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, demonstration, and deployment (RDD&D) 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 transform our renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted research, development, and demonstration supported through public and private partnerships.*

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, demonstration, and deployment (RDD&D) within the dynamic context of changing budgets and administrative 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.

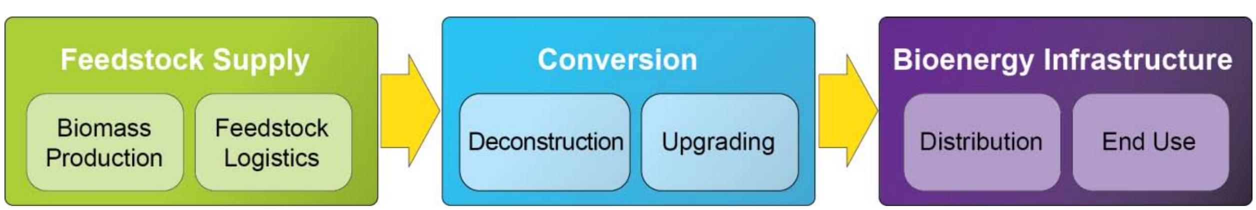


Figure A: Biomass-to-bioenergy supply chain

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 technological 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 sustainable, high-quality feedstock supply systems
- R&D on biomass conversion technologies
- Demonstration and validation of integrated biorefinery technologies up to industrial scale
- Cross-cutting 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.

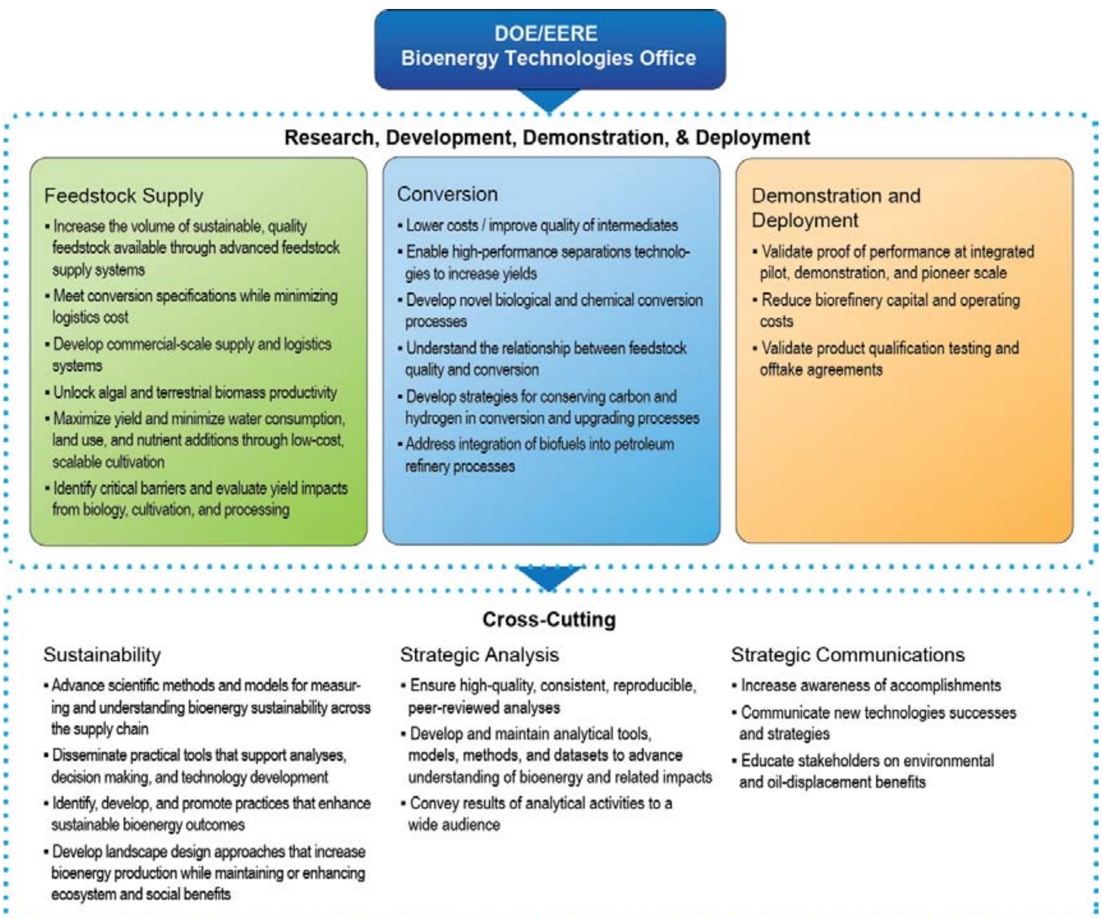


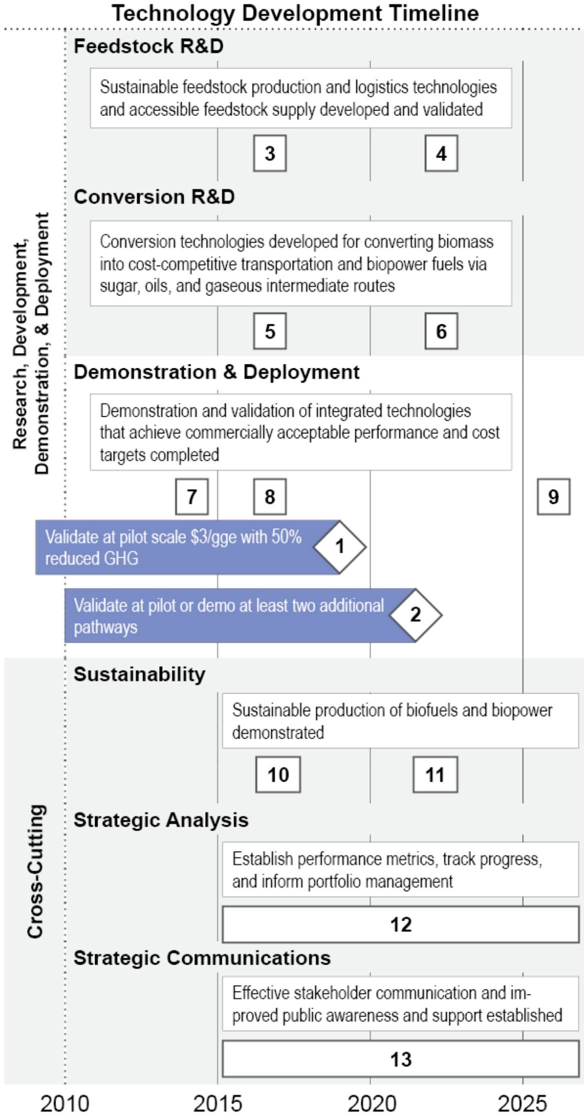
Figure B: High-impact research areas

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 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 bioenergy 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.

Technology Development Timeline



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 ($2011) with GHG emissions reduction of 50% or more compared with petroleum fuel
2. By 2022, validate at pilot or demonstration scale (>1 ton/day) hydrocarbon biofuel production from at least two additional pathways

Feedstock R&D

3. By 2017, establish criteria under which the industry could operate at 250 MDT/yr of biomass; validate feedstock supply and logistics systems that can deliver feedstock at or below $80/ dry ton ($2011)
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 350 MMDT/year of diverse biomass resources at a cost of $80/dry ton

Conversion R&D

5. By 2017, achieve an nth plant modeled conversion cost of $2.50/gge via a thermochemical pathway and an nth plant modeled conversion cost of $3.30/gge utilizing a biochemical conversion pathway
6. By 2022, achieve the conversion cost necessary to contribute to the overall Office performance goal of $3/gge ($2011)

Demonstration & Deployment

7. By 2014, validate three cellulosic ethanol or bioproduct manufacturing processes at scale
8. By 2017, validate nth plant modeled cost of cellulosic ethanol production, based on actual IBR performance data, and compare to the target of $2.15/gallon ethanol ($2007)
9. By 2027, validate nth plant modeled cost of hydrocarbon biofuel production, based on actual IBR performance data, and compare to the target of $3/gge ($2011)

Sustainability

10. 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
11. By 2022, 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, socioeconomic benefits, water consumption targets, and meet federal wastewater and air emissions regulations

Strategic Analysis

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

Stategic Communications

13. Promote the economic and job creation, environmental, and energy security benefits of sustainable biofuels production

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

Contents

List of Abbreviations

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
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
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
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
IRIS – Integrated Resource and Information System
ISO – International Organization for Standardization

KDF – Knowledge Discovery Framework
LGP – DOE Loan Guarantee Programs
LUC – land-use change
MARKAL – Market Allocation
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
NIFA – USDA'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
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
R&D – research and development
RDD&D – research, development, demonstration, and deployment
RFS – Renewable Fuels Standard
RLP – Resource Loaded Plan
RPS – Renewable Portfolio Standard
RSB – Roundtable on Sustainable Biomaterials
SC – Office of Science
SOT – State of Technology
SUV – sport utility vehicle
SWAT – Soil and Water Analysis Tool
TRLs – technology readiness levels
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

Biomass is an energy resource derived from plant- and algae-based material that includes agricultural residues, forest resources, perennial grasses, woody energy crops, algae, 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 utilization plays an important role in implementing the President's Climate Action Plan to reduce carbon pollution in America within the transportation sector. This plan proposes new fuel economy standards to reduce emissions and improve vehicle efficiency.[1]

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 could produce more than one billion tons[2] of sustainable biomass that can be used to produce reduced-carbon-emission fuel for cars, trucks, and jets; make chemicals; and produce renewable power to supply the grid. This 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 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, develop, and demonstrate technologies to produce advanced bioenergy and bioproduct from lignocellulosic and algal biomass. The Office focuses on reducing technology risks from feedstock supply and

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

[2] Robert Perlack, Bryce Stokes, et al. "U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry," Oak Ridge National Laboratory, ORNL/TM-2011/224 (2011), http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf.

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

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).

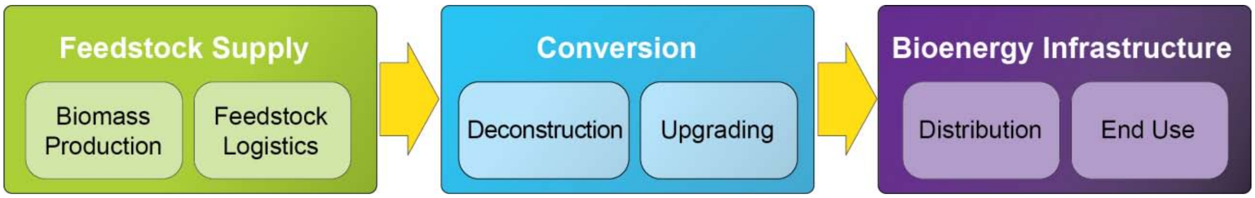


Figure 1-1: Biomass-to-bioenergy supply chain

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
- **Bioenergy Conversion:** Develop and deploy cost-effective, integrated conversion technologies for the production of bioenergy and bioproducts
- **Bioenergy Distribution:** Implement biofuels distribution infrastructure (storage, blending, and transportation—both before and after blending and dispensing)
- **Bioenergy End Use:** 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 producing ethanol from starch and producing biodiesel from oil seeds and waste oils, integrated

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 multiple fuels and products from petroleum.

biorefineries are expected to produce multiple products to take advantage of the diverse biomass components and processing intermediates—maximizing the value and decreasing the waste derived from the biomass feedstock.[4]

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, demonstration, and deployment (RDD&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 RDD&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 RDD&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 bioenergy.
- It effectively links resources with the stages of technology readiness, from applied research through commercial deployment.
- 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 RDD&D pipeline.
- It helps identify gaps within the portfolio, as well as crucial linkages across RDD&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

While the Office's overall mission is focused on developing advanced technologies for the production of fuels, products, and power from biomass, the Office's near-term goals are focused on the conversion of biomass into liquid transportation fuels and on bioproducts and biopower

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

that enable renewable fuels production. Developing reduced-carbon-emission biofuels for transportation plays an important role in plans to reduce carbon pollution. Historically, the Office's focus has been on RDD&D for ethanol production from lignocellulosic biomass. With achievement of the cellulosic ethanol cost targets, the Office has shifted toward developing other advanced biofuels that will contribute to the Renewable Fuel Standard (RFS) volumetric requirements. By focusing on these biomass-based hydrocarbon fuels (renewable gasoline, diesel, and jet fuel) and hydrocarbons from algae, the Office seeks to engage the refinery industry in developing solutions, while utilizing existing infrastructure as much as possible.

The Office has demonstrated technologies that can be scaled-up to produce modeled price-competitive cellulosic ethanol. This 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 D for more information about our recent accomplishments in cellulosic ethanol.) The investments the Office has made in technologies that can reduce the recalcitrance of lignocellulosic biomass are being leveraged toward developing new advanced drop-in, hydrocarbon biofuels, bioproducts, and bioenergy that can directly replace products created from the whole barrel of oil.

[5] U.S. Department of Energy, *Intermediate Ethanol Blends* (2013), http://www1.eere.energy.gov/vehiclesandfuels/technologies/fuels/ethanol_blends.html.

1.1 Market Overview and Federal Role of the Office

Markets for biofuels, bioproducts, and bioenergy 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. 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 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 93% 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, and cars produced since the late 1970s can run on E10. In January 2011, the U.S. Environmental Protection Agency (EPA) issued partial waivers that permit the use of E15 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 to power light duty vehicles, diesel and jet markets have few alternatives. Diesel consumption in the United States is 54 billion gallons per year and jet fuel consumption is 22 billion gallons per year.[8] Conversion technologies that produce renewable diesel and

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[6] U.S. Department of Energy, *Monthly Energy Review* (December 2013), Washington: Government Printing Office, DOE/EIA-0035.
[7] U.S. Department of Energy, Oak Ridge National Laboratory, *Transportation Energy Data Book, Edition 32* (2013).
[8] Energy Information Agency, *Annual Energy Review* (2014), http://www.eia.gov/totalenergy/data/annual/.

renewable jet fuel can fill the need for biomass-based alternatives for these diesel and jet markets.

High world 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 in recent years. Ethanol, in particular, has been buoyed by the need to replace the octane and clean-burning properties of methyl tertiary butyl ether (MTBE), which has been removed from gasoline because of groundwater contamination concerns. As shown in Figure 1-2, current domestic production capacity of ethanol has increased rapidly over the past five years—from under 8 billion gallons per year to nearly 15 billion gallons in 2013.

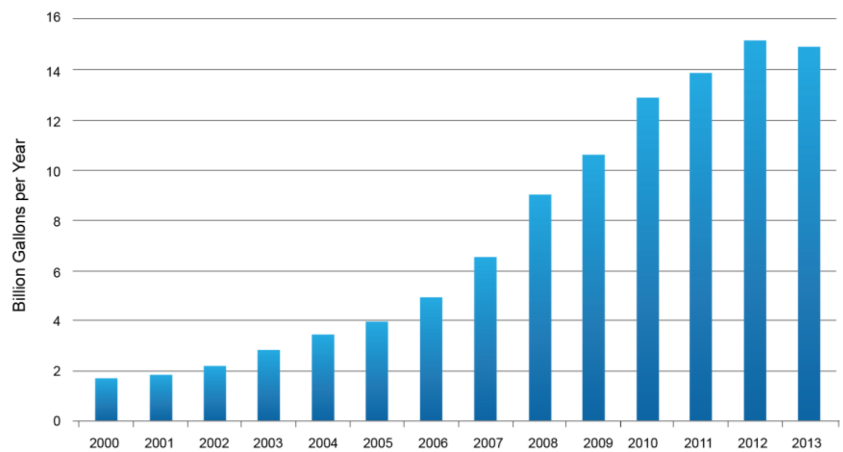

Figure 1-2: U.S. ethanol production capacity[9]

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 provides 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. These tax credits for conventional ethanol and biodiesel expired in January 2011, but most analysts have seen minimal impact on the conventional ethanol industry. The Cellulosic Ethanol Tax Credit was still in place and was set to expire at the end of 2013 without an extension by Congress.

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 the broad range of oil prices projected by the Energy Information Administration (EIA) for 2022 [$69–$162 per barrel],[10] bioenergy technology may

[9] Renewable Fuels Association, *Battling for the Barrel: Ethanol Industry Outlook* (2013), http://ethanolrfa.org/page/-/PDFs/RFA%202013%20Ethanol%20Industry%20Outlook.pdf?nocdn=1.

[10] U.S. Department of Energy, *Annual Energy Outlook 2013 with Projections to 2040,* http://www.eia.gov/forecasts/archive/aeo13/source_oil_all.cfm#tightoil.

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.[11]

Products: Up to 7% of U.S. crude oil imports are used to make chemicals and products, such as plastics for industrial and consumer goods,[12] contributing a value added to the U.S. economy of $255 billion. Many products derived from petrochemicals could be replaced with biomass-derived materials. Less than 4% of U.S. chemical sales are biobased.[13] Organic chemicals such as plastics, solvents, and alcohols represent the largest and most direct market for bioproducts.[14] The market for specialty chemicals is much smaller but is projected to double in 15 years[15] 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, fibers, cosmetics, liquid detergents, and a natural replacement for petroleum-based antifreeze.[16] These manufacturing alliances will need to demonstrate integrated production, including feedstock production and logistics through conversion, separation, purification, and market acceptance testing.

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 2% 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 67% of generation, with coal comprising 43%, natural gas 24%, and oil 1%. The balance is provided by

[11] National Science Foundation, *The Roadway to Partial Petroleum Replacement with Biomass-Derived Fuels—A Report Along the Way (2010).*

[12] Redefining Chemical Manufacture—Replacing Petroleum with Plant-Derived Feedstocks, John W. Frost, Industrial Biotechnology 2005, 1, 23-24.

[13] Biotechnology Industry Organization, *Biobased Chemicals and Products: A New Driver for Green Jobs*, http://www.bio.org/articles/biobased-chemicals-and-products-new-driver-green-jobs, March 10, 2010.

[14] Amory Lovins, et al, *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security*, Rocky Mountain Institute (2004).

[15] Biotechnology Industry Organization, *Biobased Chemicals and Products: A New Driver for Green Jobs*.

[16] U.S. Department of Energy, *Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas (2004).*

nuclear (21%) and renewable sources (10%), including 1% [17] 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.[18]

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.

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.[19]

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 biofuels applications as a means to achieve targeted reductions.

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 87 million barrels per day in 2010 to about 115 million barrels per day in 2040.[20] However, the 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

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[17] U.S. Department of Energy, *Monthly Energy Review* (December 2013), Washington: Government Printing Office, DOE/EIA-0035.
[18] U.S. Department of Energy, *Annual Energy Outlook 2013 with Projections to 2040.*
[19] U.S. Department of Energy, *Most states have Renewable Portfolio Standards* (February 3, 2012).
[20] U.S. Department of Energy, *International Energy Outlook 2013* (2013), Washington: Government Printing Office, DOE/EIA-0484.

transportation, primarily ethanol (see Figure 1-3), and several other countries have developed ethanol programs, including China, India, Canada, Thailand, Argentina, Australia, and Colombia.[21]

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.[22] The EU is also implementing additional biofuel sustainability criteria and reporting requirements.

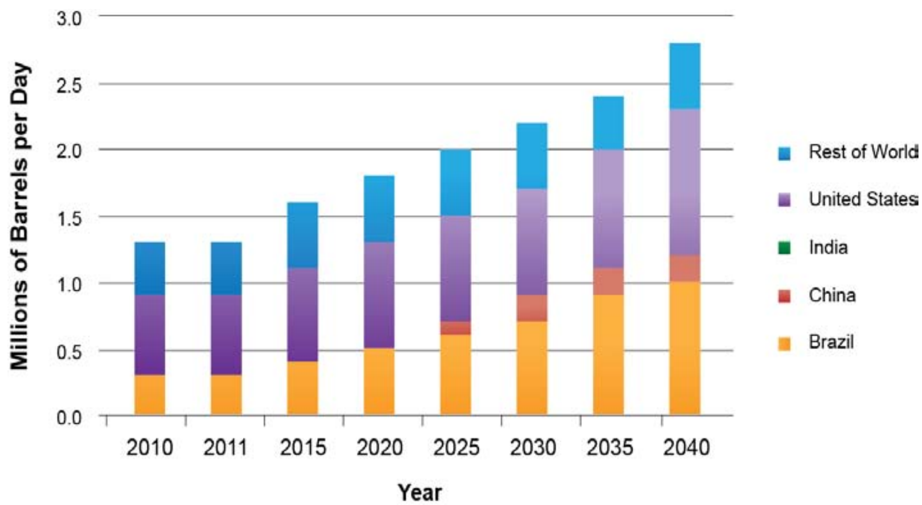

Figure 1-3: Global Production of Biofuels[23]

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 Biofuels 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

[21] U.S. Department of Energy Alternative Fuels Data Center, *Global Ethanol Production* (2013), http://www.afdc.energy.gov/data/10331.
[22] http://www.biofuelstp.eu/legislation.html.
[23] U.S. Department of Energy, *International Energy Outlook 2013* (2013), Washington: Government Printing Office, DOE/EIA-0484.

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.

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. 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, and energy crops. 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 or UN FAO).[24] The EU has also 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 have led to an expanding market for American and Canadian wood pellets and raw biomass feedstock. Proposals for EU's tax on carbon emissions in the aviation sector have helped generate interest in the market for biobased aviation fuels in the United States. 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. In the future, as oil demand and prices continue to rise, several non-traditional technologies will likely meet some of the transportation fuel needs of the United States. Those technologies include the following.

- **Hydrogen:** Hydrogen can be produced via multiple routes, including water electrolysis, algae, reforming renewable liquids or natural gas, coal gasification, or nuclear synthesis.
- **High-Carbon Intensity Fuels:** Less mature alternate fuel technologies against which biofuels should be compared include high-carbon intensity fuels such as oil-shale-derived and tar-sands-derived fuels. Oil shale is a rock formation that contains large concentrations of combustible organic matter called kerogen and can yield significant quantities of shale oil. Various methods of processing oil shale to remove the oil have

[24] "Bioenergy and Food Security," Food and Agriculture Organization of the United Nations, http://www.fao.org/bioenergy/foodsecurity/befs/en/.

been developed.[25] Tar sands (also called oil sands) contain bitumen or other highly viscous forms of petroleum, which are not recoverable by conventional means. The petroleum is obtained either as raw bitumen or as a synthetic crude oil. The United States has significant tar sands resources—about 58.1 billion barrels.[26]

- **Gas-to-Liquids**: The advent of hydraulic fracturing and horizontal drilling technologies has 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. As oil prices rise, however, coal-derived transportation fuels may become competitive. While conventional coal-to-liquid technologies can often 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.
- **Electricity:** Electricity can be used to power electric vehicles. Electric vehicles store electricity in an energy storage device, such as a battery, or produce on-board power via a fuel cell, powering the vehicle's wheels via an electric motor. Plug-in hybrid electric vehicles combine the benefits of pure electric vehicles and hybrid electric vehicles.

1.1.4 Market Barriers

Biorefineries using cellulosic and algal biomass as a feedstock 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 Feedstock Availability and Cost
Im-A Inadequate Supply Chain Infrastructure
Im-B Agricultural Sector-Wide Paradigm Shift
Im-C High Risk of Large Capital Investments
Im-D. Lack of Industry Standards and Regulations
Im-E Cost of Production
Im-F Offtake Agreements
Im-G Uncertain Pace of Biofuel Availability
Im-H Availability of Biofuels Distribution Infrastructure
Im-I Lack of Acceptance and Awareness of Biofuels as a Viable Alternative
It-A End-to-End Process Integration
It-C Technical Risk of Scaling and Fully Integrating Biomass Conversion Technologies.

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[25] U. S. Congress, Senate Energy and Natural Resources Committee. *Oversight Hearing on Oil Shale Development Efforts*. 109th Congress, 1st session. (April 12, 2005)
[26] World Energy Council, "Survey of Energy Resources" (2010), http://www.worldenergy.org/documents/ser_2010_report_1.pdf.

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 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. The 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 RDD&D

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 was formed to consolidate the biofuels, bioproducts, and biopower research efforts across EERE into one comprehensive Office. From the 1970s to the present, DOE has invested more than $4 billion [including more than $900 million in American Recovery and Reinvestment Act of 2009 (ARRA) funds] in a variety of RDD&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.

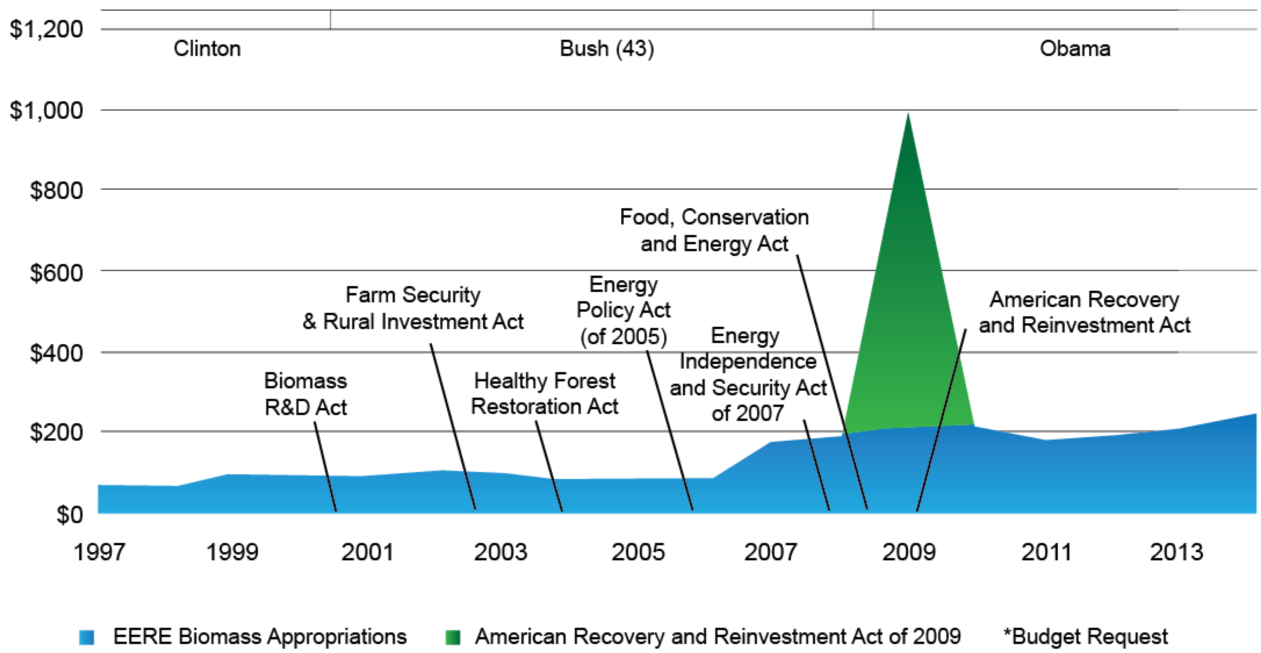

Figure 1-4: DOE EERE funding for biomass RDD&D

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

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

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 Fuels 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.
February 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.
December 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.
August 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.

1.1.6 Bioenergy Technologies Office Justification

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 a reduction in GHG emissions that lead to global warming and increased economic activity across the entire supply chain. From new jobs in the farms and forests of rural America to growing U.S. construction and manufacturing jobs in the production of bioenergy, biochemical, and vehicles, reinvesting in new U.S. technologies maintains the vital national competitive advantage and enables jobs in the renewable energy sector for future generations.

Pursuing smaller early adoption markets such as renewable aviation fuel can enable critical learning along the supply chain, de-risk technology and processes, and increase the probability of success in larger on-road fuel markets.

From 2012 to 2040, U.S. energy consumption is projected to rise by about 12%, while domestic energy production will rise by 29%.[27] Renewable liquid fuels, including biofuels, are projected to have the largest increase in meeting domestic consumption—growing from 8% in 2010 to more than 14% of liquid fuels in 2035.[28] 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 is vital for a growing economy.

The U.S. transportation sector is responsible for one-third of U.S. carbon dioxide (CO_2) emissions, the principal GHG contributing to climate change. 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 and jet aircraft. Liquid hydrocarbon transportation fuels made from biomass are advantageous because they are largely compatible with existing infrastructure to deliver, blend, and dispense fuels.

This 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. The primary challenges of sustainable feedstock supply and logistics, cost and technical risk reduction in conversion

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[27] U.S. Department of Energy, *Annual Energy Outlook 2014 with Projections to 2040*.
[28] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035*.

processes, and integrated performance validation at large-scale operation 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.[29] The Office support for validation of these new technologies at large scale helps to overcome these 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.[30] 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 RDD&D that is critical to the nation's future 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.

[29] Bacovsky, Ludwiczek, Ognissanto, Wörgetter. Status of Advanced Biofuels Demonstration Facilities, IEA Task 39-P1b, (March 2013), http://demoplants.bioenergy2020.eu/files/Demoplants_Report_Final.pdf.
[30] U.S. Energy Information Agency, *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010*, (July 2011), 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 mandatory RFS, requiring transportation fuels that are sold in the United States to contain a minimum 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 promote energy security through a diverse energy supply that is reliable, clean, and affordable.

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 tenets of the EERE Strategic Plan (which is currently being updated):

- Reduce carbon emissions from energy production and consumption
- Reduce dependence on foreign oil
- Promote the use of diverse, domestically produced, and sustainable energy resources
- Establish a domestic and globally competitive bioenergy industry.

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

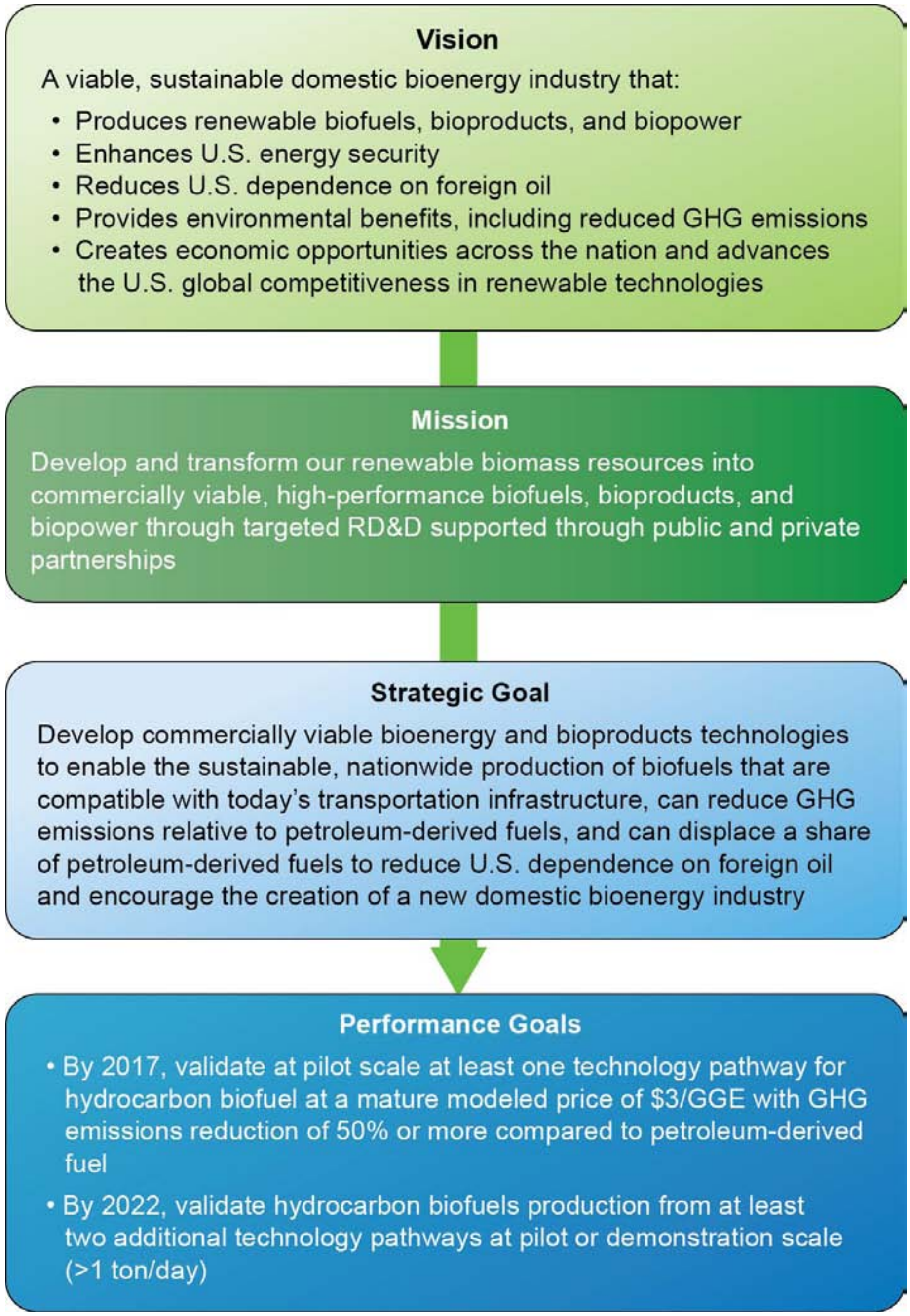

Figure 1-5: Strategic framework for the Bioenergy Technologies Office[31]

[31] Methodology for developing performance goals is detailed in Appendix C.

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: RDD&D and Cross-Cutting Activities. The first category is comprised of three technical elements: Feedstock R&D, Conversion R&D, and Demonstration and Deployment. Cross-Cutting activities include Sustainability, Strategic Analysis, and Strategic Communications.

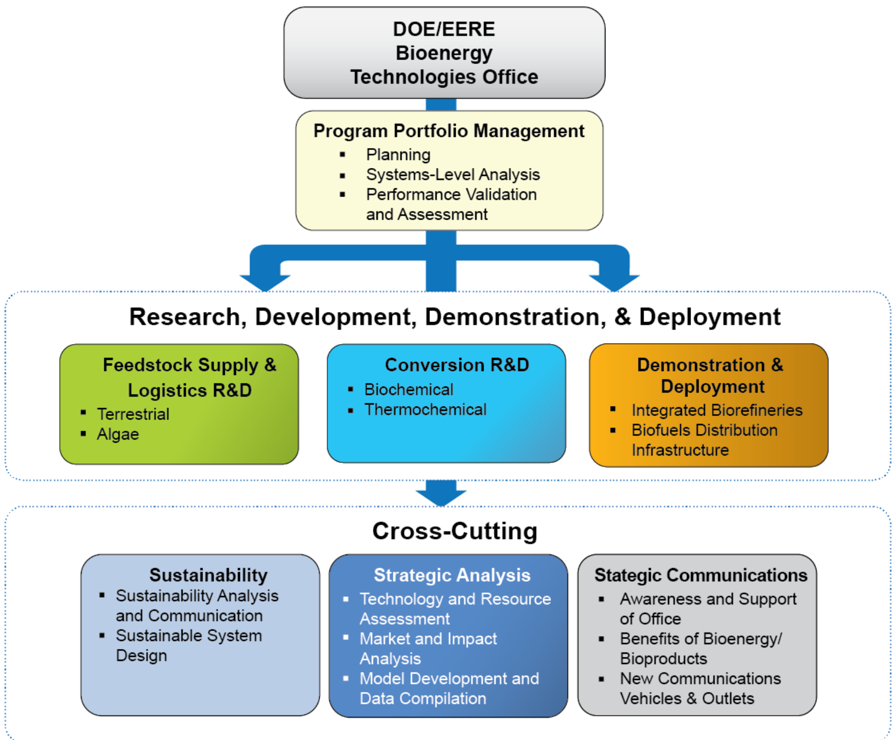

Figure 1-6: Elements of the Bioenergy Technologies Office

This approach provides for the development of precommercial, 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 elements and three cross-cutting elements are described in detail in Section 2.

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.

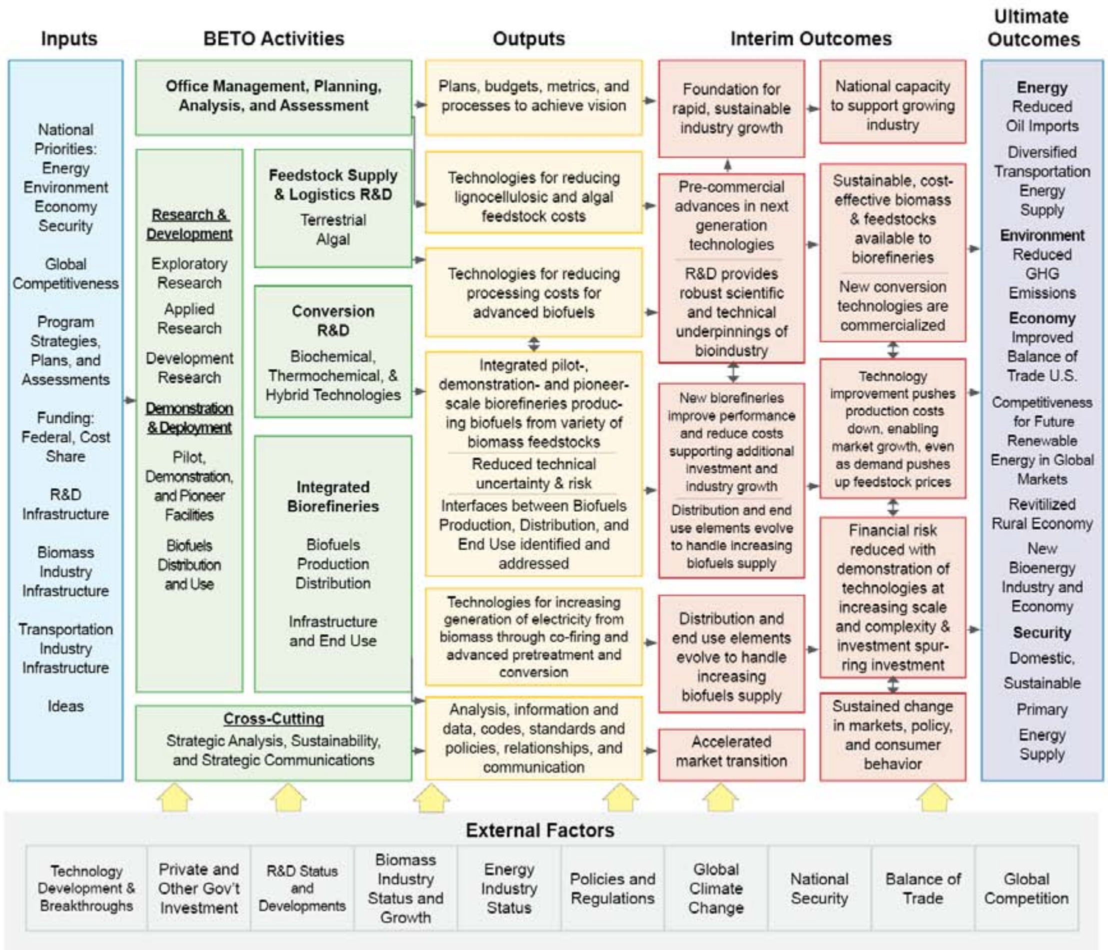

Figure 1-7: Bioenergy Technologies Office portfolio logic diagram

1.3.3 Relationship to Other Federal Offices

Coordination with other government offices 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. As shown in Table 1-3, the Office coordinates with several other federal agencies through a range of informal and formal mechanisms. In particular, through the Biomass Research and Development Act of 2000, the Biomass R&D Board (Board) was created. The Board—whose members meet quarterly to discuss updates and implementation strategies across federal agencies in biofuels, bioproducts, and biopower R&D—is an interagency collaboration that is co-chaired by the U.S. Department of Agriculture and DOE. The purpose of the Board is to maximize federal efforts to enhance the emerging biomass industry. Other Board partners include the Departments of Interior, Transportation, and Defense; the EPA; the National Science Foundation; and the Office of Science and Technology Policy.

Table 1-2: Summary of Federal Agency Roles across the Biomass-to-Bioenergy Supply Chain

Federal Agency	Feedstock Production	Feedstock Logistics	Biomass Conversion	Demonstration and Deployment	Biofuels Distribution	Biofuels End Use
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, and preprocessing systems; testing logistics systems at demonstration scale	Biochemical conversion (pretreatment/enzyme cost reductions); recalcitrance of all biomass resources; thermochemical conversion 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	Flexible, compatible, sustainable, and cost-effective biofuels transportation/distribution systems development; material compatibility; alternative fuel dispensing infrastructure	Engine compatibility and optimization; vehicle emissions testing; bioproduct testing for market acceptance; education to improve awareness regarding positive impacts of biofuels
Department of Agriculture	Sustainable land, crop, and forestry management; plant science; genetics and breeding; planting/ establishment payments to biomass crop producers	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; producers to support and expand production of advanced biofuels refined from sources other than cornstarch	Loan guarantees and grants to support (1) safe and sustainable biofuel transportation/distribution; (2) refineries and blending facilities development; (3) flex-fuel pumps installation; and (4) financing of transportation/distribution industry/businesses	Market awareness and education for end users on advantages of increased biofuels use
Environmental Protection Agency	Effects of feedstock production systems, including effects on ecosystem services (water quality, quantity, biodiversity, etc.); assessment of bioenergy crop impacts		Biowaste-to-energy; characterization of air, water, and waste emissions; regulations/permitting; TSCA 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, environmental, and public health impacts; regulation of air emissions; market awareness/ impact of biofuels on public health, ambient air, and vehicles
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
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			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 entire aviation supply chain

Federal Agency	Feedstock Production	Feedstock Logistics	Biomass Conversion	Demonstration and Deployment	Biofuels Distribution	Biofuels End Use
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 DPA	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

Coordination among DOE Programs and Offices

Office of Science (SC): The Bioenergy Technologies Office regularly coordinates with SC, a Biomass R&D Board partner, on fundamental and applied biomass and biofuel research activities and to share information about new partnerships, major research efforts, conversion- and feedstock-related activities and user facilities, and possible joint funding requests. SC and EERE jointly developed the 2005 research roadmap, *Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda*, which outlines the basic science and applied research needed to accelerate advances in cellulosic ethanol and has helped guide multi-year technical planning.

Advanced Research Projects Agency-Energy (ARPA-E): The Office coordinates with ARPA-E by sharing information on relevant biomass-related projects—in particular those from ARPA-E's Plants Engineered to Replace Oil (PETRO) and Electrofuels Programs.

Office of Fossil Energy (FE): The Office is working with FE to examine how to develop technology improvements to increase the efficiency, environmental performance, and economic viability of utility-scale biopower applications and how biomass and natural gas might be utilized synergistically to maximize outputs.

Office of Energy Efficiency and Renewable Energy: The following EERE offices also contribute to many aspects of biomass utilization and bioenergy technology development:

- **Fuel Cell Technologies Office (FCTO):** The production of hydrogen from biomass is pursued through two main pathways—distributed reforming of biomass-derived liquids and biomass gasification. Research efforts on reformation and gasification, the availability of biomass, and renewable hydrogen as an enabler for biofuel production are coordinated between FCTO and the Bioenergy Technologies Office. In addition, the offices collaborate on using algae to produce biofuels and hydrogen.
- **Vehicle Technologies Office (VTO)**: Research on the use of non-petroleum-derived fuels, particularly ethanol and diesel replacements, is coordinated with VTO. This coordination focuses on product distribution infrastructure and end use, specifically fuel characterization and combustion testing for new biofuels and biofuel blends. The Office also interfaces with VTO's Clean Cities Program, which develops public/private partnerships to promote alternative fuels, vehicles, and infrastructure.
- **Advanced Manufacturing Office (AMO)**: Biomass-based technologies for gasification and the production of biomass-based fuels, chemicals, materials, heat, and electricity are of interest to AMO's distributed energy, chemicals, and forest products subprograms. AMO and the Bioenergy Technologies Office are collaborating on renewable chemical precursors to polyacrylonitrile, which can be utilized for the manufacture of carbon fiber.
- **Federal Energy Management Program Office (FEMP)**: FEMP works with the federal fleet to increase the use of biopower, renewable and alternative fuels, and flexible-fuel vehicles.
- **EERE Office of Strategic Programs**: Bioenergy Technologies Office efforts are supportive of, and coordinated with, broader corporate efforts, such as communications and outreach, strategic analysis, international partnerships, and legislative affairs.
- **EERE Office of Budget, Office of Business Operations:** Program analysis activities support these offices in carrying out EERE cross-cutting corporate analysis.

DOE Loan Guarantee Programs (LGP): The Office is actively engaged with LGP to support construction financing for first-of-a-kind IBR facilities. LGP provides loans and loan guarantees to a range of projects to spur further investments in advanced clean energy technologies through the reduction of technical risk in pioneering technologies.

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 the 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 industry.*

The Office's high-level schedule 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 1-8).

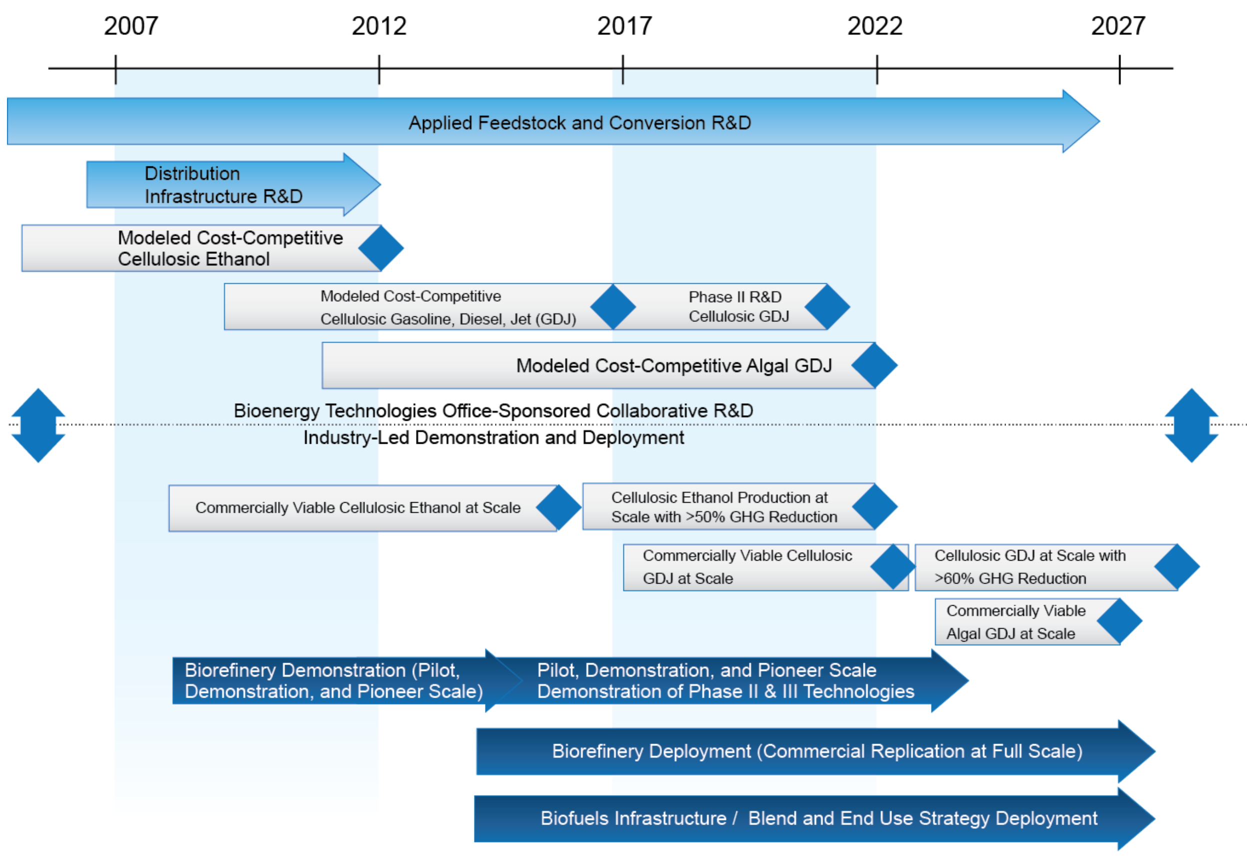

Figure 1-8: Bioenergy Technologies Office high-level schedule

The strategic goals for each element support the Office's overarching strategic goal, as shown in Figure 1-9. 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.

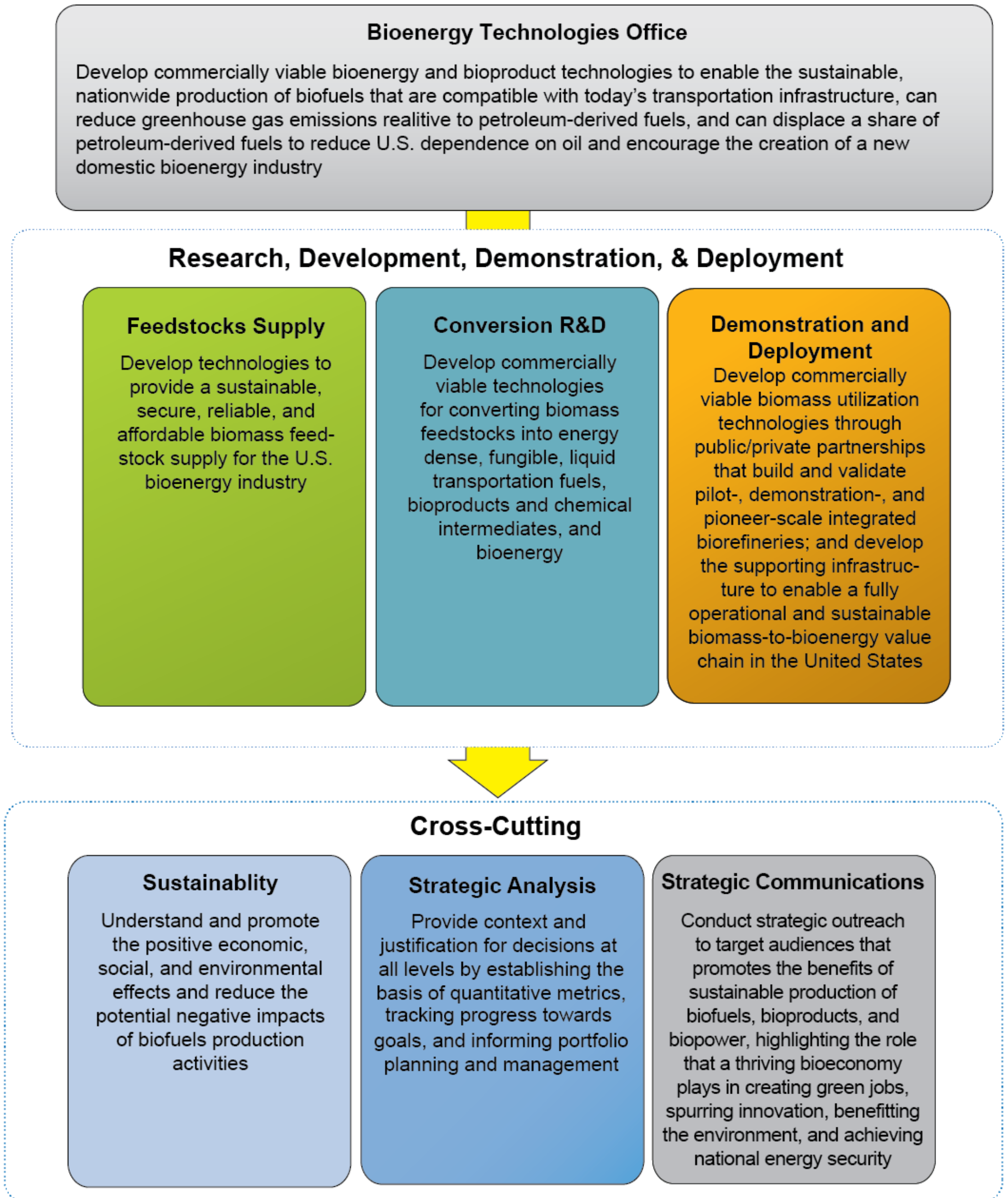

Figure 1-9: Strategic goals for the Bioenergy Technologies Office

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—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 a pilot or demonstration scale (>1 ton/day).

1.4.3 Office Multi-Year Targets

The Office's multi-year targets for 2014–2022 are listed in Table 1-3, while the high-level milestones leading to these targets are listed in Table 1-4. Section 2 describes the technical element performance goals and high-level milestones for all Office technical areas in more detail.

Table 1-3: Office Multi-Year Performance Goals

Feedstock Supply and Logistics R&D

Terrestrial Feedstocks Supply and Logistics R&D

- 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 $80/dry ton ($2011) by 2017 (including grower payment/stumpage fee)
- Establish geographic, economic, quality, and environmental criteria under which the industry could operate at 250 million dry ton per year scale (excluding biopower) by 2017
- By 2022, develop and validate feedstock supply and logistics systems that can economically and sustainably supply 350 million dry tons per year at a delivered cost of $80/dry ton to support a biorefining industry (i.e., multiple biorefineries) utilizing diverse biomass resources

Algal Feedstocks

- 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 by 2022

Conversion R&D

Biochemical Conversion R&D

- By 2017, achieve an nth plant modeled conversion cost of $3.30/GGE utilizing blended formatted biomass via a biochemical conversion pathway

Thermochemical Conversion R&D

- By 2017, achieve an nth plant modeled conversion cost of $2.50/GGE via a thermochemical pathway

Demonstration and Deployment

- By 2014, validate three cellulosic ethanol or bioproduct manufacturing processes at pioneer scale
- 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 $2.15/gallon ethanol ($2007)
- 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 ($2011)

Sustainability

- By 2014, quantify the water footprint of cellulosic feedstocks at the county level, identify modeled feedstock production systems that increase energy crop production and agricultural residue removal by 50%, increase soil quality by at least 5%, and improve water quality compared to traditional agricultural management
- 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, 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 to validate GHG reduction of at least 50% compared to petroleum, socioeconomic benefits including job creation, water consumption equal to or less than petroleum per unit fuel produced, and wastewater and air emissions that meet federal regulations

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, and social benefits of biomass as a viable alternative to fossil fuels, as well as the potential for advanced biofuels to displace petroleum-based transportation fuels

Table 1-4: Office Multi-Year Milestones for 2013–2022

Feedstocks Supply and Logistics R&D

Terrestrial Feedstocks Supply and Logistics R&D

Supply

- By 2014, establish a framework for promoting sustainable biomass production practices that consider productivity, soil quality, water quality and quantity, greenhouse gas emissions, air quality, biodiversity, and social aspects of sustainability
- By 2015, integrate feedstock quality criteria and blending strategies to generate more comprehensive supply scenarios, meeting biorefinery infeed specification targets at the lowest possible feedstock price
- 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 $80/dry ton delivered cost. (Note that woody municipal solid waste is currently incorporated into resource assessments)

▪ By 2018, establish sub-county-level environmental impact criteria and logistics strategies
▪ By 2019, determine impact of international trade and competing feedstock demands (e.g., biopower and pellet exports) on feedstock supply and price projections
▪ By 2021, determine the impact of advanced blending and formulation concepts on available volumes that meet quality and environmental criteria, while also meeting the $80/dry ton cost target
Feedstock Logistics
▪ By 2015, develop a blendstock formulation for one conversion pathway based upon meeting pathway cost, quality, and volume targets
▪ By 2017, validate sustainable feedstock supply and logistics cost of $80/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
Algal Feedstocks
▪ By 2014, demonstrate at research scale algae yield of 1,500 gallons of equivalent biofuel intermediate per acre per year
▪ By 2016, review integrated R&D approaches for high-yielding algal biofuel intermediates to evaluate potential approaches for achieving the 2018 and 2022 milestones
▪ 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 2022, model the sustainable supply of 20 million metric ton AFDW cultivated algal biomass and 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 $3/GGE (2011$), with or without co-products
Conversion R&D
Biochemical Conversion R&D
▪ By 2014, establish out-year cost goals and technical targets for catalytically derived hydrocarbon fuels based on techno-economic analysis for one technology pathway
▪ By 2017, validate the integrated production of a hydrocarbon fuel or fuel blend stock from cellulosic or algal biomass via at least one biological or chemical route at integrated bench scale to measure progress against an interim modeled cost goal (nth plant, $2011)
Thermochemical Conversion R&D
▪ By 2014, establish out-year conversion cost projections and technical targets for achieving the $3/GGE goal based on a techno-economic analysis for at least one gaseous intermediate pathway that produces gasoline and diesel blendstock fuels
▪ By 2015, select a thermochemical pathway for initially integrated operations to validate the Office's goal of $3/GGE by 2017 by evaluating R&D data from bench-scale, semi-integrated thermochemical pathways that produce gasoline and diesel blendstock fuels
▪ By 2017, validate the R&D performance goal of $2.50/GGE nth plant modeled conversion cost and thus the Office's performance goal of $3.00/GGE MFSP by performing integrated operations using on-specification feedstock via a thermochemical pathway that produces gasoline and diesel blendstock fuels
▪ By 2020, select another thermochemical pathway for integrated operations to validate the 2022 Office goal of $3/GGE by evaluating R&D data from bench-scale, semi-integrated thermochemical pathways that produce gasoline and diesel blendstock fuels
▪ By 2022, validate the Office performance goal of $3/GGE by performing integrated operations using on-specification blended, low-cost feedstock via a thermochemical pathway that produces gasoline and diesel blendstock fuels
Demonstration and Deployment
▪ By 2018, validate three infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing processes at pilot scale
▪ By 2020, validate one to two infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing processes at demonstration scale
▪ By 2024, validate one infrastructure-compatible hydrocarbon biofuel or bioproduct manufacturing process at appropriate scale
Sustainability
Analysis and Communication
▪ By 2015, identify practices that improve sustainability and environmental performance of advanced bioenergy, including results from a comprehensive case study of environmental, social, and economic sustainability indicators for a cellulosic feedstock production and biorefinery system
▪ 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
Sustainable System Design
▪ By 2015, identify conditions under which a national 2030 feedstock production scenario can be achieved that, when

	compared to the projected U.S. Department of Agriculture baseline, improves average water quality in major feedstock production regions; does not increase consumptive water use per unit of fuel produced; maintains soil quality and biodiversity; and does not impact projected needs for food, feed, and fiber production
▪	By 2018, using available field data, validate case studies of optimized feedstock production systems that reduce GHG emissions and maintain or improve water quality and soil quality compared to conventional agriculture and forestry systems; identify generalizable conclusions and strategies to translate optimized scenarios into practice
Strategic Analysis	
▪	By 2014, coordinate the delivery of new design cases and corresponding life-cycle assessments for at least two technology pathways for conversion of biomass to hydrocarbon biofuels
▪	By 2015, complete an assessment of the size and composition of current and potential markets for biofuels and bioproducts
▪	By 2016, develop and deploy a consistent methodology for including co-products in techno-economic analyses and design cases
▪	By 2017, identify near-term technology pathways for the Office based on reassessment of current state of technology development
▪	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	
▪	On an annual basis, complete outreach efforts focused on celebrating specific and timely Office contributions to new technologies, pathways, and directions, as Office-supported projects achieve important milestones and deliverables
▪	By the end of 2014, determine three key Office messages that will be amplified throughout all Office outreach
▪	By the end of 2014, complete outreach efforts focused on communicating the Office's successes in cellulosic ethanol to the ethanol-development community
▪	By the end of 2014, in collaboration with Office leadership and Strategic Programs, identify highest-value media and target audiences and set goals for targeted outreach strategies and metrics that rely on appropriate communication channels (traditional and emerging) and carefully tailored messages and sub-messages
▪	By the end of 2015, complete a national outreach campaign on the promise and benefits of developing biofuels, bioproducts, and biopower
▪	By the end of 2014, complete outreach efforts focused on the GHG emission reductions resulting from biomass-derived alternative fuels
▪	By the end of 2015, complete outreach efforts focused on landscape-scale environmental benefits of integrated biomass-based alternative fuels production with agricultural and other industrial activities
▪	By the end of 2016, complete outreach efforts focused on future consumers and workforce that will support an emerging bioenergy industry