN15.1, SN18.3 |

| | |
|---|---|
| R&D Priority – RD6.1 | Develop a feedstock infrastructure system capable of handling the biomass in a bulk mode with a goal of reducing equipment and operational costs by 50%, compared with conventional baling systems. This system should minimize dirt and rock contamination and have no negative impact on grain harvest or soil compaction. |
| **Key Technical Elements** | **TE13** Evaluate bulk collection systems as an alternative to baling.<br>**TE14** Perform baseline analysis of existing crop residue biomass harvesting equipment and document inadequacies.<br>**TE15** Define interfaces for feedstock feed requirements for both sugars and syngas conversion platforms.<br>**TE16** Perform chopping, shredding, and grinding studies to determine optimum grind size.<br>**TE17** Research densification, transportation, and storage issues and interfaces. |
| Technical Barriers Addressed | TB4.1, TB5.2, TB5.3, TB6.1, TB6.2, TB6.3, TB6.4 |
| Performance Targets Addressed | PT4.1, PT4.2, PT5.1, PT6.1, PT6.2, PT6.4, PT7.1, PT7.2 |
| Risk | Medium – Evaluating and defining the system has less risk, but the greatest risk is meeting the cost reduction goal. |
| Benefit to Strategic Goals | • Decreased harvesting and collection costs.<br>• Lower transportation costs by increasing the bulk density.<br>• Better long-term biomass storage.<br>• Better quality feedstock formatted as desired by processors.<br>• Increased safety at biorefinery site by reducing dust and fire hazards associated with grinding biomass on site. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN1.2, SN1.5, SN1.9, SN1.12, SN4.3, SN4.6, SN4.7, SN4.8, SN4.11, SN8.2, SN8.5, SN9.3, SN10.6, SN11.1, SN11.2, SN11.8, SN15.1 |

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# 4. Storage

# 4. Storage

Storage systems that are environmentally acceptable, safe, and provide the required supply of quality feedstock are critical components of a sustainable biomass conversion industry. These storage systems may store the feedstock in a wet or dry form depending on the feedstock material, environmental conditions, geography, and/or processing use. Equally critical is integrating storage systems with other elements of the feedstock supply chain. Storage costs increase feedstock costs. Processing methods and yields can be altered by compositional and other changes that occur in feedstock during storage. Storage and supply methods are linked, since supply methods must be able to deal with the feedstock as it emerges from storage to eliminate additional preprocessing steps.

Storage systems are needed that can mitigate and balance issues that arise from the competing need for a low-cost, high-density, high-yielding, perishable feedstock that is harvested only once annually and must be stored for as many as two years. Little infrastructure currently exists for nonbale storage systems. But to be capable of supplying a low-cost feedstock, biorefinery storage systems cannot require significant new infrastructure. Thus, developing cost-effective storage systems that consistently supply biorefinery feedstocks will require creative approaches and will not likely result in a single universal solution.

## 4.1 Current Technical Situation

The existing agricultural bale system, a dry bulk storage system, was developed to supply forage and bedding materials to small- and medium-scale livestock operations and has been adapted for corn stover with only limited success. A biorefinery must process as much as 1 million tons of lignocellulosic biomass annually. This storage volume is much greater than any bale system was designed for (see Figure 4.1). At this 1 million-ton scale, the economics of storing bales would likely be unfavorable. Other options need to be considered.

Presently, agricultural residues such as corn stover are typically windrowed and air-dried in the field to 15–35% moisture before baling. If this moisture level is not attained or the bales become wet from rain or humidity, biomass decomposes due to microbial activity of microbes naturally in the biomass. Heat generation from microbial activity can lead to a series of chemical reactions that could potentially cause fires and result in significant feedstock losses. Pelletizing or granulizing biomass and storing it in protected storage is an effective means of addressing these issues. The pellets are also less combustible because

**Figure 4.1. Current bale technology is not designed for the tremendous amount of feedstock required to annually supply biorefineries.**

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their density is higher and their surface area is reduced. Unfortunately, the current cost of pelletizing technologies is too high, as much as $15/dry ton. Systems and technologies exist for bulk handling ground feedstocks and can likely be used for dry bulk biomass with the appropriate formatting and handling systems.

The other storage system alternative is wet bulk storage. A potentially effective though untested strategy to minimize microbial degradation of crop residues in storage is eliminating oxygen from the storage system via ensiling. Ensiling is well developed for storing wet green forage in bunkers or sealed containers such as bags, wrapped bales, or silos. Wet green forage contains free sugars and assimilable nitrogen, which are necessary for this method to be effective. In contrast, senescent lignocellulose (not actively growing when harvested) contains few free sugars and little assimilable nitrogen. Ensiling has been used successfully to store sweet sorghum and sugar cane bagasse (which contain free sugars), sometimes with added molasses. Ensiling large, water-saturated bulk piles, if constructed and maintained at low cost, is a potential solution to the problem of feedstock stability in storage.

Feedstock source, availability, and geographical location will ultimately determine the best-suited storage system for a given biorefinery or market. It is likely that certain situations may warrant hybrid bulk storage systems that incorporate elements of both wet and dry bulk methods. Similarly, staged harvesting strategies where greener biomass is stored for shorter periods and dryer biomass is stored for longer periods may be favored in some circumstances. Finally, it is possible that a cost-effective biomass conversion economy may require that lignocellulosic feedstock be traded in bulk as a commodity (see Figure 4.2), in which case maintaining feedstock quality in storage would be necessary to define a lignocellulosic feedstock "grading" system to determine commodity end-use and market.

## *4.2 Performance Targets*

Table 4.1 presents the performance targets for storage. These targets define improvements needed in storage technologies for biorefinery feedstocks that will significantly impact attaining the strategic goals. These targets must be achieved without significantly increasing infrastructure requirements, feedstock quality, or economic competitiveness.

Biomass storage systems must be able to accommodate many different sources of feedstocks to support the national goal of 1 billion dry tons of feedstock annually by 2030. The new storage systems should be low capital, low labor, bulk systems that maintain and perhaps help to define the standards and

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specifications for trading and evaluating biomass. Blending feedstock to meet these specifications should be considered.

A significant fraction of feedstock costs arises from the expense of packaging biomass for transportation and storage. An unconventional storage system that reduces this cost may require bulk storage, different formatting, or packaging. As this requirement is linked with several other R&D areas, quantitatively

**Table 4.1. Storage performance targets.**

| | |
|---|---|
| PT8 Biomass Availability Profitability | PT8.1 Storage systems are flexible enough by 2010 to accommodate the myriad of different biomass sources needed.<br>PT8.2 Processor standards and specifications define a feedstock grading scale by 2020 that is used for valuation of feedstock stored in various ways. |
| PT9 Sustainability | PT9.1 Storage systems have no negative impact on water and air quality.<br>PT9.2 Safety standards for storage systems are developed by 2010 to minimize risk of worker injury.<br>PT9.3 By 2020, storage systems can be taken out of service temporarily or permanently without generating environmental problems. |
| PT10 Feedstock Infrastructure | T10.1 Develop cost-effective outside bulk storage of biomass for up to two years in arid and humid climates, meeting processor- or market-defined average composition and quality standards both when the biomass enters and when it emerges from storage.<br>PT10.2 Storage systems can maintain or improve feedstock quality as defined by processor standards and specifications by 2010.<br>PT10.3 Cost-effective field storage monitoring systems for fermentable carbohydrates and water content sufficiently accurate to track compositional losses are available by 2010 and are applicable to crop biomass entering storage, being stored, and emerging from storage.<br>PT10.4 Infrastructure and resources required for storage are minimized by 2020. |
| PT11 System Profitability | PT11.1 Storage systems add minimally to overall feedstock costs so that the overall economics are favorable for a wide range of end products by 2020.<br>PT11.2 Storage systems allow maximum flexibility in the use of the feedstock by 2030.<br>PT11.3 Storage systems cost-effectively improve the density of the feedstock by at least a factor of 2.5 times compared with bales.<br>PT11.4 Storage systems and compositional stability attained by 2020 allow feedstock valuation based on a common scale such as potential yields of fermentable sugars from the biomass. |

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determining the infrastructure requirements for wet and dry storage systems is critical. Finally, storage systems and practices must be developed that allow sustainable supply and operation for the most efficient and lowest cost biorefinery feedstocks.

## *4.3 Technical Barriers*

To develop storage systems that achieve the performance targets, solutions must be developed for several technical barriers, shown in Table 4.2. These have been grouped into three areas:

- Feedstock quality and monitoring
- Dry storage systems
- Wet storage systems.

The technical barriers presented within these technology areas generally address important crosscutting issues for both dry and wet storage. For example, feedstock composition and quality monitoring are important regardless of whether dry or wet storage is used, but the issues in developing and implementing such systems will not always be the same for dry versus wet storage systems. Similarly, basic barriers exist that crosscut both dry and wet storage, such as the effects of storage on biomass composition and the infrastructure required to implement such systems. Finally, some environmental and sustainability considerations will be similar for dry and wet storage systems while others will be different.

There is a lack of information on feedstock variations and its compositional and biological diversity, which limits the development of storage systems. In addition, the lack of real-time, passive, noninvasive, compositional measurement tools and sensors makes it difficult to define meaningful standards that can be used during selling, storing, and processing. This lack of processor standards and specifications for feedstocks leads to biomass use in niche markets only.

Dry bulk storage systems are closer to realization than wet systems, primarily because dry bulk handling and storage have been developed for a wide variety of feedstocks across many industries (i.e., grain, ore, and coal). But there are still a number of biomass-specific issues to be worked out (e.g., dry bulk storage systems are known to be expensive and possibly have unacceptable fire risk), as well as infrastructure requirements regarding feedstock location, format, and climate to consider. Wet storage, in contrast, is not developed as well as dry storage and will require additional R&D. Thus, there are a greater number of barriers to wet storage development. For both wet and dry systems, engineering analyses and information on storage requirements and yield losses as functions of feedstock-specific factors are critical to providing systems and defining infrastructure for stable storage. A lack of processor specifications on the allowable effects of feedstock preservation on processing makes it difficult to determine the type of storage systems to be used and limits the use of storage systems to reduce processor costs.

## *4.4 Research and Development Needs*

The barriers to developing cost-effective lignocellulosic biomass storage can be overcome through integrated research, engineering development, design, and demonstration activities. The R&D needed to achieve the performance targets for storage can be aligned with the same three areas:

- Feedstock quality and monitoring

**Table 4.2. Storage technical barriers.**

| | Performance Targets Addressed |
|---|---|
| **TB7 Feedstock Quality and Monitoring** | |
| TB7.1 Lack of information on physical, chemical, microbiological, and post-harvest physiological variations in feedstocks arising from differences in variety, geographical location, and harvest time. | PT8.1, PT10.1, PT10.2 |
| TB7.2 Lack of passive, noninvasive analytical tools and sensors for real-time compositional measurements for most lignocellulosic feedstocks. | PT8.2, PT10.1, PT10.2, PT10.3, PT11.4 |
| TB7.3 Lack of processor standards and specifications for feedstocks. | PT8.2, PT10.1, PT10.2, PT10.3, PT11.2, PT11.4 |
| TB7.4 Lack of specifications on the allowable effects of feedstock preservation on processing. | PT10.1, PT10.2, PT11.4 |
| **TB8 Dry Storage Systems** | |
| TB8.1 Lack of engineering analyses of unconventional dry storage methods, including centralized versus distributed systems. | PT8.1, PT10.1, PT10.4, PT11.3 |
| TB8.2 Lack of information on storage requirements, yield losses, and infrastructure for packaged and bulk year-round dry storage systems as a function of feedstock source, climate, and harvest time relative to the grain harvest. | PT8.1, PT10.1, PT10.2, PT10.4 |
| TB8.3 Lack of cost-effective densification technologies and knowledge regarding the effect of storage methods on feedstock density. | PT11.3 |
| TB8.4 Lack of information on dry bulk storage system emissions; potential pest, disease, and other risks; and their short and long-term effects on the environment as well as on the material in storage. | PT9.1, PT9.2, PT9.3 |
| TB8.5 Lack of infrastructure requirements for large-scale dry bulk storage and the associated impacts on worker safety. | PT9.2 |
| **TB9 Wet Storage Systems** | |
| TB9.1 Lack of engineering analyses of wet storage methods, year-round storage and supply of wet biomass, and centralized versus distributed wet storage systems. | PT8.1, PT10.1, PT10.4 |
| TB9.2 Lack of information on storage requirements and yield losses for wet storage, as a function of feedstock source, climate, and harvest time relative to the grain harvest. | PT8.1, PT10.1, PT10.2 |
| TB9.3 Lack of information on whether pretreatment in storage can or should be performed and its value to processors. | PT10.2, PT11.4 |
| TB9.4 Lack of information on the physical and chemical requirements of biomass and storage water requirements necessary for the engineering design of wet storage systems tailored to different feedstocks, climates, and biorefinery processes. | PT9.1, PT10.2, PT11.1 |
| TB9.5 Lack of information on potential wet storage system emissions, pest, disease, and other risks and their short- and long-term effects on the environment. | PT9.1, PT9.2, PT9.3 |
| TB9.6 Lack of infrastructure requirements for large-scale wet storage and the associated impacts on worker safety. | PT9.2 |

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- Dry storage systems
- Wet storage systems.

The R&D needs for these areas are presented in Table 4.3. Because dry storage systems are currently better developed than wet storage systems, the term of impact for dry storage systems is shorter term (near-term), while wet storage R&D needs generally will have mid-term impacts since more initial research is needed.

Lignocellulosic biomass is geographically distributed in areas with widely differing climates. Variations in biomass composition and other important

**Table 4.3. Storage R&D needs.**

| Priority | Term of Impact | R&D Need | Technical Barriers Addressed |
|---|---|---|---|
| **RD7 Feedstock Quality and Monitoring** | | | |
| Top | N | RD7.1 Develop valuation parameters for biorefinery feedstocks as a commodity, e.g., based on fermentable carbohydrates. | TB7.1, TB7.2, TB7.3 |
| High | M | RD7.2 Develop passive, noninvasive analytical tools and sensors for real-time compositional analysis of significant lignocellulosic feedstocks. | TB7.1, TB7.2 |
| High | N | RD7.3 Develop and standardize tests for the physical processing characteristics defining feedstock quality. | TB7.1, TB7.2 |
| Medium | M | RD7.4 Define the composition and quality of feedstock for specific processes or specified end uses (e.g., processing, soil sustainability, feed). | TB7.3, TB7.4 |
| **RD8 Dry Storage Systems** | | | |
| Top | N | RD8.1 Develop designs and equipment infrastructure for dry storage, and evaluate the variability of feedstock chemical, biological, and harvest-related parameters and their effect on yield losses in dry bulk storage systems. | TB7.1, TB7.2, TB7.4, TB8.1, TB8.2, TB8.3, TB8.4, TB8.5 |
| High | N | RD8.2 Investigate potential disease and pest problems in the dry bulk storage of feedstock material. | TB8.1, TB8.4 |
| **RD9 Wet Storage Systems** | | | |
| Top | M | RD9.1 Develop designs and equipment infrastructure for wet storage, and evaluate the variability of feedstock chemical, biological, and harvest-related parameters and their effect on yield losses in wet storage systems. | TB7.1, TB7.2, TB7.4, TB9.1, TB9.2, TB9.4, TB9.5 |
| High | M | RD9.2 Determine societal and environmental impacts and regulations regarding potential disease, pest, odor, and other emissions resulting from the transport and storage of wet feedstock. | TB7.1, TB9.1, TB9.2, TB9.3, TB9.4, TB9.5, TB9.6 |
| High | M | RD9.3 Evaluate methods for reducing water usage in wet storage, and the production and disposition of possible wastewater streams or emissions. | TB9.1, TB9.2, TB9.4, TB9.5 |
| Medium | M | RD9.4 Evaluate pretreatment and other value-add modifications to feedstock while stored in wet systems. | TB7.3, TB7.4, TB9.3 |

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Term of Impact = N: Near-term (within 3 years) M: Mid-term (within 10 years) L: Long-term (>10 years)

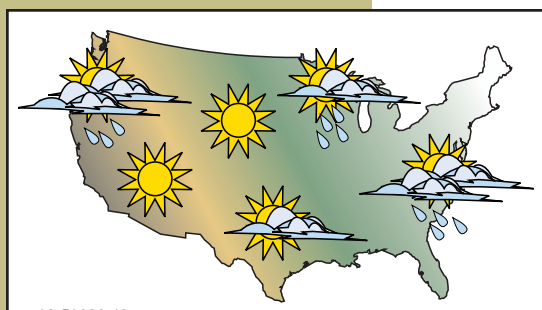


**Figure 4.3. Wet and dry storage requirements depend on regional climates.**

parameters are largely unknown, and current analytical tools are insufficient to cost-effectively determine variations in incoming feedstock in real-time, as well as feedstock in storage. Consistent feedstock valuation is impossible unless standards and specifications are developed for biorefinery feedstocks.

Both wet and dry storage system requirements and yield losses can vary with feedstock location and harvest time (see Figure 4.3). In addition, the infrastructure requirements for bulk storage methods are largely undefined for biomass, depending on the format. Since there may be different economies of scale associated with infrastructure and transportation costs depending on feedstock and location, storage scale and distribution will likely limit the feedstock supply area and the allowable biorefinery size. Without knowledge of these requirements, choice of storage systems and the overall economics of biomass use are hampered.

Little work has been done to determine potential emissions, runoff, groundwater contamination, dust, mold, odor, fire, explosion hazards, and other potential problems with wet and dry bulk storage systems. It is unknown how much water is required for wet storage systems or such a system's potential to impact the environment. Both minimal infrastructure and larger systems present greater potential for significant risks of worker injury. Finally, it is unknown whether potential pest/disease problems exist for either wet or dry storage methods.

## *4.5 Research and Development Priorities*

While all of the research needs play important roles in achieving the storage performance targets and contributing to overall targets and strategic goals, it is critical that the top six R&D priorities are initiated as quickly as possible. These priorities have large effects on attaining the performance targets in the necessary timeframe. In addition, beginning these activities as soon as possible aligns their completion with near-term needs in currently funded Office of the Biomass Program demonstration projects. The six top priorities are:

- Develop valuation parameters for biorefinery feedstocks as a commodity
- Develop passive, noninvasive analytical tools and sensors for real-time compositional analysis of significant lignocellulosic feedstocks
- Evaluate the variability of feedstock chemical, biological, and harvest-related parameters that affect the applicability of storage methods
- Evaluate feedstock yield losses in wet and dry storage systems in various climates
- Develop scalable, low-labor, and easy-to-use designs and equipment infrastructure for wet and dry storage
- Determine societal and environmental impacts and regulations on transporting and storing feedstock in various systems.

The key technical elements, technical barriers, performance targets, technical risks, timeframe for completion, benefits to strategic goals, and the necessary interfaces and partners for successful completion are presented for each priority in Table 4.4.

**Table 4.4 Storage R&D priorities.**

| | |
|---|---|
| R&D Priority – RD7.1 | Develop valuation parameters for biorefinery feedstocks as a commodity. |
| **Key Technical Elements** | **TE19** Develop method to predict the chemical and microbiological variability of corn stover and cereal straw entering storage as a function of feedstock, environment, harvest time, and harvest method.<br>**TE20** Work with manufacturers in the various biomass markets to define feedstock specifications that crosscut all the markets. |
| Technical Barriers Addressed | TB7.1, TB7.2, TB7.3 |
| Performance Targets Addressed | PT8.1, PT8.2, PT8.2, PT10.1, PT10.2, PT10.3, PT11.2, PT11.4 |
| Risk | High – Currently no infrastructure exists, and additional uses of the stored feedstock have not been identified. |
| Benefit to Strategic Goals | • Providing a basis for valuation and commodity trading of fresh and stored biomass contributes to availability and profitability.<br>• Standardization opens trading to new markets for stored biomass. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN3.4, SN3.7, SN3.8, SN3.9, SN3.10, SN3.12, SN3.17, SN5.2, SN10.3, SN18.4 |

| | |
|---|---|
| R&D Priority – RD8.1 | Develop designs and equipment infrastructures for dry storage, and evaluate the variability of feedstock chemical, biological, and harvest-related parameters and their effect on yield losses in dry bulk storage systems. |
| **Key Technical Elements** | **TE21** Determine feedstock moisture variability with crop, location, and time harvested.<br>**TE22** Determine additions (acids, water repellents) that extend the storage life of dry storage.<br>**TE23** Determine dry matter losses from dry storage piles due to chemical, physical, and microbiological factors.<br>**TE24** Assess the use of preservation using nontraditional techniques such as ionizing radiation and traditional/new preservatives to prevent spoilage.<br>**TE25** Test pilot-scale dry storage systems in varied locations and climates.<br>**TE26** Determine the required equipment, costs, benefits, and limitations of transportation of feedstock stored by dry bulk methods.<br>**TE27** Develop a computational process model to predict requirements for dry bulk storage based on feedstock, location, collection time after harvest, etc.<br>**TE28** Determine the preferred form for feedstock within dry bulk storage systems. |
| Technical Barriers Addressed | TB7.1, TB7.2, TB7.4, TB8.1, TB8.2, TB8.3, TB8.4, TB8.5 |
| Performance Targets Addressed | PT8.1, PT8.2, PT9.1, PT9.2, PT9.3, PT10.1, PT10.2, PT10.3, PT10.4, PT11.3, PT11.4 |
| Risk | Low—Methods and equipment are well developed and can be assessed in a reasonably short time. Design and infrastructure requirements are reasonably well understood. |

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| | |
|---|---|
| Benefit to Strategic Goals | • A comprehensive accounting of requirements for dry storage aids in more rapid assessment of infrastructure needs for design and implementation.<br>• Bulk handling of dry feedstocks eliminates the need for expensive packaging and makes more biomass potentially available due to this flexibility.<br>• Provides critically needed estimates of the allowable feedstock variation.<br>• Choices of stable storage system depending on climate and feedstock will allow more feedstock to be utilized.<br>• Provides information to balance trade-offs within storage and among the feedstock supply chain elements. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN5.1, SN5.2, SN5.6, SN5.7, SN5.8, SN5.10, SN5.14, SN8.6 |

| | |
|---|---|
| R&D Priority – RD9.1 | Develop designs and equipment infrastructure for wet storage, and evaluate the variability of feedstock chemical, biological, and harvest-related parameters and their effect on yield losses in wet storage systems. |
| **Key Technical Elements** | **TE29** Determine feedstock moisture and microbial load variability with crop, location, and time harvested.<br>**TE30** Assess feedstock microbial community structure and how it changes with time after harvest.<br>**TE31** Determine additions that must be made to allow stable wet storage.<br>**TE32** Determine dry matter and carbohydrate losses from wet storage systems due to chemical, physical, and microbiological factors.<br>**TE33** Determine the effects of chemical, physical, and biological changes during wet storage on feedstock processing.<br>**TE34** Determine the required equipment, costs, benefits, and limitations of transportation of feedstock stored by wet methods.<br>**TE35** Determine the preferred form for feedstock within wet storage systems. |
| Technical Barriers Addressed | TB7.1, TB7.2, TB7.4, TB9.1, TB9.2, TB9.4, TB9.5 |
| Performance Targets Addressed | PT8.1, PT8.1, PT8.2, PT9.1, PT9.2, PT9.3, PT10.1, PT10.2, PT10.2, PT10.3, PT10.4, PT11.1, PT11.4 |
| Risk | Medium – Biomass silage storage for livestock is well developed, but engineering studies that expand these systems to the scale and types of biomass needed for the biorefining industry are critical to success. |
| Benefit to Strategic Goals | • A comprehensive accounting of requirements for wet storage aids in more rapid assessment of infrastructure needs for design and implementation.<br>• Provides critically needed estimates of the allowable feedstock variation for wet storage.<br>• Choices of stable storage system depending on climate and feedstock will allow more feedstock to be utilized.<br>• Provides information to balance trade-offs within storage and among the feedstock supply chain elements. |
| Term of Impact | Mid-term |
| Stakeholder Needs Addressed | SN3.14, SN5.1, SN5.1, SN5.3, SN5.4, SN5.4, SN5.5, SN5.8, SN5.9, SN5.11, SN5.12, SN5.12, SN5.13, SN5.13, SN5.14, SN5.14, SN5.15, SN5.15, SN8.6 |

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# 5. Preprocessing

# 5. Preprocessing

Biomass, when harvested, is characterized by its low density; varying and often high moisture content; and varying size, shape, density, and chemical makeup of its differing parts. Preprocessing treatments are designed to improve biomass handling, transport, and storability (see Figure 5.1). Preprocessing can also add value by making biomass more fit for final conversion to fuels, power, and chemicals. Potential preprocessing treatments include:

- Cleaning
- Separating and sorting
- Mixing/blending
- Controlling moisture
- Physical state alteration
- Partially chemically or biochemically treating.

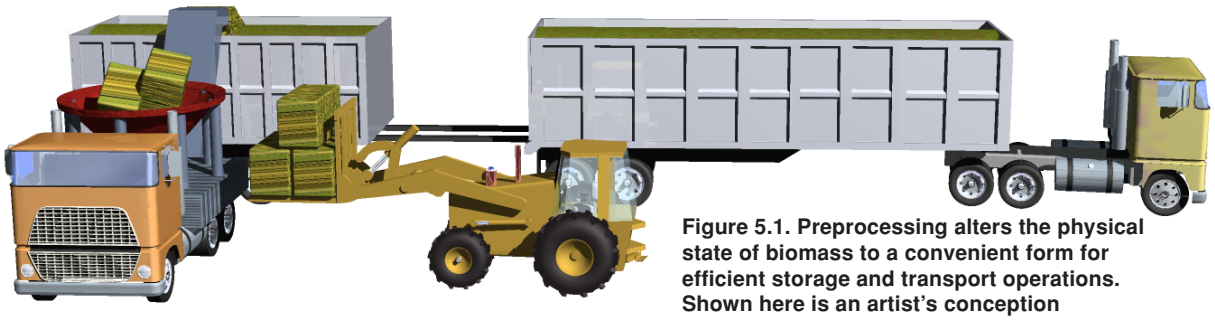

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**Figure 5.1. Preprocessing alters the physical state of biomass to a convenient form for efficient storage and transport operations. Shown here is an artist's conception of preprocessing.**

Cleaning is usually the first operation in postharvest operations. The objective is to remove dirt and other undesirable contaminants that have been mixed with biomass during harvest and subsequent handling operations.

Separating and sorting consists of operations that segregate components of plant material based on shape, size, or density. These operations commence during harvest when grain and straw are separated. Separation can also take place during later processes for producing a more uniform product.

Mixing or blending operations involve bringing two or more of the same or differing materials together for the purpose of preparing a mixture with improved biomass characteristics.

Controlling moisture, either in the field or at a central location, deals with changing the moisture content of the biomass. Drying operations may be used to reduce the moisture of biomass, or water may be added to increase moisture. In either method, the goal is to change the moisture content of the biomass to levels that are safe for long-term storage or final processing.

Physical state alteration is any operation that changes the physical state and/or reduces the volume of a given mass of biomass. This size reduction can increase the unit density of biomass, resulting in a smaller space required for storage and transportation. Plant material that is fibrous and leafy is difficult to handle in its

original form, making physical state alteration such as size reduction a desirable operation (see Figure 5.2).

Partial chemical or biochemical treatment at or near the source of biomass production could potentially reduce the overall cost of biomass conversion technologies.

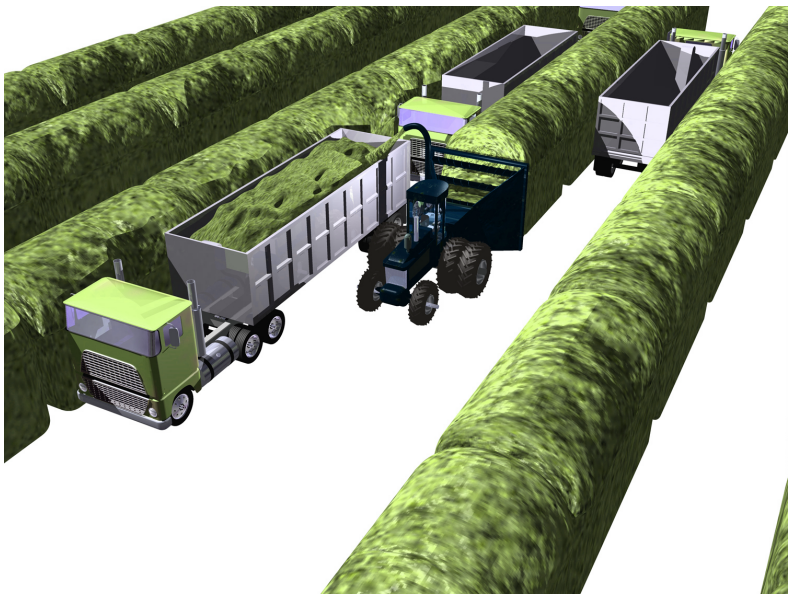

**Figure 5.2. One of several ways preprocessing can be accomplished.**

Preprocessing may consist of one or more of these treatments. For example, reducing size to increase density and ease of handling may be the only desirable operation for preparing the material as a feedstock for a biorefinery. Chopped, ground, and granulated biomass can have bulk properties and flowability characteristics similar to grains, flours, and slurried materials, thus allowing the use of more conventional equipment for handling, transporting, and storing biomass feedstocks. Additionally, feedstocks in these forms would give biorefineries the ability to mix and blend feedstock from a variety of sources to meet physical and chemical specifications for efficient and predictable conversions. Also, partial chemical and biochemical treatments on farms or at storage sites may be desirable to further improve processability of the biomass.

## *5.1 Current Technical Situation*

The critical moisture content for safely storing most low-moisture agricultural products is less than 15%. Typical moisture content of corn stover ranges from 35–50%, while corn is at about 25% moisture at harvest. Small grains and their straw are typically at 12–14% moisture at harvest. Untimely rain or snow during harvest seasons may raise moisture levels even higher. The moisture content of the crop residue biomass can be more greatly affected by climate than by crop type. Midwestern and Eastern regions of the U.S. must be capable of handling high-moisture biomass for both straw and stover. The dry climate of the western U.S. is conducive to dry, or low-moisture, biomass feedstock sources. Therefore, it is imperative to determine how the weather affects moisture content levels in various field conditions and how those levels affect various preprocessing treatments in the context of the overall feedstock system.

Several physical properties impact crop handling including stalk diameter, moisture content, resistance to shear and bending, toughness, elasticity, and compressibility. Biomass is categorized according to physical characteristics, specifically stalk diameter, dryness, and mechanical properties. Approximately 80% of the dry matter of mature plants consists of highly lignified cell wall material, which in turn affects the mechanical properties of the biomass. For example, corn stover has dry, thick, hard stalks with high shear and bending resistance, qualities that make it unsuitable for compacting in its untreated form.

Low bulk density, 4–6 lb/ft$^3$, is a fundamental characteristic of loose biomass in its raw form. Bulk density is increased to 8–10 lb/ft$^3$ when biomass is ground to 1/8 in. Bulk density can be increased to 20–30 lb/ft$^3$ by chopping and compacting biomass to form pellets. Dense biomass requires less area and volume to store and transport than loose biomass. Ground and/or pelletized biomass flows like cereal grains and can use the existing well-developed handling infrastructure for grains. Ground biomass can also be slurried for handling with conventional slurry pumping systems. Baling also increases bulk density to roughly 8–12 lb/ft$^3$. Baling and bale-handling systems are well-developed technology and may continue to be used for some feedstock applications. However, when considering very large-scale refining operations (i.e., 1 million tons or more), the loading and unloading systems and the cost of baling need to be improved substantially in order for these technologies to be economically viable.

## *5.2 Performance Targets*

Successfully commercializing the biorefinery concept demands a stable supply of high-quality biomass feedstock in large quantities at competitive prices. Most lignocellulosic feedstock is widely distributed in loose form and needs to be collected, packaged, shipped or stored, and transported to conversion facilities. Table 5.1 shows the performance targets for preprocessing technologies that deal with inherent challenges associated with biomass (i.e., low bulk density, high moisture content, and variability in quantity and quality).

Preprocessing increases the availability of biomass by making unusable biomass usable, which will help realize the target quantity of 1 billion tons annually. A well-developed understanding of the physical properties and variability of biomass will accelerate research and development in new equipment and processes while minimizing risks associated with innovations. The resulting biomass supply enterprise will be sustainable in terms of environmental footprint and economic viability. The technologies will treat and upgrade the biomass quality and quantity in terms of size, form, density, and storability.

## *5.3 Technical Barriers*

The following characteristics complicate the delivery of high-quality, low-cost biomass to a conversion plant:

- Low bulk density
- Spoilage and/or difficulty in handling due to improper moisture
- Variability in physical and chemical characteristics
- Geographical and seasonal variations in biomass
- Conflicting demands on labor and machines at harvest
- Combustibility
- Competition regarding soil fertility
- Local regulations on storage and transport
- Sensitivity to price structure for companion products and farm commodities.

**Table 5.1. Preprocessing performance targets.**

| | |
|---|---|
| PT12 Biomass Availability | PT12.1 Preprocessing treatments will upgrade low quality and diverse sources of biomass to a higher-value commodity like feedstock (i.e., uniform size, consistent composition, and predictable quality).<br>PT12.2 Innovative post-harvest preprocessing increases the total biomass availability at least 35%, by using effective storage systems for seasonal biomass sources and making formerly unusable biomass sources or components usable. |
| PT13 Sustainability | PT13.1 Preprocessing technologies inserted throughout the feedstock supply system improve energy and natural resource use efficiency by reducing biomass losses and the resulting waste streams, increasing transportation and handling efficiencies, and enabling the use of wasted biomass resources. |
| PT14 Feedstock Infrastructure | PT14.1 Preprocessing technologies produce a biomass resource with the bulk properties and flowability characteristics similar to grains, flours, and slurried materials such that it can be handled with traditional high-volume conveyance, pneumatics, and pumping material-handling systems.<br>PT14.2 Develop the data and understanding on the fundamental physical and material properties of biomass, which information will enable equipment manufacturers to invest in the development of new equipment and processes for biomass preprocessing systems. |
| PT15 System Profitability | PT15.1 Biomass preprocessing operations become local value-added enterprises that create manufacturing activities distributed throughout rural America.<br>PT15.2 Developing material properties engineering data on biomass that reduces risks associated with developing new equipment, accelerates new equipment development, and enables new equipment designs that reduce preprocessing operations (i.e., grinding, sorting, drying, and pelleting) cost by 50–60%. |

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To develop preprocessing systems that achieve the performance targets, solutions must be developed for several technical barriers, shown in Table 5.2, which are grouped into three areas:

- Biomass material properties
- Biomass physical state alteration (i.e., grinding, densification, and blending)
- Biomass bulk material handling.

These categories address uncertainties in biomass properties but also highlight several limitations within the existing infrastructure that could interfere with meeting the targeted biomass quantities. For example, the most optimal form for processed biomass depends on safety and storage considerations as well as on conversion requirements.

**Table 5.2. Preprocessing technical barriers.**

| | Performance Targets Addressed |
|---|---|
| **TB10 Biomass Material Properties** | |
| TB10.1 Lack of data on mechanical, thermal, and physical properties of biomass. | PT12.2, PT14.1, PT14.2, PT15.2 |
| TB10.2 Incomplete information on functional moisture relations on quality and physical properties for biomass as affected by crop variability and climatic conditions during harvest and postharvest operations. | PT12.1, PT12.2, PT14.1, PT14.2, PT15.2 |
| TB10.3 Lack of data on biomass quality and physical property characteristics for optimum conversion. | PT12.1, PT13.1, PT14.1, PT14.2, PT15.2 |
| TB10.4 Lack of methods and instruments for measuring physical and biomechanical properties of biomass. | PT14.2, PT15.2 |
| **TB11 Biomass Physical State Alteration (i.e., grinding, densification, and blending)** | |
| TB11.1 High levels of impurities foul downstream preprocessing and processing systems. | PT12.2, PT13.1, PT15.1 |
| TB11.2 Variability of biomass requires a wider range of equipment designs and capacities. | PT12.1, PT12.2, PT14.1, PT15.1, PT15.2 |
| TB11.3 Harvest season for most crop-based lignocellulosic biomass is short, especially in northern climates, thus requiring preprocessing systems that facilitate stable biomass storage as well as year-round feedstock delivery to the biorefinery. | PT12.2, PT13.1, PT15.1, PT15.2 |
| TB11.4 Existing biomass preprocessing infrastructure is tailored for higher value animal feeds. | PT12.2, PT13.1, PT15.1, PT15.1, PT15.2 |
| **TB12 Biomass Bulk Material Handling** | |
| TB12.1 High capital and operating costs for the existing package-based (i.e., bales, stacks, and pellets) equipment and facilities. | PT12.2, PT13.1, PT15.1, PT15.1, PT15.2 |
| TB12.2 Low density and fibrous nature of lignocellulosic biomass make the biomass handling and transportation expensive. | PT13.1, PT14.1, PT15.1, PT15.2 |

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## *5.4 Research and Development Needs*

Wide-ranging challenges facing biomass development require time and multi-institutional resources. Each of these research components has a significant effect on delivery of feedstock to biorefineries. For example, researching biomass material properties will lead to developing equipment for grinding, sorting, and cleaning. Table 5.3 prioritizes preprocessing research and development needs.

**Table 5.3. Preprocessing R&D needs.**

| Priority | Term of Impact | R&D Need | Technical Barriers Addressed |
|---|---|---|---|
| **RD10 Biomass Material Properties** | | | |
| Top | M | RD10.1 Develop understanding of physical properties of dry and wet biomass and the application of these properties to harvest, storage, and transport as well as to postharvest operations such as size reduction, sorting, drying, densification, blending, etc. | TB10.1, TB10.3, TB10.4 |
| High | M | RD10.2 Develop data and functional relations for moisture in biomass and the dependence of moisture on the surrounding environment (temperature, relative humidity, precipitation, etc.). Apply moisture relations to large-scale preprocessing and handling of biomass. | TB10.2, TB10.3, TB10.4 |
| **RD11 Biomass Physical State Alteration (i.e., grinding, densification, and blending)** | | | |
| Top | N | RD11.1 Develop in-the-field selection systems and post-harvest equipment to clean and sort wet and dry biomass and to reduce particle size, which will increase density and produce a clean, flowable bulk material. | TB10.1, TB10.2, TB11.1, TB11.2, TB11.3, TB11.4, TB12.1 |
| High | N | RD11.2 Develop physical state alteration systems, blending systems, and strategies for smoothing out feedstock variations arising from different sources of feedstock to meet feedstock quality specifications set by a biorefinery. | TB10.3, TB11.2 |
| Medium | N | RD11.3 Improve the existing low-cost packaging systems (i.e., compressed piles, bales, bundles, and stacks), and develop low capital and operating costs equipment for pelletizing biomass. | TB11.1, TB11.4 |
| Low | M | RD11.4 Develop moisture control using high-temperature drying that includes using biomass as a source of heat. | TB10.2, TB11.2 |
| Low | L | RD11.5 Develop distributed processing systems to convert biomass to intermediate chemicals immediately after collection, including on-combine preprocessing and first stage biorefinery pretreatments (i.e., processing plant on wheels). | TB10.1, TB11.3 |
| **RD12 Biomass Bulk Material Handling** | | | |
| Top | N | RD12.1 Investigate bulk handling (i.e., conveyance, pneumatic, and slurry pumping) of biomass prepossessed into a bulk flowable form, and assess the placement of single or multiple preprocessing systems in the feedstock supply chain (i.e., on-combine, pretransport, and prestorage) to maximize the benefits of preprocessing physical state changes for handling, transporting and storing. | TB10.1, TB10.2, TB11.3, TB12.1, TB12.2 |
| Low | L | RD12.2 Investigate the feasibility of a biomass slurry pipeline for handling and transferring biomass from the point of production to the refining facilities. | TB10.1, TB12.1, TB12.2 |

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Term of Impact = N: Near-term (within 3 years) M: Mid-term (within 10 years) L: Long-term (>10 years)

Preprocessing variable and moist biomass is expected to be a major challenge for safe and efficient harvest, storage, transport, and postharvest handling. The moisture content of stover could be 10 to 20% higher than the corn moisture content at the time of harvest. Unfortunately, the harvest time and crop conditions do not always provide suitable conditions for field drying. Finding ways to reduce the level of moisture content in biomass for dry storage methods and/or developing effective preprocessing treatments to facilitate wet storage methods is critical to the eventual success of the biorefinery industry.

Biomass generally comes from the fibrous part of the plant material and thus it is inherently lightweight and low in density. Transporting and storing it in its loose form is costly. Current densification methods, like grinding and pressing operations, are too costly and energy consuming. Thus, topics of important R&D are developing optimal physical state alteration technologies that will allow biomass to be efficiently handled, stored, transported, and ultimately converted to fuels and chemicals. Preprocessing technologies should also create from the wide diversity of biomass sources a delivered feedstock of consistent uniformity and physical form.

## *5.5 Research and Development Priorities*

While all preprocessing research needs play an important role in achieving biomass supply targets, three R&D priorities have the greatest potential to enable the industry to realize its vision:

- Develop understanding of physical engineering properties of biomass and their application to cleaning, densifying, and managing moisture
- Develop preprocessing technologies and equipment to clean and sort wet and dry biomass and to reduce particle size to increase density and produce a clean flowable bulk material
- Investigate bulk handling of biomass (i.e., conveyance, pneumatic, and slurry pumping).

The key technical elements, technical barriers, performance targets, technical risks, timeframe for completion, benefits to strategic goals, and the necessary interfaces and partners for successful completion are presented for each priority in Table 5.4.

**Table 5.4. Preprocessing R&D priorities.**

| | |
|---|---|
| R&D Priority – RD10.1 | Develop understanding of physical properties of dry and wet biomass and the application of these properties to harvest, storage, and transport as well as to postharvest operations such as size reduction, sorting, drying, densification, blending, etc. |
| **Key Technical Elements** | **TE36** Develop understanding of biomechanical (shear and normal stresses) and other physical properties of biomass.<br>**TE37** Develop controlled tests for time-temperature-moisture and quality relations for biomass during storage.<br>**TE38** Develop understanding of flow characteristics of whole, chopped, ground, and granulated (cubed and pelletized) biomass.<br>**TE39** Develop understanding of dielectric properties for biomass.<br>**TE40** Develop understanding of relations for moisture adsorption and desorption isotherms and thermal properties of biomass. |
| Technical Barriers Addressed | TB10.1, TB10.3, TB10.4 |
| Performance Targets Addressed | PT12.1, PT12.2, PT13.1, PT14.1, PT14.2, PT15.2 |
| Risk | Medium technical risk – Fundamental material properties research will have clear objectives, detailed research methodology, and rigorous scientific analysis, but biomechanics and flow characteristics are directly related to complex plant growth and development phenomena that require a significant research effort. |
| Benefit to Strategic Goals | • The data will assist in controlling and managing the existing equipment and processes to run more efficiently.<br>• The availability of data and models to manufacturers reduces development time and costs. |
| Term of Impact | Mid-term |
| Stakeholder Needs | SN3.1, SN3.5, SN3.7, SN6.9, SN10.3, SN10.5, SN10.7, SN10.9, SN17.5, SN18.4 |

| | |
|---|---|
| R&D Priority – RD11.1 | Develop in-the-field moisture control/selection systems and postharvest equipment to clean and sort wet and dry biomass and to reduce particle size that increases density, and produces a clean flowable bulk material. |
| **Key Technical Elements** | **TE41** Develop low-cost size reduction technologies for high- and low-moisture biomass.<br>**TE42** Develop separation and sorting equipment based on physical properties of biomass – mechanical, aerodynamic or optical properties, etc.<br>**TE43** Optimize power and energy used for the existing and new preprocessing equipment, including densification equipment.<br>**TE44** Develop pilot-scale equipment for chopping, grinding, slurry milling, separation, and other preprocessing steps, and field-test these equipment/systems. The system can be used to evaluate novel processes and biomass types and species. |
| Technical Barriers Addressed | TB10.1, TB10.2, TB11.1, TB11.2, TB11.3, TB11.4, TB12.1 |

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| | |
|---|---|
| Performance Targets Addressed | PT12.1, PT12.2, PT13.1, PT14.1, PT14.2, PT15.1, PT15.2 |
| Risk | High technical risk—As a fibrous material, biomass may not be as easily preprocessed as materials rich in starch and protein, and development of new or modification of existing equipment may require considerable capital investment. |
| Benefit to Strategic Goals | Grinding, sorting, and densification increase the density of biomass; improve the quality of biomass; and reduce storage, handling, and transportation costs. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN3.1, SN3.7, SN3.19, SN4.1, SN4.2, SN4.3, SN4.4, SN4.5, SN4.6, SN4.7, SN4.10, SN6.9, SN7.3, SN7.4, SN9.4, SN9.5, SN10.2, SN11.11 |

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| | |
|---|---|
| R&D Priority – RD12.1 | Investigate bulk handling (i.e., conveyance, pneumatic, and slurry pumping) of biomass preprocessed into a bulk flowable form, and assess the placement of single or multiple preprocessing systems in the feedstock supply chain (i.e., on-combine, pretransport, and prestorage) to maximize the benefits of preprocessing physical state changes for handling, transporting, and storing. |
| **Key Technical Elements** | **TE45** Investigate the feasibility of slurry pumping transport and its economic and environmental implications.<br>**TE46** Develop mechanical and pneumatic conveying systems for fluidized bulk biomass.<br>**TE47** Investigate multiphase flow (solid and fluid) phenomena for ground biomass.<br>**TE48** Develop an engineering economic analysis of compression methods for bulk biomass material in large bulk modules and their cost advantages over granulated biomass. |
| Technical Barriers Addressed | TB10.1, TB10.2, TB11.3, TB12.1, TB12.2 |
| Performance Targets Addressed | PT12.1, PT12.2, PT13.1, PT14.1, PT14.2, PT15.1, PT15.2 |
| Risk | Medium – Bulk-handling systems are well known and used today, and of lower risk. Integration of multiple preprocessing systems is of higher risk because of lack of experience in the system. |
| Benefit to Strategic Goals | Safe, easy, and low-cost handling and transport of biomass. |
| Term of Impact | Near-term |
| Stakeholder Needs Addressed | SN1.2, SN1.6, SN1.9, SN1.12, SN6.18, SN10.1, SN10.2, SN10.5, SN10.6, SN11.1, SN11.2 |

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# 6. Transportation

# 6. Transportation

Transportation is a key segment of the biomass feedstock supply system industry. It was discussed at each feedstock colloquy to the extent that 10% of the recorded stakeholder input deals directly with transportation issues. There was general agreement that current uses of transportation options for biomass are neither fully efficient nor effective. However, the solution to this issue does not include a separate grouping of R&D needs for developing a unique biomass transportation infrastructure. Instead, each of the previous section's R&D needs encompasses R&D for improving the use of existing transportation options.

The transportation infrastructure is a fixed constraining requirement for the biomass feedstock supply system. Biomass may be transported by truck on existing roads or by trains and barges on existing rail networks and waterways (see Figure 6.1). No matter the method, existing transportation technologies must be used. Developing new transportation technologies just for biomass is unfeasible due to the size and multiple-use nature of the existing infrastructure. In addition, current methods of transportation have set limitations such as weight and size of loads. Highway overpasses cannot be raised, railcars are already sized for multiple uses, and traffic control systems are already in place and must be accepted.

Although the transportation equipment, laws, and infrastructure are the least flexible segment of the feedstock supply system, many researchable transportation-related issues have been identified regarding developing, selecting, and integrating harvesting, storing, preprocessing, and other technologies. Each technology must employ and optimize transportation options

**Figure 6.1. The biomass feedstock supply system must use the existing transportation network and local transportation options.**

that are locally available. As such, research in production, harvesting and collection, storage, preprocessing, and systems integration includes performance targets, technical barriers, and R&D needs to achieve significant improvements in the use of existing transportation infrastructure for biomass.

# 7. System Integration

# 7. System Integration

The most critical component of a successful biorefinery is a secure and reliable feedstock supply. Ample feedstock should be available to biorefineries at the appropriate time and at competitive prices without safety, environmental, or regulatory setbacks. System integration across the whole of the feedstock supply system, from the producer, through the harvesting and collection, to storage, preprocessing and transport, addresses the seasonal nature of biomass production and the complex interactions that must occur between producers, processors, transporters, and the local community. The producer expects to make a consistent profit; the feedstock processor expects adequate and secure supply, low-cost, and uniform quality; and the community as a whole expects the benefits of an environmentally friendly, domestically produced fuel supply (see Figure 7.1).

Developing a consistent, economically viable feedstock supply system requires addressing and optimizing diverse harvesting, storage, preprocessing, and transportation scenarios. The logistics for biomass feedstocks involve geographically dispersed and varied material, time-dependent maturity and yield, a short time window for collection, and competitive demands on resources. Feedstock supply system simulation models can be used as powerful cost-saving optimization and analytical tools to evaluate the techno-economic viability of several biomass supply options while factoring in variability. An optimized network of harvesting and collection, storage, preprocessing and transportation infrastructure is the key to the viability of the biorefinery. Adding supply scenarios into an integrated feedstock supply system model will lead to a higher level decision support platform that can provide critical information necessary for designing and operating biorefinery feedstock supply systems.

Because biomass quantities, prices, and transportation costs will vary with location, it is critically important to capture geographic specificity in resource information. Given the variability that exists in biomass supplies, a standardized approach for feedstock supply systems will not work for all biomass types, in all conditions, and in all regions of the country. Instead, biomass supply systems will need to be tailored and optimized for the site-specific set of conditions.

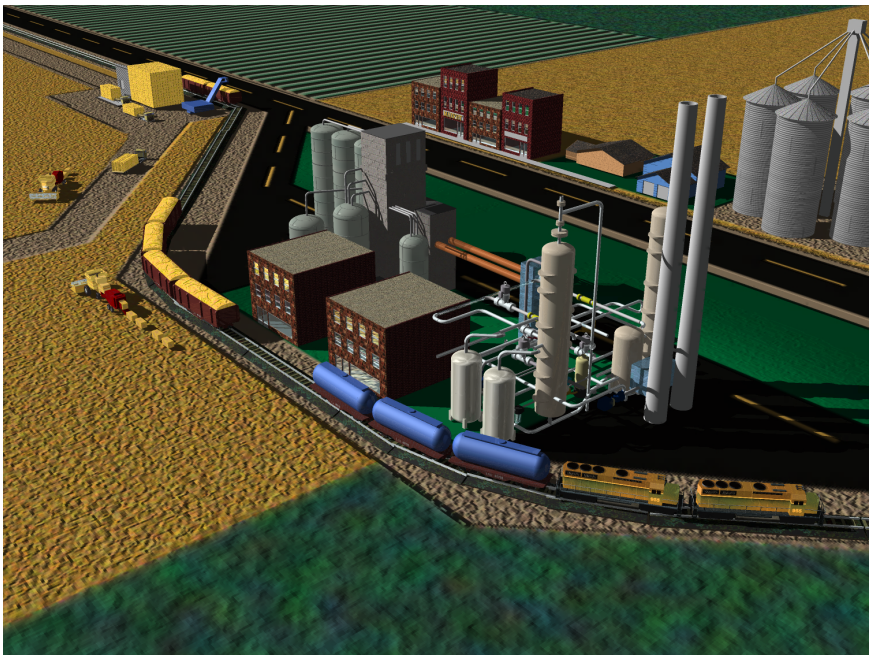

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**Figure 7.1. The producer, processor, and the community as a whole expect the benefits of an environmentally friendly, domestically produced fuel supply.**

System simulation models and market barrier analyses will provide very useful information and tools toward this end.

## *7.1 Current Technical Situation*

To meet the needs of the biorefinery, an integrated feedstock supply system must be developed. For some processes, such as biomass harvesting, new technology is most likely needed and will need to be developed near-term. For other processes, such as transportation, development of new technologies is not realistic in the time required; therefore, the feedstock supply systems must be built around existing transportation technologies and infrastructure. Other than a few integrated forest-related industries that benefit from a highly organized biomass supply chain, the low demand on other biomass sources has not warranted the development of robust, integrated biomass supply systems. System integration analyses and modeling tools will be highly valuable in integrating the various feedstock supply system process steps and in guiding the overall design of the integrated biorefinery feedstock supply system (see Figure 7.2).

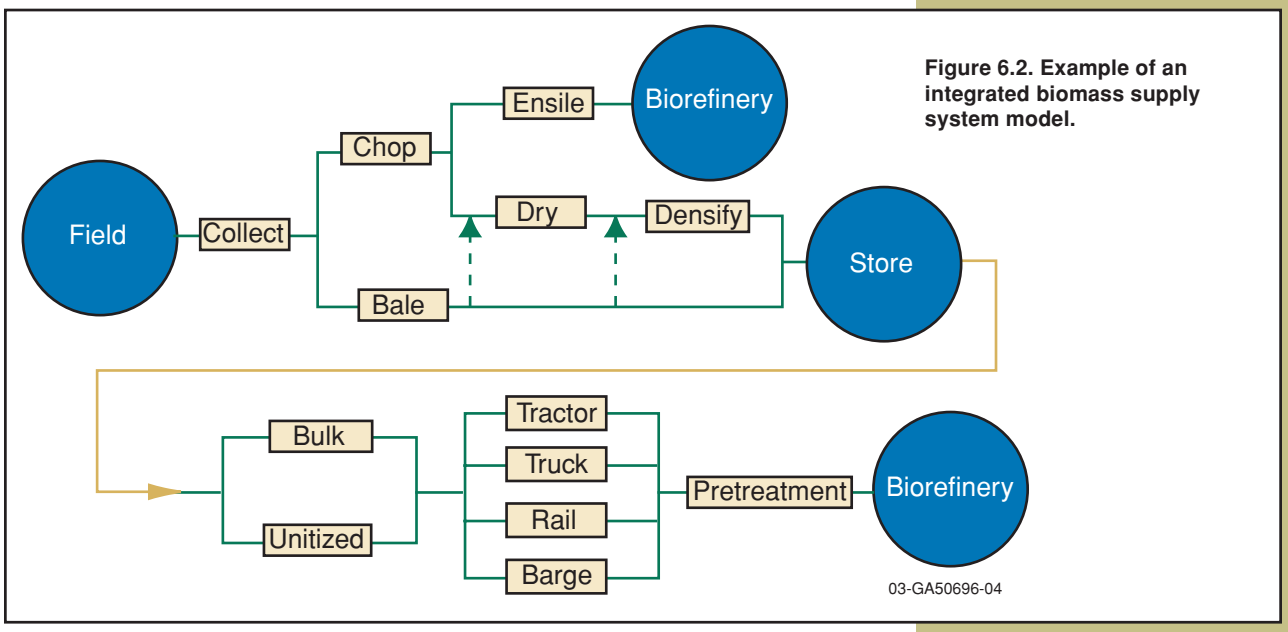


**Figure 6.2. Example of an integrated biomass supply system model.**

Figure 7.2 illustrates the envisioned flow of biomass from the field to a biorefinery. After harvesting and collection, the material is preprocessed to ease storage and transport. Several scenarios exist for the delivery of the preprocessed biomass to the biorefinery. In one scenario, wet biomass may be ensiled in large piles and shipped gradually to the conversion facility. In other scenarios biomass may be packaged, stored, and transported. The best possible scenario is dependent on factors such as climate, moisture content of biomass, and local factors.

An entire feedstock supply system model is needed to determine optimized scenarios dependent on these factors. This model will require performance data for various equipment and processes used in collecting, storing, and transporting biomass. Climate and biological data that describe the availability and characteristics (e.g., moisture content) of the biomass at any given time are also required. Finally, biomass quality requirements, processor demand schedules, transportation options as a function of location, and storage options will be needed for model input. Much of this information will be available to the model as the elements of this roadmap are implemented.

Additionally, to support policy planning and understanding of market development, a variety of national-level biomass supply analyses need to be developed. A few of these types of analyses have been performed, but policy makers and the public desire more information for making decisions that affect the feedstock supply system for the biorefinery.

## *7.2 Performance Targets*

Given the large economies of scale of biorefineries, a typical-sized biorefinery may require as many as 1 million tons/year of biomass supplied at a constant rate year-round. Delivering this volume of biomass requires knowing where and when the biomass is available and the optimal configuration of the feedstock supply system. Transportation is a critical interface element of the feedstock supply system and represents a significant fraction of feedstock costs. The model will need to track the biomass mix and available means of transport, such as water, rail, and pipeline, to meet the biorefinery feedstock transport needs at the lowest cost. Safety of persons and the environment are also paramount and need to be integrated into the analysis.

Table 7.1 shows performance targets for systems integration. Since the primary system integration activity is optimizing technical and economic

**Table 7.1. System integration performance targets.**

| | |
|---|---|
| PT16 Biomass Availability | PT16.1 Analysis tools are sufficiently developed to rigorously assess feedstock infrastructure by 2010 that would be needed to attain 150M tons/year of crop residues in a sustainable manner. |
| PT17 Sustainability | PT17.1 Complete, integrated life-cycle analysis has been performed by 2010 for biorefinery feedstock supply systems to supply 150M tons/year of crop residues.<br>PT17.2 Safety standards exist by 2010 for the handling of 150M tons of crop residues annually by various methods.<br>PT17.3 Feedstock infrastructure system has been optimized to obtain the maximum possible fossil fuel displacement by 2020. |
| PT18 Feedstock Infrastructure | PT18.1 Analysis tools and process models are developed sufficiently to rigorously assess and integrate options for feedstock harvest, collection, transportation, storage, and preprocessing of 150M tons/year of crop residues in a sustainable manner by 2010.<br>PT18.2 System models exist that can assess the cost and benefits of alternative means of bulk transportation such as rail, pipelines, etc., by 2010. |
| PT19 System Profitability | PT19.1 Detailed system and process models are available for predicting integrated system profitability by 2010.<br>PT19.2 Local, state, and national policies are developed and instituted that are supportive of biomass technology and market development by 2010. |

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outcomes through modeling and facilitating policy development, the targets will by necessity have to reflect the hoped-for outcomes of using these tools. The development of a validated robust system simulation model will support targets on biomass quantities, sustainability, feedstock infrastructure, and profitability of the system. Similarly, optimal feedstock supply and transportation networks will contribute greatly to the viability of an integrated feedstock supply system for the biorefinery.

## *7.3 Technical Barriers*

To develop adequate feedstock supply system integration, solutions to several technical barriers must be developed. These technical barriers can be divided into three general categories:

- Subsystem specifications
- Overall integration
- Market and policy.

Subsystem specification barriers refer to those barriers that hinder developing cost-effective and widely applicable harvest, collection, storage, preprocessing, and transportation subsystems. Overall integration refers to establishing integrated feedstock supply systems. Market and policy barriers include regulations and liabilities that affect the availability of biomass feedstocks. For example, competitive demands for land and biomass resources are considered a type of market barrier. Table 7.2 displays the barriers to feedstock supply systems integration categorized by the three categories listed above.

In spite of impressive progress in systems modeling tools, the challenge remains to apply these advanced modeling tools to specific cases. The necessary data and individual process models do not currently exist to create an integrated feedstock supply system model. Operational aspects of machinery in the field depend upon speeds and process efficiencies that vary widely from one field to the next and from one crop to another. The management of harvest operations depends largely on human management decisions, for which modeling may not be feasible. A time lapse exists between deploying new equipment in the field and the availability of operational and cost data. A credible systems analysis of supply logistics cannot be conducted unless reliable data are available.

Current transportation equipment is generally designed for high-density/high-value material, while biomass is usually neither. Biomass could be processed to make it denser or equipment could be modified to better suit biomass characteristics. In addition, the seasonal nature of biomass must be dealt with in terms of equipment use and availability. Rail systems or barging may be an attractive alternative because of larger load volume and weight capacities compared with trucks, however, there are institutional barriers, such as changing loaded rail cars from one rail company to another, and waterway availabiilty and access that must be addressed if rail or barges are to be a viable transportation option.

Some of the market barriers relate specifically to transportation issues. For truck transportation, weight and size limits vary by state and time of year. Some tractors are designed for higher speeds, but this may exceed state maximum allowed speed. The sugar cane, wood chip (for pulping), and beet industries store large quantities of biomass, but many areas where biomass will be produced and stored do not have experience storing such quantities. There are liability questions as well as potential health and safety issues with moving and

**Table 7.2. System integration technical barriers.**

| | Performance Targets Addressed |
|---|---|
| **TB13 Subsystem Specifications** | |
| TB13.1 Lack of data on relationships between machine performance and the variability of physical characteristics of biomass. | PT16.1 |
| TB13.2 Lack of analyses of existing transportation technologies and how they can be used in the near term to sustainably supply 150M tons of crop residues annually. | PT16.1, PT17.3 |
| TB13.3 Safety and environmental issues associated with transporting and handling huge quantities of biomass have not been addressed. | PT17.2 |
| **TB14 Overall Integration** | |
| TB14.1 Lack of data on variability of biomass resources and how this variability affects shelf life and processing yields. | PT16.1 |
| TB14.2 Sustainability analyses are suspect due to lacking and sometimes inconsistent data. | PT17.1 |
| TB14.3 Existing transportation infrastructures, regulations, and labor agreements limit transportation options and vary by region. | PT17.1 |
| TB14.4 Existing biomass collection, handling, and transport systems are not designed for the large-scale needs of the biorefinery. | PT17.1 |
| TB14.5 Feedstock infrastructure has not been defined for various locations, climates, feedstocks, storage methods, etc. | PT18.1, PT19.1 |
| **TB15 Market and Policy** | |
| TB15.1 Local, state, and federal regulations concerning weight and dimension of biomass loads constrain transportation options. | PT18.2 |
| TB15.2 The use of biomass for production of fuels and chemicals from lignocellulose has not been demonstrated to be cost effective at a significant scale. | PT17.3, PT19.2 |
| TB15.3 Lack of sufficient political awareness of the biorefinery concept hinders development and implementation of the needed incentives programs. | PT19.2 |
| TB15.4 Lack of support at the grass roots from the agricultural community because commercial viability of lignocellulosic biomass to bioenergy and bioproducts has not been demonstrated. | PT19.2 |

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storing large quantities. The lack of predictions on future competitive demands for biomass for forage, fiber, and multiple new bioproducts and between biofuels and biopower could have a paralyzing effect on the implementation of biomass projects. While no predictions will ever be precise, analyses can begin to provide information on market risks and facilitate the development of risk minimization strategies.

## 7.4 Research and Development Needs

The barriers to the development of the integrated feedstock supply can be overcome through integrated R&D activities. The R&D needed to achieve the performance targets for systems integration can be aligned with the barrier areas. Table 7.3 displays the R&D needs.

In order to meet the national goal of 150 million tons of crop residues/year by 2010, integrated feedstock supply systems will need to be developed to handle multiple sources of different types of biomass in multiple sets of conditions. Feedstock supply system simulation and modeling tools that can be used to guide the design of site-specific feedstock supply systems for individual biorefineries must be developed to account for this variability. Additionally,

**Table 7.3. System integration R&D needs.**

| Priority | Term of Impact | R&D Need | Technical Barriers Addressed |
|---|---|---|---|
| **RD13 Subsystem Specifications** | | | |
| Top | M | RD13.1 Comprehensive techno-economic, life-cycle analyses, and process models are needed on new and existing feedstock supply infrastructure subsystems including production, harvesting and collection, storage, transportation, and preprocessing interconnected with conversion pathway options. | TB13.1, TB13.2, TB13.3, TB14.1, TB14.2, TB14.3, TB14.4, TB14.5, TB15.1, TB15.2, TB15.3, TB15.4 |
| Medium | N | RD13.2 Assess the costs associated with the use of densification systems and how these systems affect processing. | TB15.1 |
| **RD14 Overall Integration** | | | |
| Top | M | RD14.1 Develop a feedstock supply system simulation tool that can be used to determine optimal feedstock supply system elements, including the tradeoffs between using multiple crops to extend biomass supply period vs. storage requirements, while accounting for interdependencies, existing transportation infrastructure, tradeoffs, and variability. | TB13.1, TB13.2, TB14.1, TB14.2, TB14.3, TB14.4, TB14.5 |
| High | N | RD14.2 Develop a framework for selecting and matching optimal transportation networks with various combinations of feedstock supply system elements. | TB15.1 |
| High | N | RD14.3 Assess the safety and standardization issues associated with the feedstock supply chain including transportation. | TB13.3 |
| **RD15 Market and Policy** | | | |
| Top | N | RD15.1 Identify market and policy barriers associated with establishing the feedstock supply system on both national and local scales. | TB14.2, TB14.5, TB15.1 |
| High | N | RD15.2 Work with producers, processors, and government to determine the framework and data necessary to support policy development. | TB15.3 |
| Medium | N | RD15.3 Identify sites with high potential for reasonably priced feedstock supplies due to feedstock availability, transport options, and supportive state and local policies; target these sites for demonstration projects. | TB15.3 |

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Term of Impact = N: Near-term (within 3 years) M: Mid-term (within 10 years) L: Long-term (>10 years)

analysis must be performed to identify the market, regulatory, land use, and other issues that must be considered when developing site-specific feedstock supply systems.

Feedstock supply simulation models will need to be developed to account for the interdependencies of the process steps and variability. The feedstock supply system will involve many highly interrelated process steps. The logistics and processes performed in one step will have significant implications in other steps. For instance, the cost driver to handle and transport the feedstock in bulk form will have major implications on harvesting, collecting, and storing. Additionally, the effects of biomass type, climate, moisture levels, transportation infrastructure and options, and regional variability issues must be accounted for. The model will need to make it possible to conduct sensitivity or risk analyses on how variations in input and resources affect the output in terms of labor, machine, cost, and energy requirements. Once it has been developed and validated, the feedstock supply simulation model will provide a powerful design and decision support tool to assist in designing and evaluating site-specific integrated feedstock supply systems.

Significant market and policy barriers on both national and local scales need to be overcome (i.e., regulatory, policy, economic, and labor rules; restrictions and competing desires for land use; and environmental, regional, and system specific issues that exist toward establishing the biorefinery industry). It is critically important that these barriers be identified early so that they can be addressed. Several types of analyses are required and must be linked to support identification of these barriers. These include life-cycle analyses, techno-economic analyses, and evaluations of competition for resources and land. The research and analyses should also be directed toward developing organizational structures for biomass acquisition and supply systems for enabling smaller producers to participate in a biomass supply enterprise.

## *7.5 Research and Development Priorities*

Developing feasible and sustainable feedstock supply systems for collecting biomass and transporting it to conversion facilities requires a thorough analysis of highly interrelated activities and numerous combinations of options. Individual process steps in the feedstock supply system can be modeled mathematically and used to develop a simulation tool. This provides a valuable tool for designing site-specific feedstock supply systems while minimizing costs. The optimization problem will be subject to constraints stemming from competing resources, competing uses of biomass, fire and safety regulations, weight limit rules, and many other obstacles.

The development of low-cost, high-volume feedstock supply systems for the biorefinery is critical. Inherent characteristics of high moisture content for most biomass, low bulk density, and seasonality of supply must be dealt with. An integrated simulation model of biomass supply systems is a complex undertaking with a moderate amount of technical risk. However, it will provide a management and decision-making tool for a biorefinery to allow optimal resource decisions for equipment and other capital, labor, and energy. Table 7.4 shows the R&D priorities.

**Table 7.4 . System integration R&D priorities.**

| | |
|---|---|
| R&D Priority – RD13.1 | Comprehensive techno-economic, life-cycle analyses, and process models are needed on new and existing feedstock supply infrastructure subsystems including production, harvesting and collection, storage, transportation, and preprocessing interconnected with conversion pathway options. |
| **Key Technical Elements** | **TE49** Assess transportation options for wet and dry feedstock of varying formats.<br>**TE50** Determine the required equipment, costs, benefits, and limitations of transportation of feedstock stored using wet and dry methods.<br>**TE51** Investigate mass and load dimensions of various transport equipment.<br>**TE52** Investigate relations between the biomass form (wet or dry chop, baled, pelleted) and transport equipment.<br>**TE53** Process modeling of each separate supply system subsystem, in tandem with design and development efforts. |
| Technical Barriers Addressed | TB13.1, TB13.2, TB13.3, TB14.1, TB14.2, TB14.3, TB14.4, TB14.5, TB15.1, TB15.2, TB15.3, TB15.4 |
| Performance Targets Addressed | PT16.1, PT17.1, PT17.2, PT17.3, PT18.1, PT18.2, PT19.1, PT19.2 |
| Risk | Low – All subsystems are defined, and modeling of similar integrated systems has been successful. |
| Benefit to Strategic Goals | • Provide optimized estimates of the requirements and costs of various permutations of system subsystems for use in techno-economic and life-cycle analyses.<br>• Provide decision-making tool for system linkages. |
| Term of Impact | Mid-term |
| Stakeholder Needs Addressed | SN1.2, SN1.3, SN1.5, SN1.10, SN5.4, SN5.9, SN6.3, SN6.4, SN6.5, SN6.11, SN6.14, SN7.4, SN8.2, SN8.3, SN8.5, SN8.6, SN8.7, SN8.10, SN8.11, SN8.12, SN8.14, SN10.1, SN11.4, SN11.9, SN11.12, SN13.2, SN13.8, SN14.1, SN18.5 |

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| | |
|---|---|
| R&D Priority – RD14.1 | Develop a feedstock supply system simulation tool that can be used to determine optimal feedstock supply system elements, including the tradeoffs between using multiple crops to extend biomass supply period vs. storage requirements, while accounting for interdependencies, existing transportation infrastructure, tradeoffs, and variability. |
| **Key Technical Elements** | **TE54** Access sustainability, storage, and biomass characterization data, including variability, to support analyses.<br>**TE55** Develop a biomass availability and characteristics database including maturity date, biomass yield, harvest duration, and traditional biomass use.<br>**TE56** Perform comprehensive techo-economic analysis and life cycle analysis of production and of individual supply system elements including both existing and new technology.<br>**TE57** Perform comprehensive integrated techo-economic analysis and life cycle analysis of the entire feedstock supply system, including transportation, accounting for system interdependencies and tradeoffs.<br>**TE58** Develop or identify a computational simulation model and use it, together with the techo-economic analysis and life cycle analysis analyses, to simulate the feedstock supply system. |

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| | |
|---|---|
| Technical Barriers Addressed | TB13.1, TB13.2, TB14.1, TB14.2, TB14.3, TB14.4, TB14.5 |
| Performance Targets Addressed | PT16.1, PT17.1, PT17.3, PT18.1, PT19.1 |
| Risk | Low to Medium – Modeling the complex tradeoffs among multiple feedstock supplies increases model complexity and risk that the models will be broadly applicable. |
| Benefit to Strategic Goals | • Increased confidence in the profitability of biobased enterprises.<br>• Allay producer and environmental advocacy groups' concerns on sustainability.<br>• Provide information for policy development support. |
| Term of Impact | Mid-term |
| Stakeholder Needs Addressed | SN2.12, SN6.1, SN6.2, SN6.3, SN6.4, SN6.5, SN6.6, SN6.8, SN6.9, SN6.11, SN6.12, SN6.13, SN6.14, SN6.16, SN6.17, SN7.4, SN8.1, SN8.2, SN8.5, SN8.6, SN8.11, SN10.1, SN10.2, SN11.4, SN14.3, SN15.3, SN18.5 |

| | |
|---|---|
| R&D Priority – RD15.1 | Identify market and policy barriers associated with establishment of the feedstock supply system on both national and local scales. |
| **Key Technical Elements** | **TE59** Evaluate competition for land and biomass resources by linking biomass resource models with agricultural demand models.<br>**TE60** Assess the regional differences of the economics associated with different geographical locations and growing conditions.<br>**TE61** Identify regulatory and liability issues with existing transportation options. Estimate and compare regional economic impacts and job creation for different feedstock supply systems.<br>**TE62** Investigate optimal enterprise structures (who does what) for feedstock supply systems. |
| Technical Barriers Addressed | TB14.2, TB14.5, TB15.1 |
| Performance Targets Addressed | PT17.1, PT18.1, PT18.2, PT19.1 |
| Risk | Low—The feedstock supply system, though widespread and geographically variable, will be very much a part of and similar to the current food, feed, and fiber agricultural production and supply system. |
| Benefit to Strategic Goals | • Obtain grass-roots and governmental support.<br>• Improve profitability. |
| Term of Impact | Near-term |
| Stakeholder Needs | SN6.3, SN8.1, SN8.3, SN13.1, SN13.2, SN13.4, SN13.6, SN13.8, SN14.1, SN14.4 |

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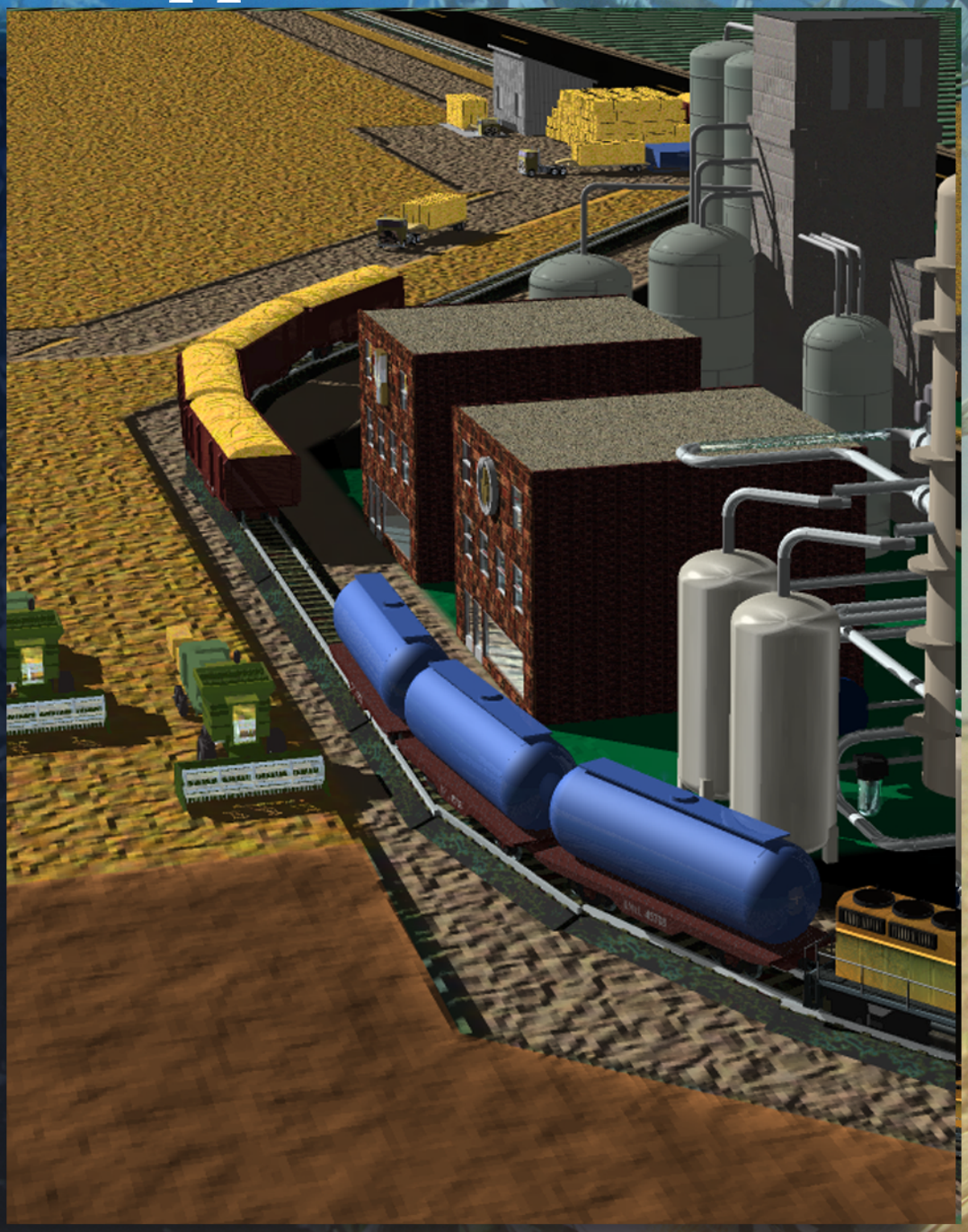
# 8. Appendixes



# *Appendix A – Grouped Colloquies R&D Need Statements*

Critical issues for supplying biomass feedstocks over the next three to ten years were discussed in seven colloquies held across the country between March and May of 2003. The purpose of these colloquies was to solicit information necessary to develop the feedstock roadmap.

Each colloquy included six to twelve participants, each a stakeholder in a position to influence the future of the industry. Participants generally had a broad knowledge of the issues, with in-depth expertise in one or more of the key areas. They represented the following segments:

- Corn and wheat growers
- Ag equipment manufacturers
- Potential biomass processors
- Environmental NGOs
- Farm group NGOs
- States/communities
- USDA/Univ/national labs
- Biomass processors.

Below is a comprehensive list of the research and technology development needs identified in these seven colloquies that were used to develop this roadmap.

| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| **SN1: General Economics** | |
| SN1.1: Need research into how the whole process will be funded. | RD1.1 |
| SN1.2: Questions about making the collection and transportation economical. | RD6.1, RD6.2, RD12.1,RD13.1, RD13.2 |
| SN1.3: Need research into the economics of hauling distances, storage facilities, and preprocessing. | RD6.2, RD13.1, RD13.2 |
| SN1.4: Questions about the high cost to the grower in time, equipment depreciation, capital costs to produce the feedstock, and there doesn't seem to be the incentive to the grower to cover these costs. | RD15.3 |
| SN1.5: Need research into the economics of the scale of operations needed to make this a viable operation. | RD1.1, RD6.1, RD13.1 |
| SN1.6: Questions about the cost of new equipment to the grower. | RD4.4, RD12.1 |
| SN1.7: Questions about utilization levels of the equipment and the reliability of the harvesting equipment. | RD4.4 |
| SN1.8: Need research into the value to the farmer of leaving the straw in the field or of removing the straw from the field. | RD2.1, RD2.2, RD2.3, RD2.4 |
| SN1.9: Questions about the cost to design and analyze the changes/impacts to harvesting equipment to meet different needs. | RD5.1, RD6.1, RD12.1 |
| SN1.10: Need research into the development of smaller processing plants with smaller capital costs including transportation and other infrastructure needs. | RD1.1, RD13.1 |
| SN1.11: Need research into the impact on the economics of the whole process when the large volume of material needed comes into play. | RD5.2, RD14.2 |
| SN1.12: Questions about the higher costs to handle the grain as a result of harvesting the stover (i.e., having to go and collect the grain from the separation site). | RD5.1, RD5.2, RD6.1, RD12.1 |
| SN1.13: Need research into the regional differences of the economics associated with different geographical locations and growing conditions. | RD1.1, RD2.4, RD13.2, RD14.2 |

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| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| **SN2: Sustainability** | |
| SN2.1: Need research into what are the long-term consequences of harvesting this material? | RD2.2, RD2.3, RD2.4 |
| SN2.2: Questions about the crop residue left after harvesting as a key component of sustainable farming in highly erodible areas. | RD2.2, RD2.4 |
| SN2.3: Need research into the impact of harvesting the feedstock on the sustainability of the field and how to reduce those impacts (e.g., one pass). | RD2.2, RD2.4, RD5.1 |
| SN2.4: Need research into the soil consequences of removing the by-product. | RD2.2, RD2.4 |
| SN2.5: Need research on what we should be leaving behind in the fields. (Research using modeling, virtual research, and field studies.) | RD2.2, RD2.4 |
| SN2.6: Can we capture value in the biomass that lies around after the grain harvest? | RD2.1, RD2.2, RD2.3, RD2.4 |
| SN2.7: Questions about what parts or amount of stover that needs to be left in the field to meet sustainability and economic needs. | RD2.2, RD2.4 |
| SN2.8: Need research into no-till and the impact no-till will have on sustainability and erosion protection (erosion control, soil conservation, carbon sequestration, environmental quality, etc.). | RD2.3, RD2.4 |
| SN2.9: Need research into the effect of residue removal in soil biota, soil moisture, temperature, and into crop yield effects. | RD2.2, RD2.4 |
| SN2.10: Need research into the geographic differences for sustainability that will impact intelligent harvesting machines' ability to deal with selective harvesting and other concepts. | RD4.2, RD4.4 |
| SN2.11: Need research to develop guidelines for residue removal rates. | RD2.2, RD2.4 |
| SN2.12: Questions about the amount of the surface area for the feedstock. | RD14.1, RD14.2 |
| SN2.13: Need research into the effects (above and below the ground) of no tilling and how this will impact biomass harvesting requirements. | RD2.2 |
| SN2.14: Need research into the benefit or detriment of the removal of straw/stover in relation to the farming practice. | RD2.2 |
| SN2.15: Need research into what part of the biomass we want to collect? Do we need to collect all of it? | RD2.2 |
| SN2.16: Questions about the need to replace the stover normally left in the field is a lot of work and expense that will impact the ability or desire of the grower to provide feedstock. | RD2.2 |
| SN2.17: Need research into the amount of biomass that can be taken off the field and what biomass needs to be left in the field. | RD2.2 |
| SN2.18: Need research into the geographic, topographic, and climatic differences in by-product removal and processing between locations. | RD2.2, RD2.4 |
| SN2.19: Need research into the benefits and conditions for no-till operations. | RD2.2 |
| SN2.20: Need research into the interaction of cover crops and the by-product removal with the research stratified on a regional or local basis. | RD3.1 |
| **SN3: Feedstock Composition and Quality** | |
| SN3.1: The simpler the feedstock form coming into the processor the better. | RD7.2, RD10.1, RD11.1 |
| SN3.2: Questions about the value of the cobs and other parts of the stover to other processors. | RD7.4 |
| SN3.3: The number and kinds of contaminants in the feedstock. | RD4.3, RD7.2, RD7.4, RD11.2 |
| SN3.4: Need research into the composition and quality of the feedstock needed for a specific process. | RD4.3, RD7.1, RD7.2, RD7.4, RD11.2 |
| SN3.5: Need research into the best form of delivering the corn stover. | RD4.3, RD7.2, RD7.4, RD10.1, RD14.3 |
| SN3.6: Need research into monitoring the quality and consistency of the feedstock (what to monitor and how to monitor it). | RD4.3, RD7.2, RD7.4 |
| SN3.7: Questions about the fineness of the feedstock coming out of the harvesting equipment. | RD4.3, RD7.1, RD7.2, RD7.3, RD7.4, RD10.1, RD11.1 |
| SN3.8: Compensation to the grower based on the composition of the feedstock. | RD7.1, RD7.2, RD7.3, RD7.4 |

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| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| SN3.9: Need research into the composition of the feedstock coming into the process and its effects on processing and storage. | RD4.3, RD7.1, RD7.2, RD7.4, RD11.2,RD11.4 |
| SN3.10: Need research into the optimal sugar contents of the feedstock material at different times. | RD7.1, RD7.2, RD7.4, RD11.2 |
| SN3.11: Need research into developing tests for straw quality. | RD7.2, RD7.3 |
| SN3.12: Questions about the moisture content of the material. | RD7.1, RD7.2, RD7.3, RD11.4 |
| SN3.13: Which of the individual stover components is important and of value to the processor or to other end-product processors? | RD11.2 |
| SN3.14: Need research into other enzymes that may be economically used at harvesting or storage. | RD3.2, RD9.1, RD9.4 |
| SN3.15: Concerned with the amount of water in the stover and the cost this adds to either the grower or the processor. | RD7.2, RD11.4 |
| SN3.16: Need research into the elimination or reduction of the lignin content of the feedstock. Low lignin content will be value-added to the processor. | RD4.5, RD11.5 |
| SN3.17: Need research into the marketability of cobs. | RD7.1 |
| SN3.18: Need research into the stover content of corn impacted by drought. | RD11.2 |
| SN3.19: Need research into the weight of the cob as part of the stover. | RD11.1, RD11.2 |
| **SN4: Harvesting Equipment** | |
| SN4.1: Questions about being able to alter the harvesting machine to differentiate between the different parts of the feedstock. | RD4.1, RD4.5, RD11.1 |
| SN4.2: Need research into selective harvest, multicomponent, intelligent machines that can take into account the sustainability needs of the field. | RD4.1, RD4.4, RD4.5, RD5.1, RD5.2, RD11.1 |
| SN4.3: Need research into the R&D of new or modified equipment to respond to the whole biomass feedstock system. | RD5.1, RD5.2, RD6.1, RD11.1 |
| SN4.4: Need research into modifying the combine to separate the material and leave the low-quality material in the field or material needed for precision-farming guidelines. | RD4.1, RD4.2, RD11.1 |
| SN4.5: Capability of the combine to automatically adjust to conditions without operator intervention. | RD4.4, RD11.1 |
| SN4.6: Questions about the need for specialized harvesting equipment. | RD4.1, RD4.4, RD5.1, RD6.1, RD11.1 |
| SN4.7: Need research into the use of alternative harvesting machines that go beyond the current technology. | RD4.2, RD4.4, RD4.5, RD6.1, RD6.3, RD11.1 |
| SN4.8: Questions about the size and configuration of the harvesting equipment for ease of use and impact on the field. | RD6.1 |
| SN4.9: Need research to address the one-pass approach and the equipment needs to make it economical to all. | RD5.1, RD5.2 |
| SN4.10: Need research into a combine that would chop material small enough, and deposit it, so it could then be picked up by a vacuum truck following along behind the harvester. | RD6.3, RD11.1 |
| SN4.11: Need research into improving the chaff capacity of the harvesting equipment. | RD6.1, RD6.2 |
| SN4.12: Need the ability to adjust the height of the stalk remaining. | RD4.1, RD4.2 |
| **SN5: Storage** | |
| SN5.1: Need research into the differences of dense bales vs. wet storage or other storage methods. | RD8.1, RD9.1, RD9.1, RD9.4 |
| SN5.2: Need research into the single-pass storage of the 1/8-inch particle in the field. | RD7.1, RD8.1 |
| SN5.3: Potential issue with the cost of a capital expense for wet storage of the stover. | RD9.1, RD9.4 |
| SN5.4: Need research into the cost, benefits, or limitations of hauling material stored using a water storage method. | RD9.1, RD9.1, RD13.1 |
| SN5.5: Need research into the effect of degradation of the straw on the processing of the straw at the processing plant. | RD8.2, RD9.1, RD9.4 |
| SN5.6: Need research into storage of the straw. | RD8.1, RD8.2 |
| SN5.7: Need research into ways to improve storage options. | RD8.1, RD11.2 |

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| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| SN5.8: Need research into how the feedstock will change over time as it is in storage. | RD7.3, RD8.1, RD9.1, RD9.4, RD11.2 |
| SN5.9: Need research into the equipment and economics of hauling and handling wet storage material. | RD9.1, RD12.2, RD13.1 |
| SN5.10: Need research into the material loss from piling the straw at central locations. | RD8.1, RD8.2 |
| SN5.11: Need research into the amount of water needed by a specific process or storage option. | RD7.3, RD9.1, RD9.3, RD9.4, RD11.4 |
| SN5.12: Need research into the acid content of wet storage material and the impact on the processing of that wet storage material into the final product. | RD7.3, RD9.1, RD9.1, RD9.4 |
| SN5.13: Need research into the smell produced by wet straw storage systems. | RD9.1, RD9.1, RD9.2 |
| SN5.14: Need research into potential disease problems in the storage of feedstock material. | RD7.3, RD8.1, RD8.2, RD9.1, RD9.1, RD9.2, RD11.2 |
| SN5.15: An issue with the water requirements of the wet storage and preprocessing needs. | RD9.1, RD9.1, RD9.2, RD9.3, RD9.4, RD11.4, RD12.2 |
| **SN6: Transportation** | |
| SN6.1: Need research into the transportation of 1/8-inch product and how it will react to transportation techniques and equipment. | RD14.1 |
| SN6.2: Need research into the existing network of co-ops, transportation, and the existence of feedstock to supply a processing plant. | RD6.2, RD14.1, RD14.2, RD15.3 |
| SN6.3: Questions about the size of the harvesting collection area per a transportation node. | RD13.1, RD13.2, RD14.1, RD14.2, RD15.1 |
| SN6.4: Questions about the distance of the haul from the collection point to the processing point. | RD13.1, RD14.1 |
| SN6.5: The volume of feedstock collected per a transportation node. | RD13.1, RD13.2, RD14.1, RD14.2 |
| SN6.6: Location of collection points to main rail lines versus use of a branch line. | RD14.1 |
| SN6.7: Use of standard rail cars versus the need for specialized rail cars. | RD14.2 |
| SN6.8: Need research into reducing the costs of packaging and transport of the straw. | RD6.2, RD14.1 |
| SN6.9: Questions about the form (dry, liquid, gas) of the material being transported. | RD10.1, RD10.2, RD11.1, RD12.2, RD14.1 |
| SN6.10: Standardization of the feedstock product moved by rail. | RD11.2 |
| SN6.11: Need research into how far dry material can be hauled to storage or preprocessing sites. | RD13.1, RD14.1 |
| SN6.12: Need research into the economics of truck hauling and what are the requirements to make the hauling efficient. | RD13.2, RD14.1, RD15.2 |
| SN6.13: Need research into the type of trucks and trailers (new purchase or conversion) that are needed and into the economics (cost) of the hauling. | RD14.1 |
| SN6.14: Questions about the number and location of preprocessing facilities in relation to transportation nodes. | RD13.1, RD14.1 |
| SN6.15: Questions about the availability of large rail cars that can accommodate stover. | RD14.2 |
| SN6.16: Need research into the economics of rail versus truck hauling (including equipment utilization levels and logistics). | RD14.1 |
| SN6.17: Need research into the liability of shipping of dry bales, either by truck or rail, and how to modify the shipping process to reduce the liability. | RD14.1 |
| SN6.18: Need research into an air-lock system to unload chopped straw. | RD12.1 |
| **SN7: Separations** | |
| SN7.1: Questions about what can be done in the field versus what can be done someplace else. | RD4.1, RD4.2 |

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| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| SN7.2: Need research into the different ways of separating the material in the field (one pass) or bringing all the material into the plant. | RD4.1, RD4.2 |
| SN7.4: Need research into pretreatment in a distributed system coupled with the storage and transport system. | RD11.1 |
| SN7.5: Questions about separating the grain out in a high quality that is not degraded by the feedstock harvest needs (treat the corn grain gently). | RD11.1, RD13.1, RD14.1 |
| N7.6: Questions about the number of separations that the harvesting equipment has to do or the number of times the feedstock has to be manipulated. | RD4.2 |
| SN7.7: Need research into harvesting the entire corn stalk and doing something different with the stalk and the grain. | RD4.1, RD4.2 |
| SN7.8: Questions about mechanical separation of the lignin in the field. | RD4.1, RD4.2 |
| **SN8: Whole Systems Analysis** | |
| SN8.1: Questions about a harvesting system to optimize the soil compaction, fuel costs, quality, time, and risk to the grower. | RD5.2, RD14.1, RD15.1, RD15.2 |
| SN8.2: Need research into how can the collection process be integrated with the whole biomass feedstock process. | RD4.2, RD6.1, RD13.1, RD14.1, RD15.2 |
| SN8.3: Need research into the whole system of the feedstock operation. | RD13.1, RD13.2, RD15.1 |
| SN8.4: Questions about the net energy loss of the entire process. | RD15.2 |
| SN8.5: Need research into optimizing the logistics of handling the product from the combine into the stack, and then into the processing plant. | RD4.2, RD6.1, RD13.1, RD13.2, RD14.1 |
| SN8.6: The processor doesn't want to store a whole year's worth of feedstock. Is interested in only a several days supply. Will need a steady stream of material. | RD8.1, RD9.1, RD11.2, RD13.1, RD14.1 |
| SN8.7: Need research into the interaction of biomass processing, sustainability, and economic components. | RD13.1 |
| SN8.8: Preprocessing has to be considered in the context of the entire life cycle (system view). | RD11.5 |
| SN8.9: Need research into the production and disposition of possible wastewater streams. | RD12.2 |
| SN8.10: Need research into the net energy profile of the process and the environmental impacts of the process (distributed versus large-scale processing plants). | RD13.1, RD15.2 |
| SN8.11: Need research into the sustainability profile of the final product and the practices used in the process chain. | RD13.1, RD14.1 |
| SN8.12: Need to understand the feedbacks in the cycle. | RD13.1, RD13.2, RD14.2, RD15.2 |
| SN8.13: Need research into the impact of an increase in the use of fossil fuel used in the process on the economics of the operations to the grower, hauler, and processor. | RD15.2 |
| SN8.14: Questions about putting a processing plant in a location and then draw a circle around the plant to determine how much biomass will need to be collected to make the plant viable. | RD13.1, RD14.2 |
| **SN9: One-Pass Harvest** | |
| SN9:1: Need research into the benefits of a one-pass harvest and what a one-pass harvest entails. | RD5.1 |
| SN9.2: Questions about one-pass harvesting taking the standing crop, grain and all. | RD4.2, RD5.1 |
| SN9.3: Need research into a single pass that eliminates contaminants (rocks and other things) during the harvesting operation so that the straw never touches the ground. | RD5.1, RD6.1 |
| SN9.4 Need research into other ways, other than one-pass, of removing dirt from stover. | RD6.3, RD11.1 |
| SN9.5: Need research into eliminating contaminants (e.g., soil) in the harvesting of by-products. | RD6.3, RD11.1 |
| SN9.6: Need research into the comparison of multiple passes with smaller equipment versus one pass with a larger machine. | RD5.1 |
| **SN10: Preprocessing** | |
| SN10.1: Questions about distance of the preprocessing plant from the harvesting field. | RD12.1, RD13.1, RD14.1, RD14.2 |
| SN10.2: Is there some interim processing that can be done to make the shipping more economical? | RD11.1, RD12.1, RD14.1 |

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| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| SN10.3: Need research into pretreatment to provide a more consistent product. | RD7.1, RD9.4, RD10.1, RD10.2, RD11.2 |
| SN10.4: Need research into how to economically unbale and rehydrate the feedstock. | RD11.3 |
| SN10.5: Need research into the cost of processing bales versus processing chopped material. | RD10.1, RD10.2, RD11.3, RD12.1 |
| SN10.6: Unbaled products are difficult to handle. This is one of the biggest problems that needs to be addressed. | RD6.1, RD12.1 |
| SN10.7: Need research into economically baling or cubing feedstock. | RD10.1, RD10.2 |
| SN10.8: Need research into adding water to cubes and the cost of doing this. | RD9.4, RD10.2 |
| SN10.9: Need research into pelletizing straw as opposed to chopping it. | RD10.1 |
| **SN11: Farming Operation** | |
| SN11.1: Need research into designing or developing a farming operation and equipment where residue capture is part of the whole integrated operation. | RD5.1, RD5.2, RD6.1, RD12.1 |
| SN11.2: Questions about the time the grower is in the field harvesting. | RD5.2, RD6.1, RD12.1 |
| SN11.3: Need research into the logistics of the by-product so that it does not interfere with the primary grain product. | RD5.2 |
| SN11.4: Questions about storing huge quantities of material. That puts a big load on the infrastructure. | RD13.1, RD14.1 |
| SN11.5: Potential issue with a conflict between no-till operations and the removal of the stover. | RD2.2, RD4.2, RD5.2 |
| SN11.6: Need research into any negative social or environmental impacts of a specific storage or processing method. | RD15.3 |
| SN11.7: Need research into how the feedstock operation will enhance the application of no-tillage operations. | RD5.1, RD5.2 |
| SN11.8: The window of opportunities for harvesting stover are getting smaller not larger. Because of the constraints on the quality of the stover, it may be difficult for the farmer to harvest when needed. | RD5.2, RD6.1 |
| SN11.9: Questions about the willingness of the grower to hire-out the harvesting activities to others. | RD5.2, RD13.1 |
| SN11.10: Need research into more and varied crop rotations. | RD2.4 |
| SN11.11: Need research into widening the harvesting window. | RD5.1, RD11.1 |
| SN11.12: Questions about harvesting when the forage is ready to harvest and the storage problem created by this limited window of opportunity. | RD13.1 |
| SN11.13: Need research into the timeliness of harvesting based on geographical differences. | RD5.2, RD14.2 |
| SN11.14: Issue with the nature or requirements of the cropping system used by the grower. | RD1.1, RD1.2, RD2.1, RD3.1 |
| **SN12: Miscellaneous** | |
| SN12.1: Need research into types of feedstock other than stover or straw. | RD2.4 |
| SN12.2: Need research into utilizing stuff that is already available and then look at the use of stover at a future time. | RD1.1 |
| SN12.3: Research needs to focus on straw in the near term and move to stover in the long term. | RD2.4 |
| SN12.4: Need research into enhancing the straw product through genetic enhancement. | RD3.1 |
| SN12.5: Need research into possible genetic engineering possibilities of the feedstock. | RD3.1, RD3.2, RD3.3 |
| SN12.6: Need research into the gasification of the lignin and possible uses for that material, including bioconversion. | RD6.3, RD11.5 |
| SN12.7: Continue research on separating the nodes and other material in the wheat harvester.<br>SN12.8: Need research into gasification bioconversion. | RD4.1 |

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# *Appendix B – Grouped Sustainability Workshop R&D Need Statements*

In 1999, the USDA Agricultural Research Service (ARS), and DOE, determined that understanding the sustainability of collecting corn stalks (stover) was relevant to both of their missions and jointly planned a project on the implications of removing corn stover from production fields. The project, "Implications of Using Corn Stalks as a Biofuel Source," added residue removal experiments to existing ARS corn production studies. It began in September 1999 and included literature reviews and field and laboratory studies designed to last through five growing seasons. By early 2003, a major review of the technical literature was complete, initial results were emerging from the research projects, and participants had begun to identify areas with remaining questions.

In 2000, DOE's National Renewable Energy Laboratory (NREL) began a life-cycle assessment of producing ethanol from stover using it as a vehicle fuel. One of the first steps in the assessment was soliciting stakeholder input on goals and scope for the study. This input was gathered in May 2000 at a workshop held at Iowa State University's Wallace Foundation Learning Center. At that time, a promise was made that the stakeholders would be invited to a follow-on meeting to review and discuss results of the project. By early 2003, a preliminary report on the life-cycle assessment was complete and ready for such a review.

In May 2003, ARS and DOE held a second workshop at the Wallace Foundation Learning Center. This workshop was designed to serve two purposes. The first purpose was to provide a forum, promised in 2000, for reviewing and discussing the NREL's life-cycle assessment of fuel ethanol from stover. The second was to solicit input from involved workshop participants on research and technology needs for the development of this roadmap predominantly for the production section and to identify important sustainability needs and concerns.

The following are the research and technology development needs identified in the May 2003 meeting.

| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| **SN13: Analysis/Assessment** | |
| SN13.1: Analyze effects of residue collection on erosion and identify production systems that would ensure erosion does not increase with residue collection. | RD15.1 |
| SN13.2: Develop a simple tool for estimating the economic and environmental sustainability of residue harvesting, incorporating relevant studies. | RD2.1, RD2.4, RD5.2, RD13.1, RD15.1 |
| SN13.3: Set forth a long-term national vision for the development of sustainable biomass resources that shows how residues fit with other potential biomass resources. | RD1.1, RD14.2, RD14.3, RD15.2, RD15.3 |
| SN13.4: Optimize crop production systems that include residue collection in terms of farm income over entire rotation. | RD2.4, RD5.2, RD15.1 |
| SN13.5: Analyze the potential impacts of new hybrid varieties with differing grain:residue ratios on the economics and sustainability of the crop production system and on the economics and sustainability of ethanol production. | RD1.1 |
| SN13.6: Develop an analysis system that integrates dynamic modeling and experimental work to enhance fundamental understanding of soil sustainability and sustainable biomass harvesting. | RD2.1, RD2.4, RD15.1, RD15.3 |
| SN13.7: Develop tools that better follow nutrients in the life cycle. | RD2.1 |

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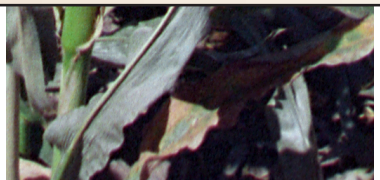

| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| SN13.8: Ensure all analysis systems are flexible enough to be applied to other residues, crops, and products. | RD1.2, RD2.4, RD13.1, RD14.2, RD14.3, RD15.1 |
| **SN14: Education/Information** | |
| SN14.1: Engage growers in planning communication efforts and decision tools to ensure the resulting products are relevant and useful. | RD5.2, RD13.1, RD15.1, RD15.3 |
| SN14.2: Review the reasons for conflicting information on energy balances for ethanol, including the estimates and assumptions behind the science. | RD15.2 |
| SN14.3: Use the web to disseminate information, including information on the energy balance of ethanol. | RD14.1 |
| SN14.4: Create information products tailored to specific stakeholder groups (growers, policymakers, environmental organizations, city dwellers, etc.). | RD15.1, RD15.2 |
| SN14.5: Develop accessible information for growers that synthesizes current understanding of the sustainability of harvesting residues. | RD1.2, RD2.1, RD2.2, RD15.2 |
| **SN15: Equipment** | |
| SN15.1: Design cost-effective harvest equipment that reduces the number of passes over field, separates plant components, and controls the types and amounts of residues left in the field. | RD5.1, RD6.1 |
| SN15.2: Develop the capability to control the return of plant components to the field. | RD4.1, RD4.2, RD4.5 |
| SN15.3: Incorporate results from environmental and economic analysis into design criteria for crop fractionation. | RD14.1 |
| **SN16: Production/Management** | |
| SN16.1: Understand the role that different components of the residue have on sustainability by crop and regions. | RD2.4 |
| SN16.2: Need to reevaluate "T" and develop criteria for acceptable soil loss rates. | RD2.4 |
| SN16.3: Need to develop data on long-term effects by maintaining, for 5 more yearrs, USDA residue removal studies. | RD2.1, RD2.2, RD2.3, RD2.4 |
| SN16.4: Need to develop management systems that optimize soil, air, water quality, and economic returns. | RD2.3 |
| SN16.5: Understand the potential for breeding crops to enhance residue production to optimize total system economics and sustainability. | RD3.2, RD3.3 |
| SN16.6: Need to understand genetic variability of plant components (roots, stem, grain, leaves, cobs, etc.) by quantity and chemistry. | RD3.3 |
| SN16.7: Need to track C in the production systems carbon may in future have direct value for sequestration in soil. | RD2.4, RD3.3 |
| SN16.8: Need to design systems that are neutral or positive to grain production. | RD3.3 |
| SN16.9: Need to link manure management into residue harvesting systems. | RD2.1, RD2.2, RD2.3, RD2.4, RD5.2 |

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# *Appendix C – Feedstock R&D Need Statements Identified in the Roadmap for Biomass Technologies in the United States*

http://www.bioproducts-bioenergy.gov/pdfs/FinalBiomassRoadmap.pdf

In December 2002, the Biomass Research and Development Technical Advisory Committee, which represents experts from wide-ranging backgrounds relevant to biomass resources, technologies, and markets, developed a roadmap for biomass technologies in the United States. This roadmap focused on three main areas: feedstock production, processing and conversion, and product uses and distribution. Following is the comprehensive list of feedstock research and technology needs identified by this group that was also used as input in developing this roadmap.

| Stakeholder Need Statement | Addressed by R&D Priority |
|---|---|
| **SN17: FACA-Biotechnology and Plant Physiology** | |
| SN17.1: Improve the technical understanding of plant biochemistry and enzymes and develop the ability to engineer enzymes within desired crops. | RD3.1, RD3.2 |
| SN17.2: Increased knowledge of the metabolic pathways that lead to lignins, proteins, and other plant components is needed. | RD3.1, RD3.2, RD3.3 |
| SN17.3: Research is needed to produce crops with desirable traits for both edible and industrial uses. | RD3.1, RD3.2, RD3.3 |
| SN17.4: Research is needed on the fundamental structure of lignocellulosic materials including the chemistry of its cell wall structures, transport properties, and genetic potential. | RD3.1, RD3.2, RD3.3 |
| SN17.5: Research should also include development and testing of cost-effective preconversion treatment processes to increase energy- and chemical-density of raw materials at the point of harvest. | RD10.1, RD11.2 |
| **SN18: FACA- Agronomic Practices** | |
| SN18.1: Research must evaluate methods to ensure the availability of land for producing the biomass feedstocks necessary to vision goals. | RD1.2, RD2.4 |
| SN18.2: This (agronomic practices to assure soil sustainability) includes research to ensure proper maintenance of soil nutrients and to identify methods to reduce or eliminate erosion. | RD2.1, RD2.2, RD2.3, RD2.4 |
| SN18.3: Improved processes for collecting materials that ensure soil sustainability should be identified and developed as part of best management practices for agricultural harvesting processes. | RD4.1, RD5.1 |
| SN18.4: Research efforts should lead to agricultural and forestry production methods that contribute to maximizing yields of biobased feedstocks that have desired characteristics. | RD7.1, RD7.2, RD7.3, RD7.4, RD10.1, RD10.2 |
| SN18.5: Analysis of the feedstock production stage of the biomass life cycle is needed to better understand and evaluate the economics of biomass resources as well as carbon cycles and other environmental costs and benefits. | RD1.1, RD2.1, RD13.1, RD14.1 |
| **SN19: FACA-General Feedstock Needs or Issues** | |
| SN19.1: Environmentally sound biomass resources are those for which life cycle assessments demonstrate their desirability. | RD1.1, RD2.1 |
| SN19.2: Scientific methods to produce and prepare plants and residues so that they meet specifications for end-use applications are needed. | RD3.1, RD3.2, RD3.3 |
| SN19.3: Agronomic practices must be improved to increase efficiency and reduce the cost of biomass feedstock production and delivery, and to ensure crop sustainability. | RD2.1, RD2.2, RD2.3, RD2.4 |
| SN19.4: Research into the agronomic, economic, and environmental impacts of harvesting lignocellulosic material must be established to ensure that these materials have beneficial life-cycle impacts. | RD1.1, RD1.2, RD2.1, RD2.3 |
| SN19.5: Improved methods for verifying the safety as well as the societal and environmental benefits of genetically engineered plants are needed. | RD3.1, RD3.2, RD3.3 |

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## A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as vital new "energy carrier's."

**Web Addresses**: www.osti.gov/bridge
http://energy.inel.gov/bioenergy/biomass_roadmap2003.pdf


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