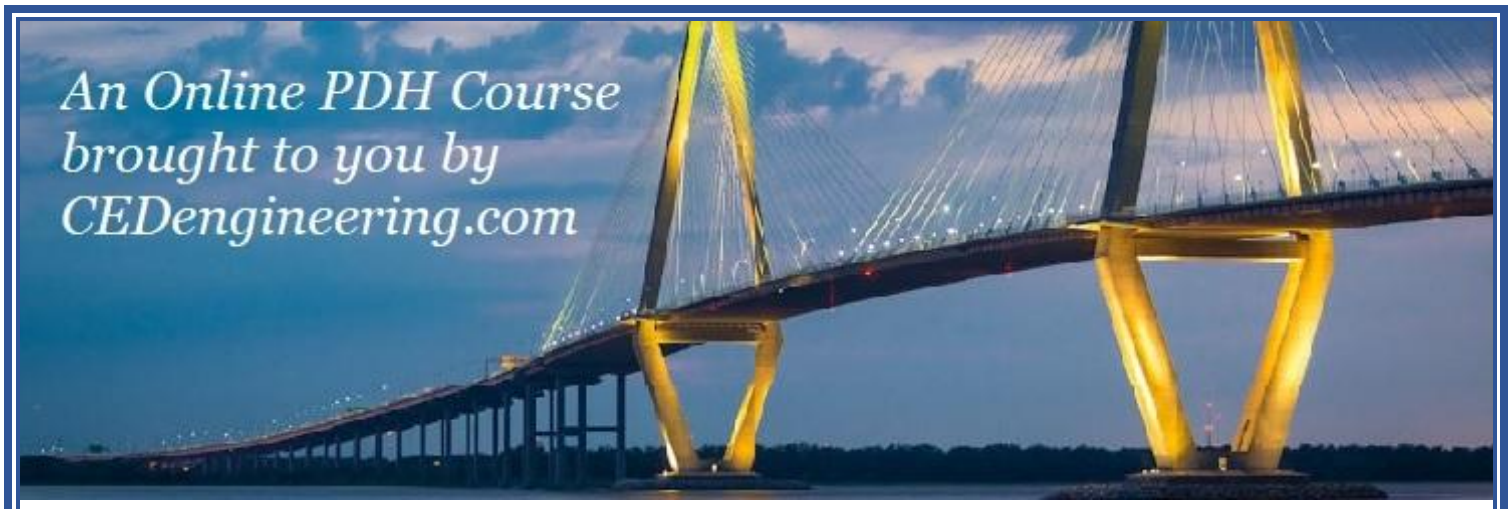

Building Resilient Biomass Supply Chains

Course No: R03-023
Credit: 3 PDH

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This course was adapted from the U.S. Department of Agriculture, Publication title "Building a Resilient Biomass Supply: A Plan to Enable the Bioeconomy in America", which is in the public domain.

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About This Report

In September 2022, President Biden signed Executive Order (EO) 14081 on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy. The EO directs the Secretary of Agriculture, in consultation with the heads of appropriate agencies as determined by the Secretary, to submit a plan to the President, through the Assistant to the President for National Security Affairs (APNSA) and the Assistant to the President for Economic Policy (APEP), to support the resilience of the U.S. biomass supply chain for domestic biomanufacturing and biobased product manufacturing, while also advancing food security, environmental sustainability, and the needs of underserved communities. This plan shall include programs to encourage climate-smart production and use of domestic biomass.[1]

This plan begins with an assessment of the biomass availability and current uses. A detailed look at biomass supply chain systems reveals considerations – climate change, food security, environmental justice, and others – that could affect biomass availability. Finally, the plan

[1] The EO also directed the plan to include budget estimates, including accounting for funds appropriated for Fiscal Year (FY) 2022 and proposed in the President's FY 2023 Budget. The White House plans to obtain this information separately.

presents recommendations for programs, research, development, and demonstration, and policies that could increase biomass availability, build supply chain systems resilience, and expand the use of domestic biomass within the bioeconomy.

Stakeholder Consultation
Public stakeholders were engaged in the development of this plan through a USDA-led listening session on July 18, 2023, and an OSTP-led Request for Information posted in December 2022.[2] Input from this outreach informed the recommendations and proposed actions.

Federal Collaboration
The United States Department of Agriculture (USDA) led the development of the plan with review and support from:

- Department of Commerce (DOC) – National Institute of Standards and Technology (NIST)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Transportation (DOT) – Federal Aviation Administration (FAA), Volpe National Transportation Systems Center
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)

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[2] Request for Information; National Biotechnology and Biomanufacturing Initiative | Office of Science & Technology Policy

Executive Summary

Biomass is the foundation of the U.S. bioeconomy. Biomass comes from crops, agricultural and food wastes, forests, and livestock. It is the basis for thousands of biobased products that we encounter every day, such as furniture, building materials, bioplastics, paper products, clothing, and biofuels. Demand for biomass is expected to grow over time for use in climate-smart and sustainable solutions to address society's needs.

For the United States, this represents a golden opportunity. The expansion of markets for domestically produced biomass will create new sources of revenue for American farmers, ranchers, and forest landowners, particularly in rural areas. This will be critical for the future vibrancy of the U.S. agricultural and forestry sectors.

Recognizing this, the White House issued Executive Order 14081 requiring USDA to lead the development of a plan to support the resilience of the domestic biomass supply chain for domestic biomanufacturing and biobased product manufacturing, while also advancing food security, environmental sustainability, and the needs of underserved communities.

The resulting *Plan to Enable the Bioeconomy in America: Building a Resilient Biomass Supply* focuses on systems of production of biomass as raw material and its preprocessing into feedstocks for many diverse types of biomanufacturing and biobased products in the U.S. bioeconomy. Some of these systems are well-established and primed for expansion, while others are newly emerging. Thus, the plan calls for three broad areas of activity: (1) research, development, and demonstration for innovation in newly emerging biomass supply systems; (2) capacity building to expand existing biomass supply systems; and (3) market development and assessment to match biomass supply to demand for the biobased products.

The plan begins by describing our understanding of current biomass use and availability. It then identifies current challenges and vulnerabilities to biomass supply chain systems. Focusing on resilience, the plan summarizes existing government policies and programs across supply chains that support the expansion of the bioeconomy. Then, it recommends additional actions in research, development, and demonstration, policies, and programs to build more resilient biomass supply chains. The plan concludes by recommending mechanisms for improving cooperation and collaboration on the bioeconomy across the Federal Government. Woven throughout are considerations for addressing climate change, advancing racial justice and rural prosperity, creating better market opportunities, and tackling food security. All of these are essential for developing a bioeconomy that works for everyone.

Some of the Plan's key conclusions about supporting resilient biomass supply chains for domestic biomanufacturing and biobased product manufacturing include:

1) **U.S. biomass supplies are abundant.** The United States is well positioned to utilize and leverage those resources for a growing range of bioenergy and biobased product applications.

2) **There are gaps in our knowledge of current and projected future biomass feedstock availability.** For example, the 2016 DOE Billion-Ton Report estimates biomass feedstock availability but primarily focuses on feedstocks for biofuels. It provides limited data for emerging feedstocks and uncertainties around market prices and policies.
3) **There is much to learn about competing markets for biomass feedstock and incentivizing new market creation.** Demand for biobased products is expected to grow, especially in response to climate change. As the bioeconomy expands, the structure of market incentives will influence choices about processing biomass into feedstocks – for example, how much vegetable oil will be used for renewable diesel relative to that for sustainable aviation fuels.
4) **Biomass crops need to be produced at scale for the bioeconomy to substitute renewable resources for non-renewables, but farmers will not risk planting crops without established markets.** There is great potential to grow emerging lignocellulosic crops on marginal lands, such as perennial grasses, shrub willow, and hemp, which could replace a wide array of petrochemical-derived products. However, farmers will not grow them unless established processing facilities and markets exist. Likewise, woody biomass resources from forestlands are abundant, but investments to harvest and collect them will not emerge without certainty about reliable markets for the final products.
5) **Emerging oilseed crops can increase biomass availability and sustainability of commodity row crop production without increasing land use, as cover crops and through double-cropping.** Incentives and risk-reduction options could be used to promote the expansion of lesser-known crops, such as camelina, pennycress, and carinata, along with research that reduces their agronomic and economic risk.
6) **Woody biomass can provide a large volume of needed biomass, but the economics of forest operation residuals, mill waste, forest health thinnings and wildfire fuel removal need to be better understood and made more cost-effective.** Policy needs to be implemented that incentivizes use of this underutilized biomass.

In addition to these conclusions, the Plan identifies how improvements in our Nation's biomass supply would also support the EO's goals of advancing food security, environmental sustainability, and the needs of underserved communities. For example:

- Innovating and expanding the production, pre-processing and demand for biomass supports food security by diversifying and augmenting revenue streams for food producers without removing cropland from food production, while also reducing the cost of soil protection and amendments.
- Environmental sustainability is an overarching purpose of the bioeconomy because it substitutes renewable resources for non-renewable resources. Biomass is the raw material that makes this possible. Improving the biomass supply chain thus contributes to a wide range of environmental sustainability objectives such as climate-smart agriculture, regenerative farming, and substituting for the use of fossil fuels.
- Expanding the production and processing of biomass can be a key element of USDA's efforts to fulfill the needs of underserved communities: increased production and demand for biomass can diversify revenues and reduce costs for small farmers, while investments

in processing infrastructure and innovative R&D supports new jobs and increased wages in rural communities.

To support these conclusions and address the issues identified in the report, the plan presents recommendations in two areas: (1) research, development, and demonstration needs, and (2) programs and policies for capacity building and market development. Some of the recommendations involve work USDA already has started, some will require USDA to increase the scope and scale of existing programs and policies, and others propose new areas of engagement.

Research, Development and Demonstration Needs

- **Resource markets and availability:** Assess, compare, and evaluate markets and availability of biomass crops, including a comprehensive inventory of woody biomass and other markets not covered in the 2016 DOE Billion-Ton Report.
- **Efficiencies in sustainable lipid supply:** Research more efficient ways to collect and aggregate waste lipids and expand the cultivation of oilseed crops as major components of biofuels and other products. For example, USDA is funding projects that will result in the commercial production of new oilseed crops (pennycress and carinata). Those new crops may be grown as cover or winter fallow crops that eliminate land use change while expanding lipid supply.
- **Production of biomass and collection of wastes and residuals:** Conduct long-term trials for emerging biomass crops, develop better methods for collecting, sorting, and processing wastes and residuals, and analyze policies to encourage biomass production/collection. For example, USDA is supporting the genetic development, agronomic evaluation, and eventual commercial deployment of biomass crops, such as the natural rubber crop guayule.
- **Biomass supply chain systems logistics:** Research improvements to biomass transportation, optimize preprocessing at farms and depots, and enhance reliability of feedstock processing systems. The USDA has programs targeting supply chain logistics for insect-damaged trees and small-diameter wood biomass that fuel catastrophic wildfires.
- **Sustainability of biomass and waste supply systems:** Improve genetics, optimize climate-smart agricultural and forest practices, develop alternative uses for co-products of manufacturing, assign values for environmental services, and perform lifecycle analyses and techno-economic assessments.

Policies and Programs for Capacity Building and Market Development

- **Development and diversification of markets for biomanufactured and biobased products:** The USDA BioPreferred Program continues to increase its outreach and product catalog. This can be leveraged to expand Federal procurement as well as domestic and international market opportunities for biomanufactured and biobased products, biofuels, and climate-smart commodities.
- **Incentivizing biomass production:** Maintaining stable and substantive support for biomass production over the long term will incentivize more farmer adoption and private-

sector investment in biomass supply chains, much as it does in other agricultural sectors. For example, USDA provides grants for increased utilization of woody biomass.

- **Risk reduction:** RMA crop insurance programs should continue to be reassessed and updated as needed to meet the changing needs of producers as new commodities and markets develop. Risk can also be reduced through promotion of cooperatives, financial safety nets for value-chain capacity building, and development of markets for co-products.
- **Infrastructure and workforce investments:** Ensure equitable benefits of biomass production across society through infrastructure investments, Bioeconomy Development Opportunity Zones, and environmental justice tools and policies.
- **Education and extension:** Support workforce training and farm workers, agriculture and forestry extension programs, programs for beginning farmers, and public outreach about bioproducts.
- **Knowledge base:** Prioritize investments in data collection/sharing, updates to NAICS/NACPS[3] and other industry and trade databases, and in tracking for carbon accounting in biobased products.

The plan concludes with implementing actions that span across the Federal Government and recommends mechanisms for improved cooperation and collaboration over the long term.

Introduction

In September 2022, President Biden signed an Executive Order (EO) on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy. To advance the U.S. bioeconomy and also support the Administration's decarbonization goals, the EO discusses the need to boost sustainable domestic biomass production. This includes creating climate-smart incentives for American agricultural producers and forest landowners and expanding market opportunities for bioenergy and biobased products and services. As part of this effort, the EO tasked the U.S. Department of Agriculture (USDA) with developing a plan to support the resilience of the U.S. biomass supply chain for domestic biomanufacturing and biobased products, while advancing food security, environmental sustainability, climate-smart production, domestic biomass use, and environmental justice.[4,5]

Biomass is the raw material for the bioeconomy. It originates from plants, animals, or microbes. It then is transformed into fuel, fibers, building materials, livestock feed, food and beverage ingredients, personal care items, and many other products. Products may be considered "traditional," meaning that they have been produced a certain way for a long time and are commonly familiar. Examples include wood for building materials, natural rubber for tires, and cotton in coffee filters. "Innovative" uses are newer, and in some cases may still be undergoing research and development. Examples of these are biofuels from woody biomass, plastics

[3] North American Industry Classification System (NAICS) and North American Products Classification System (NAPCS)
[4] Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy | The White House
[5] Revitalizing Our Nation's Commitment to Environmental Justice | Executive Office of the President

produced from algae, and building materials from hemp. Biomass availability must be sufficient to continue production of traditional products as well as the innovative products that will drive the bioeconomy forward. Given the broad range of products and biomass uses, this plan focuses on biomass feedstock availability for biomanufacturing and biobased product manufacturing.

Definitions of Key Terms

Biobased product: a product determined by the Secretary to be a commercial or industrial product (other than food or feed) that is— (A) composed, in whole or in significant part, of biological products, including renewable domestic agricultural materials, renewable chemicals, and forestry materials; or (B) an intermediate ingredient or feedstock.

Bioeconomy: economic activity derived from the life sciences, particularly in the areas of biotechnology and biomanufacturing, including industries, products, services and the workforce [a,b]

Biomanufacturing: the use of biological systems to develop products, tools, and processes at commercial scale.[a]

Biomass: any material of biological origin that is available on a renewable or recurring basis, for example, plants, trees, algae, and waste material such as crop residue, wood waste, animal waste and byproducts, food waste, and yard waste.[a]

Biological (biomass) feedstock: biomass intended for use as a starting material or an intermediate ingredient to be converted to another material through biomanufacturing or another manufacturing process.[a]

Biomass supply chain systems: the networks of resources needed to produce a product and deliver it to consumers.

Climate-smart agriculture: an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes, while adapting and building resilience to climate change and/or reducing/removing greenhouse gas emissions.[c]

Sustainability: the aspiration to meet current needs while maintaining capacity for future generations to meet their needs and while considering economic, social, and environmental impacts.[d]

[a] NIST Bioeconomy Lexicon | National Institute of Standards
[b] Within the scope of this report, bioeconomy includes the share of the economy based on products, services, and processes derived from biological resources (e.g., plants and microorganisms) and encompasses multiple sectors, in whole or in part (e.g., agriculture, textiles, chemicals, and energy). The Bioeconomy: A Primer | Congressional Research Service
[c] Terms of Reference | Aim for Climate
[d] Definitions: Sustainability and Food Systems | U.S. Department of Agriculture

Biomass supply chain systems supporting bioeconomic activity are varied and complicated, given the wide variety of manufactured products. Supply systems may be affected differently by regional, geopolitical, economic, environmental, and social components. Shortages or disruptions at any point within supply chain systems affect manufacturers, consumers, and the bioeconomy. Environmental justice, food security, and other social issues also must be considered to make certain expansion of supply chain systems and the bioeconomy benefit everyone. To ensure the U.S bioeconomy is poised to meet current and future demands, this plan examines current biomass uses and its availability, challenges, and opportunities within biomanufacturing and biobased product manufacturing supply chain systems. Research, policy, and program recommendations to increase the resilience of biomass supply chain systems are provided.

Biomass Use and Availability

The USDA BioPreferred Program estimates there are at least 40,000 non-food and nonfuel bioproducts commercially available. Table 1 provides examples of a breadth of products.

Table 1. Overview of Traditional and Innovative Bioproducts and Common Feedstocks

Product Category	*Examples of Products and Uses*	*Example Biomass Feedstocks for Products*
Medical products, personal care, and cosmetics	Antibiotics, vitamins, biopharmaceuticals, cosmetics, polyphenols, phytochemicals	Fermentable starch (e.g., corn), guar gum, beeswax, vegetable oils, lanolin, beets, herbs, wood biomass, algae
Enzymes	Detergents, saccharification, food and beverage processing, biomanufacturing, industrial processing (e.g., leather processing), biocatalysts	Fermentable sugars, wood extractives
Livestock feed	Feedlot rations, hay, feed co-products from biofuels (e.g., corn distillers grains)	Perennial pasture grasses, alfalfa, annual cereal grains, corn stover, crop residues, oilseeds, algae
Agricultural inputs	Biopesticides, biofungicides, biostimulants, compost, fertilizers, bioherbicides, vegetative mulches, soil amendments, biochar	Extracts from many plants and microbes, dry leaves and other plant material
Construction materials	Lumber, cross-laminated timber, composites, adhesives, insulation, drywall	Hardwood, softwood, lignin, soy, hemp,
Paper and packaging	Paper, newsprint, cardboard, paper napkins and plates, tissues, toilet paper, thermoform fiber products, filters, packaging, absorbent pads, rayon	Hardwood, softwood, grassy biomass, biopolymers, wood cellulose, hemp
Biobased polymers	Natural rubber products (aircraft and ground transportation tires, medical devices), bio-asphalt, packaging, bioplastics	Fermentable sugars, lignocellulose, wood, *Hevea*, guayule, soybean oil, corn oil, sugarcane
Bioenergy including biofuels	Ethanol, biodiesel, renewable diesel, sustainable aviation fuel, hydrogen, biogas, fuel pellets, combined heat and power, batteries (capacitors)	Fermentable sugars, soybean and corn oil, perennial grasses, agricultural residues oilseed crops, animal fats, hardwood and softwood, manure, algae

Estimating biomass use and availability is not straightforward, yet it is important to understand as we plan for the future. The Department of Energy (DOE) periodically updates the Billion-Ton Report, which estimates the use and current/future availability of different biomass sources. The most recent report (2016) considers supply chain costs, economic viability of biomass types, and other factors to model biomass use and availability. The biomass estimates from the 2016 Billion-Ton Report include forestry-based small-tree thinning removal and residuals, purpose-grown biomass crops, agricultural residuals (wheat straw, corn stover), and municipal solid waste (MSW) at $60 per ton (Figure 1). Microalgae estimates are provided separately; the biomass potential for a mature system is <23 million tons per year for freshwater species at $490 - $1,327 per ton and <24 million tons per year for saltwater species at $540 - $2,074 per ton.

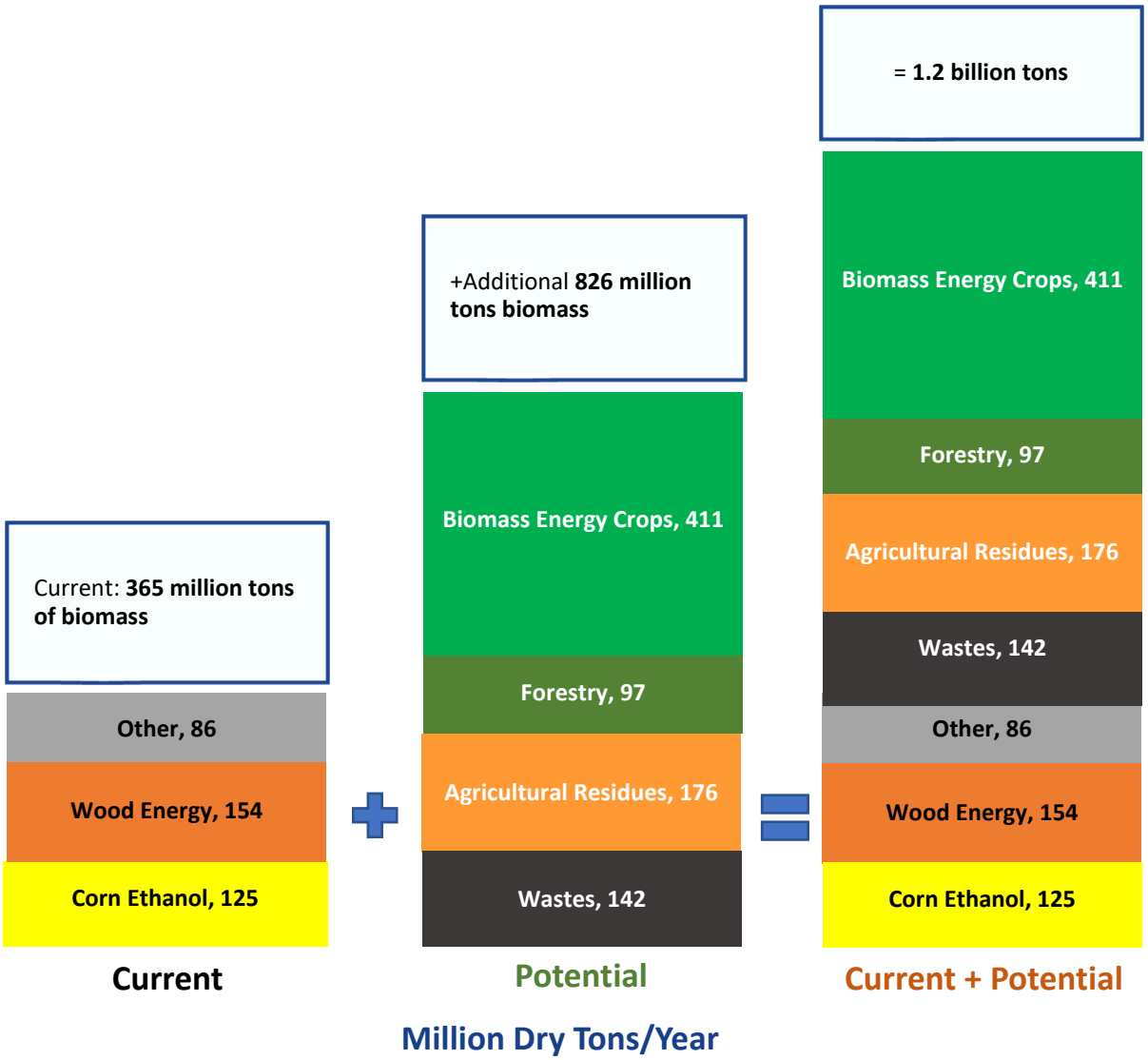


Figure 1. Biomass availability (forestry, agricultural, and waste) estimates for current use, 2040 potential that could be realized under existing policies and market conditions, and future availability in 2040 (current plus 2040 potential) under a base-case scenario.[6]

[6] Figure derived from data from the 2016 Billion-Ton Report | U.S. Department of Energy

There are some limitations in the biomass estimates from the 2016 Billion-Ton Report. The estimates cannot account for future policies that could affect biomass supply as markets grow and the field expands. Further, the 2016 Billion-Ton Report estimates of biomass availability assume the cultivation and use of dedicated biomass crops that are not in commercial use today and do not have emerging markets because of a variety of factors including cost, lack of supporting policy, and producer/landowner choice/adoption. The models also do not include macroalgae (recognized as a large potential source of biomass), oilseed crops, hazardous fuels, natural disaster salvage, urban wood waste, utility maintenance treatments, and non-marketable biomass from forest restoration treatments. See the 2016 Billion-Ton Report for more details.[7]

It is difficult to predict the future demand for biomass, given population growth, rapidly evolving innovations, new technologies, government policies, and other factors. The 2016 Billion-Ton Report does not provide estimates of future demand (in contrast to potential future use and availability), nor are other comprehensive estimates available. However, with the expansion of the fermentation industry, emphasis on sustainable aviation fuels and other biofuels, sustainable feedstocks, and many other new bioproducts, biomass and its importance to society will likely grow. The demand for biomass is expected to increase over time, even as markets for specific bioproducts decrease and are replaced by markets for different bioproducts. While keeping the 2016 Billion-Ton Report estimates in mind, the United States should take steps to expand domestic biomass availability to ensure future needs are met.

Spotlight – Local Economic Opportunities

Biomass supply chain systems bring economic opportunities to their communities. Biomass is often abundant in rural areas where production, harvesting, and transportation of the biomass occurs locally. Regional depots for preprocessing biomass and storage of the ready feedstock may also be economically viable approaches and some manufacturing facilities choose to locate their operations near feedstock resources. These local supply chain systems can have enormous economic benefits for communities outside of urban centers. With the creation of new jobs and investments by local businesses, community revenue rises. This, in turn, has a multiplier effect, creating more jobs and workforce development opportunities in economically disadvantaged areas of the country.

Biomass Supply Chain Systems

"Biomass supply chain" implies a linear relationship among its elements, but biomass supply chains are complex systems with many connections. For this reason, the term "biomass supply chain systems" or "biomass supply systems" is used throughout this plan. While there are many biomass supply chain systems for biomanufacturing and biobased product manufacturing, both traditional and innovative bioproducts rely on the same biomass supply systems elements: crop/feedstock development, sustainable production and management, harvesting/residual collection, intermodal (e.g., truck, rail, waterway) transportation, storage, and

[7] The U.S. Department of Energy is updating the Billion-Ton Report. The new update is anticipated to include new chapters on macroalgae, oilseeds, and CO_2 as well as new numbers for microalgae. It also will align with USDA's forest residue removal for forest fire prevention strategy.

preprocessing.[8] These elements link to a range of manufacturing processes and value portfolios (fuels, materials, products, chemicals). Feedback loops exist throughout supply chain systems. Consequently changes, enhancements, and perturbations in an element can affect other supply systems components and ultimately processing, distribution, and markets (Figure 2).

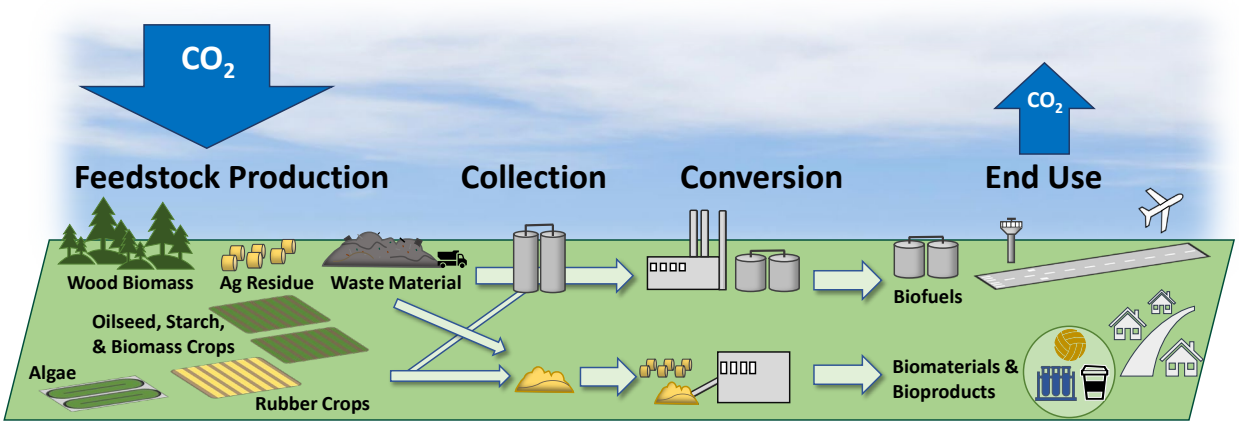


Figure 2. Example of a biomass supply chain system. Note the web of connections among feedstock sources and conversion facilities before end use.

Biomass Supply Systems Challenges

Biomass supply chain systems have a broad range of vulnerabilities, including biological, environmental, economic, geopolitical, and social challenges.

Biomass Supply Systems Challenges

- Economic Viability
- Climate Change
- Environmental Sustainability
- Environmental Justice
- Food Security
- Feedstock Variability
- Education and Outreach
- Infrastructure
- Workforce
- Policy Uncertainty
- Geopolitics and Trade Risks
- Limited Domestic Production

Economic Viability, Markets, and Opportunity Costs

One of the greatest challenges for the entire biotechnology and biomanufacturing enterprise is the availability and affordability of quality feedstock at scale. Expanding the use of biobased feedstock is not only essential for advancing the domestic bioeconomy, but also for mitigating effects from climate change. The United States needs to increase biobased feedstock production without adversely impacting landscapes or the production of other important commodities, and the communities that depend on both. Expanding biomass feedstock production will require a series of efforts including increasing agriculture crop yields, growing new and different crops, finding cost effective ways to capture waste wood and agricultural and food wastes, making changes in how crops are used, and using crop portfolios that can take advantage of economically marginal lands while maintaining or enhancing the ecosystem services these lands provide.

[8] Preprocessing is the act of transforming biomass into a feedstock that can be used to manufacture a product.

Markets for and economic viability of crops and woody biomass drive farmer and forest landowner business decisions. For example, purpose-grown[9] lignocellulosic crops for biofuels have not reached commercial scale because of transportation, storage, and preprocessing costs. Likewise, the production of certain crops, such as switchgrass and hemp, has been hindered by a scarcity of processing infrastructure. Reaching scale will require innovation, infrastructure investment, and technology to realize the potential of these underutilized waste biomass streams and new biomass crops and uses. Understanding biomass feedstock supply systems, processing, distribution, and markets can allow for strategic investments to increase the economic viability of biomanufactured and biobased products.

Climate Change Impacts

The changing climate is expected to affect the supply of a broad range of biomass feedstocks. Extreme weather events are becoming more prevalent and intense and include drought, flooding, prolonged periods of high temperatures, heavy snowfall, heavy rainfall, high winds, hail, catastrophic wildfire, and new or increased pressure from pests and disease. Any of these environmental factors can put pressure on biomass systems – whether crop- or forest-based, livestock, or residual – either by direct damage (injury/death), indirect damage (e.g., reduced yield from reduced inputs [water]), or by economic challenges to biomass availability (e.g., damaged infrastructure). Climate change may also increase the availability of some sources of biomass, such as woody biomass from forest thinnings for fire mitigation.

Environmental Sustainability

As a renewable resource, biomass is an important contributor to climate change mitigation, but only if biomass supply systems themselves are environmentally sustainable. The environmental footprint (e.g., impacts on greenhouse gas emissions, soil quality, water use, water quality, airborne particulates,

Spotlight – Sustainable Aviation Fuel

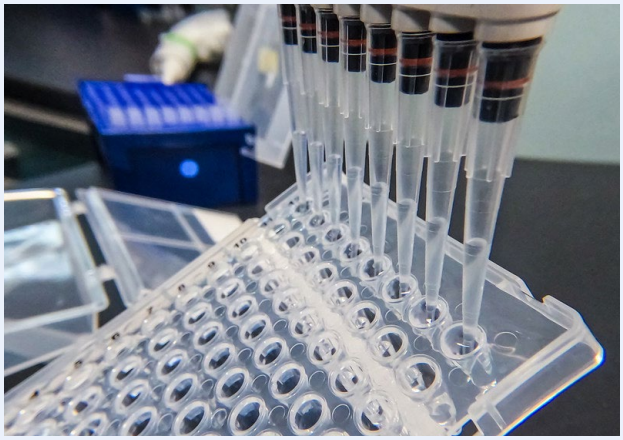
Biotechnology and climate-smart agriculture are driving the production of Sustainable Aviation Fuel (SAF). Through the SAF Grand Challenge, the United States aims to produce 100% of the SAF needed to meet the aviation sector's demands by 2050. The supply systems are complicated. Alcohol production, one potential precursor to SAF, depends on our ability to grow biomass in the face of pests and disease, extreme temperatures, drought, and reduced land area. Plant biotechnology has allowed crop development to keep pace with these and other challenges. Climate-smart agricultural practices leverage these advances and increase the sustainability of starch crops by reducing inputs and greenhouse gas emissions through, precision application of nutrients, crop protection agents, and water, along with revitalizing the soil and sequestering carbon. Under a USDA Partnerships for Climate-Smart Commodities grant and grants from DOE, Gevo and LanzaJet are developing the technology for production of ethanol and isobutanol by biotechnology-derived microorganisms and enzymes from sustainable feedstocks. These intermediates are then further processed into sustainable aviation fuel with greenhouse gas footprints less than 50 percent of petro-based jet fuel. Through the SAF Grand Challenge, the U.S. has developed a roadmap to make SAF use an everyday occurrence in aviation.

[9] Purpose-grown biomass crops are cultivated specifically to be used for feedstocks for bioenergy and bioproduct manufacturing.

ecosystems) of a feedstock is affected by the structure of supply chain systems, ultimately affecting the overall sustainability of the products produced. Biomass supply chain systems should be evaluated for their viability relative to their fossil fuels equivalent as part of the planning process. Sustainable practices will not be adopted if production costs of the feedstock or product is too high. Existing woody biomass supply chain systems provide a blueprint for establishing biomass feedstock sustainability through environmental regulation and third-party audits.

Spotlight – Biomanufactured Food and Ingredients

Advances in biomanufacturing are leading to novel sources of foods and ingredients for food and pharmaceuticals. Animal stem cell lines are being explored to produce cell-cultured meat, seafood, and proteins while synthetic biology principles are being tested to fabricate micronutrients, amino acids, vitamins, additives, and other high value food and feed ingredients. Research into microalgae, fungi mycelium, and other sources of proteins and food additives is ongoing and holds the promise of additional sources of ingredients. To support the burgeoning industry, the U.S. will need to increase its bioreactor capacity and augment its biomanufacturing ecosystem. Mass production of these new foods and ingredients will require scaling up new biomanufacturing technologies as well as social acceptance of the products. As the world's population grows, biomanufactured foods are expected to contribute to food and nutrition security and complement conventional agricultural food production practices.



Environmental Justice

While offering great potential for economic growth and prosperity, biomass supply chain systems must operate in ways that equitably benefit local communities. Likewise, any related environmental burdens – for example, air pollution, decreased green spaces, potential for accidental spills – should be equitably distributed to balance the economic benefits communities receive. Often, communities with environmental justice concerns are adversely and disproportionately affected by transportation and facility infrastructure, compared with other communities. As biomass supply chain systems grow and evolve, these costs must be balanced with community benefits, such as profits, products, and jobs.[10]

Food Security

Expanding the production of biomass for non-food biomanufacturing and bioproducts could affect food security. While many biomass crops are not food crops, they may compete for land with food crops or use crops also grown for food or animal feed. Greater biomass demand could potentially increase commodity prices, and thus global food prices. These effects would disproportionately affect lower income populations who are more sensitive to food price changes because they spend a larger share of their income on food relative to higher income populations, especially internationally. However, in the United States, commodity prices

[10] Revitalizing Our Nation's Commitment to Environmental Justice | Executive Office of the President

constitute a small component of retail food prices[11] and consumers spend a relatively small share of their income on food. Combined, these factors mean that if commodity prices rise due to increased biomass feedstock production, there would not be a significant impact on domestic food security.

Upward pressure on commodity prices from expansion of biomanufacturing and bioproducts could be mitigated through productivity growth and cropping changes. This has been shown to be the case with biofuel production in the United States where agricultural supply has responded to higher commodity prices triggered by biofuel expansion by raising productivity and changing cropping patterns. This suggests that market demand can induce technological change that increases the capacity of the agricultural sector to meet growing demands for both food and fuel.[12] Continued analysis and monitoring are needed to assess how the expansion of biomass feedstock production affects food prices and food security.

Variability of Biomass Feedstock

While the diversity of available and emerging biomass adds to overall supply systems resiliency, biomanufacturers require consistency in their feedstocks to ensure the outcome and quality of the final product. Process changes are often required to account for differences in feedstock composition, but adjustments may not be possible if the feedstock is too diverse. Further, varied biomass often leads to quality degradation during storage and transportation to system depots or biorefineries. Heterogeneity is especially prevalent in collected agricultural and forest residuals, and emerging systems such as municipal solid waste. Reducing variability may require additional supply systems elements (sorting, separating, more robust bioprocessing) that add complexity and cost.

Insufficient Education and Outreach

Education and stakeholder engagement are important factors in building resilient biomass supply chain systems. For example, the adoption of new biomass crops will only occur if growers are aware of the crop and its economic opportunities, as well as basic agronomy necessary for production. Likewise, investors and community members should understand how the infrastructure to support emerging biomass supply systems will affect their communities. Comprehending a community's willingness and social capital (e.g., workforce and training capacity, existing infrastructure) to support a new venture is important for investors. Outreach about jobs, environmental impacts, and permitting and regulation policy can help investors and communities make decisions that are mutually beneficial.

Infrastructure Availability

The amount of biomass that can be transported, stored, and preprocessed is limited by domestic infrastructure. For example, growers may need specialized equipment for high production biomass such as high-capacity forage harvesters and drying facilities. Many rural bridges have load limits of 5 tons or less, thus restricting the size of biomass shipments to manufacturing facilities; transportation of wide loads often create extra work and expense.

[11] Food Dollar Series | U.S. Department of Agriculture
[12] Lessons learned from US experience with biofuels: Comparing the hype with the evidence | Khanna, M.D. et al. 2021. *Review of Environmental Economics and Policy*

Manufacturing facilities must have sufficient storage capacity for biomass and pilot/test beds must be able to accommodate a wide range of feedstock types. Preprocessing capacity is also limited with few large-scale facilities available domestically. A more detailed discussion on infrastructure to support biomanufacturing is forthcoming under the Bioeconomy Executive Order Report 5(a).[13]

Workforce availability

Strong biomass supply systems will rely on a large workforce with varied skills. Job opportunities include scientists to develop new crops with increased yields and functional properties, farmers and farm workers to grow and harvest crops, truckers to transport biomass, feedstock quality control specialists, engineers and workers at preprocessing facilities, and many more. Education and skills training vary widely, and biomass supply chain systems will need a diverse workforce to succeed. See the Bioeconomy Executive Order *Building the Bioworkforce of the Future* report for more discussion.[14]

Policy Uncertainty

Policy and regulation govern many biomass supply systems elements and often influence decisions related to feedstock cost and availability, sustainability parameters, and even siting of biomanufacturing facilities. Policies that are vague or subject to frequent change pose a barrier to investment and long-term planning in biomanufacturing and biomass feedstock supply systems. For example, biomass supply chain systems may be affected by policies in land use, Farm Bill programs, forestry, agricultural marketing, biofuel mandates, infrastructure siting/zoning, renewable fuel standards, development, and biotechnology regulatory requirements. These policies and regulations can result in a complicated patchwork that is difficult to navigate and may ultimately discourage investments and innovations. Other programs and policies, like loans, grants, and tax incentives, can drive innovation, but may fall short if not available long-term or if they do not match the size of the capital investment required. For entrepreneurs and investors, it is helpful to have a stable policy and regulatory landscape to lessen risk and thus incentivize participation in markets. Farmers and forest landowners would benefit from longer planning horizons to justify investments in perennial production systems that require time for establishment followed by a productive lifespan of a decade or more. Under the Bioeconomy Executive Order, the Federal Government is taking a closer look at policies and regulations affecting the bioeconomy. Of relevance to this plan are Section 5(a), which addresses biomanufacturing infrastructure challenges, and Section 8, which focuses on evaluating the biotechnology regulatory framework and looking for ways to add clarity and fill gaps.

Geopolitical Challenges and Trade Risk

U.S. biomass supply systems may depend on internationally sourced inputs, which can be prone to geopolitical and trade risks. Sudden regional conflicts or export restrictions reduces global commodity supply with risk of price shocks. For example, global fertilizer prices more than doubled between 2021 and 2022, exacerbated by the Russian invasion of Ukraine and

[13] Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy | The White House

[14] Building the Bioworkforce of the Future | Office of Science and Technology Policy

Russian export restrictions (Russia accounts for 16% of global fertilizer exports).[15] A reduction in global supply influences planting decisions with cascading effects throughout supply chain systems.

Limited Domestic Production
The United States relies on imports of some important biomass feedstocks to support biomanufacturing because domestic sources are scarce. For example, almost no natural rubber is produced domestically, and imports support the manufacture of critical products such as tires and latex gloves. This dependency on foreign imports exposes the supply chain systems for these commodities, and the downstream products they enable, to disruptions outside of domestic control. See Spotlight on Domestic Natural Rubber.

Spotlight – Growing Domestic Natural Rubber

The United States produces almost no natural rubber – a critical agricultural commodity. Natural rubber has applications across military (aircraft tires), transportation (long-haul truck tires) and medical (personal protective equipment) products that cannot use synthetic rubber or other compounds as replacements. Thousands of consumer products also use natural rubber. The United States sources most of its supply from Southeast Asia where rubber production is threatened by climate change and long supply chains subject to disruption (e.g., pandemics, global competition). USDA and the Department of Defense are working to enable domestic natural rubber production from several crops: the desert shrub guayule, rubber dandelions from central Asia, and sunflowers. Bridgestone Americas and the University of Arizona, in collaboration with others in the Southwest, have been working to develop the supply chain for commercial production of natural rubber from guayule. This effort has been bolstered by USDA research and development, Partnerships for Climate-Smart Commodities awards, and an award from DOE to study guayule genomics. Research is also exploring the use of other biomass feedstocks, such as biochar, in the production of rubber products.[e]

A Plan to Optimize and Ensure Resilient Biomass Supply Systems

The full potential for the bioeconomy, driven by biotechnology and biomanufacturing, to advance the Nation's economic, environmental, and social sustainability is ready to be unleashed. However, progress will require increased investment to develop and deploy breakthrough processing technologies and build the biomass supply systems that underpin them. Within the integrated set of supply chain systems elements are opportunities to optimize and ensure resilient biomass supply systems for both traditional and innovative products.

The first section of the plan outlines core elements of biomass supply chain systems and how current policies and programs are supporting them. These efforts should continue and/or ramp up

[e] Coppiced biochars as a partial replacement of carbon black filler in polybutadiene/natural rubber composites | Peterson, S.C. 2020. *Journal of Composites Science*

[15] Impacts and Repercussions of Price Increases on the Global Fertilizer Market | U.S. Department of Agriculture

to support the expansion of the bioeconomy. Second, the plan describes research, development, and demonstration (RDD) needs that are paramount for establishing resilient biomass supply chain systems. The third section describes opportunities to expand or develop new policies and programs for biomass supply chain systems. Finally, the implementation section touches on steps the U.S. Government can take to execute the actions described in this plan.

Biomass Supply Systems Elements and Opportunities

The United States has a strong foundation on which to build better biomass supply chain systems. The following text explores the current state of each supply chain systems element and identifies opportunities to continue and expand governmental support.

Supply Systems Elements and Opportunities

- Feedstock Genetic Development
- Sustainable Production & Management
- Harvest and Residual Collection
- Transportation
- Storage
- Preprocessing
- Supply Systems Sustainability

Feedstock Genetic Development
Biotechnology, traditional breeding (not genetic modification), advanced crop breeding, gene-editing, multi-omics technologies (genomics, transcriptomics, metabolomics), and emerging bioinformatics and big data analysis technologies (e.g., artificial intelligence) may be deployed in the downstream preprocessing and processing stages. They are also applicable in upstream stages of supply chain systems, for example, through the optimization of crop, forest, and livestock genetic improvements, identification of new crops, and discovery of new biomass-related traits (e.g., reduced seed coats, lignin composition). Improved genetics may take the form of higher yields, nutrient use efficiency, water use efficiency, and resistance to biotic (pests and disease, competition with weeds) and abiotic (e.g., heat, drought, salinity, nutrient toxicity) stress. Genetic trait improvements are key to the USDA climate-smart agriculture and forestry portfolio because they help ensure a climate-resilient set of feedstocks will be available as climate conditions change. The enhanced breeding/crop improvement tools may also be deployed to affect traits that enhance biomass supply systems and processing value proposition by enabling more efficient processing, new products, new markets, improved compositional characteristics, and multiple uses.

Sustainable Production and Management
Sustainable crop, forest, and livestock production and management is at the heart of climate-smart agriculture and forestry, and essential to ensure sufficient biomass production.[16] [17] Domestic forestland has been sustainably managed for decades with sustainability metrics tracked by the USDA, Forest Service. Current and emerging crop conservation practices can optimize carbon sequestration, improve soils, reduce erosion, reduce

[16] Climate-smart agriculture and forestry is an integrated approach that enables farmers, ranchers, and forest landowners to respond to climate change by reducing or removing greenhouse gas emissions (mitigation) and adapting and building resilience (adaptation), while sustainably increasing agricultural productivity and incomes.

[17] Sustainable Productivity Growth Coalition | U.S. Department of Agriculture

greenhouse gas production, enable sustainable use of economically marginal cropland, mitigate the impacts of nutrient runoff into critical watersheds and oceans, create and preserve wildlife and pollinator habitat, reduce catastrophic wildfires, and enhance food production systems. For example, perennial grasses grown on cropland that is economically marginal for annual crops fosters these outcomes while also reducing inputs (fertilizer, herbicide, and irrigation). USDA's Natural Resources Conservation Program helps producers reduce soil erosion, improve water quality, increase wildlife habitat, and address other natural resource concerns. Efforts are also underway to expand urban agriculture with an emphasis on highly resource efficient controlled environment agriculture (CEA). New CEA systems are gaining traction in greenhouses and other structures for the sustainable cultivation of a wide range of specialty food, medicinal, and high-value chemical crops that can be intensively grown on a much-reduced land footprint in populated areas.

Sustainable management practices for MSW and other wastes are also important. In 2018, 63 percent of the 292.4 million tons of MSW generated in the United States was paper and paperboard, food, yard trimmings, and wood.[18] These are valuable feedstocks, that with appropriate planning and technology, can be shifted back into supply chain systems and used to create new bioproducts. The Environmental Protection Agency's Sustainable Materials Management Program and other circular economy approaches provide frameworks and tools for managing wastes sustainably.

Crop Harvest/Residual Collection

Both the DOE and USDA have made significant investments in reducing financial, safety, and environmental risks for the harvest of biomass crops, including woody biomass and perennial grasses,[19] and the collection and sorting/aggregating of biomass from food "waste" streams, agricultural and forest residuals,[20] MSW, and livestock and poultry operations.[21] In particular, woody biomass represents a largely underutilized resource with materials such as tree tops and limbs, fire salvage, insect and disease damaged wood, invasive species, and urban wood currently available. Investments have resulted in deployment of highly efficient circular residual systems such as on-farm production of renewable natural gas (both a potential energy supplier and feedstock for biomanufacturing), fertilizer, energy, and livestock bedding. Global Positioning Systems and advancements in technology are also impacting the efficiency, labor requirements, safety, and cost of harvesting biomass crops. Commensurate with these advances is achieving a balance between building soil carbon through leaving residues on soils and using biomass carbon for bioproducts.

The Idaho National Lab (INL) has been a leader in analyzing and working through the logistics for biomass supply systems (Figure 3). Regional depots serve to provide temporary raw feedstock storage and as preprocessing sites for converting biomass into fungible feedstocks with reduced transportation costs (through densification, liquification). Depots also serve as aggregation points for regional biomass suppliers. Preprocessed/aggregated feedstocks are then

[18] Facts and Figures about Materials, Waste and Recycling | Environmental Protection Agency
[19] E.g., the Regional Feedstock Partnership | U.S. Department of Energy and Idaho National Laboratory
[20] Northwest Advanced Renewables Alliance | Washington State University
[21] Consortium for Cultivating Human And Naturally reGenerative Enterprises | Iowa State University

transported to centralized processing refineries close to transportation arteries and with ready access to markets.

Transportation

The Department of Transportation (DOT) and private entities have been working on modelling and analyzing multimodal transport of biomass feedstocks. In support of the Federal Aviation Administration and DOE, the DOT Volpe Center has developed the Freight and Fuel Transportation Optimization Tool (FTOT), which can be used to determine options for transporting biomass and bioproducts. The tool can also aid in preliminary siting decisions for biomass depots and the major biorefineries they support or other types of processing facilities and can assist with network and supply chain systems resilience analyses. Other biorefinery siting tools have been developed.[22]

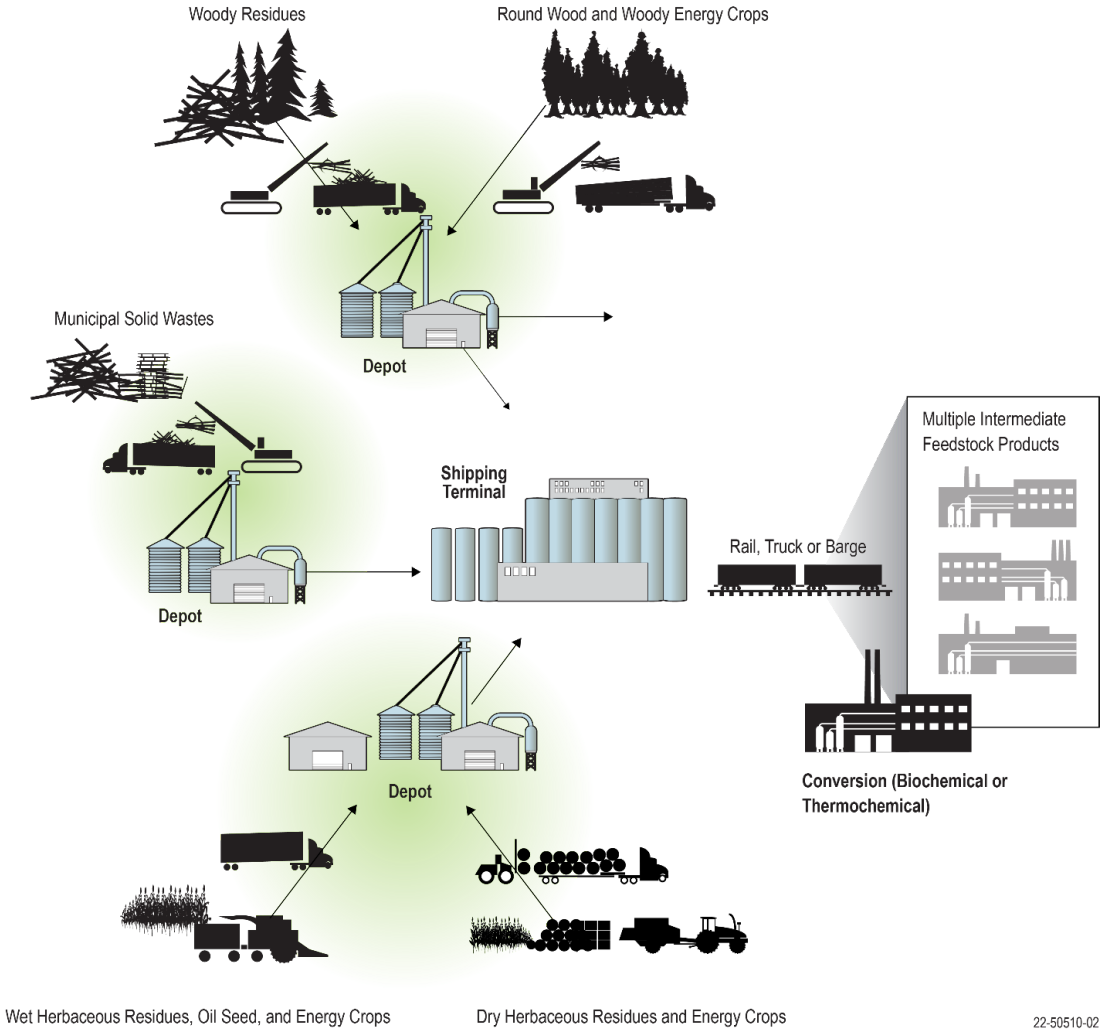


Figure 3. Example of an advanced logistics depot system[23]

[22] See First Commercial Flight Using Biojet Fuel Made from Wood | NARA; ECOSTRAT Biomass Supply Network | ECOSTRAT; and TEA/LCA Tools and Resources | Berkeley Lab

[23] Taken from SAF Grand Challenge Roadmap | U.S. Department of Energy

Storage

Storage can be a critical supply systems element, especially in cases of seasonally harvested biomass. Biorefineries may operate year-round, requiring a steady supply of biomass. Understanding the optimal storage parameters for biomass in the field, on the farm, and at facilities is important for ensuring its quality. USDA and DOE have been exploring biomass storage for a wide array of biomass feedstocks. For example, a USDA-funded project developed a year-round supply scenario to provide a fungible sugar stream for biofuel refineries using energy cane, sweet sorghum, sugar tank storage (as molasses), and lignocellulosic biomass.[24] Projects at INL and elsewhere have been studying how to store different kinds of seasonally harvested biomass and reduce degradation.[25]

Preprocessing

Preprocessing is a critical step in the logistics regime for some biomass feedstocks. Lignocellulosic biomass (woody biomass, purpose-grown biomass crops, e.g., perennial grasses, and agricultural residuals e.g., corn stover) are key feedstocks to move the bioeconomy to scale and to replace legacy carbon-based feedstocks. Much work has been done on preprocessing of lignocellulosic biomass, but it remains one of the major costs in biomass supply systems.[26] The INL recently updated a test bed center, the Biomass Feedstock National User Facility (BFNUF), to allow industry to evaluate different preprocess options to help overcome the challenges posed by biomass variability.

Preprocessing depots and modular systems are other models to efficiently collect and preprocess feedstocks close to biomass sources.[27] Both can reduce costs that are incurred when shipping raw biomass long distances. Likewise, environmental benefits (e.g., carbon footprint) may also be higher for materials processed near their source than a facility farther away. Modular systems are especially versatile because of their mobility and flexibility to adjust their capacity by adding or subtracting units. Depots and modular systems can be used to preprocess biomass feedstocks for biorefineries as well as other end uses, such as preparing fiber crops to be used in manufacturing composites, bioplastics, and construction materials. Furthermore, the option to blend regional biomass resources to defined specifications could be used to create "formatted feedstocks".[28] For smaller producers, establishing centralized regional depots or using modular systems may be beneficial as it tends to be less capital-intensive than establishing many preprocessing facilities throughout a region. In this respect, it may be advantageous for farming and forestry cooperatives, as is the case for many other commodities in the United States. Preprocessing near the biomass source is beneficial for rural development and job creation.

Supply Systems Sustainability

As biomanufacturing grows, more emphasis will be placed on the sustainability of biomass supply chain systems. Investment depends on economic viability and sustainability. As biomass feedstock production expands, food prices and food insecurity rates in lower and middle-income countries should be monitored and policies and

[24] Bioenergy and Bioproducts | Louisiana State University Ag Center
[25] CenUSA Bioenergy | Iowa State University
[26] First Commercial Flight Using Biojet Fuel Made from Wood | NARA
[27] Biomass Feedstock National User Facility | Idaho National Laboratory
[28] Biomass Feedstocks | National Renewable Energy Laboratory

programs to help ensure food security and affordability in these countries can be developed and adopted as needs arise. Domestically, commodity and retail food prices can be tracked using sources such as USDA's monthly World Agricultural Supply and Demand Estimates (WASDE) and the USDA Food Price Outlook. Research can help us to better understand how increases in biomass feedstock production impact food markets, food prices, and food security. Recent steps toward ensuring environmental and social sustainability are being manifested by government policy and consumer preference for sustainability certifications.[29] For example, the Roundtable on Sustainable Biomaterials (RSB) allows for the certification of complete supply chain systems involved in the cultivation, processing, trade, transport, blending and other production of any biomass-derived or advanced material or fuel. The RSB voluntary certification can be used to comply with certification requirements for regulatory programs such as the European Union's Renewable Energy Directive, ICAO CORSIA, or for voluntary targets.

Biomass Supply Systems Research, Development, and Demonstration Needs

Research, development, and demonstration form the foundation for strengthening and expanding biomass supply chain systems and the bioeconomy. Innovation and commercialization all rely on basic science and research; RDD informs policy and program decisions. The following section describes overarching RDD activities along with more detail in Appendix A. Appendix B contains relevant research and development actions from the *Bold Goals for U.S. Biotechnology and Biomanufacturing* report.[30]

Biomass Supply Chain Systems Research, Development, and Demonstration Needs

- Increase Understanding of Resource Markets and Availability
- Maximize Sustainable Lipid Supply
- Increase Production and Collection of Biomass
- Improve Biomass Supply Chain Systems Logistics
- Improve Sustainability of Biomass and Waste Supply Chain Systems

Understand Resource Markets and Availability

Biomass markets development can be supported by filling information gaps. For current (traditional) feedstocks, information about markets for biomass and biomass availability can help producers, forest landowners, and manufacturers make business decisions. Updated data are needed on the ability to expand oilseed crop production, wood pellet supply and markets, and a comprehensive national and regional woody biomass inventory and analysis (forests, plantation, operation residuals, urban and mill waste).[31] The Billion-Ton Report (2016)[32] provides the most comprehensive analysis of current and potential availability of dedicated biomass crops. The new Billion-Ton Report (release target 2024) will include inventory and market analysis for several emerging biomass feedstocks,

[29] ECOSTRAT Biomass Supply Network | ECOSTRAT and CORSIA Eligible Fuels | International Civil Aviation Organization
[30] Bold Goals for U.S. Biotechnology and Biomanufacturing | Office of Science and Technology Policy
[31] Quarterly baseline data already available for some crops: Agricultural Baseline Database | U.S. Dept. of Agriculture
[32] 2016 Billion-Ton Report | U.S. Department of Energy

including wet wastes, algae, secondary oilseed crops, and renewable hydrogen and renewable natural gas.

Maximize Sustainable Lipid (FOG) Supply

Research, development, and demonstration are needed to maximize the availability of lipids. Fats, oils, greases (FOG) and virgin vegetable oils are key to near-term production of petrochemical fuels including biodiesel, renewable diesel, and sustainable aviation fuel. Understanding sustainable waste lipid aggregation potential is a major information gap. Additional RD&D for lipids includes understanding potential availability of sustainable lipids from industrial effluents and byproducts, and updated data and analysis on current oilseed production and the potential to expand oilseed crop production. Widespread cultivation of second crop (cover crop, winter crop) oilseeds, such as camelina, carinata, and pennycress, have great potential to expand oilseed production and lipid availability. With their low carbon intensity scores and little, if any, indirect land use change, these second oilseed crops added to corn, soybean, wheat, and other crop rotations can help improve the sustainability and lower the carbon intensity for these rotations.[33] Additionally, costs to convert these oils into biodiesel and sustainable aviation fuel is low compared to lignocellulosic conversion. Research, development, and demonstration efforts should support these emerging crops and promote and advance the use of purpose-grown bioenergy crops in general. Developing a coordinated Federal Government lipid project plan could promote near-term lipid crop expansion.

Spotlight – A New Oilseed Crop

In the search for new oilseed crops, USDA Agricultural Research Service (ARS) identified pennycress (*Thlapsi arvense*), a common weed that grows during winter in the Midwest, as a potential source of oil. ARS bred field pennycress for reduced weediness and higher seed oil content, thus producing an oilseed crop that could fit between the corn-soybean rotation fall harvests and spring plantings. The technology was transferred to industry where CoverCress Inc. used gene-editing technology to further reduce weediness, increase oil content, and reduce antifeedant compounds to allow the press cake coproduct to be used in livestock feed. The new oilseed crop, CoverCress™, has the potential to be grown on millions of acres in the Great Plains and Midwest and provide oil for sustainable aviation fuel, renewable diesel production, and livestock feed from processing coproducts. As the oilseed industry grows, rural jobs will be created, and farm income will rise.

Increase Production of Purpose-Grown Biomass Resources and Collection of Wastes and Residues

Purpose-grown, also known as dedicated biomass crops, and the collection of wastes and residues will be the key for dramatically expanding the bioeconomy. The RDD needs are many and diverse, covering economic, environmental, and social drivers. Dedicated biomass crops, like hybrid poplar, shrub willow, switchgrass, and *Miscanthus,* are not currently grown at an appreciable scale because of a range of factors, with lack of stable markets being key. Policy

[33] Integrated Pennycress Research Enabling Farm & Energy Resilience | IPREFER

analysis in support of dedicated biomass crops is paramount and should include pesticide/herbicide labeling, crop insurance, incentives for planting perennial crops (Biomass Crop Assistance Program), producer (farmer, land manager) payment for carbon sequestration or reduced emissions, development of locally appropriate regenerative practices, and other incentives. Cover crops are another potential biomass resource and advantageous because they grow after the harvest of main crops. Long-term regional trials of dedicated energy and cover crops will provide data for modelling and analysis and could help to reduce producer risk and to quantify and predict the supply of material (both spatial and temporal) available to manufacturers.

Research, development, and demonstration also should be conducted for a range of residuals and include developing an expanded understanding of collection, sorting, decontamination, and production of feedstock from MSW; expanding research and development and modelling for agricultural residuals and urban wood waste; understanding/analyzing competing uses for agricultural residuals; and enabling expansion of forest management to increase sustainable thinning, forest health treatments, residue collection, and fire risk mitigation residuals. Similarly, evaluating other emerging potential biomass feedstocks; including micro- and macroalgae, sludge, manure and other animal wastes, industrial waste, and renewable natural gas; is important.

Spotlight – Renewable Natural Gas

USDA is supporting implementation projects that will identify new feedstocks for production of renewable natural gas (RNG). Current major sources of biogas are methane from landfills or dairy farms. Under a USDA Climate-Smart Partnerships grant and a separate USDA research grant, Roeslein Alternative Energy and other key research, outreach, and environmental partners are exploring alternative sources. Based in Iowa and Missouri, the project is using cover crops and perennial prairie grasses as feedstocks for co-digestion with manure for RNG production. Research by academic partners Iowa State and Penn State Universities have shown that co-digestion of grasses with manure produces more RNG than the digestion of grasses or manure alone. If successful, this breakthrough could improve the profitability and sustainability of commodity crop production through developing new markets for crops and expand the ability of small and medium-sized farms to supply more sustainably produced feedstock for RNG production.

Improve Feedstock Logistics, Optimize Systems Resiliency, and Increase the Reliability of Feedstock Handling Systems

Biomass feedstock supply systems logistics can strongly affect feedstock quantity, quality, and cost. Both DOE and USDA have invested in this critical area, but more RDD is needed, including expansion of modelling, design, and demonstration activities on conventional and emerging biomass supply chain systems. Some significant gaps in agriculture transportation include improved multimodal system management, lock upgrades to facilitate barge movements, refrigerated transport, unit train destinations, elevators/storage, intermodal facilities, and the

addition of transloading equipment at ports or railway depots.[34] Likewise, research on the optimization of preprocessing at farms, depots, and manufacturing facilities could improve efficiencies. Another key area for RDD investment is to increase the reliability of feedstock handling systems. It would be helpful to understand the basic science behind the flowability and processing of solid biomass and waste materials. DOE's Feedstock-Conversion Interface Consortium studies[35] on lignocellulosic feedstocks could be expanded. Lifecycle management practices would support sustainable biomanufacturing practices.

Improve Sustainability of Biomass and Waste Feedstock Supply Systems

More RDD is needed for crop genetic development and improving agronomic practices to continuously increase crop productivity, coproduct production, and environmental outcomes. Environmental service research can be expanded to cover additional locations, environments, biomass, and waste resources. Research should include assessments of carbon sequestration, greenhouse gas emissions, and nutrient and pesticide/herbicide runoff in biomass production systems. For example, the carbon intensity of crop-based biofuel production has improved considerably over time. Further improvements could occur as climate-smart farming practices become more widespread, or as facilities source renewable natural gas or participate in carbon capture and storage systems. Likewise, examining the value of ecosystem services provided by cover crops, including carbon sequestration, greenhouse gas emission reduction, water quality enhancement, biodiversity, reduction of invasive species, and pollinator habitat is important. Environmental service research should also be designed to inform emerging policy on wildland fire risk urban interfaces, watershed plans and initiatives, emerging and dedicated energy and cover crops, and monetizing ecosystem services. Evaluation of the costs and benefits of the use of biomass and water resources to produce fuels, chemicals, materials, and products on environmental justice are important too. Lifecycle and technoeconomic analyses may assist in integrating these varied data into studies. Completing the Billion-Ton Report revision is a near-term action that will provide useful analyses.[36]

[34] Study of Rural Transportation Issues | U.S. Department of Agriculture
[35] Feedstock-Conversion Interface Consortium Annual Review of Research | U.S. Department of Energy
[36] DOE is currently updating the 2016 Billion-Ton Report.

Policies and Programs for Capacity Building and Market Development in Biomass Supply Chain Systems

In assessing U.S. biomass supply chain systems, gaps were identified that could be filled by government policy and programs. Following are high-level descriptions of policies and programs that could contribute to strengthening and expanding the domestic supply of biomass and its uses in biomanufacturing and biobased product manufacturing.

Policies and Programs for Capacity Building and Market Development in Biomass Supply Chain Systems

- Market Creation and Expansion
- Biomass Production Incentives
- Risk Reduction
- Infrastructure and Workforce
- Education and Extension
- Research and Data

Create and Expand Markets for Biomanufactured and Biobased Products

Biomass demand is driven by markets for biomanufactured and biobased products. Policies that could help spur demand for biomass include:

- *Leverage the BioPreferred Program to increase demand for biobased products:* Domestic biomass supply will grow as demand for bioproducts increases. USDA's BioPreferred Program catalogs biobased products[37] for Federal purchasing mandates and provides voluntary labeling of biobased products for purchases by the public. Under the Bioeconomy Executive Order, BioPreferred is beginning to expand through establishing biobased product procurement programs across the Federal Government, procurement training, and regular reporting.[38] Increasing public awareness of the program, encouraging private industry to participate in the voluntary labeling initiative, and establishing Federal procurement targets should increase the visibility of biobased products and their market share. Through the BioPreferred Program, the Federal Government can assert its purchasing power to prioritize and increase demand for biobased products.

[37] The BioPreferred Program does not include fuels, food, and animal feed.
[38] See section 6 of Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy | The White House

- *Increase biofuels production and markets*: Biofuels (e.g., ethanol, sustainable aviation fuel, biodiesel/renewable diesel, biogas, wood pellets) represent a ripe area for expanding domestic biomass use, especially as interest in sustainable fuel sources increases. Currently, biofuels are generally more costly to produce than petroleum-based fuels. The existing market for biofuels is being driven by government policies such as biofuel mandates (via the Renewable Fuels Standard), low carbon standards (e.g., California's Low Carbon Fuel Standard), and biofuel production credits (e.g., sustainable aviation fuel under the Inflation Reduction Act). Expanding these policies and developing new ones could increase the market share of biofuels.

Spotlight – Connecting Climate-Smart Farms and Forests in New York

New York is seeking to bolster its use of wood biomass and agricultural residuals (manure) while integrating climate-smart agriculture (CSA) practices. In a changing climate, CSA is important to ensure sufficient production of biomass both now and for the future. In 2023, the New York Department of Environmental Conservation in conjunction with industry, academia, NGO, and governmental partners received a USDA Climate-Smart Commodities award. Under the project, agricultural producers and forest landowners will implement CSA practices and measure and quantify results. As a special emphasis, the project will design pilots around methane mitigation and enhanced weathering and agroforestry. Building on existing strong partnerships in New York's conservation and agricultural communities, the project will forge new connections between landowners and companies demanding climate-smart commodities. The dairy and forest products industries are expected to benefit, and New York's climate-smart markets will expand.

- *Support the development of export markets for U.S. biofuels and biomanufactured and biobased products:* International markets provide an important opportunity to expand demand – both near-term and long-term – for products made from domestic biomass, particularly in jurisdictions where procurement of such products is already incentivized or no alternative to fossil fuels is being used. In addition to working with countries to establish positive enabling environments for biofuels and biobased products, this may involve expansion of existing USDA programs for promoting U.S. agricultural exports (e.g., Foreign Market Development Program, Market Access Program, Emerging Markets Program) and other trade programs. USDA's BioPreferred Program can also serve as an example for other countries to implement similar supportive programs to further global demand for biobased products and procurement initiatives.

- *Promote markets for agricultural or forestry commodities produced with climate-smart practices*: Climate-smart practices are important to maintain crop resiliency and agricultural system health, thus ensuring biomass production capacity now and for the future. Agricultural sustainable practices include cover crops, conservation tillage, compost application, and anaerobic digesters. Climate-smart forest practices include forest thinning and dead, diseased, or hazardous tree removal. The government can play a critical role in ensuring that climate-smart practices are appropriately credited in biofuel

programs, offset markets, tax credits for sustainable fuel production, and other relevant markets. Additionally, climate-smart commodity production can generate revenue opportunities for farmers, ranchers, and forest landowners in regulated and voluntary greenhouse gas offset markets, biofuel markets, export markets, retail markets, and for companies seeking to reduce the greenhouse gas footprint of purchased inputs.

- *Create and expand markets for wildfire reduction and forest health operation residuals:* Woody material in forests from wildfire reduction strategies and other climate-amplified stressors such as insects and disease, drought, and extreme weather events represent an underutilized biomass material in the United States. Furthermore, this biomass can lead to catastrophic wildfires if left in place. Federal and other public lands that provide multiple uses such as recreation are the most affected and have the highest risk for catastrophic wildfires, as mapped by the National Wildfire Coordinating Group. Government policies that incentivize the use of these resources in products and preferences for buying products made with woody forest materials could build markets, thus benefitting the domestic bioeconomy and U.S. forest health.

Spotlight – Woody Biomass

Woody biomass is largely underutilized and has huge feedstock potential for the future. Trees are harvested for lumber and chips, but their tops, limbs, and residues from harvesting and processing wood products are also valuable. Forest health treatments remove hazardous fuels – woody material that could be fuel for catastrophic fires – to mitigate wildfire spread and intensity. Woody biomass supply chain systems differ from agricultural crops. While most agricultural crops are annual, trees are perennial and may take years to mature. Practices for harvesting woody biomass diverge too and must account for the logistics of moving harvesting equipment into remote areas. In addition to being a renewable resource, trees provide many environmental benefits. They generally come from forests where there is no competing land use to grow food, and they provide water, soil, air purification, and wildlife habitat for many years. As a feedstock, wood has unique physical and chemical properties that make it suitable for long-lived wood products that retain carbon. Increasing woody biomass feedstocks in manufacturing will benefit the U.S. economy while protecting forests from development, perpetuating ecosystem benefits and mitigating wildfire risks.

- *Create and expand markets for urban wood waste and utility corridor clearing:* Woody material that is removed to promote the health and safety of an urban community and utilities is underutilized. This biomass is primarily treated as waste and disposed of in landfills or municipal compost sites. Government actions like those proposed to expand markets for wildfire reduction residuals could augment the use of urban woody materials as well.

Incentivize Biomass Production

Some U.S. biomass resources are underutilized, such as woody materials from forests, urban communities, forest and fuel treatments, and roadside maintenance. Similarly, crops grown specifically for biomass harvesting, like switchgrass, are generally limited in acreage. Expanding the availability of domestically grown biomass will increase opportunities for bioproducts manufacturing:

- *Incentivize production and processing of newer and underutilized biomass sources:* newer biomass crops, such as pennycress, camelina and carinata, are not well known, but have great potential as biomass feedstock. Others, like switchgrass, algae, and hemp, are recognized for their potential, but present harvesting, processing, conversion, or commercialization challenges. Lignocellulosic feedstocks, such as purpose-grown crops or crop residues, have additional economic benefits that include land conservation, wildlife habitat, and ecosystem services. All are hindered by a lack of investment in infrastructure, established markets, and farmer adoption. Promoting the production and processing of these plants could expand the domestic biomass supply while bringing new opportunities to rural communities.

- *Increase double cropping:* Many of the emerging biomass crops are grown at different times of the year than main crops. Incentives or other programs could encourage farmers to grow a biomass crop in the off-season, thus, significantly increasing biomass availability and supply. It also could provide farmers with additional income and could reduce erosion and enhance soil quality.

- *Incentivize use of existing woody biomass:* Woody biomass is a largely underutilized resource, which could be incentivized through government policies. For example, modifying the interpretation of the Renewable Fuel Standard (RFS) so that woody biomass from Federal land is eligible for credits could significantly enhance economic viability for domestic supply of this important resource for renewable fuels. Another example is the suite of BIL/IRA-funded demonstration projects to move hazardous fuels or not marketable wood from its location to where it could be used. Additional benefits include improving forest health and reducing the risk of catastrophic wildfires.

- *Incentivize sustainable agriculture production*: It is important to produce biomass sustainably to ensure production capacity in the future and to protect natural resources and environmental quality. Enhancing species diversity in restricted cropping systems (such as corn/soybean rotations and wheat summer fallow systems) can increase cropping system resilience. Credible sustainability certification and other incentives for lowering carbon intensity, improving soil health, and using other conservation practices could help ensure biomass is produced in a sustainable way.

- *Food security*: As biomass supply systems expand, the U.S. should support policies and programs that help ensure that farmers and communities' benefit from expanded production opportunities and also protect vulnerable populations in lower and middle-income countries if food prices increase. Examples include extension services to support farmers who choose to enter new bio-based markets and improved food security safety nets if the need arises.

Risk Reduction

Biomass producers take a risk when growing new and lesser-known crops; crops can fail or the market demand may be too low to make a profit. Likewise, new business ventures run the risk of not having enough of a feedstock to support their operations. The Federal Government can play a role in reducing risk throughout biomass supply chain systems:

- *Financial safety nets:* Crop insurance and other safety net programs help producers manage risks. Not all crops have insurance options, including many which could be used as biomass feedstocks. Further, new biotech crops with attributes to increase yields to support biobased product manufacturing are anticipated to be developed, and other biomass feedstock crops may become more prevalent. Expanding insurance coverage programs and developing additional safety-net programs can encourage biomass feedstock production by reducing the risk for producers venturing into a new industry.

- *Financial certainty:* Most producers growing unconventional biomass crops are small businesses and require some level of financial certainty to take the risk. Federal funding for farmer assistance programs can shift, creating uncertainty for producers about whether resources they are depending on will be available. Federal assistance programs should be designed with consistency and certainty in mind.

- *Cooperatives formation:* Establishing cooperatives can be a way to reduce risk for producers and ensure sufficient supplies of biomass. Biomass production requires equipment and facilities for planting, harvesting, transporting, and preprocessing, which can be hefty investments. Especially for small businesses in rural areas with limited infrastructure, cooperatives are a way to distribute financial investment, thus lowering risk for each member of the cooperative. Government loan and grant programs for infrastructure and equipment can support and encourage the formation of cooperatives.

- *Connect manufacturers with feedstock producers:* Manufacturers require reliable quantities of biomass feedstock; however, producers are often hesitant to grow a crop unless they are sure there is a market for it. Even in cases where a biomanufacturer has announced its intent to build a facility nearby, farmers and forest landowners may be reluctant to produce biomass until the facility is established. Government programs can help with building relationships between manufacturers and producers early on in facility planning to lessen risk for both parties by ensuring sufficient biomass supplies to meet demands. The government can also facilitate the identification of Bioeconomy Development Opportunity Zones – regional areas with the biomass, infrastructure, workforce, and other resources for biobased products manufacturing.

- *Support climate-smart biomass production:* Biomass production necessitates following climate-smart practices to ensure sufficient supplies now and in the future. The government should establish programs that de-risk farmers and processors who produce biomass and adopt climate-smart practices or process climate-smart crops. For instance, USDA's Partnerships for Climate-Smart Commodities grant program provides technical and financial assistance to farmers, ranchers, and forest landowners for implementing

climate-smart practices, as well as develops downstream markets for climate-smart commodities. Some of these grant awards are supporting innovative ways to produce renewable natural gas, SAF, natural rubber, and biofuels.

Infrastructure and Workforce Investments

Infrastructure, and the workforce to support it, is costly to build and maintain, yet, moving biomass from the field or forest to the manufacturer is an essential element of biomass supply chain systems. Biomass supply chain systems can bring jobs and economic opportunities to communities, especially in rural areas where biomass sources are prevalent. The government has an interest in investing in infrastructure and a workforce so that all society benefits:

- *Infrastructure investments:* Ensuring the appropriate infrastructure is in place to support biomass supply chain systems is essential for resiliency – for example, constructing seed crushing facilities in regions that currently lack them as oil seed crop production expands. Infrastructure is often the most difficult component of a business venture to fund. The government can provide support through grants, loans, and by building national facilities to be used in the demonstration, pilot, and scaling-up phases of bioproduct development and deployment.

- *Increase efficiency of transporting biomass:* Transporting biomass to manufacturing facilities can be complicated and costly. For example, forests are an immense source of woody biomass, but accessing remote areas to harvest it may be difficult and transporting it to manufacturers – especially over long distances – is expensive. To expand biobased products manufacturing, policies should be explored to incentivize transport in the most cost effective, sustainable way. Likewise, smaller-scale depots could consolidate the transportation of material to facilities that could use it. Likewise using interactive models such as the Department of Transportation's Freight and Transportation Optimization Tool mentioned above will contribute to transportation efficiency and cost reduction allowing the use of intermodal transportation systems (e.g., truck, rail, waterway).

- *Co-location of biomass feedstock and facilities:* The availability of biomass feedstock affects the productivity of preprocessing and manufacturing facilities. Co-locating manufacturers near their feedstock supplies can strengthen the resilience of domestic supply chain systems by reducing transportation delays and costs and simplifying logistics. The government can promote the use of cluster mapping tools to help manufacturers capitalize on existing infrastructure and facilitate the identification of Bioeconomy Development Opportunity Zones, as described in the Risk Reduction section. Likewise, government support in the creation of "hubs" would build partnerships among producers, workers, communities, industry, and others to establish the infrastructure for new biobased product manufacturing ventures. Additional benefits would include local economic opportunities in rural communities.

- *Co-location of workers and facilities:* Biomass production, preprocessing, and storage require local workforces; however, especially in rural areas with low populations, the size of the workforce from which to draw may be limited or the labor force may not have the right skills to engage in the industry. Further, the community's amenities (e.g., housing,

schools, restaurants, services) may be minimal. Government policies and programs to attract new facilities can draw upon social capital analysis to provide an indication of a community or subregion's interest in siting new biomanufacturing capacities and the community's ability to provide infrastructure, workforce, and incentives (e.g., Community Assets and Attributes Model[39]). This information could be included in the identification of Bioeconomy Development Opportunity Zones.

- *Environmental justice:* The expansion of biomass supply chain systems infrastructure could have unintended harmful impacts on local communities. Environmental justice should be a key consideration in infrastructure planning to ensure that environmental justice and other underserved communities do not bear inequitable shares of burdens as infrastructure expands.[40] To ensure these communities are engaged and considered during decision processes, and the benefits and burdens of infrastructure development are equitably shared among communities, the government can require the use of demographic mapping tools, such as the Climate and Economic Screen Tool and Social Vulnerability Index during planning efforts. Analyses using these and other similar tools can be leveraged to identify communities that are particularly vulnerable and already overburdened by environmental, social, and economic conditions. The needs of these communities and unique impacts to them can then be considered during planning processes. Projects should be designed to benefit all communities equitably – for example, through job creation. Requiring demographic analysis and consideration of environmental justice will promote accuracy, consistency, and equity in decision-making and help to ensure that the bioeconomy benefits everyone.

Education and Extension

Education is a key component of improving the resilience of biomass supply chain systems and advancing the use of domestic biomass. Education is essential for bioproduct innovations, good policy development, consumer acceptance of new products, and adoption of sustainable and productive agriculture and forestry practices that ensure consistent supplies of biomass feedstock. The government can support education in several ways:

- *Workforce training and expansion:* Workers are essential to fill jobs in existing and future biomass supply chain systems. Technical and apprenticeship programs are especially relevant to train workers for these jobs. For example, non-degree training programs are available for laboratory technicians, operations/facilities managers, quality control specialists and many other jobs that support supply chain systems. Other traditional jobs, such as trucking and forestry, will call for an augmented workforce as well. The government should follow the recommendations in the *Building the Bioworkforce of the Future* report,[41] including those around vocational training, to ensure workers for all types of jobs to support biomass supply chain systems and to keep pace with expanded domestic biomass demand.

[39] Quantifying the community capitals framework: Strategic application of the community assets and attributes model | Mueller, D., et al. 2020. *Community Development*
[40] Revitalizing Our Nation's Commitment to Environmental Justice | Executive Office of the President
[41] Building the Bioworkforce of the Future | Office of Science and Technology Policy

- *Agricultural and forestry extension:* Extension services are an important mechanism for communicating agricultural and forestry advances and programs to producers. Research and development are constantly leading to advances in sustainable climate-smart practices for woody and non-woody biomass production, manure management, and other agricultural activities that will ensure efficient and reliable biomass production. With the development of new crops, producers must learn how to grow them and any special requirements. Government-backed extension services are at the forefront of communicating best practices and government programs, and they can help producers and forest landowners with long-term planning for their businesses. Services, demonstrations, and other outreach through extension programs can be expanded.

- *Bioproduct public outreach:* Public acceptance and willingness to buy biobased products is necessary to increase domestic biomass use. In general, there is confusion about bioproducts – what they are, how to identify them, and their advantages. Bioproducts may be perceived as lower quality, relative to their conventional counterparts. Labels and information about a product's sustainability or carbon footprint – often a driver in consumer purchasing decisions – are varied and inconsistent. To increase the public's trust in bioproducts and their willingness to purchase them, the government could play a role in adopting and standardizing terminology around biobased and biomanufactured products, generating data to demonstrate the economic and environmental benefits of bioproducts, and widespread education campaigns.

Research and Data

Rapid advances in technology and biomanufacturing are driven by research and will both require and create data. The Federal Government can act as a catalyst to address priority biomass supply chain systems research needs and drive the demand for domestic biomass forward. As a clearinghouse for information, the government can play a role in how it is collected and shared:

- *Research investments*: The research that Federal agencies, universities, businesses, think tanks, and other organizations undertake forms the backbone of innovations and solutions to biomass supply chain systems challenges. Through grants and partnership agreements, the Federal Government can support these efforts, even focusing on particular areas of interest or "grand challenges."

- *NAICS/NAPCS/HS codes:* North American Industry Classification System (NAICS) and North American Products Classification System (NAPCS) codes are used in analyses to track the U.S. economy, but these systems do not currently have a mechanism for comprehensively identifying bioproduct or biomanufacturing industries. Further, Harmonized System (HS) codes used for identifying and monitoring global trade do not have a mechanism for identifying biobased products or "drop-in biofuels" such as sustainable aviation fuel or renewable natural gas. Under the Bioeconomy Executive Order, NAICS and NAPCS are being updated to specifically account for bioeconomic

activities, thus directly linking specific industries and products to the bioeconomy.[42] The updated data will allow for more robust supply chain systems assessments and tracking.

- *Federal procurement data:* Through its substantial purchasing power, the Federal Government can increase demand for biobased products. Centralizing the collection of data on Federal biobased product procurement could help create a more consistent demand for biobased products.

- *Carbon accounting for bioproducts:* Producing biomass sustainably is important to create new markets for agricultural commodities. Carbon accounting is a mechanism for estimating the greenhouse gas reductions generated from bioproducts and their biomass feedstocks. The government can set carbon accounting policy and support development of models for this purpose (e.g., Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy Use in Transportation [GREET] model).

- *Data sharing*: New data and information are constantly being generated and are the underlying driver for innovations across biomass supply systems. Recommendations from the Bioeconomy EO report on data for bioeconomy research and development should be followed to ensure a solid framework for collecting and sharing information both amongst U.S. Government agencies, and as relevant to support U.S. bioeconomy goals, between the United States and international counterparts; in accordance with privacy, security, and ethical standards.[43]

Implementation

Implementing the actions in this plan will require collaboration across the U.S. Government, as well as between the U.S. Government, the private sector, and international counterparts. The Biomass Research and Development Board Operations Committee (OpsCo) is an existing platform of R&D leaders from eight Federal agencies with a shared goal of advancing biofuels and bioproducts to bolster the bioeconomy. The OpsCo and an equivalent policy entity may be a way to foster coordination across the Federal Government in the implementation of this plan. Also essential are significant contributions from private industry, non-governmental organizations, academia, State/Tribal/local governments, philanthropic organizations, and others. Public-private partnerships, particularly to support "grand challenge" initiatives, may be key in focusing efforts and achieving results. Additionally, leveraging other models for collaboration established within USDA such as Climate Hubs, Centers of Excellence, and Forest Service and Natural Resources Conservation Service landscape and stewardship programs could yield meaningful progress. International engagement and cooperation with countries and international organizations could further implementation of a robust global bioeconomy and support increased trade and investment for U.S. biomanufacturing and biobased products.

[42] Report is currently under development; see section 10 of Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy | The White House
[43] The report is expected to be finalized soon. See section 4 of Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy | The White House

There are many existing programs across the Federal Government that could be leveraged to implement parts of the work (see Appendix C for examples). Key opportunities to bolster biomass supply chain systems programs are:

- Maintain and enhance the Biomass Research and Development Initiative. This initiative has provided RDD support and U.S. Government-wide coordination among Federal agencies to promote the production and use of biofuels, bioproducts, and biopower for a stronger bioeconomy. The initiative peaked at $40 million per year and was partially matched by DOE.
- Support USDA Agricultural Research Service (ARS)/Forest Service (FS) Biomass Research and Development Centers. These centers focus on ensuring that dependable feedstock supplies use agricultural and forestry feedstocks to produce advanced biofuels that meet legislated goals and market demand and maximizing participation of U.S. rural areas in an emerging and profitable biofuels and biobased products economy.
- Continue the National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative (AFRI) Sustainable Agricultural Systems (SAS) Coordinated Agricultural Project (CAP) Program. AFRI funds projects to significantly improve the supply of affordable, safe, nutritious, and accessible agricultural and forest products, while fostering economic development and rural prosperity in America. Projects should result in societal benefits, including promotion of rural prosperity and enhancement of quality of life for all those involved in food and agricultural value chains from production to use and consumption.
- Utilize the Partnerships for Climate-Smart Commodities to advance efforts related to climate-smart biomass feedstock production and biobased products manufacturing and marketing. Several partnership projects are supporting innovative ways to produce renewable natural gas, sustainable aviation fuels, natural rubber, and purpose-grown biomass crops. Lessons learned from these projects can inform USDA's approach to advancing the bioeconomy.
- Maintain and continue the work of DOE Bioenergy Technologies Office, DOE's Office of Clean Energy Demonstrations, USDA Rural Development Grants Program, USDA's Bioproduct Pilot Program, and the four USDA ARS utilization centers.[44]
- Continue DOE/USDA bioeconomy commercial-scale projects, which support pilot and demonstration projects, and first-of-a-kind commercial biorefineries.
- Promote collaboration between USDA and DOE on the Regional Biomass Resource Hubs Initiative, regionalbiomassresourcehubs.inl.gov, which would continue to address gaps associated with the realization of the sustainable and reliable production of a billion tons of biomass to support the U.S. bioenergy industry by the year 2030.
- Increase the breadth and reach of the USDA BioPreferred Program, a vital program for expanding bioproduct markets through the purchase and use of biobased products. Through voluntary labeling and Federal purchasing mandates, the program spurs economic development and provides new markets for bioproducts.

[44] Eastern Regional Research Center (Wyndmoor); National Center for Agricultural Utilization Research (Peoria); Southern Regional Research Center (New Orleans); Western Regional Research Center (Albany) | U.S. Department of Agriculture

Appendix A. Input to the Plan's Biomass Feedstock Systems Research, Development, and Demonstration Needs

The Feedstock Innovation Interagency Working Group, an interagency team consisting of USDA, DOE, and DOT specialists, carried out a Gap and Priority Analysis brainstorming exercise between October 2022 and February 2023. That exercise yielded the following list of possible needs for research, development, and demonstration in biomass feedstock systems. The list was then used to help determine needs that would be included in the report.

Understand Resource Markets and Availability:

- Farmers will not dedicate land to purpose-grown biomass or invest in harvestable cover crops without a viable market.
    - Programs for targeted use (e.g., programs for carbon capture, Gulf hypoxia prevention, pollinator habitat, wildlife habitat, SAF feedstock) could help facilitate investment and market development.
    - Need to monetize ancillary benefits.
    - Need to understand potential return from monetized benefits compared to row crops.
    - Need to understand how a mitigation strategy targeting a small percentage of marginally productive cropland could positively impact agricultural sustainability while maintaining or increasing farmer returns.
- Need updated data on current oilseed production and ability to expand oilseed crop production.
    - What will be the positive and negative consequences of increasing oilseed crop acreages?
- Need update on corn-based ethanol market.
- Need to improve corn and soybean sustainability.
    - Reduce carbon index.
    - Reduce inputs.
    - Need to understand the role of dual-purpose small-grain and oilseed cover crops (improve sustainability while providing SAF feedstock).
- Need updated analysis of wood pellet supply and markets.
    - Need to understand total production vs. total available for SAF.
    - Need sustainability analysis for pellet production and delivery to markets.
    - Need foreign market analysis.
- Need comprehensive national and regional woody biomass inventory and analysis (forests, plantation, urban waste, primary and secondary mill residuals, forest and fuel treatments nonmarketable waste).
- Finish update of Billion-Ton Report (target 2024)
    - Data from 2016 report will not be updated.
    - Need inventory and market analysis of wet wastes.
    - Need inventory and market analysis of algae.
    - Need market analysis of renewable hydrogen and renewable natural gas.

- Need inventory and analysis of urban wood waste and forest and fuel treatment biomass.

Maximize Sustainable Lipid (FOG) supply:

- General
  - Need to develop a lipid project plan and coordinate U.S. Government support for near-term lipid crop expansion.
  - Need to understand potential positive impacts on pollinators and beneficial insects.
- Need to understand sustainable waste lipid aggregation potential. (Major information gap)
  - Livestock and poultry slaughterhouse analysis.
  - Brown grease market analysis.
  - Including cleanup cost.
- Need to understand sustainable lipid potential from industrial effluents and biproducts. (Major information gap)
- Need updated data on current oilseed production and ability to expand oilseed crop production.
  - What will be the positive and negative consequences of increasing oilseed crop acreages?
  - Can cover crops allow for soybean-cover crop-soybean rotations?
    - What would be the impact on livestock feed (corn residuals)?
    - USDA-ARS research supports small-grain cover crops that can be used to support continuous soybean production while providing livestock forage.
- Need to dramatically increase the use of cover crops (generally).
  - Second crop oilseeds need to be widely deployed.
    - Still some R&D needed to assure producers that cash crops will not be negatively affected.
    - Need some work on policy incentives.
    - Need some work on regulatory hurdles.

Increase Production of Purpose-Grown Biomass Resources and Collection of Wastes and Residue

- General
  - Need policy analysis in support of dedicated (purpose-grown) biomass crops.
    - Pesticide/herbicide labeling.
    - Crop insurance.
    - Biomass Crop Assistance Program incentives for perennials.
    - Farmer payment for carbon storage or reduced emissions.
    - Monetize and adequately incentivize farmers for other critical sustainability products (i.e., erosion reduction, pollinator habitat, wildlife habitat, etc.).
    - Other.
  - Increase adoption of cover crops.
    - Need additional program support for farmer adoption.

        - Need additional research demonstrating the value of cover crops even if products are used (i.e., grazing, haying, oilseed crop harvest).
    - Social science research
        - Determine what farmers require financially to make long-term commitments.
        - Determine what will incentivize farmers to adopt and use cover crops.
        - Support social science research that emphasizes environmental justice, as is issued in EO 14096.
    - Need USDA Regional Biomass Research Centers to have dedicated experts with availability to develop coordinated biomass research plans, respond to urgent needs, provide and coordinate expertise, and dedicate significant time and effort to new and recurring items and initiatives.
- Expand understanding of collection, sorting, and decontaminations of MSW.
    - Need better understanding of how to produce biomass feedstocks from MSW.
        - Compost/organics.
        - Gasified/processed waste.
        - Landfill methane collection.
- Expand agricultural and forestry residuals collection R&D/modelling.
- Understand/analyze competing uses for ag residuals and establish realistic dollar values.
- Expand forest management for increase of sustainable thinning, residue collection, and fire mitigation operation material.
    - Need range of studies completed:
        - Mill capacity
        - Timber transport
        - Wildfire mitigation
        - Standing dead timber
        - Invasive species
- Dedicated energy crop production trials:
    - Need to conduct long-term trials.
    - Need R&D on dedicated energy crop cultivation on economically marginal lands.
        - Also analyze competing uses of marginal lands (e.g., solar energy).
        - Analyze the current contribution of marginal cropland to the negative impacts of agriculture (i.e., is 10% of the land causing 90% of the problems with erosion, nutrient runoff, Gulf hypoxia, etc.).
    - Need to evaluate precision landscape design methodology and adoption potential.
    - Need to continue to improve feedstock genetics for best yield on marginal lands.
    - Need to align industry and Federal activities.
    - Need to improve fertility management practices for dedicated energy crops (i.e., N rates, N sources, N application, P&K inputs).
    - Need to improve efficiencies in harvesting and handling and storage.
- Need to evaluate/expand micro- and macroalgae production trials.
- Need to evaluate the role of sludge, manure, industrial waste.
- Need to evaluate the role of gaseous carbon feedstocks.
- Need to evaluate renewable natural gas as a SAF feedstock.
- Need to evaluate the role of biogenic hydrogen for producing SAF.

Improve Feedstock Logistics and Optimize Resiliency:

- Expand modelling, design, and demonstration activities on conventional biomass supply chain systems.
- Expand modelling, design, and demonstration activities on emerging biomass supply chain systems.

Increase Reliability of Feedstock Handling Systems:

- Improve the understanding of the basic science behind the flowability and processing of solid biomass and waste materials.
- Expand Feedstock/Biorefinery Interface Consortium studies on lignocellulosic feedstocks.

Improve Sustainability of Biomass and Waste Feedstock Supply Systems:

- Complete the Billion-Ton Report revision.
- Expand environmental service research to cover additional locations, environments, biomass, and waste resources.
    - Evaluate Forest Service (FS) analyses on wildland urban interfaces.
    - Evaluate FS analyses on watershed plans and initiatives.
    - Evaluate FS plans on forest health, climate resilience, restoration, and fire mitigation initiatives.
    - Expand research to cover emerging and dedicated energy and cover crops.
    - Develop policy recommendations for giving value to ecosystem services including:
        - Carbon sequestration
        - Water quality enhancement
        - Biodiversity
        - Reduction of invasive species
        - Pollinator or wildlife habits
    - Develop policy recommendations for incentivizing the utilization of small-diameter or non-marketable timber, and forest health/wildfire mitigation materials.
        - Evaluate State policies.
- Evaluate the costs and benefits of the use of biomass and water resources to produce fuels, chemicals, materials, and products on environmental justice.
    - Job creation.
    - Population displacement.
    - Environmental degradation in disadvantaged communities.
    - Quality of life.
    - Health impacts.
- Expand the assessment of the increase in carbon sequestration, greenhouse gas emission reduction, nutrient, and pesticide/herbicide runoff in biomass production systems.
- Expand crop genetic development and improve agronomic practices to continuously increase crop yields, product production, and sustainability.
- Appropriately monetize ecosystem services to incentivize farmer participation.

Appendix B. R&D "Bold Goals" Supported by the Biomass Plan

Relevant research goals are taken from the report, *Bold Goals for U.S. Biotechnology and Biomanufacturing: Harnessing Research and Development to Further Societal Goals*[45]

Biotechnology and Biomanufacturing R&D to Further Climate Change Solutions

- **Theme 1: Transportation and Stationary Fuels**
  - Goal 1.1: Expand Feedstock Availability – In 20 years, collect and process 1.2 billion metric tons of conversion-ready, purpose-grown plants and waste-derived feedstocks and utilize >60 million metric tons of exhaust gas CO_2 suitable for conversion to fuels and products, while minimizing emissions, water use, habitat conversion, and other sustainability challenges.
- **Theme 3: Climate-Focused Agricultural Systems and Plants**
  - Goal 3.1: Develop Measurement Tools for Robust Feedstock Production Systems – In 5 years, develop new tools for measurement of carbon and nutrient fluxes in agricultural and bioeconomy feedstock systems that contribute to a national framework.
  - Goal 3.2: Engineer Better Feedstock Plants – In 5 years, engineer plants and manipulate plant microbiomes to produce drought tolerant feedstocks capable of growing on underutilized land with >20 percent improvement in nitrogen and phosphorus use efficiency.

Biotechnology and Biomanufacturing R&D to Further Food and Agriculture Innovation

- **Theme 1: Improving Sustainability and Resource Conservation While Increasing Agricultural Productivity**
  - Goal 1.1 Increase Agricultural Productivity – Over the next 10 years, increase agricultural total factor productivity growth to meet global food and nutrition security needs while improving natural resource use efficiency and conservation, toward the global goal of increasing agricultural productivity by 28 percent in the next decade.
  - Goal 1.2: Increase Climate-Smart Feedstock Production and Biofuel Usage – By 2030, increase climate-smart production of conventional and alternative agricultural and forestry feedstocks for biomanufacturing, biobased products, and biofuels; reduce the lifecycle greenhouse gas intensity of biofuels by 50 percent; and expand overall biofuel blend rates in U.S. liquid transportation fuels by 50 percent.

Biotechnology and Biomanufacturing R&D to Further Supply Chain Resilience

- **Theme 1: Alternative Supply Chain Pathways via Biotechnologies and Biomanufacturing to Promote Economic Security**
  - Goal 1.2: More Sustainable Chemical Production – In 20 years, produce at least 30 percent of the U.S. chemical demand via sustainable and cost-effective biomanufacturing pathways.

[45] Bold Goals for U.S. Biotechnology and Biomanufacturing | Office of Science and Technology Policy

  - Goal 1.3: In 20 years, implement new biotechnologies into biomanufacturing workflows to produce 10 new biomanufactured products in each of at least three sectors with identified supply chain bottlenecks. Biomanufacturing Innovation to Enhance Supply Chain Resilience
- **Theme 2: Biomanufacturing Innovation to Enhance Supply Chain Resilience**
  - Goal 2.1: Predictive Capabilities – In 5 years, enable prediction of at least 50 percent of supply chain weaknesses and direction of real-time biomanufacturing adjustments to address bottlenecks.
  - Goal 2.3: Adaptive Supply Chains – In 20 years, deploy a suite of advanced biomanufacturing platforms and capabilities to respond to supply chain bottlenecks within 1 week of identification.
  - Goal 2.4: Supply Chain Flexibility – In 20 years, implement 80 percent of viable biomanufacturing technologies to address domestic production capability needs.

Biotechnology and Biomanufacturing R&D to Further Cross-Cutting Advances

- **Theme 3: Expand Capabilities to Build and Measure Performance and Quality of Biological Systems**
  - Goal 3.1: In 5 years, develop the capabilities to read and write any genome, epigenome, transcriptome, and expressed proteome to enable the construction and measurement of any single cell within 30 days.
  - Goal 3.2: In 20 years, build a synthetic minimal plant that can be used as a chassis for food, feedstock, chemical, or pharmaceutical production.
- **Theme 4: Advance Scale-up and Control of Biological Systems**
  - Goal 4.2: In 20 years, advance integration of all aspects of feedstock use, organism design, process design, and end-of-use disposal with technoeconomic analysis such that sustainability and commercial goals can be achieved for more than 85 percent of new bioprocesses within the first year of deployment.

Appendix C. Select Federal Programs for Capacity Building and Market Development to Support Biomass Supply Chain Systems

Below are examples of existing Federal programs that could be leveraged to implement parts of this biomass supply chain systems plan. Additional resources would be required to advance new work.

Agriculture

- **AgSTAR:** EPA's and USDA's program promotes the use of biogas recovery systems and sustainable manure management practices to reduce methane emissions from livestock waste. AgSTAR assists those who enable, purchase, or implement sustainable manure management practices by identifying project benefits, risks, options, and opportunities.
- **Agriculture and Food Research Initiative Foundational and Applied Science Program:** USDA awards grants to advance knowledge in fundamental and applied sciences important to agriculture in six priority areas: plant health and production and plant products; animal health and production and animal products; food safety, nutrition, and health; bioenergy, natural resources, and environment; agriculture systems and technology; and agriculture economics and rural communities. This program area funds projects that significantly advance previously established foundational and applied sciences for the following USDA priority outcomes: 1) Climate-Smart Agriculture and Forestry (CSAF): improve mitigation, adaptation, and resilience of agricultural and forestry production systems to climate change. 2) Strengthening the Bioeconomy: develop sources of clean energy and high-value biobased products from agricultural feedstocks to foster economic development and prosperity, with an emphasis toward generating benefits to underserved communities. 3) Nutrition Security: enhance the contributions of food and agriculture to improve the health of the Nation through resilient local and regional food systems, adoption, and application of new or existing technologies, tools, education, and other resources to ensure access to adequate, safe, nutritious, and affordable food.
- **Agricultural Genome to Phenome Initiative:** USDA is engaging animal and crop researchers to expand genome and phenome knowledge. The initiative will inform approaches to understanding how weather, environments, and production systems interact with genetic diversity present in crops and animals to affect growth and productivity. This will provide greater accuracy in predicting crop and animal performance under variable conditions and more efficient selection of well-adapted, superior genotypes that farmers and ranchers can produce.
- **Agricultural Research Service (ARS) Biomass Research Centers and Utilization Centers:** ARS is vertically integrated to (1) ensure dependable feedstock supplies via the four Biomass Research Centers and (2) evaluate the conversions of agricultural feedstocks in the four Utilization Centers:—Eastern Regional Research Center (ERRC), National Center for Agricultural Utilization Research (NCAUR), Southern Regional Research Center (SRRC), and Western Regional Research Center (WRRC). These

centers collaboratively work together to support the complete bioeconomy supply chain by enhancing biomass varieties, improving production systems and bioprocessing, boosting performance of biobased products including biofuels, and enabling higher value uses of co-products.

- **Crop Protection and Pest Management Program:** USDA uses integrated pest management (IPM) to address high priority pest issues at the State, regional and national levels. The program addresses IPM challenges for emerging issues and existing priority pest concerns with new technologies. The outcomes of the program are effective, affordable, and environmentally sound IPM practices and strategies needed to maintain agricultural productivity and healthy communities.
- **Plant Materials Centers (PMC):** USDA's PMCs find vegetative solutions to reduce soil erosion, increase cropland soil health and productivity, improve water quality, produce forage and biomass, improve air quality, improve wildlife habitat (including pollinator habitat), restore wetlands, protect streambank and riparian areas, and stabilize coastal areas.

Bioenergy

- **Advanced Biofuel Payment Program:** USDA's program increases the production of advanced biofuels.
- **Aviation Sustainability Center (ASCENT) Center of Excellence:** FAA funds this university research consortium to create science-based solutions for the aviation industry's biggest challenges by conducting research to explore ways to produce SAF at commercial scale, creating an industry with the potential for large-scale economic development and job creation. Within ASCENT, key programs include evaluating regional supply chains that could be used for SAF production including feedstock production, transportation, and fuel conversion. In addition, identifying potential intermediate materials and co-products for each pathway to understand potential ways to aid in making biorefineries more economical are being considered.
- **Commercial Aviation Alternative Fuels Initiative (CAAFI):** FAA sponsors this public-private partnership with the aviation trade associations Airlines for America, Airports Council International-North America, and the Aerospace Industries Association to facilitate the development, assessment, and deployment of SAF.
- **DOE Bioenergy Technologies Office:** DOE's program conducts applied R&D as well as demonstration enabling the production of chemicals from biomass and waste, including plastics, to provide low cost, low carbon emitting alternatives to the petroleum-based chemicals. In addition, funding support performance enhanced production of bioproducts, with improved characteristics, including recyclability, and potentially whole new uses.
- **Fueling Aviation's Sustainable Transition (FAST):** FAA's grant program, under section 40007 of the Inflation Reduction Act, seeks to enable production, transportation, blending, or storage of SAF. The grant program aims to make investments to accelerate the production and use of SAF, thereby supporting the goals of the SAF Grand Challenge, to meet U.S. aviation climate goals to reduce aviation carbon emissions.
- **Renewable Fuel Standard Program:** EPA oversees the program which aims to reduce greenhouse gas emissions and expand the nation's renewable fuels sector while reducing reliance on imported oil.

- **Rural Energy for America Program Renewable Energy Systems and Energy Efficiency Improvement Guaranteed Loans and Grants:** USDA provides guaranteed loan financing and grants to agricultural producers and rural small businesses for renewable energy systems or to make energy efficiency improvements. Agricultural producers may also apply for new energy efficient equipment and new system loans for agricultural production and processing.
- **Sustainable Aviation Fuel Grand Challenge:** DOE, DOT, USDA, and other Federal Government agencies have partnered to develop a comprehensive strategy for scaling up new technologies to produce sustainable aviation fuels (SAF) on a commercial scale. The Grand Challenge issued a roadmap in September 2022 which lays out 6 Action Areas to expand SAF supply and end use, reduce the cost of SAF, and enhance the sustainability of SAF.

Bioproducts

- **Agile BioFoundry and Advanced Biofuels and Bioproducts Process Development Unit:** These early applied R&D facilities, supported by DOE and NSF, are available to industry and academia at reduced costs.
- **Bioeconomy and Advanced Biotechnology Meta-Program:** NSF supports biotechnology research at all biological scales and across all scientific disciplines. The Directorate for Biological Sciences supports fundamental research that can be translated into solutions for societal problems while advancing biotechnology and the bioeconomy, including the Plant Genome Research program and the Molecular Foundations for Biotechnology solicitation. The Directorate for Engineering supports fundamental and translational engineering research that utilizes biotechnology to develop, accelerate, and support the bioeconomy. The Directorate for Technology, Innovation and Partnerships harnesses the nation's vast and diverse talent pool to advance critical and emerging technologies, address pressing societal and economic challenges and accelerate the translation of research results from lab to market and society.
- **Bioeconomy, Bioenergy, and Bioproducts Programs:** USDA's program aims to facilitate the development of sustainable regional production systems for biofuels, biopower, and biobased products, for increased rural economic vitality and national energy security through partnerships and collaboration.
- **Bioproduct Pilot Program:** USDA seeks to study the benefits of using agricultural materials to manufacture construction and consumer products. With funding from the Bipartisan Infrastructure Law, USDA is partnering with institutions to support the scale-up of sustainable bioproduct manufacturing, with the goal of providing a low-cost alternative to conventional products.
- **DOE Office of Science:** The Office of Science is the lead Federal agency supporting scientific research for energy. Two program offices in the Office of Science support research relevant to bioproducts. The Office of Biological and Environmental Research provides basic genome-enabled research on plants and microorganisms to enable biofuels production from renewable plant biomass and CO2. The Office of Basic Energy Sciences supports fundamental chemical, materials sciences, and biochemical research that can address scientific challenges, such as catalysis, biocatalysis, separation science and biomolecule synthesis, relevant to biofuels and bioproducts production.

Global Programs

- **Export Financing:** USDA's Export Credit Guarantee Program guarantees repayment when U.S. banks extend credit to approved foreign banks to finance sales of U.S. agricultural products. The Facility Guarantee Program provides credit guarantees for infrastructure improvements in countries where demand for U.S. agricultural products may be limited by lack of adequate facilities.
- **Fellowships and Exchanges:** USDA's Borlaug Fellowship Program offers mentoring and training to researchers and policymakers from developing countries to help promote food security and economic growth. USDA's Cochran Fellowship Program provides short-term, U.S.-based training opportunities to agricultural professionals from developing and middle-income countries. USDA's Embassy Science Fellows Program places U.S. government technical experts at American embassies abroad to provide expertise on issues relating to the environment, science, technology, and health. USDA's Scientific Cooperation Research Program supports joint research, education, and extension projects between United States and international agricultural professionals. USDA's Scientific Exchanges Program supports scientific training, collaborative research and mentoring between U.S. scientists and international agricultural professionals.
- **Market Development:** USDA's Market Access Program helps finance activities to market and promote U.S. agricultural commodities and products worldwide. USDA's Foreign Market Development Program provides cooperator organizations with cost-share funding for activities that build international demand for U.S. agricultural commodities. USDA's Quality Samples Program helps U.S. organizations provide small samples of their agricultural products to potential customers overseas. USDA's Emerging Markets Program funds technical assistance activities to promote exports of U.S. agricultural commodities to emerging markets worldwide.
- **USDA-Sponsored Trade Missions and Endorsed Trade Shows:** International trade missions and shows open doors and deliver results for U.S. exporters, giving them international exposure, marketing opportunities at trade shows and trade missions provide opportunity to forge relationships with potential customers, gather market intelligence, and generate sales.

Infrastructure

- **Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program:** USDA provides loan guarantees to assist in the development, construction, and retrofitting of new and emerging technologies. These technologies support: advanced biofuels, renewable chemicals and biobased products.
- **DOE Loan Program, Innovative Energy and Innovative Supply Chain:** DOE's Loan Program finances projects that deploy new or significantly improved high-impact clean energy technology, including biofuels and bioproducts (*Innovative Energy*) or that employ new or significantly improved technology in the manufacturing process for a qualifying clean energy technology or manufacture innovative products with an eligible technology end-use (*Innovative Supply Chain*).

- **Farm Storage Facility Loan Program:** USDA provides low-interest financing so producers can build or upgrade facilities to store commodities. Eligible commodities include grains, oilseeds, peanuts, pulse crops, hay, honey, renewable biomass commodities, fruits and vegetables, floriculture, hops, maple sap, milk, cheese, yogurt, butter, eggs, meat/poultry (unprocessed), rye and aquaculture. Eligible facility types include grain bins, hay barns, bulk tanks, and facilities for cold storage. Drying and handling and storage equipment is also eligible, including storage and handling trucks.
- **Higher Blends Infrastructure Incentive Program:** USDA focuses on significantly increasing the sales and use of higher blends of ethanol and biodiesel by expanding the infrastructure for renewable fuels derived from U.S. agricultural products. The program is also intended to encourage a more comprehensive approach to market higher blends by sharing the costs related to building out biofuel-related infrastructure.
- **Rural Business Development Grants:** USDA's program is designed to provide technical assistance and training for small rural businesses.
- **Rural Business Investment Program:** USDA's program provides a Rural Business Investment Company (RBIC) license to newly formed developmental capital organizations to help meet the equity capital investment needs in rural communities.
- **Wood Products Infrastructure Assistance Grant Program:** USDA provides funding to wood processing facilities to improve, establish, retrofit, or expand facilities that purchase and process byproducts from ecosystem restoration projects from Federal or Tribal lands. These facilities are located in areas at risk of unnaturally severe wildfire or insect and disease and are vital to the economic fabric of their communities.

Organic Materials Recycling

- **Solid Waste Infrastructure for Recycling (SWIFR):** EPA's SWIFR grant program, which is funded through Bipartisan Infrastructure Law, provides $275 million from FY22 to FY26. The funding will support improvements to waste management systems, allowing resources to be used more efficiently and reducing the impact on the climate and aims to create a stronger, more resilient, and cost-effective U.S. municipal solid waste recycling system. Eligible projects include development of and/or upgrades to composting facilities or anaerobic digesters to increase capacity for organics recycling, improving wasted food data and more.
- **Consumer Recycling Education and Outreach (REO):** EPA's REO grant program, which is funded through Bipartisan Infrastructure Law, provides $75 million from FY22 to FY26 to improve the effectiveness of residential and community recycling and composting programs through public education and outreach. Anaerobic digestion and rendering projects are eligible as well, along with actions to prevent food waste.

Wood

- **Community Wood Grant Program:** USDA provides grants to install thermal wood energy systems or to build innovative wood product manufacturing facilities. The program places extra emphasis on assisting sawmills in economically challenged areas to retool or add advanced technology.
- **McIntire-Stennis Cooperative Forestry Research Program:** This USDA capacity grant is allocated to States to support forestry research at State forestry schools and

colleges and to develop a trained workforce of forest scientists capable of conducting research for: 1) Reforestation and management of land for the production of crops of timber and other related products of the forest; 2) Management of forest and related watershed lands to improve conditions of water flow and to protect resources against floods and erosion; 3) Management of forest and related rangeland for production of forage for domestic livestock and game and improvement of food and habitat for wildlife; 4) Management of forest lands for outdoor recreation; 5) Protection of forest land and resources against fire, insects, diseases, or other destructive agents; 6) Utilization of wood and other forest products; and 7) Development of sound policies for the management of forest lands and the harvesting and marketing of forest products.

- **Wood Innovations Grants Program:** USDA's program stimulates, expands, and supports U.S. wood products markets and wood energy markets to support the long-term management of National Forest System and other forest lands. National focus areas include mass timber, renewable wood energy, and technological development that supports hazardous fuel reduction and sustainable forest management.

Workforce

- **Agriculture and Food Research Initiative – Education and Workforce Development:** USDA's initiative focuses on developing the next generation of research, education, and extension professionals in the food and agricultural sciences. Projects funded through this program area address projected shortfalls of qualified graduates in the agricultural, food, and renewable natural resources sectors of the U.S. economy.
- **Bioenergy Workforce Development Strategy:** DOE's program supports a workforce development strategy that enhances bioenergy literacy, improves educational resources, supports workforce training opportunities, and increases diversity in the future bioenergy workforce.
- **Directorate for STEM Education:** NSF supports initiatives that build the STEM-capable U.S. workforce of the future and ensure Americans are prepared to meet evolving workplace demands, through programs and solicitations aimed at supporting learners in elementary and secondary schools, 2-year and 4-year undergraduate studies, graduate school, and the professional workforce. NSF's Advanced Technological Education program improves education of technicians for high-technology industries important to the Nation's economy and security, and supports centers like InnovATE*BIO*, which is working to advance the education of highly skilled technicians for the Nation's biotechnology workforce by providing leadership in biotechnology technician education, including support for development and sharing of best practices and emerging technologies in biotechnology workforce development.
- **Renewable Resource Extension Act (RREA):** USDA's RREA Program expands the capacity of natural resources extension educators to deliver current, relevant, research-based programs to help forest and rangeland owners, communities, policymakers, and the public make informed decisions in areas of critical importance to the ecological, social, and economic well-being of the Nation. It supports educational programs that address the bottlenecks in the utilization of biomass for energy among sectors in the biomass industry.