EXECUTIVE SUMMARY

The Bioenergy Technologies Office is one of the 10 technology development offices within the Office of Energy Efficiency and Renewable Energy at the U.S. Department of Energy. This Multi-Year Program Plan (MYPP) sets forth the goals and structure of the Bioenergy Technologies Office (the Office). It identifies the research, development, and demonstration (RD&D), and market transformation and crosscutting activities the Office will focus on over the next five years and outlines why these activities are important to meeting the energy and sustainability challenges facing the nation.

This MYPP is intended for use as an operational guide to help the Office manage and coordinate its activities, as well as a resource to help communicate its mission and goals to stakeholders and the public.

Bioenergy Technologies Office Mission and Goals

The mission of the Office is to

> *Develop and demonstrate transformative and revolutionary bioenergy technologies for a sustainable nation.*

The goal of the Office is to develop commercially viable bioenergy and bioproduct technologies to

- *Enable sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, can reduce greenhouse gas emissions relative to petroleum-derived fuels, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil*
- *Encourage the creation of a new domestic bioenergy and bioproduct industry.*

Technology Portfolio

The Office manages a diverse portfolio of technologies across the spectrum of applied research, development, and demonstration (RD&D) within the dynamic context of changing budgets and Administration priorities. The Office portfolio is organized according to the biomass-to-bioenergy supply chain—from the feedstock source to the end user (see Figure A)—with major focus on feedstock supply and biomass conversion.

Figure A: Biomass-to-bioenergy supply chain

The Office has developed a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and selecting the most promising opportunities across a wide range of emerging technologies and technology-readiness levels. This approach is intended to support a diverse technology portfolio in applied research and development (R&D), while identifying the most promising targets for follow-on industrial-scale demonstration with increasing integration and complexity.

Key components of the portfolio include the following:

- R&D on productive and competitive advanced algal systems
- R&D on sustainable, high-quality feedstock supply systems
- R&D on biomass conversion technologies
- Demonstration and validation of integrated biorefinery technologies up to industrial scale
- Crosscutting sustainability, analysis, and strategic communications activities.

Technology Development Timeline and Key Activities

In order to achieve the Office's goals, all of the challenges and barriers identified within this MYPP need to be addressed. However, the issues identified in Figure B are critical to reaching five-year goals and will be emphasized within the Office's efforts over the next five years.

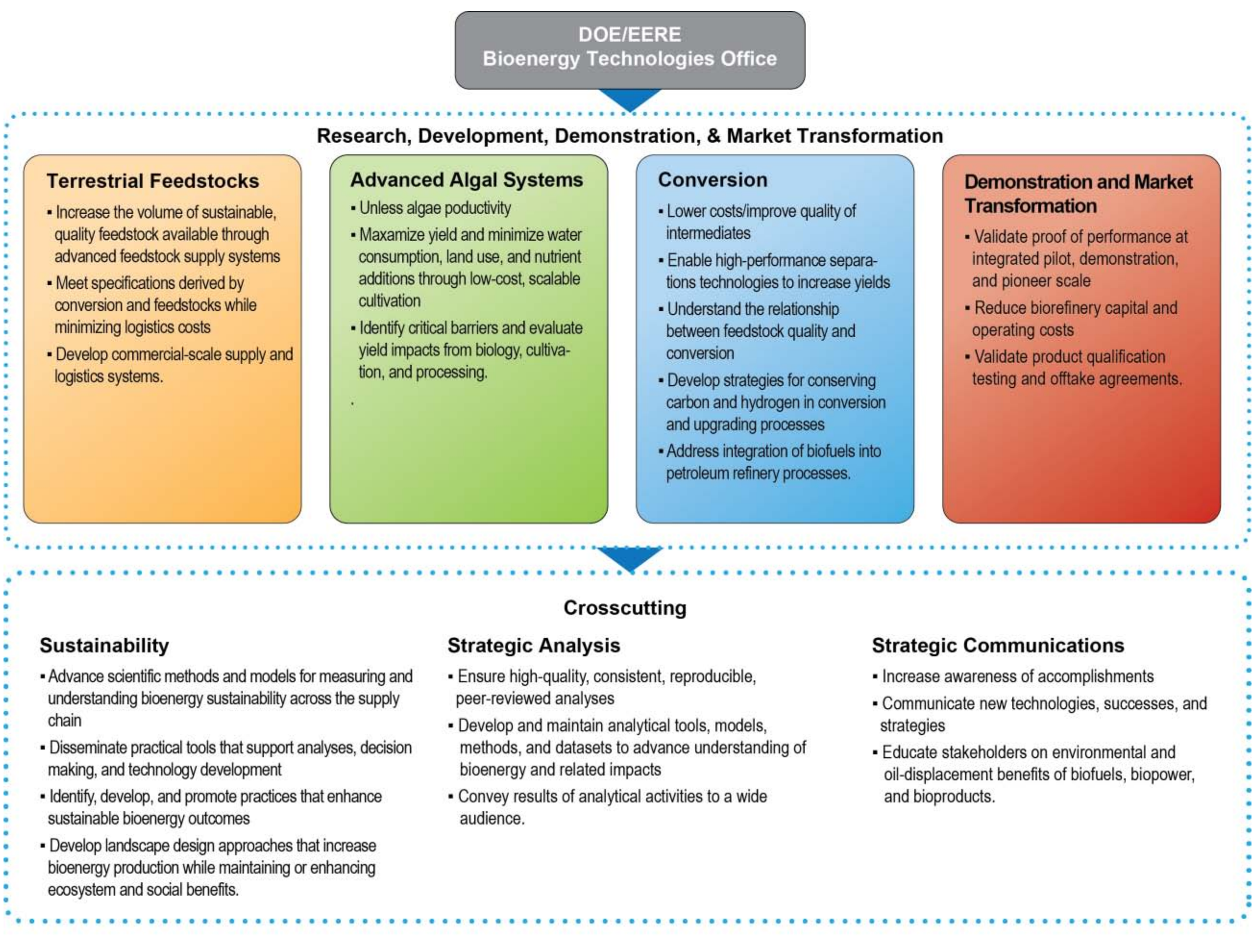
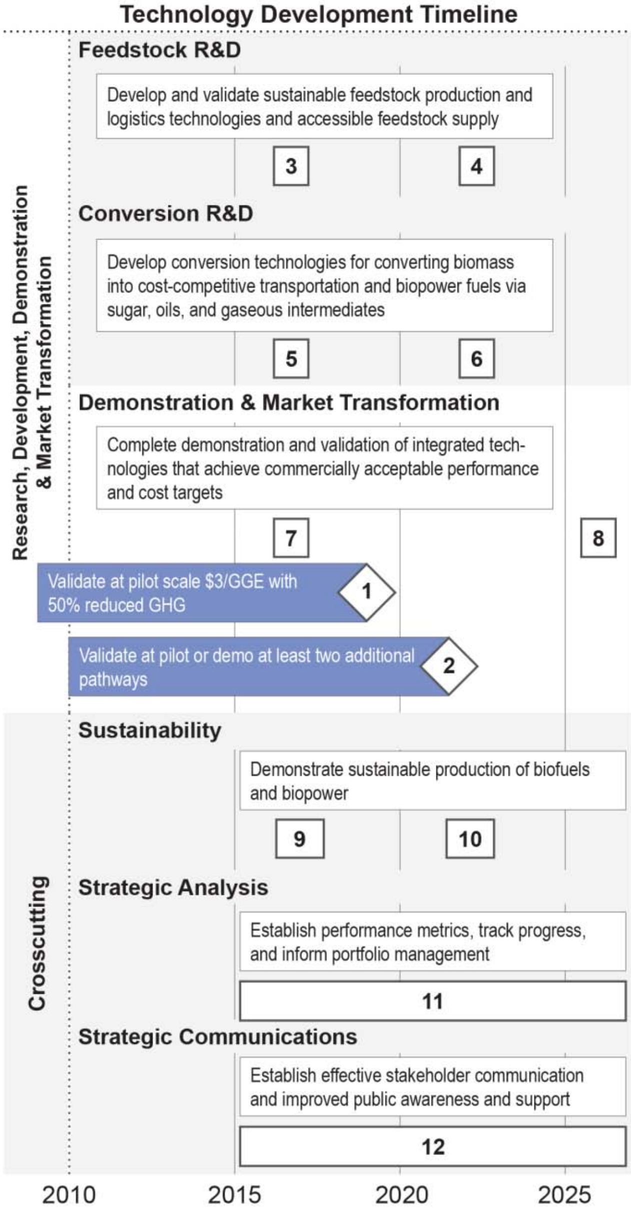


Figure B: High-impact research areas

Figure C illustrates the near-term technology development timeline and key activities of the Office. In the longer term, the Office will continue to support focused science and RD&D of advanced biomass utilization technologies. Detailed life-cycle analysis of environmental, economic, and social impacts will continue to inform decisions regarding Office activities.

This approach ensures the development of the required technological foundation, leaves room for pursuing solutions to technical barriers as they emerge, and enables demonstration activities that are critical to reduce risks and validate a robust process. This approach lays the groundwork for future commercial deployment as it reduces technical risks, which enables the emerging industries to grow and attract private investment. The plan addresses important technological advances in producing biofuels, as well as in the underlying infrastructure needed to ensure that feedstocks are available and products can be distributed safely with the quality and performance demanded by end consumers.

This MYPP is designed to allow the Office to progressively enable deployment of increasing amounts of biofuels, bioproducts, and biopower across the nation from a widening array of feedstocks. This approach will have a significant near-term impact on offsetting petroleum consumption and facilitate the shift to renewable, sustainable bioenergy technologies in the long term, while allowing the market to determine the ultimate implementation across diverse U.S. resources.



Legend for Technology Development Timeline

Overall

1. By 2017, validate at pilot scale at least one technology pathway for hydrocarbon biofuel production at a mature modeled price of $3/GGE (2014$) with GHG emissions reduction of 50% or more compared with petroleum-derived fuel.
2. By 2022, validate hydrocarbon biofuel production from at least two additional pathways at pilot or demonstration scale (<1 ton/day).

Feedstock R&D

3. By 2017, establish criteria under which the industry could operate at 245 MDT/year of biomass; validate feedstock supply and logistics systems that can deliver feedstock at or below $84/dry ton (2014$).
4. By 2022, demonstrate technologies to produce sustainable algal biofuel intermediate feedstocks in support of $3/GGE goals, and validate feedstock supply and logistics systems that can supply 285 MDT/year utilizing a diversity of biomass resources at a cost of $84/dry ton.

Conversion R&D

5. By 2017, validate an nth plant modeled MFSP of $3/GGE (2014$) via a conversion pathway to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.
6. By 2022, validate an nth plant modeled MFSP of $3/GGE (2014$) for two additional conversion pathways to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.

Demonstration & Market Transformation

7. By 2017, validate mature technology modeled cost of cellulosic ethanol production, based on actual IBR performance data, and compare to the target of $2.65/gallon ethanol (2014$).
8. By 2027, validate mature technology modeled cost of infrastructure compatible hydrocarbon biofuel production, based on actual IBR performance data, and compare to the target of $3/GGE (2014$).

Sustainability

9. By 2017, identify conditions under which at least one hydrocarbon biofuels pathway, validated above R&D scale at a mature modeled price of $3/GGE, reduces GHG emissions by 50% or more compared to petroleum fuel, and meets targets for water use, wastewater, and air emissions.
10. By 2022, validate landscape design approaches for two bioenergy systems that increase land-use efficiency and maintain ecosystem and social benefits; and evaluate environmental and socioeconomic indicators across the supply chain for three cellulosic and algal bioenergy production systems to validate GHG reduction of at least 50% compared to petroleum, water consumption and air emissions targets, and socioeconomic benefits.

Strategic Analysis

11. Provide context and justification for decisions at all levels by establishing the basis for quantitative metrics, tracking progress, and informing portfolio managment.

Stategic Communications

12. Promote the economic and job creation, environmental, and energy security benefits of sustainable biofuels production. Increase awareness of and support for the Office's accomplishments and educate audiences about the environmental and economic opportunities and social benefits.

GGE = gallon gasoline equivalent, GHG = greenhouse gas, MDT = million dry tons

Figure C: Bioenergy Technologies Office strategy and timeline for technology development

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List of Abbreviations

AHTL – Algal Hydrothermal Liquefaction
AMO – Advanced Manufacturing Office
ANL – Argonne National Laboratory
ANSI – American National Standards Institute
API – American Petroleum Institute
ARPA-E – Advanced Research Projects Agency-Energy
ARRA – American Recovery and Reinvestment Act
ASTM – American Society for Testing and Materials
BCAP – Biomass Crop Assistance Program
BIWG – Biofuels Interagency Working Group
BRDi – Biomass Research and Development Initiative
BSM – Biomass Scenario Model
CO_2 – carbon dioxide
CPS – Corporate Planning System
DME – dimethyl ether
DMT – Demonstration and Market Transformation
DOE – U.S. Department of Energy
DOD – U.S. Department of Defense
DOI – U.S. Department of the Interior
DOT – U.S. Department of Transportation
DT – dry tons
EERE – Office of Energy Efficiency and Renewable Energy
EIA – Energy Information Administration
EISA – Energy Independence and Security Act of 2007
EPA – U.S. Environmental Protection Agency
EPAct – Energy Policy Act of 2005
EU – European Union
EV – electric vehicle
FAA – Federal Aviation Administration
FAME – fatty acid methyl ester
Farm Bill – The Agricultural Act of 2014
FCT – Fuel Cell Technologies Office
FE – Office of Fossil Energy
FEMP – Federal Energy Management Program Office
FFVs – flexible-fuel vehicles
GBEP – Global Bioenergy Partnership
GGE – gallon gasoline equivalent
GHG – greenhouse gas
GIS – Geographical Information Systems
GPRA – Government Performance and Results Act
GREET – Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
HTL – Hydrothermal Liquefaction
IBR – integrated biorefinery
IBSAL – Integrated Biomass Supply Analysis and Logistics

Infrastructure – Biofuels Distribution Infrastructure and End Use
ILUC – indirect land use change
INL – Idaho National Laboratory
ISO – International Organization for Standardization
KDF – Knowledge Discovery Framework
LHV – lower heating value
LPO – DOE Loan Programs Office
LUC – land-use change
MARKAL – market allocation
MESP – minimum ethanol selling price
MFSP – minimum fuel selling price
MSW – municipal solid waste
MTBE – methyl tertiary butyl ether
MYPP – Multi-Year Program Plan
NAABB – National Alliance for Advanced Biofuels and Bioproducts
NABC – National Advanced Biofuels Consortium
NASA – National Aeronautics and Space Administration
NEMS – National Energy Modeling System
NG – natural gas
NIFA – The U.S. Department of Agriculture's National Institute on Food and Agriculture
NIST – National Institute of Standards and Technology
NREL – National Renewable Energy Laboratory
NSF – National Science Foundation
the Office – The Bioenergy Technologies Office
OSBL – outside battery limits
OPEX – operating expense
ORNL – Oak Ridge National Laboratory
PBA – EERE Office of Planning, Budget, and Analysis
PMC – Project Management Center
PMP – project management plan
PNNL – Pacific Northwest National Laboratory
Psia – pounds per square inch absolute
R&D – research and development
RD&D – research, development, and demonstration
RFS – Renewable Fuel Standard
RLP – Resource Loaded Plan
RPS – Renewable Portfolio Standard
RSB – Roundtable on Sustainable Biomaterials
SC – Office of Science
scf – standard cubic feet
SMR – steam methane reformer
SOT – State of Technology
SUV – sport utility vehicle
SWAT – Soil and Water Analysis Tool
TRL – technology readiness level
UL – Underwriters Laboratory

UN FAO – Food and Agriculture Organization of the United Nations
USDA – United States Department of Agriculture
VTO – Vehicle Technologies Office
WBS – work breakdown structure
wt% – percentage by weight

Section 1: Office Overview

Growing concerns over climate change, as well as 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 green jobs, have renewed the urgency for developing sustainable bioenergy and bioproducts. Biomass utilization for fuels, products, and power is recognized as a critical component in the nation's strategic plan to address our continued dependence on volatile supplies and prices of imported oil. U.S. dependence on imported oil exposes the country to critical 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.

Biomass utilization plays an important role in implementing the President's Climate Action Plan to reduce carbon pollution in United States within the transportation sector. This plan calls for accelerated development of cost-competitive advanced biofuels that will reduce the carbon footprint of our national transportation sector as well as new fuel economy standards to reduce emissions and improve vehicle efficiency.[1]

Biomass

Biomass is an energy resource derived from plant- and algae-based material that includes agricultural residues, forest resources, perennial grasses, woody energy crops, algae, wet waste (e.g., biosolids), 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.

Biomass is the only renewable energy source that can offer a substitute for fossil-based, liquid transportation fuels in the near- to mid-term. The United States has the capacity to produce more than one billion tons[2] of sustainable biomass, which can be used to produce reduced-carbon-emission fuel for cars, trucks, and jets; chemicals; and renewable power to supply the grid. Biofuel, bioproduct, and biopower production can create new domestic economic opportunities and jobs in agriculture, manufacturing, and service sectors, while reducing future climate impacts.

The Energy Independence and Security Act of 2007 (EISA) sets aggressive goals to reduce the nation's dependence on fossil fuels and reduce greenhouse gas (GHG) emissions from the transportation sector by increasing the supply of renewable transportation fuels to 36 billion gallons by 2022.[3]

To support pursuit of these goals, the Bioenergy Technologies Office (the Office), within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE), is focused on forming public-private partnerships with key stakeholders to research,

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[1] Executive Office of the President (June 2013), *The President's Climate Action Plan*, http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

[2] U.S. Department of Energy (2011), *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*, R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224, Oak Ridge National Laboratory, Oak Ridge, TN, 227p., http://www.energy.gov/sites/prod/files/2015/01/f19/billion_ton_update_0.pdf.

[3] United States Congress (2007), *Energy Independence and Security Act of 2007*, Washington: Government Printing Office, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf.

develop, and demonstrate technologies to produce advanced bioenergy and bioproducts from lignocellulosic and algal biomass. The Office focuses on reducing technology risks, from feedstock supply and logistics through development of biorefinery technologies, to enable industry investment in technology deployment at scale.

Scope of Effort/Framework for Success

Meeting these goals requires significant and rapid advances in the entire biomass-to-bioenergy supply chain—from the biomass source to the consumer (see Figure 1-1).

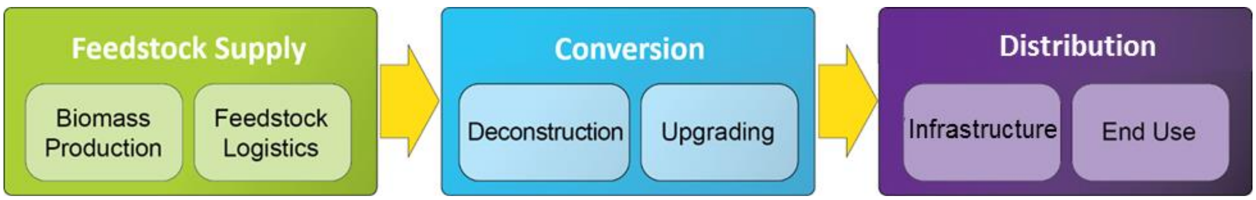

Figure 1-1: Biomass-to-bioenergy supply chain

Each element of the supply chain must be addressed to enable bioenergy and bioproducts to reach the market and ensure market acceptance. The biomass-to-bioenergy supply chain elements are as follows:

- **Feedstock Supply:** Produce large, sustainable supplies of regionally available biomass and implement cost-effective feedstock infrastructure, equipment, and systems for harvesting, collection, storage, preprocessing, and transportation
- **Conversion:** Develop and deploy cost-effective, integrated conversion technologies for the production of bioenergy and bioproducts
- **Distribution:** Implement biofuels distribution infrastructure (storage, blending, and transportation—both before and after blending and dispensing), assess impact of renewable fuel blends and bioproducts on end-user applications, and educate users.

This breadth of scope requires the participation of a broad range of public and private stakeholders of the evolving bioenergy sector, including the general public, the scientific/research community, trade and professional associations, environmental organizations, the investment and financial community, existing industries, and government policy and regulating organizations. These stakeholders possess valuable perspectives that can help identify the most critical challenges and better define strategies for effectively deploying bioenergy and bioproducts. The framework for success also requires extensive coordination and collaboration across multiple federal stakeholder agencies.

Bioenergy Technologies Office's Framework for Research, Development, and Demonstration

A critical measure of the Office's success is the development and demonstration of technologies within integrated biorefineries that can be subsequently commercially deployed and replicated. Similar to biorefineries that produce ethanol from starch and biodiesel from oil seeds and waste oils, integrated biorefineries are expected to produce multiple products to take advantage of the diverse biomass components and processing intermediates. This approach maximizes the value and decreases the waste derived from the biomass feedstock.[4]

Biorefinery

A biorefinery is a facility that converts biomass into fuels, power, and chemical products. The biorefinery concept is analogous to a petroleum refinery, which produces a slate of multiple fuels and products from a petroleum feedstock.

The wide diversity of potential biomass feedstocks, conversion technologies, and product suites allows for a multitude of biorefinery integration options. Determining which technology options are closest to commercialization is based on a number of factors, including feedstock risk, technology risk, and market size. The Office actively identifies and evaluates feedstock and technology risks through analyses of data from research, development, and demonstration (RD&D) into a broad-based set of feedstocks and conversion technologies. By applying a methodical approach to evaluating opportunities within the available feedstocks and technology options, the Office is able to prioritize RD&D at increasing scale on high-impact technologies that were assessed to have significant impacts on nearer-term bioenergy production and will most benefit from government investment.

Specific, focused technology pathways are prioritized for development to pilot-scale validation based on techno-economic analyses, feedstock impact, and market potential. Pilot-scale validation of selected technologies provides a transparent, accessible example against which private partners can assess their own technological progress while maintaining the scientific and engineering expertise to support and validate development of emerging technologies.

This approach has several distinct advantages:

- It maintains a balanced portfolio of RD&D to maintain earlier-stage, promising technologies for which specific pathways may not yet be adequately developed, while building a knowledge base of that technology relative to feedstock characteristics and potential.
- It ensures the Office will examine diverse feedstocks and conversion technologies for producing biofuels, bioproducts, and biopower.
- It effectively links resources with the stages of technology readiness, from applied research through commercial demonstration.
- It leverages breakthroughs from the Office of Science (SC) and the Advanced Research Projects Agency–Energy (ARPA-E) as a means to continually repopulate the EERE RD&D pipeline.

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[4] National Renewable Energy Laboratory (2009), "What Is a Biorefinery?" http://www.nrel.gov/biomass/biorefinery.html.

- It helps identify gaps within the portfolio, as well as crucial linkages across RD&D stages.
- It is adequately flexible to accommodate new ideas and approaches, as well as various combinations of feedstocks and processes in real biorefineries.

Expanded Office Focus on Advanced Biofuels

Historically, the Office's focus was on RD&D for ethanol production from lignocellulosic biomass. Since 2012, the Office has demonstrated technologies that can be scaled up to produce modeled price-competitive cellulosic ethanol. This achievement is the culmination of two decades of conversion technology research and development (R&D). DOE-funded R&D in this area has led to a well-developed body of work regarding the performance of ethanol as both a low-volume percentage (E10) gasoline blend in conventional vehicles and at higher blends (E85) in flexible-fuel vehicles.[5] (See Appendix C for more information about accomplishments in cellulosic ethanol.) Since the achievement of the cellulosic ethanol cost targets, the Office has shifted its focus toward developing other advanced biofuels that will contribute to the Renewable Fuel Standard (RFS) volumetric requirements. By focusing on these biomass- and algae-based hydrocarbon fuels (renewable gasoline, diesel, and jet fuel), the Office seeks to engage the refinery industry in developing solutions utilizing existing infrastructure as much as possible. The Office's investments in technologies that can reduce the recalcitrance of lignocellulosic biomass are being leveraged toward developing new hydrocarbon biofuels that can directly replace products created from the whole barrel of oil.

[5] U.S. Department of Energy (2013), *Intermediate Ethanol Blends*, http://energy.gov/eere/vehicles/vehicle-technologies-office-intermediate-ethanol-blends.

1.1 Market Overview and Federal Role of the Office

Markets for biofuels, bioproducts, and biopower exist today both in the United States and around the world, yet the untapped potential is enormous. Industry growth is currently constrained by high production costs, competing energy technologies, limited infrastructure, and other market barriers. Market incentives and legislative mandates focused at helping overcome some of these barriers, if maintained, can reduce uncertainty for investors.

1.1.1 Current and Potential Markets

Major end-use markets for biomass-derived products include transportation fuels, products, and power. Today, biomass is used as a feedstock in all three categories, but the contribution is small compared to oil and other fossil-based products. Most biomass-derived products are now produced in facilities dedicated to a single primary product, such as ethanol, biodiesel, plastics, paper, or power (corn wet mills are an exception). The primary feedstock sources for these facilities are conventional grains, plant oils, and wood.

To meet national goals for increased production of renewable fuels, products, and power from biomass, a more diverse feedstock resource base is required—one that includes biomass from agricultural and forest residues, as well as dedicated energy crops and other waste streams. Ultimately, the industry is expected to move toward large biorefineries that produce a mix of biofuels and bioproducts, with integrated, onsite cogeneration of heat and power, as well as towards scenarios in which the production of renewable fuels and products are integrated with existing petroleum refineries or corn ethanol plants.

Transportation Fuels: America's transportation sector relies almost exclusively on refined petroleum products, which account for more than 71% of the oil used. Oil accounts for 90% of transportation fuel use, with biofuels, natural gas, and electricity accounting for the balance.[6] Nearly 8.1 million barrels of oil are required every day to fuel the 232 million vehicles that constitute the U.S. light-duty transportation fleet.[7]

Biomass is a direct, near-to-mid-term alternative to oil for supplying liquid transportation fuels to the nation. In the United States, nearly all gasoline is now blended with ethanol up to 10% by volume (E10), and cars produced since the late 1970s can run on this fuel. In January 2011, the U.S. Environmental Protection Agency (EPA) issued partial waivers that permit the use of E15 (up to 15% ethanol) in model-year 2001 vehicles and newer. While E15 has not yet entered the market at significant volumes, most of the remaining hurdles are at the state level. While there are alternatives to fossil-derived fuels for light-duty vehicles, diesel and jet fuel markets have few alternatives. Diesel consumption in the United States is 54 billion gallons per year,[8] and jet

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[6] U.S. Energy Information Administration (September 2015), *Monthly Energy Review*, Washington: Government Printing Office, DOE/EIA-0035, https://www.eia.gov/totalenergy/data/monthly/previous.cfm.
[7] U.S. Energy Information Administration (2015), "Transportation Sector Key Indicators and Delivered Energy Consumption," *Annual Energy Outlook 2015*, http://www.eia.gov/forecasts/aeo/data/browser/.
[8] U.S. Energy Information Administration (2015), "Transportation Sector Key Indicators and Delivered Energy Consumption."

fuel consumption is 23 billion gallons per year.[9] Conversion technologies that produce renewable diesel and renewable jet fuel can fill the need for biomass-based alternatives for these diesel and jet markets.

Historically, volatile oil prices, supportive government policies, growing environmental and energy security concerns, and the availability of low-cost corn and plant oil feedstocks have provided favorable market conditions for biofuels. Ethanol, in particular, has been buoyed by the need to replace the octane and clean-burning properties of MTBE (methyl tertiary butyl ether), which has been removed from gasoline because of groundwater contamination concerns. As shown in Figure 1-2, in recent years, domestic production capacity of ethanol has increased rapidly—from under 7 billion gallons per year in 2007 to nearly 15 billion gallons in 2014.

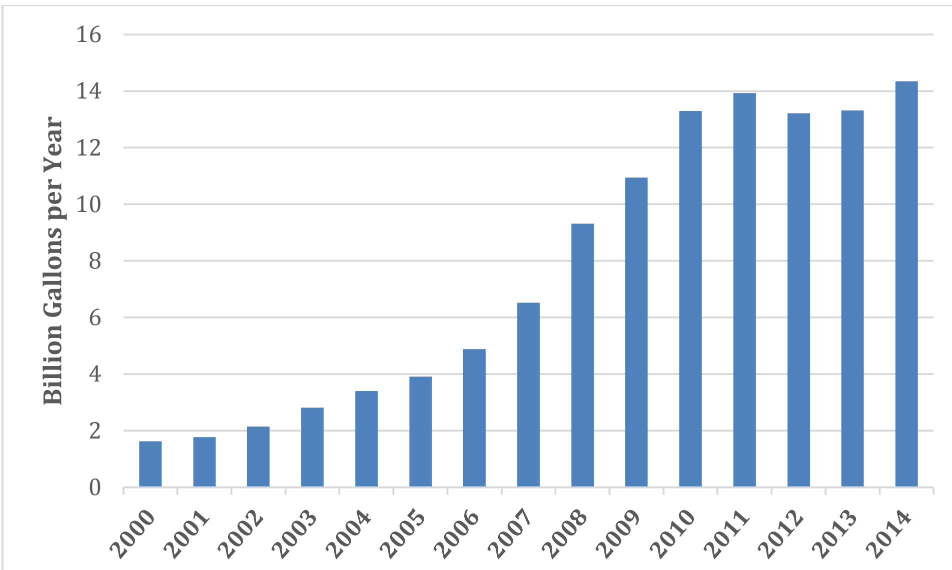

Figure 1-2: U.S. ethanol production capacity[10]

Over the last few years, commodity prices have fluctuated dramatically, creating market risks for biofuel producers and the supply chain. The national RFS legislated by EISA was designed to provide a reliable market for biofuels of 21 billion gallons of advanced biofuels by 2022. Blender tax credits for ethanol and biodiesel have historically helped to ensure that biofuels can compete with gasoline. Tax credits for conventional ethanol and biodiesel expired in January 2011, while cellulosic biofuel production credits were recently extended through January 1, 2017.

To successfully penetrate the target market, however, the minimum profitable biofuel price must be low enough to compete with gasoline. A minimum profitable fuel selling price of $3 per gallon gasoline equivalent (GGE) can compete on an energy-adjusted basis with gasoline derived from oil costing $75–$90 per barrel. Given recent declines in oil prices and historical volatility as

[9] U.S. Energy Information Administration (2013), "Jet Fuel Consumption, Price, and Expenditure Estimates 2014," http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_jf.htm.
[10] Renewable Fuels Association (2015), "Industry Statistics," http://www.ethanolrfa.org/pages/statistics.

illustrated by the broad range of oil prices projected by the Energy Information Administration (EIA) for 2022 ($61–$156 per barrel),[11] bioenergy technology may continue to require policy support and regulatory mandates in order to enable the new bioenergy sector while it is being established.

Consumer attitudes about fuel prices and performance, biofuel-capable vehicles, and the environment also affect demand for biofuels and renewable products. Consumers who are generally unfamiliar with biofuels and have been hesitant to use them, even where they are available, may shift preferences as consumer confidence in biofuel use increases and as public awareness of the positive effect of biofuels on climate change grows.[12]

Products: Up to 16% of U.S. crude oil consumption is used to make chemicals and products, such as plastics for industrial and consumer goods,[13] contributing a value added to the U.S. economy of $812 billion. Many products derived from petrochemicals could be replaced with biomass-derived materials. Less than 4% of U.S. chemical sales are biobased.[14] Organic chemicals such as plastics, solvents, and alcohols represent the largest and most direct market for bioproducts.[15] The market for specialty chemicals is much smaller but is projected to double in 15 years[16] and offers opportunities for high-value bioproducts that have higher profitability potential than the commodity fuels market. Due to this potential, bioproduct manufacturing represents a near-term market opportunity to support the development of the biorefining industry.

Some traditional fossil-based chemical companies are forming alliances with food processors and other firms to develop new chemical products that are derived from biomass, such as natural plastics used in PET Bottling, fibers, cosmetics, paints, industrial adhesives, composite materials, liquid detergents, and a natural replacement for petroleum-based antifreeze.[17] These manufacturing alliances will need to demonstrate integrated production, including feedstock production and logistics through conversion, separation, purification, and market acceptance testing.

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[11] U.S. Energy Information Administration (2015), "Energy Prices," *Annual Energy Outlook 2015*, http://www.eia.gov/forecasts/aeo/section_prices.cfm.
[12] National Science Foundation (2010), *The Roadway to Partial Petroleum Replacement with Biomass-Derived Fuels—A Report Along the Way*, available from Northeast States for Coordinated Air Use Management: http://www.nescaum.org/activities/meetings-and-workshops/endicott-house-symposia/policy-instruments-for-a-new-economic-era/antos.pdf/view.
[13] American Chemical Council (2014), *Guide to the Business of Chemistry—2014*, http://store.americanchemistry.com/Guide-to-the-Business-of-Chemistry-2014-(electronic-version).
[14] J.S. Golden et al. (2015), "A Report to the Congress of the United States of America," *An Economic Impact Analysis of the U.S. Biobased Products Industry*, U.S. Department of Agriculture, http://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf.
[15] A. Lovins, et al. (2004), *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security*, Rocky Mountain Institute, http://www.rmi.org/Knowledge-Center/Library/E04-07_WinningTheOilEndgame.
[16] Biotechnology Industry Organization (March 2010), *Biobased Chemicals and Products: A New Driver for Green Jobs*, http://www.bio.org/articles/biobased-chemicals-and-products-new-driver-green-jobs.
[17] U.S. Department of Energy (2004), *Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas,* http://www.nrel.gov/docs/fy04osti/35523.pdf and University of Florida IFAS Extension, *Bio-based Products from Biomass*, http://edis.ifas.ufl.edu/ae483.

Biomass-derived products will also compete with existing starch-based bioproducts, such as poly lactic acid. For biomass-derived products to compete, they must be price competitive with these existing products and address commodity markets. New biomass-derived products will also have to compete globally and will, therefore, require efficient production processes and low production costs.

Power: Less than 1% of the oil consumed in the United States is used for electric power generation. Fossil fuels dominate U.S. power production and account for more than 63% of generation, with coal comprising 42%, natural gas 21%, and oil less than 1%. The balance is provided by nuclear (21%) and renewable sources (13%), including 1% [18] provided by biopower. New natural-gas-fired, combined-cycle plants are expected to increase the natural gas contribution, with coal-fired power maintaining a dominant role. Renewable energy, which includes biopower, is projected to have the largest increase in production capacity between 2012 and 2040.[19]

Dedicated utility-scale biopower applications are a potential route to further reduce U.S. reliance on fossil fuels and improve the sustainability associated with power generation. Limits to the availability of a reliable, sustainable feedstock supply, as well as competing demands for biofuels to meet EISA goals, may constrain the feedstock volumes available for utilization in biopower applications and may also increase feedstock costs for both applications. A near-term opportunity to increase the use of biomass for power generation, thereby reducing GHG emissions, is to increase the deployment of co-firing applications for biomass and biomass-derived intermediates in existing power-generating facilities. However, as there are currently 2,219 registered biomass-to-power generation facilities in the U.S., BETO considers this technology to be commercially mature, and not in need of additional R&D support.[20]

1.1.2 State, Local, and International Political Climate

State and Local Political Climate

States play a critical role in developing energy policies by regulating utility rates and the permitting of energy facilities. Over the last two decades, states have collectively implemented hundreds of policies promoting the adoption of renewable energy. To encourage alternatives to petroleum in the transportation sector, states offer financial incentives for producing alternative fuels, purchasing flexible-fuel vehicles, and developing alternative fuels infrastructure. In some cases, states mandate the use of ethanol and/or biodiesel. Several states have also established renewable portfolio standards to promote the use of biomass in power generation.[21]

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[18] U.S. Energy Information Administration (2015), "Energy Consumption by Sector and Source," *Annual Energy Outlook 2015*, http://www.eia.gov/forecasts/aeo/data/browser/#/?id=2-AEO2015.

[19] U.S. Energy Information Administration (2015), "Total Energy Supply, Disposition, and Price Summary," *Annual Energy Outlook 2015,* http://www.eia.gov/forecasts/aeo/data/browser/#/?id=1-AEO2015&region=0-0&cases=ref2015&start=2012&end=2040&f=Q&linechart=ref2015-d021915a.3-1-AEO2015&sourcekey=0.

[20] U.S. Energy Information Administration (2013), "Existing Capacity by Energy Source," http://www.eia.gov/electricity/annual/html/epa_04_03.html.

[21] U.S. Department of Energy, Energy Efficiency & Renewable Energy Office (2014), "State Laws and Incentives," Alternative Fuels Data Center, http://www.afdc.energy.gov/laws/state.

Many states encourage biomass-based industries to stimulate local economic growth—particularly in rural communities that are facing challenges related to demographic changes, job creation, capital access, infrastructure, land use, and environment. Growth in the biofuels industry creates jobs through plant construction, operation, maintenance, and support, while providing risk reduction to farmers through inter-cropping and market expansion. Several states have also recently begun to develop policies to reduce GHG emissions and are looking to biopower and biofuel applications as a means to achieve targeted reductions. California has recently implemented aggressive emissions reductions targets, which call for a 10% reduction in the state's transportation sector's carbon footprint by 2020[22] and a 50% decrease in petroleum use by 2030.[23]

International Political Climate

Oil is expected to remain the dominant energy source for transportation worldwide through 2035, with overall oil consumption expected to increase from 98 million barrels per day in 2015 to about 121 million barrels per day in 2040.[24] However, the international use of renewable fuels is rising. Many nations are seeking to reduce petroleum imports, boost rural economies, and improve air quality through increased use of biomass. Some countries are pursuing biofuels as a means to reduce GHG emissions. Brazil and the United States lead the world in production of biofuels for transportation, primarily ethanol (see Figure 1-3), and several other countries have developed ethanol programs, including China, India, Canada, Thailand, Argentina, Australia, and Colombia.[25]

As countries are developing policies to encourage bioenergy, many are also developing sustainability criteria for the bioenergy they produce and use within their countries. Both the United States and the European Union (EU) specify certain land-use restrictions and GHG reduction requirements for renewable fuels.[26] The EU is also implementing additional biofuel sustainability criteria and reporting requirements.

[22] California Air Resources Board (2015), "California Climate Plan," http://www.arb.ca.gov/cc/cleanenergy/clean_fs2.htm.
[23] California Air Resources Board (2015), "California's 2030 Climate Commitments: Cutting Petroleum Use in Half by 2030," http://www.arb.ca.gov/newsrel/petroleum_reductions.pdf.
[24] U.S. Energy Information Administration (2015), "Comparison of AEO2015 and AEO2014 Reference cases and key updates to models and data," *Annual Energy Outlook 2015*, p. E-2, http://www.eia.gov/forecasts/aeo/.
[25] U.S. Department of Energy Alternative Fuels Data Center (2013), "Global Ethanol Production," http://www.afdc.energy.gov/data/10331.
[26] European Biofuels Technology Platform (2015), "Biofuels Policy and Legislation," European Biofuels Technology Platform, http://www.biofuelstp.eu/biofuels-legislation.html.

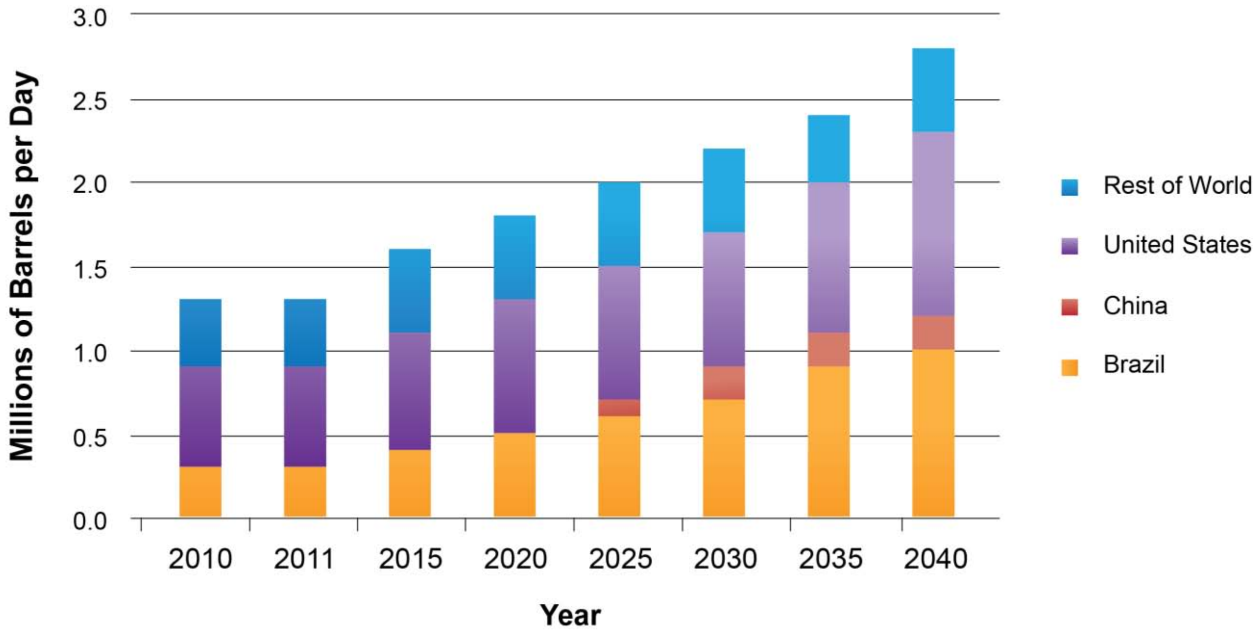

Figure 1-3: Global production of biofuels[27]

Several international groups are developing or implementing sustainability criteria and standards to promote responsible practices across the bioenergy supply chain, from biomass production to end use. For example, the Roundtable on Sustainable Biomaterials develops and maintains a global standard and certification system for organizations demonstrating compliance and commitment to sustainable and responsible practices. The International Organization for Standardization is developing criteria to advance international trade and the use of sustainable bioenergy. The Global Bioenergy Partnership facilitates information exchange, capacity building, and the adoption of voluntary sustainability criteria and indicators. These efforts, which address environmental, social, and economic aspects of bioenergy production, are building consensus among key partners on acceptable metrics and criteria to enable deployment of responsible industry practices worldwide.

The relationship among bioenergy, agriculture, and land-use change has been the subject of increasing attention, particularly with regard to the conversion of old growth forests and native prairies into agriculture production. Policymakers, eager to address this issue, have encouraged scientists in the bioenergy field to focus on researching the indirect impacts of bioenergy production in order to understand the magnitude of the linkage, as well as to identify and protect any vulnerable areas valued for their role in preserving biodiversity and sequestering carbon. Historical studies and reports, such as the UN's Sustainable Bioenergy Framework for Decision Makers complement current efforts within the Bioenergy Technologies Office.[28]

[27] U.S. Energy Information Administration (2013), *International Energy Outlook 2013*, Washington: Government Printing Office, DOE/EIA-0484. http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf.
[28] United Nations Environment Programme (2007), *Sustainable Bioenergy: A Framework for Decision Makers*, http://www.fao.org/docrep/010/a1094e/a1094e00.htm.

In recent years, attention has focused on how the expanding production of bioenergy crops can influence international markets, potentially triggering price surges and price volatility for staple foods. Some governments have addressed this issue by discouraging the use of food-based feedstocks for bioenergy production. Over the past several years, China halted construction of new food-grain-based ethanol plants and has worked to promote policies that encourage the production of biofuels from non-food feedstocks grown on marginal land. Many countries—particularly in the developing world—have identified ways to minimize competition. Others have identified strategies for producing bioenergy from residues in conjunction with food, feed, and other products that can increase food security by generating employment, raising income in farming communities, and promoting rural development (Food and Agriculture Organization of the United Nations, i.e., UN FAO).[29]

DOE develops technologies that produce biofuels from feedstocks that have no or minimal impacts on food crops. As such, DOE R&D activities focus on developing feedstocks such as agricultural residues, forestry residues, urban wood waste/mill residues, energy crops, and wet wastes (e.g., biosolids).

The EU has enacted a variety of environmental policies that have impacted bioenergy markets in the United States. European targets for the production of 20% renewable power by 2020[30] have led to an expanding market for American and Canadian wood pellets and raw biomass feedstock. The EU Emissions Trading System has expanded interest in biobased aviation fuels. It caps the total amount of allowable carbon emissions across industrial sectors, including emissions from aircraft operators performing aviation activities in the EU and European Free Trade Association states.[31] Most recently, the European Parliament has moved to impose limits on the volume of conventional biofuels in the EU market, while potentially increasing incentives for the production of cellulosic and other advanced biofuels.

1.1.3 Other Fuel Alternatives

The principal technologies that compete with biomass today rely on continued use of fossil energy sources to produce transportation fuels, products, and power in conventional petroleum refineries, petrochemical plants, and power plants. Today, there are several readily available fuel alternatives to petroleum-based liquids, such as fully electric vehicles, hybrid vehicles, and fuel cell vehicles, which store energy in the form of hydrogen.

- **Electricity:** Electricity can be used to power electric vehicles, which either store potential energy in a battery or produce power from a fuel cell as the vehicle is operating.

[29] Food and Agriculture Organization of the United Nations (2015), "Bioenergy and Food Security," http://www.fao.org/bioenergy/foodsecurity/befs/en/.
[30] European Commission: Energy (2015), "Renewable Energy," https://ec.europa.eu/energy/en/topics/renewable-energy.
[31] European Commission (2015), "The EU Emissions Trading System (EU ETS)," http://ec.europa.eu/clima/policies/ets/index_en.htm.

Sales of electric vehicles are accelerating quickly, with global sales growing by 53% from 2013 to 2014.[32]

- **Hydrogen:** Hydrogen can be produced via multiple routes, including water electrolysis, algae, reforming renewable liquids or natural gas, coal gasification, or nuclear synthesis.
- **Gas-to-Liquids**: Hydraulic fracturing and horizontal drilling technologies have enabled increased production of natural gas in the United States. Natural gas can be converted to liquid transportation fuels (diesel, jet, and gasoline) and chemicals by steam-methane reforming reactions and Fischer-Tropsch conversion processes; these are technologies that are different from those used with crude oil.
- **Coal-to-Liquids:** In terms of cost, coal-derived liquid fuels have traditionally been non-competitive with fuels derived from crude oil. While conventional coal-to-liquid technologies can be adapted to use biomass as a feedstock, both in standalone applications or blended with coal, the biomass resource does not scale as well as coal.

1.1.4 Market Barriers

Biorefineries that use cellulosic and algal biomass as feedstocks face market barriers at the federal, state, and local levels. Feedstock availability, production costs, investment risks, consumer awareness and acceptance, and infrastructure limitations pose significant challenges for the emerging bioenergy industry. Widespread deployment of integrated biorefineries will require demonstration of cost-effective biorefinery systems and sustainable, cost-effective feedstock supply infrastructure. The following market barriers are also discussed in Section 2:

Ft-A Terrestrial Feedstock Availability and Cost
Im-A Inadequate Supply Chain Infrastructure
Im-B High Risk of Large Capital Investments
Im-C Codes, Standards, and Approvals for Use
Im-D Cost of Production
Im-E Offtake Agreements
Im-F Uncertain Pace of Biofuel Availability
Im-G Biofuels Distribution Infrastructure
Im-H Lack of Acceptance and Awareness of Biofuels as a Viable Alternative
It-A End-to-End Process Integration
It-B Risk of First-of-a-Kind Technology
It-C Technical Risk of Scaling

The following additional barriers cross the entire supply chain and so are not specific to any particular technology area.

- **Mm-A: Lack of Understanding of Environmental/Energy Tradeoffs.** There is a need for a more thorough, systematic evaluation of the impact of expanded biofuels production on the environment and food supply for humans and animals. Sufficient data needs to be generated from various operational facilities' designs to provide

[32] International Energy Agency (2015), "Global EV Outlook 2015," http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf.

valid sustainability benchmarks for the nascent industry. Analytical tools are needed to facilitate consistent evaluation of energy benefits and GHG emissions impacts of all potential advanced biofuel feedstock and conversion processes. EISA requires that all biofuels be evaluated for their reduction in GHG emissions in order to qualify under the RFS. Cellulosic biofuels, a subset of "advanced biofuels," must achieve at least a 60% reduction in GHG emissions, relative to a 2005 baseline of the petroleum displaced, including indirect land-use change. Advanced biofuels must achieve at least a 50% reduction in GHG emissions. EPA has established the methodology for evaluating these impacts for some pathways.

- **Mm-B: Inconsistent or Competing Policies and Drivers to Facilitate Multi-Sector Shifts.** Expanding biofuels production to meet federal goals will require managing and responding to different markets and policy drivers and considerable federal, state, and local investments. Proper alignment and careful choice of policy tools across several different sectors is crucial. Legislation may ultimately determine the future portfolio mix for bioenergy production and use.
- **Mt-A: Optimization of Supply Chain Interfaces and Cross-System Integration.** The commercialization of biofuels technology will involve industrial-scale technology deployment across a dispersed supply chain. This will require integration and optimization of technologies within and across agricultural, forestry, equipment manufacturing, and biorefinery sectors to address cross-system risks and leverage cross-system positive synergies. Integrating information across sector interfaces will be critical to harnessing efficiencies and driving down costs.

1.1.5 History of Public Efforts in Biomass RD&D

Federal efforts in bioenergy were initiated by the National Science Foundation and subsequently transferred to DOE in the late 1970s. Early projects focused on biofuels and biomass energy systems. In 2002, the Bioenergy Technologies Office (formerly the Office of the Biomass Program) was formed to consolidate the biofuels, bioproducts, and biopower research efforts across EERE into one comprehensive office. From the 2002 to the present, DOE has invested more than $3 billion [including more than $900 million in American Recovery and Reinvestment Act of 2009 (i.e., ARRA) funds] in a variety of RD&D programs covering biofuels, biopower, feedstocks, municipal wastes, and a variety of biobased products. Considerable progress has been made in many areas, including the Office's R&D-scale validation of technologies capable of producing modeled price-competitive cellulosic ethanol. However, continued federal support is needed to fully commercialize ethanol, other hydrocarbon fuels, and other advanced biomass technologies. Key policy shifts, major new legislation, and EERE funding levels are shown in Figure 1-4. This figure does not include bioenergy-related funding for other DOE or EERE offices.

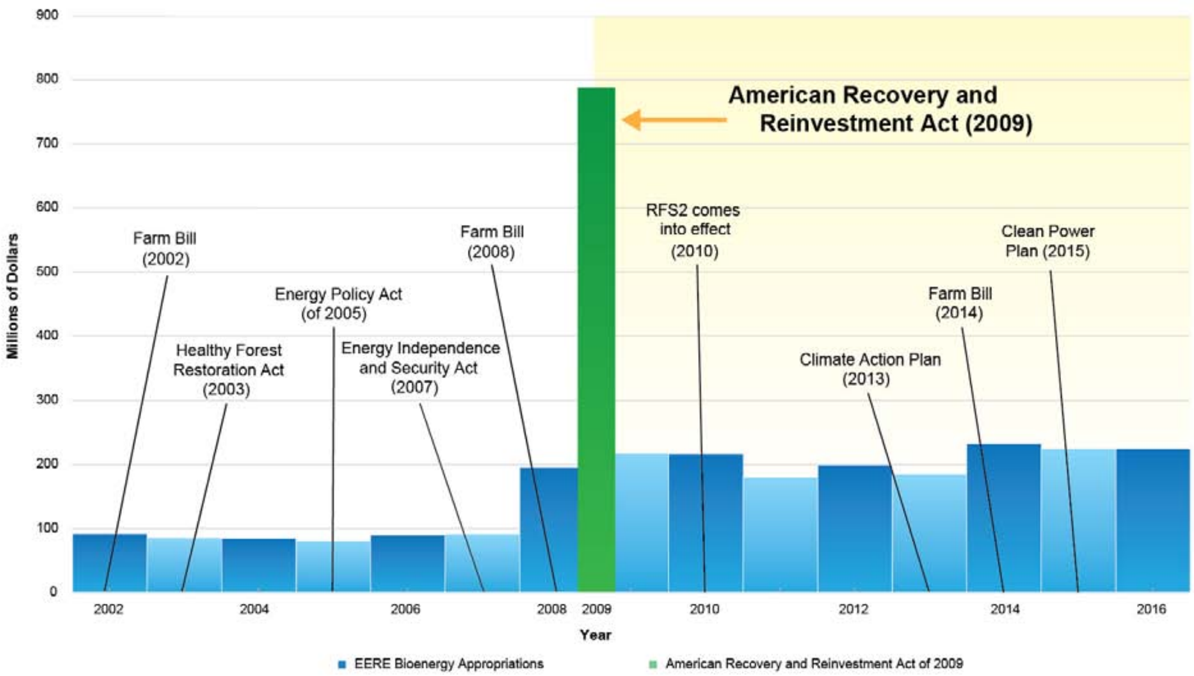

Figure 1-4: DOE EERE funding for biomass RD&D

Especially in recent years, several legislative, regulatory, and policy efforts have increased and accelerated biomass-related RD&D. These efforts are summarized in Table 1-1.

1.1.6 Bioenergy Technologies Office Justification

The Bioenergy Technologies Office is accelerating the commercialization of first-of-a-kind technologies designed to use the nation's abundant renewable biomass resources for the production of advanced biofuels and biobased products. The Office is also investigating how to improve the economics of biofuel production by converting biomass into high-value chemicals and products that are historically derived from petroleum. As the United States continues to experience the highs and lows of a volatile transportation energy market driven by fossil fuels, the need to find stabilizing solutions becomes increasingly important.

The benefits of biofuels, bioproducts, and biopower include greater economic security, as significant amounts of sustainable, domestically produced feedstocks are directed to the production of renewable energy. The environmental and social benefits of biofuels, bioproducts, and biopower include both a reduction in the GHG emissions that lead to climate change and an increase in economic activity across the entire supply chain. From new jobs in the farms and forests of rural America to growing the U.S. construction and manufacturing industries with the production of bioenergy, biochemical, and vehicles, reinvesting in new U.S. technologies helps secure our national competitive advantage and enables opportunities in the renewable energy sector for future generations.

Table 1-1: Legislative, Regulatory, and Policy Efforts

August 2015	Clean Power Plan	• Established national standards that reduce carbon pollution from power plants and set goals to reduce carbon pollution from the U.S. power sector 32% lower than 2005 levels by 2030. • Targeted reductions of sulfur and nitrogen oxides 90% and 72% below 2005 levels by 2030, respectively.
Feb 2014	Agricultural Act of 2014 (Farm Bill)	• Continued several bioenergy-related programs, including Repowering Assistance Program, Bioenergy Program for Advanced Biofuels, and the Biomass Research and Development Initiative. • Modified the Biomass Crop Assistance Program to extend crop exclusions (whole grain, algae, and bagasse) and limit one-time establishment payments to no more than 50% of the cost of establishment. • Expanded the "Biorefinery, Renewable Chemical and Biobased Product Manufacturing Assistance Program (Section 9003)" (formerly the Biorefinery Assistance Program) to include renewable chemicals and biobased product manufacturing.
June 2013	President's Climate Action Plan	• Set goals to reduce carbon pollution in America by 17% by 2020 from 2005 levels. • Outlined a strategy that focuses in part on Building a 21st Century Transportation Sector and Developing and Deploying Advanced Transportation Technologies. • Promoted partnerships between the private and public sectors to deploy cleaner fuels.
March 2011	Blueprint for a Secure Energy Future	• Outlined a comprehensive energy policy to cut U.S. oil imports by one-third by 2025 by reducing the nation's dependence on oil with cleaner alternative fuels and greater efficiency. • Promoted collaboration with international partners to increase bioenergy production. • Included research and incentives to reduce barriers to increased biofuels use and the commercialization of new technologies.
June 2011	A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022	• Developed a comprehensive regional strategy targeting barriers to the development of a successful biofuels market that will achieve, or surpass, the current U.S. Renewable Fuel Standard.
May 2009	Presidential Memorandum on Biofuels	• Established a Biofuels Interagency Working Group to consider policy actions to accelerate and increase biofuels production, deployment, and use. The group is co-chaired by the Secretaries of the U.S. Departments of Energy and Agriculture and the Administrator of the Environmental Protection Agency.
Feb 2009	American Recovery and Reinvestment Act of 2009	• Provided funds for grants to accelerate the commercialization of advanced biofuels R&D and pilot-, demonstration-, and commercial-scale integrated biorefinery projects. • Provided funds to other DOE programs for applied R&D, innovative research, tax credits, and other projects.
May 2008	The Food, Conservation, and Energy Act of 2008 (Farm Bill)	• Provided grants, loans, and loan guarantees for developing and building demonstration- and commercial-scale biorefineries. • Established a $1.01 per gallon producer tax credit for cellulosic biofuels. • Established the Biomass Crop Assistance Program to support the production of biomass crops. • Provided support for continuation of the Biomass R&D Initiative, the Biomass R&D Board, and the Biomass R&D Technical Advisory Committee.
Dec 2007	Energy Independence and Security Act of 2007	• Supported the continued development and use of biofuels, including a significantly expanded Renewable Fuels Standard, requiring 36 billion gallons per year of renewable fuels by 2022, with annual requirements for advanced biofuels, cellulosic biofuels, and biobased diesel. • The full RFS2 regulatory program went into effect July 2010, with EPA determining required cellulosic biofuel volumes annually.
Aug 2005	Energy Policy Act of 2005	• Renewed and strengthened federal policies fostering ethanol production, including incentives for the production and purchase of biobased products; these diverse incentives range from authorization for demonstrations to tax credits and loan guarantees.

From 2015 to 2040, U.S. energy consumption is projected to rise by 8%, while domestic energy production is expected to rise by nearly 19%.[33] Renewable liquid fuels, including biofuels, are projected to have the largest increase in meeting domestic transportation consumption—growing from 5% in 2011 to 15% of liquid fuels in 2035.[34] This decreased reliance on imported energy improves our national security, economic health, and future global competitiveness and revitalizes investment and cash flows in the United States, which are vital for a growing economy.

The U.S. transportation sector is responsible for 26% of U.S. carbon dioxide (CO_2) emissions, the principal GHG contributing to climate change.[35] Increased use of biofuels, bioproducts, and biopower can decrease life-cycle emissions of GHG and other pollutants substantially, depending on feedstock type, crop management practices, and processing. For liquid transportation fuels, biofuels are one important option for achieving such reductions, especially for diesel trucks, jet aircraft, and marine vessels. Liquid hydrocarbon transportation fuels made from biomass are advantageous because they are largely compatible with existing infrastructure to deliver, blend, and dispense fuels.

The resulting supply of domestically produced biofuels—intended to replace petroleum imported for the chemical and fuels industry—will also retain the full U.S. investment and help reduce price volatility. This point is underscored by the Defense Department's effort to increase national energy security through energy independence, beginning with reducing U.S. exposure to volatile global oil markets. Price spikes in these markets can have profound effects on total fuel costs for the U.S. armed services.

Despite the economic, environmental, and social benefits of bioenergy production, there are significant challenges keeping the industry from its full potential. Similar to other process industries, the advanced bioenergy industry faces significant challenges and risks in the scale-up to pilot, demonstration, and pioneer scales. These risks are related to technology, construction, environmental impact, feedstock supply, operations, market offtake, and financing.[36] The specific risks of feedstock supply and market offtake are more pronounced for advanced biofuels than for other renewable sources of energy because of the variability inherent in biomass and the lack of long-term offtake agreements in the fuel and chemicals markets.

The primary challenges of sustainable feedstock supply and logistics, cost and technical risk reduction in conversion processes, and integrated performance validation at large-scale operation

[33] U.S. Energy Information Administration (2015), "Total Energy Supply, Disposition, and Price Summary," *Annual Energy Outlook 2015,* http://www.eia.gov/forecasts/aeo/data/browser/#/?id=1-AEO2015&region=0-0&cases=ref2015&start=2015&end=2040&f=Q&linechart=ref2015-d021915a.3-1-AEO2015&sourcekey=0.
[34] International Energy Agency (2013), "Ethanol and biodiesel consumption in road transport by region in the New Policies Scenario," *World Energy Outlook 2013*, p. 205, http://www.worldenergyoutlook.org/media/weowebsite/2013/weo2013_ch06_renewables.pdf.
[35] Environmental Protection Agency (2015), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013*, http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf.
[36] S.E. Koonin and Gopstein, A.M. (2011), "Accelerating the Pace of Energy Change," *Issues in Science and Technology* 27(2), http://issues.org/27-2/koonin/.

need to be addressed to demonstrate robust processes that are ready for commercialization and replication by industry.

There is a unique federal role in partnering with leading R&D entities and industrial technologists across the entire bioenergy supply chain. From the development of sustainability standards and the logistics to reliably produce and deliver up to one billion tons of biomass to biorefineries, the federal government enables the teaming of experts to develop robust and selective conversion technologies and demonstrate the reduction of technical risk.

The Office is uniquely positioned to leverage its legislative authority for financial assistance and leverage DOE's successful track record in commercialization to assist developers in de-risking technologies through validated proof of performance at the pilot, demonstration, and pioneer scales. Obtaining traditional financing is a challenge for new innovative bioenergy technologies, and most pioneer facilities require equity financing of $200 million or more. Two recent industry studies have highlighted the necessary government role in supporting this industry, showing that 86% of the large-scale biorefinery projects in the United States have been at least partially funded by DOE.[37] The Office's support for validation of these new technologies at large scale helps to overcome financing barriers both through direct financial assistance and de-risking the technology through proof-of-performance testing.

The overarching federal role is to ensure the availability of a reliable, affordable, and environmentally sound domestic energy supply. Billions of dollars have been spent over the last century to construct the nation's energy infrastructure for fossil fuels.[38] The production of alternative transportation fuels from new primary energy supplies, like biomass, is no small undertaking. The role of federal programs is to invest in the high-impact, high-value bioenergy technology RD&D that is critical to the nation's future and that industry would be unable to pursue independently. States, associations, and industry will be key participants in deploying biomass technologies once risk reductions have been sufficiently demonstrated by federal programs.

[37] Bacovsky, Ludwiczek, Ognissanto, Wörgetter (March 2013), Status of Advanced Biofuels Demonstration Facilities, IEA Task 39-P1b, http://task39.sites.olt.ubc.ca/files/2013/12/2013_Bacovsky_Status-of-Advanced-Biofuels-Demonstration-Facilities-in-2012.pdf.
[38] U.S. Energy Information Agency (July 2011), *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010*, http://www.eia.gov/analysis/requests/subsidy/pdf/subsidy.pdf.

1.2 Office Vision and Mission

EISA aimed to increase the supply of alternative fuels and set a target for the use of 36 billion gallons of renewable fuels, including advanced and cellulosic biofuels and biomass-based diesel, by 2022. DOE has set a goal in its strategic plan to support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure.[39]

To meet both EISA and DOE goals, the Office is focused on developing and demonstrating bioenergy and bioproducts technologies in partnership with other government agencies, industry, and academia. The Office supports four key goals of the recently updated EERE Strategic Plan:[40]

- Accelerate the development and adoption of sustainable transportation technologies
- Stimulate the growth of a thriving domestic clean energy manufacturing industry
- Lead efforts to improve federal sustainability and implementation of clean energy solutions
- Enable a high-performing, results-driven culture through effective management approaches and processes.

The Office's vision, mission, and goals are shown in Figure 1-5.

[39] U.S. Department of Energy (2014), *U.S. Department of Energy Strategic Plan 2014-2018*, DOE/CF-0067, http://energy.gov/downloads/2014-2018-strategic-plan.
[40] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2016), *2016–2020 Strategic Plan and Implementing Framework*, http://www.energy.gov/eere/downloads/eere-strategic-plan.

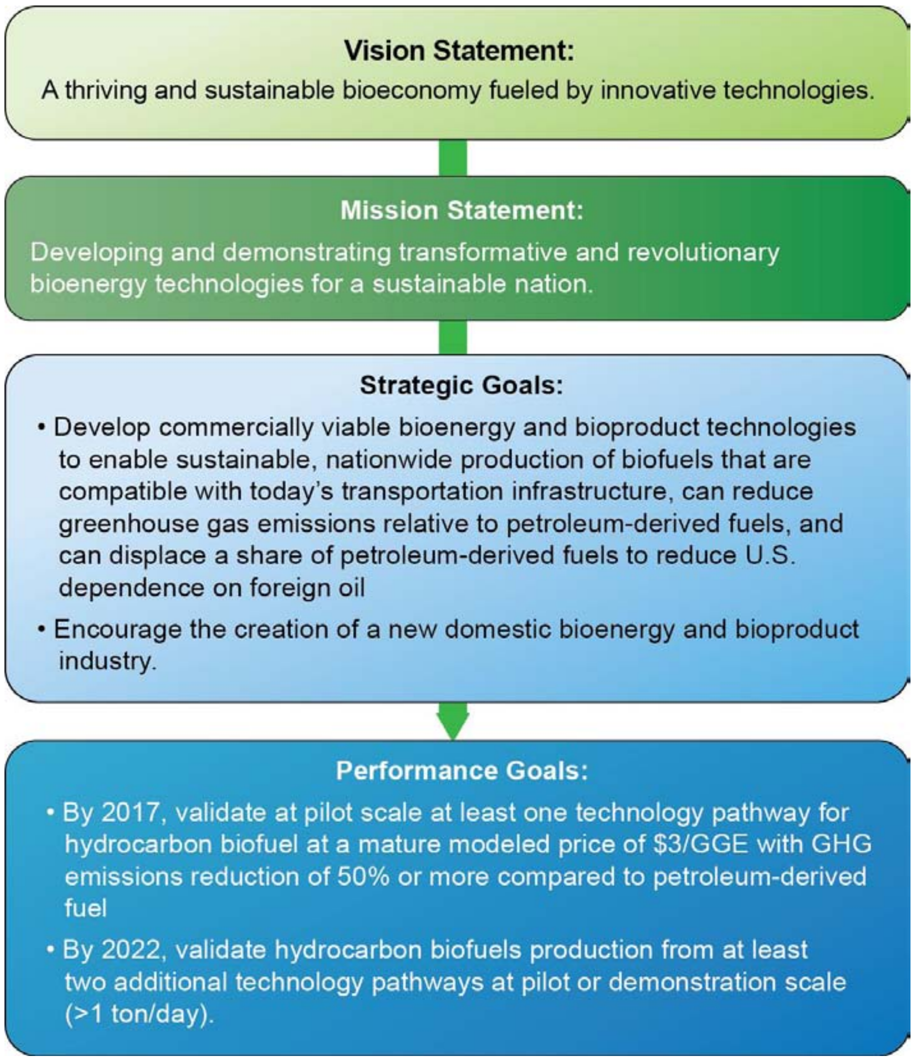

Figure 1-5: Strategic framework for the Bioenergy Technologies Office[41]

[41] Methodology for developing performance goals is detailed in Appendix B.

1.3 Office Design

1.3.1 Office Structure

As shown in Figure 1-6, the Bioenergy Technologies Office administration and work breakdown structure is organized around two broad categories of effort: RD&D and Crosscutting Activities. The first category is comprised of three technical program areas: Feedstock R&D, Conversion R&D, and Demonstration and Market Transformation. The Office's crosscutting program areas are Sustainability, Strategic Analysis, and Strategic Communications. A fourth crosscutting area is Office Portfolio Management.

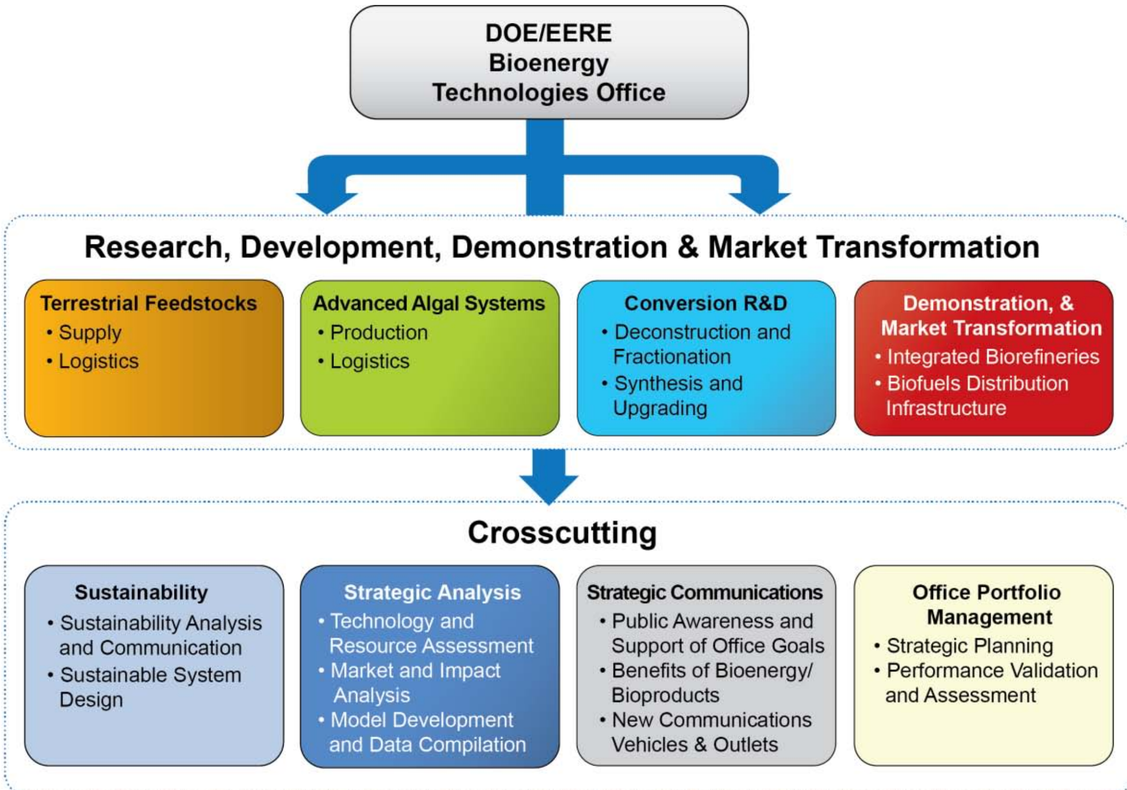

Figure 1-6: Structure of the Bioenergy Technologies Office

This approach provides for the development of pre-commercial, enabling technologies, as well as the integration and demonstration activities critical to proof of performance at increased scale and integration. It also accommodates the Sustainability, Analytical, and Strategic Communications activities needed to help the nation overcome market barriers and accelerate technology deployment.

The organization, activities, targets, and challenges of each of the Office's three technical program areas and three crosscutting program areas are described in detail in Section 2. The fourth crosscutting area, Office Portfolio Management, is described in Section 3.

1.3.2 Portfolio Logic

The portfolio logic diagram shown in Figure 1-7 identifies inputs that guide the Office strategy and external factors that require continuous monitoring to determine the need for any programmatic adjustments. The diagram shows portfolio activities and their outputs, leading to outcomes that support the Office mission and vision. This progression of linkages supports the framework for the Office strategy and this Multi-Year Program Plan.

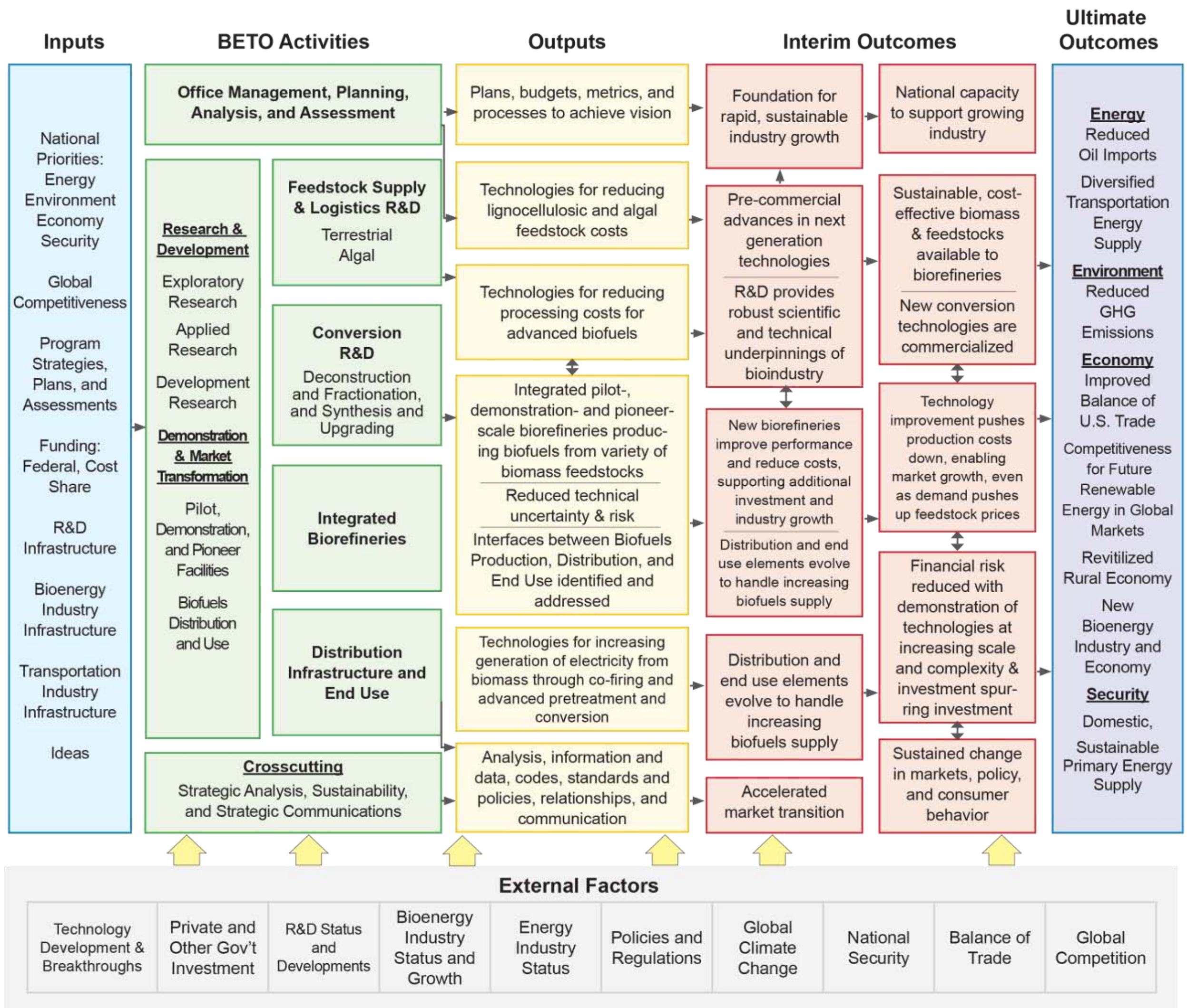

Figure 1-7: Bioenergy Technologies Office portfolio logic diagram

1.3.3 Relationship to Other Offices within DOE and Other Federal Agencies

Coordination with other DOE offices and government agencies involved in bioenergy development is essential to avoid duplication, leverage limited resources, optimize the federal investment, ensure a consistent message to stakeholders, and meet national energy goals. Collaboration is also essential for the realization of a sustainable bioeconomy, defined as "the global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits."[42] The Office maintains key partnerships with other DOE offices as shown in Table 1-2 and Figure 1-8.

Table 1-2: Summary of Partnerships with Other DOE Offices

DOE Office	Partnership Description
Office of Science	• The Office regularly coordinates with the Office of Science by focusing on fundamental and applied research activities regarding biomass and biofuels with eventual commercial applications for bioenergy.
Loan Programs Office	• The Loan Programs Office provides finance guarantees to BETO for commercial biorefinery projects to spur further investments in the bioenergy sector.
Office of Fossil Energy	• The Office collaborates with the Office of Fossil Energy to examine technology development improvements to increase the efficiency, environmental performance, and economic viability of utility-scale biopower and carbon reuse applications.
Energy Information Agency	• The Office contributes data to the Energy Information Agency to support accurate forecasting of production and consumption.
EERE Office	**Partnership Description**
Advanced Manufacturing Office	• AMO works with the Office to research and develop biomass-based technologies such as renewable, low-cost carbon fiber for lightweight vehicles, in addition to the production of biomass fuels, chemicals, materials, heat, and electricity. AMO invests in emerging technologies that include the use of biomass for fuels, chemicals, materials, heat, and electricity.
Advanced Research Projects-Energy	• ARPA-E invests in innovative technologies that include electro-fuels and the Plants Engineered to Replace Oil (PETRO) program for direct biofuel production. The Office greatly benefits from information sharing with ARPA-E.
Federal Energy Management Program Office	• FEMP works with the federal fleet to increase the use of biopower, renewable and alternative fuels, and flexible-fuel vehicles.
Fuel Cell Technologies Office	• FCTO and the Office coordinate research efforts on reformation and gasification, the availability of biomass, and renewable hydrogen for biofuel production. In addition, the offices collaborate on using algae to produce biofuels and hydrogen.
Vehicle Technologies Office	• VTO partners with the Office on fuel and infrastructure characterization, as well as the co-optimization of fuels and engines. The Office also interfaces with VTO's Clean Cities Program, developing partnerships to promote alternative fuels, vehicles, and infrastructure.
Office of Strategic Programs	• The Office efforts are supportive of, and coordinate with, broader corporate efforts, such as communications outreach, strategic analysis, international partnerships, and legislative affairs.

[42] Duke University Center for Sustainability & Commerce (2014), *Why Biobased? Opportunities in the Emerging Bioeconomy: Why BioPreferred*, http://www.biopreferred.gov/files/WhyBiobased.pdf.

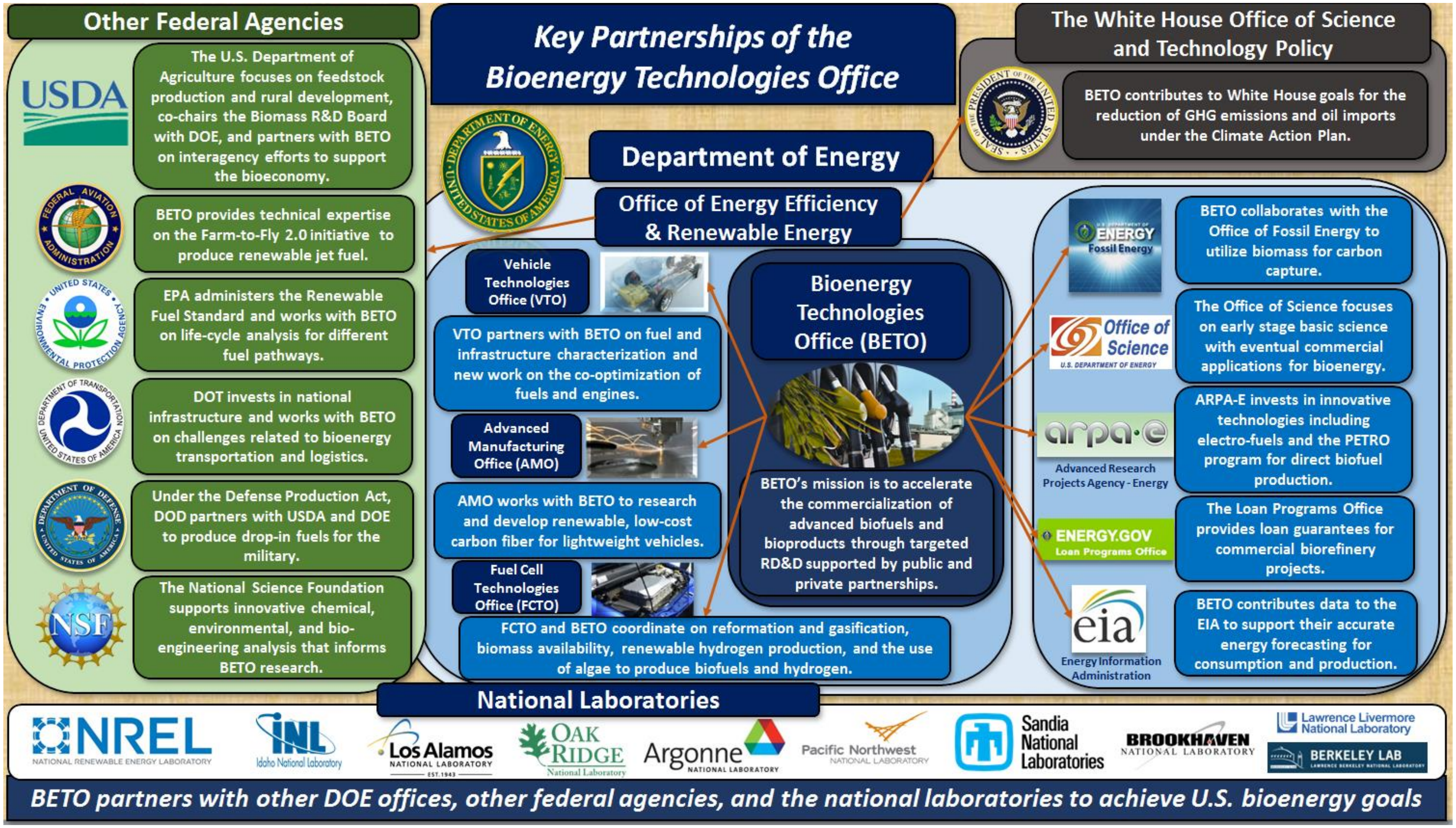

Figure 1-8: Key partnerships with other DOE offices and federal agencies

As shown in Table 1-2, the Office coordinates with several federal agencies through a range of informal and formal mechanisms. The Biomass R&D Board (the Board) is a particularly important coordination mechanism that was created by the Biomass Research and Development Act of 2000. Formed to maximize federal efforts to enhance the emerging biomass industry, the Board is an interagency collaboration co-chaired by the U.S. Department of Agriculture and DOE. Other Board partners include the Departments of Interior, Transportation, and Defense; EPA; the National Science Foundation; and the Office of Science and Technology Policy. Its members meet quarterly to discuss updates and implementation strategies across federal agencies in biofuels, biopower, and bioproducts R&D.

Table 1-2: Summary of Federal Agency Responsibilities in Supporting the Bioeconomy

Federal Agency or Partner	Feedstock Production	Feedstock Logistics	Conversion	Demonstration	Biofuels Distribution	Biofuels End Use
U.S. Department of Energy	• Plant and algal science • Genetics and breeding • Feedstock resource assessment • Sustainable land, crop, and forestry management • Algal feedstock cultivation and production systems.	• Sustainable logistics systems, including harvesting, handling, storage, & preprocessing systems • Testing logistics systems at demonstration scale.	• Biochemical conversion (pretreatment/enzyme cost reductions) • Recalcitrance of all biomass resources • Thermochemical conversion to increase yield of hydrocarbons to fuel blendstocks and energy (gasification and pyrolysis).	• Cost-shared projects and/or loan guarantees to biorefineries to demonstrate and deploy integrated conversion processes at pilot, demonstration, and pioneer scale.	• Transportation/distribution systems development • Material compatibility.	• Engine compatibility and optimization • Vehicle emissions testing • Bioproduct testing for market acceptance • Education regarding positive impacts of biofuels.
U.S. Department of Agriculture	• Sustainable land, crop, and forestry management • Payments to biomass crop producers • Plant science, genetics and breeding • Genetic improvement work directed at perennial grasses.	• Sustainable harvesting of biomass crop and forest residue removal • Equipment systems related to planting.	• Biochemical conversion (pretreatment/enzyme cost reductions) • Recalcitrance of forest resources • Thermochemical conversion to fuels and power • On-farm biofuels systems.	• Loan guarantees to viable pioneer-scale facilities and grants to demonstration-scale facilities • Payments to existing biorefineries to retrofit power sources to be renewable.	• Loan guarantees and grants to support (1) safe and sustainable biofuel transportation/ distribution (2) Refineries & blending facilities development (3) Flex-fuel pumps installation (4) Financing of transportation/ distribution industry/businesses.	• Market awareness and education for end users on advantages of increased biofuels use.
U.S. Environmental Protection Agency	• Effects of feedstock production systems, including effects on ecosystem services (water quality, quantity, biodiversity, etc.). • Assessment of bioenergy crop impacts.	• Mitigate negative impacts of feedstock production and logistics.	• Biowaste-to-energy • Characterization of air, water, and waste emissions • Regulations/permitting • TSCA (Toxic Substances Control Act) review of inter-generic genetically engineered microbes used for biomass conversion • Testing protocols and performance verification.	• Health/environmental impacts of biofuels supply chain life cycle • Characterization of air, water, and waste emissions; regulations/permitting • Policy and research on waste to energy • Testing protocols and performance verification • Market impact of biofuels production.	• Permitting, air emission characterization • Regulation of underground storage tanks • Emergency management and remediation of biofuel spills.	• Engine optimization/certification • Characterization of vehicle emissions and air quality, and environmental, and public health impacts • Regulation of air emissions • Market awareness/ impact of biofuels on public health, ambient air, and vehicles.
U.S. Department of Commerce/ National Institute for Standards and Technology			• Catalyst design, biocatalytic processing, biomass characterization, and standardization • Standards development, measurement, and modeling.		• Materials reliability for storage containers, pipelines, and fuel delivery systems.	• Standard reference materials, data, and specifications for biofuels.

Federal Agency or Partner	Feedstock Production	Feedstock Logistics	Conversion	Demonstration	Biofuels Distribution	Biofuels End Use
U.S. Department of Transportation		• Feedstock transport infrastructure development.			• Safe, adequate, cost-effective biofuels transportation/ distribution systems development.	• Promotion of safe and efficient transportation while improving safety, economic competitiveness, and environmental sustainability.
Federal Aviation Administration	• Rigorous research in advanced feedstock and renewable aviation fuel pathway development.		• Techno-economic analysis of processes that convert biomass to jet fuel.	• Builds relationships, share and collect data, identify resources, and direct research, development and deployment of alternative jet fuels by supporting Commercial Aviation Alternative Fuels Initiative.	• Safe, adequate, compatible, cost-effective biofuels transportation/ distribution system.	• Working toward certification of bio-derived jet fuels in coordination with the American Society for Testing and Materials with the entire aviation supply chain.
National Science Foundation	• Plant genetics, algal science, and other paths to improve biofuels feedstocks and wastes as energy sources.	• Basic research on modifications or processes to improve feedstock preprocessing.	• Basic and applied research on catalysts, processes, characterization for biochemical and thermochemical conversion technologies • Life-cycle analysis • Environmental impact amelioration.	• Supportive R&D on health/environmental impacts of biofuels and bioproducts		• Supportive R&D on health/ environmental/ safety/social issues of biofuels use.
Department of the Interior	• Forest management.	• Forest management/ fire prevention (recovery of forest thinnings).	• Biorefinery permitting on Department of Interior-managed lands.			
Department of Defense	• Basic R&D on feedstock processing (municipal solid waste/waste biomass).		• Solid waste gasification • Applied algal and cellulosic feedstock conversion R&D • Partner in Defense Production Act.	• Through Defense Production Act, support biorefineries to demonstrate and deploy integrated conversion at commercial scale.	• Safe, compatible, cost-effective biofuels transportation/ distribution systems developed for military use.	• Biofuels testing • Standard reference materials, data, and specifications for biofuels • Biofuel use in military vehicles/crafts.

1.4 Office Goals and Multi-Year Targets

This subsection describes the Office's goals and targets.

1.4.1 Office Strategic Goals

As stated in Section 1.2, the Office's overarching strategic goal is to *develop commercially viable bioenergy and bioproduct technologies to enable sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure, can reduce greenhouse gas emissions relative to petroleum-derived fuels, and can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil and encourage the creation of a new domestic bioenergy and bioproduct industry.*

The Office's high-level schedule, illustrated in Figure 1-9, aims for development of commercially viable renewable gasoline, diesel, and jet technologies by 2017 through R&D and enables a trajectory toward long-term renewable fuels goals.

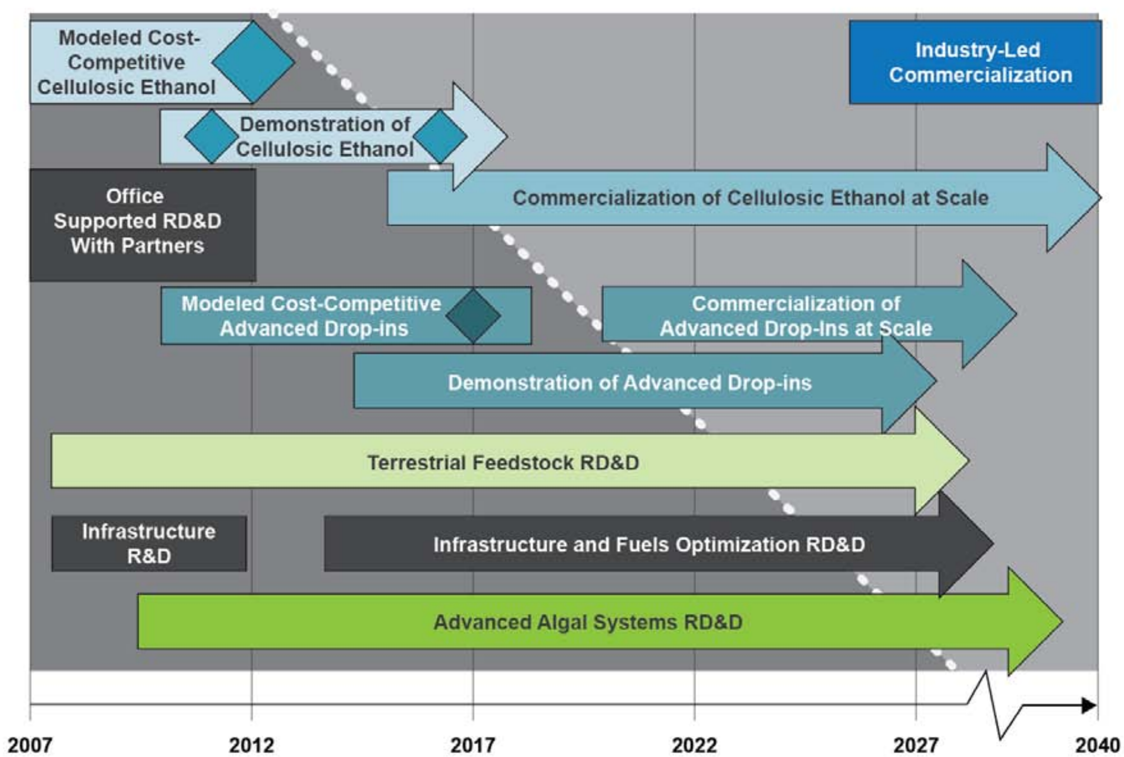

Figure 1-9: Technology Development Timeline

The strategic goals for each program area support the Office's overarching strategic goal, as shown in Figure 1-10. These goals are integrally linked: demonstration and validation activities, for example, will depend on an available, sustainable feedstock supply, commercially viable conversion technologies, adequate distribution infrastructure, and strategic alliances and outreach to catalyze market expansion.

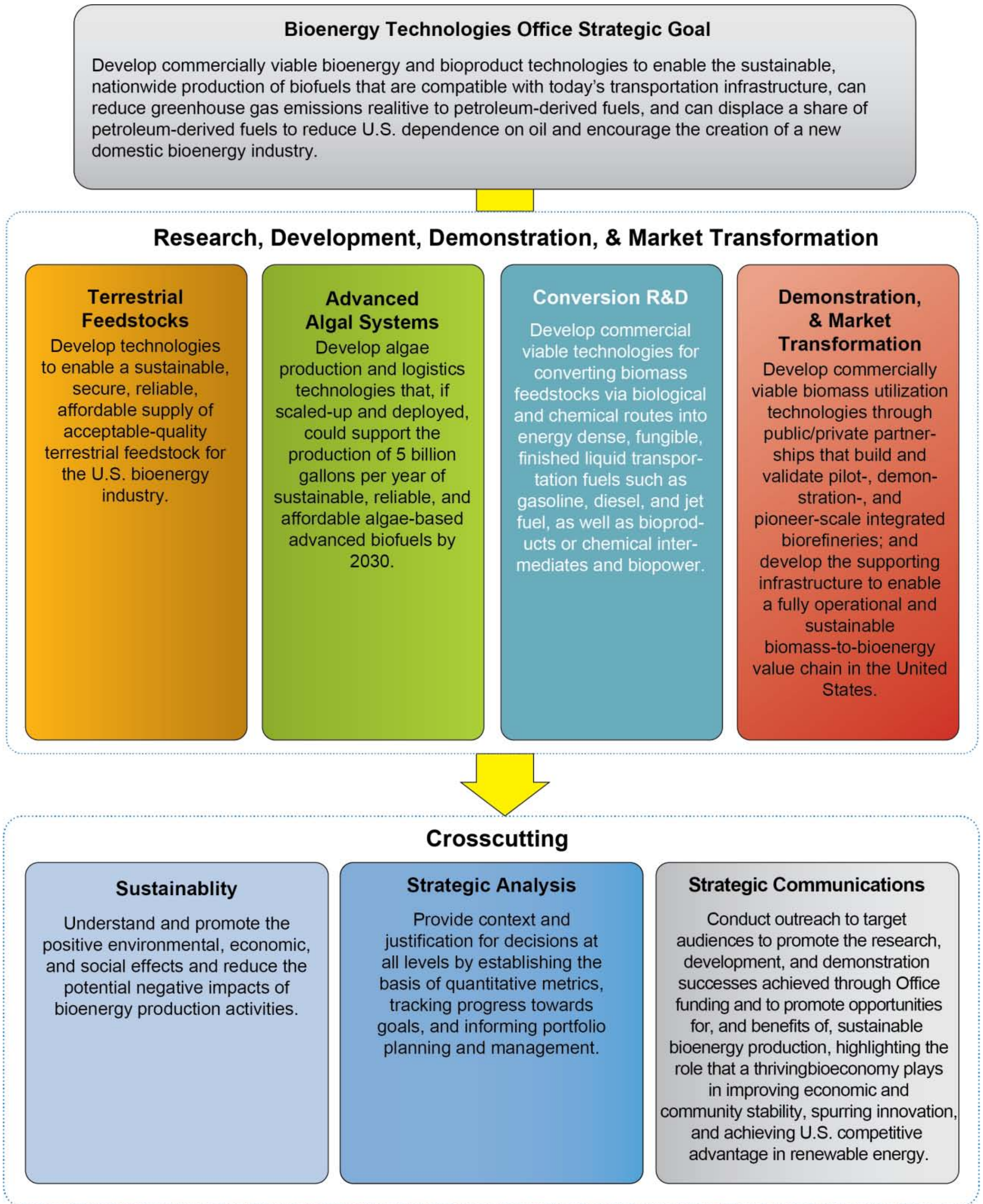

Figure 1-10: Strategic goals for the Bioenergy Technologies Office

1.4.2 Office Performance Goals

The overall performance goals set for the Office are shown below. These goals reflect the strategy of making advanced biofuels—renewable gasoline, diesel, and jet fuel—commercially viable, as the most effective path for stimulating an emerging bioenergy economy.

- By 2017, validate at a pilot scale at least one technology pathway for hydrocarbon biofuel production at a mature modeled price of $3/GGE with GHG emissions reduction of 50% or more compared to petroleum fuel.
- By 2022, validate hydrocarbon biofuels production from at least two additional technology pathways at pilot or demonstration scale (>1 ton/day).

1.4.3 Office Multi-Year Targets

The Office's multi-year targets for 2016–2027 are listed in Table 1-4, while the high-level milestones leading to these targets are listed in Table 1-5. Section 2 provides more detail on program area performance goals and high-level milestones for all Office programs.

Table 1-4: Office Multi-Year Performance Goals

Feedstock Supply and Logistics R&D
Terrestrial Feedstocks Supply and Logistics R&D
▪ By 2017, validate efficient, low-cost, and sustainable feedstock supply and logistics systems that can deliver feedstock to the conversion reactor throat at required conversion process in-feed specifications, at or below $84/dry ton (2014$) (including grower payment/stumpage fee and logistics cost). ▪ By 2017, establish geographic, economic, quality, and environmental criteria under which the industry could operate at 245 million dry ton per year scale (excluding biopower). ▪ By 2022, develop and validate feedstock supply and logistics systems that can economically and sustainably supply 285 million dry tons per year at a delivered cost of $84/dry ton (2014$) to support a biorefining industry (i.e., multiple biorefineries) utilizing a diversity of biomass resources.
Advanced Algal Systems R&D
▪ By 2022, demonstrate technologies to produce sustainable algal biofuel intermediate feedstocks that perform reliably in conversion processes to yield renewable diesel, jet, and gasoline fuels in support of the Office's $3/GGE advanced biofuels goal.
Conversion R&D
▪ By 2017, validate an nth plant modeled minimum fuel selling price (MFSP) of $3/GGE (2014$) via a conversion pathway to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel. ▪ By 2022, validate an nth plant modeled MFSP of $3/GGE (2014$) for two additional conversion pathways to hydrocarbon biofuel with GHG emissions reduction of 50% or more compared to petroleum-derived fuel.
Demonstration and Market Transformation
▪ By 2017, validate a mature technology modeled cost of cellulosic ethanol production, based on actual integrated biorefinery performance data, and compare to the target of $2.65/gallon ethanol (2014$). ▪ By 2027, validate a mature technology modeled cost of infrastructure-compatible hydrocarbon biofuel production, based on actual integrated biorefinery performance data, and compare to the target of $3/GGE (2014$).
Sustainability
▪ By 2017, identify conditions under which at least one technology pathway for hydrocarbon biofuel production, validated above R&D scale at a mature modeled price of $3/GGE, reduces GHG emissions by 50% or more compared to petroleum fuel, and meets targets for consumptive water use, wastewater, and air emissions. ▪ By 2022, validate landscape design approaches for two bioenergy systems that, when compared to conventional agricultural and forestry production and logistics systems, increase land-use efficiency and maintain ecosystem and social benefits, including biodiversity and food, feed, and fiber production ▪ By 2022, evaluate environmental and socioeconomic indicators across the supply chain for three cellulosic and algal bioenergy production systems. Environmental indicators will validate GHG reduction of at least 50% compared to petroleum, water consumption equal to or less than petroleum per unit of fuel produced, and that air emissions meet federal regulations. Socioeconomic indicators will validate socioeconomic benefits including job creation.
Strategic Analysis
▪ Ensure high-quality, consistent, reproducible, peer-reviewed analyses. ▪ Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts. ▪ Convey the results of analytical activities to a wide audience, including DOE management, Congress, the White House, industry, other researchers, other agencies, and the general public.
Strategic Communications
▪ Increase awareness of and support for the Office's advanced biomass RD&D and technical accomplishments, highlighting their role in achieving national renewable energy goals. ▪ Educate audiences about the environmental, economic opportunities and social benefits of biofuels, bioproducts, and a growing bioenergy industry.

Table 1-5: Office Multi-Year Milestones for 2013–2022

Feedstocks Supply and Logistics R&D
Terrestrial Feedstocks Supply and Logistics R&D
Supply
▪ By 2016, produce an updated, fully integrated assessment of potentially available feedstock supplies under previously established environmental and quality criteria.
▪ By 2017, establish available resource volumes for non-woody municipal solid waste and algal feedstocks at $84/dry ton delivered cost (including grower payment/stumpage fee and logistics costs).
▪ By 2017, determine the impact of competing uses, policy and market demands (e.g., biopower, pellet exports) on feedstock supply and price projections.
▪ By 2018, establish nationwide sub-county-level environmental impact criteria and logistics strategies for all potential energy crops, including agricultural and forestry residues, annual and perennial herbaceous energy crops, and short rotation woody energy crops.
▪ By 2019, validate 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 $84/dry ton cost target (2014$) (including grower payment/stumpage fee and logistics costs).
Logistics
▪ By 2017, validate sustainable feedstock supply and logistics cost of $84/dry ton at conversion reactor throat (including grower payment and logistics cost) for at least one biochemical and one thermochemical conversion process.
▪ By 2022, validate one blendstock for thermochemical conversion and one blendstock for biochemical conversion at a scale of 1 ton per day while also meeting the $84/dry ton cost target (including grower payment/stumpage fee and logistics costs).
Advanced Algal Systems R&D
▪ By 2017, model the sustainable supply of 1 million metric ton ash free dry weight (AFDW) cultivated algal biomass.
▪ By 2018, demonstrate at non-integrated process development unit-scale algae yield of 2,500 gallons or equivalent of biofuel intermediate per acre per year.
▪ By 2019, demonstrate at non-integrated process development unit-scale production and recovery of valuable co-products that can be produced along with biofuel intermediates to increase the value of cultivated algal biomass by 30%.
▪ By 2020, demonstrate at non-integrated process development unit-scale algae yield of 3,700 gallons or equivalent biofuel intermediate per acre per year.
▪ By 2022, model the sustainable supply of 20 million metric ton AFDW cultivated algal biomass.
▪ By 2022, demonstrate at non-integrated process development unit-scale algae yield of 5,000 gallons biofuel intermediate per acre per year in support of nth plant model $3/GGE algal biofuels.
▪ By 2025, demonstrate at integrated process development unit-scale algal productivity of greater than 5,000 gallons biofuel intermediate per acre per year.
▪ By 2030, validate production of algae-based biofuels at total production cost of $3/GGE with or without co-products.
Conversion R&D
▪ By 2016, based on techno-economic analysis and available data, select vapor phase upgrading catalyst and process that can cost-effectively generate refinery-ready intermediates for the 2017 pyrolysis verification.
▪ By 2017, deliver feedstocks and complete verification operations at pilot scale with fuel production cost modeled at $3/GGE for 2,000 tonnes of feedstock/day.

▪	By 2018, select an integrated bench-scale lignin deconstruction and upgrading strategy for valorization of lignin in a hydrocarbon fuel production process.
▪	By 2020, provide enabling capabilities in synthetic biology for industrially relevant, optimized chassis microorganisms and Design-Built-Test-Learn cycles for fuel and chemical production that reduces time-to-scale-up by at least 50% compared to the current average of ~10 years.
▪	By 2021, complete R&D necessary to set the stage for a 2022 verification that produces both fuels and high-value chemical to enable a biorefinery to achieve a positive return on investment.
▪	By 2022, deliver feedstocks and complete verification operations at pilot scale for an alternate conversion pathway with fuel production cost modeled at $3/GGE for 2,000 tonnes of feedstock/day.
Demonstration and Market Transformation	
▪	By 2022, validate successful runs of two biofuels and/or bioproducts manufacturing processes at pilot scale.
▪	By 2022, validate successful runs of one biofuels manufacturing process using a hydrocarbon fuels pathway at demonstration scale. By 2023, this successful demonstration of the technology enables the submission of a package for external funding sources (for example, loan guarantee) for the design and construction of a pioneer-scale facility on trajectory to market.
▪	By 2025, validate successful runs of one biofuels manufacturing process utilizing an additional pathway to fuels at pilot scale.
▪	By 2025, validate successful runs of one biofuels and/or bioproducts manufacturing process incorporating another compatible hydrocarbon biofuels/bioproducts pathway at demonstration scale. By 2026, this successful demonstration of the technology facilitates the submission of a package for external funding (for example, loan guarantee) for the design and construction of a pioneer-scale facility on trajectory to commercialization.
▪	By 2030, validate successful runs of one biofuels and/or bioproducts manufacturing process based on a different conversion pathway at demonstration scale. By 2031, this successful demonstration of the technology enables the submission of a package for external funding (for example, loan guarantee) for the design and construction of a pioneer commercial-scale facility on trajectory to market.
Sustainability	
Analysis and Communication	
▪	By 2016, evaluate environmental sustainability indicators for updated assessment of potentially available feedstock supplies and identify conditions or conservation practices under which feedstock production scenarios are likely to maintain or improve soil quality, biodiversity, and water quality in major feedstock production regions while meeting projected demands for food, feed, and fiber production.
▪	By 2016, coordinate with feedstock logistics and conversion R&D areas to set targets for GHG emissions, consumptive water use, wastewater, and air emissions for at least three renewable hydrocarbon pathways to be validated in 2017 and 2022.
▪	By 2019, quantify and clearly communicate the environmental and socio-economic benefits of emerging advanced bioenergy pathways through at least three case studies that apply BETO-supported analysis tools including but not limited to GREET, WATER, and LEAF. Disseminate findings through technical publications and public outreach.
Sustainable System Design	
▪	By 2016, apply the Landscape Environmental Assessment Framework (LEAF) to model three distinct cropping systems to analytically demonstrate the potential for integrated landscape management to increase biomass availability (energy crop production and agricultural residue removal) by 50%, increase soil quality by at least 25%, reduce nutrient loss by 10%, and reduce the risk to surface water quality by 10% as measured by the Water Quality Index, as compared to current agricultural management (conventional row crop practices).
▪	By 2018, using available field data, validate case studies of feedstock production systems that reduce GHG emissions and maintain or improve water quality and soil quality compared to conventional agriculture and forestry systems; identify strategies to translate beneficial practices into broader application.

Strategic Analysis
▪ By 2016, develop and deploy a consistent methodology for including co-products in techno-economic analyses and design cases.
▪ By 2016, hold a workshop and publish a whitepaper on the techno-economic analysis of aviation biofuels pathways.
▪ By 2017, complete supply chain sustainability analyses for at least four technology GHG emissions across biofuel pathways.
▪ By 2018, complete analysis on impact of advanced biofuels use on gasoline and diesel prices.
▪ By 2022, identify near-term technology pathways for the Office based on reassessment of current state of technology development.
Strategic Communications
From 2016 through 2022: ▪ Develop infographics to demonstrate the economic and environmental impacts of biofuel technologies in development. ▪ Identify and set goals for outreach strategies to address stakeholder concerns and recommendations on technological advancements and how the Office is meeting national energy goals. Keep metrics to track progress toward these efforts. ▪ Continually update existing outreach to consumers on the benefits of biofuels and bioproducts. ▪ Develop or update education and communications products to address inaccurate information about bioenergy using science-based data. ▪ Develop and implement a comprehensive education and workforce development program for K-Grey (elementary, middle, high school, college; grey represents non-traditional education, informal education; and veterans).
▪ From 2017 through 2022, support information sessions for agriculture, algae, and forestry communities regarding the economic, environmental, and social benefits of participating in the bioeconomy.
▪ By 2016, begin to implement the Office's new strategic plan communication and outreach activities to increase awareness of bioenergy to the general public as well as to educate decision makers on the benefits of a bioeconomy.
▪ By 2016, expand outreach efforts focused on the benefits of greenhouse gas emission reductions resulting from biomass-derived alternative fuels.
▪ By 2016, begin to develop and implement a robust communications and stakeholder engagement strategy around efforts to co-optimize the development of fuels and engines.
▪ By 2016, begin to implement the Office's new strategic plan communication and outreach activities to increase awareness of bioenergy to the general public as well as to educate decision makers on the benefits of a bioeconomy.
▪ By 2016, expand outreach efforts focused on the benefits of greenhouse gas emission reductions resulting from biomass-derived alternative fuels.
▪ By 2018, produce communication products to support conversion RD&D pathway validation of modeled nth plant and minimum fuel selling price.
▪ By 2018, notify and educate BETO stakeholders about validation of efficient, low-cost, and sustainable terrestrial feedstock supply and logistics systems.
▪ By 2019, develop a multi-agency strategy to convey the results of analytical activities to a wide audience, including DOE senior management, Congress, the White House, industry, RD&D stakeholders, and the public.
▪ By 2022, amplify technologies that produce sustainable algal biofuel intermediate feedstocks that perform reliably in conversion processes to yield renewable diesel, jet, and gasoline fuels in support of the Office's advanced biofuels goal.