STRATEGIC PLAN

FOR A THRIVING AND SUSTAINABLE BIOECONOMY

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE

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ACKNOWLEDGEMENTS

This strategic plan—with a vision for 2040—was developed through the efforts of the Bioenergy Technologies Office (BETO) staff with the help and contributions of key stakeholders from the federal government, national laboratories, industry, universities, expert professionals, and nongovernmental organizations that interact with BETO and its program activities. As the first BETO strategic plan in more than two decades, both BETO's staff and its stakeholder community have been fundamental in ensuring that the 2016 strategic plan is a reflection of the role the U.S. Department of Energy can play in providing clean energy options that create jobs, enhance quality of life, and promote a sustainable domestic bioeconomy.

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LIST OF ACRONYMS & ABBREVIATIONS

AOP	Annual Operating Plan
BETO	Bioenergy Technologies Office (DOE-EERE)
BRD Board	Interagency Biomass Research and Development Board
BSP	Biofuels Systems Program
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy (DOE)
EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
FOA	Funding Opportunity Announcement
gge	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
MSW	Municipal Solid Waste
MYPP	Multi-Year Program Plan
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RFS	Renewable Fuel Standard
USDA	U.S. Department of Agriculture
VTO	Vehicle Technologies Office (DOE-EERE)

DIRECTOR'S MESSAGE

The U.S. bioeconomy industry is on the verge of providing secure and growing diverse supplies of transportation fuels, power, and products from a range of renewable biomass resources. Abundant, renewable bioenergy can contribute to a more secure, sustainable, and economically-sound future by providing domestic clean energy sources, reducing U.S. dependence on petroleum-based fuels, and generating U.S. jobs, and revitalizing rural America. Use of bioenergy products can also help improve the quality of life for all Americans by maintaining a healthy environment for current and future generations.

This strategic plan is the first update to the original strategic plan, developed in 1994 by the predecessor organization to the Bioenergy Technologies Office (BETO), and provides the framework for responding to our changing energy landscape, while ensuring that the United States remains a global leader in a clean energy economy. This plan describes BETO's efforts and emphasizes that true success will require strategic partnerships with federal and state partners, private sector organizations, academic and research institutions, and community leaders across the country.

Biomass is the only renewable energy source that provides a substitute for fossil-based, liquid transportation fuels using existing infrastructure in the near- to mid-term. The United States has the potential to produce up to 1 billion tons of sustainable biomass, which can be used to produce alternative fuels for cars, trucks, and jets; chemicals; biobased products; and renewable power to supply the electric grid. Biofuel, bioproduct, and biopower production can create new domestic business and job opportunities in agriculture, manufacturing, and other key service sectors.

BETO is focused on strengthening partnerships with our stakeholders to research, develop, and demonstrate technologies that will produce advanced bioenergy and bioproducts from lignocellulosic and algal biomass. With steady and strategic investments in cutting-edge projects, a growing array of bioenergy technologies will become cost-competitive and be deployed throughout the nation, enabling the United States to emerge as the global leader in clean energy economy.

We welcome your involvement as a partner in our efforts.

Sincerely,

Jonathan Male, Ph.D.
Director
Bioenergy Technologies Office

EXECUTIVE SUMMARY

The Biofuels Systems Program (BSP), the predecessor organization to the Bioenergy Technologies Office (BETO), developed a strategic plan in 1994 and stated that the *"BSP is at a unique crossroads, positioned to advance biofuels science and technologies into a ready marketplace to fuel an economically competitive transportation sector with secure, clean, and renewable energy resources."* The program's vision was *"to realize the large-scale use of environmentally-sound, cost-competitive, biomass-based transportation fuels through the adoption and commercialization of the best technologies."* With its 1994 strategic plan, BSP shifted its program focus from laboratory-oriented research and development (R&D) to market-oriented research, analysis, and technology transfer activities, and focused on closing the gap between technology readiness and market opportunities for cellulosic ethanol. It also set the stage for increased industry and government sector partnership, as well as interagency collaboration.

EERE Vision: A strong and prosperous America powered by clean, affordable, and secure energy

EERE Mission: To create and sustain American leadership in the transition to a global clean energy economy

BETO Vision: A thriving and sustainable bioeconomy fueled by innovative technologies

BETO Mission: Developing and demonstrating transformative and revolutionary sustainable bioenergy technologies for a prosperous nation

The Renewable Fuel Standard (RFS) of 2005/2007 became a game changer and, along with the U.S. Department of Energy's (DOE's) robust collaborations with a number of private companies, it transformed the biofuels industry and led to 88 million gallons/year of cellulosic ethanol production capacity in 2015.[1] BETO's new strategic plan—with a vision to 2040—reflects the changing energy landscape and dynamics, considers improvements to rural economies, domestic energy supplies, reduction in harmful emissions, and public demand for alternative energy sources and environmentally friendly products. It focuses on sustainable production of biomass resources and a broader range of feedstocks, including gaseous resources, algae, municipal solid waste (MSW), and wet waste streams.

As a reflection of the industry's transformation and the advancements made since the 1990s, the 2016 Strategic Plan expands BETO's mission beyond the cellulosic ethanol market for renewable drop-in fuels (including diesel and jet fuels), biobased chemicals, and bioproducts. This new strategy also emphasizes the need to address environmental concerns associated with increased agricultural demand, including water and soil quality.

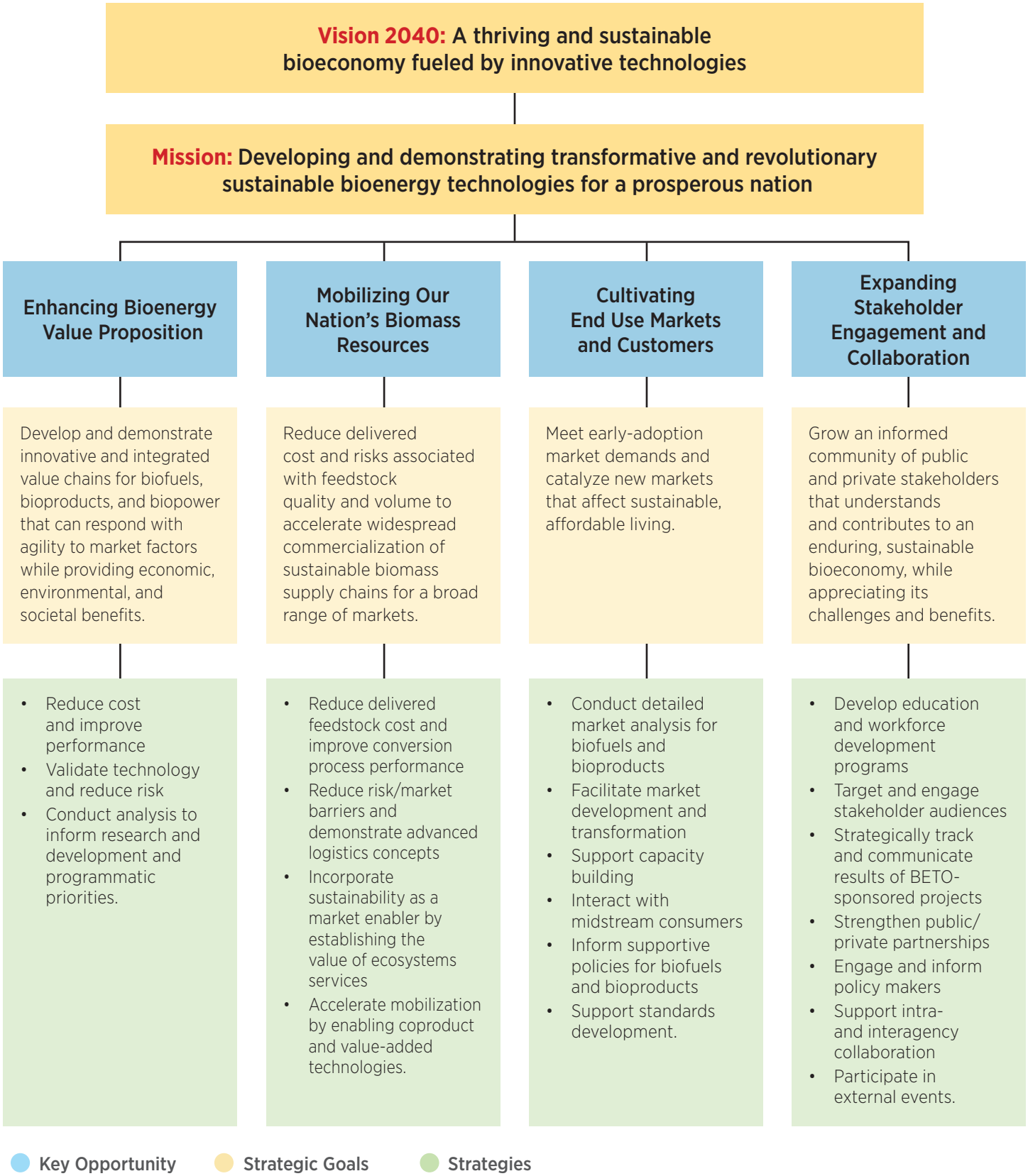
BETO's strategic plan aligns with the Office of Energy Efficiency and Renewable Energy's (EERE's) *2016–2020 Strategic Plan and Implementing Framework*, its vision and mission, and the following relevant strategic goals:

- EERE Strategic Goal 1 – Accelerate the development and adoption of sustainable transportation technologies
- EERE Strategic Goal 4 – Stimulate the growth of a thriving domestic clean energy manufacturing industry
- EERE Strategic Goal 6 – Lead efforts to improve federal sustainability and implementation of clean energy solutions.

BETO's strategic plan is intended to encompass programmatic-level guidance and set the foundation as the driver for its multi-year program plans (MYPPs), annual operating plans (AOPs), and technology roadmaps. While the BETO vision is set for 2040, it is important that processes are in place to validate progress, understand competing technologies, and revisit the strategy every five years.

The main components of BETO's strategic plan include key opportunity areas, a strategic goal for each key opportunity area, and strategies for accomplishing each strategic goal. Figure ES-1 summarizes these elements. Key opportunities reflect the best paths available to support BETO's mission and each opportunity is aligned with a strategic goal that will be achieved by implementing a range of strategies. Progress on these activities will be measured against success indicators or milestones, which are provided in each key opportunity chapter throughout this plan and mapped with strategies and/or substrategies, as applicable to each.

Figure ES-1. BETO strategic plan summary



Building on these strategies and making BETO's vision a reality require the strong support, commitment, and involvement of many individuals and organizations in the public and private sectors, including federal agencies; innovators, scientists, and technologists in industry, academia, and the national laboratories; biofuels and bioproducts producers; and investors. This strategic plan will serve as BETO's blueprint for taking advantage of the opportunities that lie ahead for building a sustainable, domestic bioeconomy—one that will lead to new industries and domestic jobs, especially in the rural regions of the nation.

INTRODUCTION

Sustainable use of domestically produced renewable biomass for fuels, products, and power can help achieve our national energy and economic goals without competing with food and animal feed, also reducing harmful emissions in the utility and transportation sectors, as well as diversifying transportation fuel alternatives. BETO supports the goals of a clean energy economy to increase national energy security and meet environmental sustainability goals through the development and transformation of domestic biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower. BETO achieves this through sponsorship of targeted research, development, and demonstration (RD&D) projects undertaken by public and private partnerships. BETO supports RD&D and market transformation activities through an integrated supply chain approach addressing supply, conversion, distribution, and end use.

In 1994, leadership within the DOE's BSP, the predecessor organization to BETO, recognized the need to develop a strong U.S. strategy for biofuels to help reduce harmful emissions from the transportation sector and increase American energy independence, with an early focus on niche markets, where infrastructure already existed. BSP developed its first strategic plan, *Biofuels at the Crossroads—Strategic Plan for the Biofuels Systems Program*,[2] with the intent of developing the technologies that can be major contributors to achieving the Energy Policy Act (EPAct) of 1992 targets of replacement fuels production for light-duty vehicles in the United States. In doing so, BSP targeted ethanol produced from waste feedstocks to supplement the small, starch-based ethanol industry with a non-food feedstock stream, biodiesel from plant oils, and components of reformulated gas—due to their near-term potential. These markets would then enable a proof-of-concept that could lead to energy crop production, supplying renewable fuels for dedicated vehicles and new infrastructure.

Technology Development Stages

Process Development Unit: Experimenting to establish proof-of-concept, preliminary process economics, and feasibility for pilot-scale operations.

Pilot Plant: Integrating unit operations and validating techno-economic assessments.

Demonstration Plant: Verifying performance at industrial scale and providing design specifications for a pioneer plant.

Pioneer Plant: Proving economic production of technology at commercial scales.

Commercial Plant: Full-scale production operations at commercial levels.

Fast forward two decades and, in 2015, the first 88 million gallons of commercial scale cellulosic ethanol capacity were built in the United States. The pioneer plants represent the result of RD&D efforts of BETO and its partners and provide real-world information about the challenges associated with supply chains, feedstock quality and availability, necessary equipment, and changes in the marketplace. As proven by the initial projects, scale-up and integration of new technologies into pioneer commercial-scale biorefineries is a challenging and high risk undertaking.

In an effort to reduce this risk, BETO conducts RD&D and market transformation activities through an integrated supply chain approach addressing supply (feedstocks), conversion, distribution, and end use. Several activities underscore the RD&D conducted by BETO—sustainability, strategic analysis, and communications—that enable development and dissemination of knowledge and tools related to the economic, environmental, and social dimensions of advanced bioenergy.

To accomplish its objectives, BETO has adopted an investment approach that supports transformative and revolutionary bioenergy technologies (see Appendix B). The approach targets specific gaps in technology-development pathways where the private sector or other nongovernmental stakeholders are unable to make necessary investments due to risk, scale, or the time frame required for commercialization.

Diversifying the Whole Barrel

Sustainability

BETO's approach to sustainability spans social, economic, and environmental dimensions consistent with Executive Order 13514 (Federal Leadership in Environmental, Energy, and Economic Performance), which provides the following definition: *To create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future.*

Social and economic considerations include energy security, social well-being, trade, profitability, resource conservation, and social acceptability. Environmental considerations include productivity, greenhouse gases, water quality and quantity, soil quality, air quality, and biodiversity.

Cellulosic ethanol's commercialization is making progress, but there are still hurdles to cost reduction and reliability that need to be addressed. BETO is investigating ways to increase the value of cellulosic ethanol by expanding its application as an intermediate for bioproducts and jet fuel. In addition, BETO has broadened its focus beyond the cellulosic ethanol market to consider the opportunity to replace the whole barrel of petroleum with a wide range of renewable fuels and products. As shown in figure 1, many products are made from a barrel of petroleum. Diversifying and providing biobased alternatives to products from the entire barrel of oil are critical—not only to increasing U.S. energy security, but also to developing a clean energy economy and creating domestic jobs. This aim has led BETO to develop a new strategic plan that is focused on maximizing the potential of a domestically produced biomass supply that accounts for all end-use markets and promotes and generates economic, environmental, and social benefits.

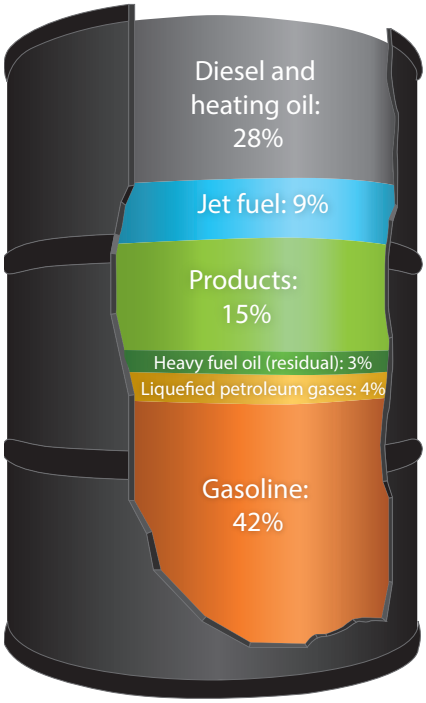


Figure 1. Products from a barrel of crude oil

While cellulosic biofuel production is the primary focus, BETO supports the production of chemical intermediates that are traditionally petroleum-derived but can be produced from biomass. These intermediates are converted into high-value bioproducts, including bioplastics, biobased chemicals, lubricants, solvents, cosmetics, and food ingredients, such as algae oil—all of which have places in today's commercial market. These successful commercial efforts illustrate the potential for bioproducts to enable biofuels development. These efforts have been made possible by a motivated industrial sector, highly innovative scientists and engineers in academia and at DOE's national laboratories, and the steadfast work of federal agencies and decision makers that proactively address energy, environmental, and societal issues, regardless of the price of oil and its volatility.

Vision for a U.S. Bioeconomy

In early 2016, the interagency Biomass Research and Development Board (the BRD Board) released a vision document for the nation: *The Federal Activities Report on the Bioeconomy*.[3] The Bioeconomy Initiative, as outlined in this report, is a systems approach to sustainably reaching the full potential of biomass-derived products, resulting in an expanded U.S. bioeconomy by 2030.

The vision document identifies a number of innovative approaches for removing barriers to using domestic biomass resources in a sustainable manner. An expanded bioeconomy provides multiple economic, environmental, and social benefits to the nation, as illustrated in figure 2.

- Revenue and economic growth
- Broad spectrum of new jobs
- Rural development
- Advanced technologies and manufacturing
- Reduced emissions and enhanced environmental sustainability
- Export potential of technology and products
- Positive societal changes
- Investments and new infrastructure

Figure 2. Benefits of bioeconomy

A strong bioeconomy will support:

- Sustainable production of biomass feedstocks and capture of usable wastes
- Development of innovative and efficient technologies that transform renewable carbon into intermediates and products
- Construction of more biorefineries and manufacturing facilities
- Expansion of the market for biofuels, biochemicals, biopower, and other biomass-derived products.

The vision document highlights the efforts of the whole federal government in creating the bioeconomy. *The Federal Activities Report on the Bioeconomy* lays the groundwork for an advanced bioeconomy through new scientific and technological breakthroughs at universities and laboratories; industrial and manufacturing innovation; engagement with financial institutions; educational and job-training initiatives; and partnerships with producers, contractors, and specialty personnel. Expanding the bioeconomy within the timeframe and to the extent envisioned will require strong commitment and involvement from these organizations and institutions.

Legislative and Institutional History in Support of a Strong Bioeconomy

Legislative drivers

DOE's involvement in R&D to facilitate increased use of alternative transportation fuels goes back to the 1980s. The Alternative Motor Fuels Act of 1988 and the EPAct of 1992 were the early drivers for development and deployment of renewable transportation fuels. For example, to assist in achieving the goals of promoting the use of alternative fuels, the Alternative Motor Fuels Act provided incentives for manufacturers of light-duty vehicles to design, develop, manufacture, and market passenger cars and light-duty trucks that operate on alternative fuels, such as ethanol.

The EPAct of 2005 defined several of BETO's priorities.[4] Section 932 states that "The Secretary shall conduct a program of research, development, demonstration, and commercial application for bioenergy…to develop…conversion technologies capable of making fuels from lignocellulosic feedstocks…biotechnology processes…using enzyme-based processing systems… processes capable of increasing energy production…with emphasis on reducing the dependence of industry on fossil fuels… [and] other advanced processes that will enable the development of cost-effective bioproducts." The legislation also authorized a program to demonstrate the commercial application of integrated biorefineries.

Further, EPAct of 2005, Section 942, established the first RFS, which set a goal of delivering 1 billion gallons of cost-competitive cellulosic biofuel by 2015 and created production incentives to reach this goal. The RFS was updated by the Energy Independence and Security Act of 2007 (EISA).[5] EISA Title II, *Energy Security Through Increased Production*, set higher mandatory levels of biofuels to help reduce greenhouse gas (GHG) emissions from the transportation sector and increase American energy independence.

EISA expanded the RFS to include not just gasoline, but also diesel, and increased the volume of renewable transportation fuels to 36 billion gallons by 2022, with specific levels for advanced and cellulosic biofuels. Besides supporting RD&D to meet the target, EISA also mandated that BETO and other federal agencies address the effects of biofuels. BETO and other DOE offices, in collaboration with the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), and the National Academy of Sciences, were required to study the effects of biofuels on air quality; nutrient and pathogen levels in waters; resource conservation issues, including soil conservation, ecosystem health, and biodiversity; and the growth and use of cultivated, invasive, or noxious plants and their impacts on agriculture and the environment. In addition, these agencies were required to study biofuel compatibility with engines and the use of algae as a biofuel feedstock.

Again in 2009, Federal legislation addressed the value of biofuels in supporting the nation's economic recovery with the American Recovery and Reinvestment Act of 2009.[6] The Act required that funding be provided for "leading edge biofuel projects that will use technologies performing at the pilot or demonstration scale that the Secretary determines are likely to become commercial technologies and will produce transportation fuels that substantially reduce life-cycle greenhouse gas emissions compared to other transportation fuels."

Federal legislative initiatives have strengthened the nation's growing bioeconomy, in large part by advocating the use of competitive funding opportunities that advance integrated biorefinery technologies, and BETO has been at the forefront of these activities.

Policy drivers

DOE has a long history of supporting national security, environmental, and economic needs across administrations, and this new strategic plan reflects the continued commitment to developing alternative fuels. As one of three offices within EERE's Office of Sustainable Transportation, BETO is focused on replacing conventional fuels with cost-competitive, domestically produced biofuels. Such products are designed to reduce pollution in the transportation sector, including (but not limited to) automotive, aviation, and marine applications.

Further, the BRD Board's Bioeconomy Initiative, combined with congressional and administrative efforts, has helped BETO shape its mission. As a member of the BRD Board, DOE works closely with other federal agencies focused on developing sustainable commercial-grade fuels and industrial products. These products include intermediates that displace petroleum in adhesives, carbon fiber, and polymers for plastics.

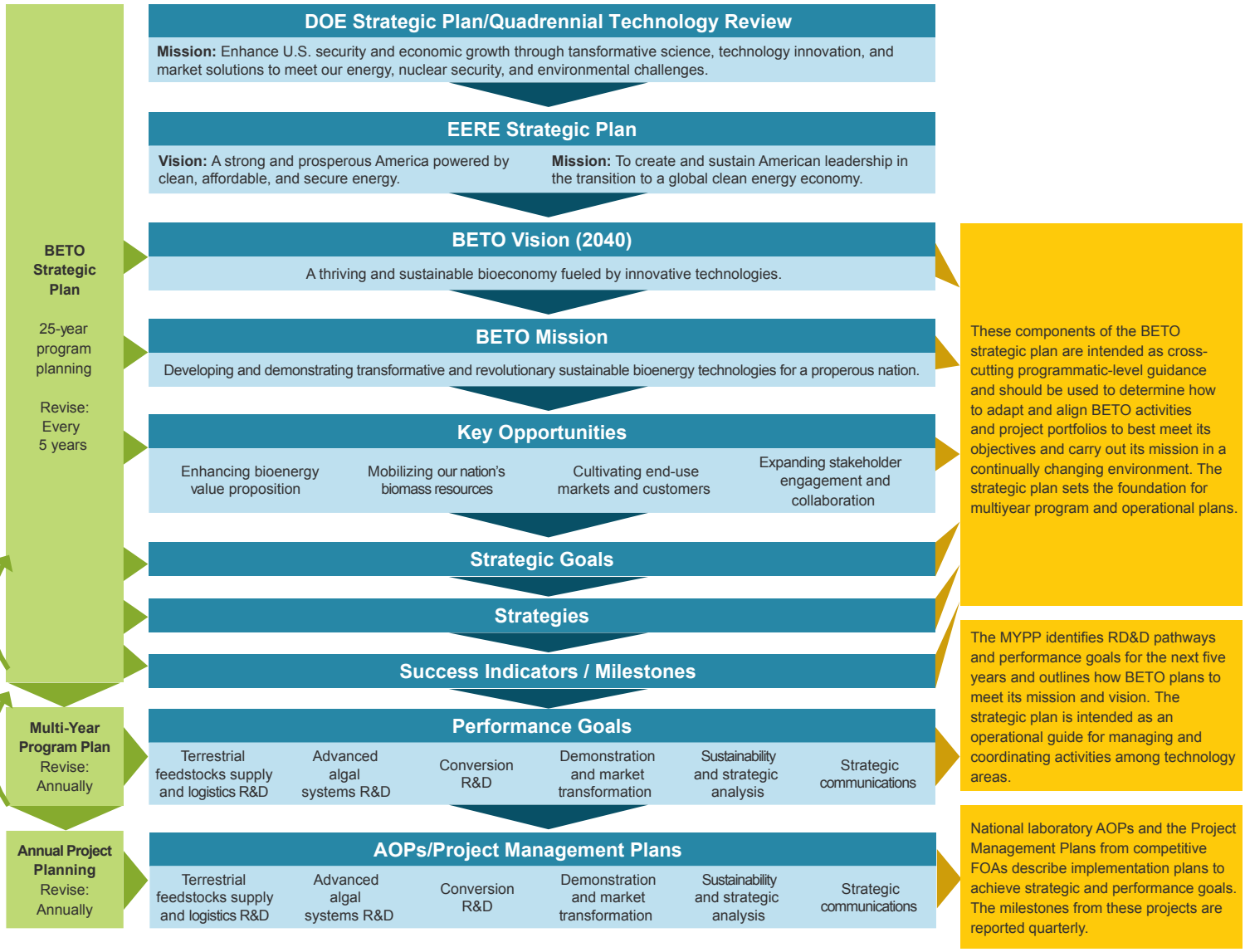
BETO Strategic Plan: An Integrated Approach

The BETO strategic plan will serve as a roadmap to achieving the bioeconomy vision as it sets the foundation for development of BETO's MYPPs, AOPs, and funding opportunity announcements (FOAs). Collectively, these guiding documents and actions will navigate the BETO program toward realizing the vision of a thriving and sustainable bioeconomy. MYPPs serve as operational guidance for program leaders and as a source of information to help DOE-EERE management identify clear linkages between key program activities and progress toward goals. MYPPs present pathways and activities that a program will pursue over a 5-year planning horizon to achieve its goals and objectives based on reasonable expectations of program budgets. It also outlines how BETO will implement its strategic plan. Performance goals within the MYPP are aligned with BETO's six key program areas:

- Feedstock Supply and Logistics R&D
- Advanced Algal Systems R&D
- Conversion R&D
- Demonstration and Market Transformation
- Sustainability and Strategic Analysis
- Strategic Communications.

The purpose of an AOP is to facilitate program planning and communication, and to establish a baseline for measuring progress (typically over the course of 1 to 3 years) of DOE-EERE programs. AOPs are prepared and reviewed annually prior to each fiscal year for all programs within DOE-EERE. Figure 3 shows the relational structure of BETO's strategic planning components with MYPP, AOP, and FOA processes. BETO's mission and vision support the mission and vision of DOE-EERE, and that of DOE as a whole, by focusing on technologies that improve the U.S. economy through sustainable energy solutions. This integrated approach ensures that BETO will continue to carry out its mission in a dynamic setting that recognizes growing environmental awareness, policy and regulatory change, and public perceptions and expectations. Coupled with this, BETO's activities will be guided further by its shared values, including dedication to strong science and engineering; bioenergy's social and environmental benefits; seeking and retaining committed and talented staff; commitment to managerial excellence and leadership; creating and working in a collaborative environment; and active communication with and among all stakeholders.

Figure 3. BETO strategic plan integration with DOE and EERE planning process, MYPP, and AOP



This new strategic plan supports EERE's *2016–2020 Strategic Plan and Implementing Framework*, which in turn is responsive to DOE's science and energy mission to advance clean energy technologies.[7,8]

It is also aligned with DOE's *2015 Quadrennial Technology Review*, which serves as a blueprint for DOE, its national laboratories, and other public and private sector organizations and institutions.[9] The *2015 Quadrennial Technology Review* guides technology breakthroughs, modernize our energy infrastructure, and enhance our energy security. Further, the first installment of DOE's *Quadrennial Energy Review*, released in April 2015, calls for continued research, development, demonstration, and deployment of drop-in biofuels and initiatives related to higher-level ethanol blends.[10]

BETO's Strategic Planning Process

Strategic planning is a continuous process that requires involvement and input from stakeholders to ensure success. The BETO strategic planning effort has been a multistage, iterative endeavor, supporting involvement from stakeholders at many points along the way. BETO formed five focus group teams, each composed of internal staff and technical and programmatic support personnel, who also reached out to external stakeholders. The five teams were as follows:

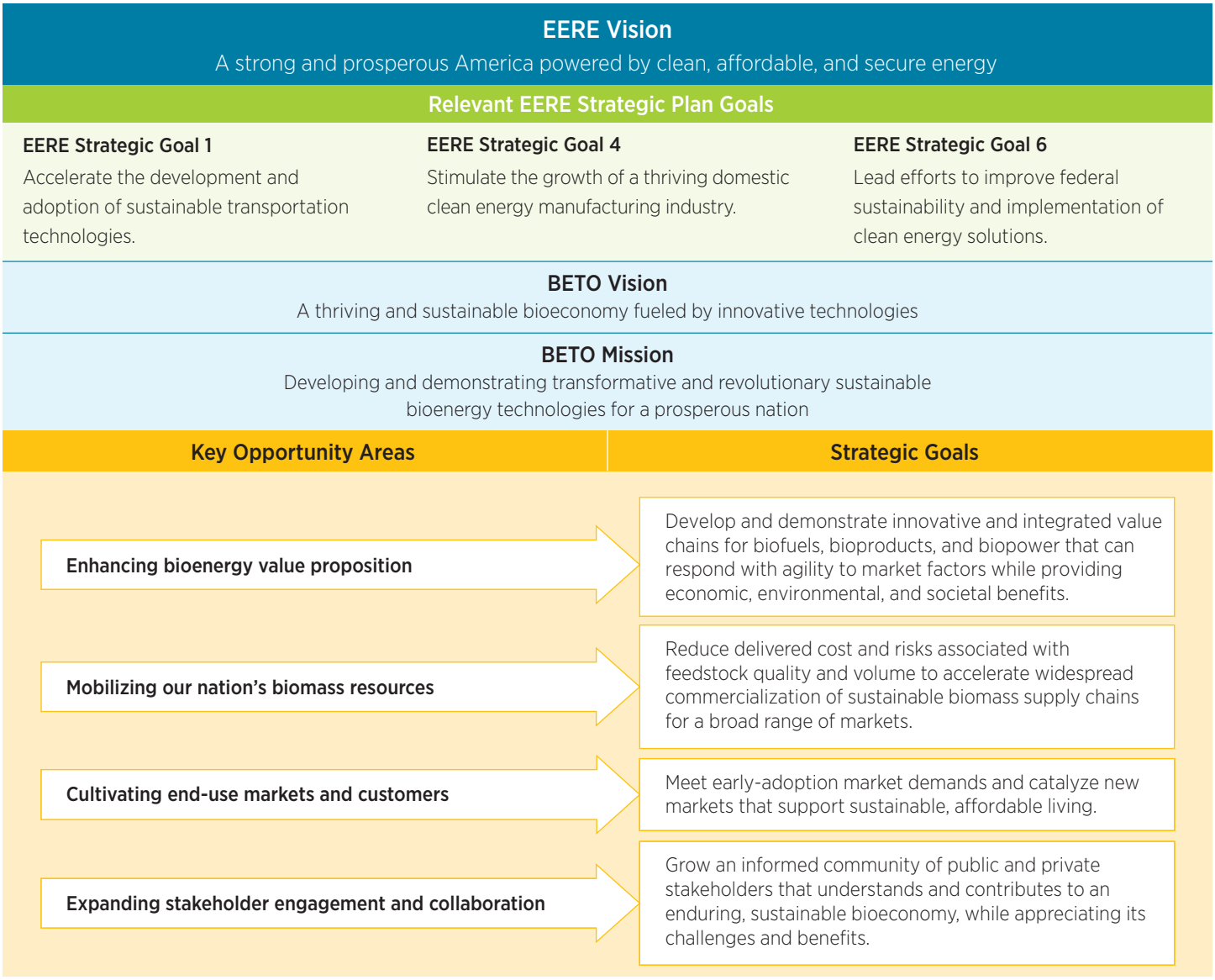
- Broadening Feedstocks
- R&D
- Scale-Up and Commercialization
- Market Penetration and Infrastructure
- Sustainability.

BETO conducted background research and analysis to determine the office's priorities and to establish the strengths, weaknesses, opportunities, and threats facing the bioenergy sector. Each focus group team met with representatives from industry, government, academia, and national laboratories to discuss and refine these analyses. Team members then developed a vision and mission for the bioenergy sector and placed their focus on key opportunity areas. After a final strategic planning effort with stakeholders, the teams crafted specific short-, mid-, and long-term activities for the plan. Near-term activities are those occurring in the 2016–2025 timeframe, mid-term activities reflect those occurring from 2026–2030, and long-term activities are those that will be conducted from 2030–2040. Each of the five key opportunity areas include strategic goals and objectives, as well as a set of specific activities developed to meet BETO's mission and the bioenergy industry's vision for 2040.

An overview of the BETO strategic plan, cascading from the EERE strategic plan, is illustrated in figure 4. Each of the three identified EERE goals are addressed by activities within multiple key opportunity areas. EERE Strategic Goal 1 is addressed by BETO's activities aimed at improving the value proposition of biofuels through investment in R&D of sustainable technologies to reduce costs of biofuel production for light- and heavy-duty vehicles, as well as the marine and aviation fleets. BETO is also focused on the adoption of these sustainable transportation technologies by cultivating end-use markets and customers through addressing infrastructure requirements, codes and standards, and stakeholder engagement. BETO is working to achieve EERE Strategic Goal 4 by supporting a robust domestic bioeconomy across the value chain by mobilizing biomass across the country's agricultural sector; manufacturing bioproducts and chemicals; and supporting design, construction, and operation of first-of-a-kind integrated biorefinery facilities. In support of EERE Strategic Goal 6, BETO has and will continue to lead efforts to implement clean energy solutions through interagency adoption of initiatives, such as the Defense Production Act, aimed at increasing the U.S. Navy's energy security by providing cost-competitive military-grade fuels.

By periodically revisiting the state of bioenergy technologies and markets, BETO will remain agile in its priorities. BETO will include various stakeholders in the process of identifying barriers and evaluating opportunities to enhance BETO's ability to address issues that impact the marketplace. This engagement across both the public and private sectors will strengthen partnerships in support of BETO's bioenergy vision for 2040—a thriving and sustainable bioeconomy fueled by innovative technologies.

Figure 4. BETO Strategic Plan summary



Key Opportunity: ENHANCING BIOENERGY VALUE PROPOSITION

Strategic Goal: Develop and demonstrate innovative and integrated value chains for biofuels, bioproducts, and biopower that can respond with agility to market factors while providing economic, environmental, and societal benefits.

Production of biofuels, bioproducts, and biopower from abundant domestic biomass resources offers the United States an opportunity to meet our energy needs in an economically, environmentally, and socially beneficial manner. The value of bioenergy to the United States extends beyond just displacement of petroleum, offering alternative fuels with an improved environmental profile, providing jobs in rural communities, generating economic benefits to growers, and valorizing untapped waste streams.

Strategies to achieve the strategic goal are discussed in the following pages, but it is critical to first understand the inherent value of bioenergy. The value rests on the three pillars of sustainability: economic, environmental, and social. The benefits of bioenergy encompass these elements and provide a strong justification for developing a strategy to accomplish this important goal.

Bioenergy Value Proposition

- Biofuels and bioproducts offer a unique complement to other alternative energy technologies
- Bioenergy enhances energy security and provides U.S. economic benefits
- Bioenergy provides value for otherwise problematic waste streams
- Bioenergy can enhance the environment with purpose-grown feedstocks.

Biofuels and Bioproducts Offer a Unique Complement to Other Alternative Energy Technologies

Most sources of alternative energy, such as solar, wind, and geothermal, produce electrical power while biofuels and biochemicals can directly replace petroleum-derived liquid fuels and chemicals compatible with today's infrastructure. Although electrification coupled to these alternative energy sources can transform the light-duty vehicle fleet, it is unlikely even in the mid- to long-term that the needs of the heavy-duty marine and aviation industries will be met by anything except an energy dense carbon-based liquid fuel.[11] Additionally, many chemicals relied upon for transportation (such as oils and lubricants) as well as other commodity chemicals and polymer precursors are, and will likely remain, carbon-based.

Bioenergy Enhances Energy Security and Provides U.S. Economic Benefits

Bioenergy relies on domestic biomass resources, bringing economic benefits to foresters and farmers, as well as communities where bioenergy is produced. The USDA estimated that the number of jobs contributed to the U.S. economy by the biobased products industry in 2014 was 4.22 million jobs.[12] This local supply chain offers insulation from volatility in petroleum-exporting nations and reduces the influence of fluctuating oil prices on the transportation sector. Recent publications provide analysis demonstrating that by 2040, the United States could produce enough biomass annually to displace 25% of all transportation fuels in the U.S.[13,14]

Bioenergy Provides Value for Otherwise Problematic Waste Streams

As crop yields have increased, farmers are faced with managing the amount of agricultural residues on their fields, especially in highly productive areas of the U.S. Corn Belt. In many locations, harvesting a portion of these residues can provide economic value while increasing overall agricultural productivity.[15] Harvesting forestry residues can also decrease the risk of fire on both managed and unmanaged lands.[16,17] In addition to these more traditional biomass feedstocks, MSW, biosolids, and biogases can be transformed into fuels, chemicals, and power by using bioenergy-conversion technologies.[18,19] Furthermore, algae and other microbes can be cultivated on wastewater, and when grown using carbon dioxide (CO_2) that comes directly from power plants and industrial waste sources, it can capture carbon emissions and produce bioderived fuels and chemicals.[20]

Bioenergy Can Enhance the Environment with Purpose-Grown Feedstocks

One of the most recognized benefits of using biomass to provide alternative to petroleum for fuels and products is reduction in harmful emissions for the full life cycle of the biomass from seed to end use, versus its competitors, such as gasoline. There are other benefits to sustainable development of a bioeconomy as well, including providing a solution to the problem of poor soil and nutrient management that is depleting soil carbon and causing excess nutrients to end up in streams and rivers, affecting water quality in local communities and creating "dead zones" or hypoxic waters (less than 2 parts per million dissolved oxygen), such as those found in the Gulf of Mexico.[21] Growing bioenergy feedstocks, such as miscanthus, willow, and switchgrass, alongside traditional crops can enhance soil carbon fixation and minimize nutrient runoff.[22,23] Landscape design principles can integrate food and energy systems in a way that reduce waste, improve crop productivity—resulting in increased yield of food and animal feed, as well as biomass residues for conversion to products—and contribute to multiple environmental and social goals. In total, proactive, stakeholder-driven design and integration of bioenergy technology adds resiliency benefits to agriculture and forestry production systems and enhances their ability to provide food, animal feed, and fiber for future generations.[24] Additionally, algae feedstocks can remediate nutrient-loaded water, thereby providing an important ecosystem service. Similarly, when microbes are grown on biosolids for wastewater treatment purposes, they can provide a valuable bioenergy feedstock in addition to clean water.

How to Make Bioenergy a Reality?

BETO will employ three strategies to ensure success:

- Cost reduction and performance improvement throughout the bioenergy value chain
- Technology validation and risk reduction
- Analysis that informs programmatic priorities and future research and development.

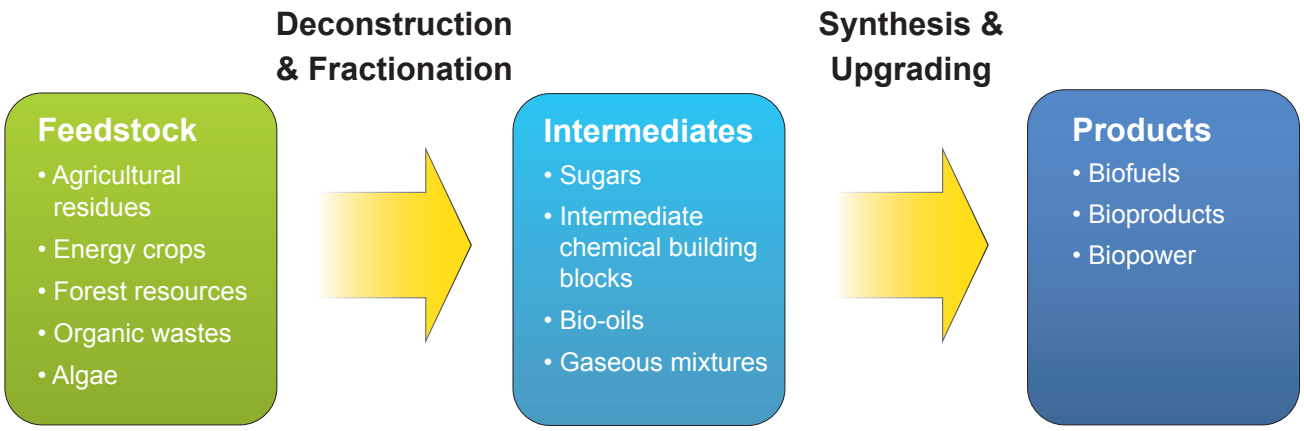
Cost Reduction and Performance Improvement throughout the Bioenergy Value Chain

Reducing the cost of the process steps along the value chain is paramount if bioenergy and biobased products are to be accepted into the market. BETO is exploring a variety of conversion technologies that can be combined into pathways from feedstock to product. Figure 5 illustrates the process steps and materials in the feedstock-to-end-products process, depicting a high-level view of primary unit operations within conversion R&D. Each conversion technology involves at least two main steps: (1) deconstruction and fractionation of feedstock into relatively stable intermediates through the breaking of chemical bonds, and (2) the controlled synthesis and upgrading of those intermediates into desired products. Reducing cost is just one component of BETO's strategy. To improve overall sustainability across the value chain, BETO will encourage integration of green chemistry and engineering principles, such as designing for energy efficiency, minimizing material use (reduced capital expenditures/inputs to improve sustainability of the design), and minimizing/eliminating wastes and releases.[25]

Technology Validation and Risk Reduction

BETO plays a key role in encouraging technology development and commercialization through scale-up and demonstration of promising technologies and biomass supply chains. BETO partners with private investors, academic institutions, and national laboratories to construct pilot- and demonstration-scale facilities. These facilities verify process performance, validate techno-

Figure 5. Conversion process for biomass-derived feedstocks into renewable products



economic assessments, resolve scale-up and integration issues, and provide designs for commercial pioneer plants. This support is critical for overcoming "valleys of death" typically encountered in the scale-up of conversion process technology due to lack of financing. Furthermore, BETO will also demonstrate and validate advanced feedstock supply systems and landscape design approaches that provide biorefineries with reliable, affordable feedstocks (see also section on *Key Opportunity: Mobilizing Our Nation's Biomass Resources, substrategy on developing advanced feedstock supply systems*). BETO's investment bolsters investor confidence and enables wide-scale deployment of bioenergy technologies.

Analysis that Informs Research, Development, and Programmatic Priorities

Deployment of new technologies requires ongoing analysis of opportunities for harnessing potential benefits and avoiding or mitigating potential negative outcomes. Analyses, such as the *2005 Billion-Ton Study*, *2011 U.S. Billion-Ton Update*, and *2016 Billion-Ton Report*, play an important role in supporting BETO as it meets these objectives, documenting process design and economics for key conversion pathways and supply chain sustainability of these pathways.[26,27,28,29] Analysis will continue to play a critical role in guiding strategy and R&D, as well as communicating progress on cost, energy, environmental, and societal targets.

The following success indicators and/or milestones illustrate near-, mid-, and long-term activities designed to meet the strategic goal.

Success Indicators / Milestones

Near-Term

- By 2017, verify at pilot scale at least one technology pathway for hydrocarbon biofuel production, demonstrating a mature modeled price of $3/gasoline gallon equivalent (gge) with GHG emissions reduction of 50% or more. (C/V) *
- By 2018, complete gap analyses to identify the barriers and solutions to potentially reaching a mature modeled price of $2/gge for biofuels. (C/V)
- By 2019, publish a multi-dimensional analysis that identifies and quantifies specific economic, environmental, and social benefits of a transition to a robust bioeconomy. (E/S) *
- By 2020, provide an analytical framework for bioproducts research by publishing market and life-cycle analyses, roadmaps, and/or reports. (C/V)
- By 2022, verify at pilot or demonstration scale two additional pathways for hydrocarbon biofuel production at a mature modeled price of $3/gge with GHG emissions reduction of 50% or more with the option of incorporating a bioproducts strategy. (C/V)

Mid-Term

- By 2023, demonstrate a suite of analytical methods for quantifying environmental benefits associated with biomass and bioenergy production—such as decreasing harmful emissions and improving soil quality and water quality—that can be used to outline and define well-justified environmental goals. (E/S)
- By 2025, demonstrate production of bioproducts at needed scales (20-100 kg) for product testing to support offtake agreements and end-user/market acceptance to displace incumbent petroleum products. (C/V)
- By 2027, demonstrate at least one biofuel and bioproduct production strategy that reduces capital cost by 30% from 2012 cellulosic ethanol baseline. (C/V)
- By 2027, verify at pilot scale, a $1/gge fuel reduction cost for the production of biofuels and bioproducts by valorizing conversion-process waste streams (such as lignin and pyrolysis aqueous streams) and producing novel bioproducts that capitalize on the highly oxygenated nature of biomass (functional replacements). (C/V)
- By 2027, demonstrate, at pilot scale, conversion technologies that meet low water use, low harmful emissions, and minimal wastewater treatment needs as defined by the 2019 multi-dimensional analysis that increase the cost of fuel by <$1/gge. (E/S)

Long-Term

- By 2030, develop process pathways to five functional replacement molecules that are sustainable, derived from biomass feedstock, and achieve >60% GHG emissions reduction and/or 25% overall energy input reductions compared to the molecules they replace. (E/S)
- By 2040, enable large-scale biomass production and conversion that allows biofuels to constitute 25% of the U.S. transportation fuel market. (C/V)
- By 2040, through R&D, support replacing 7% of petrochemicals with bioproducts. (C/V) [30,31]
- By 2040, demonstrate ecosystem services—such as improvements in soil quality, water quality, and decreased nutrient loss—that increase environmental quality stemming from large-scale biomass production. (E/V)

*(C/V) indicates an objective based on the cost/volume of biofuels and biochemicals. (E/S) indicates an objective based on environmental and societal aspects.

Strategy: Reduce Cost and Improve Performance

Substrategy: Improve Process Performance through Improved Catalysts and Separations

Improved catalyst and separation technologies are critical cost drivers for biofuel- and bioproduct-conversion technologies. Catalyst development activities—including design, production, testing, and characterization—will advance many of BETO's thermochemical and biochemical technology pathways. One of the major cost contributors to the price of a gallon of hydrocarbon biofuel is the cost of catalytic materials—up to 20% of the cost per gasoline gallon equivalent of hydrocarbon biofuel (depending on exact process configuration). There are unique challenges to developing catalysts for bioenergy applications due to the unique qualities of biomass (high oxygen content, high moisture content, highly acidic, etc.). Unfortunately, catalyst materials developed for the petroleum industry do not translate to bioenergy applications. Currently, separations costs can represent up to 70% of processing costs for biofuels and bioproducts. Carbon not contained in the biofuel or bioproduct is usually used for power generation—a low-value use. It is imperative to move cost-effective, high-performing separations technologies to market faster to enable cost-competitive biofuels production. BETO will support the development of new catalysts and optimize separations technologies to use biomass feedstocks efficiently.

- By 2017, verify at pilot scale at least one technology pathway for hydrocarbon biofuel production, demonstrating a mature modeled price of $3/gge with GHG emissions reduction of 50% or more.

Substrategy: Improve Process Performance through Engineering Biology

Scale-up of organism-based processes is a key barrier to developing biological-based conversion processes. BETO will support the development and application of novel, synthetic biology tools and genetically tractable, industrially robust microorganisms.

BETO will also support advanced fermentation-engineering and artificial photosynthetic practices, and approaches that will allow for a wide new array of product slates and significant improvements in the efficiency and reduced carbon intensity of biochemical conversion. These activities will focus intently on partnering with industry to export these technologies to the private sector.

- By 2017, verify at pilot scale at least one technology pathway for hydrocarbon biofuel production, demonstrating a mature modeled price of $3/gge with GHG emissions reduction of 50% or more.

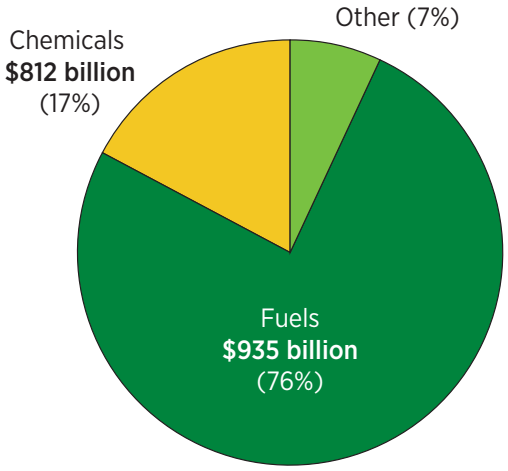
Substrategy: Develop Bioproducts that Enable Biofuels

When the cost of a barrel of oil dips below $40/barrel and federal and state renewable fuel incentives are uncertain, companies wishing to enter the fledgling advanced biofuels industry might find these external challenges insurmountable. BETO stakeholders have consistently voiced concern that new biofuels producers need portfolio diversity and alternative revenue sources to ride out market fluctuations.[32] For example, as a complement to biofuels, there is significant opportunity for the industry to produce and capitalize on bioproducts, which generally include nonfuel chemicals that are produced from biomass.

Despite the large diversity of potential commercially-viable bioproducts (both known and unknown products), all have one thing in common: they can help de-risk the deployment of biofuels. Value-added chemicals and products, if successfully demonstrated at scale, can de-risk "front-end" processes (from feedstock production and logistics through biomass deconstruction), which are necessary for producing fuels. The production of bioproducts relies on much of the same feedstocks, infrastructure, feedstock commoditization, and conversion technologies that are central to biofuels production. The market success of bioproducts will ultimately depend on producers meeting quality, performance, sustainability, and cost targets. For a bioproduct to displace a petroleum product, it must offer the same, or better, quality and performance at a competitive price. If successful, bioproducts can represent early market adoption in the bioeconomy as a whole.

The strategy of producing bioproducts alongside biofuels is analogous to the petroleum industry producing fuels and chemicals. The petroleum industry benefits from a flexible product slate that it can tune to market demand. Furthermore, the petroleum industry takes advantage of high margins commanded by chemicals as compared to fuels. As illustrated in figure 6, approximately 76% of the volume of a barrel of crude oil goes toward making fuels, corresponding to $935 billion in annual revenue.[33] In contrast, only 17% of a barrel of oil goes toward making petrochemicals; despite the much smaller volume, these chemicals produce almost as much revenue as fuels ($812 billion in annual revenue for chemicals). To realize a positive return on investment for a biorefinery generating biofuels that are cost competitive with their petroleum-derived counterparts, bioproducts need to be produced and sold at higher margins. BETO will support the development of flexible biomass-to-biofuels conversion pathways that can be modified to produce fuels and/or products based on market conditions.

Figure 6. Products from a barrel of crude oil (%) and corresponding annual revenues



- By 2025, demonstrate production of bioproducts at needed scales (20-100 kg) for product testing to support offtake agreements and end-user/market acceptance to displace incumbent petroleum products.

Substrategy: Replace Petrochemicals with Biobased Alternatives

Nearly half of the monetary value derived from a barrel of petroleum comes from just a small volume of oil in the form of petrochemicals (figure 6 above). The petroleum industry takes advantage of these higher margins commanded by chemicals in comparison to fuels to provide the industry with the flexibility to respond to fluctuating market demand. This same resilience to fuel market inconsistency could be brought to the biofuels industry via bioproducts while concurrently reducing a portion of the market share held by petroleum. To assist the development of the bioproducts industry, BETO will support the development of a robust bioproducts landscape that enables biofuels by allowing intermediates to become established cornerstones in the market and making them available for biofuel production when economic conditions are favorable. To ensure the replacement of 25% of the petrochemical market occurs, BETO will aim to demonstrate a platform chemical biomass conversion process at pilot scale and validate its ability to be converted to either fuels or products.

- By 2025, demonstrate production of bioproducts at needed scales (20-100 kg) for product testing to support offtake agreements and end-user/market acceptance to displace incumbent petroleum products.

Substrategy: Reduce Capital Costs through Process Intensification and Modularization

Reducing capital costs of cellulosic and algae-derived biofuel and bioproduct facilities remains a significant challenge. Such costs can be as high as $500 million, limiting participation from potential investors. Capital costs remain a concern, even as BETO R&D moves toward the production of biomass-derived hydrocarbon fuels, which can be drop-in replacements for gasoline, diesel, and jet fuels, or high-performance blend stocks for next-generation engines. BETO will continue to focus its research efforts on process intensification and performance improvements to drive down capital costs, minimize resource use, and minimize/eliminate releases. BETO also recognizes the strategy of reducing capital costs by collaborating with experts in modular manufacturing technologies and process intensification, such as EERE's Advanced Manufacturing Office and the Office of Fossil Energy.

- By 2027, demonstrate at least one biofuel and bioproduct production strategy that reduces capital cost by 30% from 2012 cellulosic ethanol baseline.

Substrategy: Develop Robust Technologies To Convert Waste Streams to Fuels and Chemicals

The modeled cost of producing advanced biofuels must decrease significantly to compete with petroleum-based, liquid transportation fuels. As such, key to widespread adoption of bioenergy technologies is the development of biomass or bioprocess waste stream utilization strategies for higher-value applications. This includes valorization of lignin and/or carbon monoxide, full utilization of all algal biomass components, and incorporation of price-advantaged feedstocks like organic, municipal, and wet-waste materials. This has an added benefit of solving local and regional waste disposal-related issues.

Converting waste streams into biofuels and/or bioproducts reduces risk for investors by improving biomass value. Enabling a diverse product slate from a biorefinery, including valorizing materials that are currently waste products, will substantially reduce risks associated with launching biofuel plants and biorefineries. Bioproduct strategies incorporated into techno-economic analyses can include capital equipment designs that are capable of leveraging a suite of technologies to produce various chemicals with the same feedstocks. Or, they can include the production of a platform chemical that can be sold as a commodity and then converted into various products (including fuel) based on market conditions.

BETO will continue to collaborate with DOE's Office of Fossil Energy on technologies that enable bioenergy feedstocks to utilize CO_2 from fossil energy and other sources to generate low-carbon-intensity fuels. In addition, BETO will consider innovative, early-stage technologies, such as the development of novel biological systems that can directly utilize electrons, hydrogen, or reduced metal ions for the conversion of CO_2 into liquid fuels (electrofuels).

- By 2027, verify at pilot scale, a $1/gge fuel reduction cost for the production of biofuels and bioproducts by valorizing conversion-process waste streams (such as lignin and pyrolysis aqueous streams) and producing novel bioproducts that capitalize on the highly oxygenated nature of biomass (functional replacements).

Substrategy: Leverage the Unique Properties of Biomass To Expand Its Market Potential

Biomass has the potential to deliver a robust bioproducts portfolio by utilizing unique characteristics, such as biomass' oxygen content, the polymers in lignin, or constituents in primary product effluent. These attributes make biomass not just an alternative for petroleum, but an improvement in terms of potential product quality and mix, recycle/reuse of constituent streams, and energy input requirements relative to petroleum-derived compounds. The petroleum-based products industry is built upon the paradigm of using a highly saturated hydrocarbon as a starting material; thus, many modern products require the introduction of oxygen. Biomass offers a unique opportunity to shift this paradigm; as a starting material, it is highly oxygenated, so drop-in products can be made without additional oxygen. Novel, advanced products that would be too expensive to synthesize from petroleum could thus be introduced into the market.[34] Bioproducts improve the market for biomass, helping build the feedstock infrastructure necessary to expand the bioeconomy and achieve aggressive volumetric biofuels goals. BETO will invest in technologies capable of capitalizing on the unique properties of biomass to expand available markets and advance the industry.

- By 2030, develop process pathways to five functional replacement molecules that are sustainable, derived from biomass feedstock, and achieve >60% GHG emissions reduction and/or 25% overall energy input reductions compared to the molecules they replace.

Strategy: Validate Technology and Reduce Risk

Substrategy: Conduct Conversion Pathway Cost and Performance Verifications

Verification of bioenergy-conversion pathways underpins BETO's production cost and emissions-reduction estimates. BETO uses techno-economic and emissions-reduction models based on pathway verification to focus its R&D. BETO will support both national laboratory and private-sector verification of process pathways. Data generated in these verification exercises will be used to verify a mature, modeled selling price for biofuels pathways of $3/gge with GHG emissions reductions of 50% or more. BETO will also look beyond $3/gge to determine the feasibility of further cost reductions to be competitive with low-cost petroleum products.

- By 2017, verify at pilot scale at least one technology pathway for hydrocarbon biofuel production, demonstrating a mature modeled price of $3/gge with GHG emissions reduction of 50% or more.
- By 2018, complete gap analyses to identify the barriers and solutions to potentially reaching a mature modeled price of $2/gge for biofuels.

Substrategy: Support Pilot and Demonstration Facilities To De-Risk Biofuels and Bioproducts Production

Validating performance at integrated pilot- and demonstration-scale facilities is essential to de-risk technology and enable financing that will catalyze the transition to large-scale production of renewable biofuels and bioproducts. Operation at each of these scales addresses market and technical barriers that limit growth of the fledgling bioenergy industry. Integrated pilot projects prove the end-to-end process and help to develop engineering modeling tools. Demonstration-scale facilities allow for more optimized equipment specifications and manufacturing of products for commercial testing, leading to offtake agreements for pioneer plants. Finally, pioneer plants provide continuous operations with complete supply chains, de-risking future plants. BETO will continue to support pilot and demonstration facilities with industry partners that conduct unit operations, validate techno-economic assessments, and prove a variety of technologies at scale.

- By 2022, verify at pilot or demonstration scale two additional pathways for hydrocarbon biofuel production at a mature modeled price of $3/gge with GHG emissions reduction of 50% or more with the option of incorporating a bioproducts strategy.
- By 2027, demonstrate, at pilot scale, conversion technologies that meet low water use, low harmful emissions, and minimal wastewater treatment needs as defined by the 2019 multi-dimensional analysis that increase the cost of fuel by <$1/gge.

Strategy: Conduct Analysis To Inform Research and Development and Programmatic Priorities

Substrategy: Provide Analysis on the Environmental and Social Sustainability of Bioenergy

Concern about the environmental and social effects of large-scale feedstock production is one of the greatest barriers to stakeholders' acceptance of bioenergy, both domestically and internationally. BETO will continue to produce state-of-the-art analyses and tools, such as life-cycle analyses, watershed modeling, and innovative multi-metric assessments, to address these concerns. BETO will also consider data and analyses generated by other agencies, such as EPA and USDA, and work with these agencies to make continuous progress toward more sustainable outcomes. In addition, BETO will pursue cross-cutting efforts with DOE's Energy-Water Nexus to show the sustainability impacts of bioenergy. BETO will address three areas of analysis: sustainability, technology, and market analysis. Sustainability includes analyses of the cradle-to-grave lifecycle and land and water use impacts, as well as jobs and economic development impact. Technology analysis includes examining known conversion pathways and evaluating which products can be efficiently synthesized from various feedstocks. Market analysis includes assessments on the potential cost, commercialization time, and market demands for candidate biofuels, biopower, and bioproducts to focus technology development priorities in the near-, mid-, and long-term.

- By 2019, publish a multi-dimensional analysis that identifies and quantifies specific economic, environmental, and social benefits of a transition to a robust bioeconomy.

Substrategy: Provide an Analytical Framework for Bioproducts Research

Since its initial publication in 2004, DOE's Top Value-Added Chemicals from Biomass report and its subsequent updates have shaped national R&D priorities for bioproducts.[35] These reports provide an invaluable framework for prioritizing R&D and, with more comprehensive analysis, will support the bioproducts and biofuels industries. BETO will conduct analysis to identify promising novel materials and functional replacements needed to provide researchers with target molecules for synthesis. Market analysis is necessary to determine which petroleum-derived products are appropriate to replace with bioproducts. It will be important to understand how U.S. markets transition from bioproducts to biofuels as the consumption of biomass and the

production of bioproducts and biofuels grows. These analyses can help identify promising pathways and target molecules that are economically viable and meet aggressive sustainability targets.

- By 2020, provide an analytical framework for bioproducts research by publishing market and life-cycle analyses, roadmaps, and/or reports.

Substrategy: Establish Metrics To Guide BETO's Development of Integrated Value Chains that Achieve Broad Environmental, Societal, and Economic Benefits

Building upon previous efforts to identify key indicators for bioenergy sustainability, BETO will establish metrics to guide the development of integrated value chains for biofuels, biopower, and bioproducts. BETO will establish a methodology for calculating these metrics and encourage their use throughout its program. BETO will also refine the models within its portfolio to identify integrated value chain schemes that harness available, but under-used, feedstocks and infrastructure.

- By 2023, demonstrate a suite of analytical methods for quantifying environmental benefits associated with biomass and bioenergy production—such as decreasing harmful emissions and improving soil quality and water quality—that can be used to outline and define well-justified environmental goals.

Substrategy: Evaluate Biomass Carbon Capture and Utilization Benefits

Biomass-based carbon capture and utilization can help the fossil energy industry and other industrial-point sources of air pollution comply with emission standards, thereby strengthening local economies while improving air quality. BETO will evaluate the potential environmental and economic benefits of biomass carbon capture and utilization through production of low-carbon-intensity fuels and other approaches.

- By 2023, demonstrate a suite of analytical methods for quantifying environmental benefits associated with biomass and bioenergy production—such as decreasing harmful emissions and improving soil quality and water quality—that can be used to outline and define well-justified environmental goals.

Substrategy: Improve Knowledge of Biofuels Emissions Compared with Conventional Fuel Emissions

Biofuel combustion chemistry and its impact on engine efficiency and air quality is an active area of research.[36,37] For example, combustion of some biofuels produces less particulate matter, which is one of the most potent air pollutants from internal combustion engines, when compared to petroleum-derived fuels.[38,39] BETO will work with other offices and agencies, such as EERE's Vehicle Technologies Office (VTO) and EPA, to collect information about the impact of biofuel emissions on air quality compared to emissions from conventional fuels. This will inform joint efforts between BETO and VTO to optimize vehicle engines and biofuel formulations.

- By 2023, demonstrate a suite of analytical methods for quantifying environmental benefits associated with biomass and bioenergy production—such as decreasing harmful emissions and improving soil quality and water quality—that can be used to outline and define well-justified environmental goals.

Substrategy: Better Understand the Benefits of Bioenergy to Rural Communities

Biomass production can revitalize rural communities, create jobs, and provide additional social and environmental values by supporting agricultural and forestry, hauling and shipping, and coproduct industries. These benefits can take the form of diversification of skilled and professional jobs, with expansion of investments in infrastructure, access to services, and growth in ancillary sectors. In addition, this leads to investments in farms and forests resulting in benefits to producers, such as crop diversity, new markets, additional income, and reduced financial risks due to better waste product utilization. In collaboration with USDA, BETO will analyze the impacts of a growing bioeconomy on rural communities.

Key Opportunity: MOBILIZING OUR NATION'S BIOMASS RESOURCES

Strategic Goal: Reduce delivered cost and risks associated with feedstock quality and volume to accelerate widespread commercialization of sustainable biomass supply chains for a broad range of markets.

Expanding Strategic Focus

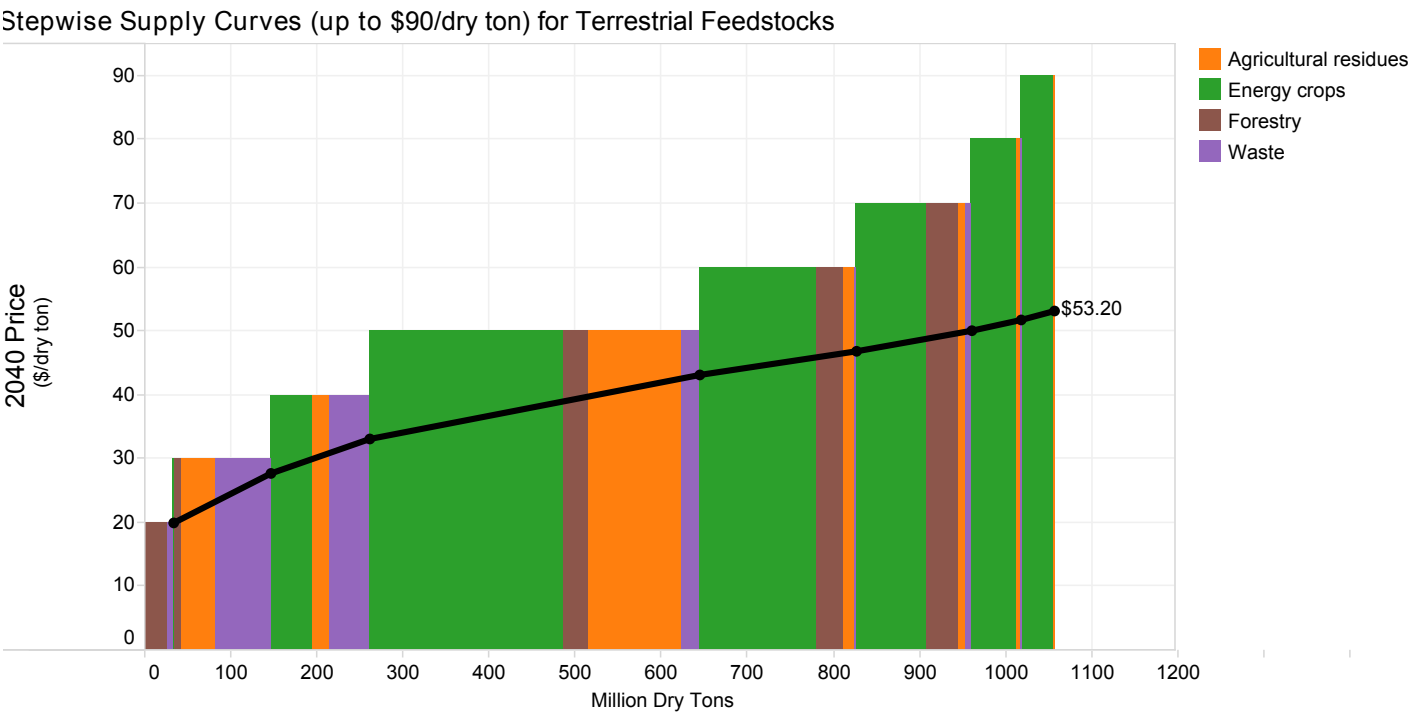
BETO's strategy focuses on reducing supply costs through technology and process improvements to catalyze market demand. This requires time for technology development, demonstration, and deployment into the marketplace. This strategic plan also targets market pull, which can have a very significant, near-term effect on mobilization.

The *2016 Billion-Ton Report* estimates potential biomass availability within the conterminous United States based on assumptions about current and future inventory, production capacity, feedstock availability, and technology.[40] BETO is working with its partners to sustainably mobilize 1 billion dry tons of renewable feedstocks annually by 2040. When achieved, this quantity of biomass could displace 25% of current transportation fuel needs.

Driving down feedstock cost has been, and will continue to be, a critical driver of biomass mobilization. Mobilization of the 1 billion dry tons requires shifting the supply curve over time (as shown for terrestrial biomass in figure 7) to produce higher volumes of feedstocks at affordable prices with low variability in quality.

In 2015, there was a significant market at the lower end of the supply curve for lignocellulosic biomass feedstocks (excluding algae and grain). BETO's vision for mobilization is that a thriving, mature bioeconomy will avoid feedstock pricing at the upper end of the supply curve. BETO's R&D strategies over the next 25 years are designed to achieve this goal by investing in technology advancements that capture efficiencies and reduce delivered cost and supply chain risk, enabling industry market strength to support self-sufficient, bioenergy-related production enterprises.

Figure 7. Biomass supply projections



Mobilization of the billion tons will require moving up the supply curve and paying more to access greater feedstock volumes. All demands for food, feed, and fiber are met prior to accessing the biomass feedstock supply projected here. Current uses of biomass (totaling 365 million tons) are not shown in this plot. (**Source:** *2016 Billion-Ton Report*).

Technology improvements in crop development, agronomic practices, logistics, and preprocessing that enter the market over time will increase demand and reduce the unit cost of biomass supply, drawing additional resources into the market.

This mobilization strategy consists of two components. The first involves cost-reduction strategies, which include improving crop yield, storage and transport operations, and machine and labor efficiency; reducing material losses during harvest; and increasing preprocessing. The second focuses on enabling markets to allow biomass to be accessed at affordable prices and providing more opportunities for sustainable operations. Both components, working together, are necessary to mobilize sufficient quantities of cost-competitive biomass.

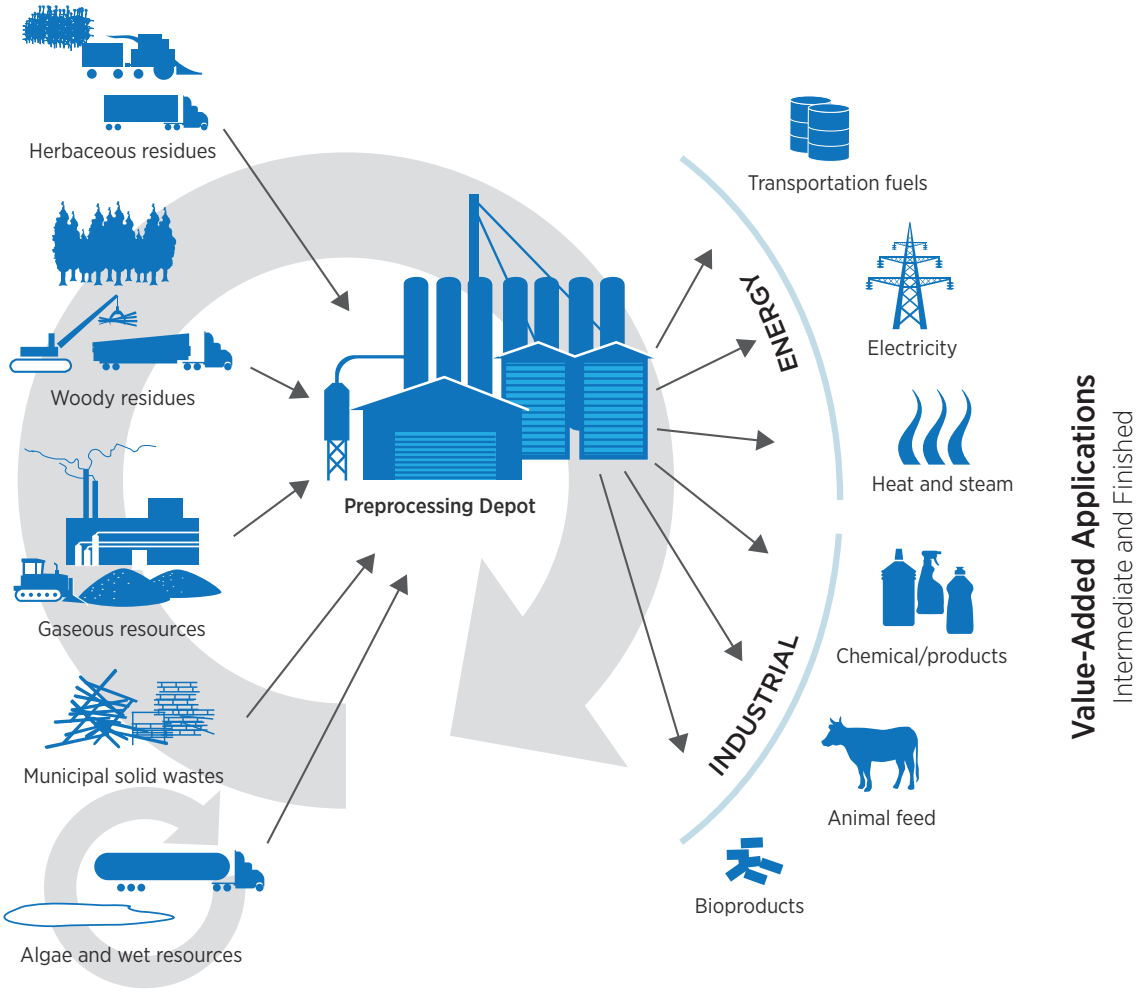
Demand for low-carbon-intensity feedstocks is increasing due to a combination of high petroleum-derived fuel prices, sustainability requirements, concern about the environment, and other market drivers. The result will be an increase in feedstock supply.

Strategies that foster market development can be characterized as "technology push" and "market pull." Broadly, strategies that increase biomass supply, decrease biomass cost, or increase biomass value, are considered technology push. Strategies that increase market demand are considered market pull. If advancements can be made in both technology push and market pull, then biomass production and use will increase.

Technology push benefits result from a combination of agricultural and logistics innovation across the feedstock supply chain, as well as from government policies and incentives. Market pull is created through innovation that adds product or value to the end use.

This biomass mobilization strategy includes companion markets that share in new supply chain infrastructure, invest in new technologies, and contribute to the reduction of supply chain risk. These companion markets broaden the liquid transportation fuels market to include biopower for electricity, heat, and steam; pulp and paper manufacturing; platform and specialty biochemicals; other industrial markets, such as production of animal feed, fertilizers, soil amendments, nutraceuticals, sorbents, and biodegradable plastics; and pellets and chips for domestic and export markets. Incorporating companion markets into the biomass mobilization strategy results in recovery and utilization of all biomass fractions generated throughout the supply system. Figure 8 provides a high-level illustration of how this is accomplished.

Figure 8. Schematic of the companion market approach for catalyzing market pull for mobilization of biomass resources



Source: *2016 Billion-Ton Report*

Biomass markets already exist within the chemicals, fuels, residential and commercial heating, and commercial sectors. U.S. consumption of lignocellulosic biomass for energy and energy products is estimated at approximately 365 million dry tons, excluding supply chain losses (which can be up to 30%). As the bioeconomy launches and matures, these market segments may shift or grow and new bioproducts will enter the market. For example, even assuming that biomass can be mobilized to meet bioenergy and bioproduct demand, a three-fold increase in lignocellulosic biomass will be needed to achieve the billion-ton bioeconomy vision.

BETO is addressing this challenge throughout the biomass supply chain and for multiple markets. The following core characteristics illustrate BETO's approach:

- **Affordable:** Reduce delivered cost and improve conversion process performance
- **Accessible:** Reduce risk/market barriers and demonstrate advanced logistics concepts
- **Sustainable:** Incorporate sustainability as a market enabler by establishing the value of ecosystem services
- **Multiple Markets:** Accelerate mobilization by enabling coproduct and value-added technologies.

These characteristics support the mobilization goal of 1 billion dry tons of renewable feedstocks annually by 2040, including herbaceous and woody feedstocks, algae, energy crops, and gaseous and wet waste feedstocks for bioenergy applications.

The following success indicators and/or milestones illustrate near-, mid-, and long-term activities designed to meet the strategic goal.

Success Indicators / Milestones

Near-Term

- By 2018, start to develop biomass feedstock grading or classification system for energy production and other end uses.
- By 2018, in collaboration with BETO's Communications Team, sponsor stakeholder engagement activities that seek to identify and enable markets for producers and users of biomass.
- By 2019, develop and provide a framework for multiple distributed processing scenarios for utilization of high-impact biomass feedstocks leading to commoditization, standardization, and risk mitigation.
- By 2019, develop and provide a framework for biomass quality grading systems for at least one woody and one herbaceous biomass supply-shed associated with an existing or planned demonstration-scale (or larger) biorefinery.
- By 2020, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $84/dry ton delivered cost target ($2014); including grower payment/stumpage fee and all logistics costs.
- By 2020, demonstrate integrated landscape management practices applied at the field scale for at least one cellulosic biomass-to-biorefinery supply chain and quantify examples of increased profitability, reduced risk, and enhanced environmental performance relative to current practices (2016).
- By 2021, demonstrate at a non-integrated field test scale, biomass composition as measured by a fractionation or equivalent approach that represent an energy content and convertibility of gasoline equivalency per ton of algae biomass in support of $3/gge algal biofuels.
- By 2021, develop and verify cellulosic feedstock supply and logistics systems that can economically and sustainably supply 258 million dry tons per year (excluding biopower) at a delivered cost of $84/dry ton ($2014) to support a biorefining industry utilizing diverse biomass sources.
- By 2022, verify at pilot or demonstration scale cellulosic feedstock supply and logistics systems that can economically and sustainably supply 285 million dry tons per year (excluding biopower) at a mature modeled delivered cost of $84/dry ton ($2014) to support a biorefining industry utilizing diverse biomass resources.
- By 2022, at non-integrated pre-pilot scale, demonstrate algal yield of 5,000 gallons of biofuel intermediate per acre per year via an outdoor R&D cultivation volume of 60,000 liters (or equivalent for non-open pond cultivation systems), in support of nth plant model $3/gge algal biofuels.
- By 2022, verify modeled techno-economic feasibility of nth plant $3/gge from wet waste streams.

Mid-Term

- By 2023, coordinate with USDA to promote new generation of farmer workforce development for roles within the agriculture sector to meet the billion-ton bioeconomy vision.
- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.
- By 2025, collaborate with original equipment manufacturers and biorefinery partners to develop and implement strategies and technologies that reduce losses by 20% in feedstock supply chains.
- By 2025, at integrated pre-pilot scale, demonstrate algal yield of greater than 5,000 gallons of biofuel intermediate per acre per year at a commercially-relevant outdoor cultivation volume for an open pond, attached growth, photobioreactor, or hybrid system design.
- By 2027, quantify and reduce risk through establishing commodity grades for multiple end users.

Long-Term

- By 2030, verify demonstration-scale production of algae-based biofuels at total production cost of $3/gge ($2014), with or without coproducts.
- By 2040, verify at least five operational supply chains that use a landscape design approach to reduce risks and costs of bioenergy production while delivering economic, social, and environmental benefits relative to current practices (2016).

Strategy: Reduce Delivered Feedstock Cost and Improve Conversion Process Performance

Substrategy: Maximize Yield and Minimize Cost of Sustainably Harvested Biomass ("Feedstock Yield")

Maximizing biomass feedstock quantity and quality is critical to reducing costs, improving grower profit and participation, and lowering risks associated with supply. To protect the land, BETO will develop a set of logistical systems that build on established soil- and water-conservation practices. These logistical systems include optimization of harvesting, handling, and storage operations to ensure minimal contamination; development of strategies and equipment that ensure harvested material is efficiently preprocessed at high yield and transported with minimal changes in quality; and development of active management procedures for stored biomass to minimize losses and changes in quality due to microbial action.

- By 2019, develop and provide a framework for multiple distributed processing scenarios for utilization of high-impact biomass feedstocks leading to commoditization, standardization, and risk mitigation.
- By 2025, collaborate with original equipment manufacturers and biorefinery partners to develop and implement strategies and technologies that reduce losses by 20% in feedstock supply chains.

Substrategy: Develop Integrated Systems and Technologies that Improve Algal Feedstock Yields

Under the right conditions, algae could be up to 100 times more productive than cellulosic bioenergy feedstocks. It is a challenge to achieve this level of productivity while maintaining sustainability, productivity, and affordability. BETO will invest in increasing algae productivity by improving strain selection, screening processes, the breeding of biologically mixed cultures, genetic engineering, and/or cultivation logistics. BETO will also continue researching cultivation strategies (such as pond design and nutrient addition through recycling) and economical algal biomass harvesting and dewatering technologies. Furthermore, BETO will focus on understanding the physical, chemical, biological, and post-harvest physiological variations in algae and how these affect and integrate with downstream processing.

- By 2021, demonstrate at a non-integrated field test scale, biomass composition as measured by a fractionation or equivalent approach that represent an energy content and convertibility of gasoline equivalency per ton of algae biomass in support of $3/gge algal biofuels.
- By 2022, at non-integrated pre-pilot scale, demonstrate algal yield of 5,000 gallons of biofuel intermediate per acre per year via an outdoor R&D cultivation volume of 60,000 liters (or equivalent for non-open pond cultivation systems), in support of nth plant model $3/gge algal biofuels.
- By 2025, at integrated pre-pilot scale, demonstrate algal yield of greater than 5,000 gallons of biofuel intermediate per acre per year at a commercially-relevant outdoor cultivation volume for an open pond, attached growth, photobioreactor, or hybrid system design.
- By 2030, verify demonstration-scale production of algae-based biofuels at total production cost of $3/gge ($2014), with or without coproducts.

Substrategy: Develop Advanced Feedstock Supply Systems that Enable Affordable Access to Distributed Biomass Resources

Advanced feedstock supply systems provide affordable access to distributed biomass resources by decoupling the feedstock supply system from the biorefinery operation and transforming raw biomass resources into a uniform, aerobically stable, high-density, tradable, and aggregated commodity. BETO will support R&D to improve the supply system and conversion performance (including depot infrastructure and active quality-control systems to minimize material losses) prior to delivery at the biorefinery in-feed system. Additional R&D will be conducted to convert existing systems into high-capacity handling, storage, and transport infrastructure, thus moving formatted, uniform biomass longer distances to a wider array of end users. BETO will also support the blending of uniform-format material with other formatted biomass and distribution of this mixture to biorefineries as an on-spec (higher quality), affordable feedstock for conversion processes with different in-feed specifications.

- By 2018, start to develop biomass feedstock grading or classification system for energy production and other end uses.
- By 2019, develop and provide a framework for biomass quality grading systems for at least one woody and one herbaceous biomass supply-shed associated with an existing or planned demonstration-scale (or larger) biorefinery.
- By 2020, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $84/dry ton delivered cost target ($2014); including grower payment/stumpage fee and all logistics costs.
- By 2021, develop and verify cellulosic feedstock supply and logistics systems that can economically and sustainably supply 258 million dry tons per year (excluding biopower) at a delivered cost of $84/dry ton ($2014) to support a biorefining industry utilizing diverse biomass sources.
- By 2022, verify at pilot or demonstration scale cellulosic feedstock supply and logistics systems that can economically and sustainably supply 285 million dry tons per year (excluding biopower) at a mature modeled delivered cost of $84/dry ton ($2014) to support a biorefining industry utilizing diverse biomass resources.

Strategy: Reduce Risk/Market Barriers and Demonstrate Advanced Logistics Concepts

Substrategy: Support Integrated Pilot and Demonstration Facilities

To encourage the successful broad-scale mobilization of biomass resources, BETO will support pilot-plant testing of feedstock systems. This testing will allow industry partners to integrate unit operations, validate techno-economic assessments, and prove various technologies' capability for producing solid and liquid intermediates at scales relevant to private investors. BETO will continue to encourage private investment by verifying performance at integrated demonstration facilities that use innovative technologies at commercial scale.

- By 2020, demonstrate integrated landscape management practices applied at the field scale for at least one cellulosic biomass-to-biorefinery supply chain and quantify examples of increased profitability, reduced risk, and enhanced environmental performance relative to current practices.

Substrategy: Support Demonstration and Validation of Affordable and Sustainable Biomass Supply Chains

BETO will support the demonstration and validation of landscape design approaches and feedstock logistics systems that enable resilient commercial bioenergy supply chains. In collaboration with USDA and other partners, BETO will explore how landscape design principles can reduce risks while supplying biorefineries with on-spec (higher quality), affordable feedstocks. Building these integrated, resilient supply chains supports the growing bioeconomy in a way that enhances economic, environmental, and social value.

- By 2020, demonstrate integrated landscape management practices applied at the field scale for at least one cellulosic biomass-to-biorefinery supply chain and quantify examples of increased profitability, reduced risk, and enhanced environmental performance relative to current practices (2016).
- By 2040, verify at least five operational supply chains that use a landscape design approach to reduce risks and costs of bioenergy production while delivering economic, social, and environmental benefits relative to current practices (2016).

Substrategy: Provide Data and Information on Genetically Engineered Algae to the Public and to Regulatory Agencies

Genetically engineered species may need to be cultivated in large-scale open ponds to meet algal yield goals and regulatory requirements. In these cases, BETO will provide information on genetically engineered algae, such as environmental dispersal mechanisms and impacts and new genetic engineering strategies, to the public and to regulatory agencies.

- By 2025, at integrated pre-pilot scale, demonstrate algal yield of greater than 5,000 gallons of biofuel intermediate per acre per year at a commercially-relevant outdoor cultivation volume for an open pond, attached growth, photobioreactor, or hybrid system design.
- By 2030, verify demonstration-scale production of algae-based biofuels at total production cost of $3/gge ($2014), with or without coproducts.

Substrategy: Conduct Supply Chain Analyses of Current and Alternative Supply and Logistics Systems for Identification of Benefits/Limitations

A vibrant bioeconomy requires a thorough understanding of the entire biomass supply chain, including available biomass resources, sustainability criteria, and the impact of various policy actions. Current and alternative supply and logistics systems must limit costs, preserve and enhance quality, and control risks. BETO will support the development of a thorough set of analyses, methodologies, and tools to gain necessary insights into the inter-dependencies of an economically and environmentally sustainable bioenergy supply chain.

- By 2019, develop and provide a framework for multiple distributed processing scenarios for utilization of high-impact biomass feedstocks leading to commoditization, standardization, and risk mitigation.
- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.
- By 2025, collaborate with original equipment manufacturers and biorefinery partners to develop and implement strategies and technologies that reduce losses by 20% in feedstock supply chains.

Substrategy: Perform Quantifiable Assessment of Supply Chain Risk

Comprehensive and systematic methods for quantifying supply chain risk are needed so that project developers and potential investors can accurately and fairly value feedstock risk and, ultimately, move more projects forward. BETO will support the development of analyses, tools, and methodologies for quantifying biomass supply chain risks. These risks include financial, technical, and social uncertainties associated with supply, logistics, preprocessing, handling, and quality characteristics.

- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.

Substrategy: Develop Monitoring, Standardizing, and Grading Approaches for Feedstocks

A standard, systematic approach for feedstock valuation will create optimal pathways for converting our diverse feedstock resources into both energy and other bioproducts. BETO will support the development of definitive feedstock quality specifications, methodologies, and architecture to support a specifications approach for biomass feedstock materials. BETO will also support the development of processes and technologies to quickly and accurately measure important physical and chemical feedstock characteristics.

- By 2018, start to develop biomass feedstock grading or classification system for energy production and other end uses.
- By 2019, develop and provide a framework for biomass quality grading systems for at least one woody and one herbaceous biomass supply-shed associated with an existing or planned demonstration-scale (or larger) biorefinery.
- By 2027, quantify and reduce risk through establishing commodity grades for multiple end users.

Substrategy: Contribute to Outreach/Training

Current education and training programs are inadequate to meet a fully developed bioenergy sector. BETO will coordinate with USDA to promote workforce development for the next generation of bioenergy stakeholders to ensure continued expansion of the billion-ton bioeconomy vision.

- By 2023, coordinate with USDA to promote new generation of farmer workforce development for roles within the agriculture sector to meet the billion-ton bioeconomy vision.

Strategy: Incorporate Sustainability as a Market Enabler by Establishing the Value of Ecosystem Services

Substrategy: Support Development, Measurement, and Monitoring of Sustainability Indicators

The bioeconomy must follow both established and emerging standards and regulations that guide responsible agriculture, forestry, and algae-cultivation practices. BETO-supported activities will follow established practices (such as soil- and water-conservation practices for residue removal and energy crop production) and gather data needed to improve them. BETO will also consider relevant measurements of emissions, soil and air quality, water quantity and quality, and biodiversity when evaluating technology alternatives. BETO will address questions regarding algal biomass sustainability, such as those about land and water use, algae dispersal, nutrient recycling, and use of pond liners. BETO will also analyze real-world case studies that apply science-based indicators to characterize and highlight the environmental and socioeconomic sustainability of these advanced bioenergy systems.

- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.

Substrategy: Develop and Demonstrate Sustainable Resource Management Practices that Reduce Cost, Improve Environmental Performance, and Increase Social Acceptability

An integrated landscape approach to implementing bioenergy supply chains can reduce a number of environmental and socioeconomic risks to the industry. These risks include public resistance, uncertainties about impacts on environmental quality and food production, and land managers' challenges in producing feedstocks in a practical and profitable way. Bioenergy supply chains must also be resilient to inevitable market swings and extreme weather events. In close collaboration with USDA and other agencies, BETO will support the development of integrated landscape-management strategies that reduce risk and enhance profitability across the supply chain. These strategies will also maintain or enhance environmental quality and meet biorefineries' needs for high-quality, reliable feedstocks. BETO will also pursue innovative ways to increase value for producers, such as capitalizing on underproductive areas within their fields and finding ecosystem-service markets that will compensate them for generating water-quality, carbon, or soil benefits. For sustainable algal biofuel production, BETO will consider the geographic location of cultivation facilities in relation to water and nutrient utilization.

- By 2020, demonstrate integrated landscape management practices applied at the field scale for at least one cellulosic biomass-to-biorefinery supply chain and quantify examples of increased profitability, reduced risk, and enhanced environmental performance relative to current practices (2016).
- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.

Substrategy: Better Characterize Waste Streams and Potential Fuel End Products from Waste

Converting waste to fuel is compelling, as it maximizes bioenergy's value proposition. However, municipal waste composition and availability is measured on a national level and is not consistently assessed locally or regionally. Other potential waste feedstocks, such as waste industrial gases, are also not well quantified. BETO will work to quantify and characterize these resources to develop an informed strategy for converting them into appropriate fuel products.

- By 2022, verify modeled techno-economic feasibility of nth plant $3/gge from wet waste streams.

Substrategy: Develop Integrated Systems and Technologies that Enable Wet and Gaseous Waste Streams as Feedstocks

Organic waste streams—including, but not limited to, manure; municipal wastewater; industrial wastewater; institutional, commercial, and residential food wastes; and the nonrecyclable fraction of MSW—represent a significant potential source of renewable energy. While substantial in size when aggregated, individual sources tend to be much smaller than the scale associated with traditional refineries. BETO will support the development of a distributed conversion strategy, potentially producing transportable intermediates, to take optimal advantage of these feedstocks. BETO will also investigate the conversion of feedstocks, such as manure or biosolids, to liquid biofuels or bioproducts, instead of the typical biogas.

Gaseous feedstocks include methane from landfills; anaerobic digesters; oil and gas operations; coal beds; carbon monoxide streams from electricity generation; ethanol production; cement manufacturing; and other industrial processes. Collection and use of carbon streams from such gaseous feedstocks, which are currently flared or vented, could replace virgin extraction of fossil resources. BETO will thus identify and develop appropriate gaseous feedstock-conversion strategies to low-carbon-intensity fuels and products, such as coconversion of sugars or other intermediate and CO_2, artificial photosynthesis, etc.

- By 2022, verify modeled techno-economic feasibility of nth plant $3/gge from wet waste streams.

Strategy: Accelerate Mobilization by Enabling Coproduct and Value-Added Technologies

Substrategy: Engage Industry Stakeholders To Enable Markets

To establish a dynamic cycle of biomass supply and use, it is critical to convince producers that markets do exist for their biomass along the entire supply chain, and end users that sufficient biomass is available at the cost and quality needed for their processes and products. Through workshops, conferences, request for information announcements, and FOAs, BETO will inform and engage market participants who can provide either the "market push" or the "market pull" for biomass for bioenergy applications.

- By 2018, in collaboration with BETO's Communications Team, sponsor stakeholder engagement activities that seek to identify and enable markets for producers and users of biomass.

Substrategy: Produce Intermediates, Coproducts, Byproducts, and Eco-Services

Recovering and extracting the highest possible value from all fractions generated in preprocessing will reduce the cost of preprocessing operations. BETO will support the development of merchandisable intermediates, coproducts, and ecosystem services that enable the cost-effective supply of feedstocks for energy markets.

- By 2018, start to develop biomass feedstock grading or classification system for energy production and other end uses.
- By 2019, develop and provide a framework for multiple distributed processing scenarios for utilization of high-impact biomass feedstocks leading to commoditization, standardization, and risk mitigation.
- By 2024, demonstrate at least three operational (>40 acres) bioenergy systems that use landscape design principles to reduce risks and costs of bioenergy production across multiple stages of the supply chain, such as coupling bioenergy production with ecosystem service markets related to water quality, carbon, or soil benefits.

Key Opportunity: CULTIVATING END-USE MARKETS AND CUSTOMERS

Strategic Goal: Meet early-adoption market demands and catalyze new markets that support sustainable, affordable living.

In the last decade, the biofuel market in the United States has grown substantially. From 2007 to 2015, ethanol production increased from 6.5 billion gallons per year to 14.8 billion gallons per year, and biomass-based diesel production grew from 0.5 billion gallons per year to 1.3 billion gallons per year. Cellulosic biofuels began to enter the market in 2013, reaching 33 million gallons in 2014.[41] The low-level-blend ethanol market is saturated, with nearly all gasoline in the United States currently blended with 10% ethanol. Further growth in the biofuels market will require tapping into new and expanded markets, exploring novel biofuel applications, and expanding distribution and dispensing infrastructure.

Biopower and bioproducts markets have also expanded—though at a slower rate than biofuels markets. In 2014, the bioproducts industry contributed $393 billion to the U.S. economy, and the biopower industry generated nearly 41.2 billion kilowatt-hours of electricity in the United States.[42, 43]

Public policies and regulations have played an important role in stimulating the nascent bioenergy industry. Biofuel production in the United States has more than doubled since the passage of EISA in 2007. California's Low Carbon Fuel Standard has also sparked biofuel demand and Corporate Average Fuel Economy standards have driven improvements in vehicle efficiency and promoted biofuel-compatible vehicles. Given the role that policy has in supporting bioenergy industry growth, BETO has an important responsibility in supporting technical analysis to inform future policy development.

Leveraging early-adopter markets that are likely to demand and sustain investments in biobased commodities, such as the aviation, maritime, and heavy-duty trucking industries, will be critical in growing the bioenergy market. These early adopters will be influential in establishing a self-sustaining bioeconomy and creating and maintaining systems for producing and supplying biobased commodities. Once a foundation is set for the bioeconomy, market analysis can identify and support expansion into new markets that will help the nation achieve its energy security and economic goals.

BETO's role in meeting early-adoption market demands and catalyzing new markets begins with understanding market needs and opportunities. This involves determining which markets are best suited to adopt biobased commodities and characterizing their primary market drivers. By shedding light on specific markets, BETO can play a role in bringing commodities to these markets. Many new commodities need approval by standards-setting organizations like the American Society for Testing Materials and the International Organization for Standardization before they can enter the market. While BETO does not have the authority to approve standards, it can facilitate the review process by convening standards-setting organizations to establish certification norms and best practices for review. Once products are market-ready, BETO can encourage initial private investment through de-risking and scale-up activities, including funding pilot- and demonstration-scale projects. These will propel market confidence that the products can be produced in an economically sustainable manner.

The following success indicators and/or milestones illustrate near-, mid-, and long-term activities designed to meet the strategic goal.

Success Indicators / Milestones

Near-Term

- By 2018, complete a robust market analysis that identifies specific future commodity fuel and bioproducts markets of interest and the near- and mid-term markets that will support technology development and scaling.
- By 2018, define the infrastructure requirements to increase current and future biofuel blend levels in commercial use.
- By 2018, develop a set of market indicators to track progress of the growing domestic bioenergy and bioproduct industrial sectors.
- By 2020, complete construction and initial operations for at least three pilot-and/or demonstration-scale, integrated biorefineries to enable the subsequent development of pioneer commercial plants for advanced biofuels and bioproducts.

Mid-Term

- By 2025, demonstrate production of bioproducts at needed scales (20-100 kg) for product testing to support offtake agreements.
- By 2025, complete testing needed to ensure that biofuels entering the market meet compatibility requirements and standards needed for commercialization and deployment.
- By 2025, complete projects that will result in 5,000-10,000 gallons of alternative jet fuel for testing in jet engines to contribute to significant net carbon emissions reductions from the aviation industry.

Long-Term

- By 2030, validate successful runs of additional two different biofuels and/or bioproducts manufacturing processes based on different conversion pathways at demonstration-scale.
- By 2030, demonstrate a 30% reduction in per-vehicle petroleum consumption resulting from co-optimized fuels and engines that have increased engine efficiency and use lower life-cycle GHG emissions fuels (>50% reduction from petroleum) (in collaboration with DOE's VTO).
- By 2040, demonstrate an additional 9%–14% reduction in transportation fleet GHG emissions resulting from the deployment of co-optimized fuels and engines (in collaboration with DOE's VTO).

Strategy: Conduct Detailed Market Analysis for Biofuels and Bioproducts

Understanding the markets for biofuels and bioproducts is critical for focusing BETO's technology-development efforts. Detailed market analyses will help guide long-term strategy; identify how smaller, near-term markets can support development of a robust bioeconomy; and guide interim target development. Analysis will evaluate the near-, mid-, and long-term markets for commodity fuels, allowing the program to focus on markets that support technology development for future commodity fuels. In addition, ancillary markets will be evaluated to leverage advanced technologies that are likely to impact future commodity fuels.

- By 2018, complete a robust market analysis that identifies specific future commodity fuel and bioproducts markets of interest and the near- and mid-term markets that will support technology development and scaling.

Strategy: Conduct Detailed Market Analysis for Biofuels and Bioproducts

Early adopters, such as the aviation industry, municipal fleets, and the U.S. Department of Defense fleets, are anticipated to play a large role in using these new biofuels and bioproducts. BETO will employ strategic analysis to identify market needs and leverage conversion R&D to de-risk advanced bioenergy production, accelerate technology adoption, advance precompetitive technologies, and create a pathway to market. BETO will support the integrated production and scale-up of fungible hydrocarbon biofuels with new investments that will accelerate the momentum for advanced biofuel manufacturing and will broaden the portfolio of hydrocarbon fuel production at pilot- and demonstration-scales.

Novel markets for advanced biofuels will be considered, including codesigning next-generation engines and biofuels through a collaboration with Vehicle Technologies Office. Co-optimization of fuels and engines offers the potential to significantly

improve vehicle engine efficiency, maximize engine performance and carbon efficiency, and reduce harmful emissions through accelerating the widespread deployment of improved fuels and engines. BETO will work with the national laboratories and stakeholders to address technical barriers and facilitate eventual market entry of co-optimized fuels and engines.

- By 2025, complete projects that will result in 5,000-10,000 gallons of alternative jet fuel for testing in jet engines to contribute to significant net carbon emissions reductions from the aviation industry.
- By 2025, demonstrate production of bioproducts at needed scales (20-100 kg) for product testing to support offtake agreements.
- By 2030, demonstrate a 30% reduction in per-vehicle petroleum consumption resulting from co-optimized fuels and engines that have increased engine efficiency and use lower life-cycle GHG emissions fuels (>50% reduction from petroleum) (in collaboration with DOE's VTO).
- By 2040, demonstrate an additional 9%–14% reduction in transportation fleet GHG emissions resulting from the deployment of co-optimized fuels and engines (in collaboration with DOE's VTO).

Strategy: Support Capacity Building

Investing in improvements to production-capacity and other supply chain infrastructure reduces technical and financial risks and enables end-use markets for new biofuels, products, and technologies. A major component of this strategy includes piloting larger-scale demonstration activities for earlier-stage technologies that still are subject to significant technical, commercial, and regulatory risks. A second component entails the development and optimization of applications, systems, and infrastructure to enable greater efficiency and impact for biobased fuels and products. Given the hesitance of private equity and debt providers to take on such risk, BETO plays an essential role at this stage by providing technical and financial support to demonstrate scalability and feasibility for new fuels, products, and processes.

- By 2018, define the infrastructure requirements to increase current and future biofuel blend levels in commercial use.
- By 2020, complete construction and initial operations for at least three pilot-and/or demonstration-scale, integrated biorefineries to enable the subsequent development of pioneer commercial plants for advanced biofuels and bioproducts.
- By 2030, validate successful runs of additional two different biofuels and/or bioproducts manufacturing processes based on different conversion pathways at demonstration-scale.

Strategy: Interact with Mid-Stream Consumers

Developing new offtake routes and leveraging existing infrastructure reduce cost, market, and technology risks. Key to this approach is adding value upstream of the final fuel or chemical product by providing process and/or intermediate product optionality. At the farthest upstream point, for example, developing and diversifying direct biomass product streams such as animal feed, food, and power generation will allow biomass growers and aggregators flexibility in their own end markets. Similarly, spurring innovation around intermediates—such as "clean," conditioned lignocellulosic sugar streams or other product precursors like biomass-derived chemical intermediates—will create market volume for the manufacturers of these platform products as value opportunities emerge for less-expensive, downstream upgrading processes.

In a complementary fashion, demonstrating, validating, and creating partnerships for petroleum refinery integration could be a critical cost-reduction strategy. This would minimize near- and mid-term capital expenditures risk by leveraging existing conversion and upgrading infrastructure. It would also engage key stakeholders with the market reach needed for large-volume fuel and chemical distribution and offtake. Finally, implementing "bolt-on" downstream conversion technologies—designed to be attached directly to an existing facility with minimal changes— into new and existing starch and cellulosic operations could be important in bridging first-generation biobased production, based on simple sugars, with technologies that employ more advanced, and currently less mature, lignocellulose-based bioprocesses.

This approach to reduce and decouple upstream and downstream technology risk will spur investment and partnerships among existing industrial biotech players, new cellulosic technology developers, and incumbent and emerging downstream product markets. Combinations of technologies, such as cellulosic biobutanol, alcohol-to-jet fuel or butanol, cellulosic terpene/

hydrocarbon, and heterotrophic algae oil and protein production, can be prioritized based on economic and sustainability analyses. DOE and BETO will work with key stakeholders to facilitate networks and support integration efforts across various mid-stream approaches.

- By 2025, complete projects that will result in 5,000-10,000 gallons of alternative jet fuel for testing in jet engines to contribute to significant net carbon emissions reductions from the aviation industry.

Strategy: Inform Supportive Policies for Biofuels and Bioproducts

Enabling the production, offtake, and end-market use of current, developing, and emerging biofuels and bioproducts rests on robust analysis and outreach regarding the benefits and implementation of supportive policies for this emerging industry. Key audiences and players include Congress, DOE offices, and other federal agencies, as well as both the research and investment communities. Factors such as land use, feedstock and conversion costs, and process safety are important for determining volume forecasts, pricing, and stakeholder benefits in the United States and globally for each new biofuel and bioproduct. BETO will continue to provide the analytical framework for maximizing positive environmental impacts of the growing bioenergy industry.

Collecting, analyzing, and validating data that augments current policy options may play an important role in this regard—for example, in increasing cellulosic ethanol blend levels to transform the market for this existing biofuel. Using a similar approach, working with industry and global policy makers will continue to be an important tool in driving production and early adoption of emerging biofuels in the aviation industry, where there is currently broad awareness and recognition of the societal and environmental benefits of biobased jet fuel. This technical analysis is critical for quantifying benefits, not only for the biofuels industry, but also for new bioproducts. Identifying ways to provide equal regulatory footing to bioproducts with a positive societal and environmental impact will be critical as the nation transitions to the bioeconomy.

Working with other DOE offices and with other federal agencies, BETO will provide analytical and communications support for policy initiatives on biobased product scaling and end-use market growth. In addition, BETO will create broader awareness within the industry and among the public about the benefits of biorefining, biofuels, and bioproducts. BETO will continue to inform policy decisions and frameworks for developing the bioeconomy, especially in light of commercial and regulatory risks that might otherwise outweigh new product introduction in the short term.

- By 2018, develop a set of market indicators to track progress of the growing domestic bioenergy and bioproduct industrial sectors.
- By 2030, demonstrate a 30% reduction in per-vehicle petroleum consumption resulting from co-optimized fuels and engines that have increased engine efficiency and use lower life-cycle GHG emissions fuels (>50% reduction from petroleum) (in collaboration with DOE's VTO).
- By 2040, demonstrate an additional 9%–14% reduction in transportation fleet GHG emissions beyond business as usual projections resulting from the deployment of co-optimized fuels and engines (in collaboration with DOE's VTO).

Strategy: Support Standards Development

BETO will continue to support the generation of critical data required to develop technically sound codes and standards needed for commercialized, safe, and responsible deployment of alternative fuels. BETO will facilitate and promote collaborative efforts among government, industry, standards-development organizations, universities, and national laboratories in an effort to harmonize regulations, codes, and standards, both domestically and internationally. BETO will also contribute technical expertise to domestic and international efforts that are developing or implementing sustainability-related standards. BETO's involvement will seek to promote science-based practices and standards that enable a vibrant bioeconomy that delivers positive environmental, social, and economic outcomes.

- By 2025, complete testing needed to ensure that biofuels entering the market meet compatibility requirements and standards needed for commercialization and deployment.

Key Opportunity: EXPANDING STAKEHOLDER ENGAGEMENT AND COLLABORATION

Strategic Goal: Grow an informed community of public and private stakeholders that understands and contributes to an enduring, sustainable bioeconomy, while appreciating its challenges and benefits.

Stakeholder engagement, including both BETO partnerships and communications with stakeholders and the public, is a vital area of BETO's work. To be vibrant and enduring, the bioeconomy must involve successful, coordinated operations among many industries and sectors of the U.S. economy, from biomass producers to end-use markets. A range of diverse groups must be involved to both produce and purchase biofuels and bioproducts. As researchers and industry overcome technical barriers to commercialization, effective stakeholder collaboration and communication plays the important role of addressing nontechnical, cultural, and social barriers to bioenergy adoption and utilization. Although it may not be feasible to gain the support of the entire American public, a strong network of coordinated, informed people among public and private sectors can enable the bioeconomy to succeed; this network is essential for the bioeconomy's long-term success. This community must not only be educated about bioenergy and the role of BETO's work, but it must also have an appreciation for the bioeconomy's challenges and benefits.

BETO will work to strengthen stakeholder relationships, improve the quality of stakeholder collaborations, and increase awareness of bioenergy and BETO's role among the general public and new stakeholder groups. BETO stakeholder groups vary from nontechnical members of the public to highly technical researchers and bioenergy industry professionals.

Across the board, members of these groups have varying levels of knowledge, including some misconceptions about bioenergy and the bioeconomy; therefore, BETO needs to educate both technical and nontechnical audiences with factual, science-based information. The general public is considered a stakeholder group because they can support bioenergy as informed citizens and consumers.

Successful stakeholder engagement will result in improved understanding among relevant stakeholder groups and more effective collaboration across BETO, Congress, and other federal agencies. It will also lead to the development of a well-trained bioeconomy workforce, an increase in timely and reliable information about BETO-supported advancements, and a better understanding of bioenergy among target audiences.

The following success indicators and/or milestones describe near-, mid-, and long-term activities for stakeholder engagement in support of an enduring, sustainable bioeconomy.

Success Indicators / Milestones

Near-Term

- Starting in fiscal year 2017, develop a series of stakeholder-specific educational tools to improve understanding within the agriculture, algae, forestry, and investment communities regarding the economic, environmental, and social benefits of participating in the bioeconomy.
- In 2017, establish at least two new channels of communication with policy makers, including notification of new state and local initiatives, informational briefings for the Administration and Congressional staff, and the amplification of state fact sheets detailing the BETO activities.
- In 2018, establish a requirement for all funding awardees to develop and implement a communications plan to disseminate results and impacts of BETO-sponsored projects.
- By 2018, sponsor 2-4 annual stakeholder information and networking sessions for identifying challenges, barriers, opportunities, and educational initiatives.
- By 2020, amplify existing initiatives and implement two new education and training programs to match the growing number of bioenergy industry workers.
- By 2020, establish vibrant and effective stakeholder engagement initiative coordinated within and between DOE, USDA, EPA, and other federal agencies to enable joint initiatives to advance and expand the U.S. bioeconomy.
- By 2022, establish annual educational materials and outreach efforts to inform general public and key stakeholder audiences about the challenges and opportunities of a thriving bioeconomy.
- By 2022, enhance public awareness and market interest in advanced bioenergy by collaborating with a highly visible organization to promote a successful technical and/or communications project and its outcomes.

Mid-Term

- By 2025, assess progress on developing education and consumer behaviors and refine strategy as needed.
- By 2025, have robust workforce development programs in place to support a group of well-trained workers to fill the demand created by a growing bioeconomy.
- By 2025, establish 3-5 collaborative initiatives with corporate and nongovernmental organizations to assist in the continued growth of a sustainable bioeconomy.

Long-Term

- By 2035, evaluate effectiveness of unified communications and outreach efforts, refine as needed.

Strategy: Develop Education and Workforce Development Programs

To maximize its mission impact, BETO will develop and implement an education and workforce development program for students and educators of all ages (K–12 schools, vocational schools, colleges, universities, and informal education programs). BETO will increase awareness of the emerging bioeconomy to better prepare and excite the future workforce for the opportunities and challenges in developing a thriving bioeconomy. The programs will aim to increase public access to information on bioenergy production, the industry, and the bioeconomy through the production of targeted tools, events, and publications that discuss the basics of bioenergy. Through the development of materials, the programs will support formal and informal education, including STEM (science, technology, engineering, and mathematics) and vocational programs, in exploring issues relevant to sustainable production of biofuels and bioproducts. BETO will support the advancement of the bioenergy workforce by developing and enhancing traditional and non-traditional pathways to bioenergy-related training and careers.

- Starting in fiscal year 2017, develop a series of stakeholder-specific educational tools to improve understanding within the agriculture, algae, forestry, and investment communities regarding the economic, environmental, and social benefits of participating in the bioeconomy.

- By 2018, sponsor 2-4 annual stakeholder information and networking sessions for identifying challenges, barriers, opportunities, and educational initiatives.
- By 2020, amplify existing initiatives and implement two new education and training programs to match the growing number of bioenergy industry workers.
- By 2025, have robust workforce development programs in place to support a group of well-trained workers to fill the demand created by a growing bioeconomy.

Strategy: Target and Engage Stakeholder Audiences

The general public and bioenergy industry stakeholders have varied knowledge about bioenergy technologies and differing interests and priorities. To engage them effectively and to build an informed community among these different groups, BETO needs to understand each of these groups and design effective strategies to reach and engage them. BETO will conduct stakeholder research, which will involve segmenting stakeholder groups (including groups within the general public and industry), and then design and implement communications strategies tailored to the specific needs and knowledge levels of each group. BETO will monitor and assess the effectiveness of these strategies to provide individuals among these different stakeholder groups a more informed view of the bioeconomy.

- By 2018, sponsor 2-4 annual stakeholder information and networking sessions for identifying challenges, barriers, opportunities, and educational initiatives.
- By 2025, establish 3-5 collaborative initiatives with corporate and nongovernmental organizations to assist in the continued growth of a sustainable bioeconomy.
- By 2025, assess progress on developing education and consumer behaviors and refine strategy as needed.
- By 2035, evaluate effectiveness of unified communications and outreach efforts, refine as needed.

Strategy: Strategically Track and Communicate Results of BETO-Sponsored Projects

BETO successes are inextricably linked to the national laboratories, private companies, universities, and other organizations that perform the work for the projects it funds. Many projects funded by BETO already implement their own communications strategy, disseminating information and coordinating with stakeholders. This approach provides stakeholders with a firsthand account of the project's results from those most intimately involved with the project. BETO believes that this strategy increases the effectiveness of its outreach and, therefore, advises that FOAs include requirements tailored to the objectives of each individual FOA, asking the awardee to describe how the project's outcomes and successes will be communicated. The BETO Communications Team will coordinate with BETO-sponsored projects and technical teams to communicate all significant project accomplishments to stakeholders and audiences in a strategic and timely way.

- In 2018, establish a requirement for all funding awardees to develop and implement a communications plan to disseminate results and impacts of BETO-sponsored projects.
- By 2025, assess progress on developing education and consumer behaviors and refine strategy as needed.
- By 2035, evaluate effectiveness of unified communications and outreach efforts, refine as needed.

Strategy: Strengthen Public-Private Partnerships

To enhance public awareness of and market demand for advanced bioenergy technologies, BETO will identify opportunities that are highly visible and relevant to communities and to peoples' everyday lives. Although not traditionally part of its RD&D activities, BETO will assist in developing relationships among bioenergy producers and end users, high-profile adopters, and advocates to promote advanced bioenergy and implement media strategies that communicate tangible success stories to local

communities and consumers. Collaborative efforts with other EERE initiatives, such as Clean Cities and the State Energy Program, will encourage and promote public-private collaborations and bioenergy projects, such as the use of advanced biofuels in public transportation vehicles and government fleets. Information sessions will be planned and hosted to share the results of research, products, and technologies. Such events will include, for example, field days that engage landowners and farmers, webinars on tools and technologies developed by the national laboratories, and workshops on emerging topics.

- By 2020, establish vibrant and effective stakeholder engagement initiative coordinated within and between DOE, USDA, EPA, and other federal agencies to enable joint initiatives to advance and expand the U.S. bioeconomy.
- By 2022, enhance public awareness and market interest in advanced bioenergy by collaborating with a highly visible organization to promote a successful technical and/or communications project and its outcomes.
- By 2025, establish 3-5 collaborative initiatives with corporate and nongovernmental organizations to assist in the continued growth of a sustainable bioeconomy.

Strategy: Engage and Inform Policy Makers

BETO must educate elected and appointed officials at all levels of government on the elements of an advanced bioeconomy and on clean energy activities through briefings, site visits, and educational materials. These educational efforts target members of Congress, policy makers in federal agencies, governors, state and tribal governments, state and territorial legislators, mayors, and county executives.

BETO will demonstrate how biofuels and bioproducts can stimulate state and local economies to create well-paying jobs, and also demonstrate that these initiatives can be achieved in a sustainable manner, for instance, by reducing the cost of renewable diesel fuel made from fats, tallow, and grease, and thus, reducing landfill wastes. BETO will establish new channels of communication with these officials to keep them abreast of the latest breakthroughs in technologies and manufacturing processes, as well as how bioproducts can be locally applied with the help of experts from DOE and the national laboratories. BETO will continually work to improve government officials' perceptions of the regional and statewide benefits of a sustainable bioeconomy by scheduling site visits, designing targeted communications and educational products, and hosting events and briefings.

- In 2017, establish at least two new channels of communication with policy makers, including notification of new state and local initiatives, informational briefings for Administration and Congressional staff, and the amplification of state fact sheets detailing the BETO activities.
- By 2020, establish vibrant and effective stakeholder engagement initiative coordinated within and between DOE, USDA, EPA, and other federal agencies to enable joint initiatives to advance and expand the U.S. bioeconomy.
- By 2022, establish annual educational materials and outreach efforts to inform general public and key stakeholder audiences about the challenges and opportunities of a thriving bioeconomy.

Strategy: Support Intra- and Interagency Collaboration

Collaboration within DOE and with other federal agencies will advance innovative technologies through interconnected R&D. By bridging the gaps between fundamental and applied R&D, existing scientific expertise and infrastructure will be maximized by leveraging knowledge from multiple sources, thus supporting specific, application-informed research. BETO will establish and coordinate technology transfer among programs, offices, and agencies. BETO will coordinate sustained office activities through jointly funded intra- and interagency working groups, workshops, personnel exchanges, and memoranda of understanding to advance innovative technologies.

- By 2020, establish vibrant and effective stakeholder engagement initiative coordinated within and between DOE, USDA, EPA, and other federal agencies to enable joint initiatives to advance and expand the U.S. bioeconomy.
- By 2022, enhance public awareness and market interest in advanced bioenergy by collaborating with a highly visible organization to promote a successful technical and/or communications project and its outcomes.
- By 2025, establish 3-5 collaborative initiatives with corporate and nongovernmental organizations to assist in the continued growth of a sustainable bioeconomy.

Strategy: Participate in External Events

Identifying new, unreached audiences is a vital part of BETO's goal to include underrepresented and underutilized communities, while leveraging improvements in how BETO communicates with our existing stakeholder communities. By making BETO more acutely aware of the livelihoods, challenges, and opportunities involved in the development of the bioeconomy, we expand our access to a diverse array of skill sets, collect more representative feedback, and better inform all stakeholder audiences on the direction of BETO's program. BETO will therefore reach out to new communities (such as educational and workforce development organizations, state and local government, grassroots environmental groups, and the research and science community), cosponsor educational programs, and participate in conferences and other events outside our conventional community to benefit these new constituencies and share the results of BETO's R&D efforts with them.

- By 2018, sponsor 2-4 annual stakeholder information and networking sessions for identifying challenges, barriers, opportunities, and educational initiatives.
- By 2020, amplify existing initiatives and implement two new education and training programs to match the growing number of bioenergy industry workers.
- By 2025, establish 3-5 collaborative initiatives with corporate and nongovernmental organizations to assist in the continued growth of a sustainable bioeconomy.
- By 2025, have robust workforce development programs in place to support a group of well-trained workers to fill the demand created by a growing bioeconomy.

CONCLUSION

The desire to stimulate a new bioenergy economy, the need to maintain a competitive advantage for the United States in renewable technologies, and the development of future generations of domestic jobs have renewed the urgency for developing sustainable bioenergy and bioproducts.

Biomass utilization for fuels, products, and power is recognized as a critical component of the nation's strategic aim to address the United States' dependence on volatile supplies and prices of oil. In 2015, U.S. net imports of petroleum from foreign countries were equal to about 24% of our consumption.[44] The U.S. reliance on petroleum-based fuels and products exposes the nation to potential disruptions in fuel supply, creates economic and social uncertainties for businesses and individuals, and exports revenues that could be invested in the U.S. economy. The use of domestically produced, advanced biofuels from renewable resources that do not compete with food and animal feed production can play a major role in diversifying fuel sources and achieving our national energy goals. A growing bioeconomy also creates a new domestic bioenergy and bioproducts industry that improves the quality of life for all Americans.

This strategic plan is BETO's blueprint on how it will tackle the challenges and opportunities that lie ahead in building a sustainable U.S. bioeconomy. BETO's talented and dedicated team will lead the execution of this plan, working with internal and external partners. BETO will leverage its resources and collectively work toward achieving its vision for 2040: *establishing a thriving and sustainable bioeconomy fueled by innovative technologies*. Making this vision a reality will require strong support, commitment, and involvement from many individuals and organizations, including federal agencies; public and private sector organizations; innovators, scientists, and technologists at national laboratories and universities; biofuels and bioproducts producers; and financiers, among others. BETO will continue to collaboratively engage, educate, and inform its stakeholders in order to reach its vision of a secure and thriving bioeconomy.

APPENDIX A

GLOSSARY OF TERMS

Algal feedstocks: Algal feedstocks are algae used as fuel or that are converted into another form of fuel or energy product. The term "algae" encompasses a great diversity of organisms—from microscopic cyanobacteria to giant kelp. Most algae convert sunlight into energy in a manner that is similar to plants. Algae's wide genetic diversity means that an incredible number of unique properties can be harnessed to develop promising algal biofuels and bioproducts.

Biochemicals: Biochemicals are biomass-derived chemicals that can act as direct substitutes for their petroleum-based equivalents in consumer products. Examples of chemicals and chemical groups of interest include levulinic acid, BTX (benzene, toluene, and xylenes), methane, ethylene, methoxyphenols, olefins, paraffins, HMF (Hydroxymethylfurfural—a chemical compound) isoprenoids, higher alcohols, and fatty acids.

Biodiesel: A biodegradable transportation fuel used in diesel engines, biodiesel is produced through the transesterification of organically-derived oils or fats. It may be used either as a replacement for, or as a component of, diesel fuel.

Bioeconomy: The global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits.

Bioenergy: Bioenergy is energy produced from biomass and includes biopower and biofuels.

Biofuels: Biofuels are biomass-derived liquid or gaseous fuels such as ethanol, methanol, methane, and hydrocarbons.

Biomass: Biomass is an energy resource derived from plant-, algal-, and waste-based materials that include agricultural and forest residues, perennial grasses, woody energy crops, algae, wet waste (e.g., biosolids), sorted municipal solid waste, urban wood waste, and food waste. It is unique among renewable energy resources in that it can be converted to carbon-based fuels, chemicals, or power.

Biopower: Biopower is the use of biomass feedstock to produce electric power or heat. Biopower can be created through direct combustion of the feedstock, gasification and then combustion of the resultant gas, or other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Bioproducts: Chemicals, polymers, and materials derived from renewable biobased feedstocks are considered bioproducts. Example products include plastic bottles, animal feed, fertilizers, lubricants, and industrial chemicals.

Biorefinery: A facility that processes and converts biomass into value-added products is called a biorefinery. These products can include biomaterials; fuels, such as ethanol; and important feedstocks used in the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

Biosolids: Biosolids are nutrient-rich organic materials obtained from wastewater treatment, which can then be recycled for beneficial use in bioenergy.

Biosupply chain: The biosupply chain is the sequence of processes involved in the production and distribution of a bioproduct in the bioindustry.

De-risk: De-risk is defined as making bioindustrial processes and products safer and more appealing by reducing the risk of negative outcomes and financial loss.

Feedstocks: Any material that is used directly as a fuel or that is converted to another form of fuel or energy product is a feedstock. Examples of bioenergy feedstocks include agricultural residues, energy crops, forest resources, organic wastes, and algae.

Fungible fuels: Fungible fuels are sources of fuel that are capable of a mutual substitution. An example is biodiesel as a replacement for diesel fuels.

Genetically engineered species/algae: Genetically engineered algae are algae whose genetic material has been altered using genetic engineering techniques.

Renewable Fuel Standard (RFS): A national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel. The RFS program was created under the Energy Policy Act of 2005, which amended the Clean Air Act. EISA further amended the Clean Air Act by expanding the RFS program. EPA implements the program in consultation with USDA and DOE.

Transesterification: Transesterification is a process that involves the chemical reactions of alcohols and triglycerides contained in vegetable oils and animal fats to produce biodiesel and glycerin.

Valorize: To valorize something is to ascribe or fix a value to it. For example, producing bioproducts from waste lignin in a biorefinery process to generate additional revenue and decrease waste is considered valorization.

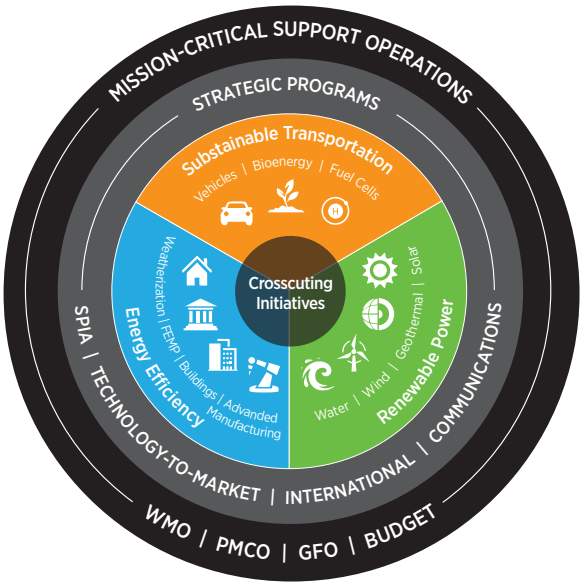
APPENDIX B

BETO'S INVESTMENT APPROACH

As one of three offices within EERE's Sustainable Transportation sector (figure B-1), BETO is primarily focused on replacing conventional fuels with cost-competitive, domestically produced, sustainable fuels that reduce harmful emissions in the transportation sector, including, but not limited to, road transportation, aviation, and marine applications. As a member of the BRD Board, DOE, through BETO, works closely with other federal agencies to develop a strong U.S. bioeconomy. The BRD Board's efforts support R&D on fuels and products, such as intermediates that displace petroleum in adhesives, carbon fiber, and polymers for plastics.

To accomplish these research objectives, BETO has adopted an investment approach that supports transformative and revolutionary bioenergy technologies. It is designed to increase the availability and reliability of biofuels, bioproducts, and biopower, while also lowering their direct and indirect costs to energy users, product users, and society as a whole. This investment approach targets specific gaps in technology-development pathways, where the private sector or other nongovernmental stakeholders are unable to make necessary investments due to risk, scale, or the time frame required for commercialization. It is divided into three distinct phases (figure B-2).

Figure B-1. EERE organization program areas and initiatives

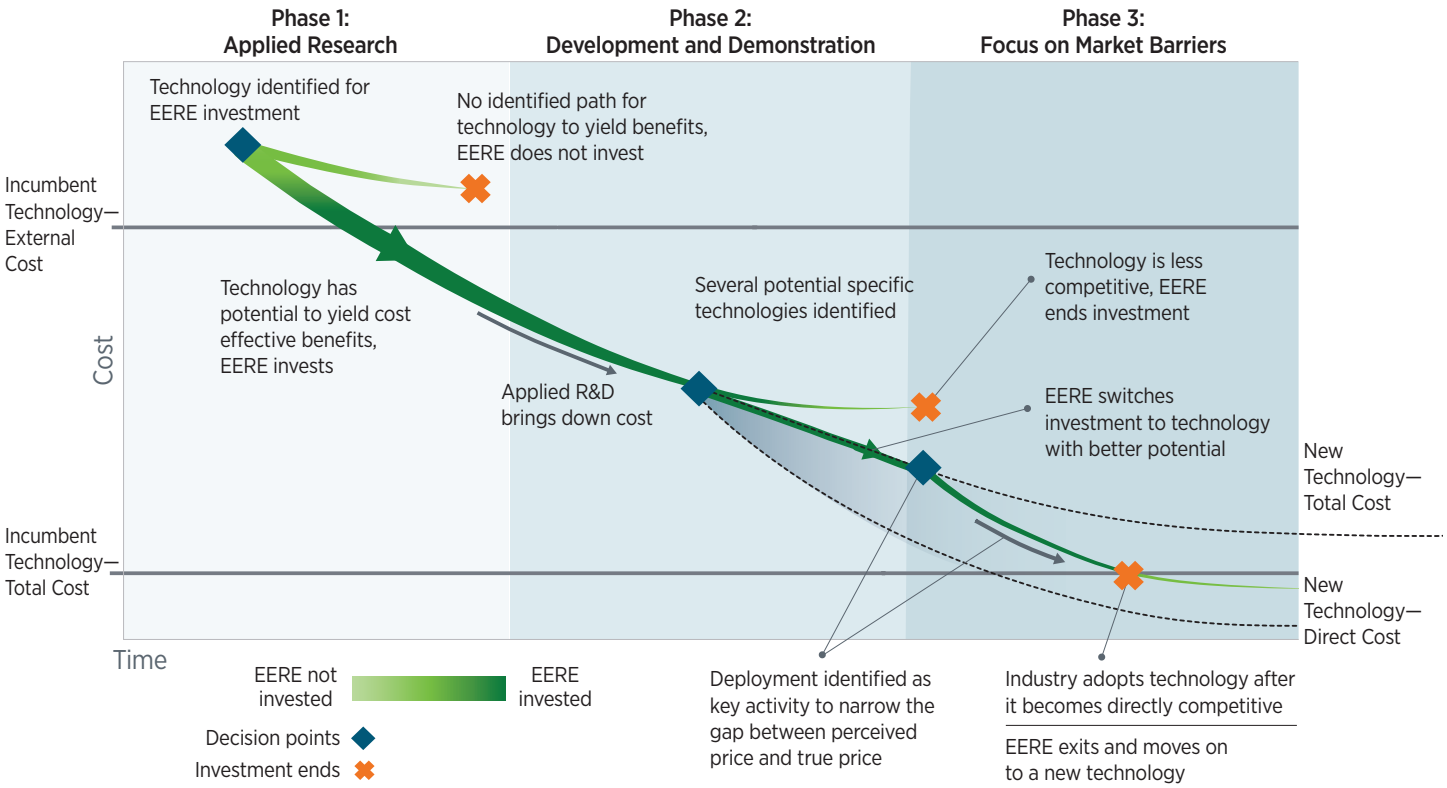


Phase 1—Applied Research: This phase initially focuses on a particular application—but often not a specific product—where high initial cost, risk in technology, and uncertainty about the timing of product development and market acceptance impede private investment. In this phase, BETO invests heavily in collaborative R&D with national laboratories, private industry, and academic institutions. Detailed analyses determine if a technology might achieve market competitiveness and result in lower societal costs when full valuation of environmental and societal benefits is factored in.

Phase 2—Development and Demonstration: As a technology nears direct market competitiveness, private capital is typically raised to validate and scale it for manufacturing and deployment. However, because of the nature of energy markets, bioenergy technologies—and specific products—often require very large amounts of capital and higher risk tolerance due to their unproven nature, complexity, risk of integration, and scaling. BETO's investments during this phase focus on testing and validating performance, reliability, and costs through pilot- and demonstration-scale technology analysis of market competitiveness. BETO may also fund small- or limited-scale demonstrations, with technologies integrated into full systems, to catalyze and leverage additional private-sector investment.

Phase 3—Focus on Market Barriers: Once a technology achieves initial market adoption, technologies that are cost effective may still face challenges to high-volume adoption and further market penetration. In this phase, BETO focuses on activities that can help overcome these market barriers, for example, providing key information and data to consumers, regulators, financiers, and other market participants, or conducting new research/activities to address specific market challenges such as technology and data development for standards or certification.

Figure B-2. Diagram of the EERE investment pathway



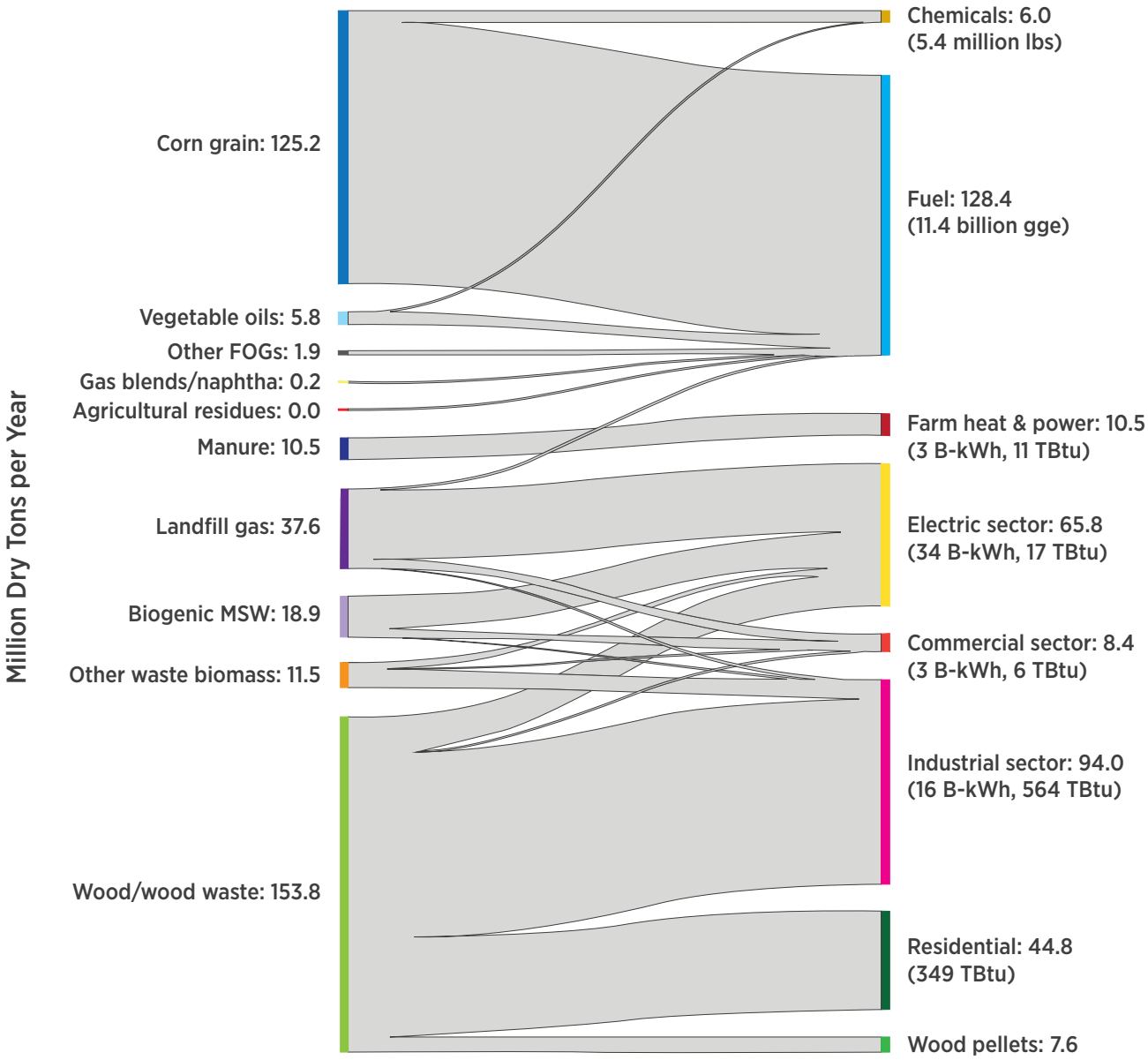
Source: DOE-EERE *2016–2020 Strategic Plan and Implementing Framework*

APPENDIX C

BIOMASS INDUSTRY EXPANSION

Agricultural and forestry/wood resources are the primary sources for today's bioeconomy. Agricultural biomass can be used to produce heat and power for the electrical, industrial, commercial, and residential sectors, while digested animal manure can be used to produce heat and power for farm use. The biogenic portion of MSW and other waste biomass is consumed to produce heat and power. The flow of resources from feedstock to end product is illustrated in figure C-1.[45]

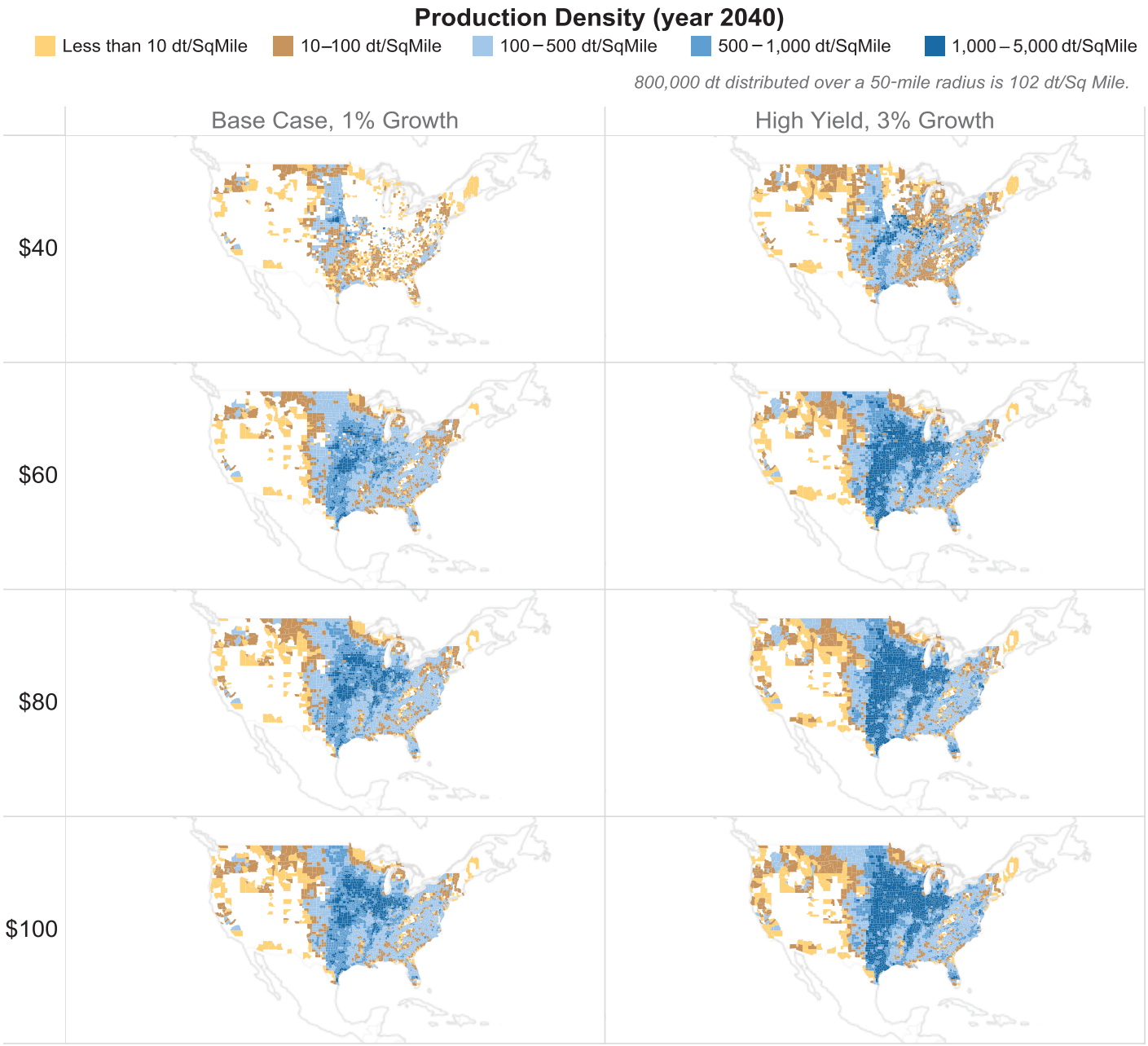
Figure C-1: Sankey diagram of feedstock, sector consumption, and final product distribution



Source: *2016 Billion-Ton Report,* Volume 1
Note: Biomass resources are shown on the left and their allocations are shown on the right. The size of the flow is representative of the amount of biomass allocated to that end use.
FOGs – fats, oils, and grease; MSW – municipal solid waste; TBtu – trillion British thermal units; B-kWh – billion kilowatt-hours

Using terrestrial feedstocks, figure C-2 illustrates how market strength is expected to enable biomass industry expansion through (1) technology improvements in crop development, agronomic practices, logistics, and preprocessing that enter the market over time (left to right); and (2) demand increases that draw additional resources into the market (top to bottom).[45] One of BETO's strategies is to improve yield from the field or forest, which includes minimizing losses in the feedstock supply chain. Another strategy is to engage multiple markets, optimizing resource marketability when practical, which draws more of the billion-ton resource into the bioeconomy. Cost-reduction strategies reduce the unit cost of biomass supply, thus mobilizing larger amounts of it into the market at a lower cost than would have occurred without technology improvements.

Figure C-2. Map matrix providing a progressive illustration of the cellulosic biomass mobilization goal based on enabling factors that progressively increase market strength

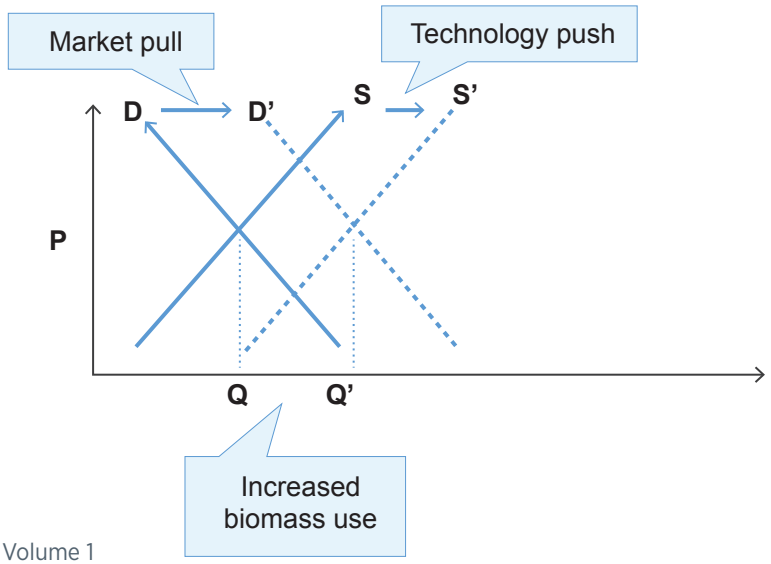


Source: *2016 Billion-Ton Report,* Volume 1
Note: dt – dry ton; SqMile – square mile.

Movement from the upper left to lower right illustrates the mobilization effects that markets are expected to have on resource availability, which is largely determined by potential profitability to biomass producers. For example, as demand for feedstocks increases due to combinations of higher petroleum-derived fuel prices, sustainability requirements, diversity of U.S. feedstocks, and other market drivers, resource supplies will increase in response to higher demand-driven prices.

As shown in figure C-3, the mobilization strategy comprises two primary thrusts: technology push and market pull. The first thrust includes crop yield improvements, reduction of material losses during harvest, preprocessing, improved storage and transport operations, machine and labor efficiency improvements throughout the supply chain, and other strategies that reduce the cost of supply. This reduction in supply cost makes more material available at lower prices (i.e., shift the supply curve to the right). This first thrust addresses the supply side of the biomass market and is referred to as "technology push." The cost of supply (S) is determined by raw material costs and fair compensation for the producer (i.e., grower payment), logistics costs (e.g., harvest, transport, and storage), and any preprocessing operations required.

Figure C-3. An economic representation of the shift of supply and demand for biomass resulting in higher biomass quantity consumed in the market



Source: *2016 Billion-Ton Report,* Volume 1

Yields, losses, physical properties, and compositional characteristics also factor into the cost of supply. Investments in improved crop variety development, agronomic best practices, equipment, infrastructure, and labor force training can reduce the cost of supply. The amount and timing of investment will affect the rate at which this can happen. To be optimally effective, investments in biomass mobilization must be matched by investments in building new biorefineries that create demand for feedstock materials.

In the second thrust, the focus is on enabling markets that allow biomass to be accessed at affordable prices and provide more opportunities for sustainable operations, i.e., shift the demand curve (D) to the right. This second thrust addresses the demand side of the biomass market and is referred to as "market pull." Demand for biomass is dictated by the capacity of the biorefining industry, competition among users, prices for substitute products, and value for biomass coproducts. Strategies for companion markets that take advantage of revenue from coproducts are part of demand-driven mobilization. Fully accounting for and monetizing primary and secondary markets for sustainably produced, managed, and utilized biomass are essential components of the value-added demand function. For example, a secondary market could be ecosystem services created by utilizing energy crops as filter strips that border other rows of crops or waterways and improve surface and groundwater quality while also potentially helping to preserve biodiversity. The net effect of an equal shift in both of these sides of the market is shown above in figure C-3, which demonstrates a higher quantity (Q) of biomass consumed at the same market price (P).

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