Biomass Research and Development Board

# Sustainable and Adequate Biofuels Feedstock Production: Recommendations for Federal Research and Development

A Report by the Feedstock Production Interagency Working Group

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# Executive Summary

Rapid progress in bioenergy feedstock production depends on scientific and technical innovation. Sustainably capturing the potential of biomass resources for energy depends on successfully addressing major challenges such as increasing the yield, reliability, and sustainability of feedstock supply; improving land and resource use efficiency; reducing feedstock production costs; and continuing to deliver needed levels of goods, services, and values now and into the future, while minimizing impacts to the environment. This report provides input for the further development of an integrated feedstock research plan for the federal government.

Research needs and anticipated products for sustainable, substantial feedstock production are outlined across four major areas: feedstock improvement, production and management, conservation and ecosystem services, and decision-support tools. Recommendations are also provided regarding cooperation, technology transfer, and scientific and technical workforce capacity. Providing the science and technology to sustainably produce the needed supply will require a substantial, sustained national commitment by federal agencies, universities, nongovernmental organizations, industry, and many other public and private partners.

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# Foreword

## The Biomass Research and Development Board

The Biomass Research and Development (R&D) Board (Board) was originally created by Congress in the Biomass R&D Act of 2000 to "coordinate research and development activities relating to biobased industrial products (A) between the Department of Agriculture [(USDA)] and the Department of Energy [(DOE)]; (B) and with other departments and agencies of the Federal government." Pub. L. No. 106-224, 114 Stat. 431-32, repealed by section 9001(b) of the Food, Conservation and Energy Act of 2008, Pub. L. No. 110-246, 122 Stat. 2095 (enacted June 18, 2009, H.R. 6124) (section 9001(a) of the Act provided new authority for the Board). The Board is co-chaired by senior officials from DOE and USDA and currently consists of senior decision makers from DOE, USDA, the U.S. Department of Transportation (DOT), the U.S. Department of the Interior (DOI), the U.S. Department of Defense (DOD), the U.S. Environmental Protection Agency (EPA), the National Science Foundation (NSF), and the President's Office of Science and Technology Policy.

In October 2008 the Board released the National Biofuels Action Plan (NBAP). The NBAP outlines areas where interagency cooperation will help to evolve biobased fuel production technologies from promising ideas to competitive solutions. The Board used a five-part supply chain framework (feedstock production, feedstock logistics, conversion, distribution, and end use) to identify Board action areas and develop interagency teams to better coordinate activities. In addition, the Board identified two crosscutting action areas (Sustainability and Environment, Health, and Safety) into which all other working groups will provide future input.

As identified by the NBAP Board Action Area 2, feedstock production is a foundational element for a sustainable biofuel supply chain. Specifically, the NBAP emphasizes a suite of key research activities necessary to ensure sustainable production by:

- Minimizing environmental and economic implications of first generation feedstocks.
- Enhancing the use of second generation feedstocks, which consist of crop and forest residues, while enhancing water and air quality, and other ecosystem services.
- Developing dedicated bioenergy crops designed with specific bioenergy crop traits, such as increased yields, increased drought and stress tolerance, and increased resource use efficiency.

The Renewable Fuel Standard calls for a substantial and aggressive increase in the production of biofuels from cellulosic feedstocks. To meet a target of 36 billion gallons of biofuels, the Feedstock Production Interagency Working Group (FPIWG) prepared recommendations for a long-term, integrated feedstock research plan across the federal government to promote enhanced coordination and collaboration necessary to enable sustainable and adequate production of biofuel feedstocks at the request of the Board.

# 1. Introduction

## Opportunities and Challenges in Feedstock Production

The nation's farms, forests, rangelands and other working lands are strategic assets in enhancing U.S. energy security, environmental quality, economic opportunity, global competitiveness, and domestic and international food supplies. With appropriate feedstock production strategies, these lands could continue to provide a critical variety of economic, environmental, and social benefits in addition to being sustainable and substantial sources of cellulosic and other biomass feedstocks. Large-scale production and utilization of cellulosic feedstocks for biofuels, biopower, and bioproducts has the potential to provide many benefits including lowering greenhouse gas (GHG) emissions, reducing the nation's dependence on petroleum, promoting domestic economic growth, and maintaining the benefits of working lands in the landscape.

Capturing the potential of biomass resources for energy depends on successfully addressing major challenges such as increasing the yield, reliability, and sustainability of feedstock supply; improving land and resource use efficiency; reducing feedstock production costs; and continuing to deliver needed levels of goods (including food supplies), services, and values now and into the future while also maintaining air and water quality. The Renewable Fuel Standard demands an aggressive timeframe for scaling to production of 36 billion gallons of biofuels; this can only be achieved through a correspondingly aggressive scale-up in cellulosic feedstock production. Sustainably producing hundreds of millions of tons of high-quality feedstocks will require the development and widespread adoption of innovative new production and management strategies and systems that are adapted to local environmental conditions. In addition, these strategies and systems must meet the complex mix of objectives of land owners, producers, conversion facilities, rural communities, and the nation. Technology transfer is needed to ensure effective adoption and deployment of research outcomes. The research and development needed to enable a robust biofuel feedstock supply will most likely require coordinated efforts from federal agencies, universities, nongovernmental organizations, industry, and many other public and private partners.

## Purpose of this Report

The purpose of this report is to identify research and development needs and strategies to provide the knowledge, plant biomass materials, technologies, production and management systems, and decision-support tools needed to surmount the barriers to large-scale, sustained production of cellulosic and other biofuel feedstocks on farms, forests, rangelands, and other working lands.

## Approach in Developing the Report

The scope and complexity of the interdisciplinary research and development effort needed to provide the foundation for the large-scale, sustainable production of biofuel feedstock requires multi-agency cooperation to

identify national needs and a coordinated strategy to address these needs. This report was developed by an interagency working group assembled across federal departments and agencies whose missions cover the research, development, technology transfer, deployment, and regulatory activities associated with feedstock production. The Working Group integrated production, management, economic, environmental, and social considerations to develop an integrated view of the research and development needed to enable effective, sustainable production and management systems.

This report acknowledges that in order to develop sustainable production systems, the primary focus on establishing and growing plant feedstock must be weighed against the economic, environmental, and social considerations of producers and landowners. Designing and testing sustainable production and management systems and strategies require integrated, interdisciplinary research at farm, ranch, forest, conversion-facility footprint, community, landscape, and national levels.

A national sustainable feedstock production research strategy must be integrated and systems oriented as well as regionally appropriate to be most effective. This strategy is presented as four major interrelated themes: feedstock improvement, feedstock production and management, conservation, and decision-support tools. Sustainable feedstock production is an integral part of the biofuels supply chain and the research must be considered in that context. The research recommended here will need to be integrated with the work of the Feedstock Logistics, Conversion, and Sustainability Interagency Working Groups of the Biomass R&D Board to ensure integration of harvest and collection operations and feedstock characteristics with sustainable production and management systems and practices.

This report focuses on sustainable biofuels feedstocks production and management. The same science and technology is applicable to producing feedstocks for other bioproducts.

## Organization of the Report

The report has four major chapters outlining research needs and opportunities.

### Feedstock Improvement

Feedstock improvement research will result in new biofuels crops and varieties with increased yields and improved feedstock characteristics for the production of renewable energy. The scope of this research includes intensified and expanded genetic improvement programs for feedstock crops, discovery of value-added traits to enhance the yield of useable energy per acre, development of breeding tools and processes to facilitate the introduction of these traits into candidate biofuel crops, the evaluation of these crops under field conditions, and the analysis of the agricultural and environmental effects of the genetic changes.

### Production and Management

Production and management systems research will create sustainable, cost-effective, high-yield feedstock production practices for large-scale use of dedicated energy crops; enhance land productivity while meeting water quality, GHG reduction, and other environmental goals; and create management practices that integrate energy feedstock production into conventional management systems. Sustainable management systems and practices will integrate productivity, economic viability, conservation of the natural resource base and associated services. The resulting systems will incorporate synergies and

tradeoffs that result when resources are managed across multiple desired outcomes. Capturing the potential of biomass resources depends on successfully addressing major research challenges such as increasing the yield, reliability, and sustainability of feedstock supply; improving land and resource use efficiency; reducing feedstock production costs; and continuing to deliver needed levels of goods, services, and values now and into the future.

### Conservation and Ecosystem Services

In order to develop sustainable production systems, research is required to understand the impacts of these systems on soil and water quality, GHG reduction, and other environmental factors such as wildlife habitat. With this understanding, sustainable management systems and practices can integrate productivity, economic viability, natural resource conservation, and support for ecosystem services. Research must also address how resource requirements for biofuel production will affect the environment and human health at different temporal and spatial scales.

### Decision-Support Tools

Decision-support tools are needed to ensure that well-informed management and policy decisions are made, with consideration for the economic, environmental, and social impacts and drivers related to biofuels feedstock production (and other stages of the biofuels supply chain). The use of decision tools will help to facilitate the efficient emergence of new technologies and practices associated with the next generation biofuels feedstock industry to meet the Renewable Fuel Standard. Toward this end, critical information gaps that are impeding production decisions will be identified so that rapid and sustainable growth of the next-generation biofuels feedstock industry can occur. These information gaps primarily concern the nature of linkages between farm, ranch, and forestry tract level production and management decisions, assessments of environmental and sustainability impacts, and forecasts of social and economic consequences.

# 2. Feedstock Improvement

**GOAL: Provide new varieties, and alternative species with traits to improve the economic, environmental, and social sustainability of biofuel feedstocks.**

Feedstock improvement research will result in new biofuel crops and varieties with increased yields and improved feedstock characteristics for the production of renewable energy. The scope of this research includes:

- Intensified and expanded genetic improvement for feedstock crops.
- Discovery of value-added traits to enhance the yield of useable energy per acre or to maximize the yield in the system.
- Development of breeding tools and processes to facilitate the introduction of these traits into candidate biofuel crops.
- Evaluation of these crops under field conditions.
- Analysis of the agricultural and environmental effects of the genetic changes.

## The Feedstock Improvement Process

Feedstock genetic improvement can occur through four basic stages (Figure 1). The first stage in an improvement program is to choose appropriate species for a region. Appropriate choice of species will vary by climate, soils, and available infrastructure. In the evaluation of "new" species, sometimes a species can be found that has better yield and conversion characteristics than existing feedstocks. When such species are found, they are further tested in large-plots for yield, quality, and environmental impacts and then made available for broader use.

Most species considered for biofuel feedstocks have undergone some preliminary laboratory-scale characterization and evaluation with respect to yield and quality and are ready for the next stage. In this second stage of genetic improvement, the natural variation found within a species is examined for important feedstock traits (typically yield and feedstock quality traits). After the amount of genetic variation is determined, traditional breeding efforts can take place on pedigreed breeding populations (collections of families) of the plants.

For some species, genes or molecular markers linked to desired energy traits have been determined. This enables breeders to use marker-assisted selection to more efficiently select for traits, which shorten breeding intervals (stage 3). However, genetic improvement of biofuel feedstocks is a relatively new process, and knowledge of genes and molecular markers linked to many energy traits is lacking.

With the advent of genetic engineering (GE) it is possible to bring new traits into some species by transferring genes from different species or by making directed changes in the plant's native genes (stage 4). This technology enables new characteristics to be incorporated into a species that were previously not possible.

Regardless of how a new feedstock variety is developed, the plants must be evaluated for productivity and quality as well as other traits impacting economic, environmental, and social sustainability prior to wide-scale deployment.

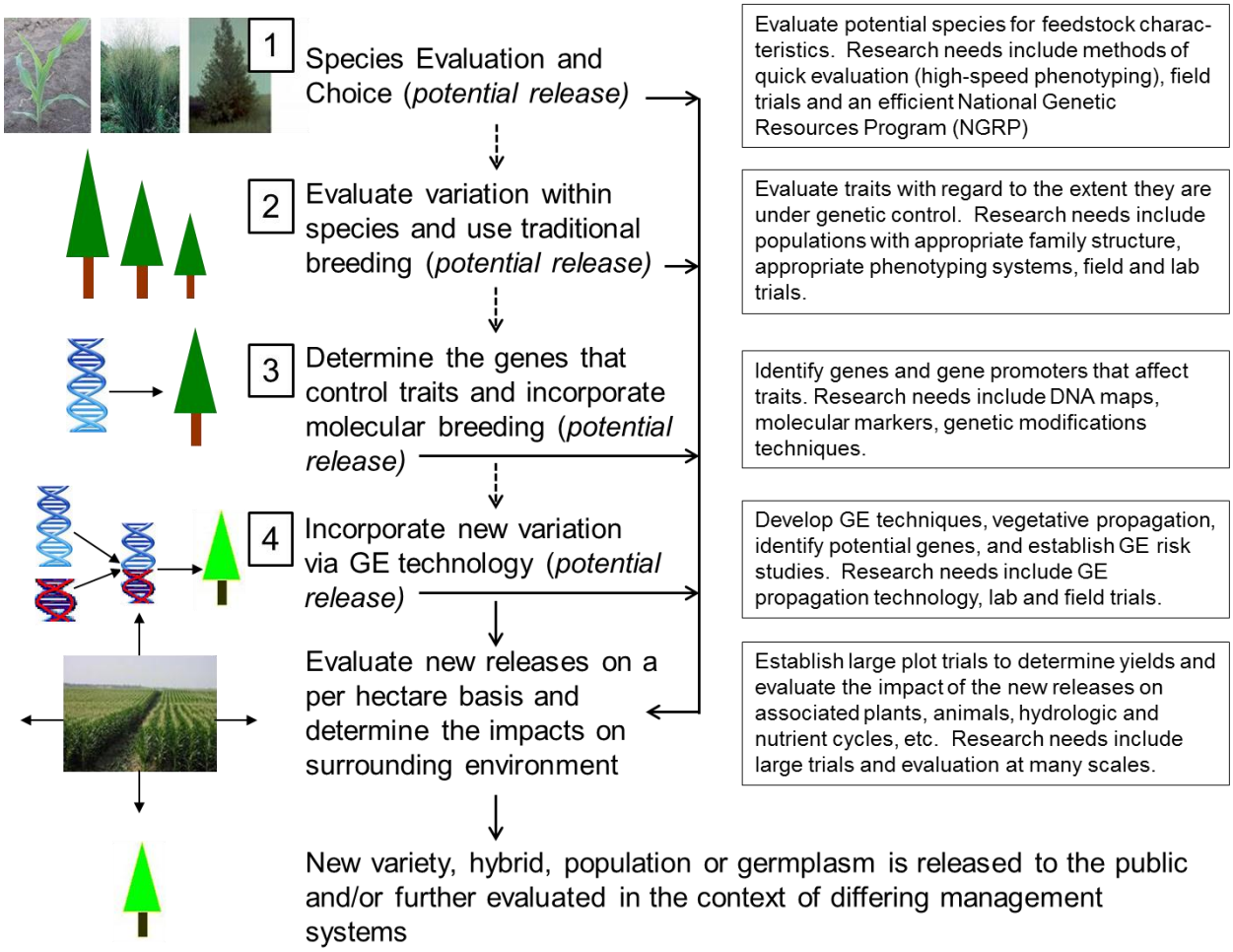


**Figure 1. Stages in the development, evaluation and release of improved biofuel feedstocks. Varieties can be produced at each step.**

## Research Needs

Research needs for developing improved biofuel feedstocks fall within three broad R&D Focus Areas. Specific research needs will vary by species, region, and desired end product.

### Research Focus Area 1—Development of biofuel crops with higher yield efficiencies

This research focus seeks to identify useful yield traits and introduce them into the best available biofuel crops through conventional breeding or biotechnology techniques. It includes traits that help lower the cost of production, improve crop yields, and reduce the level of chemicals required for the control of insects, diseases, and weeds. For biofuel crops, these traits include those that:

- Optimize root-to-shoot ratios to maximize harvestable biomass without compromising agronomic characteristics essential to plant persistence, productivity, and carbon sequestration.

- Protect the crop from environmental stresses such as heat, cold, drought, flooding, high salt concentration, and heavy metals.
- Protect the crop from pests and disease by providing genetic resistance to insects, viruses, bacteria, fungi, and tolerance to herbicides.
- Improve the efficient use of water, light, carbon dioxide, and nutrients. Improvements could be achieved through an increase in yield per unit of resource inputs, altering length of active plant growth, or developing crops for greater yields in mixed-species fields (e.g., intercropping or agroforestry).
- Extend the useful range of biofuel crops into new environments by altering or introducing genes that control plant response to day length and tolerance to both biotic and abiotic stressors, while minimizing risks associated with invasive behavior.
- Improve biological nitrogen fixation efficiency to optimize use of synthetic fertilizer.
- Discover and develop new candidate species with desired energy and environmental adaptation traits.

### Research Focus Area 2—Development of biofuel crops with improved quality characteristics for biofuels

This research focus seeks to identify useful quality characteristics and introduce them into candidate biofuel crops through conventional breeding or biotechnology techniques. Such traits enhance the quality of the product derived from the biofuel crop, which can have multiple uses. For example, in the case of biofuel crops used for cellulosic ethanol, a large benefit will be gained by modifying plants to improve the conversion of cellulose to sugars. Similar modifications could be made to optimize the conversion of cellulosic biomass to other advanced biofuels (e.g., biobutanol, gasoline, or aviation fuel). Also, modifications can be made that produce valuable co-products in addition to the biofuel. Scientists must understand the factors that impact feedstock quality so that improved energy traits can be incorporated into new germplasm and varieties. Research is needed to:

- Make the biofuel feedstocks more amenable to processing through a more complete understanding of plant cell wall synthesis, morphology, physiology, and composition to modify plant cell wall composition.
- Optimize the synthesis of valuable co-products, by investigating and applying knowledge of plant biological processes.
- Increase the yield and quality of non-cellulosic biofuel feedstocks such as plant or algal oils for green diesel/aviation fuel production by investigating and applying knowledge of plant biological processes.

### Research Focus Area 3—Development of improved woody and herbaceous feedstocks to specific production environments

This research focus seeks to evaluate the impacts of new biofuel varieties on economic, environmental, and social sustainability. Before breeders can release improved biofuel germplasm, they must understand how the new biofuel varieties will interact and impact field and forest dynamics. These factors must be understood in order to develop sustainable management systems for the wide-scale deployment of biofuel crops. Results from this research will not only provide information needed for management and regulatory considerations, but will allow breeders to develop new crops with improved environmental characteristics. Research is needed to understand how genetic improvements in yield and quality impact:

- Field-level characteristics. These characteristics include per-hectare yields, disease resistance, harvest residue quantity and quality, and others.
- Management practices. Management practices include cultivation and harvest practices, as well as post-harvest logistic operations including storage, transportation, and pretreatment.
- The surrounding environment. These impacts include: invasiveness, alterations in soil chemical, biological, and physical properties, hydrologic processes, and impacts on associated plant and animal species.
- Growth in mixed stands such that crops can be bred for greater yields in alternative mixed-species fields (e.g., intercropping or agroforestry).
- Resource availability and land use. Improving feedstock yield through plant improvements provides additional supply within current land constraints and infrastructure. This has less impact on the environment than expanding the land base to facilitate additional biofuel feedstocks resources.

## Research Resource Needs

To adequately address the three research focus areas for the next generation of biofuel feedstocks, additional resources and technologies are needed. These include:

- Develop new breeding theory, tools, and methods to assess genetic variation patterns and associations in order to accelerate breeding for biofuel crops.
- Develop new instrumentation and techniques for accessing important biofuel characteristics. For example, improved analytical methods are needed to understand the complex molecular structure of the cell wall. Employing genomic strategies to identify traits for useful cell wall characteristics requires developing high throughput methodology for efficient screening of plants.
- Expand DNA sequencing and development of genomic resources (expressed sequence tags, molecular markers, physical and genetic maps, and mutants) for all potential biofuel species.
- Develop genome analysis tools such as bioinformatics and gene-finding algorithms, especially to enable comparisons across various biofuel species.
- Develop innovative technologies for genetic improvement for biofuel crops, such as transformation of new species.
- Develop and expand genetic resources (seeds, germplasm, and mutants) for breeding biofuel crops, such as the National Plant Germplasm System.
- Target efforts to train more plant breeders in biofuel crop improvement.
- Conduct environmental studies and preparation of risk assessments, as needed, to release and deploy biofuel crops, especially those that are regulated because they are produced using recombinant DNA technology.

## Anticipated Products

In general terms, the anticipated products will be improved cultivars and parental stocks with enhanced feedstock yield, improved conversion efficiencies, extended range, viability, and value-added traits. Specifically these products will include:

- New feedstock species with improved biofuel feedstock characteristics. These new species will become some of the new biofuel feedstocks for tomorrow, but may also provide important new traits that can be incorporated into other species.
- New genetic and genomic resources for biofuel crops.
- New methods for the analysis of cell walls.

- New traits that enhance feedstock yield, adaptability and resilience, conversion efficiency, and co-product value.
- Additional risk analyses of plant species and traits that assess environmental impacts to inform decision making on sustainable management practices of GE biofuel crops.
- New strategies for deploying transgenic crops that meet regulatory requirements.
- Additional cultivar evaluation data to identify optimal adaptation zones of biofuel species and cultivars on a regional basis, allowing farmers, ranchers, and foresters to utilize the most appropriate genetic sources.
- Additional trained plant breeders with biofuel crop expertise for more resources for biofuel germplasm development.

# 3. Feedstock Production and Management

**GOAL: Develop and transfer technologies for sustainable, cost-effective, production and management strategies, systems and practices that provide adequate, affordable, and reliable quantities of biofuel feedstocks.**

## Feedstock Production and Management

Capturing the potential of biofuel feedstocks resources depends on successfully addressing major challenges such as increasing the yield, reliability, and sustainability of feedstock supply; improving land and resource use efficiency; reducing feedstock production costs; and continuing to deliver needed levels of goods, services, and values now and into the future. Research is required to develop sustainable, cost-effective, high-yield feedstock production practices for large-scale use of dedicated energy crops; enhance land productivity while meeting water quality, GHG reduction and other environmental goals; and create management practices that integrate energy feedstock production into conventional management systems. Sustainable management systems and practices integrate productivity, economic viability, and conservation of the natural resource base and its associated services. It is important to recognize that synergies and tradeoffs result when resources are managed across multiple desired outcomes including food production, forest products production, energy production, and ecosystem services.

The research outlined here builds on a long history and significant body of research on soil, crop, and forest productivity; genetics and breeding; agronomics and silviculture; nutrient management; water conservation and quality management; operations; habitat management; and analytical analyses over the entire production life cycle. This research program integrates all aspects of sustainable production and management in the development of options, strategies, systems, and practices for sustainably producing biofuel feedstocks and other goods, services, and values from our working lands. It articulates critical science needs for producing biofuel feedstocks from crops and trees purpose-grown for biofuel as well as for biofuel feedstock production systems when biofuel feedstock production is one of multiple value streams from conventional agricultural, forestry, and rangeland systems.

## Research Needs

Research needs for developing sustainable biofuel feedstock production and management strategies, systems, and practices span the broad themes of increasing yield, resource conservation, and sustainable systems and practices development. Integrating production and management with harvest, recovery, transportation, and conversion can reduce costs and increase environmental and cost efficiencies.

The research recommended here will need to be integrated with interagency work on feedstock production, logistics, conversion, and sustainability to ensure the integration of harvest and collection operations and feedstock

characteristics with sustainable production and management systems and practices. Specific research will depend on the species; regional and site characteristics; and the goods, services, and values required, in addition to feedstock production.

### Research Focus Area 1—Increase yield of biofuel feedstocks

This research focus provides the means to improve unit productivity and cost and resource-use efficiency and integrated biofuel feedstock production systems. The research is expected to supply foundational information needed to enhance efficient resource use, produce cost-effective resource delivery and use practices, develop effective management systems, and deliver needed feedstock volume while providing needed goods, services, and values.

- Develop plant stock and propagule production, nursery practices, storage and handling systems, and practices for effective deployment.
- Develop crop establishment and land transition practices that account for cropping history, environmental factors, competing land uses, and conversion-facility needs.
- Quantify resource demands (e.g., water, nutrient, and pest management) in biofuel feedstock production systems, and assess potential impacts of global change.
- Develop density-yield relationships for energy crops and integrated feedstock production systems.
- Quantify soil carbon and nutrient dynamics including air emissions in feedstock production systems and residue removal levels that conserve/enhance soil carbon, moisture, temperature and nutrient status, and retention.
- Quantify relationships between management inputs and biofuel feedstock productivity in commercial-scale energy plantings and integrated feedstock production systems.
- Develop appropriate harvest timing, frequency, and intensity options for energy crops and integrated production systems.

### Research Focus Area 2—Conserve natural resources in biofuel feedstock production

This research focus serves to integrate the foundation information on specific demands, yields, and outcomes in order to develop options and practices that cost-effectively conserve or enhance soil, water, and habitat quality while providing adequate quantities of biofuel feedstocks.

- Develop precision resource delivery systems (e.g., water, nutrient, and pest management) based on understanding demand relationships in time and space.
- Develop rotation and cover crop systems that enhance feedstock productivity while conserving natural resources.
- Develop deployment, production, and management options and practices that enhance nutrient- and water-use efficiency at the plant or site level.
- Quantify changes in nutrient and chemical runoff from feedstock production areas.
- Develop and test guidelines for appropriate levels of sustainable residue removal to conserve and enhance soil carbon, nutrient retention, and grain yields.
- Quantify habitat relationships for energy crop and integrated feedstock production systems.
- Develop options and practices that enhance the function and value of marginal sites, thereby lessening food impacts associated with conversion of prime crop land.
- Develop effective practices to use animal manure, production wastes, and byproducts as viable feedstocks.
- Develop and test best management practices integrating expanded biofuel feedstocks

removal from conventional agriculture, forestry, and rangeland systems.

### Research Focus Area 3—Develop sustainable systems and practices for biofuel feedstock production

This research focus area develops and integrates information across a variety of scales to produce feedstock production and management systems that are productive, economically viable, minimize unwanted effects, and conserve or enhance the natural resource base. Sustainable production and management systems and practices ensure efficient and effective use of genetic material, provide options for multiple sustainable value streams, and enhance delivery of goods, services, and values from fields, forests, and other landscapes.

- Integrate sustainable energy feedstock production into conventional agriculture, forest, and rangeland management systems without impacting the supply of goods and services provided by these systems.
- Develop practices and methods for sustainable production of large-scale energy crops and integrated feedstock production systems.
- Quantify sustainability criteria for biofuel feedstock management systems.
- Develop and test strategies to integrate forested systems into agricultural landscapes and to effectively deploy agroforestry systems to provide services in addition to energy feedstocks.
- Integrate biofuel feedstock production into landscape management options.
- Quantify costs and returns associated with transitioning lands to cellulosic energy crop development and integrating energy feedstock production into conventional agriculture, forest, and rangeland management systems.

## Research Resource Needs

- Establish large-scale, multi-acre field trials to support the research needs identified above at scales appropriate to assess the impacts of large-scale biofuels feedstock production.
- Develop a partnership approach to developing and deploying feedstock production and management strategies that includes federal agencies, land owners, farmers/producers, researchers, academia, and industry.
- Develop standard protocols for field data collection so results can be compared across various projects and geographical areas.
- Deploy an educated work force to research, develop, deploy, and manage sustainable feedstock production systems, practices, and technologies.

## Anticipated Products

- High quality, high density, available, affordable and sustainable cellulosic feedstock supply for an emerging U.S. biofuels industry.
- Cellulosic feedstock supply that maintains or enhances the environmental functions and values of traditional crop, forest, and rangeland management systems.
- Sustainable feedstock production and management systems that provide a high value commodity to land owners.
- Best management practices for establishing and transitioning to sustainable energy cropping systems.
- Best management practices for integrating sustainable energy feedstock production into conventional agriculture, forest, and rangeland management systems.
- Feedstock production and management systems that are productive, economically viable, minimize unwanted effects, and conserve or enhance the natural resource base.

# 4. Conservation and Ecosystem Services

**GOAL: Provide research that will assist in the development of decision-support tools to enable resource managers, agricultural/forestry producers, and other decision makers to increase sustainable feedstock production while minimizing impacts on ecosystems and the services they provide.**

## Introduction

Previous chapters have outlined the research needed to develop management strategies, systems and practices that will increase biofuel feedstock yield and quality while maintaining or enhancing environmental quality. This chapter discusses the environmental outputs in more detail and at multiple scales.

Any changes made to cropping or forest management systems subsequently impacts the lands on which these practices occur, as well as the ecosystem services they provide. Impacts on food, water, soil, and human and wildlife health, depend largely on the spatial extent and landscape pattern of land requirements for biofuels. Thus, potential environmental and human health impacts from biofuel production must be examined at various temporal and spatial scales. This will require identifying environmental, wildlife and human impacts throughout the supply chain and finding ways to quantify and manage the impacts resulting from increased feedstock production.

## Research Needs

To quantify the environmental and human health impacts resulting from increased feedstock production, multiple systems supporting broader-scale processes must be examined. Four research focus areas aimed at examining the impact of biofuel feedstock production on broad ecosystem processes and systems are indentified. It is important to recognize that, because of the integrated nature of ecosystems, all of the following systems, cycles, and processes are interconnected.

### Research Focus Area 1—Climate change mitigation by reducing GHG emissions and increasing carbon sequestration

Much of the interest in domestic biofuels is associated with the expectation of helping to mitigate climate change while enhancing energy security and rural economic opportunities. The GHG benefits of these fuels have not yet been fully quantified, and research is needed to understand the potential climate change mitigation benefits of biofuels and their potential roles in broader GHG response strategies. The following research priorities should be addressed at multiple scales, particularly watershed and landscape level:

- Emissions from land use change: Identify and quantify the direct and indirect emissions related to bringing into production new lands for biofuels feedstocks.
- GHG mitigation: Quantify the amounts and types of carbon sequestered or lost by soils and vegetation in areas of feedstock production in contrast to sequestered or lost by soils and vegetation in alternative forests, wetlands, and fallow cropland systems.

- GHG Accounting: Quantify the amounts and types of GHG emitted by various feedstock types and technology pathways over the full cycle of production and utilization at appropriate spatial and temporal scales.
- Emissions from nitrogen fertilizers: Clarify and manage the links between different nitrogen management practices and nitrous oxide emissions from the field and indirect (off-site) nitrous oxide emissions.
- Emissions and tillage systems: Clarify and manage the conditions no-till or crop residue removal results in higher soil carbon storage compared to conventional systems.
- Policy and GHG emissions: Understand how policy incentives can move producers to adopt climate change mitigating practices and land uses.

### Research Focus Area 2—Water quality and quantity

Water is a significant limiting factor for biofuels production and ecosystem sustainability across broad areas of agricultural landscapes; this could be more or less limiting as climate change compounds key interactions among ecosystem services that affect water resources and feedstock production. Research is needed to better understand the potential to increase feedstock and biofuels production without adversely affecting water availability, quantity, and quality within watersheds and basins that are intermingled with other domestic, industrial-commercial and environmental uses. Topics include:

- Water quality from nutrients: Quantify, model, and manage potential increased nutrient load and downstream eutrophication from runoff, leaching from additional fertilizer applications, and potential increased sediment load and downstream deposition and resuspension of contaminant-bearing sediments.
- Water quality baseline establishment to assess potential changes in pesticides use: Quantify and manage risks to: 1) aquatic microbes, macro-invertebrates and food web disruption; and 2) potential human health impacts of groundwater and surface water contamination.
- Landscape relationships to water quantity: Understand: 1) the geographical relationship of potential biofuel feedstocks production areas and watersheds to biofuel production plants and water supplies; 2) changes in land use and agricultural practices that increase or decrease soil disturbance and sediment loading from surface water runoff; and 3) benefits or potential adverse impacts of changes in water demand associated with shifts from irrigated crops to dry-land farming.
- Water needs of critical habitat and species: Quantify and model effects of increasing or decreasing in-stream flows and other hydrological processes related to biofuels feedstock production on critical habitats for specific endangered, threatened and candidate species; and determine which species may currently be at risk and under future scenarios.
- Watershed and aquifer water resources: Quantify: 1) changes in water entering a watershed or aquifer; 2) the amount of water available; and 3) the amount of water leaving the watershed or aquifer.

### Research Focus Area 3—Soil quality

Soil quality can significantly impact the capacity of soils to sustainably produce crops and to store carbon. Factors influencing soil quality include interactions between soils and new cropping systems, soil microbiology, interactions between soil and water, and amounts of carbon storage. Feedstock production systems must maintain or improve soil productivity in order to be sustainable. Research areas into the impacts of

feedstock production on soil productivity should include:

- Interactions between feedstock cropping systems and salinity: Quantify the potential to alter soil salinity receiving increased irrigation to produce feedstocks, particularly in arid, semi-arid, and Mediterranean climates.
- Impacts of feedstock cropping systems on soil microbiology: Evaluate the effects of production systems on microbes in the rhizosphere (root/soil interface), soil microbial crusts, soil and foliar pathogens, and the interaction between rhizosphere microbes and plant symbiotes (fungi and bacteria), and the relationships of soil microbial communities to nutrient availability and stability of nutrients.
- Conservation of soil nutrients and structure in feedstock cropping systems. Conduct erosion management research to develop best practices, including standards for herbaceous and woody biomass removal, to limit erosion and other adverse impacts on soil organic content and nutrient run-off while having beneficial impacts on carbon sequestration and GHG emissions.

### Research Focus Area 4—Ecosystems/wildlife/habitats

This research focus seeks to identify effects of biofuel feedstocks production on ecosystem functions and the nature and extent of ecological services. It includes data development and information synthesis for management decisions, maintaining biodiversity, sustaining wildlife populations, and protecting ecosystem services and functions, while increasing biofuels production. The following research priorities will be addressed, particularly at the watershed and landscape level:

- Direct effects on wildlife: Quantify and manage: 1) biotic distributions and species-habitat relations and related species of concern (e.g., endangered, threatened, and/or invasive) to biofuel feedstocks production; and 2) impacts of feedstock harvest patterns on wildlife breeding and survival to determine optimum management regimes.
- Indirect effects on wildlife species, populations, and habitats: Quantify: 1) biofuel feedstocks production in the landscape context, an increase or decrease of associated inputs of agricultural chemicals, and resulting contaminants as stressors on fish and wildlife health, biodiversity and ecological processes; 2) secondary effects (e.g., loss of native/preferred food sources) on previously untested species or suites of species; and 3) the energetic, ecological and wildlife benefits or costs of biofuel production systems.
- Potential for impacts at a genetic level: Quantify ramifications of introduction of new species and genotypes into ecological systems, including research to assess how genetically modified varieties enhance production practices.

## Research Resource Needs

New tools and technologies to address the research questions for the next generation of biofuel feedstocks are still in need of development. These include:

- Genetics, genomics and molecular tools and technologies— for use in tying exposure to effects, assessing gene flow, and quantify invasiveness.
- Biomarker test applications—laboratory and field trials using biomarkers and providing guidelines for their implementation in long-term monitoring programs.
- Remote sensing technologies—applied to monitoring large areas for surface processes, water tracking, and monitoring wildlife populations.
- Methodologies for measuring water resources that move beyond the historical behavior of

water, such as a system to track water through inter-basin transfers, water production and processing, and reuse of wastewater.

- Tools to assess differences across biofuel feedstocks types and estimate energy budgets associated with the life-cycle of biofuel production (with various feedstocks) and assess limiting factors in long-term production sustainability.
- Management practices, guidelines, and technologies that help conserve land resources while producing biofuels feedstocks and contribute to enhancing the environment.

## Anticipated Products

Anticipated products will provide information for developing appropriate biofuel feedstock management systems, decision tools, and models. These tools can help decision makers provide ecosystem services, protect air, water, and soil quality, as well as human and environmental health and wildlife habitat, while providing sound science to maximize feedstock production and minimize impacts on ecosystems and the services they provide. This information can be incorporated into models to help evaluate the impact of new feedstock production systems at various scales.

# 5. Decision Tools

**GOAL: Research, develop, and disseminate decision tools that inform decision-making at the farm and forestry tract level, and policy issues related to these decisions, in order to advance the overarching goal of rapid and sustainable growth in domestic biofuels feedstock production.**

## Introduction

Decision tools are methods, techniques, and approaches that help decision makers assess the consequences of an action and choose among alternative outcomes based on some specific criteria. These tools can help to anticipate likely outcomes, identify important factors and tradeoffs, and quantify uncertainties of a decision. Examples of decision tool frameworks include comparative-risk and uncertainty analysis, life-cycle assessments, cost-benefit and financial balance sheet analysis, operations research, integrated systems modeling, and market valuation studies.

Science-based decision tools are needed to ensure well-informed management decisions are made, which entails a consideration of the economic, environmental, and social impacts and drivers related to biofuels feedstock production (and other stages of the biofuels supply chain). For example, how might decisions at the farm/forest level be aligned with conditions at the ecological region or national level; or how to best maximize feedstock improvements and productivity while ensuring environmental sustainability? Decision tools will also facilitate the efficient emergence of new technologies and practices associated with the next generation biofuels feedstock industry to meet the demands of the Renewable Fuel Standard. To address these types of issues and questions, it will be necessary to research, develop, and disseminate decision tools that support policies and decision-making at various spatial and temporal scales.

Rapid emergence in this industry cannot occur without the broad and rapid dissemination of information to and between decision makers throughout the biofuels production system. Decision tools can help facilitate this process. Toward this end, the focus of this report is on the critical gaps in information that are impeding production decisions that lead to rapid and sustainable growth of the next generation biofuels feedstock industry. These information gaps primarily concern the nature of linkages between farm and forestry tract level production and management decisions, assessments of environmental and sustainability impacts, and forecasts of social and economic consequences. The research needs related to these information gaps fall under four broad focus areas: (1) Management decision tools; (2) Socioeconomic decision tools; (3) Environmental decision tools; and (4) Policy analysis decision tools. A summary of the purpose of decision tools in each focus area and the special considerations unique to each focus area is shown in Appendix A.

## Research Needs

Research needs for developing and disseminating decision tools can be categorized

into four broad focus areas. Within each focus area, the research will need to address a variety of geographic scales and timeframes.

### Research Focus Area 1—Management decision tools

This research focus seeks to develop and disseminate decision tools at the field-level (e.g., farm, ranch, or forest) that indicate when and where a switch in feedstock production should be made and where the optimal collocation of feedstock production and biorefinery plants occurs (i.e., site selection). Specific tools typically integrate models and frameworks that analyze multiple sources of information and data sets related to feedstock supplies, production options, management practices, and logistics to ensure that cost-effective decisions are made. Most field-level decisions are influenced by physical conditions within the farm landscape, both physical and market conditions within the local biorefinery feedstock production radius, environmental conditions in the ecological region, as well as national energy market conditions. Management decision tools will therefore require information on many factors including:

- Viable feedstock varieties and production/management systems by ecological regions.
- Feedstock production and logistical costs of alternative feedstock uses.
- Potential colocation of complementary operations regarding feedstock harvesting, conversion, and co-product use.
- Quantitative data on environmental services such as carbon sequestration.
- Quantified input cost, feedstock value and management cost, and interrelationships across markets to assess economic viability of energy crop production.
- Link management decision tools to localized area conditions.

### Research Focus Area 2—Socioeconomic decision tools

This research focus seeks to develop and disseminate decision tools that depict consequences of local land-use changes under different feedstock production scenarios, feedstock and energy price scenarios, costs of biofuels production, and potential macroeconomic factors that affect feedstock production decisions. Integrated models and frameworks are needed that incorporate spatially-explicit land-based tools, farm, ranch, and forestry-sector models (e.g., financial models aggregated to estimate supply conditional costs and prices), and regional economic models that better represent the diversity of energy crops and growing conditions. There is also a need to better tie these local and regional decision tools into national and global macroeconomic conditions and forecasts. These socioeconomic decision tools will need to account for many factors including:

- Total amount and landscape pattern, including land use shifts and impacts on other land use activities (e.g., food/feed and forest products production) of feedstock production.
- Viable feedstock varieties and production systems (and changes resulting from colocation of operations).
- Links with regional, national, and worldwide energy and food/feed markets.
- Pace of technological innovation and deployment.
- Regulations and voluntary/mandatory target goals or other policy objectives.
- Implications on rural employment, economy, and welfare.

### Research Focus Area 3—Environmental decision tools

This research focus seeks to develop and disseminate decision tools that assess the impacts of feedstock production and land-use change on biological communities (e.g., pollinators and invasive species); surface waters and aquifers (i.e., recharge rates); GHG emissions and air quality, carbon storage, soil quality, and soil erosion. Specifically, integrated models and frameworks that quantify a range of potential environmental impacts during feedstock production and across the entire biofuels supply chain are needed. Environmental decision tools will need to consider and obtain information on many factors identified and discussed within this report, including:

- Pollinators and beneficial insects.
- Invasive potential of introduced crops.
- Harvest timing and wildlife relationship.
- Low-input production systems.
- Feedstock production transition and colocation of complementary operations in watershed.
- Runoff, subsurface flow, and stream base flow changes; recharge in relation to land-use change including legacy pollutants in subsurface flows and stream bed.
- Feedstock field role in managing runoff from other fields.
- Relationship between length of rotation and timing of harvest and accumulation and storage of soil organic matter.
- Alternative bioenergy feedstock comparisons.

### Research Focus Area 4—Policy analysis tools

This research focus seeks to develop and disseminate decision tools for decision-makers and stakeholders that present the full spectrum of economic, social, and environmental impacts in natural units under alternative approaches or scenarios as well as the aggregation of these impacts using an index or single numeraire as a base value. Specifically, there is a need for integrated models and frameworks with the capability to analyze and synthesize across the other research focus areas and allow for comparisons of alternatives to facilitate optimal decisions. Policy analysis decision tools will need to account for many factors including:

- Economic, social, and environmental modeling outputs.
- Confidence in existing data and model inputs/outputs.
- Degree of sensitivity and uncertainty in model inputs/outputs.
- Aggregation methods and techniques.
- Objective criteria that integrate and balance long-term energy supplies, food security, the environment, land use, water use, social, and economic considerations.
- Interrelationships between biofuels/bioproducts and food markets, in competing uses such as land, water, and feed byproducts.
- International trade policies and implications on food/feed markets.
- Biofuels policy options and its implications, including subsidies and mandates.

## Research Resource Needs

Much of the need for new research involves the extension of existing models and other analytical tools to better represent new and emerging markets and policies. Beyond this, the anticipation that rapid growth will occur in second generation feedstock varieties requires the development of a suite of new decision tool frameworks. In addition, an assessment of interagency joint research protocols is necessary

to better leverage agency expertise and work towards a more complete systems approach to the development and dissemination of decision tools. These include:

- Develop inventory of viable feedstock varieties by local growing areas.
- Develop cost of production profiles under a representative variety of growing and production logistics conditions.
- Develop data sources to facilitate an expansion of feedstock models to accommodate the full array of second generation feedstock crop varieties and to account for localized market conditions.
- Maintain forecasts for the pace and impacts of new technology deployment.
- Extend research in the development of crop response models to be more representative of energy crops under alternative growing conditions.
- Extend research into the relationship of production management practices and various environmental indicators.
- Update environmental and market risk assessments under new land use scenarios.
- Establish a transparent and efficient framework for research collaboration and information exchange between federal agencies to allow for more effective leveraging of expertise and resources across departments and agencies.

## Anticipated Products

Some decision tools will be in the form of interactive websites and/or software that allow users to enter information germane to their operations or their local/regional management mission areas. These tools will assess metrics such as commercial viability of alternative land use decisions or local and regional impacts of alternative land use outcomes. Other decision tool research outputs will be in the form of new and enhanced analytical tools available to research analysts to better inform their constituents of issues and outcomes of events that affect or are affected by developments in the biofuels industry. These products will include:

- A farm-level financial planning tool that includes energy crop scenarios.
- A site-specific, field-based, user-friendly crop residue/biomass removal tool that would assist land owners make informed decisions on acceptable levels of residue/biomass removal. A tool that models the effect on nutrient and sediment loadings and transport of field-level management decisions whose scenarios encompass and make fine distinctions among energy crops (e.g., an augmented soil and water assessment tool).
- A fiscal analysis tool to assess the impact on local/regional governments of incentives provided to the emergent industry.
- A local/regional input-output model to assess the interindustry and interregional linkages to emerging and/or expanding biofuels industry, that also counts among its economic sector's energy crops and biofuels production.
- Global Computable General Equilibrium models that count among their economic sectors energy crops and biofuels production.
- Land-use change models that make fine distinctions among energy crops.
- Indicators of habitat condition.
- Groundwater flow models to assess the impacts of land-use changes on aquifer recharge.
- Methods and/or models that integrate multiple-objective scenarios.
- Ecological indexing as an outcome from multiple-objective scenarios.
- Tools for integrated assessment of different scales.

# 6. Recommendations

A sustainable, large-scale biofuels industry depends on access to an adequate, affordable, sustainable supply of biofuel feedstocks. For biofuels to become an integral part of the national energy supply and to meet the aggressive goals of the Renewable Fuel Standard, research must develop the plants and practices needed to increase the quantity and quality of biofuel feedstocks in ways that will maintain or improve rural economies and system function, health, and productivity. Results and outcomes need to be integrated into decision-support tools that will assist producers and decision-makers to make better informed decisions. The spatial and temporal scope of the research, development, and deployment effort needed to meet the need for biofuels is substantial. Providing the science and technology to sustainably produce the needed supply will require a sustained national commitment by federal agencies, universities, nongovernmental organizations, industry, and many other public and private partners.

**Science Needs.** To meet national energy goals, critical research and development needs have been summarized below for each of the major research areas identified previously in the report. Some of this work is currently funded by the U.S. government and partners. Critical research needs include, but are not limited to:

### Feedstock Improvement:

- Intensify and expand plant breeding for feedstock crops.
- Understand the genes controlling plant growth and cellulose properties.
- Develop breeding techniques/systems to incorporate these traits (and others) into traditional and new species.
- Accelerate development of genomic tools and resources to enhance feedstock improvement and deployment.
- Develop strategies for addressing the deregulation of biotechnology-derived biomass feedstock genotypes that are shown to be safe for humans, wildlife, and the environment.

### Production and Management:

- Develop production strategies and systems that can adapt to evolving innovations, markets, and environmental changes.
- Expand large-scale, field-level trials at a variety of locations for evaluation of cultivar potential and production practices.
- Quantify relationships between management inputs and feedstock productivity in commercial-scale production systems including those on marginal lands.
- Evaluate harvest timing, frequency, and intensity options on yield, quality, and sustainability.
- Assess the integration of feedstock production into local, regional, and national land-use systems to provide multiple goods and services.
- Develop best management practices to sustain and enhance biofuel feedstock productivity and economic outcomes, while reducing risks, and promoting ecological and environmental stewardship.

### Conservation and Ecosystem Services:

- Develop tools to quantify potential impacts and benefits of feedstock production on water, soils, air, carbon, ecological function, and wildlife habitat and populations.

- Develop biomarker and remote sensing applications for collecting environmental data that can evaluate ecological implications and monitor engineered species proposed for use in feedstock production.

### Decision-Support Tools:

- Develop models and other analytical tools based on experimental field trails that assess productivity, economic, environmental, and social factors to predict the outcomes of production options and management practices.
- Adapt and expand existing production, economic, social, and environmental data collection systems to include scale and variability in order to provide timely standardized information needed for model development and to monitor and assess feedstock production systems.

The research recommended here will need to be integrated with interagency work on feedstock production, logistics, conversion, and sustainability to ensure the integration of harvest and collection operations and feedstock characteristics with sustainable production and management systems and practices. Specific research will depend on the species; regional and site characteristics; and the goods, services, and values required in addition to feedstock production.

In addition to the science needs identified in each of the four major research areas, there are additional, overarching recommendations:

**Increase cooperation, communication, and coordination between federal agencies towards implementing research strategies and projects.** The R&D needs for developing and implementing sustainable feedstock production systems are diverse and complex. No single federal agency has the mission scope or resources to conduct a truly comprehensive program covering all aspects of these R&D needs. To promote a more interdisciplinary approach, improve efficiency and ensure appropriate geographical coverage, federal agencies should meet regularly to discuss their current and planned R&D projects and identify opportunities to eliminate duplication, improve communication, and promote cooperation.

**Promote greater cooperation between public and private sectors**. No single organization can conduct the long-term interdisciplinary R&D effort required to deliver highly productive, sustainable feedstock systems that are economically, socially, and environmentally sustainable. Therefore, a transparent and efficient protocol should be developed to promote regular R&D information exchanges and discussions between federal agencies, their public and private partners, and international entities. This protocol should focus on inventorying current partnerships, facilitating communication across the major components of the biofuel system including production, conversion and distribution and leveraging expertise and resources to achieve common goals.

**Ensure effective technology transfer**. Advances in R&D must be transferred rapidly to private and public practitioners and decision-makers to promote the timely adoption and deployment of improved systems. The transfer process can be improved by developing decision-support tools that reflect user needs identified through stronger linkages between researchers, technology transfer agents, policy makers and feedstock producers. Federal agencies should develop and implement a strategy to increase cooperation between research and development agencies and those responsible for technology transfer programs to

owners and managers of forest and agricultural lands.

**Ensure adequate research and workforce capacity**. It will be necessary to strengthen the research and technical workforce to meet the research, development, and deployment commitment needed. An adequate scientific and technical workforce must be available to develop and deploy sustainable feedstock production systems. This commitment must bring together federal agencies, universities, and the private sector to provide the critical mass of expertise, personnel and facilities. Working in close cooperation, private and public research organizations, educational institutions, and industry should assess existing capacities; identify current and emerging gaps in scientific and technical skills and staffing levels, facilities, equipment, and research field sites; and develop and execute effective strategies for filling these gaps.

# 7. Federal Biofuels Feedstock Production RD&D

| Agency | Current Agency Role |
|---|---|
| **USDA Agricultural Research Service** | U.S. Department of Agriculture, Agricultural Research Service (USDA ARS) conducts basic and applied research to enhance feedstock availability by improving feedstock germplasm and developing sustainable feedstock production systems. Research to improve feedstock germplasm includes evaluating and breeding germplasm varieties for improved energy crops including switch grass and other perennial grasses, sorghum, alfalfa, sugarcane, and oilseeds; identifying plant traits that enhance feedstock yield, conversion efficiency, and co-product value and incorporate these traits into elite germplasm; develop rapid, efficient methods for measuring key traits that define feedstock quality; conducting risk analyses of plant species and traits to assess environmental impacts and sustainability; improving breeding methods and selection strategies for use in developing bioenergy crops including developing DNA markers, molecular maps, and new genomic and gene sequence information for several bioenergy crops; identifying and validating candidate genes for improvement of targeted biofuel traits; and developing molecular understanding of plant traits involving cell-wall synthesis and structure, growth, stand establishment, persistence, biomass yield, and conversion potential.<br><br>Research to improve feedstock production systems productivity and sustainability include developing region-specific strategies to incorporate bioenergy crops into existing agricultural production systems with known effects on farm economics and natural resources quality; developing sustainable practices and systems for new dedicated energy crops that optimize feedstock harvest without degrading the quality of soil, water, air, and other natural resources; developing multiple-criteria decision tools to guide the sustainable development of a cellulose-based biofuels industry so impacts of land use change on existing food, feed, and fiber markets and biological diversity will be known; developing analytical tools to estimate production capacity and risks of dependable feedstock supply so biorefiners can develop accurate sustainable management plans; developing on-farm practices for utilizing biologically active biorefinery co-products as soil amendments and natural controls for agricultural pests; and developing integrated grass-legume production systems for major crop adaptation zones to reduce the need purchased nitrogen fertilizer inputs for dedicated cellulosic feedstock crops. |
| **USDA National Agricultural Statistics Service** | U.S. Department of Agriculture, National Agricultural Statistics Service (USDA NASS) recently began an annual bioenergy data series. Initial steps included identifying key areas of interest where data collection would provide beneficial information for program development and energy research. These areas include: on-farm energy production and utilization; production and utilization of biomass materials; county-level maps of biofuels feedstocks; and storage capacity of facilities to meet bioenergy industry needs. Through data collections and utilization of the USDA NASS remote sensing applications, efforts are underway to provide needed information. |
| **USDA National Institute of Food and Agriculture** | U.S. Department of Agriculture, National Institute of Food and Agriculture (USDA NIFA) funds both fundamental and applied extramural research, education, and extension activities that focus on the development of regional systems for the sustainable production of biofuels, biopower, and biobased products. The USDA NIFA Sustainable Bioenergy Portfolio is a team-managed set of programs that include the: U.S. Department of Agriculture, Agriculture and Food Research Initiative (USDA AFRI) Sustainable Bioenergy Challenge (Regional Approach to Sustainable Bioenergy Systems Program, Sustainable Bioenergy Research Program, and Sustainable Bioenergy Education Program); Biomass Research and Development Initiative; Department of Energy, Biological and Environmental Research (DOE BER) and USDA NIFA Joint Plant Feedstock Genomics for Bioenergy Program; Small Business Innovation Research Program; and Critical Agricultural Materials Program. This suite of USDA NIFA programs support and facilitate the integration of all aspects of regional bioenergy systems, including: feedstock genetic development; sustainable feedstock production; feedstock logistics; conversion and refining; markets and distribution; economic, environmental, and social sustainability; technology transfer and outreach; workforce development; and data acquisition and analysis. |

| Agency | Current Agency Role |
|---|---|
| **USDA Natural Resources Conservation Service** | U.S. Department of Agriculture, Natural Resources Conservation Service's (USDA NRCS) primary mission is technical and financial conservation assistance to producers. Applied research is funded largely through external agreements with partners (including USDA ARS and USDA NIFA) and USDA NRCS Plant Materials program funds. Its primary concern is biomass feedstock sustainability. Research is concentrated on impacts of residue harvest on soil productivity, biomass crop cultivar development, potential new and native biomass feedstock species, and appropriate cultivation and harvest techniques for dedicated biomass feedstocks, with special emphasis on soil, water, and wildlife implications. |
| **USDA Animal and Plant Health Inspection Service** | U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS) Biotechnology Regulatory Services regulates the importation, movement, and field release of genetically engineered plants and microorganisms including those used for biofuels. It conducts an in-depth environmental assessment during the "deregulation process." USDA APHIS/Plant Protection and Quarantine has a federal noxious weed program designed to prevent the introduction and spread of non-indigenous invasive plants within the United States. At least one species being developed as a bioenergy feedstock is on the Federal Noxious Weed list (energy cane). The USDA APHIS/Plant Protection and Quarantine Biological Control Program uses natural enemies to suppress plant pests and weeds and also control of a proposed biofuel feedstock, Giant Reed. |
| **USDA Forest Service** | U.S. Department of Agriculture, Forest Service (USDA FS) R&D funds both internal and external R&D, and both basic and applied research.<br>o Supports forestry best management practices for sustainable expanded biomass removal<br>o Supports sustainable forest management practices and production<br>o Supports sustainable harvesting and handling of biomass<br>o Funds cost and equipment information and options for field processing<br>o Develops strategies to integrate forest systems into agricultural landscapes to provide services as well as income<br>o Supports sustainable management and utilization systems integrating bioenergy feedstock production with biomass and residue management, forest health and fuels reduction treatments, and production forestry<br>o Supports plant and silvicultural science<br>o Funds genetics, genomics, and breeding including participation in the National Plant Genome Initiative with DOE and NSF<br>o Supports integrated feedstock supply systems<br>o Supports sustainable forest residue removal<br>o Funds sustainable forest energy feedstock production<br>o Investigates carbon sequestration of forest residues<br>o Supports higher resolution and consistent national and regional tools for more accurate assessment of forest bioenergy resources<br>o Maps products to identify potential sites for short-rotation woody energy crops<br>o Creates models to assist with identifying opportunity zones and site selection for bioenergy facilities considering supply, transportation, water, and infrastructure<br>o Develops sustainability criteria for forest bioenergy feedstocks<br>o Integrates models of future land use patterns, goods and services delivery, and markets as influenced by expanded bioenergy production<br>o Funds logistics and decision-support tools to reduce costs of treatments involving biomass removal and improve harvest and transport efficiency<br>o Supports small-scale demonstrations<br>o Develops life-cycle analysis |
| **DOE Office of Biomass Program** | Department of Energy, Office of Biomass Program (DOE OBP) conducts research and demonstration activities in feedstock logistics, development of integrated systems to harvest, collection, storage, and preprocessing of biomass feedstocks; leadership of the Regional Feedstock Partnership effort to identify and produce potential biomass feedstocks across the United States, including a limited effort to measure the environmental sustainability of dedicated cropping systems; and conducts resource assessment analysis activities to identify future potential biomass feedstock resources. |

| Agency | Current Agency Role |
|---|---|
| **DOE Basic Energy Sciences** | Department of Energy, Basic Energy Sciences (DOE BES) supports fundamental research to expand the scientific foundations for new and improved energy technologies and for understanding and mitigating the environmental impacts of energy use. The portfolio supports work in the natural sciences, emphasizing fundamental research in materials sciences, chemistry, geosciences, and aspects of biosciences.<br><br>Bioscience programs support basic research on the conversion of solar energy into chemically stored forms of energy, and on interdisciplinary science providing basic structure-function information to understand the basic architecture of energy transduction and storage systems. This impacts numerous DOE interests; particularly enhanced biofuel production strategies, next generation energy conversion/storage devices, and efficient and environmentally-friendly catalysts. |
| **DOE Biological and Environmental Research** | DOE BER advances world-class biological and environmental fundamental research programs and scientific user facilities to support DOE's energy, environment, and basic research missions. Support is provided for:<br>o Fundamental research underpinning the development of biotechnology solutions for energy, the environment, and carbon sequestration. The program develops genome-scale technologies needed to understand, predicatively design, and model plant and microbial systems.<br>o DOE Bioenergy Research Centers to accelerate genomics-based systems biology research to achieve the transformational breakthroughs in basic science needed for the development of cost-effective technologies to make production of next-generation biofuels from lignocellulose, or plant fiber, commercially viable on a national scale.<br>o The Joint Genome Institute, the only federally-funded large genome center focusing on genome discovery and analysis in plants and microbes for energy and environmental applications. |
| **EPA Office of Research and Development** | The Environmental Protection Agency, Office of Research and Development (EPA ORD) provides scientific information on fate and transport, environmental and human health exposures, toxicity, risks, and benefits of nutrients, pesticides, and products of biotechnology, including genetically engineered pesticides released into soil, air, and water, and their effects on ecosystems, water and air quality. This information supports environmental protection standards developed by EPA's offices of Air and Radiation, Water, and Prevention, Pesticides, and Toxic Substances.<br><br>EPA ORD conducts research on characteristics of various forms of wastes, including animal manures, agricultural and food wastes, industrial, and municipal solid wastes. This includes developing pilot demonstrations and models that help predict their value as a biofuel feedstock, and their impact on the environment and human health. |
| **EPA Office of Pollution Prevention and Toxics** | The Environmental Protection Agency, Office of Pollution Prevention and Toxics (EPA OPPTS) regulates the use of all pesticides in the United States and establishes maximum levels for pesticide residues, including genetically engineered pesticides. The role of the EPA Office of Pesticide Programs in feedstock production will be to require that any new pesticides and/or new uses of existing pesticides as well as already registered pesticide uses meet the standards set forth in the statutes governing pesticide registration. These include the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). These statutes require that EPA ensures the safety of all pesticides to: any individual exposed from such activities as mixing/loading and applying a pesticide product or from re-entering fields, to perform work activities such as weeding or harvesting, or other areas following application of a pesticide; any dietary exposure from pesticide residues that may result in food and/or water; and any environmental/ecological exposures that may occur from the use of a pesticide. Such safety determinations are necessary regardless of where the pesticide is applied (e.g., whether the use is intended for feedstock production, use on food or feed crops, or as a use in a home).<br><br>Mandatory notification and review under the Toxic Substances Control Act of 1976 of all new chemicals and genetically-engineered microorganisms (e.g., microalgae), including those involved in feedstock production (e.g., Bradyrhizobium). |

| Agency | Current Agency Role |
|---|---|
| **EPA Office of Water** | Under the Clean Water Act, EPA and the states set water quality standards for pollutants that can enter water bodies from feedstock production, i.e., nutrients, sediment, and pesticides. If those standards are exceeded, EPA and the states develop a Total Maximum Daily Load to calculate how much pollutant reduction is needed from all sources. EPA provides grants to states to assess and control nonpoint sources of pollution. |
| **EPA Office of Air and Radiation** | The Environmental Protection Agency, Office of Air and Radiation (EPA OAR), oversees under the Clean Air Act, Section 110, farming practices such as prescribed burning on a location-specific basis according to a State Implementation Plan (SIP) that determines sources of air pollution. Each state must develop a SIP which identifies sources of air pollution and determines what reductions are required to meet federal air quality standards. Locations that are in areas that have been classified as "nonattainment areas" under the National Ambient Air Quality Standards are subject to more restrictions.<br><br>The Energy Independence and Security Act of 2007 (EISA) mandated EPA to develop a new Renewable Fuel Standard (RFS) with new renewable fuel categories and associated eligibility requirements that include lifecycle GHG reduction thresholds. EPA finalized the RFS rule in 2010. As mandated by EISA, EPA established the GHG reduction thresholds by calculating the lifecycle GHG emissions, including significant direct and indirect effects. EPA's calculations included energy inputs and outputs, land use and crop rotation changes, and GHG emissions for various domestic and international feedstock production scenarios as part of a lifecycle analysis. |
| **EPA Regional Offices** | Regions, along with the states and EPA's Office of Water identify impaired or threatened water bodies, and working with the states, enforce compliance with water quality standards. |
| **Department of Interior** | The Department of Interior (DOI) plays a major role in recovery of forest thinning and other biomass materials from land management and fire prevention activities; co-chairs the federal task force on Woody Biomass Utilization Working Group that promotes the utilization of woody biomass for fuels and other uses. This group reports to the Biomass R&D Board; and provides renewable energy grants to address feedstock transport (Indian Affairs). DOI conducts research and monitoring in support of terrestrial and aquatic wildlife and habitat needs for use in management decisions by regulatory agencies, in part to aid decisions on listed and candidate species under the Endangered Species Act. |
| **National Science Foundation** | The NSF Directorate for Biological Sciences provides grants to support basic cross-cutting research to improve biofuel feedstocks (e.g., National Plant Genome Initiative, Arabidopsis 2010, Division of Molecular and Cellular Biology, Integrative Organismal Systems Division), to increase understanding of plant energy capture mechanisms, and to improve pre-processing of feedstocks. The NSF Directorate for Engineering also provides grants to improve pre-processing and processing of feedstocks as well as grants to assess potential feedstock production impacts. |

## Science Need 1: Increase feedstock productivity and quality through plant improvement

| Specific Recommendation | Current Involvement | Projected Involvement |
|---|---|---|
| Intensify and expand plant breeding for feedstock crops | USDA FS, USDA NIFA, DOE BER, USDA NRCS, USDA ARS | USDA FS, USDA NIFA, USDA NRCS, ARS, DOE BER |
| Understand the genes controlling plant growth and cellulose properties | NSF, USDA FS, USDA NIFA, USDA ARS, DOE BER, DOE BES | NSF, USDA FS, USDA NIFA, USDA ARS, DOE BER, DOE BES |
| Develop breeding techniques/systems to incorporate these traits (and others) into traditional and new species | DOE BER | DOE BER, USDA NIFA |
| Accelerate development of genomic tools and resources to enhance feedstock improvement and deployment | NSF, USDA FS, USDA NIFA, USDA ARS, DOE BER | NSF, USDA FS, USDA NIFA, USDA ARS, DOE BER |
| Develop strategies for addressing the deregulation of biotechnology-derived biomass feedstock genotypes that are shown to be safe for humans, wildlife, and the environment. | USDA APHIS, USDA FS, USDA NIFA, USDA ARS | USDA APHIS, USDA FS, USDA NIFA, USDA ARS |

## Science Need 2: Develop high-yielding, sustainable feedstock production practices and systems

| Specific Recommendation | Current Involvement | Projected Involvement |
|---|---|---|
| Develop production strategies and systems that can adapt to evolving innovations, markets, and environmental changes | USDA FS, DOE OBP, USDA NIFA, USDA ARS | USDA FS, USDA NIFA, USDA ARS |
| Expand large-scale field level trials at a variety of locations for cultivar and production practices evaluation | USDA FS, USDA NIFA, USDA ARS | USDA FS, DOE OBP, USDA NIFA, USDA ARS |
| Quantify relationships between management inputs and feedstock productivity in commercial-scale production systems including those on marginal lands | USDA FS, USDA NIFA, USDA ARS | USDA FS, DOE OBP, USDA NIFA, USDA ARS |
| Evaluate harvest timing, frequency, and intensity options on yield, quality, and sustainability | USDA FS, DOE OBP, USDA NIFA, USDA NRCS, USDA ARS | USDA FS, USDA NIFA, USDA ARS |
| Assess relationships resulting from integrating feedstock production into local, regional, and national land-use systems to provide multiple goods and services | USDA FS, USDA NIFA, USDA ARS | USDA FS, DOE OBP, USDA NIFA, USDA ARS |
| Develop best management practices to sustain and enhance biofuel feedstock productivity and economic outcomes, while reducing risks and promoting ecological and environmental stewardship | USDA FS, DOE OBP, USDA NIFA, USDA ARS | USDA FS, USDA NIFA, USDA NRCS, USDA ARS |

## Science Need 3: Assessment, mitigation, and control of potential feedstock production impacts

| Specific Recommendation | Current Involvement | Projected Involvement |
|---|---|---|
| Develop assessment tools to examine the status and potential impacts of feedstock production on water, soils, air, carbon, ecological functions, and wildlife habitat and populations | NSF, USDA FS, DOE OBP, USDA NIFA, DOI, DOE BER, USDA ARS, EPA OTAQ, EPA ORD | NSF, USDA FS, USDA NIFA, USDA NASS, USDA NRCS, DOI, DOE BER, USDA ARS, EPA OTAQ, EPA ORD |
| Develop biomarker and remote sensing applications for collecting environmental data that can evaluate ecological implications and monitor engineered species proposed for use in feedstock production | NSF, USDA NIFA, DOI, EPA OTAQ, EPA ORD | NSF, USDA NIFA, DOI, USDA ARS, USDA NASS, EPA OTAQ, EPA ORD |

## Science Need 4: Developing decision tools for land managers and policy makers

| Specific Recommendation | Current Involvement | Projected Involvement |
|---|---|---|
| Develop models and other analytical tools that assess productivity, economic, environmental, and social factors to predict the outcomes of production options and management practices | FS, DOE OBP, USDA NIFA, DOE BER, USDA ARS | FS, USDA NIFA, DOI, DOE BER, USDA ARS, USDA NASS |
| Adapt and expand existing production, economic, social and environmental data collection systems to provide timely standardized information needed for model development and to monitor and assess feedstock production systems | DOE OBP | FS, DOI, USDA NIFA, USDA NASS |

# Appendix A – Decision Tool Focus Areas

| Focus Area | Purpose | Requirements/ Considerations | Scale at Which Tool is Used | |
|---|---|---|---|---|
| Management Decision Tools | Management decision tools target field-level production and resource management decisions. These decision tools typically synthesize relevant state of the art technical, management practice, and local market information with field level growing characteristics. Emphasis is placed on the use of relevant geographic information. | Research emphasis is in acquiring spatially enhanced information on the local resource base throughout all potential feedstock growing regions. Other considerations include the matching of current and emerging technologies to relevant growing areas, and identifying outer boundaries of information to be incorporated into decision processes (e.g., degrees of uncertainty analysis, extent of reliance on long-run forecasts, and macroeconomic factors of relevance). | National Level | |
| | | | Regional/ Local Level | ✓ |
| | | | Field Level | ✓ |
| Economic and Social Decision Tools | Socioeconomic decision tools being considered are confined to data and analysis that inform decision-making at the farm and forestry tract level and policy issues related to these decisions. Aside from the consideration of local market indicators, many economic and social issues of national and international consequence can have implications for field-level decisions. Research must strike a balance between complexity and usability. | The analytical tools already in use to study the biofuels feedstock industry need to be extend in several key areas. First, primary market and demographic data sources with greater spatial detail need to be incorporated. Second, a more complete accounting of risk and uncertainty should be developed. Finally, approaches should be developed that incorporate intermediate and long-term forecasts of relevant economic indicators into field level production decisions and related policy. | National Level | ✓ |
| | | | Regional/ Local Level | ✓ |
| | | | Field Level | |

| Focus Area | Purpose | Requirements/ Considerations | Scale at Which Tool is Used | |
|---|---|---|---|---|
| Environmental Decision Tools | Similar to the socioeconomic decision tools, environmental decision tools being considered are confined to data and analysis that inform decision making at the farm and forestry tract level and policy issues related to these decisions. The potential environmental impacts of large-scale changes in land use and expansion of cropland area heightens the need for tightening the link between local land use decisions and environmental implications of those decisions. | Spatial enhancement of natural resource and biological inventories are necessary to effectively link various process and life cycle analysis' to land use decision making. Indicator assessment tools of ground and surface water quality, aquifers recharge rates, GHG emissions, air quality, carbon storage, soil quality, and soil erosion, and other indicators need to be updated to account for the emergence and anticipated growth of new cellulosic energy crop production. Analysis of risk, uncertainty and long-run forecasting should be enhanced. | National Level | |
| | | | Regional/ Local Level | ✓ |
| | | | Field Level | ✓ |
| Policy Analysis Tools | The scope of policy analysis tools discussed in this report are confined to those cellulosic feedstock production inefficiencies that impede rapid, efficient, and sustainable growth in the cellulosic feedstock industry. Policy decision tools of this type present the full spectrum of economic, social, and environmental impacts in natural units under alternative policy approaches or market scenarios as well as the aggregation of these impacts using a single or small number of assessment criteria. | An effective framework for policy decision tools requires an integration of numerous factors from feedstock improvement, production and management, and conservation and ecosystem services, to effectively model the entire production system and evaluate various policy options. For example, the likely range of production outcomes under various policy options could be used to estimate residual risk associated with environmental and sustainability indicators. | National Level | ✓ |
| | | | Regional/ Local Level | ✓ |
| | | | Field Level | |

# Appendix B – Feedstock Production Interagency Working Group

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# Appendix C – Abbreviations and Acronyms

| | |
|---|---|
| DOD | Department of Defense |
| DOE BER | Department of Energy, Biological and Environmental Research |
| DOE BES | Department of Energy, Basic Energy Sciences |
| DOE OBP | Department of Energy, Office of Biomass Program |
| DOE | Department of Energy |
| DOI | Department of Interior |
| DOT | Department of Transportation |
| EISA | Energy Independence and Security Act of 2007 |
| EPA OAR | Environmental Protection Agency, Office of Air and Radiation |
| EPA OPPTS | Environmental Protection Agency, Office of Pollution Prevention and Toxics |
| EPA ORD | Environmental Protection Agency, Office of Research and Development |
| EPA ORD NCEA | Environmental Protection Agency, Office of Research and Development National Center for Environmental Assessment |
| EPA OTAQ | Environmental Protection Agency, Office of Transportation and Air Quality |
| EPA | Environmental Protection Agency |
| FPIWG | Feedstock Production Interagency Working Group |
| GE | genetic engineering |
| GHG | greenhouse gas |
| NBAP | National Biofuels Action Plan |
| NGRP | National Genetic Resources Program |
| NSF | National Science Foundation |
| R&D | research and development |
| RD&D | research, development, and demonstration |
| RFS | renewable fuel standard |
| SIP | state implementation plan |
| USDA AFRI | U.S. Department of Agriculture, Agriculture and Food Research Initiative |
| USDA APHIS | U.S. Department of Agriculture, Animal and Plant Health Inspection Service |
| USDA ARS | U.S. Department of Agriculture, Agricultural Research Service |
| USDA ERS | U.S. Department of Agriculture, Economic Research Service |
| USDA FS | U.S. Department of Agriculture, Forest Service |
| USDA FSA | U.S. Department of Agriculture, Farm Service Agency |
| USDA NASS | U.S. Department of Agriculture, National Agricultural Statistics Service |
| USDA NIFA | U.S. Department of Agriculture, National Institute of Food and Agriculture |
| USDA NRCS | U.S. Department of Agriculture, Natural Resources Conservation Service |

USDA OEPNU ..... U.S. Department of Agriculture, Office of Energy Policy and New Uses
USDA OGC ..... U.S. Department of Agriculture, Office of the General Counsel
USDA..... U.S. Department of Agriculture
USGS ..... U.S. Geological Survey