BR&D
BIOMASS RESEARCH & DEVELOPMENT

The Bioeconomy Initiative:

IMPLEMENTATION FRAMEWORK

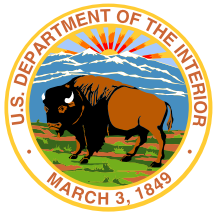


Table of Contents

Acronyms and Abbreviations

ATIP	Agricultural Technology Innovation Partnership
BETO	Bioenergy Technologies Office
BMP	best management practices
Framework	The Bioeconomy Initiative: Implementation Framework
ARPA-E	Advanced Research Projects Agency – Energy
ARS	Agricultural Research Service
BER	Biological and Environmental Research
BES	Basic Energy Sciences
BLM	Bureau of Land Management
BR&D Board	Biomass Research and Development Board
BRDi	Biomass Research and Development Initiative
BTU	British thermal unit
C&O report	The Billion Ton Bioeconomy Initiative: Challenges & Opportunities
CO_2	carbon dioxide
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FARB	Federal Activities Report on the Bioeconomy
GHG	greenhouse gas
GMO	genetically modified organism
IBR	integrated biorefinery
IWG	interagency working group
kWh	kilowatt hour
NASA	National Aeronautics and Space Administration
NIFA	National Institute of Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
R&D	research and development
RFS	Renewable Fuel Standard
SBIR	Small Business Innovation Research
STTR	Small Business Technology Transfer
TAC	Technical Advisory Committee
USDA	U.S. Department of Agriculture

Foreword

The Biomass Research and Development Board

The Biomass Research and Development (BR&D) Board was created through the enactment of the Biomass Research and Development Act of 2000[1] "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 U.S. Departments of Energy (DOE) and Agriculture (USDA) and currently consists of senior decision makers from the DOE, USDA, U.S. Department of Transportation (DOT), U.S. Department of the Interior (DOI), U.S. Department of Defense (DoD), U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), and the Office of Science and Technology Policy (OSTP) within the Executive Office of the President.

With its diverse membership, the Board functions to facilitate coordination among federal government agencies that affect the research and development (R&D) of biofuels, bioproducts, and biopower. The Board convenes several interagency working groups (IWGs) to explore and coordinate interagency work related to the bioeconomy, including: Algae; Feedstock Genetic Improvement; Feedstock Production and Management; Feedstock Logistics; Conversion; Transportation, Distribution Infrastructure, and End Use; Analysis; and Sustainable Bioeconomy.

Purpose of The Bioeconomy Initiative: Implementation Framework

The Bioeconomy Initiative: Implementation Framework (Framework) was developed by the Board's Operations Committee and IWGs with oversight and leadership from Board members. The Framework provides a guiding structure for federal agencies to address key scientific and technical challenges that limit expansion of a domestic bioeconomy. The Framework will serve as a guiding document for the BR&D Board member agencies to (1) increase government accountability and efficiency, (2) maximize interagency coordination on bioeconomy research and other activities, and (3) accelerate innovative and sustainable technologies that harness the nation's biomass resources to enhance U.S. security, economic growth, job creation, and environmental quality.

This effort does not supersede or override the statutory and regulatory authority, mission, program, or approach of the participating agencies or their organizational components.

[1] Biomass Research & Development Act of 2000, Pub. L. No. 106-224, biomassboard.gov/pdfs/biomass_rd_act_2000.pdf.

Executive Summary

Created through the Biomass Research and Development Act of 2000, the Biomass Research and Development (BR&D) Board facilitates coordination among federal government agencies that affect the research and development of biofuels, bioproducts, and biopower. Since 2013, the BR&D Board has worked to shape an interagency initiative that addresses key scientific and technical challenges to enable the sustainable production and utilization of biomass for affordable domestic biofuels, bioproducts, and biopower—the Bioeconomy Initiative.

The vision of the Bioeconomy Initiative is a *vibrant U.S. bioeconomy that enhances economic growth, energy security, and environmental quality by maximizing sustainable use of the nation's domestic biomass resources for affordable biofuels, bioproducts, and biopower.*

The Bioeconomy Initiative: Implementation Framework will serve as a guiding document for the BR&D Board member agencies to increase government accountability and efficiency, maximize interagency coordination on bioeconomy research and other activities, and accelerate innovative and sustainable technologies that harness the nation's biomass resources. The cutting-edge research and development (R&D) described in this Framework can advance technologies to provide a secure, reliable, affordable, and enduring supply of U.S. energy and products.

There has been great progress to date, but many opportunities remain to unlock the full potential of the U.S. bioeconomy. This Framework lays out activities that will help understand and mitigate technology uncertainty; leverage government, academic, industrial, and non-governmental resources and capabilities; stimulate public-private partnerships and investment; and generate technical information that can inform decision-makers and policymakers across complex value chains. No singular agency has the expertise for all aspects of the bioeconomy supply chain; it is only by leveraging the strengths of all BR&D Board agencies and external partners that technology challenges can be addressed.

This Implementation Framework lays out collaborative goals and actions for addressing knowledge and technology gaps in the following areas:

- Advanced algae systems
- Feedstock genetic improvement
- Feedstock production and management
- Feedstock logistics
- Biomass conversion and carbon utilization
- Transportation, distribution infrastructure, and end use
- Analysis
- Sustainability.

The Implementation Framework also discusses approaches to knowledge sharing, stakeholder engagement, technology transfer, and partnerships. These approaches will help accelerate the transition of discoveries into the marketplace and ensure that federal activities benefit diverse stakeholders engaged in the U.S. bioeconomy.

The Bioeconomy Initiative builds upon previous federal investments in basic research and applied R&D as well as extensive private sector investment to date. *The Bioeconomy Initiative: Implementation Framework* provides a strategic approach for future coordination and collaboration between the federal government and various stakeholders. Through these partnerships, the Bioeconomy Initiative aims to facilitate innovation on affordable, sustainable, domestically produced bioenergy and bioproducts—while complementing other U.S. technologies—to benefit the rural, agricultural, forestry, energy, and manufacturing sectors of the U.S. economy.

1 Introduction

1.1 Overview of the Bioeconomy Initiative

The Bioeconomy Initiative is a coordinated federal effort to expand the sustainable use of the nation's abundant biomass resources for biofuels, bioproducts, and biopower. The vision of the Bioeconomy Initiative is *a vibrant U.S. bioeconomy that enhances economic growth, energy security, and environmental quality by maximizing sustainable use of the nation's domestic biomass resources for affordable biofuels, bioproducts, and biopower.*

A general definition of the **bioeconomy** is: "The global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits."[2] Within this definition, the Bioeconomy Initiative focuses on biofuels, bioproducts, and biopower produced from renewable biomass material and wastes.

By increasing the use of renewable biomass material and waste feedstocks, an expanded domestic bioeconomy could stimulate job growth and economic opportunities, increase the nation's energy security and resilience, and contribute to improved environmental quality and greenhouse gas (GHG) mitigation. However, an expanded bioeconomy could displace economic output and jobs in other sectors and could compete with other advanced technologies (e.g., electric vehicles). Additional analyses are needed to more fully understand both the net costs and benefits of an expanded bioeconomy so that agencies and stakeholders can enhance economic, social, and environmental outcomes.

Analyses suggest that the United States has significant potential to expand its bioeconomy. In 2016, the U.S. Department of Energy (DOE) released a report estimating that the United States has the potential to produce at least 1 billion dry tons of biomass resources annually by 2040.[3] Of this potential, roughly 365 million dry tons are currently used in the existing U.S. bioeconomy. Untapped resources in the form of agricultural residues, wastes, and forest residues are available now, while energy crops, algae, and additional waste streams offer growth potential in

[2] Jay S. Golden, Robert Handfield, Jesse Daystar, and Eric McConnell, "An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America." *Industrial Biotechnology* 11 (2015): 201-209, https://www.researchgate.net/publication/280979090_An_Economic_Impact_Analysis_of_the_US_Biobased_Products_Industry_A_Report_to_the_Congress_of_the_United_States_of_America.

[3] U.S. Department of Energy, M. H. Langholtz, B. J. Stokes, and L. M. Eaton (Leads), *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks* (Oak Ridge, TN: Oak Ridge National Laboratory, July 2016), energy.gov/eere/bioenergy/2016-billion-ton-report.

the coming years. For example, utilizing 1 billion dry tons of biomass could equate to about 50 billion gallons of biofuels, 50 billion pounds of biobased chemicals and bioproducts, 75 billion kilowatt-hours (kWh) of electricity, and 990 trillion British thermal units (BTUs) of thermal energy.[4,5]

An expanded, sustainable bioeconomy will require new scientific and technological breakthroughs across a broad spectrum of research at universities and federal laboratories; industrial and manufacturing innovation; engagement with financial institutions; education and job-training initiatives; and partnerships with producers, contractors, and specialty personnel. To enable diverse stakeholders to harness the nation's biomass potential, the Bioeconomy Initiative aims to maximize interagency coordination to yield greater impact from federal investments and accelerate innovation on affordable biofuels, bioproducts, and biopower.

The Bioeconomy Initiative builds upon previous federal investments in basic research and applied research and development as well as extensive private sector investment to date. Future progress will continue to require federal support as well as leadership from industry and other stakeholders. The Bioeconomy Initiative will involve continued collaboration between the federal agencies of the Biomass Research and Development (BR&D) Board to focus on key scientific and technical barriers with the goal of empowering external stakeholders to realize the full sustainable potential of the nation's abundant biomass resources.

[4] Jonathan N. Rogers, Bryce Stokes, Jennifer Dunn, Hao Cai, May Wu, Zia Haq, and Harry Baumes, "An Assessment of the Potential Products and Economic and Environmental Impacts Resulting from a Billion Ton Bioeconomy," *Biofuels, Bioproducts, and Biorefining* 11, no. 1 (2017): 110–128, doi: 10.1002/bbb.1728.

[5] This analysis is not a projection. It is an assessment of various potential bioeconomy scenarios that could result from utilizing approximately a billion tons of biomass annually. Estimates assume 27 billion kWh and 90 trillion BTUs from livestock anaerobic digesters.

1.2 Purpose of the Implementation Framework

The Bioeconomy Initiative: Implementation Framework (Framework) provides a guiding structure for federal agencies to address key scientific and technical challenges that limit expansion of a domestic bioeconomy. The Framework will enable federal agencies to advance progress on the Bioeconomy Initiative's key goals by providing a strategic approach for coordination and collaboration between the federal government and various stakeholders, such as farmers; producers; forest landowners; universities; industry groups; civil society; and state, regional, and local governments.

The Implementation Framework covers critical components of a continuum of activities, beginning with conceptual and foundational research, applied research and development, sustainability analysis (economic, social, and environmental), pre-commercialization R&D and demonstration, community and individual education, and workforce development. This Framework lays out activities that will help understand and mitigate technology uncertainty; leverage government, academic, industrial, and non-governmental resources and capabilities; stimulate public-private partnerships and investment; and generate technical information that can inform decision-makers and policymakers across complex value chains. No singular agency has the expertise for all aspects of the bioeconomy supply chain; it is only by leveraging the strengths of all BR&D Board agencies that technology challenges can be addressed.

The Framework serves as a guiding document for the BR&D Board member agencies to (1) increase government accountability and efficiency, (2) maximize interagency coordination on research and other activities, and (3) accelerate innovative and sustainable technologies that harness the nation's biomass resources to enhance national security, economic growth, job creation, and environmental quality. This effort does not supersede or override the statutory and regulatory authority, mission, program, or approach of the participating agencies or their organizational components. In addition, execution of the actions outlined in this plan are subject to the availability of appropriated budgetary resources.

Sustainability is the aspiration to meet current needs while maintaining capacity for future generations to meet their needs. Consistent with the BR&D Board's mission to maximize the benefits deriving from federal investments, it is important that those investments result in technologies that are economically and environmentally viable, socially acceptable, and protective of human health and welfare.[6] While Board member agencies have different areas of focus with regard to sustainability, the Board considers multiple dimensions of sustainability in an integrated manner:

- economic (e.g., economic growth, affordability, resilience, energy security)
- social (e.g., jobs, workforce development, food security, health, and safety)
- environmental (e.g., energy and water consumption, material intensity, GHG and other air emissions, ecological impacts).

[6] Consistent with the National Environmental Policy Act Sec. 101, 42 USC § 4331 (1969).

1.3 Background

The BR&D Board was established under 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." As an extension to the Board's focus on R&D, the Board also facilitates coordination and communication of related activities that agencies conduct as part of their missions, including data collection, analysis, demonstration, extension, stakeholder engagement, and workforce development relevant to enable biofuels, bioproducts, and biopower. Coordination and communication on these efforts is critical for bringing coherence to federal strategic planning and ensuring that the products of R&D investments can be integrated into the bioeconomy.

Although the United States is a global leader in the use of biomass for energy and products, there is ample opportunity to grow this sector of the economy. As the nation considers a robust range of energy choices, including integrating renewable energy in an affordable and resilient energy economy, a coordinated effort is needed to overcome challenges for biomass if it is to contribute more significantly to the process. Since 2013, the BR&D Board and its member agencies have led an effort to shape an interagency initiative that addresses key scientific and technical challenges to enable the sustainable production and utilization of biomass for affordable domestic biofuels, bioproducts, and biopower.

The effort has evolved over the last few years through two federal strategy workshops in 2015 and 2017, as well as multiple stakeholder engagement workshops. In early 2016, the BR&D Board released the *Federal Activities Report on the Bioeconomy*[7] (FARB), which emphasized the potential for a stronger U.S. bioeconomy and summarized the wide-ranging, federally funded activities already underway to bolster the production and use of biofuels, bioproducts, and biopower. Later in 2016, the Board engaged with more than 400 stakeholders through four in-person bioeconomy listening sessions, which were held in conjunction with major bioenergy industry events, and one public webinar. *The Billion Ton Bioeconomy Initiative: Challenges & Opportunities*[8] (C&O) report summarizes key challenges and opportunities that federal and external stakeholders identified, as outlined in Table 1. When evaluating these challenges, the Board focuses on areas where the federal government can play a beneficial role, rather than challenges that are best addressed by the private sector or other organizations.

[7] Biomass Research and Development Board, Federal Activities Report on the Bioeconomy (BR&D Board, February 2016), biomassboard.gov/pdfs/farb_2_18_16.pdf.

[8] Biomass Research and Development Board, Billion Ton Bioeconomy Initiative: Challenges & Opportunities (BR&D Board, 2016), biomassboard.gov/pdfs/the_bioeconomy_initiative.pdf.

TABLE 1. Summary of the Challenges and Opportunities for Expanding the Bioeconomy

Challenges
• Major technical hurdles for development and scale • Steep competition from traditional petroleum-derived resources • A lack of necessary infrastructure • Access to capital for large financial investments • Uncertainties about sustainability—understanding environmental, social, and economic outcomes • Growth instability and increased investment risk caused by policy uncertainty • The need for a capable workforce • Lack of access to knowledge, data, and tools to understand impacts of the bioeconomy* • Lack of a formal, collaborative mechanism for sharing knowledge, deploying technology, and developing cooperative activities with stakeholders*
Opportunities
• Develop feedstock and fundamental innovations that reduce cost and technology uncertainty in the supply chain • Seek opportunities to utilize low-cost waste resources • Quantify, communicate, and enhance beneficial effects and minimize negative impacts • Increase public education on biomass-derived products in a bioeconomy • Develop bioproducts that can accelerate biofuel production • Enable the testing and approval of new biofuels and bioproducts • Expand the market potential for biomass • Encourage private-sector financing • Support analysis as a foundation for stable, long-term policies • Ensure a ready workforce to meet the needs of the bioeconomy

** Resulting from the ATIP Bioeconomy Regional Stakeholder Forums, stakeholders identified two additional challenges that were not reflected in the C&O report.*

Additionally, in 2016, the Agricultural Technology Innovation Partnership (ATIP) Foundation, in partnership with DOE and USDA, co-hosted five Bioeconomy Regional Stakeholder Forums throughout the United States. The ATIP regional workshops brought together about 250 bioeconomy stakeholders from six sectors, with 29% from academia, 21% from industry, 17% from state governments, and the remaining from workforce development, finance, agricultural, and environmental organizations. ATIP synthesized and presented this stakeholder input to the Board. This collective stakeholder input, as well as prior Board activities, provided a foundation for developing the Framework.

1.4 Developing the Implementation Framework

In April 2017, the BR&D Board hosted a federal strategy workshop to formulate the Framework and develop a roadmap of crosscutting interagency activities and collaborative actions to catalyze the expansion of a sustainable domestic bioeconomy. A diverse group of federal employees attended this workshop, with nearly 100 representatives from DOE's Office of Science and Bioenergy Technologies Office (BETO); USDA's Agricultural Research Service (ARS), National Institute of Food and Agriculture (NIFA), Office of the Chief Economist, Rural Development mission area, and U.S. Forest Service; EPA; DOT's Office of the Secretary of Transportation, Federal Aviation

Administration (FAA), and Volpe National Transportation Systems Center; DoD; DOI's Bureau of Land Management (BLM); NSF; and the National Oceanic and Atmospheric Administration (NOAA).

During the federal strategy workshop, the BR&D Board's eight interagency working groups (IWGs) discussed challenges previously identified by stakeholders, key goals and approaches to address specific scientific challenges, agency actions to implement the Bioeconomy Initiative, and metrics to measure success. The IWG breakout sessions included the following: Algae; Feedstock Genetic Improvement; Feedstock Production and Management; Feedstock Logistics; Conversion; Transportation, Distribution Infrastructure, and End Use; Analysis; and Sustainable Bioeconomy. Additionally, participants also discussed crosscutting topics, including knowledge transfer, technology transfer, project finance, stakeholder engagement, and industry partnerships.

Following the workshop, the IWGs used the feedback from the IWG breakout sessions to identify current capabilities, as well as knowledge and technology gaps, and to develop ongoing and new actions within each R&D priority area along the supply chain (see Chapter 4). The BR&D Board's Operations Committee used the feedback from the crosscutting breakout sessions to develop the fundamental actions for implementing the Bioeconomy Initiative (see Chapter 5). The resulting Framework lays out collaborative strategies to support the Bioeconomy Initiative's overarching vision while maximizing the public value of federal investments.

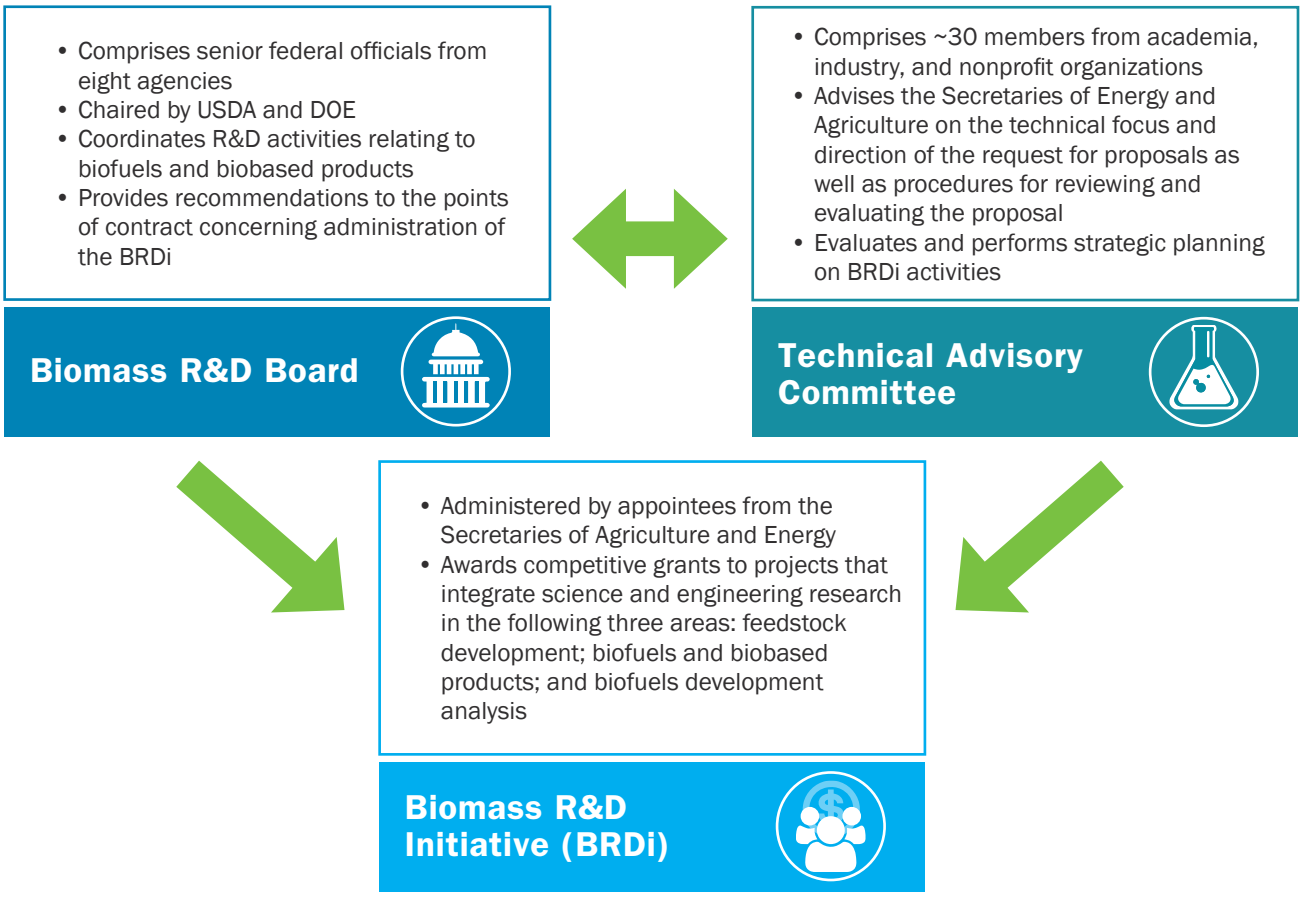
[9] Biomass Research and Development Board, National Biofuels Action Plan (BR&D Board, October 2008), eere.energy.gov/bioenergy/pdfs/nbap.pdf.

[10] Biomass Research and Development Board, National Biofuels Action Plan 2012 (BR&D Board, January 2013), biomassboard.gov/pdfs/national_biofuels_update_2013.pdf.

2 Maximizing Interagency Coordination

The Biomass Research and Development Act of 2000 established the interagency BR&D Board, the Technical Advisory Committee (TAC), and the Biomass R&D Initiative (BRDi), as illustrated in Figure 1. Prior to formation of the Board, active program planning and coordination among the agencies began in earnest with the development of the 2008 National Biofuels Action Plan, which was later updated by the Board in 2012. Simultaneously, the BR&D Board formalized eight IWGs to enhance information sharing and program coordination for specific components of the supply chain. In 2008, at the request of the Board and as directed by the National Biofuels Action Plan, the IWGs began developing reports and white papers that were relevant to the IWG's stakeholders, based on each IWG's expertise. Since 2002, the TAC has continuously provided input to the BRDi solicitation, as well as annual reports to the BR&D Board. The TAC has also provided reports and vision documents from 2002 to 2007.[11] During 17 years of operation, this organizational structure has provided needed background and institutionalized cooperation and capacity to support the Bioeconomy Initiative.

FIGURE 1. Biomass R&D structure



[11] "Reports," BR&D Board, last modified December 6, 2010, biomassboard.gov/committee/reports.html.

This Framework will be used to guide the Bioeconomy Initiative, which will be collaborative, have targeted objectives, evolve over time, and involve actions by complementary but independent agencies. To be successful, a management framework must be in place that builds on the current foundational organization and improves coordination of numerous and interrelated actions supporting the goal to accelerate the expansion of the bioeconomy.

This section explains the structure, roles, and management of the Bioeconomy Initiative. The agency roles and approaches are meant to fall within the mission and authority of each individual agency and program thereof, with contributions to the Bioeconomy Initiative based on self-prescribed capabilities, resources, and budget alignment. The roles are strictly cooperative and collaborative without mandates or legalistic intent.

2.1 Roles and Responsibilities

The BR&D Board has authority over the Bioeconomy Initiative in terms of strategy, direction, and governance. By statute, the Secretaries of Energy and Agriculture designate points of contact for DOE and USDA, with the consent of the Senate.[12] The point of contacts from DOE and USDA serve as Co-chairs of the Board and have oversight of Board activities. The Board consists of senior officers of DoD, DOI, DOT, EPA, NSF, and OSTP, each of whom has a rank that is equivalent to the rank of the Co-chairs. Board members provide executive leadership for Board activities, including the Bioeconomy Initiative. The Operations Committee, which consists of career federal employees from each Board agency, serves as the lead body coordinating the work of the Board and the Bioeconomy Initiative. The IWGs work to implement activities that address specific topic areas in relation to the Bioeconomy Initiative.

The roles and responsibilities of the entities that comprise the Bioeconomy Initiative are as follows:

BR&D Board

- Requests, reviews, and approves IWG work plans and technical documents produced by IWGs
- Conducts annual reviews of IWG accomplishments and develops annual plans to update strategy and direction, provide recommended actions, and discuss changes in agency roles and responsibilities
- Receives quarterly updates from the Operations Committee and selected agencies
- Approves all Board reports (but not those of individual agencies)
- Interfaces with agency leadership, the Office of Science and Technology Policy, and the Office of Management and Budget on progress and accomplishments

Operations Committee

- Provides a working interface between the agencies and the Board
- Provides continuity across the federal government during administration transitions
- Keeps abreast of technologies and facilitates information exchange across the agencies
- Provides coordination oversight of the Bioeconomy Initiative on an ongoing basis

[12] The Board was established by the Biomass Research & Development Act of 2000 and was continued under Section 9008 of the Farm Security and Rural Investment Act of 2002, as revised by the Food, Conservation, and Energy Act of 2008 and the Agricultural Act of 2014.

- Works with agencies to implement the Bioeconomy Initiative and provides guidance on major activities and actions
- Prepares progress reports (annually or as needed) on the Bioeconomy Initiative to present to the Board.

IWGs

- Coordinate actions and activities for specific topic areas
- Develop IWG-specific Annual Work Plans in relation to the Bioeconomy Initiative.

TAC

- Provides input, information, and special reports on the Bioeconomy Initiative at the request of the Board
- Receives an annual progress report from the Operations Committee on the Bioeconomy Initiative and provides comments
- Provides technical knowledge on an as needed basis.

2.2 Structure and Management of the Bioeconomy Initiative

In 2016, the BR&D Board formally approved the Bioeconomy Initiative, and Board member agencies have participated in the Bioeconomy Initiative's formulation over the past few years. The Operations Committee will provide coordination oversight of the Bioeconomy Initiative on an ongoing basis. For example, the Operations Committee will coordinate the process of determining annual actions and securing commitment from member agencies for specific projects and resources as appropriations allow. The Operations Committee will also oversee development and maintenance of a database to maintain the record of planned actions and accomplishments. The FARB and other Board documents provide the general agency roles and mission areas, and the Operations Committee will update these documents as needed.

Board member agencies will cooperate to align budget requests, as appropriate. However, budget formulation and prioritization are at the discretion of each individual agency with OMB oversight. Enhanced cooperation and coordination of actions among all the agencies will improve the quality of and justification for each individual agency's budget formulation and program planning.

3 The United States' Bioenergy and Bioproducts Industries

The current bioeconomy is dominated by starch-based ethanol, while other technologies are emerging at different scales and technology readiness—such as biodiesel from plant and waste oil; the production of heat and power from biomass; and advanced biofuels, including renewable diesel, jet, and gasoline. Additionally, the bioeconomy includes the production of renewable chemicals and chemical intermediates that can offer advantages relative to conventional products.

3.1 State of the Bioenergy Industry

The current state of the industry is mostly a combination of biopower (heat and electricity) and biofuels—primarily starch-based ethanol and soy-based oils. Rogers et al.[13] reported that the United States consumed 365 million dry tons of biomass in 2014. Wood and wood waste accounted for 43.4% of this total, while corn grain composed about 34.3%. Rogers et al. estimated that biomass resources provided 56 billion kWh of electricity and 947 trillion BTUs of thermal energy. In 2016, the 143.4 billion gallons of finished motor gasoline consumed in the United States contained about 14.4 billion gallons of fuel ethanol, about 10% of the total volume.[14]

Most biopower to date is produced from direct firing of biomass. For decades, biopower was the second-largest contributor to U.S. renewable electricity production after hydroelectric power. U.S. Energy Information Administration data[15] indicate that hydropower provided 97% of renewable generation in 1984, and hydropower remains the single largest source of renewable electricity. Wind generation and solar power have gained rapidly on biopower, with wind generation becoming the second-largest contributor of renewable electricity in 2008. Similar to other renewable sources, biopower has the potential to provide several benefits compared to traditional nonrenewable energy production. Biopower can provide: (1) a clean, domestic, and dispatchable renewable source; (2) feedstock supply diversity; (3) unique opportunities for greater biomass resource management and closure of biomass waste streams; and (4) reduced impacts on the environment and climate.[16]

In June 2017, there were 198 commercial fuel ethanol plants in the United States with a nameplate capacity of 15.5 billion gallons.[17] All biorefineries were starch-based ethanol plants using mostly corn grain as a feedstock, except for 19 facilities that used some form of lignocellulosic feedstocks. The U.S. biodiesel industry has grown to 124 commercial production facilities with a total capacity of 2.5 billion gallons per year as of December 2017.[18] The industry reached a key 1-billion-gallon production milestone in 2011, and then hit a record high of 2.8 billion gallons in 2016.[19]

[13] Jonathan N. Rogers, Bryce Stokes, Jennifer Dunn, Hao Cai, May Wu, Zia Haq, and Harry Baumes, "An Assessment of the Potential Products and Economic and Environmental Impacts Resulting from a Billion Ton Bioeconomy," Biofuels, Bioproducts, and Biorefining 11, no. 1 (2017): 110–128, doi:10.1002/bbb.1728.

[14] "How Much Ethanol Is in Gasoline, and How Does It Affect Fuel Economy?" Frequently Asked Questions, U.S. Energy Information Administration, last modified March 29, 2017, eia.gov/tools/faqs/faq.php?id=27&t=10.

[15] Energy Information Administration, Monthly Energy Review July 2018, Table 7.2a Annual tab. https://www.eia.gov/totalenergy/data/browser/xls.php?tbl=T07.02A&freq=m Renewable generation is defined as the sum of generation from hydroelectric power, wood, waste, geothermal, solar, and wind.

There are a variety of types of renewable fuels, including renewable gasoline, diesel, and jet fuels that can be direct replacement fuels, commonly referred to as "drop-in" fuels. Renewable hydrocarbon biofuels (drop-in biofuels or advanced hydrocarbon biofuels) are fuels produced from various types of renewable feedstocks, including cellulosic biomass and wet and gaseous waste streams, through a variety of conversion technologies. Drop-in biofuels may use conventional petroleum distribution systems and may not require special storage, distribution systems, or pumps. Testing of these fuels in vehicles—as illustrated by the aviation sector's many hours of rig and engine testing, fit-for-purpose testing, and flight time using biofuel-blended jet fuel—is helping to introduce them into the market.[20] Additionally, vehicle technologies are being optimized alongside fuels to maximize performance.[21] The advancement of drop-in biofuels production capabilities could be a game changer for the industry and the bioeconomy.

Cellulosic biofuels (i.e., biofuels produced from the structural fibers of plants) are in their infancy, with a limited number of commercial facilities operating in the United States.[22] Attempts to increase the number of cellulosic facilities have faced challenges, leading to several false starts and closed facilities. Research and development can address these challenges by reducing technology uncertainty and the risk of scaling up to long-term commercial operations.

3.2 State of the Bioproducts Industry

Biomass can be used to create valuable renewable chemicals and other bioproducts in addition to heat, power, and fuels. Chemicals and materials co-produced with biofuels can improve the overall economics of a biorefinery. Indeed, there are clear opportunities to improve the economics and sustainability of biomass pathways by producing higher-value bioproducts alongside bioenergy.

A 2016 USDA study reported that the U.S. biobased products sector—which excluded the energy, livestock, food, feed, and pharmaceutical industries—produces at least 40,000 biobased products such as chemicals, enzymes, bioplastic bottles and packaging, and textiles. The study also estimates that the U.S. biobased products sector grew by $24 billion from 2013 to 2014 and contributed $393 billion and 4.2 million jobs to the U.S. economy in 2014.[23]

There is a growing market for renewable biochemicals (e.g., succinic acid, propylene glycol, lactic acid, amino acids, and 1,4-butanediol) and biopolymers (e.g., polylactic acid, polyhydroxybutyrate, carbon fibers, and polyethylene furandicarboxylate). Cutting-edge synthetic biology, genetics, and genomics research is enabling new conversion technologies and approaches, as well as new non-food and non-feed plants that can be engineered in ways that

[16] "Biopower," U.S. Department of Energy, Bioenergy Technologies Office, March 2010, energy.gov/sites/prod/files/2014/04/f14/biopower_factsheet.pdf.

[17] "U.S. Fuel Ethanol Plant Production Capacity," U.S. Energy Information Administration, June 20, 2017, http://eia.gov/petroleum/ethanolcapacity/index.php.

[18] "U.S. Biodiesel Plants," Biodiesel Magazine, last modified December 13, 2017, biodieselmagazine.com/plants/listplants/USA/.

[19] "Production Statistics," National Biodiesel Board, biodiesel.org/production/production-statistics.

[20] "Alternative Fuel Vehicles," U.S. Department of Energy, energy.gov/public-services/vehicles/alternative-fuel-vehicles.

[21] "Co-Optimization of Fuels & Engines for Tomorrow's Energy-Efficient Vehicles," National Renewable Energy Laboratory, March 2016, nrel.gov/docs/fy16osti/66146.pdf.

[22] "U.S. Ethanol Plants," *Ethanol Producer Magazine*, last modified September 23, 2017, ethanolproducer.com/plants/listplants/US/Operational/Cellulosic.

make them more amenable to conversion (e.g., easily degradable cell walls reduce biomass deconstruction challenges). Microbial genome engineering technologies are advancing strategies to more efficiently deconstruct and convert biomass and are enabling consolidated bioprocessing systems. Fundamental research on biochemical and chemical catalysis and on separations is providing a foundation for developing novel efficient catalysts and processes, as well as for enhancing the efficiency of existing catalysts and processes. The increased generation of bioproducts as biorefinery system co-products can help de-risk construction of biorefineries seeking to produce drop-in fuels.

The USDA BioPreferred program, which was created by the 2002 Farm Bill and reauthorized and expanded as part of the 2014 Farm Bill, works to increase the development, use, and purchase of biobased products through a federal procurement program and a voluntary certification and labeling program. Effectively, the program offers a mechanism to identify biobased products and provides a visible label that promotes commercial products in the emerging bioeconomy.[24] The growing market for biobased products increases the use of agricultural, marine, and forestry materials and also supports jobs and economic growth throughout the rural United States. Biobased products range from construction and janitorial products purchased by federal agencies to personal care and packaging products used by consumers every day. Biobased products also include "upstream" materials, such as biopolymers and biobased chemicals used to create commercial, industrial, or consumer goods. Since the launch of the BioPreferred program's voluntary certification initiative in 2011, more than 3,000 bioproducts have been certified and labeled. In fiscal year 2016, USDA achieved a 98% biobased compliance rate by including the biobased purchasing clause in its eligible contracts.

Given bioproducts' current popularity and projected growth, this is an opportune time to review the frameworks for assessing the life-cycle sustainability of bioproducts. In the future, the BioPreferred program could offer distinguished sustainability levels, providing companies with a standardized means to advertise corporate environmental stewardship while incentivizing improvements to the environmental footprints of biobased products. This voluntary program could promote consumers' selection of increasingly more sustainable products and drive corporate competition to improve the sustainability profiles of biobased products.

[23] Jay S. Golden, Robert Handfield, Jesse Daystar, and Eric McConnell, "An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America," Industrial Biotechnology 11 (2015): 201-209, https://www.researchgate.net/publication/280979090_An_Economic_Impact_Analysis_of_the_US_Biobased_Products_Industry_A_Report_to_the_Congress_of_the_United_States_of_America.

[24] "What Is BioPreferred?" U.S. Department of Agriculture, biopreferred.gov/BioPreferred/faces/pages/AboutBioPreferred.xhtml.

4 Innovating Across the Supply Chain—R&D Priority Areas

Federal agencies, in collaboration with universities, industry, stakeholders, and non-governmental organizations, will need to continue to conduct R&D in support of technology transfer to the bioeconomy industry. Knowledge derived through agricultural, forestry, manufacturing, refining, transporting, and processing is useful and applicable to the bioeconomy. Due to the challenges of biomass supply and access, sustainability, high costs, and financial and ecological risks, targeted R&D can improve technologies and processes to sustainably and reliably produce, supply, and use large quantities of biomass for biofuels, bioproducts, and biopower. New breakthroughs can accelerate the development of advanced biofuels, which could play a vital role in the global realization of sustainable, renewable energy.[25] Advanced biofuels and bioproducts offer resource resilience in a world that depends on carbon for everyday life.

4.1 Knowledge and Technology Gaps

There has been great progress to date, but there are opportunities remaining for changing the state of the bioeconomy. R&D is a major thrust area in overcoming identified gaps in knowledge and technology. The federal government, universities, and industry have made steady progress in technology development over the past decade to support the expansion of the bioeconomy.[26] Current gaps are associated with researching, developing, and deploying efficient, large-scale, high-volume, and distributive production, conversion, and use systems. Future R&D focus areas include the use of multiple feedstocks, the production of intermediates and multiple products, and the introduction of these products into various markets.

The following are some examples of these broadly defined gaps:

- Additional comprehensive data needed in the inventory, analyses, and access of biomass
- Limited ways to densify feedstocks and manage their variability, low yield, inaccessibility, and high cost
- Insufficient feedstock collection, harvest, transport, storage, preprocessing, and distribution technologies, and inefficient supply and distribution systems
- Recalcitrance of feedstocks and need to improve separation/purification processes for conversion to competitive products
- High risks and limited commercialization in the number and capacity of feedstock production systems and facilities that are thoroughly integrated with robust conversion processes
- Need to refine methods for measuring, verifying, and showcasing sustainability

[25] Genevieve Alberts, Maria Ayuso, Ausilio Bauen, Francisco Boshell, Claire Chudziak, Jan Peer Gebauer, Lizzie German, et al., Innovation Outlook: Advanced Liquid Biofuels: Summary for Policy Makers (International Renewable Energy Agency, 2016), irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Biofuels_2016_summary.pdf.

[26] Biomass Research and Development Board, Federal Activities Report on the Bioeconomy (BR&D Board, February 2016), biomassboard.gov/pdfs/farb_2_18_16.pdf.

- Limited transfer of knowledge and demonstration of technology as a catalyst for expansion of the bioeconomy (e.g., encouraging producers, developers, and investors while informing consumers, educators, and the general public)
- Lack of knowledge and tools to identify and develop approaches to use macro- and micro-algae for oil with increased productivity
- Lack of resilient crops that are highly productive in marginal environments where water and nutrients are limited and under stress conditions such as heat, high salinity, and pests.

4.2 Critical Research Areas

New scientific discoveries will lead to applied research and engineering advances for implementing efficient production, conversion, and use systems. With a current federal emphasis on foundational breakthroughs, the biomass research community is primed to deliver fundamental science and early technology development to promote and encourage industrialization using biomass and waste streams. More specifically, foundational discoveries could accomplish the following:

- Develop superior feedstock crop plants with improved yields and quality and less recalcitrance to deconstruction using the tools from genetics and genomics
- Improve enzyme and catalyst effectiveness, efficiency, and regeneration through a combination of biology, chemistry, genetics, and genomic approaches
- Improve catalytic and separations processes through chemical, biological, electrochemical, and material science approaches
- Develop new products, co-products, and robust processes via leading-edge chemistry, synthetic biology, biochemistry, biological, and thermochemical processes
- Advance industrial efficiency through a more complete understanding of cellulosic breakdown and reformulation
- Understand and model materials characteristics and handling.

Then, applied R&D, engineering, and demonstration will help move scientific innovations through the technology readiness levels to implementation.[27] Identified R&D and applied engineering can help resolve barriers in feedstock handling, conversion systems, transportation, and use:

- Techno-economic analysis of alternatives to improve systems
- Market analysis to understand drivers and constraints
- Experimentally derived models of robust conversion pathways for system integration and enhanced performance
- Integration of supply chain from crop establishment to bioproduct use/disposal
- Enhancement of ecological functions through feedstock use and management
- Life-cycle analysis and other sustainability assessments for system improvement and environmental performance

[27] U.S. Department of Energy, Multi-Year Program Plan (DOE, March 2016), energy.gov/sites/prod/files/2016/03/f30/mypp_beto_march2016_2.pdf.

- Increased molecular efficiency of conversion processes
- Development of process intensification and robust advanced separations.

Several Board member agencies conduct R&D, as do their various national laboratories and research centers. The BRDi[28] supports research through USDA- and DOE-funded grants, focusing on the following technical areas: feedstocks development, biofuels and biobased products development, and biofuels development analysis. Additional R&D is funded by the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs at the various agencies. These research activities help support the development of new technology, from molecular mapping of genes to landscape models to properly-designed placement of biomass energy crops within agricultural and forestry landscapes.

The BR&D Board and member agencies have identified several new areas of research as vital additions to the current federal portfolio. These areas may need to be accelerated, expanded, or developed from scratch. Examples of new research areas for member agencies to undertake—in partnership with stakeholders—include, but are not limited to, the following:

- Use metabolic engineering and synthetic biology approaches to improve feedstock production and quality, as well as conversion options
- Understand biotic and physio-biochemical control factors and manipulate microbial, soil carbon, and nitrogen cycling to improve yield and manage site productivity and resilience
- Manage land, water, nutrients, pesticides, and other inputs to protect and conserve U.S. resources, reduce and eliminate negative ecological impacts, and increase yields to reduce land competition and improve economics
- Develop cost-effective preprocessing methods and pathways, beyond moisture management and contaminant removal, to produce molecular and structural changes in feedstocks that enhance conversion
- Apply biological technologies such as synthetic biology[29] in biochemical conversion to improve hydrolysis, fermentation, and catalysis
- Develop new catalysts and catalytic and separations processes based on increased fundamental understanding of biochemical and chemical catalytic mechanisms and separations processes and materials
- Research and develop strategies to increase the viability and cost-effectiveness of carbon utilization and management including direct carbon dioxide utilization
- Incorporate low-cost intermediate production pathways to more easily produce advanced bioproducts and biofuels
- Engineer pyrolysis systems to produce bio-oils from cellulosic feedstocks at high efficiency rates, while understanding the molecule species present and cross reactions of species during upgrading
- Fully integrate the supply chain and link biophysical, weather, engineering, transportation, environmental, and economic models to more fully and holistically understand options and impacts of supply chain decisions
- Evaluate environmental and economic sustainability within the context of promoting quality of life and resource conservation within and beyond the bioeconomy sector.

[28] "Initiative," Biomass Research and Development Board, last modified December 9, 2010, biomassboard.gov/initiative/initiative.html.

[29] Christopher E. French, Damian K. Barnard, Eugene Fletcher, Steven D. Kane, Sahreena Saleem Lakhundi, Chao-Kuo Liu, and Alistair Elfick, "Synthetic Biology for Biomass Conversion," in New and Future Developments in Catalysis: Catalytic Biomass Conversion, edited by S. L. Suib (Elsevier B.V., July 2013), 115–140, doi.org/10.1016/B978-0-444-53878-9.00006-0.

4.3 Algae R&D

4.3.1 Current Capabilities

Algal biomass encompasses a broad category of aquatic organisms that can be classified into two main categories: microalgae (unicellular organisms) and macroalgae (seaweed). Harvested algal biomass can be fractionated and converted into biofuels and products via biochemical or thermochemical means. For the private sector to commercialize algae-derived biofuels and bioproducts, the costs of large-scale algae production and harvesting will need to be decreased. Increasing the productivity of algal biomass is an area of research that can contribute to lowering the cost of algal-derived biofuels and products. DOE has recently made substantial investments in this area through the Advanced Research Projects Agency–Energy (ARPA-E), Office of Science, SBIR/STTR, Small Business Vouchers Program, BETO, and Office of Fossil Energy. DoD has also invested in this research area through DARPA (the Defense Advanced Research Projects Agency) and the Air Force's Office of Scientific Research. NOAA and NSF also have programs that support algae research.

Furthermore, EPA has approved several algal biofuels producers for participation in its Renewable Fuel Standard program and continues to work with producers to increase advanced fuels production under the program. USDA and U.S. Food and Drug Administration involvement is also critical to the implementation and qualification of algae for human and animal consumption. Other products derived from algae, such as lubricants, will need to meet the specifications of their petroleum counterparts and will require testing and acceptance from the government agencies, such as DOT.

These programs address a wide array of activities and approaches to reduce the cost of algae production involving biology, ecology, engineering, economics, and other disciplines.

These federal programs are working toward the following objectives to achieve low-cost advanced algal systems: (1) increasing algal biomass productivity and yield; (2) developing strategies for co-production of value-added chemicals, energy, and materials to meet market needs; and (3) sustainably leveraging resources for a national algal industry.

4.3.2 Knowledge and Technology Gaps

In recent years, algal biofuels R&D has achieved technological advancements that can bring about transformational changes, including the ability to predict, breed, and select the best-performing strains; the ability to harvest algae at high throughputs; and the ability to extract and convert more algal biomass components into fuels. In addition, the field has developed information resources to support evaluations of the utility, safety, and sustainability of algal biomass production and commercialization, according to local resources in the United States. However, much work remains to achieve cost-competitive algal biofuels.

Addressing identified technology gaps in the areas of feedstocks, conversion, and infrastructure would enable algae to support the bioeconomy. Below are specific challenges that should be considered when federal agencies are funding research:

- **The ability to grow and harvest highly productive algae at large scale.** Challenges to address this area include developing advanced molecular biology tools to utilize state of the art techniques in systems biology and omics

tools; the ability to maintain healthy cultures and identify and avoid crashes while limiting the costs of carbon dioxide (CO_2), nutrients, and water resources; and harvesting techniques that limit the energy input and maximize recycling of nutrients and water.

- **The fractionation and conversion of algae into fuels and products.** When increasing the scale of these technologies, the ability to economically fractionate the biomass while maintaining chemical stability can be challenging. In addition to considering challenges of scale, one must also consider the differences in biomass composition as the result of species and growth conditions. The ability to identify and evaluate the co-production of value-added chemicals, energy, and materials to meet market needs will be necessary to the burgeoning algae industry.
- **Addressing the resources needed for the distribution and utilization of a national algal industry.** Increased regional knowledge of available resources, such as water, climate, available land, sun, nutrients, and CO_2, is required. On a national scale, the ability to characterize algal biomass, intermediates, biofuel, bioproducts, contaminants, ideal storage and transportation conditions, weather impacts, stability, and end-product variability will be critical for algae to contribute to a successful bioeconomy.
- **Evaluating sustainability of algae cultivation.** While analytical assessments on water and nutrient use and recycle indicate the ability to produce algal biomass sustainably, these assessments need to continue. The industry must demonstrate that sustainability indicators developed by analytical and non-integrated R&D are achievable at scale in long-term, integrated production.

4.3.3 Ongoing and New Actions for Algae R&D

To complement existing research strategies developed by Board member agencies, the Algae IWG has identified the following goals and actions to undertake in partnership with stakeholders:

4.3.3.1 Goal #1: Continue dedicated R&D for algal biofuels and bioproducts

Subject to the availability of appropriated budgetary resources, BR&D Board member agencies should support dedicated R&D for micro- and macroalgal biofuel and bioproducts production, addressing challenges related to scale-up, biotechnology tools, strain development, harvesting, agronomy strategies, and sustainable resource use. DOE, NSF, USDA, DoD, and NOAA will share information, best practices, and "state-of-the-science" to coordinate research strategies. DOE will continue its support of a variety of micro- and macroalgae production projects. DOE-supported studies of algal photosynthesis and metabolism will identify genetic modification strategies for improving photosynthetic efficiency and redirecting metabolic pathways for effectively producing specific products. Additionally, through the projects selected in the FY17 MARINER funding opportunity, DOE's ARPA-E is supporting the deployment of advanced automation tools to improve macroalgae aquaculture yields. NOAA will develop macroalgae R&D strategies and nursery facilities at national laboratories to cultivate key seaweeds and will encourage the development of efficient marine aquaculture cultivation and harvesting equipment and processes. NOAA will work to make these resources available to aquaculture farmers to jumpstart macroalgae nursery development. NSF will continue to support investigator-initiated projects that develop algal biotechnology and processes that apply algal systems to the production of sustainable biofuels and bioproducts.

4.3.3.2 Goal #2: Develop techno-economic models to inform research

In order to evaluate and strategically address the most impactful R&D priorities, BR&D Board agencies will

support techno-economic modeling of cultivation systems (pond, photobioreactor, attached-growth, and open-ocean designs), as well as bioproduct supply chain analysis. Specifically, NOAA will investigate incorporation of seaweeds into the IMPLAN model framework to enable economic impact analysis. Development of analytical tools can help producers to understand potential prices and entry points for end products versus the cost of production. These models can also help to quantify the ecosystem services of micro- and macroalgae.

There is potential to take advantage of micro- and macroalgae farming's environmental sustainability benefits, depending on location siting and resource requirements. For example, moving toward strain selection that permits use of non-potable water, including wastewater and saline water, is an important goal. Resource assessments for microalgae will help to identify opportunities for resource co-location (particularly with CO_2 sources), and water models will help to inform where and when to grow macroalgae in support of an ecosystem-based approach to marine aquaculture.

4.3.3.3 Goal #3: Leverage high-value bioproducts to develop algae industry infrastructure

In the near term, algae companies are focusing on food and bioproducts. Board member agencies will support research that enables the best uses for both micro- and macroalgae biomass as the industry grows. Increasing the diversity of products from algal biomass could have positive economic effects within this sector.

4.3.3.4 Goal #4: Coordinate regulatory and policy guidance to support algae companies

Algae cultivation facilities will face an array of permitting requirements, and regulatory Board member agencies will coordinate guidance to make application processes more transparent, both at the federal and the state level. EPA is developing guidance on Toxic Substances Control Act Experimental Release Applications for genetically modified algae, working closely with DOE and the algae R&D community. EPA has approved at least one strain of genetically modified algae for outdoor cultivation, and more are expected in the near term. The federal government's Coordinated Framework for Regulation of Biotechnology was revised in 2017 and includes consideration of coordinated oversight of engineered algae used for multiple purposes. NOAA will work with the U.S. Army Corps of Engineers to develop regulatory processes for ocean-based farming and streamline permitting processes for macroalgae cultivation. In addition to permitting, Board member agencies will support the growing industry by determining which existing agricultural financial support programs may apply to micro- and macroalgae cultivators.

BR&D Board member agencies will also support the future of the algae sector through advocating science, technology, engineering, and math (STEM) education programs and encouraging phycology education and scholarships. Board member agencies will support communication efforts to educate people on macroalgae and genetically modified algae.

4.4 Feedstock Genetic Improvement R&D

4.4.1 Current Capabilities

The foundation of a vibrant bioeconomy lies in the production of a sustainable, steady source of feedstock materials, including dedicated, domestically grown bioenergy feedstocks such as lignocellulosic biomass, oilseed crops, and algae. While feedstock genetic improvement is the farthest upstream element of integrated biomass feedstock supply chains, it is inextricably linked to downstream supply chain elements, including sustainable production, logistics

(i.e., harvest, transportation, storage, and preprocessing), and conversion to fuels, chemicals, and other biobased products. Several federal agencies conducting or supporting genetic and genomic research on bioenergy feedstock development include DOE's Office of Science, ARPA-E, and BETO; NSF Biological Sciences and Engineering Directorates; and USDA's NIFA, ARS, Forest Service R&D, and Natural Resources Conservation Service (crop evaluation). Utilizing grants, research centers, and the national laboratories, these programs focus on basic research into the molecular mechanisms and processes underlying key bioenergy crop traits (e.g., biomass yields, biomass recalcitrance, oil quality and lipid composition, stress tolerance, photosynthetic efficiency, and water and nutrient use efficiency), classical and advanced plant breeding (e.g., marker-aided, phenomics, and metabolomics), plant genetic and genome engineering, and regional crop adaptation and production evaluation.

The past decade has seen significant activity from federal agencies towards these goals. For example, the DOE Biological and Environmental Research (BER) program's Bioenergy Research Centers have worked towards reducing plant cell walls' recalcitrance to deconstruction through genetic manipulation of lignin composition and deposition without compromising plant vigor using Zip-lignins™.[30] Additionally, the joint USDA-DOE Plant Feedstocks Genomics for Bioenergy program has recently included research on the genetic improvement of non-food oilseed crops in its portfolio,[31] and the BER Biosystems Design program supports research for advanced engineering of bioenergy crops.[32] Fundamental research in DOE's Office of Basic Energy Sciences (BES) Photosynthetic Systems and Physical Biosciences programs is providing a more complete biochemical understanding of photosynthesis and energy conversion, which can aid future development of new strategies for enhancing photosynthetic efficiency and enzyme function. Phenotyping tools under development by ARPA-E's Transportation Energy Resources from Renewable Agriculture (TERRA) program will facilitate the incorporation of these genetic improvements into elite crop varieties. These programs complement and leverage important programs within other DOE offices and federal agencies, such as USDA-NIFA's Coordinated Agricultural Projects and NSF's Plant Genome Research Program. One important example is LibertyTM, the first publicly available switchgrass cultivar, which was released by USDA-ARS as part of NIFA's CenUSA Coordinated Agricultural Project[33] in conjunction with USDA's Regional Biomass Research Centers. Another success story is the NIFA-funded project led by USDA-ARS to domesticate and develop a commercial guayule farming system. With university partners and rubber and tire industry leaders, the team achieved their ultimate goal when they successfully built 100% guayule-rubber passenger tires that met all industry specifications.[34]

These efforts are addressing some of the major barriers to cost-effective production of biofuels and bioproducts by (1) overcoming the recalcitrance of the plant cell walls to deconstruction and the resultant high cost of conversion

[30] U.S. Department of Energy, Office of Science, *Lignocellulosic Biomass for Advanced Biofuels and Bioproducts: Workshop Report* (U.S. Department of Energy, Office of Science, February 2015), genomicscience.energy.gov/biofuels/lignocellulose/.

[31] "Plant Feedstock Genomics for Bioenergy," U.S. Department of Energy, Office of Science, Genomic Science Program, last modified April 6, 2017, genomicscience.energy.gov/research/DOEUSDA/index.shtml.

[32] "Systems Biology-Enabled Biosystems Design," U.S. Department of Energy, Office of Science, Genomic Science Program, last modified December 6, 2017, genomicscience.energy.gov/biosystemsdesign/.

[33] Michael D. Casler and Susan J. Harlow, "CenUSA Feedstock Development Creates Improved Switchgrass Varieties," *eXtension*, March 1, 2017, articles.extension.org/pages/74210/cenusa-feedstock-development-creates-improved-switchgrass-varieties.

[34] U.S. Department of Agriculture-National Institute of Food and Agriculture, *National Institute of Food and Agriculture 2016 Annual Report* (USDA-NIFA, 2016), nifa.usda.gov/sites/default/files/resource/NIFA-2016-Annual-Report-Print-Version.pdf.

to sugars; (2) improving yield, oil composition, and oil quality of oilseed crops; (3) developing and producing sustainable, high-yielding, regionally adapted dedicated biomass feedstock crops without disrupting existing land use or agricultural markets; (4) developing and expanding a well-trained workforce; and (5) promoting public outreach efforts on the benefits of developing domestically grown renewable sources of energy.

4.4.2 Knowledge and Technology Gaps

Currently, the high cost of producing biofuels from lignocellulosic biomass is due in part to plant cell walls' recalcitrance to deconstruction, which impedes extraction of the fermentable sugars within the complex polymeric matrix. The mechanisms by which genes involved in cell wall biosynthesis are regulated is unclear, and there are likely hundreds more such genes that remain unidentified; this knowledge is essential for the rational design of biomass characteristics amenable to efficient deconstruction. Oilseed crops have tremendous potential for drop-in fuels and bioproducts, but there is a need for increased yields and optimized oil composition and quality fit to conversion technologies to make them cost-competitive with fossil fuels. Novel approaches that make use of other parts of the plant, not just the seed, for oil production may further enhance the use of oilseed crops for fuels and bioproducts. Innovative genetic and genomic tools and resources must be developed to translate genomic data to phenotype in the field, enabling accelerated breeding for optimized traits. The relationship between plant genotype, the environment, and crop management and the ensuing effects on phenotypic expression are not fully understood. This knowledge will be critical to develop more adaptable and resilient bioenergy crops and will facilitate building predictive crop models that will inform plant performance under changing environmental and market conditions.

As annuals, oilseed crops can be double-cropped with more conventional agricultural crops (e.g., a winter oilseed can be integrated within a corn-soybean rotation), providing additional income to the farmer and ecological benefits such as reducing weeds and runoff. Perennial bioenergy feedstocks such as switchgrass should be regionally adapted and complement existing land uses, thereby reducing risk through diversification. For both annuals and perennials, it is imperative to develop highly productive crops that require minimal inputs (e.g., irrigation, fertilizer) and can provide beneficial ecosystem services (e.g., hydrologic cycle, nutrient cycling), presenting a breeding challenge that can be tackled using the tools of genetics and genomics.

Fully understanding the effects of bioenergy agriculture on biodiversity, soil quality, water quality and quantity, other resources use, GHG emissions, and carbon footprint will require an integrated approach involving whole ecosystems. It has also become increasingly clear that the microbial communities associated with plants (the "phytobiome") can significantly influence plant growth and development, but the mechanisms underlying the communications that occur between plants and microbes, as well as expected genotype-specific interactions and interactions with the environment and crop management regime, are largely unknown.

Genetic engineering and new genome editing technologies (i.e., CRISPR/Cas9) provide potentially powerful tools that could greatly facilitate the development of superior bioenergy feedstock crops with the desirable agronomic and end-market traits described above. However, broader understanding of genetically modified organisms (GMOs) and genome editing has fallen behind the pace of technology development. Regulatory uncertainties, together with a negative public perception of GMOs, could hinder acceptance of bioenergy feedstocks that have been genetically engineered.

Finally, the next generation of plant scientists will need well-rounded, transdisciplinary training that includes breeding, genomics technologies, computational methods, and data analysis and their application to advancing the bioeconomy.

Specific barriers to the development of sustainably grown, highly productive biomass feedstocks include the following:

- **Knowledge of the molecular mechanisms underlying key phenotypic traits is incomplete, as is the translation of this knowledge to developing high-yielding, dedicated feedstock crops.** Genomic and genetic tools and resources, along with fundamental molecular and biochemical analyses, can facilitate the breeding of lignocellulosic feedstock crops with easily digestible cell walls without sacrificing plant health; they could also facilitate the breeding of oilseed crops with oil composition and quality optimized for drop-in fuels and specific, industrial chemicals and bioproducts. This includes tools to incorporate key genes into commercial lines of bioenergy crops through the breeding process more quickly, translating insights identified from basic research programs at DOE, NSF, and USDA to the field.
- **Sustainability of feedstock crop production is currently uncertain.** The impacts of bioenergy crop production on biodiversity, soil and water quality, resource use, GHG emissions, and carbon footprint, as well as whole-system productivity, profitability, and stewardship of natural resources and human capital, need to be defined specifically to regional systems. Bioenergy feedstocks must be developed in the context of the whole ecosystem to limit adverse environmental impacts, not disrupt existing land uses and markets, and ensure feasibility for all participants in the value chain.
- **Feedstock development should be linked to the value proposition driving the economics of an integrated biorefinery (IBR).** The economic value of commodity liquid transportation fuels can be challenging for IBRs. Co-products can round out the value proposition, such as animal feed, high-value lignin products, industrial chemicals, and other biobased products. Feedstock genetic development can play a role in either creating or diminishing co-product value.
- **There is insufficient broad understanding and acceptance of GMO technologies.** Insufficient knowledge and uncertainty around GMOs has impacted public and investor acceptance. It remains to be seen whether genome editing technologies will receive more widespread support and, hence, investment. Clearly articulated science on the efficacy and safety of these new technologies can provide useful and objective information to the public and policymakers.
- **Formal mechanism(s) should be created for sharing knowledge, deploying technology, and developing cooperative activities with stakeholders.** The lack of access to knowledge, data, and tools to understand the impacts of the bioeconomy hinders the smooth deployment of genetically improved bioenergy feedstock crops through the pipeline to full deployment. Feedstock improvement must be linked to all value chain processes (e.g., production, logistics, conversion), with feedback loops and fine-tuning. A shared interagency vision for collaborations must be developed, including industry partnerships and a framework showing both individual and crosscutting activities leading to expanded use of improved feedstocks for the manufacture of biobased products.

4.4.3 Ongoing and New Actions for Feedstock Genetic Improvement R&D

Advances in genomics and related technologies over the past several years are providing tremendous opportunities for the genetic improvement of bioenergy feedstocks. These opportunities lead to the goals and activities discussed below.

4.4.3.1 Goal #1: Develop productive, high-yielding, regionally adapted biomass and oilseed crops for cost-competitive production of biofuels and bioproducts

To make biomass feedstocks competitive with petroleum-derived sources, basic research should focus on how to develop healthy plants with reduced recalcitrance and to optimize the full genetic potential of oilseed crops for yield and oil quality. The genes and regulatory networks underlying key traits must be identified, functionally characterized, and, most importantly, validated in the field. To develop more resilient bioenergy crops, the relationship between the genotype, environment, and management and the effects of these interactions on phenotypic expression should be studied using germplasm collections replicated in multiple geographically diverse locations and maintained over several years. Development of high-throughput platforms for both above- and below-ground phenotyping can allow collection of high-quality field data, facilitating development of predictive crop models and shortening the conventional breeding process.

Specific actions from Board member agencies to achieve this goal include the following:

- Increase cost-effectiveness through valorization of lignin streams for bioproducts
- Breed, evaluate, and increase propagation of biomass feedstock crops for public release and deployment
- Identify, functionally characterize, and field-validate underlying key traits of genes and gene networks, such as stress resistance, drought tolerance, and yield, and translate information to crops in the field using traditional breeding, genetic engineering, and/or genome editing approaches
- Produce the genetic and genomic tools and resources needed to enable accelerated breeding for optimized traits by linking genetic markers with observed plant performance
- Investigate the influence of the phytobiome on these traits, and how it can be manipulated to maximize benefits and reduce inputs; develop breeding programs that incorporate findings to improve plant adaptability and resilience to environmental stressors; and develop more sustainable bioenergy plant feedstocks with reduced input requirements
- Investigate the impacts of bioenergy feedstock production on biodiversity, soil and water quality, resource use, GHG emissions, and carbon footprint
- Integrate biophysical and ecosystem-level crop models to predict how specific genotypes will perform in the field under fluctuating environmental conditions and validate models with high-throughput field characterization.

4.4.3.2 Goal #2: Establish a fully developed biofuel and bioproducts production pipeline—from basic science through translation to improved feedstocks, production, and technology transfer—for manufacturing advanced biofuels, industrial chemicals, and other biobased products

Feedstock improvement should be linked to all value chain processes, including production, logistics, and conversion, with feedback loops to ensure all participants can effectively participate. Knowledge of the bioproducts

and co-products currently possible, newly discovered compounds, and the technologies that will utilize them will allow fine-tuning in the genetic improvement of feedstocks.

Specific actions to achieve this goal include the following:

- Develop feedback loops to coordinate basic research with downstream areas that most efficiently facilitate technology transfer
- Identify downstream limitations to inform science needs to understand basic mechanisms and provide solutions
- Synergize with USDA's ARS and NIFA to launch local or regional programs to conduct ongoing stakeholder engagement and to gather data on plant breeding and informatics.

4.4.3.3 Goal #3: Provide science-based information on the impacts of GMOs and biotechnology to support sound decision-making, regulations, and education efforts

Uncertainty about the regulation of GMOs and new genome editing technologies, as well as the public perception of genetically engineered plants, causes instability in growth of the value chain and increased investment risk. The fiscal year 2017 spending bill includes $3 million earmarked for the U.S. Food and Drug Administration to coordinate with USDA on a consumer outreach and education effort on agricultural biotechnology. Under this legislation, the Agricultural Biotechnology Education and Outreach Initiative aims to provide consumer outreach and education through the publication and distribution of science-based educational information on the environmental, nutritional, food safety, economic, and humanitarian impacts of agricultural biotechnology.[35] The Biotechnology Regulatory Assessment Grants program, jointly administered by NIFA and ARS, supports risk assessment on the effects of introducing genetically engineered animals, plants, or microorganisms into the environment and the management of identified risks. This program provides science-based information relevant to regulatory issues to assist federal regulatory agencies in making decisions regarding genetically engineered organisms.

Specific actions to achieve this goal include the following:

- Conduct techno-economic and bio-risk assessment of emerging approaches to genetic improvement
- Issue new guidance documents based on research studies to inform regulatory processes
- Educate the public about the environmental, nutritional, food safety, economic, and humanitarian impacts of biotechnology, biotech crops, food products, and feed.

4.5 Feedstock Production and Management R&D

4.5.1 Current Capabilities

Biomass production involves the design, planting, and management of biomass feedstocks. A premise of the bioeconomy is that biomass can be grown in a productive, profitable, and environmentally beneficial manner to meet the growing demands for food, feed, fiber, and fuel. If biomass is not grown in such a manner, biofuel production will be limited, will be cost-prohibitive, and/or will not be adopted at the scale needed to meet regional

[35] "Agricultural Biotechnology Education and Outreach Initiative," U.S. Food & Drug Administration, last modified November 29, 2017, fda.gov/Food/ResourcesForYou/Consumers/ucm579348.htm.

and national targets. USDA, DOE, and DOI are actively involved in biomass production, management, and resource assessment, and each agency has various research programs supporting the sustainable production of high-quality, non-food feedstocks for conversion into bioenergy, which is composed of biofuels, bioproducts, and biopower. Below is a summary of their capabilities in bioenergy.

USDA. USDA's ARS, Forest Service, and NIFA have taken the leadership role in federal support for biomass production R&D and implementation of best management practices (BMPs).[36] These agencies have a broad renewable energy portfolio that supports growers, landowners, producers, and biorefinery workers. USDA's programs work to support (1) feedstock production systems with a focus on sustainability and economic impact, (2) conservation planning for biomass crops, and (3) BMPs for the production of biomass crops. Specifically, USDA's Regional Biomass Research Centers provide research coordination, and the Biomass Crop Assistance Program provides financial assistance to owners and operators of agricultural and private forestland who wish to establish, produce, and deliver biomass feedstocks for bioenergy.

DOE. DOE's BETO released the 2016 Billion-Ton Report, representing a joint effort from DOE's national laboratories and USDA, which summarizes the future potential of the United States to produce approximately 1 billion dry tons of biomass resources (composed of agricultural, forestry, waste, and algal materials) on an annual basis in the United States by 2030, while continuing to meet demands for food, feed, industrial uses, and exports.[37,38] In addition, DOE's BER supports basic research that examines the intersection between plants, their associated microbiomes, and their ecosystems to understand responses to changing environmental variables and identify factors critical to sustainable biomass production. Within DOE BES, the Photosynthetic Systems and Physical Biosciences programs support basic research to understand the fundamental mechanisms of energy capture, conversion, and storage in plants. DOE's ARPA-E has advanced high-potential, high-impact energy technologies that are too early for private-sector investment.

DOI. DOI's BLM manages and conserves public lands for the use and enjoyment of present and future generations under its mandate of multiple-use and sustained yield. Nearly one-fourth of the lands that BLM manages—58 million acres—are forests or woodlands. BLM conducts forest management activities, such as forest health treatments and wildfire hazardous fuels reduction, which produce biomass feedstock that some energy companies use to produce renewable energy that helps meet various state and federal renewable energy portfolio standards. From 2010 to 2017, BLM sold an average of 151,000 tons of biomass for energy through contracts and permits.

These current intra- and interagency activities and coordination efforts allow the development of production systems that effectively and economically utilize limited land resources to optimize feedstock production to meet biorefinery needs for cost, quality, and quantity.

[36] Biomass Research and Development Board, Feedstock Production Interagency Working Group, *Bioenergy Feedstock Best Management Practices: Summary and Research Need* (Biomass Research and Development Board), biomassboard.gov/pdfs/bioenergy_feedstocks_bmps.pdf.

[37] U.S. Department of Energy, M. H. Langholtz, B. J. Stokes, and L. M. Eaton (Leads), *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks*, (Oak Ridge, TN: Oak Ridge National Laboratory, July 2016), energy.gov/eere/bioenergy/2016-billion-ton-report.

[38] U.S. Department of Energy, edited by R. A. Efroymson, M. H. Langholtz, K. E. Johnson, and B. J. Stokes, *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*, (Oak Ridge, TN: Oak Ridge National Laboratory, January 2017), energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-volume-2-environmental-sustainability-effects.

4.5.2 Knowledge and Technology Gaps

Among the broad challenges outlined in the C&O report,[39] the Feedstock Production and Management IWG is targeting the following critical challenges:

- **There are suboptimal feedstock yields due to lack of uniform implementation of BMPs at the farm-scale for dedicated agricultural and forestry energy crops and crop residues.** The cost of delivered feedstock to the conversion facility must be reduced to ensure long-term viability to the industry. Increasing yield per unit of land area is one way to rapidly decrease feedstock cost. Unless biomass feedstock production revenue meets and exceeds the revenue potential for existing practices, producer participation will be limited. Increased revenue potential from greater feedstock production in response to R&D and BMPs focused on increasing yields of dedicated energy crops will inspire producers to meet feedstock demand. This is an important crosscutting gap with feedstock genetics and can be addressed in coordination with the Feedstock Genetic Improvement IWG.
- **Infrastructure (e.g., planting and other production equipment, land access for growing and storage) specific to biomass feedstocks is limited or outdated on most farms.** As with the lack of equipment for feedstock logistics (e.g., harvesting, storing, transporting) described in Section 4.6.2 below, there is also a lack of equipment for feedstock production. Farmers have made significant investments in machinery to perform the necessary management practices on existing row crops, with machinery exceeding more than $1 million to plant, spray, and cultivate grain. Transitioning even a small portion of farmland to biomass feedstocks will require purchase of new feedstock-specific machinery or the development of custom operations.
- **The effect of growing large quantities of biomass for bioenergy on environmental, social, and economic outcomes is not well known.** Life-cycle analysis surrounding the sustainability of energy crops is insufficient. Major environmental concerns include potential impacts on soil and water quality, biodiversity, GHG emissions and carbon footprint, net energy values, and direct and indirect land-use changes. Additionally, there are concerns about economic and social issues, such as food security, workforce development, human health, and landowner adoption. R&D activities, decision support tools, and outreach information at the landscape scale could improve environmental, social, and economic outcomes. Biofuel production from large-scale cultivation of corn and soybeans contributes to beneficial and adverse environmental and resource conservation impact when compared against alternative energy sources.[40]
- **Awareness of and access to existing databases should be improved to ensure information is readily available to stakeholders.** These databases often contain both production and logistics data. Thus, the Feedstock Production and Management IWG is coordinating with the Feedstock Logistics IWG. The first goal in the Feedstock Logistics R&D section lays out the actions needed to address this challenge.

4.5.3 Ongoing and New Actions for Feedstock Production R&D

Activities concerning the bioeconomy across the federal government are extensive, and agencies have made progress in understanding the emerging bioeconomy's impacts on each agency. This IWG, in conjunction with the

[39] Biomass Research and Development Board, *Billion Ton Bioeconomy Initiative: Challenges & Opportunities* (BR&D Board, 2016), biomassboard.gov/pdfs/the_bioeconomy_initiative.pdf.

[40] EPA's recently released: "Biofuels and the Environment: The Second Triennial Report to Congress" provides further discussion of the environmental impacts related to biofuel production.

Feedstock Logistics IWG, understands the importance of feedstock production and logistics activities toward delivering feedstocks to a refinery, as well as innovations that can significantly reduce the cost of converting feedstocks into fuels, products, or power. The federal government has also made efforts to develop sustainable supply chains, establish standards, and perform extensive testing of fuels for aviation and surface transportation. However, to further reduce technology uncertainty and overcome barriers to achieving a robust bioeconomy, the bioenergy community must do more, as listed in the following goals and approaches.

4.5.3.1 Goal #1: Achieve available production and management strategies, systems, and practices adapted to local environmental and social conditions to produce large quantities of high-quality feedstock

Increasing energy crop yields, improving feedstock quality and robustness, and uniformly implementing regional BMPs will support sustainable production goals for expanding the bioeconomy.[41] Implementing state-of-the-art BMPs for field trialing of agricultural and forestry energy crops across wide geographies in the United States is needed to achieve bioenergy targets.

Specific actions from Board member agencies to achieve this goal include the following:

- Conduct research that increases feedstock production and decreases variability per unit of land area
- Conduct regional research comparing revenue potential for biomass feedstocks and current production options, in addition to evaluating scenarios for producer participation
- Increase delivery of extension publications on BMPs for agricultural and forestry bioenergy crops, as well as waste resources, to stakeholders
- Continue fundamental crop breeding research to increase energy crop yields, improve rate of establishment, improve feedstock quality and robustness, provide clear guidance on BMPs with respect to chemicals, and maintain a repository of commercial breeding material
- Collaborate with the Conversion IWG to assess and characterize agricultural and forestry crop residues and waste resources and identify the feedstock characteristics that need to be improved to meet desired conversion specifications
- Develop precision agricultural and forestry systems suited to bioenergy landscapes
- Encourage rapid establishment of energy crops through better management guidelines, as well as availability of planting stock through integration with the Feedstock Genetic Improvement IWG (via use of local and regional cultivars and potentially minimal herbicide application where absolutely required)
- Conduct regional field trials and management of energy crops across varying climate and soils to encourage adoption of regional BMPs.

4.5.3.2 Goal #2: Enable new markets for biomass by facilitating feedstock establishment and management

It is necessary to develop robust risk-management tools for biomass producers that promote rural development to maintain agricultural and forestry feedstock production. Feedstock production includes both biomass growth and biomass recovery. For example, according to a joint DOE and USDA report, an estimated 8.4 billion tons of woody

[41] Biomass Research and Development Board, Feedstock Production Interagency Working Group, *Bioenergy Feedstock Best Management Practices: Summary and Research Needs* (Biomass Research and Development Board), biomassboard.gov/pdfs/bioenergy_feedstocks_bmps.pdf.

material needs to be removed from national forests to reduce the risk of fire, insects, and drought.[42] Removal of this woody material poses a significant economic challenge, and converting this biomass to valuable products would help offset the cost of removal. Agencies will encourage a coordinated, government-wide bioeconomy that advances feedstock production and conversion to biofuels and co-products.

Specific actions to achieve this goal include the following:

- Take advantage of current land management practices, cost shares, and loan programs for feedstock production and to increase access to land
- Educate feedstock producers on currently available cost-share and crop insurance programs
- Increase land productivity through integrated landscape cropping systems
- Develop alternative models for providing production infrastructure for custom operators to complete all management practices, or for the biorefinery to rent land and directly provide all management activities, limiting producer input and risk.

4.5.3.3 Goal #3: Establish the relationship between the costs and benefits of growing biomass using environmental, social, and economic sustainability indicators to enable continuous improvement and adaptive management

Agencies will work with stakeholders to enhance overall land productivity to support sustainable biomass, food, feed, and fiber production while meeting other environmental and socioeconomic goals (e.g., maintaining/improving water quality and other ecosystem services).

Specific actions to achieve this goal include the following:

- Support empirical data collection and modeling on the environmental, social, and economic effects of biomass production, using models such as those employed in the *2016 Billion-Ton Report, Volume 2*[43]
- Support R&D of landscape design principles for a range of biomass types and regional contexts
- Support on-the-ground projects that test landscape design principles while monitoring key measures of sustainability; disseminate the practices and tools developed to enable private-sector replication and scale-up.

4.5.3.4 Goal #4: Identify the correlation among crop investment, adoption risk, and policy for several scenarios to inform R&D

Agencies will employ analytical models to assess the outcomes of relevant policies (e.g., RFS and Farm Bill) as they relate to the magnitude and success of biomass production and provide information on the results by evaluating cost share and risk assessment under different policy scenarios. These activities will inform R&D while also identifying issues that need to be addressed through interagency coordination.

[42] U.S. Department of Energy and U.S. Department of Agriculture, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* (Washington, D.C.: DOE and USDA, April 2005), energy.gov/sites/prod/files/2014/04/f14/final_billionton_vision_report2.pdf.

[43] U.S. Department of Energy, edited by R. A. Efroymson, M. H. Langholtz, K. E. Johnson, and B. J. Stokes, *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*, (Oak Ridge, TN: Oak Ridge National Laboratory, January 2017), energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-volume-2-environmetal-sustainability-effects.

Specific actions to achieve this goal include the following:

- Identify and compile a combination of relevant previous and current federally funded work. Provide links to active, completed, and archived projects (such as from projects funded by the Biomass Crop Assistance Program and BRDi) to identify barriers to implementation
- Reduce landowner risk through guaranteed long-term, consistent market participation, using mechanisms such as crop insurance products and cost-share opportunities for bioenergy crops
- Increase the sustainable production of energy crops on marginally productive acres.

4.6 Feedstock Logistics R&D

4.6.1 Current Capabilities

Several federal agencies have R&D programs or activities that are addressing the challenges of improving feedstock logistics systems and are thus reducing the cost of biomass-derived fuels and products.[44] USDA and DOE are the leading agencies for feedstock logistics R&D.

Most feedstock logistics R&D efforts are part of an agency program that has a broader mission and a wider range of goals and activities. Of these programs within DOE, most are either part of BETO, the Office of Science, or ARPA-E. USDA has programs in several offices, but most efforts are in NIFA, ARS, and the Forest Service.[45] NIFA funds extramural feedstock research, development, education, and outreach that includes its Agriculture and Food Research Initiative.

These R&D efforts are completed through approaches that vary by organization. Primary approaches include research centers or units, grants to other organizations (including public/private partnerships), and national laboratories. The programs reflect the complexity of logistics and include a wide array of activities involving agronomy, silviculture, biology, ecology, engineering, economics, and other disciplines.

4.6.2 Knowledge and Technology Gaps

As outlined in the C&O report, there are major technical hurdles for developing a bioeconomy that uses large quantities of biomass annually. Several of these hurdles are pertinent to the area of feedstock logistics. First, there is a lack of specially designed, robust equipment and advanced systems for high-speed, high-volume, low-loss collection, harvest, and preprocessing of biomass. The existing and even newly developed equipment is not universally adaptable to the characteristics of local biomass resources. Second, access to knowledge, data, and tools to understand the impacts of feedstock logistics on the bioeconomy could be improved. Third, with some exceptions (e.g., woody biomass), little operational, reliable, and real-application cost data are available for both conventional and advanced machinery and systems. Finally, decision-making tools could be developed or improved to enable

[44] For the purposes of this plan, the Feedstock Logistics IWG begins with harvest and supply, while the Feedstock Production and Management IWG covers all aspects of biomass growth (or generation) and management. The two IWGs work closely with each other.

[45] For specific information on each Board member agency and their capabilities related to feedstock logistics, see Interagency Feedstock Logistics and Biofuels Distribution Working Group, *Biomass Feedstocks Logistics Research, Development, Deployment, and Demonstration Programs in the Federal Government: Review and Recommendations for Coordination and Collaboration* (Biomass Research and Development Board, July 2014), biomassboard.gov/pdfs/interagency_feedstocks_logistics_july_2014.pdf.

farmers, wood producers, contractors, and supply managers to select machines and operational approaches and to design and manage systems to be cost-competitive.

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

Machines and systems exist that are capable of performing each biomass supply chain operation, but the technology is not designed for the scale and efficiency required for cost-competitive feedstocks and subsequent production of biofuels and bioproducts. Challenges associated with the inherent heterogeneity of biomass and with inconsistent and low-quality feedstocks remain. Therefore, the costs of supplying biomass using currently available technologies are too high for market acceptance of biofuels. Reducing logistics costs is essential to create an economically competitive, sustainable biofuels industry.

The following feedstock considerations are challenges for commercialization:

- **Biomass from agricultural and forest resources has both low bulk and energy densities.** The low bulk and energy densities of these feedstocks make transport, handling, and storage inefficient. Low-cost densification and other preprocessing technologies are needed to achieve higher bulk and/or energy densities for more efficient transportation, storage, and other logistics operations.
- **The moisture content of biomass at the time of harvest—whether agricultural, silvicultural/woody, or algal—makes it conducive to rotting, leading to quality degradation and material loss.** High moisture content can cause aerobic instability during storage and reduce the efficiency of transportation and preprocessing operations. Strategies and equipment are needed to deal with high-moisture biomass.
- **Currently, feedstock logistics equipment is inefficient.** Existing equipment has insufficient capacity to efficiently and economically harvest, store, and deliver feedstocks for biofuels, and it does not address various quality considerations that are critical to conversion processes. Industry collaboration to develop innovative equipment and systems designed specifically for lignocellulosic feedstocks would facilitate eventual transition of innovative technologies to commercial application. New methods of integrating system components can also increase efficiency and reduce costs.
- **Biomass quality is variable and inconsistent within a given species and among different species.** Biomass attributes vary with feedstock source and season, resulting in inefficiencies in handling and conversion systems. There is a need to develop logistics operations that maximize uniformity and consistency of delivered feedstock attributes. Quality standards for delivered feedstocks, as well as instrumentation to determine feedstock quality quickly at the point of sale, would facilitate market transactions and improve the commoditization of feedstocks.
- **Biomass transportation could potentially overburden transportation networks.** Trucking is commonly used for biomass transportation, which is not only costly over long distances, but it is also often damaging to roadways, leading to increased traffic. Research can improve current understanding of how trucking regulations

impact payload limits, reduce costs, and reduce traffic impacts, as well as explore opportunities to use other transport modes, such as rail and waterways. Innovative transportation solutions, such as improved containers and lighter vehicles, could also reduce cost. The first goal in the Transportation, Distribution Infrastructure, and End-Use R&D section lays out the actions that can address this challenge; the Feedstock Logistics IWG will collaborate on these actions.

4.6.3 Ongoing and New Actions for Feedstock Logistics R&D

In addition to BR&D Board member agencies' existing research, the Board has identified new goals to undertake in partnership with stakeholders. The corresponding actions, identified by goal, are discussed below:

4.6.3.1 Goal #1: Provide easily accessible nationwide data on feedstock characteristics and attributes with management applications

To overcome challenges around feedstock logistics, it is critical to have an accessible nationwide database of feedstock characteristics and attributes with management applications from production/supply site to conversion/upgrading location, in addition to having available information on biomass inventory, distribution, and accessibility at various prices, enhancements, and limitations. The overall approach to achieve this goal is to continue to conduct biomass assessments locally, regionally, and nationally; develop a national characteristics database for raw material and feedstocks; and develop methods to quantify and modify characteristics and attributes to meet quality needs for various conversion processes with integration across the supply chain.

Specific actions from Board member agencies to achieve this goal include the following:

- Build a national feedstock network with improved public accessibility by
  - Utilizing existing databases, such as the following (not an exhaustive list):
    - Bioenergy Feedstock Library at Idaho National Laboratory
    - Bioenergy Knowledge Discovery Framework at Oak Ridge National Laboratory
    - Databases on Ag Data Commons, including the Feedstock Readiness Level repository and the Life-Cycle Assessment archive
    - Forthcoming in 2018, an oilseed database available through the BRDi project, "Accelerated Development of Commercial Hydrotreated Renewable Jet Fuel from Redesigned Oil Seed Feedstock Supply Chains"
    - Data available through the USDA-ARS Regional Biomass Research Centers
    - Forthcoming supply chain analysis data available through the FAA-funded ASCENT Center of Excellence[46]
  - Integrating feedstock characteristics, availability, distribution, actual or projected costs, and sustainability analysis along the supply chain.

[46] "ASCENT," FAA Center of Excellence for Alternative Jet Fuels and Environment, ascent.aero/.

[47] "National Program 213: Biorefining; Regional Biomass Research Centers," U.S. Department of Agriculture Agricultural Research Service, ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/biorefining/docs/regional-biomass-research-centers/.

- Incorporate characterization data and procedures from USDA's Regional Biomass Research Centers,[48] DOE's Office of Science's Bioenergy Research Centers,[47] and NSF- and EPA-funded research programs[49]
- Coordinate the collaborations on waste biomass utilization and incorporate quality data and logistics data of various waste streams that are available at EPA, USDA, and DOE into a nationwide feedstock network
- Initiate curated data collection and dissemination at the county, regional, and national levels and ensure standardized characteristics (e.g., units of measure)
- Utilize USDA National Agricultural Statistics Service's Survey and Program for county-level energy crop potential
- Collaborate with NOAA and the National Aeronautics and Space Administration (NASA) on large data collection activities through remote sensing technology
- Through government-funded projects, develop and advance (1) analytical technologies for consistent and reliable measurements, and (2) defined protocols for measuring biomass characteristics along the supply chain.

In the short term, characterization data from USDA and DOE laboratories and research centers, as well as from NSF- and EPA-funded programs, should be inventoried and disseminated with the goal of forming a standardized dataset that is reported in the medium- to long-term. As described in Section 5.1, Knowledge Sharing, a single Bioeconomy Initiative–focused website could help centralize this information with links to the relevant programs.

4.6.3.2 Goal #2: Develop standard costing procedures and cost-rate models for individual equipment and systems

Logistical decision-making information and tools should be more readily available in handbooks, manuals, and websites. The available knowledge for organizing the modern supply chain in other industries is protected as proprietary and is not readily available for application to bioproducts. Board member agencies could help to fill knowledge gaps by organizing available data, disseminating handbooks, and developing cost models. Cost analyses should address the full spectrum of assumptions for equipment to be used in other agricultural or forestry crops when not working in bioenergy crops. In addition, agencies should provide operational costs that demonstrate current, intermediate, and long-term targeted costs based on commercial practice, working technical improvements, and future plans/goals.

Specific actions to achieve this goal include the following:

- Conduct an evaluation of baseline conventional equipment capacity in the near-term; conduct an inventory of existing cost data and cost analysis models for individual equipment and systems; and help increase access to up-to-date data and models of real-world application and operation in the long-term
- Develop advanced and biomass-specific equipment and practices with associated cost analyses, in collaboration with manufacturers and industry stakeholders, for high speed, high volume, and low loss during harvesting, storage, and processing biomass crops to achieve aggressive yield, quality, and cost targets.

[48] "DOE Bioenergy Research Centers," U.S. Department of Energy, Office of Science, Genomic Science Program, last modified April 11, 2018, genomicscience.energy.gov/centers/.

[49] "Public Access to Results of NSF-Funded Research," National Science Foundation, https://www.nsf.gov/news/special_reports/public_access/index.jsp.

4.7 Conversion R&D

4.7.1 Current Capabilities

Realizing the bioeconomy's full potential will require technologies that convert cellulosic, lignocellulosic, organic waste, atmospheric carbon dioxide, and other sustainable and renewable feedstocks (e.g., sustainable oilseed crops) into high-value intermediates, bioproducts, and biofuels. The conversion of lignocellulosic feedstocks into fuels and chemicals can be broadly grouped into two categories: (1) thermal and catalytic processing (typically higher temperature) and (2) biological processing (typically lower temperature). Certain hybrid approaches combining these two processes have also been developed and demonstrated. Independent of the method, conversion proceeds in two phases: (1) biomass deconstruction and (2) bioproduct synthesis.

DOE and USDA have ongoing efforts at scales ranging from basic research and proof of concept to industrial-scale demonstrations. Both of these agencies are working to reduce process costs by increasing the overall biological or chemical catalyst efficiency and maximizing carbon conversion efficiency. DOE supports fundamental scientific discovery and applied R&D to overcome technical barriers to deliver a more diversified range of affordable biofuels, bioproducts, and biopower to U.S. consumers. USDA-ARS concentrates on technologies and strategies to expand demand for agricultural feedstocks from all U.S. regions by improving yield and bioconversion efficiencies, which benefits the farmer. USDA-ARS also facilitates improved bioprocessing utility of feedstocks by developing high-value bioproducts that benefit the bioprocessor. This spurs economic incentives to create new jobs in rural communities. In order to address challenges facing conversion technology development and to facilitate the transition to private-sector deployment, DOE and USDA have established a collaborative approach with DOT to provide the supporting science for fuel and lubricant specifications, with standard-setting organizations such as ASTM International, with EPA to meet requirements of the RFS, and with the FDA to determine acceptable human exposure and/or consumption specifications.

NSF funds fundamental science and engineering research that generates knowledge of physical and chemical phenomena and advances understanding of the performance of chemical and biological catalysts, reaction networks, and conversion reactors for biomass conversion technologies. In addition, DOT, FAA, DOE, USDA, and DoD are investing in efforts to support the research, development, assessment, and deployment of sustainable fuels for the aviation sector.[50] The coordinated R&D strategies aim to achieve rapid development and deployment of alternative jet fuels and identify how each agency is addressing specific alternative jet fuel challenges, from feedstocks to conversion to fuel testing, including testing military-grade fuels. Continued coordination between federal offices, agencies, and departments can enable the sustainable growth and expansion of a successful bioeconomy.

The primary barriers being addressed by these government agencies include, but are not limited to, (1) persistent high cost of bio-derived products relative to petroleum-derived products; (2) feedstock impurities and heterogeneity causing catalyst deactivation, biological toxicity, and/or undesirable process dynamics during conversion; (3) slow

[50] National Science and Technology Council, Alternative Jet Fuel Interagency Working Group, *Federal Alternative Jet Fuels Research and Development Strategy* (Washington, DC: Executive Office of the President of the United States, June 2016), caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf.

rate and low yield of biological and chemical catalysts; (4) uncertainty about technological and economic performance at an integrated scale; and (5) inconsistent distribution and supply of intermediates and fuels to be integrated into existing infrastructure.

4.7.2 Knowledge and Technology Gaps

Addressing significant scientific and technological challenges could enable industry to achieve efficient, cost-effective methods for converting recalcitrant cellulosic and lignocellulosic feedstocks into liquid transportation fuels and bioproducts. Both thermocatalytic (higher temperature) and biological (lower temperature) conversion methods begin with preprocessed biomass that has been subject to some degree of grinding to reduce the biomass particle size and increase the surface area for accessibility to the plant cell wall matrix. The extent of the physical and chemical pretreatment is dependent on the downstream conversion and upgrading compatibility. See section 4.5, Feedstock Production and Management R&D, for more information about current biomass availability and technical challenges.

A major challenge with cellulosic and lignocellulosic feedstocks is recalcitrance—the inherent structural and chemical complexity that nature has built to protect plants from assault by both biological and non-biological forces. This recalcitrance makes it difficult to cost-effectively process plant fiber into usable intermediates that can be converted into liquid fuels and higher-value products. Processes that process whole biomass and attempt to circumvent recalcitrance can face issues of activity, selectivity, separations, and durability.

Another major challenge facing virtually all cellulosic and lignocellulosic processing methods is that the intermediates never emerge in pure form. Intermediates are always mixed with other chemicals (or in the case of bio-oils, are themselves a complex chemical mixture). The extraneous chemicals in these mixtures come either from the plant itself or from the substances used in deconstruction. This makes subsequent processing of the intermediates more difficult. However, technical advances in recent years are beginning to put critical solutions to these problems within reach.

The federal government has already committed substantial resources to both basic and applied research on biomass conversion. Members of the Biomass Conversion IWG will foster the interagency cooperation and coordination necessary to help meet goals for developing cost-competitive, next-generation biorefineries.

Besides challenges for recalcitrant feedstocks, there are different technology challenges for converting sustainable oilseed crops and wet organic wastes. Transesterification to biodiesel and anaerobic digestion to biogas, respectively, are mature technologies for those feedstocks. Efforts to convert oilseed crops primarily focus on conversion to higher-value bioproducts, or more efficient conversion to jet fuel. Challenges in wet organic waste conversion include developing technologies scalable to the resource and developing technologies to more efficiently produce higher-value liquid fuels and higher-value products, rather than biogas.

Conversion considerations that are barriers to commercialization include the following:

- **The persistent high cost of bio-derived fuels and products.** Technical advancements to enable more valuable biobased products (which will create new manufacturing fields) as well as greater quantification and communication of environmental services provided by a sustainable bioeconomy (e.g., improved soil quality and GHG/carbon mitigation) are needed to allow the value proposition of the bioeconomy to be fully realized.

- **Impurities present in feedstocks and/or produced during conversion.** Impurities, residues, and contaminants in feedstock supplies (or generated as intermediates during conversion) can limit biocatalytic viability or poison catalysts, increasing overall biomass conversion process costs. Additionally, undesirable side reactions or excessive accumulation of residual impurities during biomass conversion can limit overall process efficiency and drive up reactor and separations costs.
- **Slow conversion rates and low yields from biological and chemical catalysis.** Advances in chemical and biological reaction engineering are needed to increase conversion kinetics and to enhance the carbon and biomass conversion efficiencies.
- **Uncertainty about technological and economic performance at an integrated scale.** Technology uncertainty, and lack of predictable scale-up and integration of technologies into robust systems, can create reticence to invest in new biorefining processes. Additional R&D with significant industry involvement should focus on addressing challenges to scaling biorefining conversion technology, thereby driving down overall system costs.
- **Inconsistent distribution and supply of intermediates and fuels to be integrated into existing infrastructure.** Leveraging existing refining capacity is one way that certain bio-derived intermediates and oils could be upgraded inexpensively. However, inconsistencies in the quality and type of these bio-derived intermediates and oils, as well as their broad geographical distribution, limit adequate insertion into existing infrastructure. Strategies to normalize and control consistent intermediate production from biomass, as well as more robust supply chains for them, are required.

4.7.3 Ongoing and New Actions for Conversion R&D

In order to better contextualize and re-focus the existing research conducted at Board member agencies, the BR&D Board has identified new goals in partnership with stakeholders. Achieving these goals will require addressing many identified biomass conversion challenges simultaneously and will serve to highlight some critical and overarching outcomes to target. The corresponding actions, identified by goal, are discussed below:

4.7.3.1 Goal #1: Remove barriers to biointermediate refining and upgrading via existing infrastructure

Building a robust bioeconomy would involve substantial new infrastructure, but strategies to leverage existing refining capacity in the short term could defray those costs while scaling up components on the front end of the biomass supply chain.

Specific actions from Board member agencies to achieve this goal include the following:

- Study and identify key platform chemicals
- Address barriers to generating intermediates and products at relevant scales
  - Develop new and effective biomass handling and pretreatment technologies
  - Utilize chemogenomics to study how inhibitors impact metabolisms of biochemical conversion organisms
  - Develop technologies and strategies to build single carbon intermediate platforms for fuel and chemical synthesis that enable direct carbon dioxide utilization
  - Develop strategies to avoid (bio)catalyst toxicity and/or increase resiliency to it
    - Crosscutting strategies to avoid toxicity may include interfacing with feedstock genetics researchers to inform them of inherent feedstock constituents that are inhibitors

- Conversion-only strategies to increase resiliency include pretreatment processing to remove the inhibitors, and increasing the tolerance of the conversion system (organism or catalyst/solvent)

- Focus on new chemical and biochemical reaction engineering strategies to improve overall system reaction kinetics and conversion product yield
  - At the fundamental research level, discover new catalysts, organisms, and related technologies
  - At the early-stage applied research level, build on fundamental discovery to establish meaningful performance targets in titer, rate, and yield.

4.7.3.2 Goal #2: Address critical technical uncertainties to improve the prospects for technology transfer to the private sector

Although bioprocesses can be engineered to offer new and better products with much improved environmental attributes compared to petroleum-derived products, the private-sector investments to scale up new biomass supply chains and optimized biorefining capacity have not been realized due to technology uncertainty. This challenge underscores the relevance of research and development to reduce technology uncertainty and drive down the cost of biofuels and bioproducts. Furthermore, simply comparing the price of biobased products to petroleum-derived products does not fully quantify the additional product values and environmental attributes associated with biobased products. To identify where the Bioeconomy Initiative will create U.S. competitive advantages (e.g., agricultural opportunities, energy security, job creation, GHG mitigation to address climate change, and clean air and water maintenance), Board member agencies seek to systematically address technology uncertainty up and down the biomass supply chain and support relevant supply chain life-cycle and techno-economic assessments that quantify and characterize the comparative values of biobased products. Technical information must then be provided to decision-makers to help inform policies and regulations that are straightforward and effective. The Board will seek to address these challenges with specific actions.

Specific actions to achieve this goal include the following:

- Promote R&D in valorizing residual side streams produced in biomass conversion processes
- Promote R&D to increase efficiency of biomass and carbon conversion and separations processes to drive down the cost of biofuels and bioproducts
- Promote R&D to increase the viability and cost-effectiveness of carbon utilization and management
- Inform a technical communications strategy that better characterizes the advantages and value proposition of a robust bioeconomy in order to reduce the time from early-stage R&D to hand-off to the private sector (see Section 5.2, Stakeholder Engagement)
- Develop and provide technical information to relevant agencies on the emerging bioeconomy to help inform decision-making on policy and regulatory frameworks.

4.8 Transportation, Distribution Infrastructure, and End-Use R&D

4.8.1 Current Capabilities

End-user demand drives the successful private-sector deployment of biomass technologies, and strong market pull is critical for bioeconomy growth. To utilize domestic biomass to make biofuels, bioproducts, and biopower, both the raw materials and final products must be reliably, safely, and efficiently transported and distributed to end users.

DOT, USDA, DOE, and EPA are leading agencies for transport, distribution, and end-user research, development, and demonstration to foster private-sector deployment. Some examples of recent and ongoing agency activities include the following:

DOT. Multiple modal administrations within DOT are engaged in activities related to transporting and distributing biofuels and bioproducts, as part of the agency's critical mission. DOT is responsible for critical aspects of alternative fuel transport, distribution, and end use, including safety, infrastructural adequacy, potential materials compatibility issues, emergency responder education, and training on optimal emergency response to renewable fuels spill incidents. These agencies also support research on novel biofuel characteristics, performance, and specification (e.g., at ASTM), identifying and designating key alternative fuel corridors, modeling potential future scenarios, and developing templates and informational materials to facilitate end-user purchasing and evaluation of new fuels.

USDA. USDA's focus is on feedstock development, production, logistics, sustainability (i.e., economic, environmental, social), education, and outreach. Agencies within USDA provide grants for expanding the nationwide availability of renewable fuel compatible equipment at stations; they also provide financial assistance to owners and operators of agricultural and non-industrial private forestland who wish to establish, produce, and deliver biomass feedstocks. USDA also tracks shipments and deliveries of ethanol, biodiesel grain, and other agricultural commodities.

DOE. The two primary DOE offices involved in transport, distribution, and end-user R&D are BETO and the Vehicle Technologies Office. These offices work in close collaboration to identify and evaluate the highest-value bio-derived fuel options for various market segments, understand material compatibility challenges and infrastructure needs, and facilitate renewable fuel end-user education and outreach. BETO's R&D efforts also focus on improving biomass densification and commoditization to facilitate feedstock transportation.

EPA. EPA addresses the environmental safety of biofuels and bioproducts. This includes studying materials compatibility issues and testing underground storage tank systems and other equipment in which gasoline and diesel blended with renewable fuels are stored, as well as understanding the potential air quality impacts of biofuels and bioproducts at the points of end use and along the supply chain. EPA also qualifies new biofuels for inclusion under the RFS based on their life-cycle GHG emissions and other requirements.

These federal activities are helping to identify the challenges and impacts associated with increased roadway, rail, marine, and pipeline transport of feedstock and bioproducts across the supply chain.[51] They are also addressing issues inhibiting biofuel end-use distribution infrastructure and supporting biofuels adoption among all modes of transportation.

4.8.2 Knowledge and Technology Gaps

As outlined in the C&O report, there are both significant infrastructure challenges and major technical hurdles associated with the development of the bioeconomy. These challenges are especially relevant for the transport and

[51] Note that although work has been done on transport, distribution infrastructure, and end use for biofuels, much less work has considered these challenges for other types of bioproducts (e.g., synthetic chemicals).

distribution of bioproducts. In addition, transport, distribution, and end-use elements are also impacted by challenges related to lack of knowledge, data, and tools for understanding the impact of the bioeconomy.

Transport, distribution, and end-user-related challenges for private-sector deployment include the following:

- Transportation and distribution infrastructure challenges
  - **Safe, efficient transport methods and supporting infrastructure for biofuels and bioproducts are constrained.** Scaled long-distance transport of commodities requires modal infrastructure that may not be compatible with the products, may be limited in capacity and/or unavailable, and may also run geographically opposite to conventional petroleum product distribution patterns. Ethanol and biodiesel, as well as other bioproducts such as synthetic chemicals, rely on truck, rail, and (limited) barge transportation. These modes can also put biofuels at a competitive disadvantage to conventional fuels, which are largely transported by more cost-efficient pipeline service. Biofuels (including advanced hydrocarbon fuels) could be transported in pipelines, but currently they are not in large quantities due to concerns about cross-contamination, blend tracking, insufficient volumes, and economic viability; work needs to be done to establish guidelines and increase pipeline operators' comfort level to transport these fuels efficiently.
  - **Safe, efficient distribution methods for biofuels and fuel blends may require upgrades and retrofitting at stations.** Federal codes require that equipment be compatible with the fuel stored and dispensed. Each station must compare their list of equipment to compatible lists of equipment to determine if equipment needs to be replaced to accommodate a biofuel.[52]
  - **Transportation infrastructure requires locating near the anticipated geographic development patterns of biofuel/bioproduct industries.** Distribution pathways for biofuels and bioproducts will be dictated by conversion facility siting, which in turn will be informed by feedstock production location. Because there is still uncertainty about the scale and structure of the bioeconomy and the biofuel/bioproduct industries, future transport and infrastructure needs are not fully understood. These derived needs should be defined based on regional supply and demand, feedstock, and fuel/product production geography.
  - **Biomass from agricultural and forest resources has various bulk loads and energy densities, requiring high transport volumes.** Therefore, feedstock movements pose a significant transportation challenge. Biomass transportation by truck is costly over long distances and, at high volumes, can damage roadways and lead to increased congestion. As discussed in more detail in the Feedstock Logistics section, research could improve understanding of the implications of trucking regulations on payload limits, costs, and roadway maintenance needs, as well as to explore opportunities to use other transport modes, such as rail and barge, for biomass transport or to adopt a more efficient conversion system to minimize these issues.
- End-user challenges
  - **Vehicle engines for sale in the United States may not be compatible with or optimized to use future biofuels or fuel blends that are being considered.** Advanced engine and biofuel development have not been tightly coupled, which has resulted in vehicles that are not fully compatible with or optimized to run on biofuels that could provide critical properties to maximize performance and value to the consumer.

[52] Compatible equipment lists are available in the appendices of the *U.S. Department of Energy Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends* (Office of Energy Efficiency and Renewable Energy, February 2016), afdc.energy.gov/uploads/publication/ethanol_handbook.pdf and the Biodiesel Handling and Use Guide (Office of Energy Efficiency and Renewable Energy, November 2016), http://biodiesel.org/docs/using-hotline/nrel-handling-and-use.pdf?sfvrsn=4.

- **Testing and qualification of new biofuels are expensive and time-consuming**. End users need assurance of a fuel's performance in both equipment and distribution platforms, which can be achieved through acceptance by an existing specification body. However, fit-for-purpose, compatibility, and performance testing to qualify new products under existing bodies such as ASTM is expensive and can take several years of review and iteration to receive approval.
- **Additional end-user markets have not yet been effectively tapped.** Aviation, marine, rail, medium- and heavy- duty trucks, military, off-road, and other non-light-duty vehicle end-use applications represent substantial opportunity markets for biofuels. In order to realize widespread adoption among these transportation sectors, various technical and market barriers need to be well-understood and addressed. These specialty fleets, which may already use private fuel distribution systems for conventional fuels, present an opportunity for rapid ramp up of biofuels, biofuel blends, and/or other novel fuel introduction; such set-ups have enabled municipal government fleets to become early adopters of alternative fuel vehicles.
- **Consumers are not aware of their options for using biofuels and bioproducts.** As biofuel types and blend choices evolve, education and outreach efforts can enable blenders and fuel retailers to better understand how to reach potential markets and can educate consumers about their vehicle and fuel options and a range of bio-derived products.

4.8.3 Ongoing and New Actions for Transportation, Distribution Infrastructure, and End-Use R&D

In addition to existing research conducted at member agencies, the Board has identified five additional goals to pursue in partnership with stakeholders:

4.8.3.1 Goal #1: Develop efficient transport methods for new biofuels and bioproducts

In order to fully realize private-sector deployment of biofuels and bioproducts, the nation needs a reliable and efficient transportation network, as well as distribution methods that can safely deliver these materials over long distances to their end-use destinations, and/or the development and deployment of systems that minimize the need or impacts associated with the transport of biomass. Currently, insufficient volumes of biofuels and lack of operator experience in transporting these fuels are keeping biofuels and biomaterials from being integrated fully into existing distribution networks. The BR&D Board should promote research to identify and overcome barriers to efficient transport methods and promote the integration of biobased products into existing distribution systems.

Specific actions from Board member agencies to achieve this goal include the following:

- Address pipeline transportation challenges through collaborations among DOT and DOE
- Analyze the availability, capacity, and cost of non-pipeline transport infrastructure for bioenergy feedstock and biofuels, including trucking, rail, barge, and intermodal facilities, based on anticipated industry geography
- Collaborate with the Feedstocks Logistics IWG to increase understanding of truck transport impacts on highway and rural roadway infrastructure, as well as tradeoffs between truck, barge, and rail transportation for moving feedstocks
- Assess workforce needs associated with biofuel/bioproduct transport and delivery across the supply chain (storage, distribution, handling, and end delivery); incorporate projected needs into other federal analyses estimating workforce growth and economic development potential associated with the bioeconomy

- Foster collaboration among DOT, DOE, USDA Rural Development, the Occupational Safety and Health Administration, and the U.S. Department of Labor to identify challenges related to the safe transport of f eedstocks, biofuels, and bioproducts.

4.8.3.2 Goal #2: Develop efficient distribution methods for new biofuels

An efficient and compatible distribution system is needed for biofuels to enter the market and for end users to utilize them. Some upgrades at stations may be needed for ethanol and biodiesel blends higher than E10 or B20, respectively. Furthermore, compatibility of advanced drop-in hydrocarbon fuels and existing distribution equipment may require testing and confirmation. The BR&D Board should identify opportunities to upgrade distribution equipment, improve safety, and address compatibility concerns with existing infrastructure. The Board should reach out to stakeholders to help them take advantage of programs that facilitate equipment upgrades. Specific actions to achieve this goal include the following:

- Collaboration among DOT, DOE, USDA Rural Development, the Occupational Safety and Health Administration, and the U.S. Department of Labor to identify and address challenges and opportunities related to the storage and delivery of feedstocks, biofuels, and bioproducts
- Collaboration among EPA, DOT, USDA, and stakeholders to enhance understanding of new infrastructure needs and enable equipment upgrades
- Collaboration among DOT, DOE, USDA, DoD, EPA, and advanced alternative fuel stakeholders to identify tractable approaches to tracking, chain of custody, and blending for advanced biofuels and bioproducts.

4.8.3.3 Goal #3: Optimize vehicle engines and systems for alternative fuels and advance adoption of low-level biofuel blends across existing on-road vehicle fleet

Specific actions to achieve this goal include the following:

- Leverage DOE's Co-Optimization of Fuels and Engines initiative to identify technology options for advanced biofuel blends and high-performance engines powering the entire on-road vehicle fleet (passenger to light truck to heavy-duty commercial vehicles, including hybrid electric vehicle architectures)
- Identify blendstocks that can provide target ranges of key fuel properties, identify tradeoffs on a consistent and comprehensive basis, and share information with stakeholders
- Identify and streamline regulations to assist with the development of co-optimized fuel and engine technology, prior to private-sector deployment
- Work with original equipment manufacturers (OEMs) to identify current technical issues
- Support an effort to increase data sharing among OEMs on biofuels.

4.8.3.4 Goal #4: Facilitate end-user market expansion by streamlining testing and certification of novel fuels for use in existing surface vehicles, vessels, and aircraft

Introducing a new transportation fuel requires updating or creating a fuel specification, which takes a significant amount of time and consensus and requires coordination between ASTM, fuel manufacturers, OEMs, various government agencies, and industry groups. The BR&D Board should identify opportunities to streamline efforts related to tracking biofuels, blending biofuels, and testing fuels, as well as qualification by standard-setting organizations. The Board should also work towards enhancing scientific knowledge on compatibility of equipment throughout the fuel path.

Specific actions to achieve this goal include the following:

- Collaboration among DOT, DOE, DoD, EPA, and advanced alternative fuel stakeholders to develop tests and predictive models that will enable ASTM qualification of fuels with lower-cost testing methods and lower volumes of novel biofuels
- Coordination among DOT, DOE, EPA, and industry to accelerate testing to advance compatibility of new equipment and generate technical information for standards adoption
- Collaboration among participating agencies to support the execution of action items outlined in the *Federal Alternative Jet Fuels R&D Strategy*,[53] a number of which focus on alternative jet fuel ASTM qualification processes.

4.8.3.5 Goal #5: Engage in outreach to new and existing end users

While biofuels and some biomaterials are already widely used across the nation, consumers are largely unaware of this and, hence, may be resistant to new bioproducts as they become available. Furthermore, there are opportunities to expand bioproduct use across the transportation system that the BR&D Board can help identify and promote. Members of the BR&D Board should engage in stakeholder outreach and data gathering to facilitate expansion of the market for biofuels and bioproducts and help consumers recognize current uses and future potential. A significant portion of this goal strongly relates to the Framework's Stakeholder Engagement strategy for the Bioeconomy Initiative. Therefore, the Transport, Distribution, and End User IWG should coordinate activities under this goal with the actions under that strategy for messaging and outreach methodologies to expand the bioproducts user base.

Specific actions to achieve this goal include the following:

- Execute research to better enable stakeholder outreach:
  - Foster collaboration among DOT, USDA, EPA, and DOE to inventory all current known transportation applications of biobased products and materials (e.g., biobased vehicle and asphalt components, and aviation deicing fluids) as a basis for letting the public/consumers know about the range of biobased products they already use or could be using
  - Analyze national market potential for sulfur-compliant renewable fuels among medium- and heavy-duty vehicles, marine, rail, and other off-road segments, incorporating the market driver associated with international marine cargo shifting to ultra-low-sulfur diesel
- Foster collaboration among Board agencies to enhance stakeholder awareness, in coordination with the Framework's broader Stakeholder Engagement strategy:
  - Coordinate public messaging on biofuel facts, impacts and benefits, success stories, technology readiness, and progress among federal agencies, as well as opportunities to deploy and use bioproducts and biofuels
  - Strive to ensure that auto dealerships selling new and used cars understand the science of biofuels, do not promote myths, and can inform consumers on fuel choice and availability in the local market

[53] National Science and Technology Council, Alternative Jet Fuel Interagency Working Group, *Federal Alternative Jet Fuels Research and Development Strategy* (Washington, DC: Executive Office of the President of the United States, June 2016), caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf.

- Increase coordination with states on consumer education and outreach to bolster local and regional market demand

- Gather input from industry and transportation stakeholders to better identify gaps, needs, and opportunities:
  - Collaborate with industry and other stakeholders to develop a research agenda that addresses gaps and opportunities for expanded bioproduct use in transportation, helping to achieve sustainability and domestic productivity goals
  - Coordinate with state DOTs and Port Authorities to conduct needs and opportunities analysis for incorporating biofuels into the transportation system; target multimodal regional distribution and ports (i.e., trucks, marine, and rail) for renewable fuels demonstration and deployment
  - Partner with state DOTs and industry to advance opportunities for bioenergy production along highway and other transportation corridor rights-of-way.

4.9 Analysis R&D

4.9.1 Current Capabilities

Understanding the potential benefits and issues of a future scaled-up bioeconomy requires analyses and knowledge across a wide array of disciplines, including plant science, agronomics, silviculture, genetics, engineering, economics, and other R&D areas across the supply chain. The BR&D Board recognized this need when developing the bioeconomy concept.

The Analysis IWG was organized in 2014 to coordinate federal analytical activities in the areas of biofuels, bioproducts, and biopower. The goals of the Analysis IWG are to keep the Board informed about analysis activities, leverage resources across the member agencies, and provide value to the Board through accurate and transparent data, information, and analyses. The Analysis IWG brings together researchers and personnel from across the federal government with complementary research efforts and expertise vital to modeling and interpreting a range of economic, technological, and environmental dimensions of the bioeconomy. Additional personnel and supporting resources are located in DOE laboratories and centers; USDA laboratories, centers, and research stations; EPA regional offices; DOI bureaus; NSF-funded research studies; and DOT (FAA).

Collectively, the agencies involved in the Bioeconomy Initiative and the Analysis IWG have the research and analysis capabilities to address almost any aspect of the bioeconomy—from the production of biomass to international trade of biomass-derived products. Appendix I of the FARB provides a general overview of agency activities that contribute to examining the functional aspects of the bioeconomy. These activities include modeling and interpreting the intricate relationships among supply chain components and the micro- and macro-economic aspects of bioeconomy.[54]

Research efforts are supported by various databases and models. Databases include the Billion-Ton reports, Bioenergy Knowledge Discovery Framework, BioEnergy Atlas, Integrated Microbial Genomes, Forest Inventory and Analysis, U.S. Geological Surveys, National Water Information System, ENVIROATLAS, Landfill Methane

[54] Biomass Research and Development Board, *Federal Activities Report on the Bioeconomy* (BR&D Board, February 2016), 14-43, biomassboard.gov/pdfs/farb_2_18_16.pdf.

Outreach Program, USDA's Agricultural Baseline, Major Land Uses, and many other publicly available and accessible data sources. Some of the bioeconomy-related models include the Integrated Farm System Model, Crop Profitability Calculator, Regional Environmental and Agriculture Programming, GREET (The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation), Biomass Scenario Model, POLYSYS (Policy Analysis System), FASOM (Forest and Agricultural Sector Optimization Model), FAPRI (Food and Agricultural Policy Research Institute), and the Freight and Fuel Transportation Optimization Tool.

Access to these databases, models, and analytical tools has been a boon to the Analysis IWG researchers. One of the Analysis IWG's significant accomplishments was evaluating the impact of expanding the current bioeconomy three-fold by 2030. Researchers within the IWG constructed a model to derive revenue from various scenarios of available biomass and product distribution, based on the 2016 Billion-Ton Report. The resulting report estimates potential economic impacts and provides a limited analysis of environmental impacts associated with the use of maximum potential biomass in 2014 and 2030.[55] Additionally, a 2018 report summarizes and analyzes trends on bioenergy, renewable chemicals, and biobased products pertinent to the bioeconomy.[56] The Analysis IWG intends to build on these efforts and has identified additional opportunities for further data collection, model development, and analyses needed to enable the bioeconomy.

4.9.2 Knowledge and Technology Gaps

The C&O report identified several barriers to the expansion of the bioeconomy. The primary barriers identified were achieving adequate sustainable feedstock supply, developing low-cost conversion technology, optimizing distribution infrastructure, and educating consumers of bioeconomy products. Researchers, scientists, economists, modelers, and others are currently addressing many of these barriers through more detailed analyses. Major analysis activities and focus areas include the following:

- Biomass assessments—quantifying the potential amounts and distributions of biomass resources
- Costs and techno-economic analyses—estimating feedstock, final product, unit, and system costs and cost drivers
- Feedstock and product markets—understanding supply and product allocations and technology and policy impacts at various levels of sector growth
- Benefits and negative impacts—addressing sustainability, environmental, social, technical, and economic factors.

The BR&D Board has identified additional needs for analytical development, data availability, and bioeconomy systems integration:

- **The most pressing technical challenge is the lack of real-world operational economic, technical, and engineering data.** To date, most widely accessible data and analyses are from pilot- and demonstration-scale

[55] Jonathan N. Rogers, Bryce Stokes, Jennifer Dunn, Hao Cai, May Wu, Zia Haq, and Harry Baumes, "An Assessment of the Potential Products and Economic and Environmental Impacts Resulting from a Billion Ton Bioeconomy," *Biofuels, Bioproducts, and Biorefining* 11, no. 1 (2017): 110–128, doi:10.1002/bbb.1728.

[56] Jay S. Golden, Robert Handfield, Janire Pascual-Gonzalez, Ben Agsten, Taylor Brennan, Lina Khan, and Emily True. *Indicators of the U.S. Biobased Economy*, (U.S. Department of Agriculture, Office of Energy Policy and New Uses, Office of the Chief Economist, 2018) https://www.usda.gov/oce/energy/files/BIOINDICATORS.pdf.

projects, or simulation runs of modeled systems. More empirical field data would enable a better understanding of system costs and the variables that influence them. This type of data is of great benefit to researchers and engineers, who can use them to design successful supply chains and commercially viable enterprises. Additionally, there is a need for improved analytical tools and models to better understand linkages and to fully integrate functions and inputs/outputs along the supply chain. Operational unit and system-scale information can provide more effective analysis of integrated production systems and their broader supply chains. Engineering models that predict process performance at large scales would be helpful to the establishment of the bioeconomy.

- **There are significant gaps in the nationwide, macroeconomic analysis of the entire bioeconomy.** Analysis gaps include (1) costs, prices, financial information, and business cases; (2) market potentials, drivers, and global implications; (3) infrastructure requirements and dependence on other manufacturing sectors, transportation systems, workforce, financing, and regulatory requirements; (4) quantification and verification of environmental and social effects; and (5) risk reduction strategies. Additional understanding of bioeconomy systems and processes could ensure the environmental sustainability of any development efforts. Analysts need to work with ecological and ecosystems scientists to quantify and interpret benefits and drawbacks to the environment at various scales from the field/stand to the landscape and national levels.[57]

4.9.3 Ongoing and New Actions for Analysis R&D

The FARB provides descriptions of existing and ongoing agency programs and research.[58] The Analysis IWG actions listed above will continue, and additional efforts are needed to support the growth of biomass utilization. Because analysis activities span the supply chain, there are significant cross-connections between the activities proposed below and the work proposed in other IWG sections of this report. Goals, approaches, and actions for the analyses required in support of agency programs and stakeholders are discussed below:

4.9.3.1 Goal #1: Evaluate available economic, technical, and engineering data so agencies, stakeholders, and the public can understand the impacts of an expanding bioeconomy and can adequately consider the benefits and tradeoffs associated with bioenergy, bioproducts, and biopower development

In the future, it would be desirable to have operating data at-scale for all functions of the supply chain—from feedstocks production, to distribution systems, to final product use. However, since this is not readily available, engineering models could be used to predict operational performance characteristics from the bench to pilot scale. The lack of facilities operating at scale and the restricted access to proprietary data have resulted in a scarcity of real-world data. Access to such data will require creative approaches to partnering with commercial operators as new facilities come online. Laboratory, bench, pilot, demonstration-scale, and simulated commercial data have been used and will continue to be refined to inform technologies and methods as efforts to obtain more operational data persist.

[57] See Section 4.10, Sustainability R&D, for more information on addressing environmental and social effects.

[58] Biomass Research and Development Board, *Federal Activities Report on the Bioeconomy* (BR&D Board, February 2016), 14-43, biomassboard.gov/pdfs/farb_2_18_16.pdf.

Specific actions from Board member agencies to achieve this goal include the following:

- Identify, inventory, source, and characterize operational, economic, technical, and engineering data resources (e.g., yield, product selectivity, land-use impacts, biomass allocation to products, operating and capital costs, employment). It is desirable to have data and models using realistic feedstocks with all anticipated variances in properties. This will allow a more robust understanding of research issues and realistic process performance upon which techno-economic analysis and GHG profiles can be calculated.
- Develop a common data repository using quality standards and uploading/downloading interfaces for easy access and management. Robust models are needed that capture real world excursions.
- Use innovative collaboration, licensing, and intellectual property sharing to access operational and industrial data.

4.9.3.2 Goal #2: Validate cost estimates and market prices at representative engineering scales under various scenarios and assumptions to examine process robustness and fully understand research issues with scale-up

A significant obstacle to investments in the bioeconomy are is the technology uncertainties associated with wrongly estimating costs and production for full-scale, high-volume facilities and biorefineries. Sensitivity analyses for variables, such as feedstock variability and process excursions, help to frame or bound these potential risks. While real-world operational data remains difficult to obtain and publicly unavailable, efforts will focus on modeling process capability to help steer research investments that will enable scaling. Models need to incorporate best practices from prior projects.

Specific actions to achieve this goal include the following:

- Adhere to standardized costing and accounting methods
- Derive and develop cost estimates under various feedstock types, conversion pathways, technology changes, and sensitivity to inputs
- Conduct supply chain analyses that consider variability of data inputs and processes
- Perform strategic analysis of intricacies among demand, supply, state of readiness, and acceptability to minimize scale-up risks.

4.9.3.3 Goal #3: Conduct analyses to understand biomass supply, infrastructure, workforce, and other resources needed to expand the bioeconomy

Investors, developers, and researchers must consider several factors when striving to grow the bioeconomy. Research and improved models could mitigate some technology uncertainty pertaining to the production and maintenance of biomass supply, both in terms of short-term availability and cost sensitivities as well as long-term availability due to variability in climate conditions and biomass market disruptions. Additional factors that should be evaluated in modeling efforts include the availability of transportation systems, permitting and licensing access, workforce availability and development (both pertaining to geographic distribution and having the prerequisite skills), and access to resources, such as the steel and power supplies needed to construct and operate facilities needed in the bioeconomy (e.g., feedstock processing/crushing/blending, conversion systems, and product distribution systems). Analyses focused on developing the above infrastructures could provide some strategies for mitigating resource issues.

Specific actions to achieve this goal include the following:

- Continue and enrich feedstock availability analyses that are more regionally specific and include sensitivities to variability in climate conditions, production and yield changes, and environmental/social concerns
- Map feedstock types by regional diversity with possible end-product slates, based on factors including yield and product selectivity
- Develop workforce models to assess worker requirements over time
- Identify infrastructure needs (e.g., facilities, transportation systems, and power supplies)
- Identify and analyze capital requirements, resource needs, machine system and equipment needs, and workforce factors required to support the bioeconomy.

4.9.3.4 Goal #4: Evaluate available tools and models and develop new ones as needed to improve decision making and inform R&D

While several tools and models are available and regularly used by Analysis IWG researchers and bioeconomy stakeholders, new tools should seek to improve cost analyses and evaluate sustainability.[59] Scale is an issue in that models are needed from the field/stand to the landscape and to regional and national levels. In some cases, existing and historical systems can provide useful data, while in others, new approaches can help to identify and measure specific impacts on select key indicators. See Section 4.10, Sustainability R&D, for more information on assessing environmental, social, and economic effects of the bioeconomy.

Specific actions to achieve this goal include the following:

- Complete inventory of tools and models
- Continue to improve life-cycle analysis models, including their estimation of the environmental effects of direct and indirect land-use change
- Link U.S. domestic economic and trade models to global models
- Improve and expand models estimating bioeconomy impact on job creation and economic development at local, regional, and national scales
- Summarize modeling results to date to help the stakeholder community understand environmental and economic effects of an expanding bioeconomy.

4.10 Sustainability R&D

4.10.1 Current Capabilities

Sustainability is the aspiration to meet current needs while maintaining capacity for future generations to meet their needs. When developing the bioeconomy concept, the BR&D Board recognized the need to expand the bioeconomy in a manner that benefits the environment, the economy, and national security. To strengthen its commitment to sustainability, the Board created the Sustainable Bioeconomy IWG in 2016. The Sustainable Bioeconomy IWG fosters collaboration and communication to accelerate scientific understanding of the potential impacts and benefits of an expanded bioeconomy and seeks to provide actionable information to help agencies and stakeholders optimize economic, social, and environmental outcomes.

[59] See Section 4.10, Sustainability R&D, for more information on assessing environmental, social, and economic effects of the bioeconomy.

A number of federal agencies support data collection, analysis, and R&D aimed at enabling a bioeconomy that is socially acceptable, economically and environmentally viable, and protective of human health and welfare. Leading agencies in this effort include the USDA, DOE, EPA, NSF, DoD, and DOT. For example, several offices within DOE and USDA have specific goals related to understanding and enhancing the economic, environmental, and social effects of the bioeconomy. Within DOE, these efforts are primarily supported by BETO and the Office of Science. Within USDA, primary research offices are the ARS, the Economic Research Service, the Forest Service, and NIFA. USDA's Foreign Agricultural Service works to disseminate U.S. research on the bioeconomy to enhance scientific understanding worldwide while fostering transparent, science-based trading standards and expanding foreign market access for U.S. bioeconomy-related products. NSF supports several innovative research and education programs relevant to sustainability analyses of biofuel and biorefinery processes. Furthermore, EPA implements a number of regulatory and research functions that are critical to protecting human health and the environment as the bioeconomy expands. Further details on the activities supported by these and other federal agencies can be found in the FARB.

4.10.2 Knowledge and Technology Gaps

As identified in the C&O report, addressing uncertainties about sustainability is a major challenge and requires a better understanding of potential environmental, social, and economic benefits and costs related to biomass and its use for energy and products. Despite progress in scientific research to date, the following sustainability considerations must continue to be addressed:

- **The environmental, social, and economic effects of growing and using large quantities of biomass are still not well understood.** Major environmental concerns include potential impacts on soil quality, climate, water resources, biodiversity, and air quality. In addition to environmental concerns, economic security and social issues such as food security, human health, and social acceptability must be sufficiently addressed. Strategies are needed to integrate biomass and bioenergy production into existing agricultural and forestry systems in a way that enhances energy security, economic growth, and environmental outcomes while minimizing adverse effects. There is also a continued need to evaluate and verify outcomes using credible and current data.
- **Stakeholder involvement should be integrated throughout the research, development, and implementation cycle.** The path towards a successful and sustainable bioeconomy not only requires that science-based information is accessible to the public and policymakers, but also requires that stakeholders are engaged throughout the research, development, and implementation cycle so that the bioeconomy is shaped by goals and priorities at the local, regional, and national levels.

4.10.3 Ongoing and New Actions for Sustainability R&D

In addition to existing efforts conducted at Board member agencies, the following collaborative goals under the Bioeconomy Initiative will help to maximize the economic, social, and environmental benefits of producing and using biomass resources, while also ensuring that efforts are coordinated such that each agency contributes according to its unique strengths and missions and that limited government resources are used judiciously.

4.10.3.1 Goal #1: Identify relevant metrics and indicators to facilitate evaluation of environmental, social, and economic effects

BR&D Board member agencies will work together to streamline and improve diverse stakeholders' access to a variety of resources pertinent to evaluating and monitoring the sustainability of biomass, bioenergy, and the bioeconomy. Publicly disseminating evidence-based results can create more transparency and certainty about the benefits and costs of the bioeconomy and support adaptive management so that the bioeconomy contributes to sustainability goals at multiple scales.

Under this goal, three general actions will be pursued collaboratively:

- Collaborate to develop a catalogue of key metrics and indicators, making use of efforts already initiated by EPA, DOE, USDA, and other agencies, as well as nonprofit and international organizations. The goal would be to compile a range of metrics across agencies to serve as a compendium for different applications and stakeholder interests.
- Coordinate development of methods and guidance to support the application of sustainability indicators to the bioeconomy. This effort could assist agencies in selecting key sustainability indicators that are compatible across programs at the national level and enable monitoring of long-term trends that are relevant to sustainability. The objective is not to define a set of metrics and indicators for all purposes, but rather to help create a set of indicators appropriate for national-scale evaluation of the benefits and costs of the bioeconomy.
- Maintain a body of case studies that quantify the benefits and costs of existing and emerging bioenergy and bioproduct systems in different contexts, such as corn stover ethanol production in the Midwest or forest residue utilization in the Southeast. These case studies can help identify best practices that can then be translated into broader applications and help assess whether progress is being made towards intended outcomes.

4.10.3.2 Goal #2: Support decision making at the agency, program, and stakeholder level that enables continuous progress towards sustainability

For the concept of sustainability to be operational, frameworks and tools can support decision making towards defined environmental, social, and economic goals. With this in mind, BR&D Board member agencies will collaborate to provide frameworks and tools that can be used by agencies, industry, and other external stakeholders to bring about a bioeconomy that is socially acceptable, economically and environmentally viable, and protective of human health and welfare.

A guiding principle for this goal is to facilitate continuous improvement towards increasing the socioeconomic value and reducing the environmental footprint of producing and using biomass. Increasing socioeconomic value includes, for example, enhancing prosperity, economic resilience, health and safety, and ecological resilience. Reducing the environmental footprint includes, for example, reducing or minimizing energy and water intensity, toxic emissions, GHG emissions, material intensity, and any negative ecological impacts from producing biofuels, bioproducts, and biopower.

Under this goal, two general actions will be pursued collaboratively:

- Create a sustainability framework that considers multi-dimensional impacts and benefits to prioritize the most promising sustainable pathways. The creation of this framework will involve considering existing sustainability frameworks, including those that agencies and multilateral groups have already developed that are pertinent to the bioeconomy. Agencies have diverse approaches to sustainability and different measures of success, relatable to various missions and responsibilities that range from research to implementation to regulatory oversight. The sustainability framework will enable agencies to accomplish their unique missions while contributing to a sustainable bioeconomy. The framework will be accompanied with examples on how it could be applied to different types of research, development, and demonstration programs.
- Maintain a body of databases and tools that support site-, local-, and regional-level planning and evaluation of biofuel, bioproduct, and biopower technologies. A number of databases and tools already exist, so agencies will work collaboratively to ensure these resources not only use the best-available data but are also streamlined, easily accessible, and user-friendly for diverse stakeholders.

4.10.3.3 Goal #3: Understand and assess potential environmental, social, and economic effects as the bioeconomy evolves

As the bioeconomy evolves, it is critical to stay at the cutting edge of understanding and assessing potential environmental, social, and economic effects of various technologies and bioeconomy scenarios. Agencies will collaborate with research partners from the public and private sectors to continuously apply the best science and models to evaluate near- and long-term future scenarios that can inform R&D to enhance benefits and prevent or minimize adverse effects.[60]

Agencies use diverse models originating from agriculture, energy, ecological, and economic research to investigate the potential effects of biofuel, bioproduct, and technologies. While agencies continuously strive to coordinate these efforts, there is an opportunity to further link models to explore more complex, broader questions about the sustainability of the bioeconomy. Many of these questions are best addressed by bringing together diverse agencies' capabilities. It is critical that multiple agencies and diverse stakeholders contribute and have buy-in on the studies' approach and methods to increase the overall impact and usefulness of the results. Furthermore, key questions and research priorities will need to be reevaluated as the bioeconomy and stakeholder interests evolve.

Under this goal, the following actions will be pursued:

- Pursue studies of mutual interest that address key research questions and advance scientific capabilities for quantifying the effects of the bioeconomy at multiple scales. Some topics include GHG emissions, land-use change modeling, landscape design, food security, and the nexus of food, water, and energy resources.
- Inventory models and modeling efforts across agencies that are relevant to understanding the environmental, social, and economic effects of the bioeconomy. Such efforts will be conducted in collaboration with the Analysis IWG.
- Work with relevant stakeholders to identify opportunities for increased model integration and to ensure consistency of modeling assumptions and datasets.
- Facilitate integration and consistency by supporting workshops or other platforms that bring together multi-disciplinary modelers and researchers.

[60] See Section 4.9, Analysis R&D, for more information on analysis and modeling activities relevant to the Bioeconomy Initiative.

5 Implementing the Bioeconomy Initiative—Fundamental Actions

The discovery of new knowledge and the development of innovative technology alone will not overcome the barriers to expanding the bioeconomy in the near term. Scientific breakthroughs and new technologies will require interdisciplinary, crosscutting interagency actions across the bioenergy and bioproducts supply chains. All R&D focus areas will require dedicated approaches to knowledge sharing, stakeholder engagement, technology transfer, industry partnerships, and project finance. The sections below describe fundamental interagency approaches and planned actions that will help ensure R&D investments can be integrated into the bioeconomy.

5.1 Knowledge Sharing

5.1.1 Introduction and Approaches

Key to expanding the bioeconomy is developing reliable information, data, and knowledge and making these available to feedstock and bioproduct producers, financiers, investors, end users, and other actors along the supply chain. Knowledge transfer is the sharing or disseminating of knowledge and informed decision making from one person to another.[61] A priority of the Bioeconomy Initiative will be to make scientific knowledge, technical information, data, and other knowledge as readily available and accessible to the biomass community and to the public as possible. At the same time, knowledge creation by the private sector can be bolstered by strong intellectual property protections that allow innovators to reap substantial benefits before sharing their knowledge publicly.

Currently, most BR&D Board agencies already have formal knowledge transfer programs, activities, and capabilities.[62] Although many of these programs are broader in focus than biomass-specific topics, they currently enable access to bioeconomy information and are providing a needed, but not necessarily sufficient, mechanism for information sharing. The following section provides recommendations and actions for the Bioeconomy Initiative to ensure that users, stakeholders, and the bioeconomy community have ready access to the most current information on the production, conversion, distribution, and use of products derived from biomass.

5.1.2 Planned Actions

The federal government has a myriad of mechanisms for sharing information online, usually specific to an agency or an agency program.[63] Agency websites provide a wealth of information, often including downloadable data or access to publications, contacts, and a broad spectrum of other information. Although such sites are relevant to the bioeconomy, they often cover broader topics and may not be the most accessible or practical for bioeconomy stakeholders.

[61] Knowledge transfer concepts are adapted from the U.S. Department of Defense Strategic Command Knowledge Transfer Office, *United States Strategic Command Knowledge Transfer Office Guide* (Strategic Command Knowledge Transfer Office, January 2009), usacac.army.mil/cac2/AOKM/Knowledge%20Transfer%20Book.pdf.

[62] Good examples include USDA's Energy Web (usda.gov/our-agency/initiatives/energy) and Extension Service (extension.org/).

[63] A list of representative agency websites is located in Appendix A.

An action item planned for the Bioeconomy Initiative is to evaluate existing online portals for federally funded data and information that are relevant to the bioeconomy, identifying gaps and opportunities for integration where appropriate. One priority for this initiative is a synergistic website that provides a single access portal to information from the BR&D Board, the Bioeconomy Initiative, and the Board's member agencies. Links to agency programs, models, and data will facilitate and streamline stakeholder access.

As part of the Bioeconomy Initiative, the Board will provide information and interactive opportunities online, such as the following:

- Scientific, technical, and general interest publications
- Information about federal R&D facilities
- Access to select models for either downloading or running
- Updates on federally funded projects as appropriate
- Information on conferences, workshops, and events
- "Ask an expert" forums (live as well as online).

Beyond conducting a gap analysis of existing online resources and identifying and using government mechanisms for formalizing data sharing with collaborators and stakeholders, other internal and external efforts will support knowledge transfer and build synergy across Board member agencies. Targeted activities will help transfer the most up-to-date information and science to the community users. Some activities include the following:

- Use the STEM Workforce Development program as a way to transfer scientific innovation into education and build intellectual and human capital[64]
- Host regular formal and informal information exchange meetings and webinars
- Publish technology innovation success stories.

An important role of the Bioeconomy Initiative is to provide stakeholders and the public with access to the newest scientific discoveries, technologies, and reliable data in easily accessible formats, in a manner that is as comprehensive as possible and consistent with intellectual property laws. It is also important to have mechanisms in place to share data and information internally to facilitate the collaboration among the agencies and cooperators.

5.2 Stakeholder Engagement

5.2.1 Introduction and Approaches

Strategic and sustained stakeholder engagement across the supply chain is essential to growing the bioeconomy. Key stakeholders include, among many others, researchers, regulators, trade associations, biomass and bioproduct producers, logistical suppliers, vehicle fleets, infrastructure providers, end users, government agencies (i.e., federal, state, and local), standard-setting organizations, non-governmental organizations, educators, the general public, and Congress. Active collaboration and communication among these key stakeholder groups will help build a strong network of informed public and private partners, enabling the bioeconomy to succeed.

[64] Information about STEM programs at the Oak Ridge Institute for Science and Education can be found on the institute's website: orise.orau.gov/stem/index.html.

Effective stakeholder communication and engagement on the bioeconomy faces challenges. Persistent misconceptions exist about the production and use of bioenergy and bioproducts, and bioeconomy stakeholders sometimes disseminate inconsistent messaging for addressing these, leading to less effective stakeholder partnerships as well as confusion and disengagement from the public and new stakeholder audiences. Challenges can also lie in communicating the high-level or commercial significance of bench-scale research, especially to non-technical stakeholders. Meanwhile, lack of engagement and collaboration among active stakeholders participating across the bioeconomy inhibits supply chain integration, causes missed partnership opportunities, and stifles innovation.

The expanded bioeconomy may be complex as a result of the diverse array of feedstocks, conversion technologies, products, byproducts, co-products, distribution and use systems, input supplies, equipment, services, and operations and management alternatives being used. This biomass sector diversity could result in very heterogeneous groups of stakeholders with various roles, goals, and priorities. As the bioeconomy grows and matures, so may the diversity of the stakeholders, especially into the development of secondary and tertiary roles (e.g., in research, education, finance, insurance, marketing, brokering, equipment manufacturing, and hauling and transport).

The federal government employs many methods for engaging public and industry bioeconomy stakeholders. This includes access to scientific, technical, and business information, primarily through their websites. Many outlets, printed or electronic, provide technical information in science articles and technical magazines. Other actions include grants and funding opportunities; educational outreach; direct contact and knowledge transfer among researchers, bioenergy industry professionals, and supply chain partners; bioeconomy workforce training; and facilitating collaborations. These activities can take place in varied venues, such as agricultural extension agents and offices; scientific and trade meetings; and workshops, webinars, and public meetings. The federal government has a fundamental role in nurturing these public-private stakeholder engagement opportunities. The following section summarizes actions for the Bioeconomy Initiative to continue to foster a two-way flow of information that will help stakeholders make decisions that are critical to the sustainable growth and competitiveness of the bioeconomy.

5.2.2 Planned Actions

Engaging participants within the various bioeconomy supply chains and improving communications to the general public, industry, and the press regarding the importance of the bioeconomy are central priorities for federal agencies supporting the bioeconomy vision. The BR&D Board will continue to listen to stakeholder input and solicit ideas through various forums. As described elsewhere, the TAC has a formal role in providing recommendations to the Board. This formal process, in addition to less formal input channels, will be very helpful in identifying evolving challenges and opportunities. Board agencies will focus on emulating existing successful public-private partnership models (e.g., the Commercial Aviation Alternative Fuels Initiative[65]), engaging early on with non-governmental organizations to facilitate buy-in, identifying "missing" or neglected elements of the supply chain for targeted stakeholder outreach, working across agencies to reach out to appropriate stakeholders, and promoting bidirectional stakeholder engagement.

[65] Commercial Aviation Alternative Fuels Initiative website, www.caafi.org.

Increased message transparency and public access to bioeconomy information is also vitally important. A bioeconomy communications plan, led by USDA, would help to identify impactful messaging and outreach strategies tailored for each stakeholder group and their unique interests, needs, and access preferences. Many consumers and businesses are bioeconomy stakeholders without knowing it, given the increasing share of bio-produced material being used in goods manufacture. "Branding" of the bioeconomy may aid the public in recognizing the presence, strength, value, and diversity of bioeconomy activities, products, careers, and economic development opportunities.

A revamped federal bioeconomy stakeholder engagement and communications strategy for the near-, medium-, and long-term will build and deploy tools and resources for educating a variety of stakeholders, develop additional public-private partnership models, penetrate new stakeholder markets, and catalyze a paradigm shift towards a bioeconomy-focused future.

Board member agencies will leverage public-private partnerships to engage key stakeholders, the general public, and the press with the following actions:

- Near-term actions
  - Synthesize lessons learned from existing successful stakeholder engagement models (e.g., the Commercial Aviation Alternative Fuels Initiative)
  - Develop a communication plan addressing the value proposition and benefits of the bioeconomy and developing a bioeconomy "brand"
  - Clearly identify messages to be disseminated, as well as tactics for dissemination
  - Identify two to three targeted challenges/topics for each IWG that could be addressed by partnerships
  - Provide opportunities for stakeholder input, such as workshops and listening days
  - Identify potential broader, non-federal partners for message dissemination (e.g., public-private partnerships, grantees, academic institutions, foundations, museums, targeted social media networks)
- Mid-term actions
  - Implement communications plan utilizing broader networks and partnerships
  - Assess what challenges remain after obtaining near-term milestones
  - Develop a plan to engage stakeholders to address targeted challenges and identify approaches to reducing technology uncertainties and improving supply chain performance
  - Provide opportunities for stakeholder input
- Long-term actions
  - Evaluate bioeconomy development and status, progress, and stakeholder engagement; adjust communications plan as needed; and continue outreach.
  - Provide opportunities for stakeholder input.

5.3 Technology Transfer

5.3.1 Introduction and Approaches

Federal funding of both basic and early-stage applied research is critical to the the nation's research enterprise, as it lays the foundation for new technology deployment and commercialization by industry partners. Enabling the full

potential of the bioeconomy will require continued federal investment in new technology development that enables industry to deploy and commercialize new technologies. The operational goal of the Bioeconomy Initiative is to work collaboratively with industry and other stakeholders in the foundational science discovery and applied technology development stages, and then allow these stakeholders to lead projects at the demonstration and commercialization phases. However, the hand-off of technology from federal research programs to private industry can be complicated by securing private capital, protecting intellectual property, encountering supply chain resource constraints, and other entrepreneurial hurdles to success. Particularly within bioeconomy-related research fields, there are many technical and logistical barriers to technology deployment and commercialization throughout the biomass supply chain. It will be critical to foster an environment that effectively allows federal resources and expertise to examine these highly diverse barriers to commercialization. The Bioeconomy Initiative will leverage new approaches with the goal and commitment to support innovation so that those with the capabilities to commercialize can readily do so.

The linkages between technology uncertainty and financial risks must be fully appreciated and addressed by federal technology transfer programs. Existing federal investments in technically focused consortia, interagency collaborations, private sector incubators, and broadly applicable technology areas, such as genomics and pathway engineering, have demonstrated strong results. For example, NSF requires higher education institutions with NSF funds to submit a universal record locator that contains information on their transfer of technology and commercialization of research efforts.[66] All BR&D Board member agencies use the SBIR[67] program and the STTR program to bridge the gap between basic science and commercialization. Continuing to support private-public partnerships, information sharing mechanisms, and collaborative research centers can accelerate and improve technology transfer. Agencies will provide different levels of technology transfer support depending on authority and mission.

The federal government already has in place some outstanding technology transfer programs, which include funding high-risk innovation as well as providing physical resources, such as access to national laboratory facilities. As mentioned above, the SBIR and STTR programs are highly competitive and well-recognized federal efforts with many individual success stories of government-supported entrepreneurial innovation; these can be found on their website, sbir.gov. These and other programs are briefly described in Appendix B as examples of current federal technology transfer programs.

In addition to funding innovation and supporting resource access, agencies can leverage opportunities to improve technology deployment and acceptance for the provider and the user. The most notable opportunity is understanding industrial barriers to deployment and trying to address them through early-stage R&D. Then there is educating users so that they understand the value of the new technology—market analyses and information transfer are pivotal parts of technology acceptance (see Sections 5.1 and 5.2, Knowledge Sharing and Stakeholder Engagement). Technology developers, distributors, and users need to collectively address these concerns and work to overcome uncertainties and risks. The use of verification processes and standards are helpful in increasing early acceptance and adoption of new technologies.

[66] "Academic Technology Transfer and Commercialization of University Research," Research.gov, National Science Foundation, research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Generic/PublicAffairs/CommercializationofResearchResults.html.

[67] Small Business Innovation Research program website, sbir.gov/.

5.3.2 Planned Actions

Technology transfer needs to be a continuum over the research, development, demonstration, and deployment process. With that in mind, BR&D Board agencies will continue to collaborate and cooperate with technology deployment entities such as businesses, manufacturers, and service providers to help facilitate the commercialization of new technologies. New interagency activities or mechanisms to catalyze technology deployment and commercialization will include the following:

- Provide access to experts to discuss technology and technology transfer opportunities and pathways
- Develop consensus on roles and responsibilities among the agencies across the research, development, demonstration, and deployment continuum (as appropriate based on which agencies have authority for these activities) and increase communication on technologies and projects
- Utilize points of contact between IWGs to communicate grant, loan, and other activities that support technology transfer
- Assess opportunities to improve and streamline implementation of technical regulatory requirements (e.g., codes, standards, and qualifications) to enable technology market penetration
- Develop and streamline funding transfer and joint funding selection processes to encourage federal funding of R&D projects and better support technology transfer, while ensuring that agencies require strong cost-share from industry partners
- Protect intellectual property for industry while working with public entities
- Provide a database of updates on new technology and information on technology transfer
- Continue to support existing and new consortia on technologies to support commercialization
- Facilitate the creation of bioproducts, lignin, and alternative jet fuel technology and education centers, consortiums, and networks with universities, industry, and researchers
- Create a national feedstock network including USDA, DOE, NSF, DOI, and industry, as described in Section 4.6, Feedstock Logistics R&D.

There are two major hurdles that obstruct the transfer of new technology to industry and the commercialization of that technology. One is the "Valley of Death" in which four out of five technologies globally never make it to the commercial world.[68] This is often due to businesses and investors not understanding a given technology platform's market potential and not focusing on the long-term potential (see Section 5.5, Project Finance). The second major hurdle is the uncertainty and perceived risk associated with new technology. Many companies prefer lower rates of return while waiting for technology to be put into operation by others and proven at the industrial scale.

Actions to help overcome these hurdles include the following:

- Involve the potential manufacturers and distributors of new technology upfront during the development stage to help reduce concerns about technology uncertainty and risks

[68] "Sophie Curtis, "Four in Five Technologies Fail To Cross the 'Valley of Death,'" *Techworld*, May 2, 2013, techworld.com/news/apps/four-in-five-technologies-fail-cross-valley-of-death-3445285/.

- Understand and quantify technology uncertainties, financial risks, and policy uncertainty, and develop mitigation strategies
- Focus on high-value bioproducts, co-products/byproducts, and other risk-reducing strategies (see Sections 5.4 and 5.5, Industry Partnerships and Project Finance, for these and other risk-reduction actions).

5.4 Industry Partnerships

5.4.1 Introduction and Approaches

In order to expand the bioeconomy, key industries will need to engage across the supply chain. Key industries in the bioeconomy include agriculture, forestry, manufacturing, waste, biotechnology, chemicals, fuels, heat, and power industries. These industries represent the intermediate and end-use sectors that will respond to market pull and bring biofuels and bioproducts into the existing markets currently serviced by petroleum. It is important for the Bioeconomy Initiative to consider when, where, and how these industrial entities will engage, as well as how much technology uncertainty and risk they will accept.

Federal agencies support industry in developing the U.S. bioeconomy through analysis, coordination, and direct financial assistance via grants, loans, cooperative agreements, technology transfer activities, and incentives (e.g., biofuels mandates and tax credits, as determined by Congress). However, industry development and expansion must be increasingly supported by market drivers.

The private market is not currently ready to heavily invest in developing biofuels and bioproducts without additional R&D support from the federal government. While being globally competitive in innovation and technology development is a U.S. priority, other countries such as China, India, and Europe have rapidly increased their R&D spending on advanced biofuels and biochemicals. Potential loss of technical leadership in this field will result in reduced U.S. competitiveness, lost economic benefits, and less job creation associated with this emerging industry.

Advocating for federal policy in support of key bioeconomy industries or products is beyond the scope of the Bioeconomy Initiative and is not considered in this Framework. However, assisting policymakers by providing technical policy evaluation and subject matter expertise is still within the purview of Board activities as they relate to interactions with industry and the private sector.

As described in Section 5.2 of this report, stakeholder engagement is a priority of the Bioeconomy Initiative, and with respect to industry partnerships, engagement includes seeking input and exchanging information (within legal frameworks), collaborating on R&D, and using formal mechanisms to hand off scientific knowledge and technologies to industry. Engaging key domestic bioeconomy industries at the right time and with the right level of investment will require continued education and outreach for both success stories and lessons learned from failures. This outreach and the resulting data will enable industry to make informed investment decisions.

Engaging the finance community through stakeholder workshops and federal loan programs can aid the technical industry across the supply chain to understand what will be needed to attract investment. Lastly, the government has a role in supporting strong technology-to-market activities—such as crop insurance, standards development programs, and predictive models—to accelerate the growth of the bioeconomy.

5.4.2 Planned Actions

New interagency activities or mechanisms to facilitate engagement with industry include the following:

- Short-term actions
  - Summarize existing and potential future activities to engage industry, including federal incentive programs and a review of existing domestic and international models for engagement (this activity will be led by USDA)
  - Add new BR&D Board members, as necessary and upon approval
- Mid-term actions
  - Prioritize new models for public-private partnerships that accelerate market adoption
  - Establish licensing guidelines to incentivize long-term development
- Long-term actions
  - Implement prioritized models for public-private partnerships that accelerate market adoption
  - Build on the BioPreferred program by identifying a broader range of bioproducts, including intermediates and components.

5.5 Project Finance

5.5.1 Introduction and Approaches

A key challenge to realizing the bioeconomy vision is the large private-sector financial investment required to develop the necessary infrastructure (e.g., biorefinery facilities) and supply chains. Much of the current bioeconomy development has been dependent on public-sector financing, as well as federal incentives, mandates, and other support. The federal government has worked to encourage private-sector project funding through initial project financial assistance, loans, loan guarantees, and support of public-private collaboration and partnerships aimed at reducing risk and fostering investor confidence. However, access to capital for demonstration projects remains a barrier.

The expansion of the bioeconomy has been limited in part because of perceived and actual technology uncertainty and investment risks for biorefineries. One clear way to reduce risks is to expand the market potential for biomass, ensuring that research develops multiple end uses. Simultaneously, expansion of the bioeconomy must be consistent with meeting society's need for food, fiber, and forage, as well as energy and products.

For the bioeconomy to grow in the future without supporting policy, bioenergy and bioproducts have to be price-competitive, without relying on policy mandates. Lowering bioenergy prices, as well as expanding bioenergy and bioproduct market potential through funding of technology advancements, will greatly improve financing decisions in the bioeconomy.

5.5.2 Planned Actions

Agencies involved in the Bioeconomy Initiative have several options in providing financing support, from conducting analyses and education to coordination of interagency research funding. New interagency activities or mechanisms to improve project financing include the following:

- Work to better understand funding barriers, key risks, and options with the finance community. Agencies will interact with and solicit input from the finance community, such as financial workshops, strategy sessions, and stakeholder discussions.
- Work with non-traditional sources of investment. Engage with financial communities related to farms, forests, waste management, non-governmental organizations, and industry to identify innovative business and financing models that are working in other sectors and could be adopted for the bioeconomy.
- Improve coordination of options and mechanisms for providing financial funding support. The BRDi model for interagency coordination could be expanded to other funding programs, in which several agencies sponsor and coordinate proposal development, review, and selection, but fund separately. Standardized protocols in the proposal process and project management and oversight would improve program delivery, as well. Sharing process information and lessons learned will help to improve the delivery of financing support.
- As appropriate, make efforts to engage investors early in the development phases of new technology to be a partner from concept to application.
- Develop strategies for technology uncertainty and risk reduction, especially for feedstock supply, novel technologies, and cost sensitivities.
- Use success stories from across the value chain to educate the industry, investors, and the general public about how key federal technology development research is reducing technology uncertainty and overall risk to private industry and financiers of the bioeconomy.

6 Measuring Success

The Framework provides a guide for implementing the Bioeconomy Initiative at a relatively high level of coordination and planning. However, with the complexity of having multiple agencies involved with different missions and approaches, full integration of all the programs and access to more resources may take a while to evolve. With such a caveat, it is still important to track how well the Bioeconomy Initiative is doing in meeting the goals set forth by the BR&D Board. Furthermore, progress and accomplishments must be monitored to measure success and make adjustments as needed. The BR&D Board will oversee the process of measuring and evaluating success with regard to growth of the bioeconomy and realization of diverse economic, social, and environmental benefits.

6.1 Programmatic Coordination and Progress

Chapter 2 of the Framework provides the framework for managing the Bioeconomy Initiative. The coordination and management of the research, development, and demonstration efforts will require periodic review and feedback to establish annual work plans, manage long-term projects, and evaluate progress.

6.1.1 Coordinating Efforts and Establishing Accountability

Agencies will continue to develop their respective programmatic plans, aligning activities with the Bioeconomy Initiative as appropriate. The Board's Operations Committee will coordinate with member agencies to develop an annual plan of work for the Bioeconomy Initiative that includes specific actions and milestones for long-term studies. As needed, the Operations Committee and Board member agencies will conduct workshops to develop this plan of work. Complementary to this, the IWGs will prepare their specific annual work plans in support of the Bioeconomy Initiative. To ensure accountability, one or more agencies will be designated as the lead(s) on specific actions and/or topic areas. The Operations Committee will track assignments and targeted goals, milestones, and products. This will allow for continuous feedback and status updates on activities among all the agency programs within the Bioeconomy Initiative plan of work. To maintain accountability, the Operations Committee will prepare annual progress reports on the Bioeconomy Initiative and provide regular updates to the Board.

6.1.2 Monitoring Programmatic Progress

The Bioeconomy Initiative needs programmatic indicators of progress toward its goals and milestones. Each agency will develop technical milestones to indicate the status and success of major actions and multi-year/complex efforts. Once milestones are established, the Board will track and monitor them every fiscal year. Reviews will be based on information on programmatic, project, and individual action levels, provided at the discretion of the responsible agency. The Operations Committee will collect and compile the actions and accomplishments for overall coordination, management, and reporting.

Each year, agencies and the Operations Committee will use the annual accomplishments to analyze gaps in knowledge and technology development. Such review will help agencies and the Operations Committee conduct adaptive management to keep the Bioeconomy Initiative on track.

6.2 Success Indicators for the Bioeconomy

The success of the Bioeconomy Initiative will be monitored periodically using key metrics and indicators that measure progress. Board member agencies will complete an annual or biennial evaluation, leveraging resources such as EPA reports and RFS databases; USDA's various databases, statistical services, and market reports; DOE's biomass assessments; and other data and reports.

Overall, the vision of the Bioeconomy Initiative is a vibrant U.S. bioeconomy that enhances economic growth, energy security, and environmental quality by maximizing sustainable use of the nation's domestic biomass resources for affordable biofuels, bioproducts, and biopower. Monitoring growth in the bioeconomy, as research progress is attained, would likely include assessing feedstock production, product production and consumption, markets, jobs, sales and revenues, and indirect value added from the bioeconomy.[69] Since the bioeconomy is closely aligned with the agricultural and forestry sectors, there will be opportunities to apply indicators for these sectors in analyzing impacts and measuring expansion resulting from increased use of biomass for energy, chemicals, and other bioproducts. This will become increasingly relevant as the bioeconomy evolves in support of agriculture and forestry and in enhancing rural communities.

6.3 Transparent Reporting

Due to the number of agencies involved and the wide range of ongoing efforts, summary reports will bring the information together in a comprehensive manner. These reports will showcase the progress made towards accomplishing goals and provide frameworks to address gaps. More importantly, regular reporting of actions and progress—along with readily available data, knowledge, and analyses—will help stakeholders and collaborators contribute to expanding the bioeconomy.

6.4 Protecting Intellectual Property Rights

The U.S. government has all the rights for its data and developed software, which can be granted to third parties. The government has the right to patent inventions, and the allocation of rights is defined by contracts when the invention is outside the government. Government works are not entitled to domestic copyright protection under U.S. law and stay in the public domain.

A goal of the Bioeconomy Initiative is to place as much data, software, patents, and works for public access and use as possible within the statutes and rules governing such property. A basis for advancing the Bioeconomy Initiative is through collaborative efforts with universities, industry, and other stakeholders. Efforts will be made to predetermine intellectual property rights and ensure that questions of ownership do not affect performance and outcomes.

[69] Jay S. Golden, Robert Handfield, Janire Pascual-Gonzalez, Ben Agsten, Taylor Brennan, Lina Khan, and Emily True, *Indicators of the U.S. Biobased Economy* (U.S. Department of Agriculture, Office of Energy Policy and New Uses, Office of the Chief Economist, 2018).

7 Conclusion

As R&D progress is attained, the best measures of success for the Bioeconomy Initiative are positive energy security, economic, social, and environmental changes in the bioeconomy and related sectors. As part of the Bioeconomy Initiative, BR&D Board member agencies will develop strategies to effect such change through (1) developing new science and technology to improve systems efficiencies and reduce costs and uncertainties; (2) providing support and resources within agencies' missions and capabilities that enable knowledge and technology transfer and support infrastructure development; and (3) supporting policy development, education and training, information and operational exchange, professional interaction, and business case development. Through the diverse actions and partnerships described in this Implementation Framework, the Bioeconomy Initiative aims to facilitate innovation on affordable, sustainable, domestically produced bioenergy and bioproducts—while complementing other U.S. technologies—to benefit the rural, agricultural, forestry, energy, and manufacturing sectors of the U.S. economy.

Appendix A: Biomass-Related Websites and Information[70]

- Bioeconomy Initiative
  - BR&D Board
- General State-of-Technology Resources
  - Biomass Energy Data Book
  - Alternative Fuels Data Center
  - U.S. Bioenergy Statistics
  - Careers in Biofuels
  - Alternative Aviation Fuels Report
  - 2015 Bioenergy Market Report
- Knowledge sharing
  - Conferences
    - BETO annual conference (see BETO homepage)
  - USDA Cooperative Research and Extension Services
    - Includes Rural Development Cooperative Services, Cooperative Research, and Extension Services
    - Focus areas include food safety and quality, plight of young children, revitalizing the rural United States, sustainable agriculture, and waste management
  - USDA Current Research Information System
    - Administered by NIFA
    - Public data with citations to the technical literature it references; useful resource for farmers
  - EPA EnviroAtlas
    - Provides scenarios of land-use cases for land-use managers (among other resources)
  - USDA Forest Service Research
    - Supports industry, including through the Forest Products Laboratory
    - Publication database that offers scholarly articles for free on "Treesearch" portal
    - Science and technology tools available via homepage
  - DOE Office of Science
    - Two scientific program offices, BER and BES, in the Office of Science support fundamental research in plants and microbes
    - The BER program supports fundamental research and scientific user facilities to address diverse and critical global challenges, with a focus on translating genomic information to functional capabilities, enabling more confident redesign of microbes and plants for sustainable biofuels and bioproducts production, improved carbon storage capabilities, and controlled biological transformation of materials such as nutrients and contaminants in the environment.

[70] Links can be accessed through the online version of this report, available at https://biomassboard.gov/.

    - The BES program supports fundamental research and scientific user facilities to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels, providing knowledge and tools to help understand the natural world and build the foundation for breakthroughs in energy technologies.
    - The Community Resources webpages for BER and for BES provide a range of resources including brochures and reports.
  - DOE Bioenergy Research Centers
    - The BER Genomic Science website provides general information on the Bioenergy Research Centers.
    - Each Bioenergy Research Center has a website of publications and patents.
    - The DOE Center for Bioenergy Innovation (CBI) is led by DOE's Oak Ridge National Laboratory in Oak Ridge, Tennessee.
    - The DOE Great Lakes Bioenergy Research Center (GLBRC) is led by the University of Wisconsin in Madison, Wisconsin, in close collaboration with Michigan State University in East Lansing, Michigan.
    - The DOE Joint BioEnergy Institute (JBEI) is led by DOE's Lawrence Berkeley National Laboratory.
    - The DOE Center for Advanced Bioenergy and Bioproducts Innovation (CABBI) is led by the University of Illinois at Urbana-Champaign.
- Capacity building
  - USDA-NIFA Sun Grant Program
    - The purpose of this program is to provide a consortium of universities—including a university from each of the Sun Grant regions and subcenter regions—with a grant to support a North-Central, Southeastern, South-Central, Western, and Northeastern Sun Grant Center and a Western Insular Pacific Subcenter.
  - USDA-NIFA Capacity Grants
    - These grants were created via the Hatch Act of 1887, Evans-Allen Program, McIntire-Stennis (forestry).
    - Funds go to land-grant universities for research and extension.
  - SBIR Program
    - SBIR is a Small Business Administration program that encourages domestic small businesses to engage in federal research/R&D that has the potential for commercialization.
    - Examples of partner agencies include DOE, USDA, EPA, NSF, and DOT.
- Workforce development
  - USDA-NIFA Agriculture and Food Research Initiative
  - DOE Early Career Research Program
  - NSF Faculty Early Career Development Program
  - Joint BioEnergy Institute
    - Developed teaching module for local community college for producing biofuel
- Education
  - EPA EnviroAtlas
    - Provides training materials to teachers.

- DOE Bioenergy Science Center
  - Education and outreach materials for 4th–6th grades
  - Classroom resources and distance-learning tools, including "Farming for Fuels Program"
- Biodiesel Fuel Education Program
  - Project partners include the National Biodiesel Board and the University of Idaho
  - Funded by NIFA and USDA's Office of the Chief Economist
  - Provides information about biodiesel for biodiesel producers and distributors, fleet operators, farmers and feedstock producers, policymakers, and consumers
- USDA-NIFA Agriculture and Food Research Initiative
- Joint BioEnergy Institute
  - Provides resources for internships at the high school, technical college, and university levels.

- Across the BR&D Board
  - FAA Center of Excellence for Alternative Jet Fuels & Environment
    - ASCENT—The Aviation Sustainability Center
  - USDA-NIFA Agriculture and Food Research Initiative
    - NIFA provides AFRI grants to support research, education and extension activities in six Farm Bill priority areas, including a bioeconomy-relevant area on bioenergy, natural resources, and environment.
    - AFRI Regional Bioenergy System Coordinated Agricultural Projects—Over five years, NIFA has committed $186 million in nine projects across the United States to facilitate the development of regionally based industries producing advanced biofuels, industrial chemicals, and other biobased products.
    - AFRI Sustainable Bioenergy Challenge Area—The long-term goal is to implement regional systems that materially deliver liquid transportation biofuels to help meet the Energy Independence and Security Act (EISA) of 2007 goal of 36 billion gallons/year of biofuels by 2022 and reduce the national dependence on foreign oil and, as appropriate, produce biopower and biobased products.

Appendix B: Representative Agency Technology Transfer Programs

- **SBIR/STTR**—Through a competitive awards-based program, SBIR/STTR supports scientific excellence and technological innovation through the investment of federal research funds in critical U.S. priorities to build a strong national economy.
- **NSF Engineering Directorate**
  - **Division of Engineering Education and Centers**—The Division of Engineering Education and Centers supports innovative projects and collaborations in the advancement of engineering, including the Engineering Research Center program, center-based transformational research, and the Research Experiences for Undergraduates and Teachers workforce development programs.
  - **Division of Industrial Innovation and Partnerships**—The Division of Industrial Innovation and Partnerships supports high-tech small businesses and collaborations between academia and industry to transform discoveries into innovative commercial technologies with societal benefits. Programs include the NSF Innovation Corps, which identifies valuable product opportunities and helps researchers translate discoveries into technologies with near-term benefits for the economy and society; the Partnerships for Innovation: Accelerating Innovation Research-Technology Translation Program, which serves as an early opportunity to move previously NSF-funded research results with promising commercial potential along the path toward commercialization; and the Industry-University Cooperative Research Centers Program, which develops long-term partnerships among industry, academia, and government.
- **DOE Bioenergy Research Centers**[71] —These centers are structured to facilitate knowledge sharing among multiple disciplines so that breakthroughs in one area can be capitalized on and translated to other areas of emphasis. In these integrated and collaborative environments, the centers pursue the necessary fundamental research to improve the processes needed for large-scale, cost-effective production of advanced biofuels from cellulosic biomass.
- **USDA Biomass Research Centers**[72]—These centers were established to develop the best feedstocks and sustainable feedstock production systems for specific agro-eco regions where advanced biofuels will likely be produced. In addition, each Regional Biomass Research Center fosters collaborative research within the complete bioenergy supply chain so as to accelerate the creation of commercial supply chains for the production of advanced biofuels.
- **USDA-NIFA Coordinated Agriculture Projects**[73]—Seven consortia projects are developing regional systems for the sustainable production of biofuels, biopower, and biobased products. In total, the projects involve 26 land-grant universities; six other public universities; one regional consortium of community colleges; two nonprofit organizations; 10 federal agencies; and 28 private industry partners.

[71] "DOE Bioenergy Research Centers," U.S. Department of Energy, Office of Science, Genomic Science Program, last modified November 14, 2017, genomicscience.energy.gov/centers/.

[72] "Regional Biomass Research Centers," U.S. Department of Agriculture, Agricultural Research Service, last modified August 11, 2016, ars.usda.gov/natural-resources-and-sustainable-agricultural-systems/biorefining/docs/regional-biomass-research-centers/.

[73] "Current USDA NIFA AFRI CAPs," eXtension, October 17, 2015, articles.extension.org/pages/73513/current-usda-nifa-afri-caps.

- **DOE Office of Technology Transitions (OTT)**[74]—OTT was established in 2015 to oversee and advance the commercial impact of the Department of Energy's research and development portfolio, advancing the economic, energy, and national security interests of the nation. The office develops the Department's policy and vision for expanding the commercial impact of its research investments, and it streamlines information and access to DOE's national labs and sites to foster partnerships that will move innovations from the labs into the marketplace.
- **DOE Energy I-Corps**[75]—This program (formerly known as Lab-Corps) offers a new pathway to advance greater collaboration between industry and national laboratories. Energy I-Corps is managed by the National Renewable Energy Laboratory and seeks to strengthen the impact national laboratories have on the nation's energy landscape. The two-month training curriculum enables laboratory-based teams to define technology value propositions, conduct customer discovery interviews, and develop viable market pathways for their technologies.
- **DOE Small Business Vouchers Program**[76]—The Small Business Vouchers program provides clean energy small businesses with access to select national laboratories—making the contracting process simple, laboratory practices transparent, and access to the laboratories' unique facilities practical. Through this program, selected small businesses receive access to the state-of-the-art facilities and experts at participating DOE national laboratories, while the laboratories expand their knowledge of and involvement with the private sector, helping small businesses with advanced technologies contribute to U.S. competitiveness and economic growth.
- **ARPA-E**[77]—ARPA-E requires its funding awardees to spend a portion of their award on technology transfer and outreach and assigns Technology-to-Market Advisors to work with each project. Awardees have formed startup or spin-off companies.
- **USDA Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program**[78]—This program assists in the development, construction, and retrofitting of new and emerging technologies for development of advanced biofuels, renewable chemicals, and biobased product manufacturing by providing loan guarantees for up to $250 million.
- **DOE Loan Programs Office**[79] —The Loan Programs Office issues loan guarantees for innovative energy projects and loans for advanced technology vehicles manufacturing projects through its Title XVII and Advanced Technology Vehicles Manufacturing programs.

[74] Office of Technology Transitions website, U.S. Department of Energy, Office of Technology Transitions, https://www.energy.gov/technologytransitions/office-technology-transitions.

[75] Energy I-Corps website, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, energyicorps.energy.gov/.

[76] Small Business Vouchers program website, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, sbv.org/.

[77] "ARPA-E Impact," Advanced Research Projects Agency – Energy, U.S. Department of Energy, arpa-e.energy.gov/?q=site-page/arpa-e-impact.

[78] "Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program," U.S. Department of Agriculture, Rural Development, rd.usda.gov/programs-services/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance.

[79] "Loan Programs Office," U.S. Department of Energy, energy.gov/lpo/loan-programs-office.

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