

# Roadmap for bioenergy & biobased products in the US

## Executive summary

The United States has become increasingly dependent in recent decades on imported petroleum to meet its energy needs. A portfolio of more diverse and domestic feedstocks for the US's energy and chemical supply must be found to reduce dependence on fossil fuels and to secure future energy supply. Biomass resources are a sustainable and environment-friendly feedstock that can contribute significantly to a diverse energy portfolio.

The Biomass Research and Development Technical Advisory Committee ("the Committee") developed its *Vision for Bioenergy and Biobased Products in the United States* and *Roadmap for Bioenergy and Biobased Products in the United States* to define a set of achievable quantitative goals and develop an R&D strategy to enable those goals. Developed in 2002, these documents have since been used to guide the joint research solicitation issued each year by the US Departments of Agriculture and Energy. Important progress has been made since that time, and in 2005, the Committee was asked by the Secretaries of Agriculture and Energy to update its *Vision* and *Roadmap*. The *Vision* was updated in November 2006 and contained aggressive goals for the role that biobased fuels, power, and products can have in the US economy.

The *Roadmap* was updated based on a series of regional meetings held across the United States to ensure that region-specific issues and opportunities were adequately addressed. The Committee established Regional Roadmap Workshop chairs for each of the Western, Eastern, and Central Regions to guide the updating of the *Roadmap*. At each of the workshops, facilitated discussions helped local experts identify feedstocks, production, infrastructure, and market-related barriers to achieving *Vision* goals. Workshop participants then mapped technical and policy strategies to overcome those barriers.

The updated *Roadmap for Bioenergy & Biobased Products in the*

*United States* will continue to be used as a reference document for industry, academia, and policy makers to implement the steps necessary to achieving the *Vision* goals. The *Roadmap* identifies a concrete strategy of research and policy measures for decision makers. It identifies measures needed to advance biomass technologies and enable an economically viable, sustainable and economically desirable biobased industry.

**REGIONAL OPPORTUNITIES:** Several important barriers to biomass R&D technologies were identified during the Regional Roadmap Workshops. Most important are the key regional differences in the United States that must be addressed. The Western US contains large amounts of land that are underutilized and could otherwise be used to grow alternative biomass feedstocks. Also, because the Western US is so large, the feedstocks currently available are widely dispersed and are a challenge to harvest. The Eastern US comprises many small land owners, which presents significant challenges in economies of scale for production of biomass feedstocks. In addition, most Eastern biomass feedstocks are woody and therefore not as easily convertible into fuels, power, and products as are other high-starch feedstocks. The Central US has a significant amount of feedstock that can easily be converted into fuels but it lacks the necessary infrastructure to transport finished products to large-population areas in the Eastern and Western US. Distributed configurations where feedstock production, conversion facilities, and end markets are in close proximity could help make biomass technologies competitive.

**FEEDSTOCKS:** Significant research breakthroughs are needed in a number of key areas, including advances in plant science to improve the cost-effectiveness of converting biomass to fuel, power, and products. In addition, R&D in geographical information systems will help the US more accurately identify biomass availability. R&D should focus on advanced harvesting methods such as single-pass harvesters and precision forest-residue machinery. This will enable

greater amounts of biomass feedstocks to be harvested at a lower cost. Whether the feedstock is agricultural residue, forest residue, or urban waste, there are several barriers that must be overcome. Biomass can be expensive to collect, store, and transport; which the current infrastructure is not equipped to handle.

**PROCESSING & CONVERSION:** Efficiencies need to be made in the processing and conversion of biomass feedstocks. Science should strive to replicate processing systems found in nature. Major breakthroughs are needed to demonstrate that oil, sugar, and protein platforms can displace petrochemical platforms. Greater efforts are needed to utilize by-products of biomass conversion and add value. Although improvements have been made in enzyme technology, significant improvements must still be made to further cut enzyme costs, increase the speed of reactions, and increase the cost-effectiveness of fuels and products manufacture. Siting of modular, decentralized processing and conversion facilities in proximity both to feedstocks and retail markets will reduce transportation and distribution costs.

**INFRASTRUCTURE:** R&D is critical in transportation and infrastructure of biomass products. The most cost-effective method of transporting products in fluid form is through pipelines. However, biofuels cannot currently be transported through the same pipelines as petroleum fuels. This barrier must be overcome.

**END-USE MARKETS:** To develop end-use markets, targeted research is needed to evaluate biofuels and develop biofuels that are suitable for mass markets. Continued research also is needed to identify new uses for co-products.

**NON-R&D MEASURES:** A mix of policies and incentives supportive to biobased fuels, power, and products should be pursued in combination with education of both decision makers and the public on their benefits. Workforce education also will be required, as the US lacks the technical workforce to harvest, handle, and integrate biomass into existing infrastructure.

With increased national interest in bioenergy, the *Roadmap* can also provide strategic guidance to other national initiatives that seek to increase energy security and reduce dependence on oil. In particular, the *Roadmap* can provide guidance to help achieve President George W. Bush's "Twenty in Ten" goals, which established an even more aggressive goal for biofuels than did the Committee's *Vision*. Although "Twenty in Ten" was announced after the completion of the Regional Roadmap Workshops, the Committee has coordinated with the interagency Biomass R&D Board and submitted fifteen recommendations to the Board and to the Departments of Energy and Agriculture for consideration during implementation of the "Twenty in Ten" goals. These recommendations are listed in *Section 2* of this *Roadmap*.

## 1 Introduction

The United States has become increasingly dependent on imported petroleum to meet its energy needs. A more diverse portfolio of feedstocks for the nation's energy and chemical supply must be found to reduce dependence on fossil fuels and secure future domestic energy supply. Biomass resources are sustainable and environment-friendly feedstocks that can contribute significantly to a diverse energy portfolio. Electricity, transportation fuels, chemicals, and materials currently produced from petroleum and natural gas can instead be produced from biomass.

The *Roadmap for Bioenergy and Biobased Products in the United States* identifies research and policy measures needed for converting the US's biomass resources into economically and environmentally desirable biobased fuels, power, and products. It represents the collective assessment of the Biomass Research and Development Technical Advisory Committee, as well as experts from industry, academia, and government. (Members of the Biomass Research and Development Technical Advisory Committee are representatives of the biofuels industry, academia with expertise in biobased fuels and products, commodity trade associations, environment and conservation organizations, US state governments, and agricultural economics.) The research strategies outlined in the *Roadmap* will help achieve the goals established by the Committee's *Vision for Bioenergy and Biobased Products in the United States*.

Achieving the *Vision* will result in the following key benefits for the United States:

- Improved balance of trade from reduced dependence on petroleum imports
- Spur in economic growth, particularly in rural America, from newly developing bioindustries
- Reduced carbon emissions
- A more diverse energy portfolio and greater energy security

The *Roadmap* also supports the "Twenty in Ten" objective of offsetting 20% of gasoline consumption by 2017 through alternative and renewable fuels and vehicle efficiency. The *Roadmap* also outlines specific technology, infrastructure, and policy recommendations to accelerate biofuels' contributions towards this goal.

### 1.1 BIOMASS R&D TECHNICAL ADVISORY COMMITTEE

The Biomass Research and Development Technical Advisory Committee was established by the Biomass R&D Act of 2000 {PL 106-224}. Its responsibilities include advising the Secretaries of Agriculture and of Energy on the technical focus and direction of requests for proposals issued under the Biomass R&D Initiative ("the Initiative") and evaluating and performing strategic planning of pro-

gram activities relating to the Initiative {PL 106–224, §306}. The Committee represents experts from wide-ranging backgrounds relevant to biomass resources, technologies, and markets. The 2007 Committee members are listed in *Appendix A*.

## 1.2 ROADMAP UPDATE PROCESS

The original *Vision for Bioenergy and Biobased Products in the United States* was established by the Committee at the request of the Secretaries of Agriculture and of Energy in 2002. The *Vision* set aggressive goals for the use of biobased fuels, power, and products in the US for the years 2010, 2020, and 2030. The Committee followed its *Vision* with the *Roadmap for Bioenergy and Biobased Products in the United States*. Since then, the *Vision* and *Roadmap* documents have helped guide research under the joint solicitation issued annually by the Departments of Agriculture and Energy.

The Energy Policy Act of 2005 required that both the *Vision* and *Roadmap* documents be updated. To begin this process, the Committee assessed progress in achieving its *Vision* goals and held a *Vision* update workshop in November 2005. Following the workshop, the Committee developed its updated *Vision* which went through extensive peer review by the Committee, Biomass R&D Board, and independent peer reviewers. The updated *Vision* was released in November 2006.

To update its *Roadmap*, the Committee held a series of regional meetings across the United States to that ensure region-specific issues and opportunities were adequately addressed. The Committee established a *Vision* and *Roadmap* subcommittee and identified Regional Roadmap Workshop chairs for each of the Western, Eastern, and Central regions to shepherd *Roadmap* development. Each chair organized a roadmap workshop comprised local experts who, through facilitated discussion, identified feedstock, production, infrastructure, and market-related barriers to achieving *Vision* goals. The Regional Roadmap workshops and *Roadmap* development were facilitated by BCS, Incorporated (<http://bcs-hq.com>). Regional workshop participants are listed in *Appendices B–D*. Workshop participants then mapped technical and policy strategies to overcome those barriers. Many of the barriers facing biomass technologies are common across the US, so workshop discussions addressed both national and region-specific barriers and strategies. Summaries of each of the workshops were developed and provided to workshop participants for review. The results of those summaries were then evaluated and used to develop this *Roadmap* document.

## 1.3 ROADMAP STRUCTURE

The updated *Roadmap* provides research recommendations in the following categories:

### FEEDSTOCK SYSTEMS (*Section 4.1*)

- Plant Science Research
- Harvesting and Treatment
- Resource Management and Sustainable Development
- Economic Analysis

### PROCESSING & CONVERSION (*Section 4.2*)

- Analysis of Processes Found in Nature
- Oils, Sugars, and Protein Platforms
- New Approaches to Separations
- Modular and Decentralized Preprocessing and Conversion Systems
- Biodiesel Production
- Conversion Processes (Biochemical and Thermochemical)

### TRANSPORTATION, STORAGE, & DISTRIBUTION

#### INFRASTRUCTURE (*Section 4.3*)

- Pipelines
- Rail, Barge, and Highway
- Systems Integration
- Regional Markets

#### END-USE MARKETS (*Section 4.4*)

#### CROSSCUTTING PROCESSES & TECHNOLOGIES (*Section 4.5*)

- Biorefinery Demonstration and Deployment
- Transportation Studies
- Modular/Distributed Systems
- Integrated Systems Analysis
- Metrics Development
- Other Analytical Studies

In addition to R&D recommendations for all stages of biomass technology, this *Roadmap*-update discusses policy measures and related efforts to assist with market penetration of biofuels, biopower, and bioproducts (*Section 5*).

## 1.4 PROGRESS IN ACHIEVING 2002 VISION GOALS

In updating its *Vision*, the Committee first assessed progress made in achieving the goals the Committee set in its 2002 *Vision*, and in particular, the likelihood that the goals set for 2010 would be met. The Committee used this assessment to evaluate and update its *Vision* goals. In the case of biofuels, the results were positive. However, progress in biopower and in biobased products were not as promising. Rather than modify its goals for 2010, the Committee decided that its updated *Vision* would keep the same goals originally established in 2002. The Committee acknowledged where progress had been made in meeting 2010 goals and where progress was lacking. The Committee did, however, set interim goals for 2015 and modified its goals for 2020 and 2030 as follows:

**BIOFUELS:** The 2002 *Vision* set a target of 4% market share for biofuels by 2010. Since then, strong support by Federal and State lawmakers to increase the use of biofuels has caused a sharp increase in demand for and production of ethanol and biodiesel. Biofuels will reach 4% of market share before 2010, surpassing the goal set by the Committee in 2002. The Committee recognizes this important accomplishment and did not modify its goals for 2010; however, the *Vision* update in 2006 established more aggressive goals for 2015, 2020, and 2030.

**BIOPOWER:** The 2002 *Vision* set a goal of 4% market share for biopower by 2010. The United States is not on track to meet this goal. As stated, the Committee did not modify its 2010 goal when it updated its *Vision* in 2006 and has recognized the lack of progress in this area. The Committee has increased its market share goals for biopower for 2015, 2020, and 2030.

**BIOBASED PRODUCTS:** Due to lack of publicly available data on production of biobased products, it is uncertain how close US industry is to achieving the original *Vision* goal of capturing a 12% market share of products by 2010. Baseline estimates are that biobased products increased from about 5% of the market in 2002 to about 8% of the market in 2005. In its updated *Vision*, the Committee modified the units used in its goal for biobased products, changing from market share to a volumetric goal (in terms of pounds).

A full description of progress made on the Committee's 2002 *Vision* goals as well as the Committee's updated *Vision* goals can be found in the updated *Vision* released in November 2006. (See [www.biomass.govtools.us](http://www.biomass.govtools.us).)

## 2 Key recommendations for achieving the gasoline-offset "Twenty in Ten" goal

There has been rapid growth in biofuels markets since the Committee first set to update its *Vision* and *Roadmap* beginning in late 2005. In his 2007 State of the Union address, President Bush established his aggressive "Twenty in Ten" goal to offset 20% of gasoline consumption by 2017. This is anticipated to be met through a combination of renewable and alternative fuels as well as vehicle efficiency, with ethanol playing a significant role in displacing gasoline demand. The Bush Administration has also increased its focus on pursuing methods for making cost-competitive cellulosic ethanol.

The Committee fully supports this "Twenty in Ten" objective. Although the Committee's *Vision* document and its Regional Roadmap Workshops were finalized before the launch of the "Twenty in Ten", achieving aggressive gasoline-offset this goal will require major advances in the same categories of research and policy as outlined by the Committee in this *Roadmap*. This includes advances in

plant sciences and conversion technologies to make cellulosic ethanol cost-competitive. It will require infrastructure development to harvest, store, transport, and treat feedstocks, as well as advances in technology and infrastructure to produce and distribute biofuels.

At the request of the Biomass Research and Development Board, the Committee has identified priority measures that the Federal agencies should evaluate and consider as they work towards the "Twenty in Ten" goal. These key recommendations complement the technical and policy strategies outlined in later sections of this *Roadmap* (see below).

### 2.1 RECOMMENDATIONS FOR FEDERAL AGENCIES WORKING TOWARDS THE GASOLINE-OFFSET "TWENTY IN TEN" GOAL

#### 2.1.1 FEEDSTOCKS

- **R&D funding:** Government should provide funding for R&D to increase crop yields of existing crops that are producing, or can be used to produce biofuels. This should include funding for conventional crop breeding, genetic modification of crops, improved agronomic practices, and the efficient and environmentally conscious use of chemical and natural inputs. The focus should primarily be on grain and oilseed crops that help with creation of petroleum substitutes used in biobased fuels, power, and products.

- **Food sector- & environmental impact studies:** Since working toward the "Twenty in Ten" goal will require continued reliance on grain-based ethanol and soybeans for biodiesel, a study is recommended on the potential impacts (as well as mitigation strategies) on the food sector (availability of feed, cost of food, etc.) and the environment.

- **Streamline wood-waste access:** USDA should explore measures to streamline access to wood waste on both private and public lands, provided that appropriate environmental safeguards are retained. Increased access to wood products and waste will be essential to the long-term development of biofuels.

#### 2.1.2 PROCESSING & CONVERSION

- **Accelerate cellulosics R&D:** R&D should be accelerated for production of biofuels from cellulosic feedstocks to reduce costs.

- **Accelerate thermochemical research:** Thermochemical research must be accelerated to produce renewable gasoline, diesel, and higher-value chemicals (e.g., propylene, ethylene, and other short-carbon-chain compounds). Focus must be on total enterprise value, not

single-product (e.g., fuel) costs, and on by-products that have value in displacing petroleum and improving conversion costs.

- **Policies to support scale-up cellulosic biofuels:** The government should create policies that will support the scale-up of the first 2 billion gallons of cellulosic biofuels, including the establishment of several million acres of energy and bioproducts crops (non-food) and the building of plants capable of producing 2 billion gallons per year of cellulosic biofuels from the feedstocks across the nation; this will help these industries to develop themselves for future success.

- **Establish workforce training:** Academic faculty must be engaged in the research and development of the feedstocks and collection and conversion technologies if they are to be effective in training and developing the future workforce that this rapidly growing industry will need over the next 10 years. It will be challenging to produce the necessary science, engineering, and technological operations workforce if research universities and community colleges are not actively and fully engaged in this endeavor. It is also imperative to establish a program that helps community colleges develop the necessary technical training programs for associate-degree students who will likely contribute significantly in operating the biorefinery facilities.

### 2.1.3 INFRASTRUCTURE

- **Focus on resolving infrastructure issues:** Focus should be prioritized on resolving infrastructure issues, including the challenges in transporting biomass to refineries and in transporting biofuels from refineries to distributors/end points. These efforts should include infrastructure requirements for:

- Transportation of feedstocks and biofuels (including railroad car inventory and traffic control, trucking, highways, etc.).

- Dedicated bioliquid pipelines from the Midwest to East Coast, Florida, and West Coast products terminals. These could be organized like the Colonial and Plantation pipelines, as an industry consortium, with 100% US Treasury loan guarantees, eminent domain, and tariffs to repay debt service and allow for future privatization. Bioliquids would include fuels that substitute gasoline and diesel, vegetable oils that are used for food/feed and for industrial bioproducts, and chemicals derived from oilseeds.

Analyses should be conducted to determine how the existing infrastructure can be best utilized (e.g., retrofit pipelines or use pipe-in-a-pipe, upgrade rail and water transport systems, and/or increase load limits on key highways), and these results taken into account to build new infrastructure as necessary.

- **Establish a dedicated national initiative:** The government should begin a significant national initiative, similar to the US space program of the 1960s to land the first person on the Moon, to ensure that the needed infrastructure, human resources, research and development support, and policies are in place to enable the level of growth in biomass-based fuels, products, and power as proposed by President Bush and as contained in the Committee's *Vision* statement.

### 2.1.4 END-USE MARKETS

#### • Support E-85 blends

- Fund or provide new incentives for fuel retailers to install E-85 fueling infrastructure, targeting 30% of US stations in five years.

- Provide policy incentives to drive 50% of spark ignition engine vehicles to be E-85 flex-fuel vehicles by 2012. Further policy incentives are required to achieve 90% of spark-ignited engine equipped vehicles being E-85 flex-fuel vehicles by 2017. Easy identification of flex-fuel vehicles to consumers through use of yellow fuel cap and/or badging would also be beneficial.

- Provide equal tax and policy treatment for renewable gasoline and any other non-fossil fuel gasoline as for ethanol.

- **Consider all alternatives:** It is important to treat all biobased fuels, power, and products equally to encourage the development of petroleum substitutes. Bioproducts and biopower should be included along with biofuels in any policy, by setting voluntary private and mandatory public preferences for use of renewable bioproducts and biopower based on the USDA Biopreferred product labeling initiatives. Market economics and sustainability should be key considerations, not political rationalizing. The US Federal government should not set preferences for suitable transportation fuels and should encourage the development of both:

- Diesel substitutes, including renewable diesel and biodiesel.

- Other liquid transportation-fuel substitutes. All fuels generated from renewable feedstocks should be included along with ethanol and biodiesel incentive programs.

- **Federal support for biofuels, bioproducts, & biopower initiatives:** The Federal government should maintain support for existing incentives and apply these same incentives for bioproducts and biopower. Current incentives for biodiesel and renewable diesel are set to expire on December 31, 2008. Extension and expansion of these incentives through the year 2017 are needed to continue to encourage nascent technologies and stimulate R&D. A permanent extension of the volumetric ethanol excise tax credit (VEETC) subsidies for ethanol and biodiesel (and any other domestic biofuel) at current rates, or

higher if crude prices fall, should be considered. This is an absolute must for continued financing of the industry. The extended subsidies should be expanded to include bioproducts and biopower.

- **Revise fuel blend levels:** The rapid increase in production and use of renewable fuels in the last few years has created a strong need to revise the 10% blend level for biofuels (i.e., ethanol) to a more aggressive goal approaching 20%. To ensure that the mandated blend level will be an acceptable fuel, there is an *immediate* need to undertake and fund a comprehensive study of the impact of E12, E15, and E20 blends on the US car parc (fleet) and the US small-engine parc in service since 1990. This study should engage automakers, small-engine manufacturers, the ethanol industry, the petroleum industry, and their trade associations in the planning and execution through the Coordinating Research Council (CRC).

- **Tax credits:** The Internal Revenue Service (IRS) should establish tax credits (not subject to the Alternative Minimum Tax) equal to 20% on all flex-fuel, biodiesel-compatible, and hybrid vehicles (cars, trucks, and buses) produced in the US. Also, tax credits should be established for industrial and transportation machinery that use renewable petroleum substitutes for lubrication and energy transfer fluids.

- **Develop communications & outreach:** The Federal government needs to develop a comprehensive communications and outreach program that creates an industry/government voice to support the aggressive market goals of “Twenty in Ten.” Such a program should focus on developing consumer and industry awareness, reducing barriers resulting from lack of understanding, and addressing misperceptions on issues such as net energy balance, impact on food prices, and net cost of subsidies to government. While “Twenty in Ten” addresses substitutes for automotive gasoline, this program should also build awareness for bioproducts and biopower, because they can synergistically support “Twenty in Ten” goals by creating greater understanding of areas such as harvesting, collection, and processing of biomass feedstocks. It may take a new organization to provide such a cross-biomass-industry voice.

### 3 Barriers to Vision goals

Achieving the *Vision* goals will require that various barriers be overcome in all stages of the life cycle of developing biomass feedstocks and converting them to biobased fuels, power, and products. The major technical and nontechnical barriers identified that impede greater use of bioenergy and biobased products in the United States are discussed briefly below.

### 3.1 FEEDSTOCK BARRIERS

The quantities of biobased fuels, power, and products sought by the Biomass R&D Technical Advisory Committee’s *Vision* will require that biomass feedstocks be produced at low cost, in significantly higher quantities, and with properties suitable for efficient conversion. Moreover, feedstocks must be produced in an environmentally sound manner. Greater use of lower-cost feedstocks (e.g., crops, agricultural plant and animal residues) must also be pursued. These objectives require overcoming barriers in the following areas:

#### 3.1.1 PLANT SCIENCE, GENETICS, & GENOMICS

Significant breakthroughs, as well as changes in public perception and protection of intellectual property rights, are needed to overcome barriers in genomics research.

- **Scientific challenges in genetic & genomic research:** The cost-effectiveness of fuels, power, and products can be improved through genetic research to identify and develop crops with properties suitable for conversion to those end uses. Research to modify plant genes to produce specific traits (such as resistance to pests, high and low temperatures, and drought) is necessary. More understanding of plant biochemistry is needed; in particular, the intractable biochemistry of lignin is inhibiting greater use of biomass resources for advanced applications. Other barriers include the need to reduce hemicellulose content and develop yeast that will ferment cellulose sugars more effectively.

- **Acceptance of GMOs:** It is important for the biomass industry to develop new feedstocks that will be easier to grow, produce higher yields of biomass, and be efficiently processed into fuel, power, and products. These new materials will be developed through scientific advances in genetic engineering or genetically modified organisms (GMOs). Research results must convince the public, including the press, that GMOs are safe and strategically important to US energy and economic security. The biomass industries and scientific community should work together with environmental organizations and communities concerned about GMOs to communicate relevant issues more effectively. There must be a clear and consistent policy on GMOs and GMO funding aimed towards near-term commercialization. Furthermore, there must be a requirement for GMO certification (e.g., require ISO 9000 or similar type of quality control for GMO chain of custody).

#### 3.1.2 HARVESTING & TREATMENT

In the area of harvesting and treatment, high-priority technical barriers include the high cost of harvesting, of pretreatment, and of separations.

An improved biomass-collection infrastructure must be developed to support a wider variety and larger quantity of feedstocks. Feedstock handling and forest residue collection are inefficient, making biomass resources costly to harvest. Harvesting equipment designed specifically for biomass to bioenergy is nonexistent and will remain so until there is a market.

Currently, feedstock purity is not at sufficient levels to facilitate *Vision* goals for biobased power, fuels, and products. In addition, the variety of potential biomass applications requires separation of useful oils, proteins, or carbohydrates. Fractionation currently is not cost-effective, and there is also a lack of cost-effective separation technologies. Improved separation technologies and processes can create plant-based feedstocks for high-value products and end-uses.

Improvements in feedstock analysis and preparation technologies as well as in mechanical harvesting practices should help to lower the cost of harvesting and storing biomass feedstocks.

### 3.1.3 RESOURCE MANAGEMENT & SUSTAINABLE DEVELOPMENT

Challenges remain in sustainable agriculture, feedstock diversity and processing, and analysis. Specific examples include:

- **Feedstock diversity:** Currently there is not enough diversity in crops to meet the needs for bioenergy, food, and other uses. R&D needs to be conducted to develop a greater variety of feedstocks and ensure adequate year-round production. Given market conditions, growers are yet resistant to growing greater varieties of crops or new crops for fuel, power, and products, such as soy, canola, and wood.

- **Sustainable feedstock production:** Nutrient loss from soil and soil contamination are major challenges that will be faced with increasing demand for biomass feedstocks. For example, growers need to learn how to make more efficient use of nitrogen. In addition, there is a lack of data on the limits of removal of residual biomass and whether or not it will ensure sustainability. The availability of sufficient arable land and of water resources are issues that must be addressed.

More-efficient agricultural and forestry practices can result in higher yields per unit of input. New methods in erosion control, fertilization, and preprocessing can result in improved life cycle performance, sustainable practices, and enhanced feedstock production.

### 3.1.4 ECONOMIC ANALYSIS

A lack of knowledge about biomass feedstocks as well as advanced biomass technologies leads to a lack of willingness to invest in these technologies and in new crops.

- **Full systems analysis:** An entire systems analysis from feed-

stock production to end use will help both technology developers and investors identify viable applications of biomass for fuels, power, or products.

- **Higher-quality tools & data:** More-informative tools such as global positioning systems, geographic information systems for biomass feedstocks, and better “on farm” analytical resources are needed to evaluate feedstock properties, production and harvesting costs, and transportation. Such data can improve quality analysis, including risk management, analytical tools to perform large-scale biomass planning, fertilizer and pesticide inventory and tracking tools, and life cycle assessment tools.

- **Additional data** is also needed to evaluate the effectiveness of biomass conversion to fuels, power, and products.

## 3.2 PROCESSING & CONVERSION BARRIERS

Specific barriers in preprocessing and conversion include:

**ENZYMES:** Although improvements have been made in reducing enzyme costs, significant improvements must still be made to cut enzyme costs further yet, increase the speed of reactions, and decrease the cost of fuels, power, and products manufacture. Advances have been made in enzymes for processing corn stover; however, they are not yet cost-effective. Pretreatment of lignocellulose to support fermentation is being researched, including lime pretreatment methods. These may hold promise for processing and ultimately improving conversion efficiency.

**SCALABILITY:** One of the major barriers facing growth in the development and large-scale production of biobased fuels, power, and products is scalability. New and advanced conversion technologies and facilities need to be tested, developed, and demonstrated at a production-level scale in order to prove commercial viability. Overall, higher refining capacities need to be reached to achieve economies of scale. Without adequate demonstration at commercial scale, financing may be difficult to obtain.

**FLEXIBLE CONVERSION TECHNOLOGIES:** Advanced technologies are needed for mixed feedstocks (i.e., via enzyme hydrolysis; hydrolysis of cellulose) rather than one-feedstock facilities and technologies. Moreover, conversion efficiencies need to be improved overall for both thermochemical and biochemical processes. Conversion facilities should be developed and operated in an environmentally sustainable manner. For example, there may be opportunities to incorporate multiple renewable technologies at conversion facilities to improve overall energy efficiency of the facility (balance-of-plant). Water consumption is a key issue in both feedstock production and conversion. Conversion facilities requiring less water must be developed.

### 3.3 TRANSPORTATION, STORAGE, & DISTRIBUTION INFRASTRUCTURE BARRIERS

The lack of infrastructure to transport and store the feedstocks required to produce the quantity of biofuels and biobased products targeted by *Vision* goals, as well as to move finished fuels and products to market, is a major barrier facing the biomass industries.

Although improvements have been made in the transportation sector to mitigate long-distance hauling of feedstocks, the collection and transportation of a year-round supply of large and often bulky feedstocks from the field to biorefineries remains an economic challenge. This will require expanding the infrastructure of rail, trucks, and barges to handle materials in the biorefinery processing chain.

Other high-priority barriers include the loss of efficiencies in storage of wet and dry feedstocks. The storage in rural areas of bulk material harvested, such as agricultural residue, forest residue, and new energy feedstocks such as switchgrass, remains a challenge, due to the dynamic composition of these materials (which changes based on climatic conditions and biological makeup). The moisture content and low bulk density create problems for long-term storage, given that chemical composition of these material can change. The logistical challenges of building and maintaining massive warehouses to store the feedstocks are also problematic. Barriers to handling and storing unique combinations of biomass tailored for specific applications need to be overcome without sacrificing the integrity of the feedstock.

Pipelines are one of the cheapest modes of distribution. However, finished products derived from biomass are often restricted from pipelines (as well as rail, barge, and highway) due to low volume and the cost of modifications to address the different attributes of finished biobased products. For example, ethanol is both hydrophilic and corrosive. Its hydrophilic properties make ethanol absorb water residue in pipelines, and water is used in pipelines to separate different grades of gasoline. Ethanol also corrodes rubber, plastics, and metals at a greater rate than gasoline. Investments to equip pipelines and fuel pumps to handle the properties of ethanol are currently greater than the return on investment.

A better model may be to enable distributed feedstock production, conversion, and fuel/product distribution systems. In this model, feedstocks are transported over shorter distances and converted into fuels, power, or products for local use. Other high-priority technical barriers including the high cost of permitting, and certification of finished products.

### 3.4 END-USE MARKETS BARRIERS

Major barriers in end-use markets, particularly in the area of biofuels, include the need to develop nationwide fuel specifications and

performance standards for biofuels. In addition, different blend options (e.g., E-5, E-10, E-20, E-85, B-5, and B-20) that may lessen the impact on infrastructure for the deployment of biofuels need to be evaluated. There is a lack of national standards for biofuels specifications. Such standards would be necessary to ensure fuel compatibility, quality, and performance. Currently, there are too few retail outlets to dispense the biofuels production projected over the long term. While there have been improvements in flex-fuel vehicle (FFV) technologies suitable for E-85, a larger number of FFVs must be produced.

### 3.5 REGION-SPECIFIC BARRIERS

Biomass feedstocks, distribution and production systems, and retail markets for biobased fuels, power, and products vary widely by region. The Regional Roadmap Workshops were designed to ensure that these regional variations were identified and addressed in the Committee's *Roadmap*. Region-specific barriers include:

#### 3.5.1 WESTERN US

- **Underutilized resources in the West**

There needs to be greater public education on the biomass resources available in the Western US. There are limits on using Conservation Reserve Program (CRP) lands to grow biomass to produce biobased power, products, and fuels. Large portions of public land in the West could be used for bioenergy production, but must compete with farming and ranching uses. In addition to municipal solid wastes, large quantities of underutilized waste matter could be obtained if access were possible and profitable. Wildfire suppression by removing forestry residue is expensive. To offset these costs, the residue could be used to produce energy, allowing these resources to be used for bioenergy instead of posing a significant wildfire risk.

- **Accessibility to feedstocks:** The vast Western US presents challenges in managing dispersed feedstocks. There is a lack of access to biomass resources in the region and a need for technology to deal with rugged landscape, to reach agriculture and forest residues.

- **Environmental performance data:** In the West in particular, there is a lack of environmental performance data and life cycle cost analysis for western-specific biomass resources.

#### 3.5.2 CENTRAL US

- **Infrastructure:** The Central US possesses biomass feedstocks that can be easily converted into fuels, power, and products. However, the major areas of consumption are in the Western and Eastern US, and current infrastructure cannot support a cost-effective movement of biobased products to these regions.

- **Environmental issues:** The effects are not yet clear of shifting

agricultural production from food to fuel or of harvesting massive amounts of forest and agricultural residues.

### 3.5.3 EASTERN US

- **Risk management:** Land ownership in the Eastern US is characterized primarily by small landowners who cannot benefit from the economies of scale present in other regions. This increases the importance of risk evaluation tools and methods to offset or reduce financial risk.
- **Woody biomass:** Applications for woody biomass resources, more widely available in the East than in other regions, are needed to encourage Eastern growers to produce feedstocks for biobased power, products, and fuels.

## 3.6 ADDITIONAL BARRIERS

Regional Roadmap Workshop participants identified a large number of crosscutting technical and institutional barriers that must be overcome in order to achieve *Vision* goals. These include:

### 3.6.1 ABSENCE OF LONG-TERM NATIONAL COMMITMENT TO R&D

Historically, the US has not made a long-term national commitment to R&D, including, in particular, biomass-related R&D. This has been a disincentive for academia and research laboratories to invest in resources and equipment needed to make major research advances. It also has created a disincentive for universities to make major investments in biomass-related curriculum development. This consequently hinders the ability of both the industry and the academic community to attract strong researchers, reduces student enrollment in curricula such as plant sciences, and cuts the pool of technical and scientific personnel entering the industry.

Without adequate research funding, the technical breakthroughs needed to make biomass technologies competitive will not occur. With little or no funding for exploratory R&D, research on new or innovative concepts that are still in very early stages and may help identify solutions to major barriers may be at risk.

In terms of private sector R&D, industrial markets for biobased fuels, power, and products are not yet mature. Investigating fundamental biochemistry is still largely not profitable. The result is a lack of incentive to invest in research required to make feedstock advances for those products. Conversely, there is a high return on research directed to food crops and agricultural systems; similar returns and scope of research should be sought for biomass.

### 3.6.2 LACK OF LONG-TERM CONSISTENT ENERGY POLICY

Meeting the *Vision* goals of building a biobased industry cross-cuts several areas of development including feedstock production,

conversion, and distribution infrastructure. Such wide-scale efforts will require massive investment. This will not occur without a long-term national commitment. The short-term nature of energy policy and changing focus on favored energy resources and technologies has created a disincentive for industry to make long-term investments in new technology and research. The lack of a long-term consistent energy policy has also contributed to the absence of a sustained will among the public for sound and sustainable energy practices. Also, some existing farm policies provide a disincentive to grow, wasting a potentially valuable biomass resource. There is a need for a more level playing field in agricultural policy as it relates to biomass feedstocks for energy and products.

### 3.6.3 RISK-MANAGEMENT TECHNIQUES & FINANCING AVAILABILITY

A major barrier facing further development of biobased fuels, power, and products is that of financial risk. The capital costs required for achieving *Vision* goals include, among others: costs associated with testing and developing new feedstocks; construction of production facilities for fuels, power, and products; and associated infrastructure costs. With significant uncertainty about the viability of new feedstocks or conversion technologies, as well as uncertainty in end-use markets, many investors are averse to making the financial investments needed. Specific barriers include a lack of risk management techniques or risk sharing, as well as an absence of funding to bridge the gap between successful demonstration of a new technology and commercialization. In addition to the barriers facing facilities construction, there are no incentives or crop insurance policies for emerging biomass feedstocks used to produce bioenergy or biobased products.

### 3.6.4 REGULATORY BARRIERS

Roadmap Workshop participants identified several regulatory and policy-related barriers to biomass:

- **Environmental externalities:** Most important was the failure to value and account for environmental benefits of these technologies in consumer markets. For example, the low purchase price of coal makes it difficult for many alternative power generation technologies to compete on a cost basis, as does the lack of a framework or requirement for incorporating environmental factors and other externalities into purchasing decisions. Tax credits and other incentives should be implemented for biobased fuel, power, and products.
- **Permitting & siting:** These remain major obstacles to development of biorefineries. The overall permitting process is time consuming and complex. In particular, New Source Review programs are costly and delay facility development.

- **“Open” versus “closed loop”:** The Federal distinction between “open loop” and “closed loop” biomass has hampered development of widely available biomass resources, the use of which could contribute significantly to energy production. “Closed loop” biomass refers to dedicated energy crops such as corn and soy; “open loop” biomass refers to everything else used to produce finished products derived from biomass. Currently, power projects using “open-loop” biomass receive the production tax credit (PTC) at only one half the rate for wind, solar, and geothermal energy projects. In addition, the PTC has a sunset (2008) clause that creates a disincentive for capital investments in biopower.

### 3.6.5 EDUCATION/AWARENESS

A major barrier facing biomass technologies is poor public perception or lack of consumer awareness. Many United States citizens do not know what “biomass” means or how it can contribute to the country’s energy and chemicals portfolio. This was one of the most significant barriers identified by Roadmap Workshop participants.

- **Public awareness:** There is a need to educate growers, industry, retailers, and consumers about biomass, biomass products, and energy security and environmental benefits of using biomass. Consumer acceptance of biofuels, for example, is still lagging due to a misperception regarding the impact of ethanol on gasoline prices, vehicle performance, and other factors. More information resources need to be developed on the benefits of biomass, and these made accessible to consumers.

- **Voice for the industry:** One factor contributing to lack of consumer awareness is the absence of a single strong voice to represent the industry. Biomass industries and technologies are diverse; so while there are many industry organizations, associations, and others speaking on behalf of particular aspects of the industry, there is no spokesperson for the industry as a whole. This can lead to fragmented efforts to promote bioenergy, overcome ineffective policy, and educate consumers. Barriers to development of biopower include continued negative perceptions on the use of municipal solid waste (MSW) as a resource for power generation. The lack of consumer knowledge is a barrier to biobased products. Biobased procurement standards at the State level will help to increase market demand and consumer awareness and acceptance of the benefits of biobased products.

- **Curricula:** There is a need for curricula and training related to biobased fuels, power, and products. K–12 education does not adequately inform students about the benefits of biomass. At the college level, there is a serious lack of students pursuing careers in the sciences related to biomass (e.g., as plant breeders, geneticists, agronomists, and

engineers). In addition, vocational training is needed in the fuels, chemicals, and electric power industries on how biomass resources processes, products, and technologies can be integrated into those industries. Emergency first-responders must also be trained about properties of biofuels so that they can respond to emergencies that may arise.

## 4 Research and development strategies

At the core of this *Roadmap* is a highly focused research and development strategy for achieving the Committee’s *Vision* goals and President Bush’s “Twenty in Ten” goal. The recommended R&D strategies to advance all the processes that comprise the biomass-to-biofuels chain are categorized as follows:

|   |               |
|---|---------------|
| Feedstock Systems   | (Section 4.1) |
| Processing and Conversion                                   | (Section 4.2) |
| Transportation, Storage,<br>and Distribution Infrastructure | (Section 4.3) |
| End-Use Markets   | (Section 4.4) |
| Crosscutting Processes and Technologies                     | (Section 4.5) |

### 4.1 FEEDSTOCK SYSTEMS

Biomass feedstocks include forest resources and residues, agricultural crops and residues, animal wastes, and municipal solid wastes. Since the development of the Committee’s original *Roadmap*, a number of important improvements have been made in feedstock production; for example:

- The scientific community is learning more about the composition of switchgrass and the biochemistry of lignin.
- Yields are improving for crops such as miscanthus, canola, soy, wheat, and other rotational crops.
- Siloed storage capabilities have improved. Five years ago, the general consensus was that long-term storage needed to be dry, but recent research has shown that wet ensilage (45–50% moisture) is viable for 2+ years.
- Improvements have been made in the efficiency of cotton gin waste baling and storage.
- Efficiencies in pulp and paper have resulted in smaller waste streams.
- Diverse feedstocks and large quantities of underutilized waste matter represent strong opportunities for future energy and products development, including agriculture and forest residues, high-Btu-content distiller grains, hog/poultry/dairy/human manure, and municipal solid waste.

However, cost-effective production of biobased fuels, products, and power sufficient to penetrate markets significantly and attain

wider market acceptance is still needed. An important element in reducing costs will be to reduce the cost of biomass feedstocks. This includes cost reduction throughout the field-to-plant chain of feedstock systems.

Roadmap Workshop participants identified numerous strategies to overcome barriers in the feedstock system. Major objectives that will need to be achieved include:

- Producing biomass feedstocks in large enough quantities and with the desired properties that they can be more cost-effectively converted to useful fuels, power, or products
- Reducing the cost of harvesting, transportation, and storage
- Fostering the development of agricultural production designed for the purpose of energy and products (which will involve education and risk management)
- Ensuring sustainable, environmentally sound agronomic practices

This section provides research guidance in several key areas related to feedstock systems and also identifies region-specific R&D needs. Key areas for R&D in feedstock systems are:

- Plant Science and Genomics
- Harvesting and Treatment
- Resource Management and Sustainable Development
- Economic Analysis and Workforce Development

#### 4.1.1 PLANT SCIENCE GENETICS & GENOMICS

There is a strong need to identify and develop feedstock crops that have the desired yield, properties, and growth cycles. However, the current lack of plant breeders willing to assume the associated risk is inhibiting major advances in plant sciences and new crop development. Significant investment is therefore needed in basic and applied research to overcome barriers in plant science and genomics.

Research needs range from gene mapping to demonstration and testing of new crops. The following are specific research needs listed in descending order of priority:

- **Feedstock characteristics:** Research must be continued to map the genomes of plant species, as well as in breeding of new plant species. This research will allow design of plants with improved yields, drought- and temperature-tolerance, and disease- and insect- resistance. This research should also lead to improved plant characteristics such as composition, structure, yield, and other traits suitable for desired fuel, power, and product applications. Desirable traits may include high cellulose content, essential oils, tocopherols, and reduced lignin content. In the near term, researchers should identify the properties of crop oils that are desir-

able for industrial use and work towards developing plant characteristics that will produce those oils.

- **Microorganisms:** There is a strong need to understand the biochemistry of microorganisms to control biochemical reactions and to develop superior microorganisms. This includes chemical modification of proteins and harvesting high-energy-content microorganisms in nature.

- **Biodiversity:** Greater understanding of the fundamentals of plant biochemistry will lead to increased biodiversity, improving chance of success. In particular, over the near term, the biomass industry needs basic research in carbohydrate, lipid, and protein chemistry and underlying genetics.

- **Rotational crops:** In the near term, more R&D is needed in winter canola, winter wheat, and grain sorghum to evaluate their potential as rotational crops. Research is also needed to enable greater feedstock diversity.

- **Breeding:** There must be an integrated plant-breeding approach across the biomass industry.

- **Field trials:** Over the long term, feedstock research should include multi-season and multi-location field trials (e.g., 10-year trials).

- **Carbon flow:** There is a near-term need to improve the understanding of carbon flow and balance, as well as other input/output relationships in biomass feedstocks, to enable greater control of carbon and other properties.

- **Improved photosynthesis:** Basic plant science research should be conducted to increase photosynthesis efficiency from ~3% to 4% (i.e., 25% increase). Basic organic chemistry research is needed on proteins, carbohydrates, oils, and C-1 photosynthesis. A greater understanding of basic platform chemistry and the physical chemistry underlying basic chemical structures will help in chemistry design activities.

- **Replication of natural processes:** Processes found in nature should be analyzed, that they may be replicated to improve efficiency and increase yields.

- **Sustainable harvesting:** There is a need to study woody and grassy perennials and chemicals signaling for optimal harvest and transport of nonenergy nutrients back to the rest of the system.

- **Eastern feedstocks:** R&D is needed to evaluate the potential of Eastern-region feedstocks such as southern pine, willow, switchgrass, energy cane, sugarcane, hybrid poplar, and miscanthus to support varied fuel, power, and product applications.

- **Increased yields & production:** The US must gradually increase yields of current feedstocks used for fuel, power, or products (such as corn ethanol) while increasing the volumes of cellulosic fuels produced from crop residue.

4.1.2 HARVESTING & TREATMENT

The biomass/agricultural communities must identify, develop, test, and implement best practices for cost-effective and environmentally sound pretreatment, collection, storage, and transport of plant and animal residue-based biomass feedstocks. This should lead to improved plant and animal residue recovery, more effective separation, improved handling and storage technologies and procedures, and reduced environmental impacts. Achieving this will require research, development, and demonstration in a number of science and technology areas.

- **Technologies to reduce harvesting costs:** One-pass harvesting and feedstock densification systems must be developed to reduce harvesting time and cost. These systems should include technologies or methods for nutrient recycling. Similarly, there is a need for research to facilitate quick and cheap densification and demonstration of energy crops on CRP and marginal land.

Harvesting technologies are currently designed for food-based agriculture. These technologies need to be retooled to address harvesting requirements specific to biofuels, power, or products. For example, new equipment is needed for small forestry and agriculture-stover residue collection. In addition, to maximize the value received from crops, technologies should be developed to harvest more components than just the grain; resources valuable to the production of fuels, power, and products should also be extracted.

Additional analysis and research needs include economic analysis of harvesting methods and technologies to identify how to reduce costs in a sustainable way. Also, harvesting technologies that simplify downstream processing and reduce those processing costs can help to reduce overall feedstock costs for fuels, power, and products.

- **Separations:** A number of advances are needed in separation technologies. These will require analysis and research, such as:

- Analysis to identify separation science and technology needs
- Analysis to develop a better understanding of the composition of feedstocks
- R&D in separation technologies that will enable production of high-value products on a small scale

- Research to reduce particle size and enable fractionalization of feedstocks, such as research into nanotechnologies from National Science Foundation, as well as other science developed through Federal agencies, must be incorporated into feedstock operations.

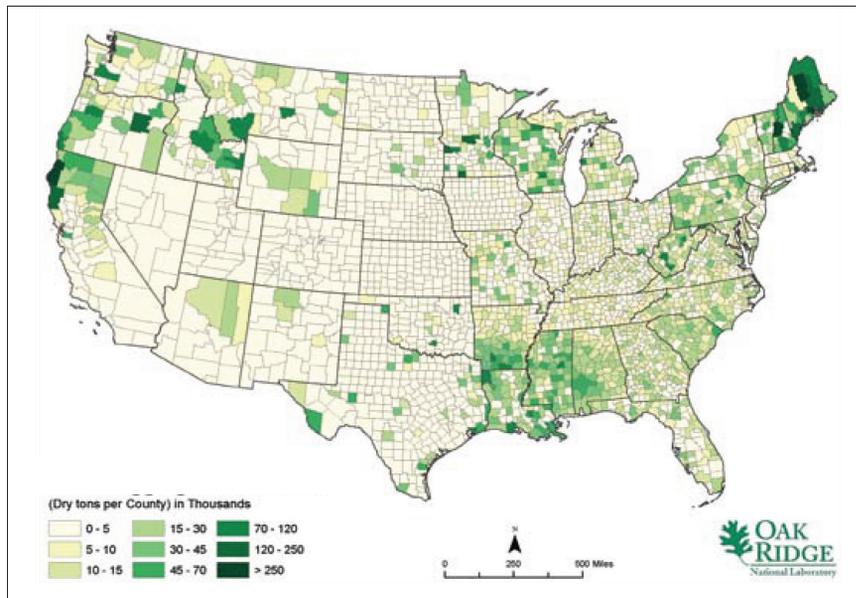


Exhibit 1: Total logging residue, 2005

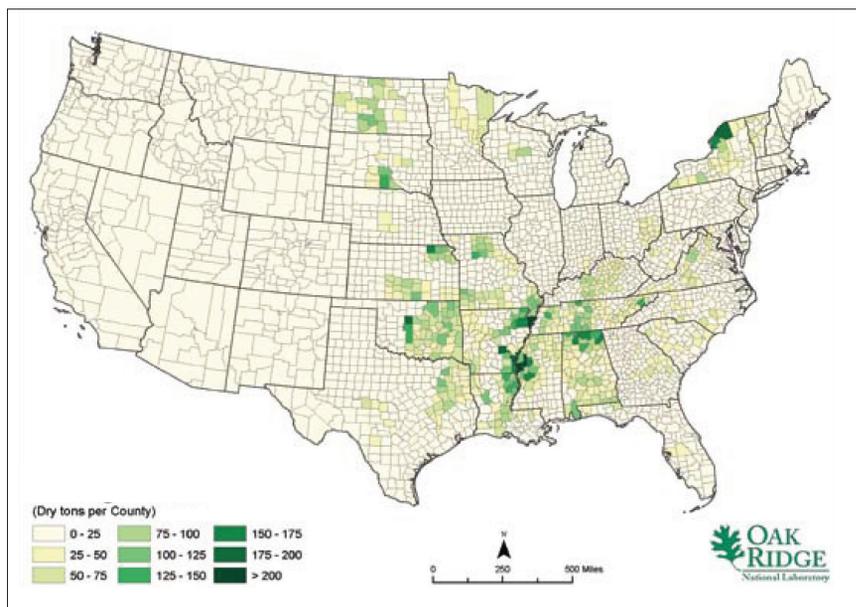


Exhibit 2: Total switchgrass, 2017

- **Field trials:** Long-term field trials are needed to test new crops, multicropping, new harvesting technologies, and sustainable agronomic practices. Over the next five years, field trials on new crops should be conducted to reduce risk, increase grower acceptance, and

develop more-efficient agronomic practices. Normalized field tests specific to each US geographic region are needed to evaluate factors such as yield, soil impact, etc. These tests should follow the US EPA model. Moreover, analysis is needed to perform comparisons and to evaluate inputs/outputs of bioenergy crops in specific soils. In the near term, there is also a need for modeling and field trials to develop an understanding of soil and ecosystem impacts of biomass removal.

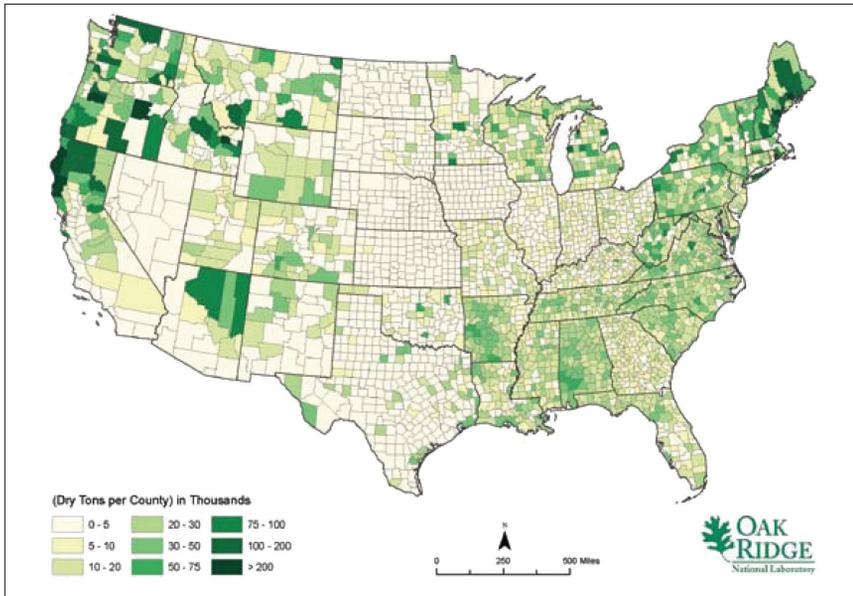


Exhibit 3: Total fuel treatment thinnings on timberlands, 2005

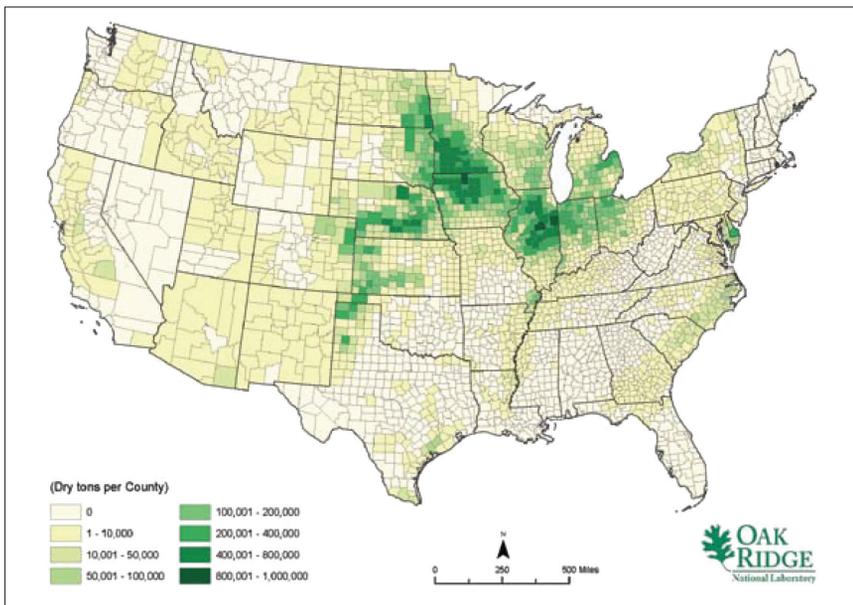


Exhibit 4: Total corn stover, 2006

#### 4.1.3 RESOURCE MANAGEMENT & SUSTAINABLE DEVELOPMENT

Attaining *Vision* goals will require increased feedstock diversity; a more sound understanding of the feedstock availability and analytical tools to evaluate land use options and feedstock potential throughout the US, and new, sustainable feedstock development practices. Research and analysis needs include the following:

- **Feedstock availability:** Current survey maps for feedstocks available in the US do not provide sufficient information (*Exhibits 1 to 4*). Specific analytical needs related to feedstock availability include:

- Developing a comprehensive land-owner survey to inform policy makers on current land use, identify opportunities for additional biomass production, and create a highly detailed feedstock-availability map. This analysis should include a perspective regarding availability of biomass as a function of cost of the material. This is especially important with regard to forestry resources.

- In the Western US, analysis is needed to quantify biomass potential, which should include natural vegetation, water, availability of CRP lands, animal resources, municipal solid waste, and marine resources. The results should be used to identify large, reliable, and consistent sources of biomass or intermediates for the Western US. There is also a need to characterize bioenergy potential from forest/grassland residues.

- **Feedstock diversity:** There is a need for low-cost methods to diversify feedstocks if *Vision* goals are to be met. A diverse feedstock portfolio will help ensure supply security and reduce the impact of price swings for a single crop. A diverse feedstock portfolio should ensure that feedstocks are available nationwide and

allow for a more localized and decentralized supply system. Feedstocks that more efficiently convert to fuels, power, and products should be developed so that growers can specifically supply those end uses.

Analysis is needed to identify undesirable plant and animal species in the US and surrounding countries and evaluate their use as a biomass resource. Impacts on wildlife and wildlife biodiversity must be included in any analysis related to feedstock diversity.

Feedstock diversity analysis will need to be region-specific. Additionally, in the Eastern and Western US, analysis is needed to evaluate greater use of domestic (municipal) solid waste and sludge as a regional solution. Such analysis should be conducted in the near term.

• **Sustainable development practices:** In order to increase feedstock development for the future needs of the US, sustainable development practices, including reduced energy inputs, are necessary. Analysis is needed to evaluate the following:

- Soil fertility issues
- Impact of residue removal
- Best practices for residue removal
- Soil management and cultivation methods for ensuring soil quality
- Sustainable feedstock production
- Methods for increasing productivity, i.e., producing more feedstock per acre

In addition, both basic and applied research is needed to evaluate opportunities for intercropping to establish multicrop farms, and production practices for alternative crops. This will require long-term growing programs and field trials. A common Federal-agency recommendation on sustainable practices will eliminate counterproductive practices and confusion among the public. Finally, a mechanism for certifying sustainability should be investigated to help market biobased energy and products.

In the Eastern US, new agronomic practices such as double cropping are needed to increase land-use efficiency. The objective is to produce more tons per acre per year as well as to develop cold-resistant plants over the next five years.

#### 4.1.4 ECONOMIC ANALYSIS

A variety of economic analyses need to be performed and models developed/implemented to evaluate the impact on the agricultural sector of attaining *Vision* goals. Specifically, this includes economic modeling of new farm-payment systems for bioenergy crops, which must be conducted in the near term. The economic and social impacts on rural communities that would result from increased use of bioenergy and biobased products should be evaluated. This analysis will evaluate impacts on rural development and energy security. Finally, the implications of utilizing the billion ton annual supply described in the US DOE/USDA report, *Biomass as a Feedstock for a*

*Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, should be analyzed for the impact on economics, supply, and the environment.

*Exhibit 5* explains the progression of research and development activities needed for the feedstock system in order to achieve the *Vision* goals. The pathways are organized into four different categories: Biofuels and Co-products, Bioproducts, Biopower and Co-products, and crosscutting Research. They are also categorized under suggested timeframes for when the research would need to be performed (near-, mid-, and long-term).

## 4.2 PROCESSING & CONVERSION

Processing and conversion include a range of activities, from enzyme development and separations in the preprocessing/processing stage to conversion of diverse biomass feedstocks into useful fuels, power, or biobased products and chemical intermediates. Conversion processes include thermochemical and biochemical conversion.

Technical advances in processing and conversion will improve production efficiencies and input/output ratios. Since the Committee's 2002 *Roadmap*, several critical improvements have been made, dramatically reducing the cost of enzymes and improving conversion efficiencies. However, a number of technical barriers still exist to commercially viable and environmentally sound processing and conversion systems for a suite of biobased fuels, power, and products. Overcoming these barriers will not only increase the variety of feedstocks that can be converted into fuels and products in particular, but also reduce cost.

Roadmap Workshop participants brainstormed R&D needs to advance processing and conversion capabilities to achieve *Vision* goals. These R&D needs fell into six subcategories:

- Analysis of processes found in nature
- Oils, sugars, & protein platforms
- New approaches to separations
- Modular and decentralized preprocessing and conversion systems
- Biodiesel and biochemical conversion
- Thermochemical conversion

While the majority of the identified R&D needs are not unique to any particular region of the US, region-specific measures are noted wherever applicable. *Exhibit 6* summarizes the R&D needs for thermochemical, biochemical, and crosscutting processes.

#### 4.2.1 ANALYSIS OF PROCESSES FOUND IN NATURE

Emphasis on agriculture and animal science research will decrease the cost of processing and conversion significantly. Specifically, analysis of processes found in nature will improve the knowledge of natural

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Exhibit 5: Feedstock Systems R&D by End-Product

**Modeling and Analysis Precursors to R&D Recommendations**

- Quantify biomass potential (particularly in the West) from all sources, including region specific: natural vegetation, waste water treatment plants, CRP model, animal, and marine
- Identify large reliable consistent sources of biomass or intermediates for Western region
- Estimate a realistic biomass production level from current CRP lands
- Characterize bioenergy potential from forest/grassland residue

**NEAR TERM (2007–2012)**

**MID-TERM (2012–2020)**

**LONG TERM (2020 FORWARD)**

**BIOFUELS AND CO-PRODUCTS**

**Existing Crops**

- Sugar/grain ethanol and biodiesel
- Residuals (agriculture, forest, urban)

**Agronomy**

- GIS and remote sensing for land use planning inventory and monitoring and enforcement
- Gray water/water treatment
- Research on yield–pest–water of poly-cultures versus genomics of monoculture

**Western-Specific**

- Ensure Western biomass assessments (sustainability)
- Year-round feedstock; R&D to stagger harvest windows for different regions in the West
- Develop agronomy for Western oil seed crops by rainfall/climate zone
- R&D on feedstocks for Western states that minimize water and fertilizer inputs
- Biomass crops systems R&D for multiple conditions unique to the West
- Modification of feedstocks to reduce environmental impacts of product
- R&D to develop Western energy crops
- Develop/improve Western-specific feedstocks/crops that are saline and drought tolerant
- Dramatically increase crop yields and reduce fossil energy inputs
- Evaluate competing water uses and competing energy crops

**Economics: Cellulosic Ethanol and Green Diesel**

- Research on the production of less expensive carbohydrates
- Improve soil productivity and maximize value added per acre in low and no-water environments

**Crop Adaptation Breeding and Genetics**

- R&D in feeds (yield increases, harvesting, reducing inputs, densification)
- R&D on biofuel options with low water demand
- Improve the utility of crop residues
- New crop development

**Advanced Feedstocks/Outputs**

- Algae feedstocks (crosscuts fuels and products)
- Hydrogen production
- Investigate plants that contain cellulases (crosscuts fuels and products)

| Exhibit 5: Feedstock Systems R&D By End-Product (continued from p. 81)   |   |  |
|--|---|--|
| NEAR TERM (2007–2012)  | MID TERM (2012–2020)  | LONG TERM (2020 FORWARD)   |
| <b>BIOPRODUCTS</b>   |   |  |
| <p><b>Biochemistry</b></p> <ul style="list-style-type: none"> <li>• Research long-term sustainability of feedstock production (soil health, residual removal)</li> <li>• Identify opportunities to utilize animal waste as bioproduct feedstocks</li> <li>• Biochemical research on forest resources, oils, and residues; wood fiber products; and animal rendering/oils</li> <li>• Utilize fish/coastal production waste</li> </ul>   | <ul style="list-style-type: none"> <li>• Investigate plants with improved oil characteristics/yields</li> <li>• Modify carbohydrate composition of plants for improved utilization</li> <li>• Research mechanisms to transfer water value to watersheds for bio growth and integration</li> <li>• Study methods to control and optimize use of GMO crops and improve public perception</li> </ul>   | <ul style="list-style-type: none"> <li>• Optimize soil chemistry by adding c-60 carbon</li> <li>• Develop multi-trait crops suitable for bioenergy and bioproducts</li> <li>• Develop plants that are suitable for dual uses (grain and cellulose availability)</li> </ul> |
| <b>BIOPOWER AND CO-PRODUCTS</b>  |   |  |
| <ul style="list-style-type: none"> <li>• R&amp;D to build waste water treatment plants as better biogas / bioenergy producers; R&amp;D on landfill design that will facilitate biogas production and harvest</li> <li>• Natural vegetation</li> <li>• Wood and biogas</li> </ul>   | <ul style="list-style-type: none"> <li>• Develop low-silicone feedstock</li> <li>• Phytoremediation and energy crop co-production</li> </ul>  |  |
| <b>CROSSCUTTING RESEARCH</b>   |   |  |
| <p><b>Existing Crops</b></p> <ul style="list-style-type: none"> <li>• Region-specific feedstock yield research (e.g., poplar, willow, etc.)</li> </ul> <p><b>Agronomy</b></p> <ul style="list-style-type: none"> <li>• Normalized field tests by region (yield, impacts) with EPA modeling; conduct head to head comparison of inputs-outputs of biocrops in specific soils</li> </ul> <p><b>Eastern-Specific</b></p> <ul style="list-style-type: none"> <li>• Develop new agronomic practices (double cropping); increase land use efficiency (tons/acre/year); cold-resistant plants for Northeast region</li> <li>• Develop methods for increased productivity per acre for small acreage growing areas</li> <li>• Region-specific feedstock yield research to identify which species/crop provide best biofuel/ energy for a specific local condition (max Btu); Eastern region feedstock (southern pine, willow, switchgrass; energy cane, sugarcane, hybrid poplar, miscanthus)</li> </ul> | <p><b>Agronomy</b></p> <ul style="list-style-type: none"> <li>• Dramatic improvement needed in water use efficiency</li> <li>• Develop standards and address challenges with using new feedstock species when there are invasive species and pest issues</li> </ul> <p><b>Soil Ecosystems</b></p> <ul style="list-style-type: none"> <li>• Study impacts of soil nutritive and productivity as a function of take-off (data)</li> <li>• Develop understanding of soil/ecosystem impacts of different types of biomass removal. Modeling and field studies</li> </ul> <p><b>Harvesting &amp; Equipmen</b></p> <ul style="list-style-type: none"> <li>• Develop new equipment for harvesting one-pass harvesting of small forestry and agriculture stover residues</li> <li>• More economic analysis of harvesting</li> <li>• Develop harvesting technology that facilitates downstream processing</li> </ul> <p><b>Harvesting &amp; Equipment, Eastern-Specific</b></p> <ul style="list-style-type: none"> <li>• Enhance/support "bio" species evaluation for Eastern region</li> <li>• Investigate other bio species not in the East</li> </ul> |  |

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processes to enable efficient deconstruction of plant material in the same environment as it was manufactured. Natural processes convert plant matter into coal, petroleum, and natural gas over millions of years. R&D identified as high-priority includes analyzing effective biological processors, such as in ruminants. R&D should seek to mimic these natural processes of converting biomass but on a much shorter time scale. By understanding how the natural world processes biomass, researchers can replicate effective biological processes in a laboratory and perhaps eventually in an industrial environment.

Additional research needs include:

- Establishing a clear route to commercialize genome technologies
- Creating models to overcome intellectual property issues
- Fostering information sharing
- Combining Federal research efforts to maximize both knowledge exchange and effective, targeted funding

#### 4.2.2 OILS, SUGARS, & PROTEIN PLATFORMS

Major breakthroughs are needed to demonstrate that oil, sugar, and protein platforms can displace petrochemical platforms. Economic analysis and modeling are needed to identify opportunities for increasing yields in these areas, including incremental yields. The following R&D needs are identified as high priority:

- Basic chemistry research on proteins, carbohydrates, and lignin to provide the fundamental knowledge for developing biobased processing.
- Research to develop commercially viable replacements for petrochemicals (as petroleum prices increase, so does the cost of petrochemicals). If the biobased industries can utilize the existing manufacturing and/or distribution infrastructure, it will facilitate faster market entry.
- Economic analysis to identify opportunities for oil and proteins to displace petrochemicals.

Additional research needs include:

- Physical chemistry of biomass to understand basic structures
- Methods to use macromolecules already applied in industry
- Technical and process improvements to increase yields of corn ethanol, as well as increase cellulosic fuels production from feedstocks other than energy crops (e.g., crop residues)

Investments in biochemical research and development should be at much higher levels, similar to investment in the petroleum industry.

#### 4.2.3 NEW APPROACHES TO SEPARATIONS

Separations research must focus on new approaches that improve efficiencies and reduce cost. High-priority R&D needs include:

- Comprehensive economic modeling, which includes all aspects of processing and conversion to enable more accurate identification of appropriate feedstocks, processing and conversion technologies, and end products for the consumer
- Identifying pathways for syngas fermentation and catalyst separation process improvement

Additional research needs include:

- Identifying pathways for enzymatic mobilization process improvement.
- Filling gaps in materials science data. R&D needs to be devoted to increasing our knowledge base on separations, which will help maximize processing and conversion.
- Reducing particle size and fractionalization to decrease transportation, processing and conversion costs.
- Advancing research devoted to biocomposite production of new materials that can utilize biomass feedstocks.

#### 4.2.4 MODULAR & DECENTRALIZED PREPROCESSING & CONVERSION SYSTEMS

A high priority for research is the development of modular pretreatment, processing, and fractionalization methods. These “on-farm” methods can reduce feedstock transportation and overall life-cycle costs as well as provide a new value stream for feedstock producers. Researchers should design economic, modular, and/or distributed systems for pretreatment and processing/fractionalization. Creating a new source of revenue for growers will encourage greater farmer interest in investing in feedstocks for fuels, power, or products. Economies-of-scale issues will need to be resolved, and systems will need to be designed to account for region-specific feedstock, harvesting, and market characteristics. Researchers should evaluate highly distributed feedstock densification, transportation, and transformation systems (e.g., gasification, saccharification) to reduce transport and storage costs for decentralized applications.

#### 4.2.5 BIODIESEL PRODUCTION

Research should be performed to reduce the cost of biodiesel production and increase biodiesel consumption. In the near term, research should be conducted to identify applications for by-products from biodiesel, identifying new value streams for biodiesel producers. Over the mid-term, methods for recovering corn oil from dry mills should be developed to provide a new method for producing biodiesel. Also in the mid-term, research should identify alternative uses of biodiesel, so that diesel facilities can remain economically viable if fuel markets move away from biofuels over the mid- to long term.

**Exhibit 6: Thermochemical and biochemical conversion R &D needs (continued on p. 85)**

| NEAR TERM (2007–2012)  | MID TERM (2012–2020)   | LONG TERM (2020 FORWARD) |
|--|--|--------------------------|
| <b>THERMOCHEMICAL</b>  |  |                          |
| <p><b>Syngas</b></p> <ul style="list-style-type: none"> <li>• Demonstration of cutting-edge syngas technologies</li> <li>• Gasification: feeding to pressurized reactors; lower tar production; economics at smaller scale</li> <li>• Gasification: gas cleaning; better synthesis catalysts</li> <li>• Demonstrate commercial-scale gasification of biomass</li> <li>• Demonstrate clean up and use for biopower</li> <li>• Understand catalytic conversion of syngas to “optimal” transport fuel</li> <li>• Convert syngas to fuel and products at appropriate scale</li> <li>• Demonstrate commercial-scale co-gasification of biomass with coal</li> </ul> <p><b>Pyrolysis Liquids</b></p> <ul style="list-style-type: none"> <li>• Improve qualities of biofuels</li> <li>• Separations by or after pyrolysis</li> <li>• Pyrolysis oil upgrading and extraction</li> <li>• Maximize development of anaerobic digestion for fuels and biopower</li> <li>• Methods for using pyrolysis liquid in crackers</li> <li>• Address ES&amp;H issues of transporting pyrolysis liquids</li> </ul> <p>Co-firing—Research long-term use of pollution control equipment.</p> <p>Develop methods to produce diesel from lignin.</p> <p>Power/Heat—Utilize biorefinery residues for CHP to contribute to biopower goals.</p> | <p><b>Syngas</b></p> <ul style="list-style-type: none"> <li>• Syngas fermentation</li> <li>• Demonstrate commercial-scale co-gasification of biomass and coal, with carbon capture and storage</li> </ul> <p><b>Pyrolysis Liquids</b></p> <ul style="list-style-type: none"> <li>• Characterize environmental properties; transportability and storage issues</li> <li>• Generate higher yields</li> <li>• Utilize more varied feedstocks</li> <li>• Upgrade to transportation fuels</li> <li>• Use in direct combustion</li> </ul> <p>Process development for high intensity small-scale facilities</p> <p>Develop highly selective thermochemical catalyst</p> <p>Develop improved mixed alcohol catalysts</p> |                          |

4.2.6 CONVERSION PROCESSES

R&D needs, to advance biochemical and thermochemical technologies with projected time frames, are summarized in *Exhibit 6*, along with the needs for integration of the developed technologies into the broader fuels, power, and chemical production infrastructures. In addition, catalyst R&D is critical for catalysts that are used in thermochemical conversion processes.

• **Biochemical conversion:** Advances are needed in biochemical conversion processes to make production of biobased fuels and products more cost-effective and to increase the variety of products

available. These technologies must be scaled up to produce quantities necessary to achieve *Vision* goals.

• **Thermochemical conversion:** Biomass resources are currently used to produce heat and power for industrial and utility-scale applications. This is primarily in the form of direct combustion or co-firing. Advances in thermochemical conversion technologies are needed to reduce the cost and environmental impacts of converting biomass to useful fuels, power, and products.

• **Catalysts:** Moreover, thermochemical technologies could be applied to the production of value-added fuels and products. Several

| Exhibit 6: Thermochemical and biochemical conversion R &D needs (continued from p. 84)   |   |   |
|--|---|---|
| NEAR TERM (2007–2012)  | MID-TERM (2012–2020)  | LONG TERM (2020 FORWARD)  |
| <b>CROSSCUTTING NEEDS</b>  |   |   |
| <p><b>Use existing infrastructure for for:</b></p> <ul style="list-style-type: none"> <li>• Co-processing of biomass streams in petroleum refineries (triglycerides, bio-oil, deployment and development)</li> <li>• Co-processing (add products) to pulp and paper mills</li> <li>• Corn mills</li> <li>• Develop ethanol from food wastes</li> <li>• Establish R&amp;D team focused on pulp and paper industry</li> <li>• Demonstrate integrated biorefinery</li> <li>• Create model biorefinery for Eastern feedstocks</li> <li>• Develop biorefinery reactors for mixed/blended and staged feedstocks (production, storage, blending and logistics)</li> </ul> | <ul style="list-style-type: none"> <li>• Deploy technologies that utilize existing infrastructure</li> <li>• Deploy emerging new technologies and demonstration of advanced technology</li> <li>• Use co-products as chemical feedstocks</li> <li>• Diversify conversion technologies</li> <li>• Conversion processes to transform proteins and lignin's into valuable co-products</li> <li>• Conversion technologies for multiple feedstocks—large and small scale</li> <li>• Improve efficiency and cost-effectiveness of separation technologies</li> <li>• Demonstrate cost competitive cellulosic ethanol</li> <li>• Achieve economy of scale in genomics for bioenergy</li> </ul> | <ul style="list-style-type: none"> <li>• Ionic liquids supercritical (SC) fluid membrane</li> <li>• Improve effectiveness of conversion technologies</li> <li>• New energy sources (e.g., hydrogen)</li> <li>• Deploy advanced technology for high cost feedstocks</li> <li>• Integrate processes to use bio and thermochemical conversion for multiple feedstocks</li> </ul> |
| <b>BIOCHEMICAL CONVERSION</b>  |   |   |
| <ul style="list-style-type: none"> <li>• Lower cost conversion of cellulose to monomer sugars; develop capability for low-cost hydrolysis</li> <li>• Combine corn starch and cellulose feedstocks in ethanol plants</li> <li>• Optimize enzyme hydrolytic efficiency based on rational understanding of feedstock chemistry and pretreatment</li> <li>• Begin new research on next generation technologies</li> </ul>  | <ul style="list-style-type: none"> <li>• Minimize water use and waste water generated</li> <li>• Fermentation: improved use of C-5 and C-6 sugars; improve efficiency of cellulosic ethanol production (enzymes, process technologies)</li> </ul>   | <ul style="list-style-type: none"> <li>• CBP—Consolidated bioprocess one-stop shop</li> </ul>   |

areas of catalysis R&D are important, including biological catalysts with greater thermo-tolerance, and highly selective catalysts to improve efficiency.

Also, R&D is needed in catalytic substrates designed for specific fuels, power, and product applications so that less processing and conversion are required.

**4.3 TRANSPORTATION, STORAGE, & DISTRIBUTION INFRASTRUCTURE**

Infrastructure issues include activities such as transportation and storage of feedstocks, as well as distribution of biobased fuels, power, and products. Technical advances in transportation and storage will improve bulk weight capacity of highway transport and rail and improve storage

| Exhibit 7: R&D needs for Biomass Infrastructure   |   |
|---|---|
| NEAR TERM TO MID-TERM (1–10 YEARS)  | MID-TERM TO LONG TERM (10–20 YEARS)   |
| <b>TRANSPORTATION- AND DISTRIBUTION-RELATED RESEARCH</b>  |   |
| <ul style="list-style-type: none"> <li>• Research to reduce transportation costs and move more tonnage per unit of energy</li> <li>• Study methods to improve rail throughput</li> <li>• Improve logistics and equipment for rail, barge, and truck transport</li> </ul>  | <ul style="list-style-type: none"> <li>• Develop an R&amp;D “test loop” for biofuel pipeline</li> <li>• Explore the transport of biomass as slurry/conduct R&amp;D on slurry movement of feedstocks &amp; water</li> <li>• LCA studies on equipment development and integration</li> </ul>  |
| NEAR TERM (1–5 YEARS)   | MID-TERM (6–10 YEARS)   |
| <b>STORAGE-RELATED RESEARCH</b>   |   |
| <p><b>Wet Storage for Biomass</b></p> <ul style="list-style-type: none"> <li>• Research integration/densification (bulk, energy)</li> <li>• Research characterization, purification, separation, and scalability</li> <li>• Develop advanced equipment for material handling</li> <li>• Improve processing technologies to increase density, extend storage life and address wet/dry storage issues</li> </ul> <p><b>Dry Storage of Biomass</b></p> <ul style="list-style-type: none"> <li>• Research integration/densification (bulk, energy)</li> <li>• Research characterization, purification, separation, and scalability</li> <li>• Improve stability and methods for quality assurance, water treatment and integration</li> <li>• Develop equipment for reclamation and densification</li> <li>• Develop ability to granularize feedstocks for optimum performance</li> </ul> | <p><b>Wet Storage of Biomass</b></p> <ul style="list-style-type: none"> <li>• Conduct densification research</li> <li>• Improve stability and methods for quality assurance, water treatment and integration</li> <li>• Improve ability for distributed manufacturing and transportation</li> <li>• Develop technology to convert biomass to easily transportable form</li> <li>• Develop technologies to collect, handle, transport, and store diverse feedstocks</li> <li>• Develop methods for feedstock pretreatment to improve ability to utilize diverse feedstocks</li> </ul> <p><b>Oil Storage for Biomass</b></p> <ul style="list-style-type: none"> <li>• Research integration/densification (bulk, energy)</li> <li>• Research characterization, purification, separation, and scalability</li> <li>• Develop portable pyrolysis for bio-oils</li> <li>• Classify feeds by “processibility” or conversion type</li> <li>• Separate lignin and cellulose or hemi-cellulose in forestry &amp; agricultural residues</li> <li>• Develop portable conversion systems for field use to enable higher density feeds</li> <li>• Ensure compatibility of feedstock blend to optimize economics</li> <li>• Develop year-round feedstock capability</li> <li>• Conduct R&amp;D to understand process robustness for different feeds in biochemical conversion</li> </ul> |

efficiencies of dry and wet materials. Advances in the distribution of biobased materials such as biofuels have already begun with increased rail car capacity, highway trucking, and distribution through pump retail centers, i.e., fueling stations. But to facilitate commercially viable infrastructure systems for biobased fuels, power, and products, a number of technical barriers must still be overcome. Overcoming these barriers will increase the variety of feedstocks and products that can be transported to processing and distribution centers. It will also improve cost-effectiveness and increase the application of biobased energy and products.

The following sections describe the major barriers to increased storage, transportation, and distribution of biomass resources, as well as research and policy measures needed to overcome those barriers. The majority of these barriers and research and policy measures are not unique to any particular region of the US; region-specific measures are noted. R&D fell into three categories:

- Pipelines
- Rail, Barge, and Highway
- Systems Integration.

*Exhibit 7* summarizes the R&D needs for biomass infrastructure.

#### 4.3.1 PIPELINES

Much of the research and development needed to improve infrastructure for deployment of biomass technologies lies in pipelines. Feasibility studies of larger pipelines and test loops are needed to test all aspects of design and manufacturing of pipelines, to open the opportunities for biofuels. Working with Federal agencies such as the Department of Transportation will help invigorate economic research on pipeline transport of biofuels and stimulate innovation on corrosion protection and online analytical sensors.

#### 4.3.2 RAIL, BARGE, & HIGHWAY

Research and development is needed in multimodal transport involving various sectors of industry to help manage bulk density and link preprocessing and transportation techniques. A greater understanding is needed of the ability of road, rail, and barge systems to handle a large increase of bioenergy feedstocks.

#### 4.3.3 SYSTEMS INTEGRATION

It is necessary to use an integrated approach to the entire processing stream from harvesting to preprocessing, conversion, transportation, and distribution, in order to maximize efficiency. An assessment of current technology is necessary to meet the *Vision* goals. Harvest, storage, and transport equipment must be optimized for each feedstock. Systems efficiency must be designed to focus on the transport stage in order to become competitive with petroleum. Efficient feedstock logistics are critical; this requires research to optimize distribution systems at volumes that make economic sense. A specific research and development objective related to systems and product integration is to identify technology that will allow ethanol to be blended at the refinery site.

#### 4.4 END-USE MARKETS

The Committee set aggressive goals for consumption of biobased fuels, power, and products in its 2006 *Vision*. These will require production improvements to lower costs, as well as measures to increase demand for and viability of biobased fuels, power, and products in end-use markets. This section outlines research recommendations to overcome those barriers.

In the near term, targeted research is needed to evaluate biofuels and develop biofuels that are suitable for mass markets. Over the

| Exhibit 8: Research Timeline to Increase Market Applications   |  |
|--|--|
| NEAR TERM (2007–2008)  | MID-TERM (2008–2012)   |
| <b>MARKET APPLICATION RESEARCH</b>   |  |
| <ul style="list-style-type: none"> <li>• Conduct research to stabilize biofuels markets</li> <li>• Develop research methods for testing quality of biofuels</li> <li>• Implement consumer awareness certification process for</li> <li>• Research low-permeability seal materials</li> </ul> | <ul style="list-style-type: none"> <li>• Develop end-use applications for industrial products, e.g., polymers and materials (high priority)</li> <li>• Develop new uses for co-products (e.g., synthetic fibers out of soy protein; biocomposites)</li> <li>• Identify specific applications for biobased products; capitalize on unique properties</li> <li>• Identify higher-value uses for lignin</li> <li>• Develop appliances that can use bioheat; involve end users in the development of user-friendly applications</li> </ul> |

longer term, continued research is needed to identify new uses for co-products. *Exhibit 8* identifies research needed to increase the penetration of biobased fuels and products into end-use markets.

Economic and market analysis should be performed to evaluate the cost and benefits of expanding biobased fuels, power, and products.

Additional research needs on market applications are as follows:

- Biotechnology research and development for very specific market applications. Clear routes to commercialization should be developed.
- Methods to produce hydrogen from biomass for fuel cell applications must be developed, including stationary hydrogen applications for distributed energy as well as fuel cells for automotive applications.
- Process technologies for better management of animal wastes and identification of value-added applications or conversion opportunities for those wastes.
- Market applications of biobased fuels, products, and power should be designed with recycling in mind. Any waste or by-products should be reusable or recyclable.

### 4.5 CROSSCUTTING PROCESSES & TECHNOLOGIES

During each of the Regional Roadmap Workshops, experts identified technical and institutional barriers as well as research and policy solutions that were crosscutting in nature and did not fit in one specific stage of the biomass technology life cycle. R&D needs addressing the crosscutting technical barriers are described below.

#### 4.5.1 BIOREFINERY DEMONSTRATION & DEPLOYMENT

Full-scale implementation of commercial-scale biorefineries (e.g., processing a minimum 700 tons of feedstock per day) is required for the long-term economic viability of biomass industries. These biorefineries will produce fuels, power, and biobased products, be environmentally sustainable, and ensure revenue streams for local growers.

Demonstrating the technical and economic viability of cellulosic biorefineries is vital, and Federal support authorized in the Energy Policy Act of 2005 should be fully funded through appropriations. Through adequate R&D and demonstration at the front end, industry should be able to develop cellulosic biorefinery technologies. A potential timeline for cellulosic biorefinery development is as follows:

- 2010 – 3 plants operational; combined production capacity of 60 million gallons
- 2011 – 6 plants operational; combined production capacity of 120 million gallons
- 2012 – 9 plants operational; combined production capacity of 300 million gallons

- 2015 – 18 plants operational; combined production capacity of 1.2 billion gallons
- 2020 – 93 plants operational; combined production capacity of 8.7 billion gallons
- 2030 – 388 plants operational; combined production capacity of 37 billion gallons

#### 4.5.2 DATA & INFORMATION

In the near term, there is a greater need for data and information to help make informed decisions on biomass. Specific recommendations include:

- A vehicle across the Federal sector and between the Federal sector and industry/academia is needed for exchange of information on technical analysis, research results, scientific and technical barriers and future plans, and other information that will add to the body of knowledge and understanding of biomass. There is a wealth of information available, and accessibility should be made easier. A clearinghouse is needed on biomass resources that should include lessons learned from related industries. For example, much has been learned in the pulp and paper and forest products industries that could be applied to biofuels. It also should include a database of biomass resources specific to Native American communities.

- Greater data is needed on the properties of diverse feedstocks as well as the processing characteristics and impact of various catalysts on different feedstocks.

- Additional life cycle analysis should be performed to help identify best practices in all stages of development for biobased fuels, products, and power, taking into account all stages from feedstock development to end use and disposal/recycling. Results will help identify sustainable agronomic practices and address issues associated with carbon removal from soil and soil sustainability, soil responsiveness to various management practices, nutrient recycling, and best practices for transportation, conversion, and distribution.

- Material science research to develop data on properties of materials used in mills as well as materials used in equipment through all stages of the biomass life cycle will help in technology and infrastructure development.

#### 4.5.3 TRANSPORTATION STUDIES

A broad-based, multimodal transportation study should be conducted, with industry involvement, to analyze transportation options for biomass feedstocks and the resulting biofuels and biobased products. In the case of biofuels, it should test all aspects of the design and manufacturing of pipelines for biofuels. These studies should involve relevant state and Federal agencies such as the US

Department of Transportation. The option of a containment model for biomass should be investigated as part of these studies (to transfer costs back to the origin, not the transporter).

#### 4.5.4 INTEGRATED SYSTEMS ANALYSIS

A near-term analytical need is the development of an integrated systems analysis to help optimize biomass systems. Manufacturing of biobased fuels, power, and products should be feedstock-driven. An integrated life-cycle economic modeling and systems optimization effort would require experts such as process, technical, financial and market analysts, engineers, distributors and retailers, agronomists, foresters, biologists, and economists. Systems integration must include technical and economic evaluations integrated with existing oil, power, chemical, and other industries. Systems analysis should identify how to optimize bioenergy systems. Systems analysis can also tackle analytical issues such as food versus fuel, land use policy, and other national and international impacts of greater use of biomass to displace fossil fuels for producing fuel, power, and products.

#### 4.5.5 METRICS DEVELOPMENT

Metrics of sustainability across the entire process should be developed over the near to mid-term. These include environmental, economic, energy, and societal metrics. Specific examples include metrics for life cycle costs or environmental impacts, carbon recycling, and others.

#### 4.5.6 OTHER ANALYTICAL STUDIES

- An economic analysis is needed to evaluate opportunities for oils and proteins to displace petrochemicals. The results of such analysis can be used to focus future R&D activities.
- Risk analysis is needed to evaluate trade-offs and investment risk/opportunity of various feedstocks. This will help growers to better make investment decisions and provide them information needed to obtain financing.
- Analysis on scalability of new technologies to evaluate cost competitiveness and facilitate technology deployment, including scaling, logistics, and safety issues, is required.
- Analyses should be conducted on the economics of biomass technologies, in particular biofuels and biobased products, under various oil price scenarios. Similarly, analysis should be performed on the strategic implications of a sharp and sustained increase in the cost of oil and the impacts of this on national and economic security and on major oil-consuming industries such as the chemicals industry, etc. This could be a collaborative analysis carried out jointly by USDA, DOE, and the Department of Defense. Similarly, the biomass industries

should lead the analysis of food-versus-fuel issues, conducting an objective and balanced evaluation of the implications, if any, on food supply and foods costs resulting from pursuit of *Vision* goals.

## 5 Policy & other enabling measures

In addition to the research strategies described in the previous sections, the Regional Roadmap Workshops generated a large number of recommendations related to the direction of future energy and research policy and incentives, education and outreach activities, and other nontechnical measures designed to foster development of biobased fuels, power, and products. A description of each of these recommendations follows.

### 5.1 FEEDSTOCK SYSTEMS

A number of policy measures can be implemented to improve the status of biomass technologies in the marketplace. For example, the Energy Policy Act of 2005 §942 mandates a reverse auction of cellulosic biofuels. This measure will, in effect, jumpstart the cellulosic biofuels industry and peg a “market” price on a gallon of ethanol. Federal policies such as this must be encouraged by the biomass industry to help deploy technologies and provide a safe environment for potential investors in cellulosic biofuels.

Recommended measures are as follows:

- **Analysis of existing policies & incentives:** There are many agriculture- and energy-related policies, incentives, and other programs that may or may not encourage greater use of biomass resources and technologies. An economic analysis of subsidy programs and other policies that promote the commercialization of successfully demonstrated, environmentally sound biobased technologies should be prepared and widely distributed. This will help to focus future activity on sound policy and incentive development by enabling informed choices among alternatives and allowing the cost of difficult-to-quantify benefits (such as energy security and environmental benefits) to be understood. A supply-chain analysis is needed on incentives and whether these would address barriers. A life cycle assessment on the environment is also needed. The impact of subsidies on world trade agreements should be included in these analyses.
- **Commodities & exchange for biomass feedstocks:** In order to encourage financial institutions to invest in the biobased fuels, power, and products market, a products commodity exchange, including futures contracts for energy crops, could be developed. An evaluation of such an exchange should be conducted. An exchange system, similar to lumber futures contracts mechanisms, would assist farmers and producers to secure financing. Cooperatives must be created in order to grow and process feedstocks that would be traded through a

national exchange. Furthermore, an effort to monetize carbon dioxide (CO<sub>2</sub>) emissions and sequestration will support investments made in biomass technologies. A commodity program for energy crops should be considered as part of the 2007 Farm Bill to restructure farm subsidies and incentivize biomass production for energy, and Congress should evaluate the costs and benefits of such a program.

- **Incentives for energy crops:** Farm subsidies should be evaluated and modified so that they reflect energy crop values. Policies that encourage energy crops can be designed to foster biomass feedstock development. Other options may include investment tax credits for productive lands, carbon credits, and a reduction in state property tax to incentivize development of energy crops and encourage farmers to preserve land for agricultural uses. Also, incentives that promote farm energy-independence should be investigated (e.g., a credit for using biomass residues for energy generation instead of disposing them). Crop insurance programs should be more accessible for energy crops. Grants and technical assistance should be provided to farmers to establish growing trials for new biomass crops. Sunset provisions should be included in subsidies and incentives so, that once crops are successful commercially, subsidies are removed.

Additional options for tax incentives include encouraging:

- Infrastructure development and investment
- Less water-intensive crop production (particularly in the Western US)
- The opening of CRP lands so that they can be used for R&D for converting biomass feedstocks to biofuels and bioenergy, and encouraging use of CRP lands to produce energy crops
- Production and harvesting of agricultural residues
- Development by forest landowners of a sustainable harvest management plan
- **GMO acceptance:** Education and collaboration efforts are needed to overcome GMO-related barriers. Environmental advocacy organizations must become partners in the effort of the biomass industry to help the US achieve less dependence on fossil fuels. The biomass industries and scientific community should work together with environmental organizations and communities concerned about GMOs, to help educate them. There must be a clear and consistent policy on GMOs. Furthermore there must be a requirement for certification for the GMO chain of custody (e.g., require ISO 9000 or similar type of quality control).

- **Basic science, intellectual property rights:** Increased research funding is needed in the basic sciences to develop the biomass feedstocks required for fuels, power, and products. There must be an effort to promote consortia of national labs, universities, and private companies to conduct basic science research. Federal agencies such

as the National Science Foundation should commit funding for basic research in areas such as biochemistry. Finally, the issue of intellectual property rights (IP) and public release of publicly funded IP after a set period of time without use needs to be addressed.

- **Land use:** There is a lack of arable land, and productive agricultural land is under pressure from urban sprawl. Incentives are needed to put land back into agricultural production. Issues related to zoning of land used for biomass storage, processing, and conversion need to be investigated to facilitate the necessary infrastructure development. Farmland protection (i.e., purchasing of development rights) is also needed and may be facilitated through Federal agencies such as the USDA Agricultural Research Service.

### 5.2 PREPROCESSING & CONVERSION

High-priority policy requirements in the area of processing and conversion include:

- **Improvements in the permitting process:** There is a need for increased flexibility in environmental permitting to implement emerging conversion technologies and facilities. Moreover, in order to reduce time, complexity, and cost, permitting processes should be consolidated and opportunities for coordination should be identified.

- **Investment incentives:** Incentives should be developed for capital investment in biorefineries as well as construction of demonstration facilities and scale-up. This is needed to support the development of a supplier base sufficient to achieve *Vision* goals. In addition, tax incentives and policies should be created to support market entry of lignocellulosics and other conversion technologies.

- **Federal research funding:** The US Federal government should substantially increase research funding to the order of two to three billion dollars to overcome barriers in basic sciences. Federal agencies should not "pick winners," and instead make this funding available for research into multiple conversion processes, including biochemical and thermochemical. Funding should be available for investigation on multiple biofuels (not only ethanol) and diverse biobased products. Also, federal funding can be applied to support development of smaller/decentralized facilities, which can cost-effectively produce biofuels.

### 5.3 INFRASTRUCTURE SYSTEMS

A number of policies are needed to improve biomass technologies in infrastructure systems. There is a lack of financial assistance to deploy R&D technologies for development of large-scale industrial (biomass) production facilities or to utilize the existing production and distribution infrastructure that was established by the petrochemical industry.

High-priority policies in storage, transportation, and distribution include the following recommendations:

- **Tax incentives & credits:** High-priority barriers identified in infrastructure systems are transportation and distribution of feedstocks, since existing feedstock-distribution infrastructure will be unable to support the aggressive *Vision* goals. Infrastructure improvements, though critically important, are expensive to implement. Thus additional incentives are needed for development of biomass depots for distributed harvest and collection sites, such as property tax credit/reduction for biofuel station owners, incentives for more coops (feedstock, producer, and marketer), and incentives for upgrading the lock and dam system in the US.

- **Policy research & studies:** Analysis should be performed to help develop rational policies for developing the infrastructure needed for the biobased economy. Analysis topics may include but are not to be limited to grid access for biopower, development of short-line railroads for transporting biomass feedstocks, feasibility of ethanol pipelines, economic impacts of biomass using various costs of oil, and the full environmental costs of fossil fuels.

- **Shared financial risk:** Federal agencies need to share the financial risk and show their support for building the biomass infrastructure, through R&D dollars, grants, and loans for collection sites and storage centers. It is critical that financial risk be shared at the early stages in order to develop pipelines and large biorefinery centers.

## 5.4 END-USE MARKETS

In considering end-use markets, Workshop participants identified policy measures specific to biobased fuels, power, and bioproducts that, if implemented, could increase their market penetration. These measures would help stimulate demand, help to reduce risk, and create incentives to produce and consume biobased energy and products. Policy measures specific to each market area are described below:

### BIOFUELS

- Develop incentives for consuming biofuels. Incentives should be based on energy and carbon content of the fuel in order to be equitable across the range of potential biofuels (high priority). This could be complemented with a product labeling program that reflects the carbon footprint and the embodied energy (e.g., Energy Star Program).
- Restructure vehicle efficiency and pollution-control policies to encourage fuel diversity and efficiency (high priority).
- Create equitable tax incentives to encourage market entry. Examples may include reducing personal property taxes for flex-fuel vehicles. Tax incentives should take into account energy and

environmental performance of the vehicles (high priority).

- Support an E85 corridor along the major interstates.
- Increase vehicle fuel efficiency through technology improvements and by increasing Corporate Average Fuel Economy Standards (CAFE) requirements.
- Reclassify ethanol as nontoxic emission.
- Set production quotas for flex-fuel vehicles.
- Require Federal and state agencies to meet a certain portion of fuel requirements with biofuels. Moreover, educational and other institutions that rely on Federal dollars should be required to have minimum standards for biofuels consumption.

### BIOWPOWER

- Enact a long-term extension of the renewable energy technologies Production Tax Credit (PTC) for the full amount.
- Alternatives to the PTC should likewise be developed or continued (e.g., the Clean Renewable Energy Bond Program).
- Increase the biomass portion of the renewable portfolio standards (especially in the Southeastern US).
- Investigate policies regarding infrastructure access in Western states to increase the opportunity for remote generation of biopower with sale to the grid.

### BIOPRODUCTS

- Create tax and other incentives to encourage production and consumption of biobased products. These should be similar to incentives for biofuels (high priority).
- Increase programs to require procurement of biobased products by Federal agencies. Increased emphasis should be placed on Department of Defense (potentially a very large biobased products customer).
- State and Federal “Buy Bio” programs should be created to jump-start markets.

## 5.5 CROSSCUTTING MEASURES

### 5.5.1 LONG-TERM AND SIGNIFICANT LEVELS OF R&D FUNDING

One of the most often recommended strategies for overcoming the lack of R&D funding was to create a national commitment similar to that of the US space program in the 1960s, applied to R&D in bioenergy and biobased products. A major boost in funding should be applied toward a multiyear, multi-agency R&D initiative. Such an initiative should include basic and applied science, focusing on all stages of biomass product development, from plant sciences to end-use markets. It should provide a higher percentage of government cost share for high-risk research and be acceptable of failure of some

scientific pursuits as part of the natural research process. Such an initiative would emphasize the sense of urgency involved in developing biomass technologies.

The initiative should involve multiple Federal agencies, including US Department of Agriculture, Department of Energy, National Science Foundation, Environmental Protection Agency, Department of Transportation, Department of Defense, and others. It should, for example, leverage biogenetics work at NIH, feedstock research at USDA, basic sciences and conversion research at DOE, and relevant work across other agencies.

Congress should fund basic research through demonstration phase, to identify several large-opportunity technology options. Selected options should be funded through commercialization to prove the technologies and identify lessons learned.

This initiative should be developed based on strong technical analysis that identifies technology and market paths with the greatest likelihood for success for reducing dependence on fossil fuel. Analysis should integrate market and financial dynamics and involve experts from the financial sector and the various industries that comprise biomass systems. Analysis should also include life cycle comparisons of various biomass and nonbiomass technology options. It should evaluate food-versus-fuel issues, and environmental impacts and sustainability issues associated with increased agricultural production and forest harvesting.

The initiative should have well-defined goals, milestones, and performance measures to evaluate progress. The initiative should build upon other current efforts and go beyond targets such as the “Twenty in Ten” goals. It should seek to reduce the level of congressionally directed funding that does not contribute to national energy goals.

One method of funding such an initiative is to place a “floor” price on petroleum via a tax. The tax would encourage efficiency and alternative fuels while also providing a revenue source for this major scientific initiative. So long as oil is relatively inexpensive compared to other energy resources, there will always be a disincentive for long-term investment or R&D in alternatives.

Roadmap Workshop participants identified other measures to increase availability and effectiveness of R&D funding for biomass:

- Integrate funding for the Biomass R&D Technical Advisory Committee’s *Roadmap* into the appropriations process so that there is a consistent flow of funding to this research
- Include Federal funding of Native American communities to develop biofuels and biopower resources and technologies
- Enact policies or incentives to foster development of renewable energy parks that may integrate distributed generation produced from biopower, wind, solar, or geothermal, as well as utilize biofuels

- Fund a new “National Presidential Bioresources Award” on the order of \$1,000,000 annually
- Increase the level of funding available through NSF grants that is directed to biomass technologies

### 5.5.2 REGULATORY & POLICY STRATEGIES

Workshop participants identified a large number of regulatory and policy strategies. High-priority recommendations include the following:

- Collect data to support development of codes and standards as well as best practices. This strategy must be employed as the industry grows to ensure successful technology and end-product performance and acceptance.
- Institute a carbon tax or petroleum displacement credit at the state and/or Federal level to create a revenue stream for alternative technologies and encourage more-efficient use of fossil fuels.
- Create a consistent, long-term, and rational energy policy. This could include region-specific policies in the form of fuel mandates or incentives.
- Reduce risk of both R&D and plant construction through state or federal government cost share, loan guarantees, or other mechanisms. Incentives should consider the entire supply chain such that conflicting incentives and disincentives are removed.
- Develop and certify sustainable practices throughout the supply chain and have them adopted internationally through multilateral agreements. This is to preclude products in other countries with lower environmental standards from being imported into countries with higher standards.
- Identify, quantify, and internalize in the market value the external costs and benefits of biomass technologies (environmental, economic, social, etc.).
- Increase transportation funds provided to states that adopt renewable fuels standards, convert fleets to biofuels, and support standards and education.
- Establish regulation and policy for carbon management.
- In the Western Roadmap Workshop specifically, participants recognized the need for regional environmental regulations and policies that address the unique characteristics of particular regions.

### 5.5.3 RISK MANAGEMENT TECHNIQUES & FUNDING AVAILABILITY

Lack of funding to move technology from the research phase to the marketplace was identified as a major barrier. Investors are often wary of new and advanced technologies until these are proven. There is often a “first-mover” syndrome with new technology, such that the majority of industry and the financial community will not invest until technology and markets are proven and perceived risk has been reduced.

Risk management mechanisms to bridge gaps in technology or project financing are needed, to encourage growers to invest in energy crops and sustainable agronomic practices, to foster investment in facilities for converting biomass to fuel, power, or products, and to encourage retailers to make the investments needed to distribute those products. Mechanisms to accomplish this include:

- Greater government cost-share of high-risk technology
- Loan guarantees
- Crop insurance and new mechanisms for financing feedstock development
- Government-supported construction of first commercialized plants to demonstrate the technology to the industry and to the investment community, and to overcome “first mover” syndrome
- Income insurance for early adopters of new feedstocks or technologies

In addition, Workshop participants called for full funding for programs authorized in the Energy Policy Act of 2005.

#### 5.5.4 PUBLIC AWARENESS & WORKFORCE DEVELOPMENT

A major push is needed to develop and encourage enrollment in biomass-related engineering and science curricula and programs. This will require a long-term commitment. A Blue Ribbon panel should be convened to develop core undergraduate and graduate curricula. Four-year degree programs are needed, but general well-rounded training and education also are needed. Future industry workers should have some level of well-rounded education in chemistry, genetics, plant biology, and economics. Extension programs should also be created to ensure life-long learning as new feedstocks, technologies, science, and industrial processes are developed.

Expanding funding for university research, grant opportunities, and graduate training fellowships, as well as funding for both university and trade programs related to biomass technologies can encourage increased faculty engagement and student enrollment, and improve curricula. Because of the opportunity biomass offers to improve energy security, a model should be developed to focus on security issues and reduction of dependence on imported fuels and chemicals. These programs should take a multidisciplinary approach and attract a combination of environmental science, agronomy, engineering, and business students. Biomass programs should be offered at both universities and trade schools. Opportunities to establish enterprise zones to foster economic development in local areas (i.e., through tax breaks) as well as opportunities to develop partnerships between industry and academia should also be investigated.

Education at the K–12 level as well as education directed toward consumers and policy makers is needed to inform them of the bene-

fits of biomass technologies. Messages should emphasize the life cycle environmental benefits of biomass, the role it can play in reducing oil imports and improving energy security, and its role in economic development.

Local guidelines need to be established on rotation of crops. This must be based on sound knowledge, with active outreach to farmers and stakeholders. Federal and state government agencies should inform and educate the agricultural sector regarding bioenergy policies to communicate opportunities for feedstock development and reduce the perception of risk associated with energy crops. These activities will have to be cognizant of the regional differences in the US, which require different policies to encourage biomass technologies in the marketplace.

Farmer and forester education programs need to be developed to reach mid-term *Vision* goals. These should include education on risk management, sustainable agricultural practices, and opportunities for growers interested in supplying the feedstocks needed to reach these *Vision* goals. Outreach activities should also help to develop the biomass industry workforce that will be needed in the near to mid-term, specifically in the areas of plant sciences, breeding, growers, and feedstock infrastructure.

Frequently, misinformation is conveyed in the mainstream media regarding biofuels and other biomass-based products. The biomass industry should make a concerted effort to correct resulting misconceptions, by developing and publishing fact-based articles, analyses, and technical papers, as well as by developing educational films appropriate for educational television broadcasts (such as PBS and the Discovery Channel). This effort should include a survey or assessment of public opinion regarding the biobased products, followed by development of messages to overcome misconceptions. These articles and films should fully describe the life-cycle energy and environmental costs and benefits of biobased fuels, power, and products. They should be developed for technical audiences as well as the general public and should convey energy-environment-society linkages, “green” aspects of biomass, adverse impacts of increased dependence on fossil fuels and imported oil, and the importance of efficient and sustainable energy and industrial practices.

A biomass coalition should be developed to represent the industry to policy makers and others. This coalition should involve environmental groups and participate in frank and open discussions and debates with detractors of biomass technologies.

#### 5.5.5 STANDARDS & CERTIFICATION

The biomass industry needs to be at the forefront of standards and certification activities and must ensure that biobased fuels, products,

and power can meet established standards of performance. The standards should be based on the function of a material and not on the product with which it competes. Evaluation of standards used in Europe for packaging materials, for example, and other standards set where biomass-based products have been implemented successfully, would be of great value. A methodology, along with analytical techniques, must be developed to establish standards and specifications. Developing standards should involve independent and government testing as well as certification on sustainability. Data will also be required to help establish safety standards for storage and conversion facilities. Standards should be set for biodegradability, and incentives should be provided for biodegradable packaging where appropriate. Standards should also be created for performance of biobased products.

A system for certifying sustainability can help in marketing biomass products. These efforts will need to address the issue of differing impurity profiles of various products and the implications for distribution and end use.

## 6 Conclusion

Considerable progress has been made in raising the profile of biomass to help offset petroleum-dependency since the Committee published its first *Roadmap* in 2002. This updated *Roadmap* outlines research and policy measures to achieve not only the Committee's updated *Vision* goals, but also newer and more aggressive national goals for biofuels. Specifically, this *Roadmap* is a tool for researchers in industry and academia, as well as policy makers in government, to understand the barriers to advancing biobased fuel, power, and products. It is also a guide for implementing the R&D strategies and policy measures needed to support biomass technologies.

The *Roadmap* will be used to guide research funded jointly by DOE and USDA under the Biomass R&D Initiative joint solicitation. Each year, the Biomass R&D Technical Advisory Committee evaluates progress of R&D performed under the joint solicitation and provides recommendations to the Secretaries of Energy and Agriculture on furthering the goals of the Biomass R&D Initiative.

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This report was prepared by the Biomass Research and Development Technical Advisory Committee, under the auspices of the Biomass Research and Development Initiative.

This text is an edited version of the report *Roadmap for Bioenergy and Biobased Products in the United States*, reprinted with permission. For more information, visit [www1.eere.energy.gov/biomass/pdfs/obp\\_roadmapv2\\_web.pdf](http://www1.eere.energy.gov/biomass/pdfs/obp_roadmapv2_web.pdf).

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|  |   |
|--|---|
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