THE BILLION TON BIOECONOMY INITIATIVE:

Challenges and Opportunities

BR&D

BIOMASS RESEARCH & DEVELOPMENT

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Foreword

The Biomass Research and Development (R&D) Board (the Board) was created through the enactment of the Biomass Research and Development Act of 2000 "to coordinate programs within and among departments and agencies of the federal government for the purpose of promoting the use of biobased industrial products by (1) maximizing the benefits deriving from federal grants and assistance; and (2) bringing coherence to federal strategic planning."[1]

The Board is co-chaired by senior officials from the U.S. Departments of Energy (DOE) and Agriculture (USDA) and consists of senior decision makers from DOE, USDA, the 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 facilitates coordination among federal government agencies that affect the research, development, and deployment of biofuels and bioproducts.

In February 2016, the Board released the Federal Activities Report on the Bioeconomy (FARB) to highlight the potential for a stronger U.S. bioeconomy, specifically some of the impacts of increasing biomass utilization threefold by 2030.[2] The goal of the Billion Ton Bioeconomy Initiative (Bioeconomy Initiative) is to develop innovative approaches to barriers in order to expand the sustainable use of America's biomass resources and maximize economic, social, and environmental outcomes.

Since the release of the FARB, the Board has engaged with the bioenergy stakeholder community to further develop the Bioeconomy Initiative. This report is foundational to the Board's objective to strengthen the commitment and coordination between the U.S. Government and the bioeconomy community. Early feedback from stakeholders has underscored the importance of biofuels, bioproducts, and biopower. This report addresses several challenges and opportunities that stakeholders have identified as critical to the success of the Bioeconomy Initiative.

[1] U.S. Congress (1999). HR 2827. 106th Congress, first session. http://www.gpo.gov/fdsys/pkg/BILLS-106hr2827ih/html/BILLS-106hr2827ih.htm

[2] http://www.biomassboard.gov/pdfs/farb_2_18_16.pdf

BIOECONOMY INITIATIVE

Introduction

Overview of the Bioeconomy Initiative

The goal of the Bioeconomy Initiative is to develop and coordinate innovative approaches to expanding the sustainable use of America's abundant biomass resources, while maximizing economic, social, and environmental benefits. By increasing use of renewable plant material and waste feedstocks for biofuels, bioproducts, and biopower, the Bioeconomy Initiative has the potential to stimulate job growth and economic opportunities in certain industries;[3] support a secure, renewable energy future; and contribute to improved environmental quality. The Bioeconomy Initiative differs from "business as usual" by creating a sustainability framework that considers multi-dimensional impacts and benefits to prioritize the most promising sustainable pathways.

To achieve its goals, the Initiative will require collaborative data sharing; peer reviewed analyses; optimized financial mechanisms and contract services; research, development, demonstration, and deployment for feedstocks; conversion technologies; manufacturing; infrastructure; harmonized policies and regulations; and market development of products.

The Need for the Bioeconomy Initiative

The last decade has been unstable for the emerging bioeconomy, wherein the bioeconomy is defined as 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. While the Renewable Fuel Standard (RFS) and a variety of subsidies have helped first-generation biofuels penetrate U.S. markets and second-generation biofuels move closer to reality, the bioeconomy has yet to reach its full potential.

The economic recession of 2008 affected many bioproduct-related commodity markets, and the recent drop in oil prices has created further difficulties for biofuels to reach price parity with fossil fuels already on the market. The biobased sector has not received the amount of capital necessary to thrive in today's markets. This lack of investment in the U.S. bioeconomy contributes to the continued reliance on foreign and fossil-based energy supplies.

The U.S. consumes over 19 million barrels of petroleum per day. In 2015 ,when imported oil was at $40 per barrel, the U.S. spent nearly $1 billion every day on domestic and imported crude oil, with imported oil accounting for nearly half of this cost.[4] When imported oil was over $100 per barrel in 2012, the U.S. spent about $1 billion dollars per day on just oil imports.[5] These dollars spent on oil imports could be reinvested to develop domestic, renewable biofuels.

Although the United States is a global leader in promoting the use of sustainably produced feedstocks to fuel economic activity and growth, more efforts are needed to overcome challenges and maximize opportunities associated with creating products from renewable sources. Our nation is transitioning from a fossil-based economy to an economy that is fueled by sustainable and renewable energy, of which biomass plays a critical role. As outlined in the FARB, to accelerate the ex-

[3] Some example opportunities are agricultural and forestry feedstock production and biorefineries. USDA has a broad renewable energy portfolio that supports growers, landowners, producers, pulp workers, and biorefinery workers in allied bioenergy industries. http://www.usda.gov/wps/portal/usda/usdahome?contentid=usda-results-energy.html

[4] Energy Information Administration, Monthly Energy Review, July 2016, Tables 3.1 and 9.1. 2013

[5] Energy Information Administration, Monthly Energy Review, July 2016, Tables 3.1 and 9.1. 2013

pansion of the bioeconomy, the Board is formulating a collaborative effort across the government and is currently seeking input and cooperation from stakeholders in support of the Bioeconomy Initiative. The Bioeconomy Initiative is defined by several agreed-to principles:

- Bioenergy is part of an extensive, evolving renewable energy portfolio as well as an "All of the Above" energy strategy for the U.S.
- The Bioeconomy Initiative includes biomass-derived products—such as biofuels, bioproducts, and biopower.
- The development of America's bioeconomy must incorporate sustainability and consider environmental, economic, and social factors to minimize potential negative impacts and maximize benefits. The bioeconomy should be used to conserve, enhance, or repair ecological functions.

The investment community seeks to minimize risk and maximize process capability prior to investing in large facilities. Due to price parity issues, competing demands for and potential impacts on natural resources, and policy-related market uncertainties, the private sector remains hesitant to provide investments to continue scaling up advanced technologies. However, the potential for a domestic bioenergy and bioproducts industry—that reduces our reliance on foreign and fossil-based energy supplies through the sustainable use of agricultural, forestry, and waste biomass— remains a driving force behind diversifying the U.S. energy sector. If successfully expanded, the bioeconomy can keep energy dollars in the country as well as provide rural, energy, and manufacturing jobs and revitalize domestic manufacturing capabilities in biobased industries, while increasing the nation's competitive advantage and improving the environment.

Federal agencies are coordinating their efforts to overcome the technical and financial barriers that may preclude the expansion of a bioeconomy:

- DOE funds research, development, and demonstration of advanced biofuels to lower production costs.
- USDA supports the sustainable production of high-quality, nonfood feedstocks for conversion into bioproducts, bioenergy, bioheat, and biopower.
- EPA implements the Renewable Fuel Standard[6] and regulates the processes and safety of biobased products.
- The U.S. Department of Navy supports the use of alternative fuels for its maritime fleet and national security.
- DOT funds research to develop alternative energy pathways for the U.S. transportation sector.
- DOI manages and conserves the public lands for the use and enjoyment of present and future generations under its mandate of multiple-use and sustained yield.
- The NSF funds research and education in engineering and areas that involve the transformation and/or transport of matter and energy by chemical, thermal, or mechanical means.
- The Executive Office of the President's OSTP ensures that the scientific and technical work of the Executive Branch regarding biobased products is properly coordinated so as to provide the greatest benefit to society.

[6] https://www.epa.gov/renewable-fuel-standard-program

Potential Benefits of the Bioeconomy Initiative

Informed by the Analysis Interagency Working Group[7] (AIWG) of the Biomass R&D Board, the Bioeconomy Initiative has the potential to benefit the environment, the economy, and national security. An expanded bioeconomy could help mitigate challenges associated with national resource management, environment, and public health if done in an appropriate manner.

While an expanded bioeconomy raises sustainability concerns such as increased nutrient runoff, soil disturbance, conversion of fragile lands, and water use, the Bioeconomy Initiative could be implemented in such a way as to encourage environmental benefits. For example, non-food crops capable of thriving on marginal lands, which require fewer inputs for production, could help to reduce nutrient run-off, soil erosion, and water usage relative to food crops. Using diverse sources of renewable biobased feedstocks—such as manures, biosolids, food waste, and sorted municipal solid waste—could help to reduce greenhouse gas (GHG) emissions, management costs, and water quality degradation, as well as provide revenue streams and renewable energy. Some of these potential benefits are discussed in the FARB and preliminary analysis of the bioeconomy.[8]

The Bioeconomy Initiative could also enable the development of rural economies by sustainably utilizing land resources, algae, and waste systems in rural America. Homegrown biofuels can help bolster U.S. renewable energy markets. There is significant opportunity for higher value bioproducts and materials to enter the market, reducing technology risks and ensuring feedstock supplies for biofuels. More biobased energy and product options could provide the United States with the flexibility to address environmental and energy challenges.

Stakeholder Engagement

To increase the potential benefits of the U.S. bioeconomy, the Bioeconomy Initiative relies heavily on public engagement. The Board's Operations Committee held five Bioeconomy Listening Sessions[9] to gather feedback on many of the areas impacting the growth of the bioeconomy. Bioeconomy stakeholders represent a wide number of sectors and interests: non-governmental organizations; international governments and organizations; environmental and industry groups; manufacturers; growers; and other members of the supply chain.

In the first phase, the Operations Committee gathered feedback from over 400 stakeholders across the United States. Session attendees reported that the federal government, research community, and industry could be doing more to build a Billion Ton Bioeconomy by 2030. Stakeholders identified areas that need support and suggested ways to address perceived gaps in federal support. Suggestions addressed a variety of topics such as technical barriers, workforce readiness, and public engagement.

Stakeholders expressed dissatisfaction with access to capital and incentives necessary to develop and grow the Bioeconomy Initiative. One reason is the low oil prices which makes it hard for biofuels to compete, which in turn

[7] http://www.biomassboard.gov/board/working_groups.html

[8] Rogers J, Stokes B, Dunn J, Cai H, Wu M, Haq Z, Baumes H. 2016. An Assessment of the Potential Products and Economic and Environmental Impacts Resulting from a Billion Ton Bioeconomy. *Biofuels, Bioproducts & Biorefining.* (in press).

[9] Advanced Bioeconomy Leadership Conference in DC (2/29); International Biomass Conference & Expo in Charlotte (4/10); BIO World Congress on Industrial Biotechnology in San Diego (4/17); 38th Symposium on Biotechnology for Fuels and Chemicals in Baltimore (4/27); GoToWebinar hosted in DC (5/5)

increases investor risks. Cheap oil, coupled with increased pressure to reduce biofuels mandates, are significant concerns to new start-up cellulosic plant developers.[10] Many investors believe "that the RFS will need to remain in place for the 20-year life of a prospective investment, or a strong belief that low oil prices will not last long."[11]

There are additional concerns regarding whether we have enough land to produce the needed food, forage, feed, and fiber in the future, as well as high volumes of biomass, in an expanded bioeconomy.[12] This land availability issue is further compounded with concerns over the potential impacts on food prices. There are also concerns about potential negative environmental impacts, including GHG emissions and land conversions.

Many of the stakeholders involved in these sessions believe that a Billion Ton Bioeconomy is possible by 2030, but it will require the support of Congress and policies that advance the Bioeconomy Initiative. Finally, stakeholders agreed that stronger market pull is critical to the success of the Bioeconomy Initiative.

With help from stakeholders, the Board will continue to find ways to overcome identified challenges, gaps, and barriers in order to create opportunities.

Expanding the Bioeconomy: Challenges and Opportunities

This report discusses seven key challenges and ten opportunities recognized by the bioeconomy community, as identified via the stakeholder input process outlined above. The federal government has a potential role to play in mobilizing support across the supply chain to develop sustainable bioeconomy systems. By mobilizing partnerships between industry, government, and academia, the federal government and stakeholders can spur progress towards validated technologies, which attract investment for the scale-up and deployment of the most promising solutions that deliver sustainable economic, environmental, and social outcomes. However, this report is not a policy or budget document nor an action plan, and it does not commit the federal government to any new activities or funding.

Challenges

Challenge: Major technical hurdles for development and scale

Before there can be investment in large-scale biorefineries capable of utilizing one billion tons of biomass to produce fuels and bioproducts, investors must be confident that the technology is sound, and that its supply chain is economically and environmentally sustainable. Technology risk has been a major focus of the research programs funded by industry, NSF, DOE, and USDA, as innovations are moved from the lab to pilot- and demonstration-scale. New discoveries can support innovations at the applied and engineering scales to reduce technical risks. Developments in biotechnology, whether for biomass plants or conversion-enabling microbes, are reaching early adopters.

[10] Talbot, David. 2014. Cheap Oil Could Kill Off Cellulosic Ethanol. *MIT Technology Review*. https://www.technologyreview.com/s/532956/cheap-oil-could-kill-off-cellulosic-ethanol/

[11] Tyner, Wallace. 2015. How will low oil prices affect biofuels? *World Economic Forum*. February 6, 2015. https://www.weforum.org/agenda/2015/02/how-will-low-oil-prices-affect-biofuels/

[12] Marshall, Elizabeth and Margriet Caswell. 2011. Biofuels and Land-Use Change: Estimation Challenges. Amber Waves, USDA. July 16, 2011. http://www.ers.usda.gov/amber-waves/2011-june/biofuels-and-land-use-change.aspx#.V6yspjZTHcs

Collaboration among scientists, and the industries their inventions will support, has yet to be commonplace in the bioeconomy. Technical and environmental risks introduced by new catalysts or organisms for conversion are compounded by the diversity of the feedstocks locally, regionally, nationally, and seasonally as well as by the multitude of products that can be produced.

Challenge: Steep competition from traditional petroleum-derived resources

Market uncertainty is a major challenge for the emerging bioeconomy. For more than 20 years, the variability in the cost of petroleum has led to waning interest in furthering the development of a bioeconomy. Through research and development, the cost of various renewable energy alternatives—such as wind, solar, and bioenergy—is continually dropping, which is revitalizing interest in renewables despite relatively low oil prices. However, for bioenergy, the uncertainty of the market limits the financial investment that is needed to scale-up and validate technology performance and the ultimate availability and price of bioproducts.

Historically, driving down the consumer price of biofuels has been challenging. Since 2012, DOE has demonstrated technologies that can be scaled-up to produce modeled mature, price-competitive cellulosic ethanol.[13] Current efforts focus on modeling mature, price-competitive "drop-in" biofuels for various types of transportation fuels. Biofuels have been supported by a variety of economic incentives, including grants, income tax credits, subsidies, and loans to promote biofuels research and development.[14] The RFS mandates the use of biofuels and monitors and tracks their use through RINs (Renewable Identification Numbers). It is unlikely that the consumer will voluntarily pay more for biofuels than for petroleum-derived fuels. Thus, price parity would enhance investments in biofuels.

Certain products, such as power and electricity, drop-in fuels, and biochemical replacements, can displace a portion of the existing products derived from fossil fuels with a renewable product; however, the products must reach the end user with consistent price and performance for consumer preference or demand to increase.

Challenge: A lack of necessary infrastructure

Unless a new biofuel is truly compatible with existing infrastructure, lack of infrastructure for new biofuels is another challenge to increasing market penetration. Investments in new fuel dispenser pumps and potential vehicle improvements are costly and suffer from "the chicken or the egg" problem.

While it is potentially exciting to introduce new biobased products to the market, even those that are chemically identical to their fossil-based competitor may have some risk to the end user. Extensive testing of new products is required to ensure that there are no unforeseen performance issues with the bioproducts that are considered as replacements for fossil-based products, yet testing has lagged.

Challenge: Access to capital for large financial investments

Overcoming technical, logistical, and market risks is difficult but essential to re-energize the financial community to invest in the bioeconomy. However, overcoming the "first-of-a-kind" barrier will require more than science and engineering as it is inherently more expensive to build and operate a pioneer facility. Publicly supported

[13] BETO, MYPP. http://www.energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf

[14] https://www.epa.gov/environmental-economics/economics-biofuels

loan guarantee programs and mandated incentives, including the RFS, have led to pioneer commercial-scale demonstrations for cellulosic ethanol, but the availability of large financial investments is still lower than what is necessary in order to achieve a Billion Ton Bioeconomy.

Challenge: Uncertainties about sustainability—understanding environmental, social, and economic outcomes

One area of uncertainty highlighted via the stakeholder engagement process is the role of sustainability in the bioeconomy, and efforts to understand the potential environmental, social, and economic benefits and impacts related to its expansion.

There are ongoing discussions and scientific processes focusing on the potential effects related to increasing production of biomass and its use as energy and/or for products, including continuing efforts to scientifically evaluate those potential effects. 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 and economic security. Another issue highlighted by stakeholders is efforts to evaluate and verify outcomes from the application of sustainability practices. The challenge identified there is to rely on relevant, credible, and validated data, develop and employ the necessary tools and methods, and adopt (scientifically proven) technologies to reduce the uncertainties concerning sustainability across the entire supply chain, but most certainly in feedstock production. The challenge includes not just being successful but also demonstrating and documenting that success to the public and policy makers.

While an increasing number of studies demonstrate the benefits from the use of biomass, questions remain about how the bioeconomy will evolve over time, and how the costs and benefits can be consistently evaluated relative to other energy options.

Challenge: Growth instability and increased investment risk caused by policy uncertainty

The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 have provided the most support for biofuels. The RFS mandates the use of sugar-, cellulosic-, and non-fossil-derived biofuels. Congress set very ambitious goals in the law for growth of cellulosic biofuels, advanced biofuels, and total renewable fuel. The RFS supports emerging technologies and is intended to give companies the stability they need to continue expanding investments. However, technologies for advanced fuels—made from cellulosic feedstock such as grasses and corn stover—have not developed as fast as Congress had anticipated and required volumes have had to be adjusted. This can be a challenge with any policy that requires new and/or emerging technologies.

Industry responds to incentives and/or clear supportive policy for investing in new infrastructure that supports the use of renewable fuels, power, or products and will not invest in a venture if profits cannot be made in the foreseeable future.

Challenge: The need for a strong and capable workforce

As the United States experiences a shift in manufacturing competencies, new training could help the American workforce to meet the evolving demands of the bioeconomy. As an emerging industry, jobs will take time to develop, which could create difficulties for trade schools, community colleges, and universities looking to invest in developing programs.

The rural workforce—including farmers, forest landowners, harvesting equipment operators—will need to learn new ways of doing business, harvesting crops, and managing logistics as new feedstocks and end uses emerge.

Opportunities

Opportunity: Develop feedstock and fundamental innovations that reduce cost and technology risk in the supply chain

The Bioeconomy Initiative focuses on developing feedstocks that do not disrupt existing markets for agricultural crops such as food, feed, and fiber. In bioenergy supply chains for the production of biofuels, the diversity of the feedstock is a key consideration because diversity can insulate producers against economic shocks to the system.[15] An advanced system reduces the variability of feedstock supply by allowing a wider range of sources that mitigate supply

The Importance of Food Security in the Bioeconomy

The food crisis of 2008 indicated how many factors contribute to the state of global hunger. Rising oil prices, increased ethanol production, growing middle class populations, as well as the increased need for meat in China and milk in India, have all been blamed for recent increases in food prices.[16] At the same time, shrinking energy resources and the possibilities that biomass can spur the development of a bioeconomy where energy, chemicals, and materials can all be produced without fossil fuels, have advanced the conversation regarding the impact of bioenergy production on food security and prices. It is a complex consideration that requires assessing the impact through careful analysis of many variables.

Through responsible planning, innovations could be applied to enable improved food production, while increasing the availability of biomass for fuels and chemicals. For example, landscape design principles can be used to integrate food and energy systems in a way that reduces waste, maintains crop yields, and contributes to multiple environmental and social goals. By proactively applying these design principles, the bioeconomy can potentially add resilience to agriculture and forestry production systems and may enhance their ability to provide food, feed, and fiber into the future.

The Bioeconomy Initiative applies innovations to overcome the barriers defined by this report, while prioritizing sustainability principles to ensure that as products from biomass increase in the marketplace, there are more positive outcomes across market sectors.

[15] Lamers, P. et al. 2015. Strategic supply system design –a holistic evaluation of operational and production cost for a biorefinery supply chain. Biofuels, Bioproducts, and Biorefining 9: 648–660. doi: 10.1002/bbb.1575

[16] https://poldev.revues.org/145

risks associated with feedstock outages, such as those associated with local weather, pests, and diseases. Feedstocks can be purpose-grown plants, wood, and wastes from agriculture, forestry, or industrial processing. Each of these feedstocks comes with characteristics that need to be understood for efficient conversion. In addition, large quantities of feedstocks of consistent quality need to be delivered to the biorefinery or distributed pre-processing center to reduce conversion risk. There are opportunities to densify feedstocks for more efficient transport, as well as to blend or otherwise pre-process feedstocks to ensure consistent quality and to enable larger volumes of delivered feedstocks at a lower cost to biorefinery.

Additionally, there is an opportunity to improve technologies, systems, and infrastructure that will enable higher productivity of biomass crops that could result in increased productivity of food, feed, and fiber, improved soil quality, and reduced water usage across the entire sector. Applying sustainability criteria to renewable feedstocks will likely add costs to these feedstocks; however, ensuring that petroleum products must also adhere to environmental standards will help to level the playing field and enable cost comparison on an "apples-to-apples" basis. Overall, an integrated, multi-disciplinary effort creates opportunities to reduce risks throughout the entire supply chain.

Opportunity: Seek opportunities to utilize low-cost waste resources

Growing a sustainable, thriving bioeconomy could involve the development of biomass or bioprocess waste stream utilization strategies for higher-value applications. This includes the valorization of lignin and/or carbon dioxide, full utilization of all algal biomass components, and the incorporation of price-advantaged feedstocks like organic, municipal, and wet waste materials.

Converting waste streams to fuel, products, and chemicals can contribute to accelerating the widespread adoption of bioenergy technologies and to maximizing bioenergy's value proposition through valorizing underutilized biomass resources. These resources include landfill gas, municipal sludge, animal manure, industrial organic wastewaters (including ethanol stillage), food wastes, and organic fractions of sorted municipal solid waste that could otherwise incur social and economic costs.

In addition to improving economic value, reliability, and availability of aggregate biomass resources, waste streams can supplement or be blended with traditional biomass feedstocks, which directly contributes to the viability, quality, and resilience of individual biomass supply chains. To capture the value offered by waste streams, collaborations among government agencies, industry stakeholders, research institutions, and national labs could include the following activities:

- Promoting a better understanding of feedstocks and modifying those feedstocks to improve downstream processing efforts;
- Applying research concepts to conversion processes to achieve breakthroughs in operations;
- Developing and testing engineering concepts to known processes to reduce operational and capital costs and make liquid fuels/renewable chemicals more cost-competitive;
- Conducting detailed and rigorous resource availability and techno-economic analyses to identify feasible combinations of waste streams and target markets; and
- Supporting the development of a distributed conversion strategy.

Food-Energy-Water Nexus (FEW Nexus)

Several federal programs are coordinating research, development, and demonstration to improve the understanding and management of sustainable food, energy, and water systems. This includes development of enhanced tools and methods for monitoring, data collection, and forecasting. In addition, efforts are underway to improve integrated decision-making at the federal, state, and local levels to help ensure stewardship of U.S. resources.

One example of ongoing collaborations is the Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) program sponsored by NSF and USDA. The overarching goal of INFEWS is to catalyze the interdisciplinary research efforts to transform scientific understanding of the FEW Nexus in order to improve system function and management, address system stress, increase resilience, and improve sustainability.

DOE is focused on the use of water with regard to energy production. In 2014, the *Water-Energy Nexus Challenges and Opportunities* report[17] identified six strategic areas to focus on, (1) energy efficiency of water management through end use; (2) optimization of energy production and its use of fresh water; (3) enhanced reliability of energy and water technologies; (4) safe and productive use of nontraditional water sources through improved technology; (5) responsible energy operations with respect to water quality, ecosystem, and seismic impacts; and (6) productive synergies among water and energy systems.

EPA is focused on partnerships with government agencies and business to achieve sustainable outcomes of advanced technologies. One such partnership is with the U.S. Army in support of its Net Zero Initiative, which is geared to dramatically reduce and even eliminate energy consumption, water use, and waste generation of military bases. To support this initiative, EPA is developing tools to assess the impacts of decisions and provide quality sustainability data.

Opportunity: Quantify, communicate, and enhance beneficial effects and minimize negative impacts

Realizing the full benefits of the bioeconomy requires commitment to rigorous science-based quantification of benefits and impacts across multiple environmental, social, and economic dimensions. This will enable the development of technologies and practices that deliver the benefits of renewable energy and the bioeconomy, while maintaining healthy communities and natural ecosystems. As more sustainable business practices are encouraged, investments in renewable technologies—including biofuels, bioproducts, and biopower—could grow.

The Bioeconomy Initiative will create a sustainability framework that considers multi-dimensional impacts and benefits from the use of biomass. This framework will help the Bioeconomy Initiative simultaneously address pressing economic, social, and environmental challenges, including the preservation of ecosystem services and biodiversity; improved materials, water, and energy conservation; a shift from non-renewable to renewable feedstocks in industrial and consumer product manufacturing; the capture and recovery of non-renewable and renewable materials from wastes; improved air quality; improved economic opportunities; and public health.

[17] http://www.energy.gov/under-secretary-science-and-energy/downloads/water-energy-nexus-challenges-and-opportunities

Developing a Sustainability Framework

A framework is needed to help coordinate a sustainable approach to expanding the bioeconomy across agencies. The framework is not envisioned as a rigid, sustainability oversight tool, but rather a way to improve cooperation. At the Bioeconomy Federal Strategy Workshop, experts identified ways to make and ensure the approach to expanding the bioeconomy is sustainable:

- Coordinate **analyses and research that demonstrate the positive contributions** the bioeconomy can make to environmental sustainability—improving land use, water use, water quality, and air quality—as well as socio-economic sustainability.
- **Establish a common framework** across agencies to reflect sustainable futures and establish **a common understanding of sustainability goals, impacts, and benefits from the bioeconomy**.
- Build a **library of economic, social, and environmental metrics** across agencies, and compile **data** on environmental, social, and economic impacts, costs, and benefits of specific practices, technologies, and bioeconomy pathways.
- Coordinate the development of **user-friendly models** that can improve decision-makers' understanding of options in designing the bioeconomy, its benefits, and impacts.
- **Synthesize information on impacts, costs, and benefits** to address questions from diverse stakeholders. Measuring the economic, social, and environmental outcomes of bioenergy, biochemicals, and biopower will provide clarity on the short-term and long-term availability of resources; impacts of the use of renewable, non-renewable, virgin, and recycled resources; and the feasibility of creating closed-loop systems for optimal efficiencies.
- **Accelerate innovation on sustainable system design** that integrates economic, social, and environmental dimensions with consideration of synergies and trade-offs.

The Board and the federal agencies involved with the Bioeconomy Initiative are dedicated to sustainability and will make it a paramount goal in implementation. However, achieving sustainability in the bioeconomy or any other sector is a tenuous goal. Even with the use of indicators and other metrics and tools, achieving sustainability is a challenge that is readily recognized. In developing a common framework, sustainability can reflect an approach, rather than an absolute. Agencies have diverse approaches to sustainability and different measures of success, according to various missions and areas of responsibilities that range from research to implementation to regulatory oversight. The sustainability framework will allow the agencies to contribute to a sustainable bioeconomy, while still accomplishing their missions. A framework is needed to help direct and coordinate all of these approaches. Working with industry and collaborators can exacerbate the difficulty of achieving sustainability, which highlights the need for an agreed-upon framework.

Opportunity: Increase public education on biomass-derived products in a bioeconomy

Public perception plays a key role in market risk. A third-party analysis comparing bioenergy and bioproducts to fossil energy and fossil-based products could help communicate the underlying potential benefits of developing the bioeconomy.

By better understanding and communicating the potential economic, social, and environmental benefits of biofuels, bioproducts, and biopower, as well as developing more practices that will mitigate potential negative impacts, the Bioeconomy Initiative can garner more public acceptance and demand for a larger bioeconomy. There is an opportunity to raise awareness about the positive impacts of bioenergy and bioproducts and discuss the synergies of the bioeconomy with other renewable opportunities and economic sectors.

In recent years, industry has focused on the interconnectivity between global bioenergy production, the food and feed required to meet global needs, and the impacts of bioenergy production has on water resources and water quality. Industry must recognize the food, water, and energy sectors as a system of interdependent components and develop solutions based on multi-sector engagement to enhance the sustainability of the nation's food, water, and energy supplies. Through the Bioeconomy Initiative, the Board can help develop a greater coordination among these three sectors.

Bioproducts and Biomanufacturing

In April 2016, the National Science and Technology Council Subcommittee on Advanced Manufacturing published *Advanced Manufacturing: A Snapshot of Priority Technology Areas Across the Federal Government.*[18] The document highlighted both ongoing activities to strengthen U.S. manufacturing and emerging advanced manufacturing priority areas. Two of the five priorities support the growth of a bioeconomy through engineering biology to support biomanufacturing and advanced bioproduct manufacturing.

Federal investments have helped establish the processes and platforms needed to generate high-value intermediate and end-use products, thus supporting the growth of bioproduct manufacturing in the United States. Areas for improvement include the demonstration of biomass feedstock delivery systems at commercial scale; development of technologies to reduce costs for conversion processes that produce intermediates with multiple product potential, including the use of lignin to produce chemicals with unique characteristics; and scale-up demonstrations of common processing steps to reduce risk for commercialization.

USDA, DOE, NSF, and DOD are actively involved in supporting engineering biology and biomanufacturing, and each agency has research programs working from fundamental discovery through applied research and scale-up.

Opportunity: Develop bioproducts that can accelerate biofuel production

Without portfolio diversity and alternative revenue sources to ride out market fluctuations, many of the early stakeholders working to develop a bioeconomy experienced significant barriers to continued biofuels development. Bioproducts—which include high-value chemicals, reagents, materials, and other biobased intermediates—are a viable option to reduce petroleum use, while potentially offering a diversification of market risk to investors once technology risks have been overcome.

Within the bioeconomy, biofuels represent the product with the largest market share, yet carry challenging price requirements to compete with existing petroleum-derived fuels. The U.S. has become accustomed to readily available, low-cost fuels, which makes this a difficult and risky path to follow. Using biomass for power and electricity is less risky, but it derives the lowest economic value from the resources and must compete with other renewable technologies, such as solar and wind.

[18] https://www.whitehouse.gov/sites/whitehouse.gov/files/images/Blog/NSTC%20SAM%20technology%20areas%20snapshot.pdf

Generally, biochemicals provide the highest value use of biomass products, and successful technologies can have a positive return on investment, making these more likely to scale-up to commercial production. Coupling biofuels and bioproducts development can result in an accelerated timeline to reduce risks versus a fuels scenario alone.

Opportunity: Enable the testing and approval of new biofuels and bioproducts

Biofuels and bioproducts must meet current specifications set for fossil-derived products, requiring various testing and approval procedures ahead of market entry. The ability to provide enough feedstocks, intermediates, and final products to enable testing is a barrier in the fledgling industry, but it also represents one of the greatest opportunities. Industry needs capital, new and repurposed, to perform the necessary testing of new products to ensure they meet industry standards. Industry also requires capital to develop new standards across the value chain for bioenergy and bioproducts. Acquiring this capital will require large public and private investments that will only materialize if there is a stronger demand push or market pull for these renewable fuels and products. Leveraging more progressive international markets by exporting fuels and products, as well as technologies, can help secure a stronger market pull that would enable more investment in U.S. pioneer technologies, thus lowering overall risk while providing benefits to the U.S.[19]

Co-Optimizing Fuels and Engines

Recognized as an integral part of the bioeconomy vision, DOE's Co-Optimization of Fuels and Engines (Co-Optima) initiative[20] seeks to accelerate widespread deployment of significantly improved fuels and vehicles. Two parallel research tracks are focused on the identification and co-development of fuel and engine technologies that, when used in tandem, offer the greatest combination of efficiency, GHG reduction, and performance.

The Co-Optima initiative contributes to the Bioeconomy Initiative by accelerating the deployment of advanced biofuels, targeting 16 billion gallons per year of by 2030, and contributing to a potential 30% reduction in petroleum consumption nationwide versus the current 2030 projections.[21,22]

Opportunity: Expand the market potential for biomass

To the extent that biomass products have demonstrable environmental advantages relative to fossil fuel-based or other alternatives, measures that monetize the value of environmental externalities will increase demand for biomass products. Without being able to monetize the value of externalities, the low cost of petroleum will result in a decreased market pull from industry to include renewables in their portfolios.

The airline industry and its need for jet fuel is an example of an exception due to multiple factors: industry commitments to achieving carbon neutral aviation growth by 2020; the U.S. and other member states development at the International Civil Aviation Organization (ICAO) of a global market-based mechanism limiting international aviation emissions; and the potentially devastating effects of price volatility associated with petroleum-based jet fuels.

[19] https://www.whitehouse.gov/sites/whitehouse.gov/files/images/Blog/NSTC%20SAM%20technology%20areas%20snapshot.pdf

[20] http://energy.gov/eere/bioenergy/co-optimization-fuels-engines

[21] http://www.energy.gov/sites/prod/files/2016/08/f33/farrell_bioenergy_2016.pdf

[22] http://energy.gov/eere/articles/co-optima-initiative-fuels-combustion-engine-efficiency

Cellulosic ethanol has found a small niche in the oxygenate market where it will need to compete with starch-based ethanol for the 10% blend with gasoline. To further pursue this route will require expanding this market beyond the blend wall by increasing ethanol blends that are acceptable in current vehicles and by providing current or reasonable infrastructure upgrades, making room for both starch and cellulosic ethanol. Innovations and new technology also have the potential to increase this market by using ethanol as a precursor for new bioproducts that have a higher value for the production of polymers. The Bioeconomy Initiative can support the market and further enable pathways for biofuels and bioproducts, including aviation, maritime, and surface transportation applications.

Opportunity: Encourage private-sector financing

Through strategic use of its convening power, the federal government has the ability to forge new partnerships and collaborations that could enable the development of policies and incentives to encourage private sector investment across the entire value chain, from feedstock production in the field to market driven product development and end use.

Federal Alternative Jet Fuel Research and Development (R&D) Strategy

Commercial and military aviation are fundamental drivers of national economic development, mobility, and security. However, aviation faces significant energy and environmental challenges due to dependence on petroleum jet fuels. Drop-in alternative jet fuels (AJFs) can address these challenges by enabling a diverse, secure, and reliable fuel supply, increasing energy price stability, displacing fossil-based emissions that impact air quality and global climate, while also generating rural economic development. Efforts are needed to quantify emissions displacement using life-cycle analysis models.

In June 2016, the National Science and Technology Council's Aeronautic Science and Technology Subcommittee published the *Federal Alternative Jet Fuel Research and Development Strategy.*[23] The strategy was developed with input from the non-federal stakeholder community by representatives from the U.S. Departments of Agriculture, Commerce, Defense, Energy, State, Transportation, EPA, NASA, and the NSF.

The document highlights current federal agency AJF R&D expertise, responsibilities, and collaborations. It aligns federal agency R&D efforts across the AJF development path and sets out prioritized federal R&D goals and objectives to address key scientific and technical challenges that inhibit the development, production, and use of economically viable AJFs. This strategic approach is intended to contribute to the successful mobilization of both the federal agency and the non-federal stakeholder communities towards a common effort to develop and deploy cost-effective AJFs.

Creative public-private partnerships with the insurance industry to cover a range of areas from crop insurance to regulatory-risk insurance could be considered to survive the early stage of development and deployment for this new industry. Programs such as the BioPreferred Program at USDA support and encourage the use of bioproducts throughout the federal system. Long-term secure product off-take contracts and long-term feedstock supply contracts are important for industry stakeholders when working to secure financing and ensure investors.

[23] https://www.whitehouse.gov/sites/default/files/federal_alternative_jet_fuels_research_and_development_strategy.pdf

Opportunity: Support analysis as a foundation for stable, long-term policies

If carefully crafted policies were in place to encourage the sustainable expansion of a U.S. bioeconomy, many of the challenges discussed above could be reduced. For decades, the federal government has employed many different types of policy incentives to encourage energy production in the United States. Moving forward, such policies must be based on sound science and reflect our best efforts to identify and mitigate any potential negative environmental, economic, and social impacts. There are ongoing federal scientific processes, such as the EPA's technical review of the carbon implications of biomass use for energy at stationary sources, that can help us identify forms of biomass that reflect carbon benefits.[24] Information from such scientific processes can advance technical understanding of the role that biomass can play in GHG emissions strategies by enabling us to identify and promote biomass that is carbon-beneficial versus those that could result in CO_2 emissions increases or other potential consequences.

There are a number of policy pathways forward that can help foster thoughtful expansion of the bioeconomy. For example, policies that encourage the use of otherwise unused byproduct materials for renewable bioenergy and bio-products should be considered. However, any policies relating to bioenergy must be founded on appropriate analysis and abide by current standards set in the Clean Air Act and meet established guidelines to maintain and improve the U.S. environment.

Opportunity: Ensure a ready workforce to meet the needs of the bioeconomy

A growing bioeconomy will require a knowledgeable and well-trained workforce. U.S. K-12 and post-secondary education programs have put an increased focus on science, technology, engineering, and mathematics, but there is still room for growth. This will benefit the bioeconomy by providing a multidisciplinary workforce that will not only include engineers and scientists, but communications experts, human resource specialists, and other supporting positions as well. Additionally, workers will need experience across the supply chain, which could take the form of apprenticeships, internships, and volunteer opportunities in the growing industry.

Next Steps

The activity across the federal government is extensive, and agencies have made progress in understanding many aspects of an emerging bioeconomy, including the production and logistics of delivering feedstocks to a refinery, as well as innovations that have significantly reduced the cost of converting feedstocks into fuels and products. The Bioeconomy Initiative will expand the focus beyond biofuels, increasing the value and potential benefits of biomass.

The federal government has also made efforts to develop sustainable supply chains, establish standards, and has performed extensive testing of fuels for aviation and surface transportation. However, to further reduce the risks of the technology and overcome barriers to achieving a robust bioeconomy, the bioenergy community must do more.

The Board will continue to develop the Bioeconomy Initiative in partnership with stakeholders. Building on the release of the FARB, this report is the next step in forming the coalition to drive the Bioeconomy Initiative forward by identifying many of the obstacles that need to be addressed, and understanding how to move forward cooperatively.

[24] Information regarding the EPA's draft technical report, *Framework for Assessing Biogenic CO_2 Emissions*, and the related scientific peer review process can be found at: https://www3.epa.gov/climatechange/ghgemissions/biogenic-emissions.html