Official Disclaimer:
This update to the 2008 National Biofuels Action Plan was based on federal laws and regulations in effect as of the end of 2012. The potential impacts of technical progress, pending or proposed legislation, regulations, standards, or any other changes that may have occurred after 2012 are not reflected in the update.
# TABLE OF CONTENTS

## FOREWORD

| Biomass R&D Board                                      | 1 |
| Purpose of this Update                                 | 1 |

## EXECUTIVE SUMMARY

| Biofuels in the Market Today                          | 3 |
| Biomass Feedstocks                                     | 3 |
| Conversion Technologies                                | 4 |
| Transport & Distribution Infrastructure and End Use    | 5 |
| Summary                                               | 6 |

## BACKGROUND

| Growth of the Biofuels Industry                        | 7 |
| Market Dynamics and Economics                          | 9 |
| The Biofuels Supply Chain                              | 10 |

## BIOMASS FEEDSTOCKS

| United States Supply Potential                         | 12 |
| Feedstocks Challenges                                  | 14 |
| Conversion Interface                                   | 17 |
| Accomplishments to Date                                | 17 |
| Feedstocks RD&D Needs                                  | 17 |
| Addressing RD&D Needs                                  | 19 |

## CONVERSION TECHNOLOGIES

| Introduction                                           | 20 |
| Accomplishments to Date                                | 20 |
| Current Status of Conversion Processes                 | 21 |
| Supply Chain Considerations                            | 21 |
| Biological and Catalytic Platforms                     | 23 |
| Thermochemical Platforms                               | 24 |
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4A</td>
<td>Airlines for America</td>
</tr>
<tr>
<td>ABPDU</td>
<td>Advanced Biofuels Process Demonstration Unit</td>
</tr>
<tr>
<td>AFRI</td>
<td>Agriculture and Food Research Initiative</td>
</tr>
<tr>
<td>ARPA-E</td>
<td>Advanced Research Projects Agency–Energy</td>
</tr>
<tr>
<td>ARS</td>
<td>USDA’s Agricultural Research Service</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>BGY</td>
<td>billion gallons per year</td>
</tr>
<tr>
<td>BILT</td>
<td>Biofuel Infrastructure, Logistics, and Transportation</td>
</tr>
<tr>
<td>CAAFI</td>
<td>Commercial Aviation Alternative Fuels Initiative</td>
</tr>
<tr>
<td>CAPs</td>
<td>Coordinated Agricultural Projects</td>
</tr>
<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>CRP</td>
<td>Conservation Reserve Program</td>
</tr>
<tr>
<td>DDGS</td>
<td>Distillers Dry Grain Solubles</td>
</tr>
<tr>
<td>DI-IWG</td>
<td>Distribution Infrastructure Interagency Working Group</td>
</tr>
<tr>
<td>DOE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>DOT</td>
<td>U.S. Department of Transportation</td>
</tr>
<tr>
<td>E10</td>
<td>gasoline at low-level blends of up to 10% ethanol and 90% gasoline</td>
</tr>
<tr>
<td>E15</td>
<td>gasoline at low-level blends of up to 15% ethanol and 85% gasoline</td>
</tr>
<tr>
<td>E85</td>
<td>blend of gasoline with up to 85% ethanol</td>
</tr>
<tr>
<td>EFRCs</td>
<td>Energy Frontier Research Centers</td>
</tr>
<tr>
<td>EISA</td>
<td>Energy Independence and Security Act</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>EPAct</td>
<td>Energy Policy Act</td>
</tr>
<tr>
<td>FAA</td>
<td>U.S. Federal Aviation Administration</td>
</tr>
<tr>
<td>FFVs</td>
<td>flexible-fuel vehicles</td>
</tr>
<tr>
<td>FS</td>
<td>USDA’s Forest Service</td>
</tr>
<tr>
<td>FSRL</td>
<td>Feedstock Readiness Level</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>H₂</td>
<td>dihydrogen</td>
</tr>
<tr>
<td>IBR</td>
<td>Integrated Biorefinery</td>
</tr>
<tr>
<td>IBRF</td>
<td>Integrated Biorefinery Facility</td>
</tr>
<tr>
<td>KDF</td>
<td>Knowledge Discovery Framework</td>
</tr>
<tr>
<td>LCA</td>
<td>life-cycle assessment</td>
</tr>
</tbody>
</table>
NABC  National Advanced Biofuels Consortium
NBAP  National Biofuels Action Plan
NIFA  National Institute of Food and Agriculture
OAR   EPA’s Office of Air and Radiation
ONR   Office of Naval Research
PDU   Process Demonstration Unit
QTR   Quadrennial Technology Review
R&D   research and development
RD&D  research, development, and demonstration
RDD&D research, development, demonstration, and deployment
RFS2  Renewable Fuel Standard
TDI-IWG Biofuels Transport & Distribution Infrastructure Interagency Working Group
USDA  U.S. Department of Agriculture
FOREWORD

Biomass R&D Board
The Biomass Research and Development (R&D) Board was created by enactment of the Biomass Research and Development Act of 2000 “to coordinate programs within and among departments and agencies of the Federal Government for the purpose of promoting the use of biobased industrial products by (1) maximizing the benefits deriving from federal grants and assistance; and (2) bringing coherence to federal strategic planning.” The Board is co-chaired by senior officials from the Departments of Energy (DOE) and Agriculture (USDA) and currently consists of senior decision makers from the DOE, USDA, Department of Transportation (DOT), Department of the Interior (DOI), Department of Defense (DoD), Environmental Protection Agency (EPA), National Science Foundation (NSF), and the Office of Science and Technology Policy (OSTP) in the Executive Office of the President.

With its diverse membership, the Board functions to facilitate coordination among federal government agencies that affect the research, development, and deployment of biofuels. The Board convenes several interagency working groups to explore and coordinate interagency work related to these challenges.

Purpose of this Update
The 2008 National Biofuels Action Plan (NBAP) identified important challenges to meeting the national goals set forth in the Renewable Fuel Standard (RFS2). The Board’s efforts strategically focus on collaboration and implementation of research and development across the federal government, in part, to identify and mitigate these challenges. Since the completion of the 2008 NBAP, technology advances and changes in economics and energy policy have altered the landscape. This update highlights many of the efforts and accomplishments of federal investments in increasing the production and use of biofuels and identifies actions needed to accelerate the biofuels industry in order to meet the RFS2. A detailed list of agency accomplishments is provided in the Appendix.

3 The United States Environmental Protection Agency (EPA) provides information about the RFS at http://www.epa.gov/otaq/fuels/renewablefuels/index.htm.
Interagency Working Groups

Since 2008, the Board has charged interagency working groups to fulfill certain objectives in accordance with its mission. Made up of technical experts from the Board member agencies, these groups meet more regularly than the Board and have been charged to complete several activities.

Feedstocks: The feedstocks working groups are assessing research and development needs to promote next-generation biofuels while conserving natural resources. Production and logistics efforts are focused on R&D to ensure sustainable feedstock supply at sufficient scale to meet the needs of a growing biofuels market. Specific focal points for feedstock production include genetic improvement and best management practices.

Distribution Infrastructure: The distribution infrastructure working group is working on infrastructure needs for biofuel distribution, including both modal transportation system and storage infrastructure. Key transportation issues for both upstream feedstock and downstream biofuel movement are being evaluated.

Conversion: The conversion working group is assessing research and development needs to improve and/or optimize the technical, economic, social, human health, and environmental performance of biomass conversion technologies and stimulate movement to commercialization.

Algae: The algae working group is advising, communicating, and coordinating federal research, development, demonstration, and deployment activities relating to the production and use of algae and their products/co-products in a sustainable manner within an appropriate regulatory framework.
EXECUTIVE SUMMARY

Biofuels in the Market Today

Since the publication of the 2008 National Biofuels Action Plan (NBAP), the growth of biofuels in the market has been considerable. The Energy Independence and Security Act (EISA) of 2007, the Food, Conservation, and Energy Act of 2008, and the American Recovery and Reinvestment Act of 2009, which authorized many bioenergy research, development, demonstration, and deployment efforts, have been driving forces in accelerating feedstock production, logistics, and conversion technology. As a result of these policies, research, pilot, and demonstration projects on biomass feedstock production, logistics, and conversion technology are in progress across the country. An effective public-private partnership has fueled tremendous technology advancements, and biofuels are expected to account for the most growth in domestic liquid fuels over the coming decades.4

The Renewable Fuel Standard (RFS2), implemented under EISA, mandates 36 billion gallons per year (BGY) of renewable fuels by 2022—a marked increase from the volumes required under the previous Energy Policy Act (EPAct) in 2005. With the RFS2 volume requirements in place, ethanol production capacity nearly doubled since 2007, leading to a near-saturation of the E10 market. In April 2012, EPA approved the first applications for registration of ethanol for use in gasoline blends that contain up to 15% ethanol (E15), enabling further expansion of the ethanol market.

While the United States is on schedule to meet RFS2 targets for conventional biofuels, meeting the cellulosic biofuel volume requirements has been challenging. Acknowledging the lack of U.S. capacity, EPA reduced the required annual volumes of cellulosic biofuels from the original statutory goals for 2010, 2011, and 2012. Major challenges stem from insufficient capital investment to establish new, commercial-scale feedstock production, logistics, and conversion technology systems.

Despite these challenges, there have been important advances in cellulosic biofuel production. The first commercial-scale cellulosic ethanol plants broke ground in 2011, and cellulosic ethanol is on the verge of cost-competitive commercialization. Additionally, drop-in fuel technologies from cellulosic feedstocks show promise in the mid- to long-term, and it is likely that other advanced biofuels will help make up shortfalls in reaching cellulosic ethanol targets.

Biomass Feedstocks

The United States has abundant agricultural and forestry resources that could be a significant resource for bioenergy. With research, land resources could be effectively used for feedstock production and still meet demand for production of other goods and services. By 2030, about 1 to 1.6 billion dry tons of sustainably available biomass could be produced annually from forestry, agricultural, and waste resources. Each feedstock can be converted into a range of fuels through various pathways. Feedstock availability will be regionally determined depending on local land, water, and growing conditions. In addition to terrestrial resources, preliminary analyses indicate that sufficient domestic land and water resources exist to potentially support production of advanced biofuels from algae.

**Major Accomplishments**

Since the publication of the first NBAP, federal agencies have made substantial investments in basic and applied research and development (R&D) for feedstocks development and in the deployment of feedstock production systems, including new programs for algal systems. Financial assistance to owners and operators of agricultural and non-industrial private forestland has supported biomass feedstock production.

In 2011, a comprehensive biomass resource assessment was completed. Partnerships with industry and universities are addressing barriers to sustainable feedstock supply. In addition, several efforts are underway to facilitate the development of advanced feedstock supply systems.

**Remaining Needs**

There have been significant advances in feedstock supply and logistics technologies, but more advances are needed to achieve the potential one billion tons annually. Improvements in production, harvest, and transport systems for bioenergy feedstocks are needed and will likely require significant efforts from industry, academia, and government.

**Conversion Technologies**

Conversion R&D is focused on advancing the state of biofuels conversion technology so that non-food biomass sources can be used in addition to conventional starch feedstocks. Multiple conversion technologies are required to accommodate the diverse characteristics of the broad range of feedstock materials and final products. Process intensification strategies are essential to this development. To date, significant R&D funding has been committed to developing technologies for cost-competitive production of cellulosic ethanol. Ongoing efforts to develop multiple conversion routes to produce a suite of hydrocarbon products and fuels will leverage previous work on ethanol production. However, new organisms, catalysts, and processing strategies are required to produce a new array of products, including transportation hydrocarbon fuels and chemicals from bio-oil.

**Major Accomplishments**

The 2008 NBAP identified research areas needed to advance biomass conversion science and technology to develop the next-generation biofuels. Federal agency research investments and partnerships with private firms have focused on engineering novel enzymes or microorganisms with enhanced metabolic capabilities and improved catalysts to economically convert lignocellulosic feedstocks to biofuels. Multiple consortia research centers for basic and applied sciences have been established to coordinate efforts in conversion technology. The results of this research are beginning to impact biofuel production practices in the commercial sector.

Since 2008, technology improvements have led to improvements in pretreatment processes, the commercialization of two enzyme packages, and catalyst and process improvements to biomass-to-syngas conversion. Recently, the first commercial-scale lignocellulosic ethanol biorefinery broke ground. Several other conversion processes are meeting their targets at pilot scale and will be ready for commercial scale soon.
Remaining Needs

In order to fully address remaining technology challenges, research is needed to gain a deeper understanding of the fundamental science, processes, and materials involved in conversion processes. The development of efficient and robust enzymes and catalysts is required for further progress. Additionally, validation of pre-commercial technology and processes will be essential to gauge progress in conversion R&D.

Transport & Distribution Infrastructure and End Use

To date, there have been few major transport and distribution bottlenecks that have impacted the transportation of increasing volumes of biofuels into the market. Policies driving biofuels deployment have helped industry meet the rapid growth in demand for biofuel infrastructure over the past decade. However, further growth of the biofuels market will likely require rapid changes to existing transport and distribution infrastructure systems.

Ethanol and biodiesel are not fully compatible with conventional petroleum infrastructure; therefore, the transportation of these biofuels requires a separate infrastructure. Long-distance transport of current biofuel products at scale requires infrastructure that is either limited in capacity (e.g., rail) or unavailable at sufficient scale (e.g., dedicated pipelines). For ethanol, the development of the necessary transportation infrastructure has been shaped by ethanol production’s unique footprint. Approximately 98% of current ethanol production capacity is located in the Midwest, close to agricultural-based feedstock production (typically 35–50 miles from corn-producing farms).

New, drop-in biofuels will also encounter distribution challenges, as the nation’s existing petroleum-based transportation infrastructure is geographically misaligned with the biofuel supply chain. These geographic constraints could be eased by building future biorefineries closer to population centers and by fueling them with locally cultivated feedstocks. However, a significant share of biofuel production would still be expected to remain in the Midwest.

Major Accomplishments

Since the 2008 National Biofuels Action Plan, several federal research studies, projects, and tools have been developed that are aimed at better understanding the biofuel supply chain and transportation barriers. Meanwhile, private industry has made notable efforts to advance biofuel distribution research, development, and deployment (RD&D). National pipeline operators have conducted materials compatibility and fuel quality testing and have deployed short-distance ethanol pipelines. The Intermediate Blends Test program, completed in 2011, led to the EPA approval of a partial waiver for the use of E15 in light-duty vehicles from 2001 and newer. Further, the sector has seen successful commercial and military trials of biomass-based jet fuel.

Remaining Needs

For the nation to meet RFS2, the U.S. biofuels industry will require a responsive, reliable, and efficient transport and distribution infrastructure that can safely deliver biofuel products to their end-use locations. Understanding current and future biofuel supply chain logistics, capacity constraints, and safety issues, and ensuring material compatibility with existing and new fuels remain important areas for continued interagency focus.
The deployment of multimodal transport infrastructure is essential, including rail, highway, waterway, and pipeline assets to move biofuel feedstock and product. The development of this infrastructure can be constrained by geography, transportation systems, finance, policy, and market volatility. If not addressed, these issues could impede the existing transportation enterprise’s ability to accommodate future biofuels production and distribution requirements. Economics, policy, and market uncertainty also significantly affect infrastructure development.

**Summary**

Biofuels are a home-grown source of economic value, energy production, and environmental improvement. To fully realize their potential impact, it is essential to continue to advance innovative technologies that will enhance their commercial development and deployment. For these efforts to be successful, there is a need for continued coordination and collaboration of research efforts across federal agencies and with industry stakeholders, academia, and state and local governments. This report puts forth recommendations from the Biomass Research and Development Board to further the progress of research and development in the biomass sector. Key agency accomplishments, activities, and major publications are detailed in the Appendix.
Growth of the Biofuels Industry

Transportation is one of the largest uses of energy in the United States, accounting for approximately 28% of primary energy consumption in 2010. Biofuels are projected to account for the most growth in domestic liquid fuels over the coming decades. The Renewable Fuel Standard (RFS2), under the Energy Independence and Security Act (EISA) of 2007, calls for 36 billion gallons per year (BGY) of renewable fuels by 2022 and establishes several fuel categories, each with specific annual volume requirements and life-cycle greenhouse gas (GHG) reduction thresholds. EISA significantly increased levels from the previous Energy Policy Act (EPAct) in 2005, which required only 7.5 BGY of renewable fuel to be blended into gasoline by 2012. As mandated by EISA, the RFS2 was implemented in 2009. It is expected to reduce GHG emissions by more than 138 million metric tons annually when fully phased in by 2022.

Of the 36 BGY of renewable fuels mandated by the RFS2 in 2022, 21 BGY are required to be advanced biofuels, which are defined as renewable fuels—other than ethanol derived from corn starch—that have a 50% reduction in GHG emissions over the life cycle of production and use when compared to conventional fuels. Of the 21 BGY of advanced biofuels, 16 BGY must come from cellulosic sources (cellulose, hemicellulose, or lignin) and achieve a 60% reduction in life-cycle GHG emissions, and 1 BGY is mandated to be biomass-based diesel. Contributions from conventional biofuels such as corn starch ethanol are capped at 15 BGY. Annual volume targets for each of the above categories of renewable fuels are included in the legislation. Figure 1 depicts the biofuel volume requirements from both EPAct and EISA.

---


The past few years have seen marked growth in conventional biofuel development. According to the Renewable Fuels Association, 14.8 BGY of boiler plate capacity and 209 facilities with operating capacity of 14.2 BGY and/or 25 MGY of planned expansion or new construction exists. Ethanol production capacity has nearly doubled in the past 4 years, reaching nearly 14 BGY in 2011, up from 7.8 BGY in 2007. Although the ethanol volumetric excise tax credit and the ethanol import surcharge, two major economic incentives for domestic ethanol production, expired on December 31, 2011, domestic ethanol production has not exhibited signs of slowing. In addition, in April 2012, the U.S. Environmental Protection Agency (EPA) approved the first applications for registration of ethanol for use in making gasoline that contains up to 15% ethanol (E15), opening the doors for expansion of the ethanol market.

While the United States is on target to meet the required volumes of conventional biofuels, meeting the cellulosic fuel volume requirements will be more challenging. These challenges stem from insufficient capital investment to establish new commercial-scale feedstock production, logistics, and conversion technology systems. EPA acknowledged the lack of U.S. capacity to produce adequate volumes of cellulosic biofuels and reduced the required annual volumes of cellulosic biofuels from the original statutory goal of 100, 250, and 500 million gallons per year (MGY) in 2010, 2011, and 2012 to 6.5 MGY, 6.6 MGY, and 8.65 MGY respectively. In January 2012, EPA noted that “other advanced biofuels, such as biomass-based diesel, sugarcane ethanol, or other biofuels may make up shortfalls in cellulosic biofuel volumes,” demonstrating the potential evolution of the biofuel market toward a broader range of renewable fuels.

Despite slower than expected growth, cellulosic ethanol is on the verge of cost-competitive commercialization, and drop-in fuel technologies from cellulosic feedstocks show promise in the mid- to long term. Drop-in fuels refer to substitutes for conventional fuel that are completely interchangeable and compatible with conventional fuel. These fuels should not require adaptation of the engine, fuel system, or the fuel distribution network, and can be used “as is” in currently available engines in pure form and/or blended in any amount with other drop-in neat, drop-in blend, or conventional fuel. New technologies and facility retrofits may allow traditional and cellulosic ethanol to continue to contribute to the pool of biofuels as intermediates for the drop-in fuels and fuel blends.

Technology advancements, fueled by government assistance, have made tremendous progress since the 2008 National Biofuels Action Plan was released. The policies of both EISA and the Food, Conservation, and Energy Act of 2008 (which authorized many bioenergy research, development, demonstration, and deployment efforts), have been driving forces in accelerating feedstock production, logistics, and conversion technology. Through the Biorefinery Assistance Program authorized in the Food, Conservation, and Energy Act of 2008 and additional programs in the American Reinvestment and Recovery Act of 2009, several biorefineries have been supported that use new technologies to convert a variety of feedstocks, including woody biomass, agricultural

---

7 Renewable Fuels Association, 2012 Annual Industry Outlook. [http://ethanolrfa.3cdn.net/d4ad95ffdb7ae8fbee_1vm62ypzd.pdf](http://ethanolrfa.3cdn.net/d4ad95ffdb7ae8fbee_1vm62ypzd.pdf).
residues, algae, industrial pulp, food processing waste, and other municipal solid waste into biofuels. Research, pilot, and demonstration projects on feedstock production, logistics, and conversion technology are in progress within every region of the country.

Market Dynamics and Economics

Continued investments are needed to overcome the “valley-of-death” between fundamental research to proof-of-concept, commercial-scale development of advanced biofuel systems. Federal financial support and shared risk have been effective in instances in which the private sector cannot or is not willing to bear the entire risk of burden for demonstration and first-of-a-kind facilities. As progress is made in achieving cost competitiveness in advanced biofuel production, the private sector should underwrite the continued development of commercial-scale efforts.

Many factors influence fuel prices in addition to market supply and demand. Despite the steady decline in domestic demand due to the recent economic downturn, petroleum and gasoline prices have been high and are expected to remain so in the near-term due to global market dynamics. The Energy Information Administration projects U.S. gasoline monthly prices (plus taxes) to be in the $3.50-$4.00 per gallon range through 2013. West Texas intermediate crude is expected to rise to more than $100 per barrel for 2012 and 2013, compared to $79 and $95 per barrel in 2010 and 2011, respectively. The potential for biofuels to be produced at a more stable, yet cost-competitive price, may be advantageous to accelerated biofuels development.

Although this revised National Biofuels Action Plan specifically focuses on liquid biofuels, it is important to acknowledge the importance of other biobased products. Only about 42% of a barrel is actually used to produce gasoline; the remainder is used for the production of specialty and industrial chemicals, diesel and aviation fuels, heating oil, and plastics (Figure 2). Biomass feedstocks and biofuels can be used to produce each of these classes of product. For example, non-fuel, petroleum-based chemicals can be replaced by those made from biological feedstocks. In addition, high-value, diverse co-products, such as key chemical intermediates and products can improve economic feasibilities, reduce risks to biorefinery investments, and expand rural economic opportunities.

![Figure 2. Products from a barrel of crude oil. Approximately 42% of a barrel of crude oil goes to gasoline production with the remainder going to other products, including diesel, jet fuel, heating oil, and other industrial products.](http://205.254.135.7/forecasts STEO/steo_full.pdf)
DOE published the Quadrennial Technology Review (QTR) in the fall of 2011. This publication was motivated in part by a request from the President’s Council of Advisors on Science and Technology (PCAST)\(^1\) for better prioritization and planning of the Federal Government’s energy-related activities to address the national energy challenges articulated by President Barack Obama.

The QTR defined a framework for thinking about the nation’s complex energy systems and investing in research and development and strategies to address these challenges. DOE considered several criteria in selecting technology priorities, including whether technologies can be demonstrated at the commercial scale within a decade (maturity), whether they will have a consequential impact on meeting the Nation’s energy goals in two decades (materiality), and whether technologies could be broadly adopted by relevant markets (market potential). In the transportation sector, DOE’s strategies include increasing vehicle efficiency, electrifying the light-duty vehicle fleet, and deploying alternative hydrocarbon fuels for heavy duty vehicles (HDVs). Biofuels are seen by DOE as the most significant source of these alternative fuels.

\(^1\) Report to the President on Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy, November 2010. \text{http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-energy-tech-report.pdf}.

**The Biofuels Supply Chain**

The biofuel supply chain can be separated into five major components: feedstock production, feedstock logistics, conversion, biofuels infrastructure, and biofuels end use (Figure 3). It is essential that these interdependent components be developed as a system. Competitive cost of the entire biofuel supply chain is critical. Overall supply chain costs are influenced by proximity of biomass to conversion technologies, infrastructure, and end-use markets. Modification of existing, and development of new, infrastructure components of the supply chain are needed to link feedstock production and logistics with conversion technologies, to move feedstocks to biorefineries and product to storage and end-use infrastructure. Throughout the supply chain, there must be cost-effective compatibility; this includes compatibility between feedstock types and conversion technologies as well as among fuels, distribution infrastructure, and vehicle technologies. Technologies that are feedstock neutral or fuel neutral will have greater economic flexibility. There is also a need to ensure that vehicles will be available to use the suite of fuels that are being produced, including ethanol, biodiesel, and advanced biofuels.

Research efforts since publication of the 2008 NBAP have focused on achieving sustainable production of 36 billion gallons of biofuels by 2022. These efforts touch on sustainable feedstock development and production systems; logistical systems for harvest, storage, transportation, and pre-processing of biomass; system performance metrics, modeling, and life-cycle analysis; conversion and refining technologies; markets and distribution systems; health and safety in context of the biofuels industry; and public health and environmental impacts of increased use of biofuels.
New supply chains will increase demand on a diverse suite of natural resources and man-made systems. Understanding the economic, environmental, and social implications (both positive and negative) is essential.

From an economic perspective, feedstock producers will require a long-term positive return for their investments. Similarly, biorefineries will require long-term profits to enable reinvestment in operation and maintenance, improved efficiencies, and potential expansions for new business opportunities. Uncertainty regarding potential policy shifts results in higher perceived risks associated with certain biofuel-related investments. Understanding potential economic impacts in other sectors is also important.

As new environmental conditions evolve, sustainable biofuel production will need to ensure that there are cost-effective systems that are resilient to unfamiliar pests, diseases, and environmental stressors in order to help maintain long-term health of soil, air, water, other natural resources, and public health. The EISA Section 204-mandated report, *Biofuels and the Environment*, identifies several environmental factors to consider in achieving large-scale sustainable production systems for biofuels.12

Socioeconomic factors are also critical to understand. Socioeconomic behaviors can directly and indirectly affect and be affected by biofuel production. Examples include technology adoption rates, risk and willingness-to-change acceptability, regional income and welfare effects and shifts, employment and human capital investments, and environmental attitudes and norms.

The following chapters discuss the issues, highlight major accomplishments, and identify research and development needed to accelerate the production and use of biofuels. The three chapters that follow—Feedstocks, Conversion, and Transport and Distribution infrastructure—address the five components of the biofuels supply chain.

**Figure 3.** The biofuels supply chain has five major components: (1) feedstock production, (2) feedstock logistics, (3) conversion, (4) distribution, and (5) end use.

BIOMASS FEEDSTOCKS

United States Supply Potential

The United States has abundant agricultural and forestry resources that have the potential to provide significant volumes of biomass feedstocks. Potential feedstocks can be divided into several categories: (1) conventional crop-based carbohydrates or lipids, (2) cellulosic feedstocks, and (3) other feedstocks for advanced biofuels, including municipal solid waste, algae, and photosynthetic microbes (Figure 4). Each feedstock can be converted into a range of fuels through various pathways.

By 2030, about 1 billion to 1.6 billion dry tons of sustainably available biomass could be produced annually from forestry, agricultural, and waste resources (Figure 5). Feedstock availability will be regionally determined and depends on local land, water, and growing conditions. In addition to terrestrial resources, preliminary analyses indicate that sufficient domestic land and water resources exist to potentially support significant production of advanced biofuels from algae.

Figure 4. Major biofuel feedstock types.

---


**Figure 5.** Feedstock supply potential, 2012–2030 at $60 per dry ton *(U.S. Billion Ton Update, https://bioenergykdf.net.)*
Feedstocks Challenges

New feedstock production and logistic systems must be integrated into current agriculture, forestry, and waste management systems if the biomass supply potential is to be realized. Use of land resources for feedstock production must accommodate continued production of goods and services for which the land is already used without adversely affecting soil, water, air, and habitat resources.

The development of low-cost, high-quality feedstocks at sufficient scale is needed to reliably and sustainably support a rapidly growing fuels industry, but significant technical barriers must be addressed before lignocellulosic biofuels can be widely deployed. Major challenges include developing cellulosic feedstocks to improve biomass yields, ease of conversion, or sustainability characteristics; developing sustainable feedstock management systems; reducing production, harvest, transport, storage, and processing costs; improving land and water resource use efficiency; and providing data and information necessary for business and policy development.

Current production systems are adapted from conventional agricultural and forestry systems that have proven records of economic efficiency for commodity and food production, but which are capacity limited and have not been optimized for bioenergy feedstocks. Improvements to existing production systems and implementation of new systems are slow because they are dependent on niche markets for new products that restrict broad commercialization and widespread deployment of new production technologies.

Production, harvest, and transport systems must be optimized for each specific bioenergy feedstock and therefore require great diversity in technical approach. Two major supply chain shifts are required for future feedstock production: (1) in the near term, current niche and waste stream utilization systems must become more efficient; and (2) in the long term, new feedstock production and logistics systems must be developed. In addition, achieving a national-scale biofuels industry will require supply systems that convert raw biomass into infrastructure-compatible commodity feedstocks. This production could be achieved by coupling high-quality energy crops with logistics systems to provide dense, uniform feedstocks tailored to specific biorefinery requirements.

Figure 6. Investments are facilitating the development of new technologies to harvest and process high-yielding dedicated energy crops. This photo shows the New Holland Willow Harvester, a forage harvester that has been adapted to harvest willow trees for bioenergy production.

In order to encourage feedstock production for renewable energy, the 2008 Farm Bill authorized the U.S. Department of Agriculture (USDA) to administer a program to incentivize hundreds of growers and landowners farming nearly 48,000 acres to provide biomass to energy conversion facilities.\textsuperscript{16} Currently, projects in more than 100 counties include crops such as giant miscanthus, camelina, and hybrid poplar trees; switchgrass, big bluestem, Illinois bundleflower, and purple prairie clover, suitable native grasses, legumes, and forbs, and native grass located on expired Conservation Reserve Program (CRP) fields. To reduce the risk for farmers looking to produce biomass for renewable energy, insurance coverage for farmers growing biofuel crops is under development and is helping to identify American farmland most suitable for growing energy crops. In National Forests, contracts have been made with private businesses to remove 3.7 million tons of biomass to produce energy. The U.S. farm and forestry sectors are showing that they are capable of producing a diverse complement of feedstocks to make the biofuels industry a truly National effort.

\textbf{Figure 7.} Location of current Biomass Crop Assistance (BCAP) projects.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{Biomass Crop Assistance Program Approved Project Areas}
\end{figure}

\textsuperscript{16} USDA Farm Service Agency. \url{http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap}
Figure 8. Advances in science and innovations in technology are needed to overcome challenges in feedstock logistics.

**New Logistics Approach**

**Current Near-Term Approach**

**Future Long-Term Approach**
Conversion Interface

Significant advances in feedstock supply and pre-processing are required before lignocellulosic biofuels can be cost-effectively produced at a commercial scale. The physical and compositional characteristics of the feedstock will impact which conversion process is appropriate. Feedstock properties—including including particle size, density, and moisture content—affect the technologies needed for effective conversion. For most locales, a variety of lignocellulosic materials could potentially be supplied to a conversion facility. Different feedstocks are composed of varying amounts of cellulose, hemicellulose, and lignin. They hence require variations in optimal processing conditions and result in product variability. Even within the same biomass species, variability attributed to changes in year-to-year growing seasons, time of collection, and storage presents additional complications. Similarly, hardware for specific conversion processes affects the range of usable feedstocks. Thus, the development of the feedstocks and conversion technologies are not independent events.

Accomplishments to Date

Since the publication of the 2008 NBAP, federal agencies have made substantial investments in basic and applied R&D for feedstock development and in the deployment of feedstock production systems. Several new centers have been established to coordinate research and development activities, and initiatives have been kicked off to facilitate the development of advanced feedstock supply systems. Partnerships with industry and universities are addressing barriers to sustainable feedstock supply. To address future feedstock potential, an algae R&D program was launched to explore the long-term potential of algal biofuels and facilitate industry efforts. A major accomplishment was the completion of a comprehensive biomass resource assessment in 2011. A detailed list of agency accomplishments and activities is provided in the Appendix.

Feedstocks RD&D Needs

In order to ensure rapid progress in the sustainable production of bioenergy feedstocks, several issues need to be addressed through research and technology development and deployment:

**Improved systems efficiency and economics**

- Continue development of dedicated biomass feedstocks focused on optimizing yield, nutrient/water utilization, and conversion of lignocellulose to biofuels and bioproducts. These goals will require further emphasis on developing genetic/breeding tools and understanding the underlying genomics and systems biology of relevant plant species.
- Improve productivity and resource-use efficiency of integrated biomass feedstock production systems, including cost-effective resource delivery and use practices and effective management systems.

**Improved management of sustainable production systems**

- Develop improved feedstocks and management practices for specific production environments associated with regional variability. Increase understanding and mitigation of long-term impacts of biomass production on soil, water, air, and habitat resources.
- Perform long-term maintenance of water quality. Examine issues related to water demand and quality. Develop feedstocks and management systems to increase feedstock and biofuels production while sustaining or enhancing water availability, quantity, and quality within watersheds and basins.

---

17 Feedstock Partnerships, SunGrant Initiative. [http://www.sungrant.org/Feedstock+Partnerships](http://www.sungrant.org/Feedstock+Partnerships)

• Perform long-term maintenance or enhancement of soil quality. Examine impacts of biomass production on soil carbon content, nutrient status, and biogeochemical processes under different feedstocks and management practices. Develop management systems that maintain or enhance soil productivity, quality, and carbon retention.

**Development of effective decision support tools**

• High-capacity feedstocks can have significant social and economic impacts on rural communities. Appropriate deployment depends on having sufficient data to reduce risks and to successfully commercialize all components of the production/use cycle.

Specific RD&D needs include the following:

**Plant material**

• Intensify and expand plant breeding for feedstock crops for yield, quality, and adaptation to specific environments.

• Understand the genes controlling plant growth, water utilization, nutrient acquisition, and the physical and chemical properties of cellulose, lignin, and other structural polymers.

• Accelerate development of genomic tools and resources to enhance feedstocks.

**Production**

• Quantify resource demands (e.g., water, nutrient, and pest management) and management inputs.

• Evaluate cultivar potential and develop best management practices for sustainable production.

• Evaluate harvest timing, frequency, and intensity options on yield, quality, and sustainability.

• Develop systems and practices to integrate sustainable energy feedstock production into conventional agriculture, forest, and rangeland management systems without impacting output.

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

• Develop algal production systems to utilize wastewater and CO₂.

**Logistics**

• Develop densification and other preprocessing technologies and strategies to increase bulk and/or energy density and to handle moisture issues.

• Design innovative equipment and systems specifically for cellulosic biofuel feedstocks.

• Develop logistics operations that maximize uniformity and consistency of delivered feedstock attributes.

• Develop new transportation technology to reduce truck traffic and transportation costs, reduce impact on roads and bridges, and reduce undesirable social impacts.

• Provide live demonstrations of evolving and new technologies.
Information, data, and models

- Develop biomarker and remote sensing applications for collecting environmental data.
- Develop models and other analytical tools based on experimental field trials that assess productivity, economic, environmental, and social factors to predict the outcomes of production options and management practices.
- Adapt and expand existing production, economic, social, and environmental data for model development and to monitor and assess feedstock production systems.
- Understand interrelationships between biofuels/bioproducts and food markets, in competing uses for land, water, and feed byproducts.

Addressing RD&D Needs

The barriers and corresponding RD&D needs are organized among the major components of a biofuels feedstock production cycle that collectively evolve into feedstock production systems. The roles of specific federal agencies in addressing the barriers and in developing and deploying the feedstock production systems are dependent on program missions, authorities, capabilities, organizational structure, and resources. Figure 9 shows conceptually the involvement of the agencies in the biomass production systems activities.

Figure 9. A conceptual model for the coordination of RD&D for feedstocks production cycle.
CONVERSION TECHNOLOGIES

Introduction

Because of the diversity in biomass resources, multiple conversion technologies are needed to accommodate the physical and chemical characteristics of the broad range of feedstock materials. Therefore, final products and strategies that consider the whole supply chain must be employed. To date, significant R&D funding has been committed to developing technologies for cost-competitive production of cellulosic ethanol. Beyond cellulosic ethanol, developing multiple conversion routes to produce a suite of hydrocarbon products and fuels will leverage previous work on ethanol production, particularly in the production of stable intermediates such as cellulosic sugars/carbohydrate derivatives and syngas. However, new organisms, catalysts, and processing strategies are required to produce a new array of products, including transportation hydrocarbon fuels and chemicals from bio-oil.

There are two major routes for converting cellulosic biomass to biofuels: (1) biological processes that employ enzymes and/or microbes to generate biofuels such as alcohols, fatty acid esters, or hydrocarbons as products, and (2) thermal and chemical catalytic processes that use heat and catalysts to deconstruct biomass components and produce fuel-type hydrocarbon molecules, such as alkanes, as products. These approaches have been characterized as biochemical and thermochemical “platforms” for biomass conversion, respectively. While this categorization allows for a general appraisal of progress based on the end product, many hybrid approaches are also possible.

Conversion R&D is focused on advancing the state of biofuels conversion technology so that non-food biomass sources can be used in place of conventional starch feedstocks. In order to fully address remaining technology challenges, the Board is supporting a suite of R&D efforts, including the following:

- Research to gain a deeper understanding of the fundamental science, processes, and materials involved, such as the make-up and deconstruction of the plant cell wall
- Development of efficient and robust enzymes and catalysts
- Validation of pre-commercial technology and processes.

Accomplishments to Date

The 2008 NBAP identified research areas needed to advance biomass conversion science and technology for development of next-generation biofuels. Federal agency research investments and partnerships with private firms over the past four years have focused on engineering novel enzymes or microorganisms with enhanced metabolic capabilities to economically convert lignocellulosic feedstocks to biofuels. The results of this research are beginning to impact biofuel production practices in the commercial sector.

Since the publication of the previous 2008 National Biofuels Action Plan, the private sector has commercialized two enzyme deconstruction packages developed, in part, with R&D funding from DOE. Improvements in technologies have enabled demonstration of small-scale commercial deployment of cellulosic ethanol facilities. Recently, the first commercial-scale lignocellulosic ethanol biorefinery broke ground, and other commercial-scale biorefinery processes are planned for the near term. The effectiveness of pretreatment methods for biomass feedstocks has been
improved, increasing xylan to xylose conversion\textsuperscript{19} by 13\% in 4 years, resulting in more efficient, less-expensive pretreatments while generating higher yields of intermediate sugars.\textsuperscript{20} Also, fermentative organisms have been improved to show enhanced titers, rates, and yields, as well as enhanced temperature and inhibitor tolerance and increased carbon utilization using multiple hydrolyzate streams.

For thermochemical catalytic routes to ethanol, federally supported efforts have resulted in improved reforming catalysts and process engineering schemes to improve methane and benzene conversion efficiencies. Methane and benzene are notoriously difficult to catalytically convert into syngas, and are used as benchmarks for other tars that are less recalcitrant to cracking into syngas. From 2007 through 2012, there was a 60\% improvement in tar reformer methane conversion and a 19\% improvement in tar reformer benzene conversion to syngas (indicating the percent of gasification derived methane and benzene, which were converted to CO and H\textsubscript{2} on a single pass over the catalyst). Additionally, improved fuel synthesis catalysts have increased ethanol yields by nearly 20 gallons per ton of cellulosic feedstocks, equating to a 58\% improvement in ethanol synthesis catalyst productivity overall (g-EtOH/kg-catalyst/hr). By the end of 2012, the target is to demonstrate a conversion cost of $1.31/gal EtOH (2007\$).\textsuperscript{21} A detailed list of agency accomplishments and activities is provided in the Appendix.

**Current Status of Conversion Processes**

Agency efforts in conversion R&D have been guided by two technology roadmaps, “Breaking the Biological Barriers to Cellulosic Ethanol (2005),” and “Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels (2007).” A comprehensive database of federal projects has been created that is evaluated against the barriers identified in these roadmaps. This tool provides integrated information on existing gaps and on the concentration of activities around high-impact barriers.

In December 2011, a roadmapping workshop with industry, academic, and national laboratory researchers was held to update both aforementioned roadmaps in terms of hydrocarbon biofuel production from the intermediates of the various biomass conversion platforms.\textsuperscript{22} The main purpose was to identify and propose activities to address major technology barriers to the production of cost-competitive transportation biofuels by 2017 and 2022.

**Supply Chain Considerations**

In the preceding chapter, the feedstock-conversion interface was identified as an area of vital importance that continues to require R&D efforts. The chemical and physical properties of a given feedstock can impact its conversion into fuels. Conversion technologies have unique requirements for feedstock properties, and different conversion technologies lead to different products. Feedstock pre-processing may be required to improve the operability and results from subsequent conversion processes, as will improved capability in end-product separation.

\textsuperscript{19} The efficient conversion of “xylan to xylose” introduces additional sugars to the fermentation organism, which in turn can lead to an increase in fuel production.


\textsuperscript{22} Conversion Technologies for Advanced Biofuels Proceedings.
Two principal challenges arising from diverse feedstock resources are (1) the low-energy density of lignocellulosic biomass and (2) biomass recalcitrance. The density issues are twofold: (1) Due to the chemical composition of the biomass, there is low chemical energy density, and (2) the nature of biomass materials is inherently low physical and bulk density. Processes are under study to address each of these features. Various treatment processes, such as torrefaction, aim to reduce the oxygen content and increase the energy density of the feedstock prior to the conversion process. In addition, some densification processes are employed to increase the bulk density of the biomass. These processes reduce transportation issues and control the scale of conversion units.

The recalcitrance of biomass materials rests largely with the lignin components. Decomposition of these components is not an easy process either chemically or thermally. The varying lignin content of different feedstocks is an additional complication.

The range of potential feedstocks for longer-term solutions includes whole or residual algal biomass, as well as extracted algal lipids. With algae, although there is no lignin recalcitrance to deal with, the algal oils have other features that require process differences. Just like cellulosic compositional variations, the type of lipid molecules in terms of chain length, degree of saturation, and the relative abundances of fatty acids and lipids vary depending on the species and the growing conditions. These factors may impact the stability of algal lipids under different storage conditions and the conversion requirements (separation challenges and/or hydrocracking severity). Depending on the method of algal harvesting and extraction, there may also be inorganic impurities in the resulting algal oils (phosphorus, chloride) that can be catalyst poisons.

Whether using a biochemical, thermochemical, or hybrid conversion route, achieving the desired purity of an end product is a major challenge. The process effluent is a mixture of dilute chemical compounds, and further separation, concentration, and processing are required to fully separate the fuel products from other chemical compounds. These co-products impact the suitability for the final end use and may have deleterious effects on the conversion processes. For the biochemical platforms, the additional components may inhibit or poison the microbes and enzymes that convert sugars to ethanol. In an analogous fashion, some compounds will poison the catalysts in the thermochemical platforms, reducing the final product yields. Addressing enzyme or catalyst poisoning requires additional conversion process steps, which can increase production costs and complicate the logistics of the conversion facility footprint. Pre-processing either the raw biomass or a stabilized intermediate product in existing refinery facilities, where some of these ancillary processes are already available, may help mitigate these impacts.

An added advantage to focusing on hydrocarbon biofuels production is that some of the necessary separation processes for fuel purification exist and are available. Additional separation technologies for stand-alone biomass conversion facilities have not been adequately addressed, and require further R&D. The impact of these on the profitability through production of bioproducts in addition to biofuels cannot be ignored.

Land and water use, waste production and disposal, toxin control, and energy use all must be considered while demonstrating and commercializing these conversion technologies. In addition, environmental impact and process sustainability need to be assessed for all conversion routes.
Biological and Catalytic Platforms

Biomass pretreatment processes often include cost- and energy-intensive techniques that may limit the overall carbon efficiency of biofuel production from lignocellulose. Some current pretreatment techniques also produce by-products that inhibit downstream bioprocesses in biofuel production. Examples of potential cost savings through advanced processing include mild- and non-enzymatic pretreatments, which limit the production of such inhibitors. Milder pretreatment techniques such as ammonia fiber expansion treatments for corn stover produce degradable biomass with fewer inhibitory compounds, facilitating downstream bioconversion processes and eliminating detoxification and other steps. Additionally, non-enzymatic routes to sugars and carbohydrates show promise since they dissolve lignocellulose fibers from biomass and quickly decompose the fibers into component sugars or carbohydrate derivatives in a single step. These sugars are then available for fermentative or catalytic conversion to biofuels.

There is a comprehensive portfolio of research that also looks at producing more economically viable enzyme packages. Recently identified cellulases from nature show promise in leading to the development of enzyme cocktails with multi-function plant degradation activity and/or specificity. Additionally, basic research efforts on enhanced enzyme-based biomass conversion parallel the technical process developments on enzymatic cocktails for cellulose degradation being pursued by private firms. Pilot plant projects utilizing cellulase cocktails for converting lignocellulose to its component sugars for ethanol production are currently being built or are planned for 2013.

Capital cost savings can be realized if two or more treatment and conversion processes can be combined in a single process step, effectively reducing the necessary process equipment. For example, using principles of synthetic biology, researchers have incorporated cellulase production and metabolic pathway modifications within single microorganisms to combine lignocellulose breakdown with biofuel production from the resulting sugars. Such modified bacterial strains may be able to break down intact cellulose fibers to component sugars without the need for conventional physical/chemical pretreatment techniques.

Efforts are underway to develop the techniques to biochemically produce different types of advanced biofuels from lignocelluloses. These efforts include higher energy content alcohols such as isobutanol, biodiesel, and hydrocarbon compounds with similar properties to gasoline, diesel, and jet fuel. Genetic modification techniques are moving beyond traditional single gene mutations to include engineered technologies to be used to easily modify microorganisms for specific purposes.

Studies of cellulose-degrading bacteria such as *Clostridium thermocellum* are providing a detailed understanding of the functioning of the cellulosome and how activity and specificity are linked to cellular metabolism and external stimuli. The observed ability of *C. thermocellum* to alter cellulosome specificity and activity in response to plant fibers of differing composition offers the potential to develop “designer” cellulosomes tailored to specific biomass feedstocks and/or optimized for biomass breakdown efficiency.

There are several projects in the OBP Integrated Biorefinery projects that utilized commercial cellulase cocktails. Please see the biochemical IBR projects: [http://www1.eere.energy.gov/biomass/integrated_biorefineries.html](http://www1.eere.energy.gov/biomass/integrated_biorefineries.html).

**Thermochemical Platforms**

Thermochemical processing technologies for biomass can be broadly classified in two general categories: (1) gasification and (2) liquefaction. In gasification, biomass-derived syngas must be generated at high temperatures (800–900°C), separated in high purity, and finally, upgraded to fuel-grade products. In thermochemical liquefaction technologies, biomass-derived vapors are typically generated at moderately high temperatures (500–700°C) and quenched into crude, liquids (oils) for further processing into hydrocarbons and chemicals.

Gasification upgrading can be accomplished using either catalytic or biological means, but a majority of R&D has focused on catalytic transformations. Fischer-Tropsch processes have been developed to work with biomass-derived syngas, which requires removing acid gases and other inorganic contaminants and implementing water gas shift reactions to adjust the ratio of CO and H₂ to an optimal level for conversion to hydrocarbon fuel.

Since 2007, a large R&D emphasis has been placed on generating mixed alcohols from syngas, which has required advances in catalyst robustness and durability. Optimizing hot gas cleanup and filtration technologies for high temperature operation can improve thermal efficiencies in gasification, which are lost any time a syngas stream must be cooled to meet operating conditions of current unit operations. Other opportunities exist as well for oil- and aqueous-based extraction of syngas particulates and tars. Central challenges to these tasks are water cleanup, recycling and reducing water/oil consumption.

Thermochemical liquefaction technologies include fast pyrolysis, catalytic fast pyrolysis, hydropyrolysis, hydrothermal liquefaction, and solvent-assisted liquefaction. A defining aspect of all these technologies is the production of oxygenated, low-quality, and unstable (corrosive and acidic) oils that must be hydroprocessed and catalytically treated to yield transportation fuels.

In fast pyrolysis, vapors are typically generated via direct or indirect heating. Macroscopic char, ash, and fines are removed by cycloning, and the hot gas is filtered and condensed. Catalytic fast pyrolysis employs the same processing scheme but uses a catalyst mixed in the biomass, which partially deoxygenates the ensuing vapors upon heating. Hydropyrolysis uses excess hydrogen as a reducing agent during the pyrolytic step instead of a catalyst.

Alternately, hydrothermal liquefaction and solvent-assisted liquefaction liquefy and solvate biomass components in the presence of supercritical or near supercritical water or solvents, respectively, to generate their bio-oil products. Current efforts in liquefaction have investigated vapor phase catalysis as a means to preemptively deoxygenate and stabilize the bio-oil by removing deleterious species before they condense.
Submicron particulate removal from pyrolysis oil presents an interesting opportunity that could enable removal of char from liquid phases. Char acts as a catalyst for condensation of high molecular weight molecules in pyrolysis oils and thereby increases the instability and aging rates of pyrolysis oil. Additionally, there is a need to better understand the fate of trace biomass components (e.g., alkali, chlorides, non $\text{H}_2\text{S}$ sulfur species, and other inorganics) and formulate strategies for their removal and/or management as waste streams. It is currently estimated that the conversion contribution to producing diesel and gasoline from fast pyrolysis in 2017 is $1.56$/gallon, with a total fuel cost of about $3$/gallon.

**Figure 10.** Crystal structure of a cellulose-degrading enzyme. Fundamental understanding of this and similar cellulases allows researchers to produce better enzyme packages that reduce the cost of saccharification. (T. reesei CBH1, courtesy of NREL.)
TRANSPORT & DISTRIBUTION INFRASTRUCTURE AND END USE

Introduction

For the nation to meet RFS2, the U.S. biofuels industry will require a responsive, reliable, and efficient transport and distribution infrastructure that can safely deliver biofuel products to their end-use locations. Understanding current and future biofuel supply chain logistics, capacity constraints, and safety remain important areas for continued interagency focus.

The deployment of multimodal transport infrastructure—including rail, highway, waterway, and pipeline assets to move biofuel feedstock and product—is essential. Biofuel product distribution infrastructure includes both transportation elements and a network of stationary infrastructure, including fuel terminals and storage facilities. The development of this infrastructure can be constrained by geography, transportation systems, finance, policy, and market volatility. If not addressed, these issues could impede the existing surface transportation enterprise’s ability to accommodate future biofuels production and distribution requirements. In addition, because all steps of the supply chain are highly interdependent, uncertainties about future feedstock production or fuel demand can have an impact on the pace of infrastructure planning and investment. Thus, it is important for transport and distribution stakeholders to follow emerging developments and indicators within other biofuel supply chain areas and to coordinate research priorities appropriately.

Current Biofuels Production & Distribution Landscape

Approximately 98% of current ethanol production capacity is located in the Midwest, close to agricultural-based feedstock production (typically 35-50 miles from cornproducing farms). Ethanol distribution patterns have been shaped by this geographic production footprint (Figure 11). Also, transporting ethanol in bulk requires a separate infrastructure, since mid- and high-percentage ethanol blends are not fully compatible with conventional petroleum infrastructure.

Figure 11. Regional variation in ethanol production capacity in 2011.
Conversely, biodiesel production plants often produce lower volumes, handle more diverse feedstocks including vegetable oils, animal fats, recycled cooking oil, and yellow grease, and are more geographically dispersed than ethanol plants. RFS2-certified biodiesel is commercially produced at more than 100 plants across all major regions of the United States. Non-certified production at a smaller scale is occurring at dozens of additional sites.

Because of its market dominance, research on biofuel distribution infrastructure has primarily focused on the supply chain for ethanol. Yet, the more geographically diverse supply chain of biodiesel may present a closer match to the structure of a future cellulosic biofuel industry.

Biofuels production in the Midwest requires products to be transported over long distances (1,000–1,800 miles) to reach their markets. Transportation typically represents the third-highest expense to an ethanol producer, after feedstock and energy costs. This geographic problem is at the root of many modal transportation infrastructure bottlenecks.

Long-distance transport of biofuel products at scale requires infrastructure that is either limited in capacity (e.g., rail) or unavailable (e.g., dedicated pipelines). The nation’s existing petroleum-based transportation infrastructure is misaligned with the biofuel supply chain; ethanol and gasoline have nearly opposite geographic fuel distribution patterns (Figure 12). These geographic constraints could be eased by building future biorefineries closer to population centers and by fueling them with locally cultivated feedstocks. However, a significant share of biofuel production would still be expected to remain in the Midwest.

---


27 Spurred by the need for an oxygenate to replace MTBE after it began to be phased out in 2004, the U.S. ethanol industry has been the lead driver for sharply increased biofuel transport and distribution services since 2005.

**Figure 12.** The general distribution pattern for gasoline (top) is contrasted with that of ethanol (bottom). The current flow pattern for domestically produced ethanol is generally opposite to the flow of gasoline.
Future Landscape: New Range of Biofuels & Higher Transport Volumes

Emerging biofuels may alter the biofuel supply chain and transport model. Biofuel feedstock is anticipated to eventually include significant quantities of cellulosic material in addition to cornstarch. While the Midwest is expected to remain a leading feedstock production area due to the volume of cellulosic-based crop residues produced there, there is a large base of abundant and widely distributed domestic cellulosic feedstocks in other regions of the nation. Meanwhile, other advanced biofuels may draw on unconventional and geographically widespread feedstocks.

The geographically decentralized production of these feedstocks in development could change biofuel production and distribution patterns dramatically. Fuel distribution pathways for advanced biofuels will be dictated by biorefinery siting, which, in turn, will be informed by feedstock production location. Because the future biofuel production map is uncertain, derived demand for transportation services and distribution infrastructure remains unclear. Developing tools to help understand what the future geographical landscape and timing for advanced biofuels may look like is fundamental for infrastructure planning.

Among these new fuels are hydrocarbon drop-in biofuels, which are expected to be seamlessly mixed with petroleum and distributed through existing infrastructure with no compatibility or performance issues. Therefore, drop-in biofuels may experience few infrastructure constraints if their production is co-located with existing petroleum refineries.

Moreover, while existing transportation infrastructure is expected to accommodate biofuel shipments through 2015, it is likely inadequate to move the additional volumes of ethanol to market needed to meet further RFS2 requirements. Hauling increased volumes of biofuel production co-products, such as Distillers Dry Grain Solubles (DDGS) require added transportation capacity—particularly, rail and roadway assets (Figure 12). Investments in transportation system capacity will be critical to ensure the continued movement of both biofuel product and co-product alike.

29 DOE. Report to Congress (EISA Sec. 245): Adequacy of Railroads and Other Modes of Transportation for Domestically Produced Renewable Fuel, May 2009.
31 These advanced, renewable hydrocarbon fuels are highly attractive alternatives to ethanol-based fuels. Unlike lower-order alcohols, they are designed to be chemically similar to conventional gasoline, diesel, and jet fuel.
33 For every gallon of ethanol produced, 6.34 pounds of DDGS are produced as a commercial by-product; in fact, a 100 million gallon per year ethanol plant can expect to ship about 10 rail tank cars of ethanol and nine hopper railcars of DDGS co-product per day.
Accomplishments to Date

Since the inception of the original RFS in 2006, the total annual volume of renewable fuel required under the standard has risen from 4 billion gallons to more than 15 billion gallons in 2012. During this period, there have been few major transport and distribution bottlenecks. Policies driving biofuels deployment have helped industry meet the rapid growth in demand for biofuel infrastructure throughout the 2000’s. The economic recession has reduced commerce and volumes of competing rail traffic so that railroads have been better able to handle expanded biofuel shipments. Some technical challenges, such as adapting existing distribution infrastructure for E10 and implementing new compatibility standards across 50 states, were addressed with moderate effort.

The 2008 National Biofuels Action Plan recognized and focused on anticipated challenges to meeting the infrastructure demands of RFS2 beyond 2015 through a distribution infrastructure action area. The plan directed DOT to assemble and coordinate a Federal Biofuels Distribution Infrastructure Interagency Working Group (DI-IWG), which was formed immediately. In response to charges outlined in the 2008 Action Plan, the DI-IWG has coordinated the development of interagency reports and activities (See Appendix.). In addition, several other Federal research studies, projects, and tools aimed at better understanding biofuel supply chain and transportation barriers have been developed since 2008 (See Appendix.).

Meanwhile, private industry has made notable efforts to advance biofuel distribution RD&D. National pipeline operators have conducted materials compatibility and fuel quality testing. This research has led to the start of short-distance biofuel pipeline transport in Florida, as well as further private sector planning for the world’s first long-distance, dedicated ethanol pipeline stretching 1,800 miles from Iowa to New Jersey.34 A detailed list of agency accomplishments and activities is provided in the Appendix.

Modal Infrastructure Availability, Capacity, & Adequacy

An increasing volume of biofuels will increase the demand for tank barges, rail tank cars, and tank trucks that can haul biofuel. Biofuels moved by these modes are often at a competitive disadvantage to gasoline, which is primarily transported long-distance by cost-efficient pipeline service.

Class 1 rail is the primary transport mode for delivering biofuels to end-use demand centers, now transporting 66% of ethanol from production plants to blending facilities near retail markets. If 70% of the biofuel mandated by RFS2 will be transported by rail, rail shipments will need to increase to more than 800,000 carloads per year (up from 167,000 carloads in 2007), necessitating the addition of 34,000 to 40,000 additional rail tank cars to the national fleet (a near 10% increase). An increased number of railroad terminals would also be needed to specifically accommodate the large unit trains required for economies of scale for competitive biofuel production. The creation of such rail infrastructure is highly time and capital intense.

Future railroad congestion and competition for railway access among private sector shippers may also challenge logistics and increase shipping costs. Information about the biofuels market, supply chain geography, and projected logistical need is needed to inform decisions on rail infrastructure projects.

While rail is typically the most time and cost efficient for hauls beyond 400 miles, trucking can be economical for shorter distances required to carry harvested feedstock supplies to the biorefinery and deliver biofuel product to final end users. It also may be the only transportation option for biorefineries situated outside of established rail service.

As with rail, expanding the trucking service to meet RFS2 targets presents capacity, safety, and congestion challenges. It has been estimated that the renewable fuel industry will require up to 900 new dedicated tank trucks to meet RFS2 goals, increasing truck congestion on roadways. Average annual daily truck traffic for roads with more than 10,000 trucks per day is projected to triple between 2002 and 2035. Ultimately, rural roads in bioenergy regions will need to invest in upgrading, expanding, and maintaining local road, highway, and bridge infrastructure to accommodate an increase in all heavy-duty truck traffic. For biorefineries located in rural areas, increased truck traffic may necessitate the construction of hard surface access roads with acceleration/deceleration lanes. The road curvature and geometry of rural highway entrance and exit ramps also need to be analyzed to minimize rollovers. Roads may require reinforcement or other improvements to accommodate more and larger trucks.

---


Finally, the trucking industry as a whole faces a driver shortage, particularly for drivers qualified to transport hazardous materials. According to the Federal Highway Administration (FHWA), there is already a shortage of qualified truck drivers to meet the anticipated growth in shipping demand, even without renewable fuel demand stimulated by RFS2.

Although water transport currently plays a very limited role in today’s biofuels supply chain, its role may grow due to its efficiency. Yet, expanded waterborne-based biofuel transport faces fundamental challenges, including lack of access points near biorefineries and inability of the nation’s locks to accommodate the increase in tank barges needing passage. In addition, freezing of waterways creates seasonal variation in biofuel transport. Renewable fuel production volumes present another logistical and economic consideration for water transport, since typical barge shipments hold the equivalent of 10 days of biorefinery output. (A 100-mgy ethanol plant produces, on average, approximately 274,000 gallons of fuel per day.) In addition, barge-to-train or tank truck transloading may increase transportation costs. Further, like rail and trucking modes, additional equipment is needed to support waterborne biofuel transport at peak RFS2 levels. EPA estimates that up to 167 new barges will be required by 2022 to serve the renewable fuel industry. It is also estimated that 14–18 new ethanol import locations will be required to accommodate biofuel imports from Brazil and other nations by 2022 along the East, West, and Gulf Coasts.

Pipelines are the most efficient and cost-effective means of transporting large volumes of liquid fuels over long distances. In 2008, pipelines transported about 2/3 of all petroleum products (on a ton-mile basis), and more than 80% of gasoline in the United States. The existing liquid pipeline system has been in place for many decades, and pipelines are expected to have a multi-decade lifespan. However, as with the other transport modes discussed above, key logistical challenges exist. Pipelines must transport very large volumes of biofuel product in order to operate economically. Today’s existing pipeline infrastructure is also largely geographically misaligned with major midwestern biofuel production centers. Pipelines require enormous investments (pipeline construction often costs $1–2 million or more per mile). Barge service, providing it is available, could offer a cost-efficient means for supplying large volumes of biofuel from midwestern production centers to pipeline terminals via the Mississippi River, alleviating some of these challenges. However, like other modes for biofuel transport, informed planning and coordinated development are necessary to overcome logistical and technical obstacles.

---

44 In 2005, barge transport cost half of rail transport per ton-mile.
Infrastructure constraints such as these are now emerging within conventional energy supply chains based on new oil and natural gas production from horizontal drilling and hydraulic fracturing of shale rock in North Dakota, the Midwest, and the Mid-Atlantic. While shale resource development is still early, its rapid expansion since 2008 has had clear impacts on transport and distribution infrastructure and may provide lessons for the biofuels industry.

Sudden domestic shale energy booms have resulted in an inability to move all new production to market and have produced high stress on local infrastructure in shale oil and gas production areas. Lack of pipeline infrastructure has prevented new energy supplies from North Dakota from reaching tight East Coast markets, and has created an overreliance on trucks and railcars for oil transport. Meanwhile, new fuel exploration and development in North Dakota, Ohio, and Pennsylvania have severely overtaxed local roads and bridges and caused substantial congestion and delays on rural area roads.

Because most recent shale energy production was unexpected, little or no advance infrastructure planning and investment took place. As biomass and biofuels production capacity is planned around the nation, an opportunity exists for localities to be more aware of likely transport and distribution issues, begin advanced planning, and better avoid the jostle for strained and inadequate infrastructure now experienced by the shale energy industry.

**Impacts of Economics, Policy, & Trade on Transport Infrastructure Investment**

The current inability to use pipelines for biofuels reflects both technical and economic factors. The technical barriers—the corrosive properties of ethanol (and other biofuels)—may be overcome, but the economics will remain less favorable because of a smaller potential volume than that of conventional pipelines and less flexibility for operators to move other fuel products to increase revenues.

Planning for future distribution remains difficult because of uncertainty about the scale and structure of the biofuel industry as it moves beyond corn ethanol. Private investment is hindered because of high risks and uncertain returns on investments. This is unlike much of the corn ethanol expansion in which a known technology, strong producer margins, and supportive policies encouraged private sector investments.

With smaller capacity plants distributed across a broader geographic region rather than aggregated at any single location, there may be more reliance on trucking, requiring new or higher-capacity rural roads. New storage tanks and facilities would also be required. At the same time, a distributed biofuel production model could greatly alleviate the geographic and long-distance transport issues. Further, if drop-in biofuels were to become available, their distribution economics would improve because there would be less separate handling required, reducing costs and facilitating logistics.

The potential expansion of a road-based distribution system for an expanded biofuels industry will present a large financial burden for many rural areas, since repair and maintenance of bridges and roads and new construction can be expensive. The recent recession and continuing drop in gasoline sales have reduced motor fuel tax revenues (e.g., Highway Trust Fund) available for infrastructure.
Although biofuel industry development may increase local rural revenues, there will be a lag before these funds could fund public infrastructure. This lag poses a dilemma for some rural areas that have biomass or biomass potential but lack funding to make infrastructure improvements required for biofuels industry development. Some creative and new policy approaches will be needed.

Meanwhile, the export and/or import of biofuels can affect overall distribution needs by increasing or decreasing movement in some regions of the country. Such potential shifts add uncertainty to planning. Trade flows are influenced by both policy and economics, which are intertwined. Rapid changes in the structure and dynamics of the ethanol industry, both in the United States and abroad, make trade forecasting difficult. Market demand for biofuels is shaped by policy abroad (including mandates for use) and is often accompanied by import tariffs.

**Ensuring the Safety of Biofuel Movements across the Supply Chain**

Safety is an important consideration across the biofuel supply chain—from new truck traffic moving feedstock supply to multimodal distribution and delivery of biofuel products. Biofuel producers will need to obtain hazardous material certifications and provide the hazardous materials training required by federal law. New engineers and commercial drivers will require training, oversight, and periodic inspection when handling and transporting these commodities. Increased freight rail and truck activity can lead to an increased chance of accidents due to congestion, which may be especially dangerous when involving fuel transport. It is fundamentally important to have a clear and thorough understanding of all safety issues associated with both existing biofuels and emerging advanced biofuels.

Like other non-petroleum fuels, many people are not familiar with biofuels. Thus, public perception of safety issues regarding biofuel movements may pose a barrier to developing distribution infrastructure, including storage facilities and distribution end-points in populated areas. As with other hazardous materials facilities with flammable combustible liquids, community and local government outreach will be needed in conjunction with planning and citing of biofuel distribution facilities. A key strategy for maintaining facility safety is to train and empower local or state officials to inspect biofuel distribution facilities and enforce fire and spill prevention requirements. The development of specific safety equipment, such as proper ethanol fire-fighting foams, and the setting of national-level safety codes and standards for local enforcement are important to ensure safety across the country as biofuel distribution facilities multiply and expand.

**Fuel Applications and End Use**

Assuming challenges to production and distribution are mitigated, biofuels must be able to enter the market and be utilized by the intended end user. In order to accommodate increasing volumes of biofuels entering the market, issues around market demand and end use infrastructure compatibility must be addressed.

---


46 End-use infrastructure includes fuel storage tanks, fuel dispensers, vehicles, and other engines.
To date, much of the work on end-use infrastructure compatibility has focused on ethanol, as it is the predominant biofuel currently available in commercial volumes. Approximately 99% of ethanol in the market today is blended with gasoline at low-level blends of up to 10% ethanol/90% gasoline (E10) for use in conventional vehicles. Low level ethanol blends are compatible with existing vehicles and dispensing infrastructure. With more than 95% of U.S. gasoline currently blended with low-levels of ethanol, however, the E10 market is nearly saturated, and potential growth in E10 is limited.

A very small amount of ethanol in the market today is consumed as E85, a blend of gasoline with up to 85% ethanol. Because high-alcohol blends have some of the same compatibility issues with end-use infrastructure as those discussed for transport and distribution infrastructure, a key barrier to deployment is availability of compatible vehicles and dispensing equipment. E85 requires flex-fuel vehicles (FFVs) and separate fuel dispensing infrastructure. While the market for FFVs and E85 stations has grown over the past four years, market penetration remains limited.

The 2008 NBAP highlighted the challenges to deployment of E85 blends and identified an opportunity for increasing the market for ethanol through the introduction of intermediate ethanol blends (E15 or E20) for use in conventional vehicles. Over the past four years, DOE, in partnership with EPA, completed an Intermediate Blends Test program to evaluate the potential impacts of intermediate blends on the existing vehicle fleet, specialty engines, and dispensing infrastructure. The test program looked at the impact of E15 on vehicle emissions, catalyst durability, driving performance, and other factors as well as end-use infrastructure material compatibility and equipment performance. Based in large part on the results of this test program, EPA issued a decision in 2011 to approve a waiver allowing the use of ethanol blends up to 15% (E15) in 2001 and newer vehicles. Further research is needed to ensure material compatibility of E15 in storage and dispensing infrastructure.

The upcoming introduction of E15 highlights the immense undertaking necessary to introduce any new fuel. A crucial and typical first step is updating or development of a fuel specification, which takes a significant amount of time and consensus to develop and requires coordination between American Society for Testing and Materials (ASTM), fuel manufacturers, EPA, and industry groups such as the Coordinating Research Council (CRC). Additionally, due to dispensing infrastructure compatibility concerns and concerns about potential misfuelling, introducing E15 to the market may require the deployment of new dispensing equipment and special labeling. New dispensing equipment may include dedicated dispensers and flexible fuel pumps that can dispense a range of fuels (E85 and mid-level blends such as E30 and E15). While some existing refueling infrastructure equipment and vehicle models may now be approved for use with E15, a degree of consumer uncertainty still exists since the public remains largely unfamiliar with E15 fuel. Thus, retail fuel providers, vehicle and equipment manufacturers, and insurance underwriters maintain substantial liability concerns.

The growth of advanced drop-in biofuels that are anticipated to be fully compatible with existing dispensing infrastructure and end-use equipment could substantially alleviate end-use compatibility concerns. The aviation industry and military complex have been at the leading edge of research, development, and demonstration of these advanced biofuels since 2008 and are committed to the proactive use of drop-in alternative jet fuels as they become available (See Box on p. 38). These efforts have led ASTM International to establish a specification (ASTM D7566) that officially allows certified, drop-in, alternative fuels to be used as jet fuels. The successful trials of biomass-based jet fuel by commercial airlines, the U.S. Air Force, and the U.S. Navy highlight the achievements for the commercial aviation industry, the military, and advanced next-generation biofuels.

Collaboration and the Advancement of Bio-Based Jet Fuels

Collaboration both within the aviation community (military and commercial) and among key biofuel organizations has greatly accelerated the development and adoption of alternative jet fuels, including biofuels.

Since 2006, the Commercial Aviation Alternative Fuels Initiative (CAAFI) has been promoting the development of safe, cost-effective, and sustainable drop-in alternative jet fuels. CAAFI is a public–private coalition of airlines, aircraft, and engine manufacturers, energy producers, researchers, international participants, and government agencies. The U.S. Federal Aviation Administration (FAA) and three U.S. aviation trade associations cosponsor the initiative: the Airports Council International–North America, Airlines for America (A4A), and the Aerospace Industries Association. CAAFI plays a leadership role in facilitating evaluation, qualification, environmental assessment, and deployment of alternative jet fuels.

Aviation and agricultural organizations have participated in collaborative efforts to facilitate new bio-based jet fuel deployment. For example, in July 2010, the U.S. Department of Agriculture (USDA), A4A, and the Boeing Company signed a resolution formalizing their commitment to work together on the FARM to FLY initiative to “accelerate the availability of a commercially viable and sustainable aviation biofuel industry in the United States, increase domestic energy security, establish regional supply chains, and support rural development.”

Since 2008, these collaborative efforts have led to the following:

- Certification of ASTM Specification D7566 for drop-in alternative jet fuels (currently includes annexes for fuels created by Fischer-Tropsch synthesis and Hydroprocessed Esters and Fatty Acids (HEFA))
- Development of the internationally recognized Fuel Readiness Level, the Feedstock Readiness Level, and the Path to Alternative Jet Fuel Readiness tools to understand and communicate fuel development status
- Development of greenhouse gas (GHG) life-cycle assessment (LCA) guidance for alternative jet fuels
- Execution of GHG LCA studies for a range of drop-in alternative jet fuels.
- Extensive grants and initiatives from FAA, USDA, and DOD to research and facilitate the use of alternative jet fuels as a critical part of meeting future environmental and energy security targets
- The FARM to FLY report documenting technical and market readiness of aviation biofuels and affirming a “flight plan” for development of a long-term aviation biofuels supply chain.\(^2\)
- Execution of several memoranda of Understanding between airlines and fuel producers for alternative fuel purchases
- First-ever biojet-powered commercial-service airline flights in the United States, by Alaska Airlines and United Airlines, during the week of November 7, 2011
- Facilitation of national and state-level initiatives to commercialize alternative jet fuels.

---

\(^1\) For more information, see www.caafi.org.

RECOMMENDATIONS

Biomass Feedstocks

• Develop a white paper on the integration of feedstock into the entire supply/use chain. A key focus should be characterizing how existing high-efficiency material handling infrastructures can be leveraged through advanced preprocessing/pretreatment and densification technologies and the potential impact on downstream conversion processes.

• Develop sustainable biomass feedstock production and management systems and practices for energy crops and for integration into conventional agriculture, forest, and rangeland management systems.

• Develop an information resource to support evaluations of the utility, safety, and sustainability of specific algae proposed for commercialization.

Conversion Technologies

• Complete the updated roadmap/barriers documents for conversion technologies, identify any technology recommendations, and use the roadmap as one input to defining multi-agency R&D. Additional agency specific roadmaps will be produced as required.

• Develop and employ an evaluation process tool that gauges technoeconomic performance, energy effectiveness and efficiency, and environmental impact and sustainability in a consistent manner for all conversion technologies. Use the tool to re-focus research and development efforts in conversion science.

• Develop inter-agency mechanisms to focus research and development efforts on gap identification and filling to speed delivery of multiple selected conversion processes to the pilot and commercialization scales.

Transport & Distribution Infrastructure and End Use

• Develop consensus on a national roadmap that will provide direction for developing modeling tools and capabilities for national policy and regional and local transport and infrastructure development.

• Define future transport and infrastructure needs based on regional supply and demand, feedstock, and fuel production geography.

• Develop strategies to address constraints facing existing fuel distribution infrastructure, including local and regional petroleum distribution and blending facilities.

• Coordinate with industry to accelerate development and implementation of new standards adoption and testing to ensure compatibility of all equipment in the fuel path. Research, evaluate, and implement findings for transport, storage, and dispensing infrastructure to ensure material compatibility.

• Identify opportunities to reduce time to introduce a new fuel to commerce once it is available on a commercial scale.
Crosscutting

- Conduct analysis of life-cycle air and GHG emissions, water quality and quantity, nutrients, and pesticide use across the entire biofuels supply chain and identify steps to protect water quality and reduce emissions and negative impacts.
- Establish an interagency analysis working group that will focus on coordinating federal efforts to identify and address analysis needs as they relate to biofuels RD&D.
- Designate an interagency workgroup to review biofuels laws and regulations to identify barriers, duplicative requirements, information and regulatory gaps, and address jurisdictional authority across the entire biofuels supply chain.
APPENDIX – Index of Selected Agency R&D Accomplishments and Activities

Crosscutting Activities

• **Implementation of National Renewable Fuel Standard Program**: EPA successfully initiated annual standard setting and on-going assessments of renewable feedstock and fuel technical pathways.

• **Growing America’s Fuel**: This is the presidential initiative that supports the existing biofuels industry while accelerating the commercial and sustainable establishment of the advanced biofuels industry by using the best skill and knowledge across many federal departments and public-private partnerships.

• **USDA Roadmap to America’s Renewable Energy Goals**: USDA developed a regional roadmap to help determine whether U.S. crop and forest lands have the capacity to provide the biomass required to meet the RFS mandate to use 36 billion gallons of biofuel per year in America’s fuel supply by 2022.

• **Biomass Research Centers**: USDA’s Agricultural Research Service (ARS) and Forest Service (FS) have formed five intramural regional biomass research centers and developed regionalized strategies for developing different feedstock systems using resources that are regionally available, with an emphasis on partnerships with other federal agencies and private industry.

• **Coordinated Agricultural Projects (CAPs)**: USDA’s National Institute of Food and Agriculture’s (NIFA) Agriculture and Food Research Initiative (AFRI) is taking a regional approach to developing bioenergy systems through CAPs, agricultural projects that consist of partnerships between government, industry, and universities, including 1890 land-grant universities, tribal nation colleges, and Hispanic-serving institutions.

• **Sun Grant Regional Biomass Feedstock Partnership**: The Partnership has three tasks: (1) biomass resource assessment, (2) biomass resource development, and (3) biomass resource education and outreach. Many of the activities address the identified logistical barriers to full-scale biofuels commercialization.

• **DOE Bioenergy Research Centers**: DOE established multidisciplinary fundamental research centers to examine systems biology and synthetic biology approaches for development of dedicated biomass feedstocks and conversion of plant biomass to transportation fuels.

• **Biomass Research and Development Initiative**: USDA and DOE jointly publish an annual solicitation for projects that integrate the three legislatively directed technical areas to address feedstocks development, biofuels and biobased products development, and biofuels development analysis.

• **EPA Biofuels Report**: EPA published a draft report, *Biofuels and the Environment: the First Triennial Report to Congress*. EISA Section 204 calls for EPA to report to Congress on the environmental and resource conservation impacts of increased biofuel production and use. The report reviews impacts and mitigation tools across the entire biofuel supply chain, including feedstock production and logistics, and biofuel production, distribution, and use.
• **Farm to Fly Report**: USDA, Boeing, and Airlines for America collaborated on this report to examine efforts to accelerate the availability of commercially viable and sustainable aviation biofuels in the United States to increase domestic energy security, establish regional supply chains, and support rural development.

**Education and Outreach to Stakeholders**

• **Technology Transfer**: Using USDA’s Technology Transfer Centers and the Land Grant System, new breakthroughs and improvements along the biofuel supply chain are rapidly disseminated to ensure these advances are meeting the needs of stakeholders and improving efficiencies in infrastructure and end-use deployment.

• **Sustainability Stakeholder Workshop**: DOE and USDA hosted this workshop in October 2008, and it resulted in a report, DOE/SC-0114, in 2009. This report summarizes critical research areas and knowledge gaps relevant to the environmental, economic, and social dimensions of biofuel sustainability. It also underscores the critical need for a common socioecological framework to develop a systems-level understanding for how these dimensions interact across different spatial scales.

• **Research Stakeholder Workshop**: The USDA Regional Biomass Research Centers’ National Customer/Stakeholder Workshop was held in March 2010. A special focus was placed on gaining information about the perspectives and research needs of downstream industry sectors that require feedstocks to produce biofuels that are competitively priced with petroleum-based fuels.

• **Regional Workshop Report**: The Soil and Water Conservation Society and USDA hosted a workshop to develop regional-specific roadmaps for sustainable feedstock production and delivery.

• **Education and Training**: USDA and its academic partners are developing new vocational and higher-education programs to ensure that the next generation of crop developers, technicians, land managers, process engineers, and analysts are well positioned in the emerging bioeconomy.

**Biomass Feedstocks**

• **U.S. Billion-Ton Update**: DOE released this comprehensive biomass resource assessment released by in August 2011. This report represents the efforts of 50 contributors and includes cost estimates on a county level for key biomass feedstocks.

• **Biofuels Interagency Working Group**: Co-chaired by USDA, DOE, and EPA, this group develops a comprehensive approach to accelerating the investment in and production of American biofuels.

• **USDA Biomass Crop Assistance Program (BCAP)**: This program supported production and delivery of biomass feedstocks through financial assistance to owners and operators of agricultural and non-industrial private forestland. As of 2013, the USDA BCAP has supported contracts for 53,000 acres that provide more than 250,000 dry tons of feedstock per year.

• **Deployable Process Demonstration Unit (PDU)**: The PDU established a pilot-scale (5 tons/hour) system for development, demonstration, and validation of feedstock pre-processing technologies. The DOE supported PDU, which is re-configurable and has baseline systems for biomass deconstruction, stabilization, thermal treatment, and densification. The PDU also supports industry and research community collaboration.
• **National Algal Biofuels Technology Roadmap:** The 2010 Roadmap summarized the state of technology and future challenges for algae-based fuels at commercial scales.

• **Algae Research and Development Consortia Initiative:** A technology development initiative was launched through the establishment of four multidisciplinary algae R&D consortia to explore the long-term potential of algal biofuels and to facilitate industry efforts.

• **USDA/DOE Plant Feedstock Genomics for Bioenergy Joint Program:** This program funds projects that accelerate plant breeding programs and improve biomass feedstocks to lay the groundwork for a new class of fuels derived from lignocellulosic biomass materials.

• **DOE High-Tonnage Supply Systems/Industrial Partnerships:** DOE initiated a program to stimulate the design and demonstration of a comprehensive system to handle the harvesting, collection, preprocessing, transport, and storage of sustainably produced feedstocks. Five projects accelerate the development and deployment of innovative logistical systems for grasses, stover, and wood; program includes industrial, university, and national laboratory collaborators.

• **Uniform-Format Feedstock Supply System:** DOE has led the engineering design, analysis, and conceptual strategy for this commodity-based supply system to provide stable, uniform-format lignocellulosic feedstocks.

• **Feedstock Readiness Level Tool:** The commercial air transportation industry requested that USDA develop the Feedstock Readiness Level (FSRL) Tool to complement the internationally recognized Fuel Readiness Tool that was developed by the Commercial Air Alternative Fuel Initiative (CAAFI). A USDA/FAA/RITA team created the FSRL to track progress on the development of agricultural and forest-based feedstocks needed to produce jet fuels for the aviation industry.

• **Modeling Emissions and Energy Return from Forest Residues:** USDA Forest Service led a team that spatially analyzed collecting, grinding, and hauling forest residue biomass on a 515,900 ha area in western Montana, and compared total emissions of burning forest residues in a boiler for thermal energy with the alternatives of onsite disposal by pile-burning and using either natural gas or No. 2 distillate oil to produce the equivalent amount of useable energy.

• **Fuel Reduction Cost Simulator:** USDA Forest Service and DOE conducted a study to assess the potential biomass supply economically by deriving county-level supply curves for farm and forest biomass. This paper describes the forest harvesting model that was used to estimate the costs associated with collecting and preparing forest biomass for transport to processing facilities. This revised model has been designed for use in all regions of the contiguous United States.

• **Woody Biomass Grants:** Several grants have been awarded to facilitate woody biomass production for bioenergy. USDA Forest Service manages and awards grants each year dedicated to help improve the utilization of woody biomass removed from forest restoration projects.

• **Bioenergy Knowledge Discovery Framework (KDF):** DOE developed the Bioenergy KDF to provide web-based data and tools to synthesize, analyze, and visualize vast amounts of information for biomass supply/use chain.

• **RFS2 Biomass Supply Analysis:** An interagency working group was established to evaluate the biomass supply to meet the RFS2. The BRD Board commissioned a report to inform research recommendations to address the constraints surrounding biomass feedstock availability.
• **Advanced Biofuels for Military and Commercial Transportation**: USDA, DOE, and the Navy announced in 2011 a $510 million investment for partnership with the private sector to produce advanced drop-in aviation and marine biofuels to power military and commercial transportation.

• **USDA ARS/Navy Office of Naval Research (ONR)**: USDA ARS and Navy ONR are partnering to develop decision tools to assess the most sustainable options for producing feedstocks that will ensure dependable supplies of advanced biofuels from biomass in Hawaii and North America for use by the Department of the Navy.

• **Advanced Research Projects Agency–Energy (ARPA-E)**: DOE established ARPA-E to spur innovation. The program includes selected biomass energy projects.

**Conversion Technologies**

• **National Advanced Biofuels Consortium (NABC)**: The DOE-led NABC was formed under the Recovery Act to bring at least one hydrocarbon biofuel production processing strategy to pilot-scale readiness by 2014.

• **Advanced Biofuels Process Demonstration Unit (ABPDU)**: Constructed at Lawrence Berkeley National Laboratory, the ABPDU acts as a flexible, integrated user facility to accommodate biochemical processing strategy development from pretreatment through fuel production.

• **Integrated Biorefinery Facility (IBRF)**: The IBRF was established at NREL as a 1-ton-a-day pilot facility that enables industry users to test biological and chemical conversion technologies for the production of biofuels and biobased chemicals. The IBRF 2011 plays a vital role in supporting industry and program partners meet their internal demonstration and deployment goals.

• **Energy Frontier Research Centers (EFRCs)**: Established in 2009 by DOE, the EFRCs conduct fundamental research focusing on barriers associated with conversion of biomass to fuels/products.

• **Conversion Technologies for Advanced Biofuels Workshop**: DOE conducted this workshop in December 2011 to generate a new roadmap for biochemical and thermochemical conversion barriers for biofuels production technologies. This exercise was necessary as the 2006 and 2007 barrier roadmaps (for biochemical and thermochemical conversion respectively) were becoming dated.

• **Cellulosic Ethanol Conversion Cost Reduction**: DOE research over the last decade has resulted in reduction in the conversion cost of biochemically produced cellulosic biofuels from corn stover and wood products respectively. The 2011 end of year results show a 29% reduction in conversion cost of biochemically produced cellulosic ethanol and a 23% reduction in conversion cost of thermochemically produced cellulosic ethanol from 2008.

• **Improved Enzymes**: Since 2008, two recipients of biomass program funds have supported the biomass programmatic goal to reduce enzyme cost by increasing the efficiency of their cellulosic enzyme cocktails. Both companies had commercial product releases from 2010 to 2012, which helped reduce the projected biofuels production cost and allowed for pilot and demonstration-scale evaluation of first-of-a-kind technologies.
• **Commercial-Scale Biorefinery Construction:** Three federally funded commercial-scale biorefineries have begun construction utilizing technologies developed through the applied research funding for conversion. Key technologies that will be in operation are gasification, pretreatment, enzymatic conversion, and fermentation.

• **Cellulosic Ethanol Conversion Models Updated:** In 2011, DOE sponsored the update of two techno-economic analysis models for the production of cellulosic ethanol. Each model represents one detailed potential conversion process through either thermochemical or biochemical technology routes and is available for public use.

• **Pilot-Scale Gasification of Woody Biomass:** The gasification of pine and mixed-hardwood chips has been carried out in a pilot-scale system at a range of gas flow rates. Based on the composition and energy content of the gas produced, pine and hardwood chips give very similar results. The process can effectively convert many different feedstocks with varying compositions to producer gas with reasonably uniform properties.

• **Integrated Biomass Gasification Model:** Researchers constructed a spreadsheet-based computer model to aid in preliminary evaluation of engineering and economic feasibility of integrating biomass gasifiers with existing pulp mills. This model can be easily modified to consider different options. Gasified biomass can be burned directly to replace natural gas, or it can be cleaned and refined to produce Fischer-Tropsch biofuels, including low-sulfur diesel and other synthetic hydrocarbons.

**Transport & Distribution Infrastructure and End Use**

• **Biofuels Transport & Distribution Infrastructure Interagency Working Group (TDI-IWG):** The TDI-IWG was assembled by DOT in response to the 2008 NBAP and convenes members of DOT, DOE, USDA EPA, and DOI to explore potential technical, geographic, economic, policy, regulatory and other key factors that may challenge transport and distribution infrastructure development across the biofuel supply chain.

• **Interagency Biofuels Infrastructure Workshop:** The Interagency Biofuels Infrastructure Workshop, led by DOT and co-organized by the TDI-IWG, convened federal agency stakeholders with state, industry, and academic key experts to examine factors that may cumulatively impede the ability of existing U.S. surface transportation infrastructure to support expanded biofuels production and end-use to meet RFS2. The workshop identified needed steps for facilitating the adequate, safe, and efficient transport, distribution, and storage of both conventional and advanced biofuels.

• **Intermediate Ethanol Blends Testing:** DOE, in partnership with the EPA, completed an Intermediate Blends Test program to evaluate the potential impacts of intermediate blends on the existing vehicle fleet, specialty engines, and dispensing infrastructure. Based in large part on the results of this test program, EPA issued a decision in 2011 to approve a waiver allowing the use of ethanol blends up to 15% (E15) in 2001 and newer vehicles.

• **DOE Report to Congress on Dedicated Ethanol Pipeline Feasibility (EISA Sec. 243):** Published in 2010, this report considered the economic feasibility of a hypothetical ethanol pipeline linking large East Coast demand centers with a stable ethanol supply from the Midwest.
• **DOT Report to Congress on Transportation’s Role in Reducing U.S. Greenhouse Gas Emissions (EISA Sec. 1101(c)):** Published in 2011, this report identified transportation’s contributing role to U.S. GHG emissions and how to minimize its effect through a range of mitigation strategies, including the development of biofuels and biofuel infrastructure.

• **USDA/DOT Joint Report to Congress on Rural Transportation Issues (FCEA Sec. Section 6206):** Published in 2010, this USDA and DOT collaborative report focused on defining rural transportation issues and community impacts.

• **Ethanol Life-Cycle Analysis Study:** DOT funded research with the Rochester Institute of Technology to conduct life-cycle analysis of 20% and 85% ethanol blends (also known as E20 and E85, respectively) on medium- to light-duty vehicle models, made from 1998–2004, with approximately 30,000–120,000 miles.

• **Biofuel Infrastructure, Logistics, and Transportation (BILT) Model:** Developed by Oak Ridge National Lab, the BILT is an optimization model capable of simultaneously specifying infrastructure for the entire biofuel supply chain, including selection of biomass, transport mode, location and capacity of preprocessing and refinery facilities, and distribution.