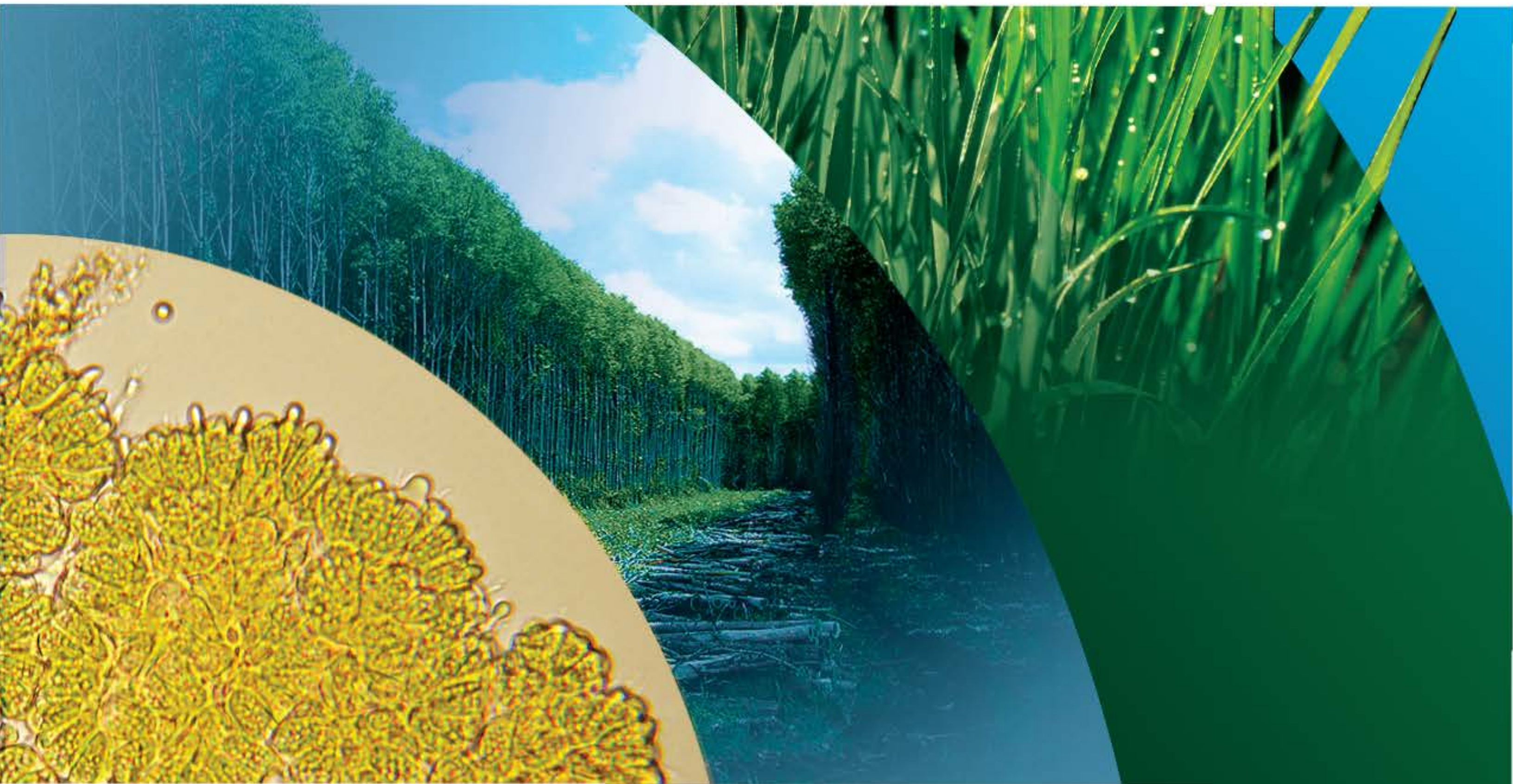
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE

Multi-Year Program Plan

May 2013



EXECUTIVE SUMMARY

The Bioenergy Technologies Office is one of the 11 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. 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 Bioenergy Technologies Office (the Office) manage and coordinate its activities, as well as a resource to help articulate the Office's mission and goals to management 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, demonstration, and deployment supported through public and private partnerships.*

The goal of the Office is to develop commercially viable biomass utilization technologies to:

- *Enable sustainable, nationwide production of advanced biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil*
- *Encourage the creation of a new domestic bioenergy industry supporting the Energy Independence and Security Act of 2007 goal of 36 billion gallons per year of renewable transportation fuels by 2022.*

Technology Portfolio

The Office manages a diverse portfolio of technologies across the spectrum of applied RDD&D within the dynamic context of changing budgets and administrative priorities. The portfolio is organized to reflect the biomass-to-bioenergy supply chain—from the feedstock source to the end user (see Figure A).

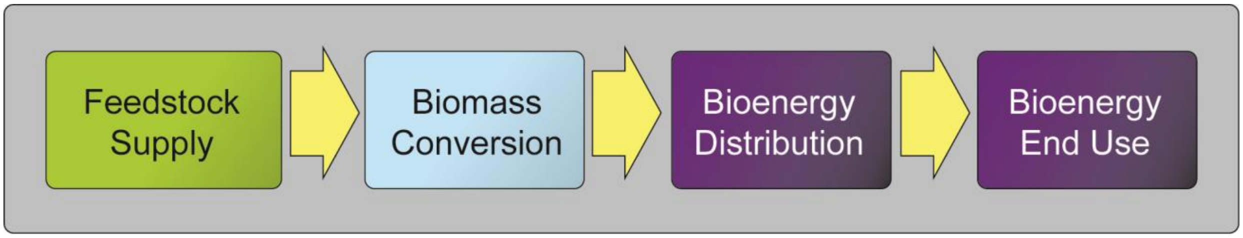


Figure A: Biomass-to-Bioenergy Supply Chain

The Office has developed a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and down-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 and deployment.

Key components of the portfolio include:

- R&D of a sustainable, high-quality feedstock supply system
- R&D of biomass conversion technologies
- Industrial-scale demonstration and validation of integrated biorefineries
- 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 and will be emphasized within the Office's efforts over the next five years:

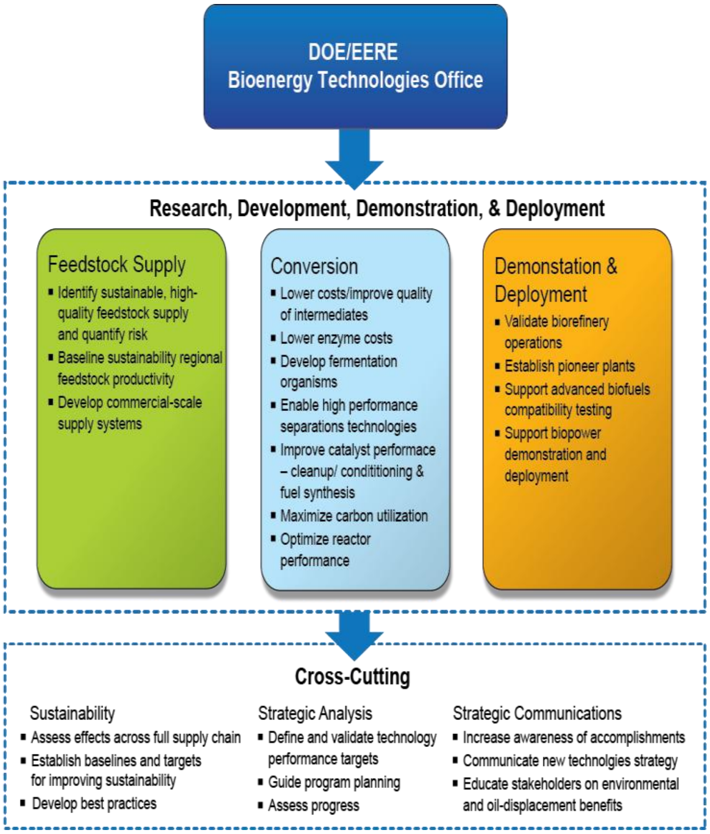
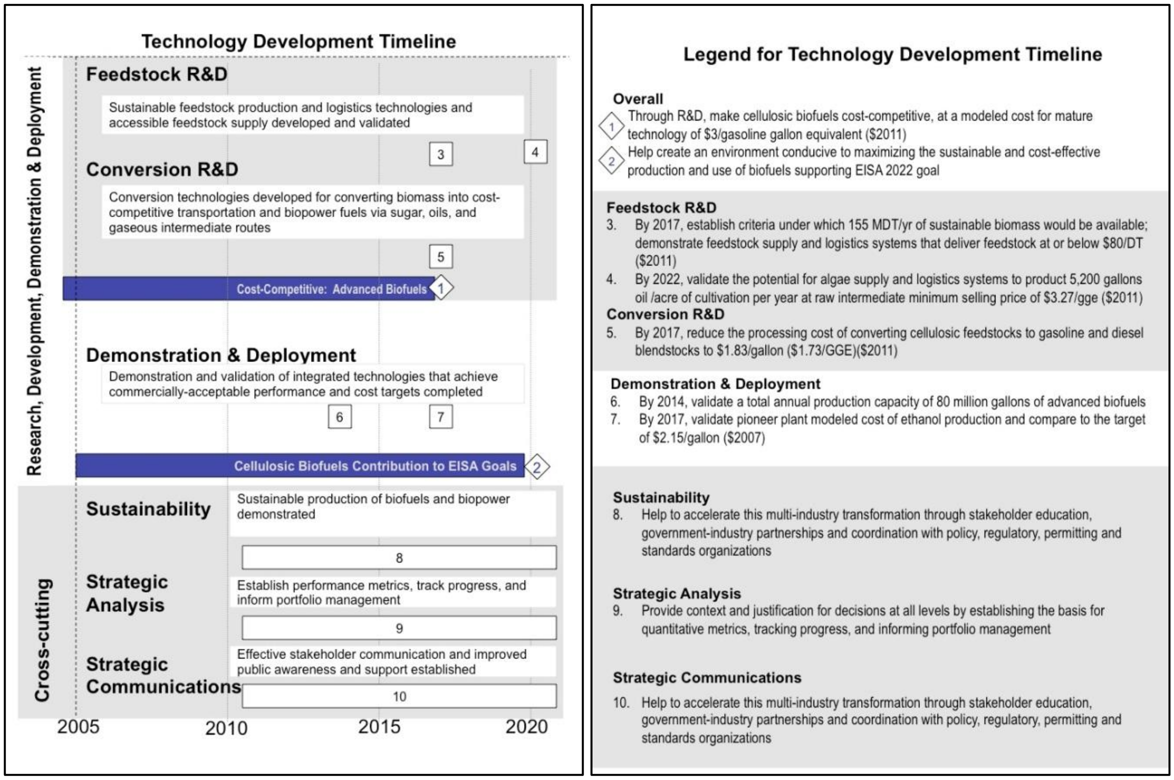


Figure B: Office Structure with High-Impact Research Areas

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 basic science and RDD&D of advanced biomass utilization technologies. Detailed life-cycle analysis of environmental, economic, and social impacts, while not specifically detailed as milestones, 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, enables demonstration activities that are critical to proof of performance, and lays the groundwork for future commercial deployment without competing with or duplicating work in the private sector. The plan addresses important technological advances to produce biofuels, as well as 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.

The Bioenergy Technologies Office's 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 not only have a significant near-term impact on oil displacement, but will also facilitate the shift to renewable, sustainable bioenergy technologies in the long term.



Legend for Technology Development Timeline

Overall

1. Through R&D, make cellulosic biofuels cost-competitive, at a modeled cost for mature technology of $3/gasoline gallon equivalent ($2011)
2. Help create an environment conducive to maximizing the sustainable and cost-effective production and use of biofuels supporting EISA 2022 goal

Feedstock R&D

3. By 2017, establish criteria under which 155 MDT/yr of sustainable biomass would be available; demonstrate feedstock supply and logistics systems that deliver feedstock at or below $80/DT ($2011)
4. By 2022, validate the potential for algae supply and logistics systems to product 5,200 gallons oil /acre of cultivation per year at raw intermediate minimum selling price of $3.27/gge ($2011)

Conversion R&D

5. By 2017, reduce the processing cost of converting cellulosic feedstocks to gasoline and diesel blendstocks to $1.83/gallon ($1.73/GGE)($2011)

Demonstration & Deployment

6. By 2014, validate a total annual production capacity of 80 million gallons of advanced biofuels
7. By 2017, validate pioneer plant modeled cost of ethanol production and compare to the target of $2.15/gallon ($2007)

Sustainability

8. Help to accelerate this multi-industry transformation through stakeholder education, government-industry partnerships and coordination with policy, regulatory, permitting and standards organizations

Strategic Analysis

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

Strategic Communications

10. Help to accelerate this multi-industry transformation through stakeholder education, government-industry partnerships and coordination with policy, regulatory, permitting and standards organizations

Figure C: Bioenergy Technologies Office Strategy and Timeline for Technology Development

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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
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 Food, Conservation, and Energy Act of 2008
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
INL – Idaho National Laboratory
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
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
RD&D – research, development, and deployment
RDD&D – research, development, demonstration, and deployment
RFS – Renewable Fuels Standard
RLP – Resource Loaded Plan
RPS – Renewable Portfolio Standard
RSB – Roundtable on Sustainable Biofuels
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% – weight percent

Section 1: Office Overview

Growing concerns over national energy security and climate change have renewed the urgency for developing sustainable biofuels, bioproducts, and bioenergy. 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 imported oil. The United States' dependence on imported oil exposes the country to critical disruptions in fuel supply, creates economic and social uncertainties for businesses and individuals, and impacts our national security.

Biomass is the only renewable energy source that can offer a substitute for petroleum-based, liquid transportation fuels in the near term. The United States could produce more than one billion tons[1] of sustainable biomass resources that can provide fuel for cars, trucks, and jets; make chemicals; and produce power to supply the grid, while creating new economic opportunities and jobs throughout the country in agriculture, manufacturing, and service sectors.

Biomass

Biomass is an energy resource derived from organic matter. It includes agricultural residues, forest resources, perennial grasses, woody energy crops, wastes (municipal solid waste, urban wood waste, and food waste), and algae. It is unique among renewable energy resources in that it can be converted to carbon-based fuels and chemicals, in addition to power.

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.[2]

To support these goals, the Bioenergy Technologies Office (the Office), within the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), is focused on forming cost-share partnerships with key stakeholders to develop, demonstrate, and deploy technologies for advanced biofuels production from lignocellulosic and algal biomass.

Scope of Effort/Framework for Success

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

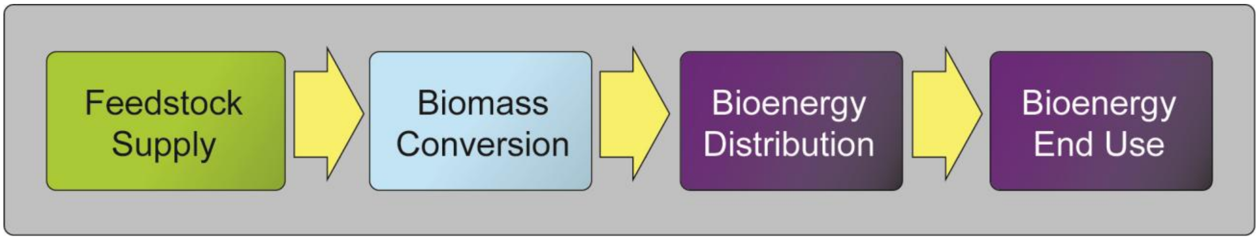

Figure 1-1: Biomass-to-Bioenergy Supply Chain

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[1] 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.

[2] 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.

Each element of the supply chain must be addressed:

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

This breadth of scope requires the participation of a broad range of public and private stakeholders, 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 insights and perspectives that can help identify the most critical challenges and better define strategies for effectively deploying biofuels. The framework for success also requires extensive coordination and collaboration across multiple federal stakeholder agencies.

Bioenergy Technologies Office's Framework for RDD&D

The Office uses an integrated framework to manage its research, development, demonstration, and deployment (RDD&D) activities. The Office down-selects the most promising opportunities through systematic investigation and evaluation of a broad range of emerging technologies. This approach supports a diverse technology portfolio in applied research and development (R&D), and identifies the most promising targets for follow-on industrial-scale demonstration and deployment.

The Office implements this framework through a series of Resource Loaded Plans developed around two broad categories of effort: RDD&D and Cross-Cutting Activities. The Resource Loaded Planning process takes a rigorous approach to identifying the critical path activities and resources required to advance selected technologies through the stage-gate hierarchy of technology readiness levels in the RDD&D pipeline.

This approach has several distinct advantages:

- 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.
- The Resource Loaded Planning process identifies 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.
- It incorporates a stage-gate process, which guarantees a series of periodic technology readiness reviews to help inform the down-selection process.

Expanded Office Focus on Advanced Biofuels

While the overall mission of the Office 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. Historically, the Office's focus has been on RDD&D for ethanol production from lignocellulosic biomass. More recent national and DOE goals require the Office to expand its scope to include the development of other advanced biofuels that will contribute to the volumetric requirements of the Renewable Fuel Standard (RFS). This includes biofuels such as biomass-based hydrocarbon fuels (renewable gasoline, diesel, and jet fuel), hydrocarbons from algae, and biobutanol.

The Office has demonstrated technologies to produce cost-competitive cellulosic ethanol, the culmination of two decades of conversion technology 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. The investments the Office has made in technologies that can reduce the recalcitrance of lignocellulosic biomass are being leveraged toward the development of third-generation advanced biofuels, bioproducts, and bioenergy.

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 limited infrastructure, high production costs, competing energy technologies, and other market barriers. Market incentives and legislative mandates are helping to overcome some of these barriers.

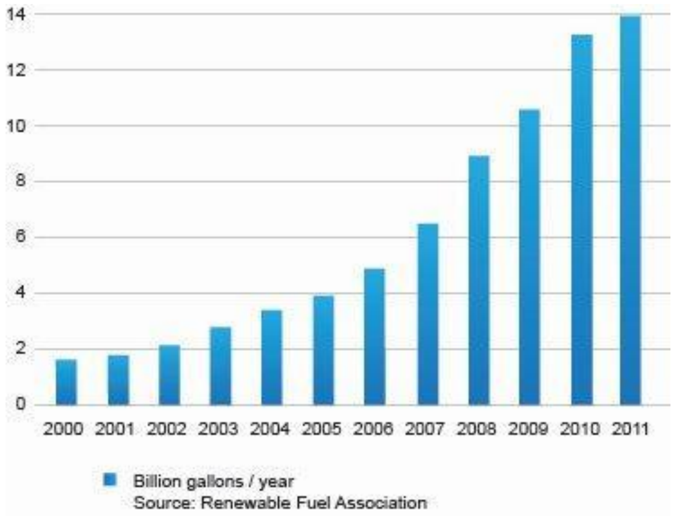
1.1.1 Current and Potential Markets

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 bio-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, and dedicated energy crops. Ultimately the industry is expected to move toward large biorefineries that produce a portfolio of biofuels and bioproducts, with integrated, onsite cogeneration of heat and power.

Transportation Fuels: America's transportation sector relies almost exclusively on refined petroleum products, accounting for over 70% of the oil used. Oil accounts for 94% of transportation fuel use, with biofuels, natural gas, and electricity accounting for the balance.[3] Nearly 9 million barrels of oil are required every day to fuel the 247 million vehicles that constitute the U.S. light-duty transportation fleet.

Biomass is a direct, near-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.



Source: Renewable Fuel Association

Figure 1-2: U.S. Ethanol Production Capacity

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 of ethanol from grains has increased rapidly over the past five years, from under 4 billion gallons per year to nearly 14 billion gallons in 2011.[4]

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 2007 provides a reliable market for biofuels of 24 billion gallons by 2017. Blender tax credits for ethanol and biodiesel have historically helped to ensure 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 is still in place and set to expire at the end of 2012 without an extension by Congress.

To successfully penetrate the target market, however, the minimum profitable cellulosic fuel price must be low enough to compete with gasoline. A minimum profitable fuel selling price of $2.50/gallon gasoline equivalent (GGE) can compete on an energy-adjusted basis with gasoline derived from oil costing $75 to $80/barrel. Given the broad range of oil prices projected by the

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[3] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035* (2012), Washington: Government Printing Office, DOE/EIA-0383.

[4] Renewable Fuels Association, *Accelerating Industry Innovation 2012: Ethanol Industry Outlook* (2012), http://ethanolrfa.3cdn.net/d4ad995ffb7ae8fbfe_1vm62ypzd.pdf.

Energy Information Administration (EIA) in 2017 [$58 to $186/billion barrels (bbl)],[5] cellulosic technology may continue to require policy support and regulatory mandates.

Consumer attitudes about fuel prices and performance, biofuel-capable vehicles, and the environment also affect demand for biofuels. Consumers who are generally unfamiliar with biofuels have been hesitant to use them, even where they are available.

Products: Approximately 10% of U.S. crude oil imports are used to make chemicals and products such as plastics for industrial and consumer goods.[6] Many products derived from petrochemicals could be replaced with biomass-derived materials. Less than 4% of U.S. chemical sales are biobased.[7] Organic chemicals such as plastics, solvents, and alcohols represent the largest and most direct market for bioproducts.[8] The market for specialty chemicals is much smaller, but is projected to double in 15 years[9] and offers opportunities for high-value bioproducts. These higher-value products could be used to increase the product slate and profitability of large integrated biorefineries. The price of bioproducts remains relatively high compared to petroleum-based products, largely due to the high cost of converting biomass to chemicals and materials.

As the price of oil has increased, so have U.S. chemical manufacturers' interest in biomass-derived plastics and chemicals. Some traditional 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.

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 cost 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 power generation. Fossil fuels dominate U.S. power production and account for more than 70% of generation, with coal comprising 48%, natural gas 24%, and oil 1%. The balance is provided by nuclear (18%) and renewable sources (10%), of which biopower accounts for 1%. 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, including biopower, is projected to have the largest increase in production capacity between 2009 and 2035.[10]

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[5] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035*.

[6] 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.

[7] Ibid.

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

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

[10] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035*.

Dedicated utility-scale biomass power applications are a potential route to further reducing our reliance on fossil fuels and improving 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.

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. Several states have also recently begun to develop policies to reduce GHG emissions and are looking to biomass power 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 2030, with consumption expected to increase from 86.1 million barrels per day in 2008 to about 110 million barrels per day in 2035.[11] 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 transportation, primarily ethanol (see Figure 1-3), and several other countries have developed ethanol programs, including China, India, Canada, Thailand, Argentina, Australia, and Colombia.[12]

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) have focused on GHG reduction requirements for their fuel. The EU has also established a committee to coordinate the development of further biofuel sustainability criteria.

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[11] U.S. Department of Energy, *International Energy Outlook 2011* (2011), Washington: Government Printing Office, DOE/EIA-0484.

[12] Renewable Fuels Association, *Ethanol Industry Outlook 2005* (2005), http://www.ethanolrfa.org/outlook2005.pdf.

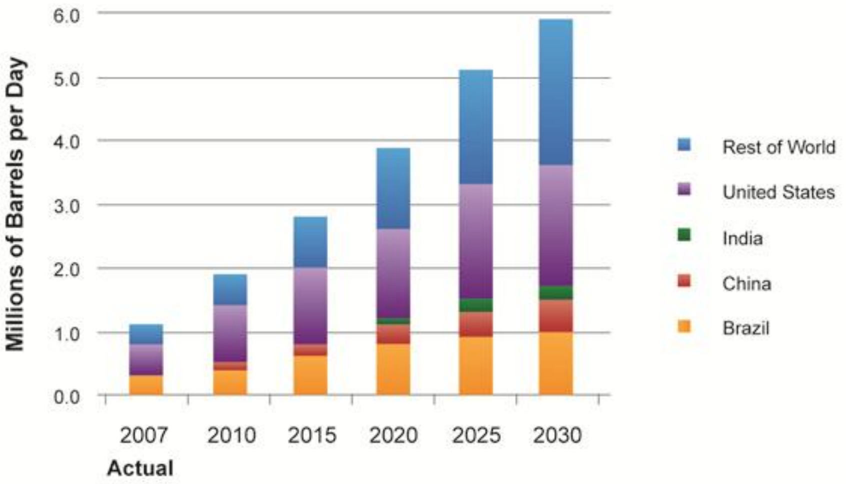

Figure 1-3: Global Production of Biofuels

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 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 between 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 field of bioenergy to focus on researching the indirect impacts of bioenergy production in order to understand the magnitude of the linkage and 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. Some governments have addressed this issue through 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).[13]

1.1.3 Competing Alternative Fuel Technologies

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:

- **Hydrogen:** Hydrogen can be produced via water electrolysis, reforming renewable liquids or natural gas, coal gasification, or nuclear synthesis routes.
- **Oil Shale-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 been developed.
- **Tar Sands-Derived Fuels:** 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.[14]
- **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 continue to rise, however, coal-derived transportation fuels may become competitive. It should be noted that conventional coal-to-liquid technologies can often be adapted to use biomass as a feedstock, both in standalone applications or blended with 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 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 discussed fully in Section 2:

- Feedstock Availability and Cost
- Agricultural Sector-Wide Paradigm Shift

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

[14] World Energy Council, "Survey of Energy Resources" (2010), http://www.worldenergy.org/documents/ser_2010_report_1.pdf.

- Inadequate Supply Chain Infrastructure
- Lack of Understanding of Environmental/Energy Tradeoffs
- High Risk of Large Capital Investments
- Lack of Industry Standards and Regulations
- Cost of Production
- Off-Take Agreements
- Availability of Biofuels Distribution Infrastructure
- Market Uncertainty
- Inconsistent and Unpredictable Policy Landscape and Priorities
- Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel
- Poorly Understood Role of Government versus the Role of Industry

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 demonstration of technologies capable of producing cost-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.

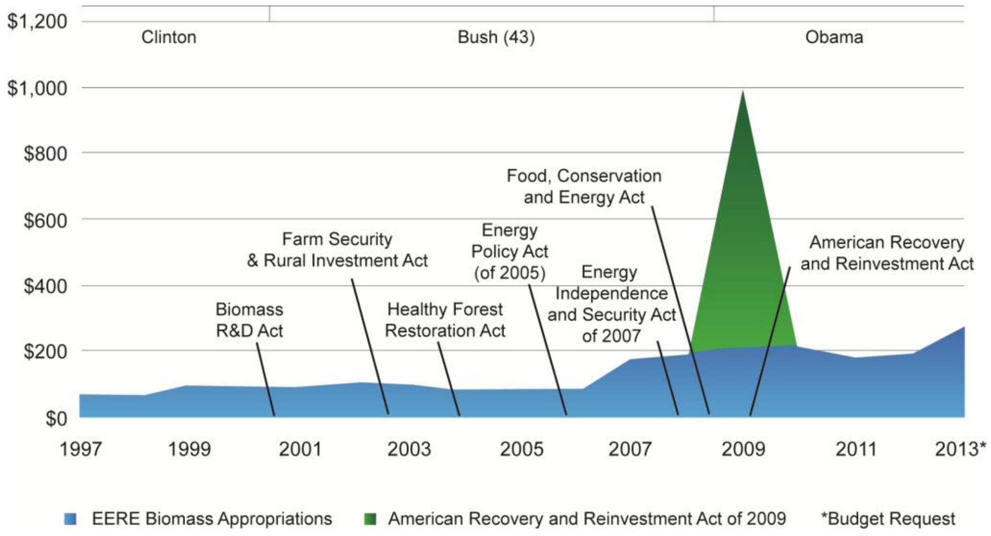

Figure 1-4: DOE EERE Funding for Biomass RDD&D

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

March 2011	Blueprint for a Secure Energy Future	• Outlines a comprehensive energy policy that cuts U.S. oil imports by one-third by 2025 through reducing the nation's dependence on oil with cleaner alternative fuels and greater efficiency. • Promotes collaboration with international partners to increase bioenergy production. • Includes research and incentives that aim to reduce barriers to increased biofuels use and the commercialization of new technologies.
May 2009	Presidential Memorandum on Biofuels	• Memorandum that, among other requirements, 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 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 commercialization of advanced biofuels R&D and pilot-, demonstration-, and commercial-scale integrated biorefinery projects. • Provided funds to other DOE programs for basic 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 Technical Advisory Committee.
December 2007	Energy Independence and Security Act of 2007	• Supported the continued development and use of biofuels, including a significantly expanded RFS, requiring 36 bgy renewable fuels by 2022 with annual requirements for advanced biofuels, cellulosic biofuels, and biobased diesel.
August 2005	Energy Policy Act of 2005 (EPAct)	• 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 energy market driven by fossil fuels, the need to find stabilizing solutions becomes increasingly important. The advantages to the nation include economic security as significant amounts of domestically produced feedstocks are directed to the production of energy. There is no "one size fits all" solution when considering domestic alternatives to fossil fuels as the United States has multiple domestic energy sources that will lead to diversification. However, the specific benefit of a biomass-derived alternative to fossil fuels is an increased level of economic activity and new jobs in the farms and forests of rural America. Farming and forestry are both vital industries today, and robust biomass-based industries can produce food and feed alongside new crops dedicated to energy, thus providing more job opportunities for agriculture and forestry.

From 2010 to 2035, U.S. energy consumption is projected to rise by about 8%, while domestic energy production rises by 25%. 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.[15] This decreased reliance on imported energy improves our national security, economic health, and future global competitiveness.

In addition, 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, bio-products, 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 transportation fuels made from biomass are advantageous because they are largely compatible with existing infrastructure to deliver, blend, and dispense fuels. The Office's supported biomass conversion technologies are targeted to enable displacement of over 20 billion gallons of petroleum-based liquid transportation fuel, annually, by 2022. These efforts are in direct support of the goals set in the RFS.

This resulting supply of domestically produced biofuels, intended to replace petroleum imported for the chemical and fuels industry, will also retain the full investment in the U.S. and help reduce price volatility. This point is underscored by the Department of Defense's effort to increase national energy security through energy independence, beginning with reducing their 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.

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. 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-risk, high-value biomass technology RDD&D that is critical to the nation's future, but that industry would not pursue independently. States, associations, and industry will be key participants in deploying biomass technologies once risks have been sufficiently reduced by federal programs.

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[15] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035*.

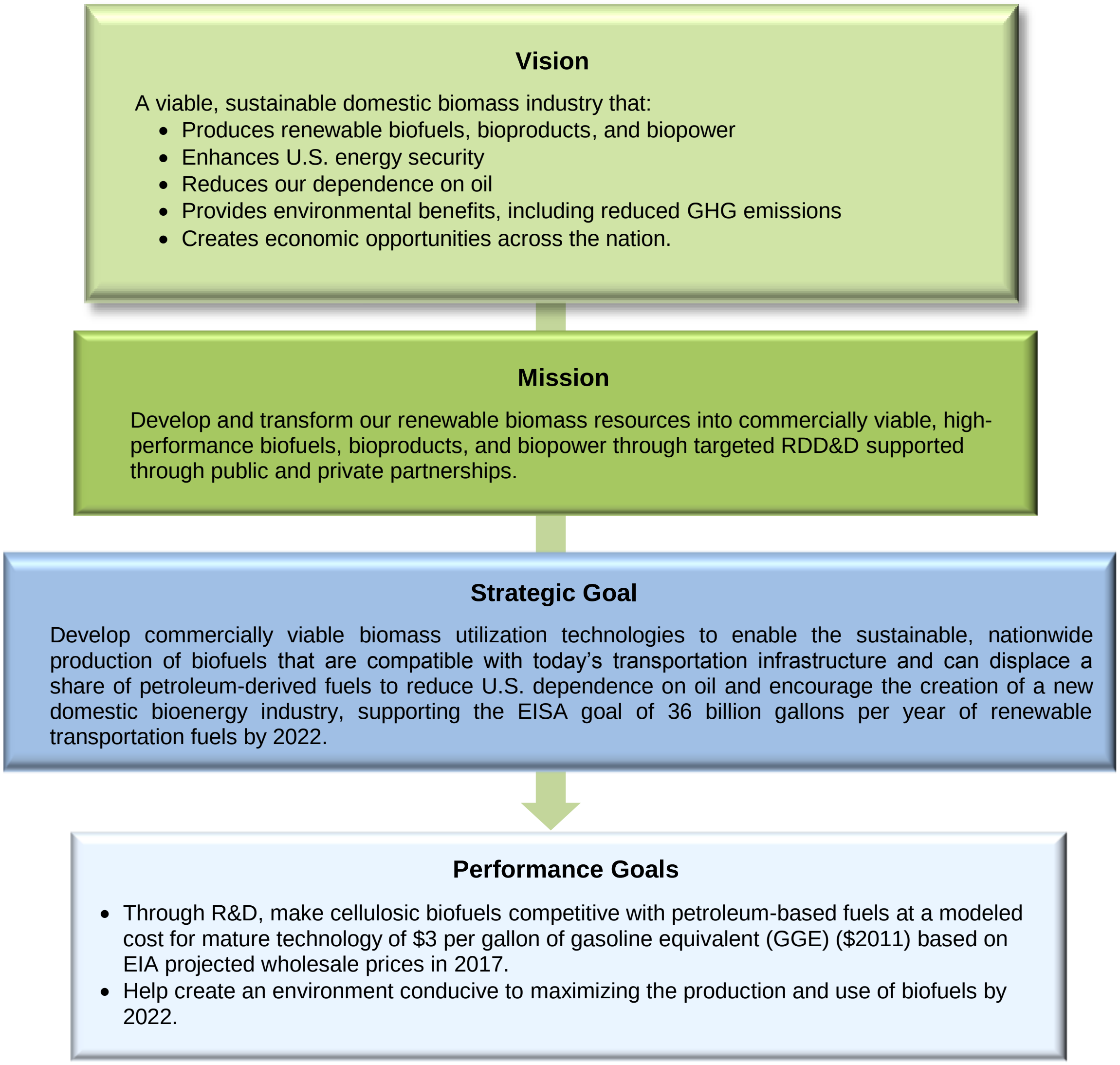
1.2 Office Vision and Mission

EISA aimed to increase the supply of alternative fuels and set a mandatory Renewable Fuel Standard (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 Bioenergy Technologies Office is focused on developing, demonstrating, and deploying biofuel, bioproducts, and bioenergy 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 dependence on foreign oil
- Promote the use of diverse, domestic, and sustainable energy resource
- Establish a domestic bioenergy industry
- Reduce carbon emissions from energy production and consumption.

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



Vision

A viable, sustainable domestic biomass industry that:

- Produces renewable biofuels, bioproducts, and biopower
- Enhances U.S. energy security
- Reduces our dependence on oil
- Provides environmental benefits, including reduced GHG emissions
- Creates economic opportunities across the nation.

Mission

Develop and transform our renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted RDD&D supported through public and private partnerships.

Strategic Goal

Develop commercially viable biomass utilization technologies to enable the sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry, supporting the EISA goal of 36 billion gallons per year of renewable transportation fuels by 2022.

Performance Goals

- Through R&D, make cellulosic biofuels competitive with petroleum-based fuels at a modeled cost for mature technology of $3 per gallon of gasoline equivalent (GGE) ($2011) based on EIA projected wholesale prices in 2017.
- Help create an environment conducive to maximizing the production and use of biofuels by 2022.

Figure 1-5: Strategic Framework for the Bioenergy Technologies Office[16]

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[16] 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 (WBS) 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.

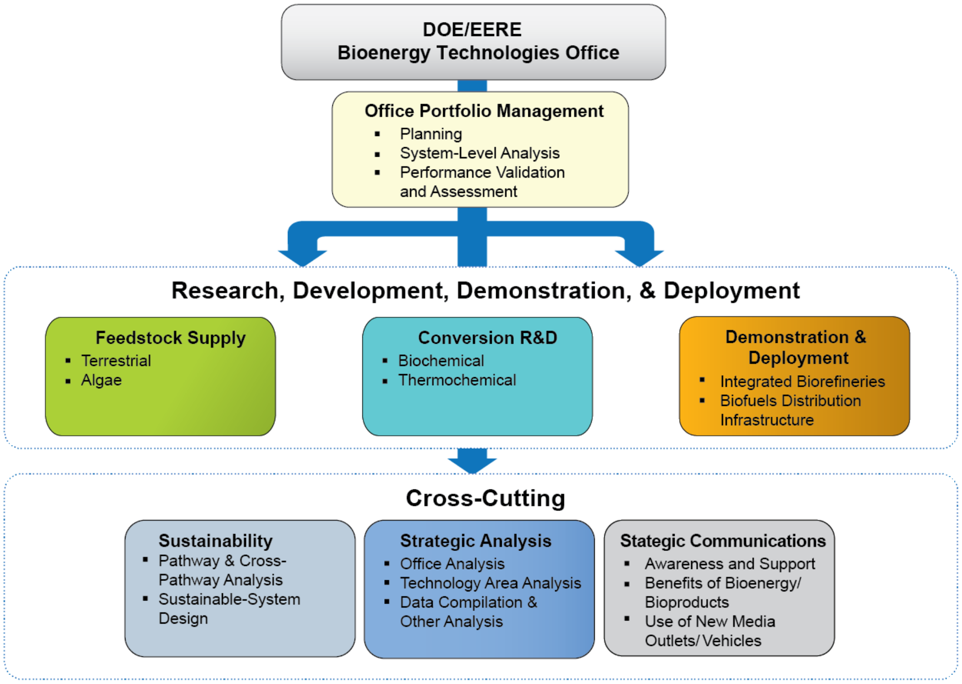


Figure 1-6: Elements of the Bioenergy Technologies Office

This approach provides for the development of pre-commercial, enabling technologies, as well as the integration and demonstration activities critical to proof of performance. It also accommodates the sustainability, analytical, and strategic communications activities needed to help the Office 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 Office Logic

The Office 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 Office 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.

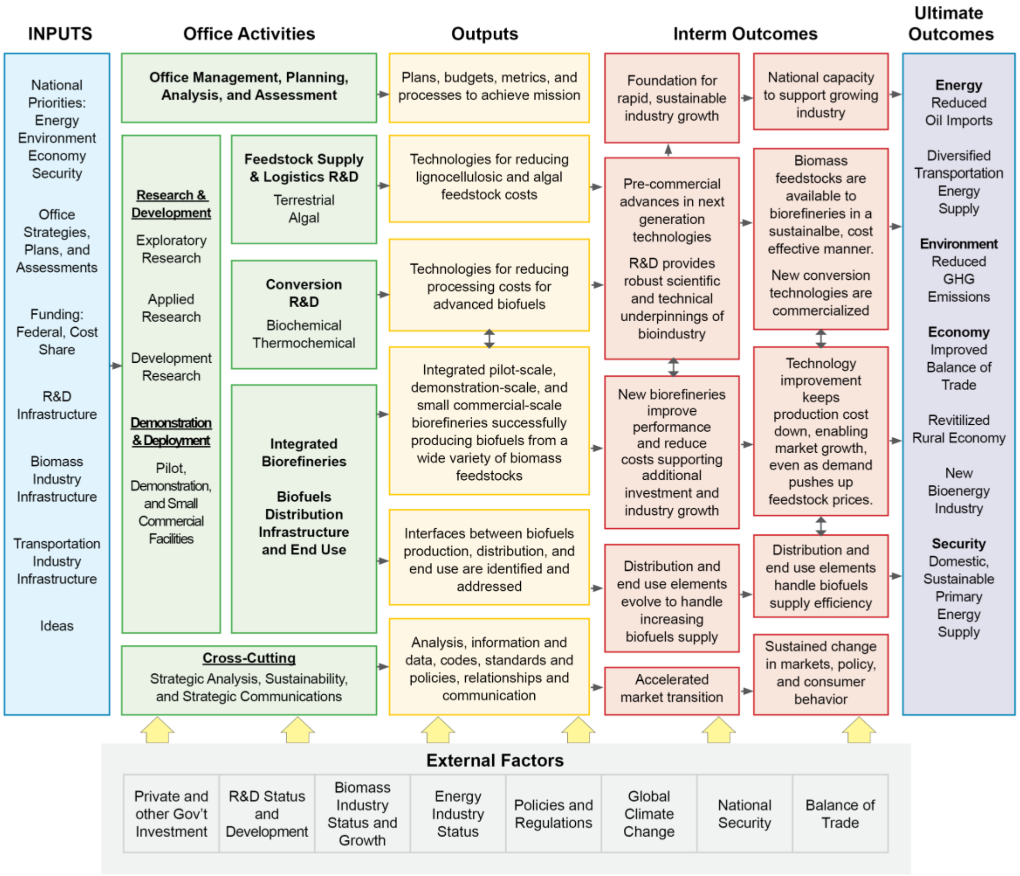


Figure 1-7: Bioenergy Technologies Office Logic Diagram

1.3.3 Relationship to Other Federal Offices

Coordination with other government offices involved in bioenergy 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 Bioenergy Technologies 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 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	Biorefineries and Biopower	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 to fuels and power (gasification and pyrolysis)	Cost-shared projects and/or loan guarantees to (1) biorefineries, to demonstrate and deploy integrated conversion processes at pilot-, demonstration-, and commercial-scale and (2) biopower combustion systems related to biomass as a co-firing feedstock in coal-fired boilers; demonstrations of biomass co-firing	Safe, adequate, sustainable, and cost-effective biofuels transportation/distribution systems development; material compatibility; alternative fuel dispensing infrastructure	Engine optimization; vehicle emissions testing; market reporting and education to improve awareness regarding 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 commercial-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 (1) support safe and sustainable biofuel transportation/distribution; (2) refineries and blending facilities development; (3) flex fuel pumps installation; and (4) support 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.)		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		Working towards certification of bio-derived jet fuels in coordination with the American Society for Testing and Materials
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 R&D	Support for biorefineries, to demonstrate and deploy integrated conversion processes at pilot-, demonstration-, and commercial-scale		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-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 projects—in particular those from ARPA-E's Plants Engineered to Replace Oil (PETRO) and Electrofuels Programs—on biomass-related projects.

Office of Fossil Energy (FE): The Office is working with FE to develop technology improvements to increase the efficiency, environmental performance, and economic viability of utility-scale biopower applications.

Office of Energy Efficiency and Renewable Energy (EERE): The following EERE programs also contribute to one or more aspects of biomass utilization technology development:

- **Fuel Cell Technologies Office (FCT):** The production of hydrogen from biomass is pursued through two main pathways—distributed reforming of bio-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 FCT 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 fuels, particularly ethanol and diesel replacements, are coordinated with VTO. This coordination focuses on product distribution infrastructure and end use, specifically fuel characterization and combustion testing for novel 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 biobased fuels, chemicals, materials, heat, and electricity are of interest to AMO distributed energy, chemicals, and forest products subprograms.
- **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.

1.4 Office Goals and Multi-Year Targets

This subsection describes Bioenergy Technologies 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 biomass utilization technologies to enable the sustainable, nationwide production of biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry, supporting the Energy Independence and Security Act of 2007 goal of 36 billion gallons per year of renewable transportation fuels by 2022.*

The Office's high-level schedule aims for commercially viable renewable gasoline, diesel, and jet by 2017, and supports EISA 2022 renewable fuels goals (Figure 1-8).

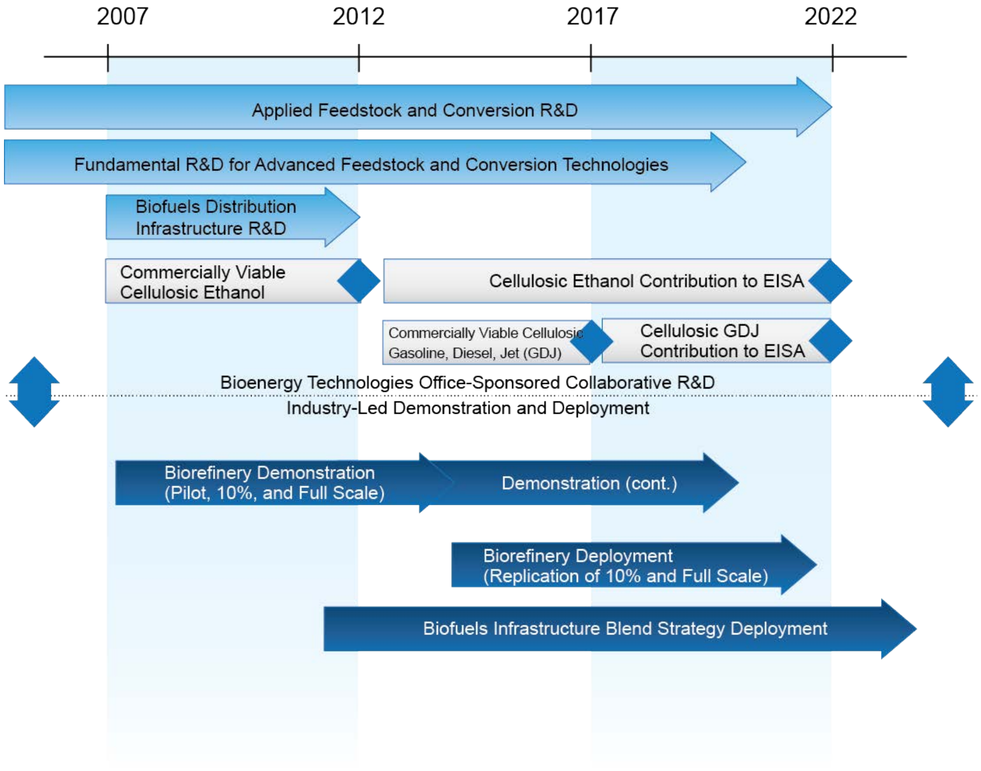
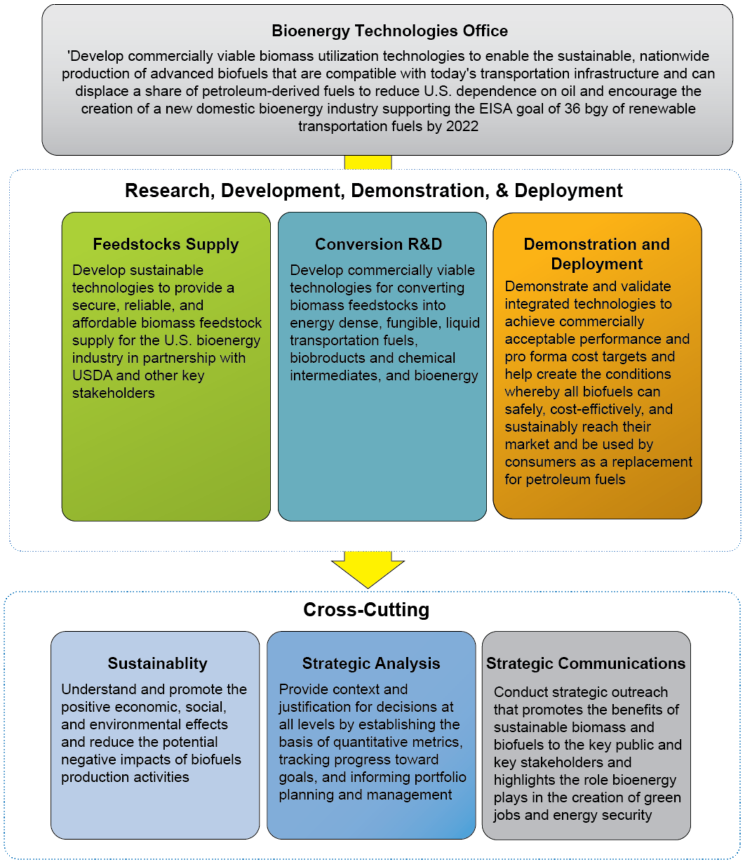


Figure 1-8: Bioenergy Technologies Office High-Level Schedule

The strategic goals for each Office element support the overarching Bioenergy Technologies Office strategic goal, as shown in Figure 1-9. These goals are integrally linked—demonstration and validation activities, for example, will depend upon an available, sustainable feedstock supply, commercially viable conversion technologies, adequate distribution infrastructure, and strategic alliances and outreach to catalyze market expansion.



'Develop commercially viable biomass utilization technologies to enable the sustainable, nationwide production of advanced biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry supporting the EISA goal of 36 bgy of renewable transportation fuels by 2022

Develop sustainable technologies to provide a secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry in partnership with USDA and other key stakeholders

Develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible, liquid transportation fuels, biobroducts and chemical intermediates, and bioenergy

Demonstrate and validate integrated technologies to achieve commercially acceptable performance and pro forma cost targets and help create the conditions whereby all biofuels can safely, cost-effectively, and sustainably reach their market and be used by consumers as a replacement for petroleum fuels

Understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of biofuels production activities

Provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management

Conduct strategic outreach that promotes the benefits of sustainable biomass and biofuels to the key public and key stakeholders and highlights the role bioenergy plays in the creation of green jobs and energy security

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 meeting EISA goals:

- Through RDD&D, make cellulosic biofuels competitive with petroleum-based fuels at a modeled cost of mature technology of $3/gallon gasoline equivalent ($2011), based on EIA projected wholesale prices in 2017.[17]
- Help create an environment conducive to maximizing the sustainable production and use of biofuels by 2022.

1.4.3 Office Multi-Year Targets

The Office's multi-year targets for 2013–2022 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.

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[17] U.S. Department of Energy, *Annual Energy Outlook 2012 with Projections to 2035: Table 131* (2012), Washington: Government Printing Office, http://www.eia.gov/oiaf/aeo/supplement/suptab_131.xlsx.

Table 1-3: Office Multi-Year Targets

Feedstock Supply R&D

Resource Assessment

- Establish geographic, economic, quality, and environmental criteria under which 155 million DT per year would be available by 2017
- Establish feedstock resource assessment models with geographic, economic, quality, and environmental criteria under which algal resource supply can be identified to support cultivation of 1 million metric tons ash free dry weight (AFDW) algae biomass by 2017 and 20 million metric tons AFDW by 2022

Feedstock Logistics

- Demonstrate feedstock supply and logistics systems that can deliver non-pulpwood feedstock to the conversion reactor throat at required conversion specifications at or below $80/dry ton (DT) ($2011) by 2017
- Validate the potential for algae supply and logistics systems to product 5,200 gallons oils (or equivalent biofuel intermediate) per acre of cultivation per year, achieving a modeled nth plant minimum selling price of $3.27/GGE ($2011) of raw biofuel intermediate (corresponding to projected $3.73/GGE ($2011) of renewable diesel minimum fuel selling price) by 2022

Conversion R&D

Biochemical Conversion R&D

- Achieve the overall Office performance goal of $3 per GGE ($2011), based on data at the integrated pilot-scale by 2022

Bio-Oils Pathways R&D

- Achieve a conversion cost of $1.83 per gallon of total blendstock ($1.73 /GGE)($2011) via a bio-oil pathway by 2017

Gaseous Intermediate Pathways R&D

- Achieve the overall Office performance goal of $3 per GGE ($2011) via catalytic upgrading of biomass synthesis gas to gasoline and diesel range hydrocarbons by 2022

Integrated Biorefineries

- Validate a total annual production capacity of 80 million gallons of advanced biofuels by 2014
- Validate a mature technology plant model for cost of ethanol production based on actual integrated biorefinery project performance data and compared to the target of $2.15/gallon ethanol($2007) by 2017

Sustainability

- Identify metrics and set targets for soil quality and air quality for agricultural residues, energy crops, and forest resources and at least one conversion pathway by 2013
- Evaluate, quantify, and document sustainable integrated pilot-scale production of biofuels from agricultural residues, energy crops, forest resources, and algae by 2022

Strategic Analysis

- Select and complete techno-economic modeling and set goals and targets for at least two hydrocarbon pathways by 2013
- Select and complete techno-economic modeling and set goals and targets for at least two additional hydrocarbon pathways by 2014

Strategic Communications

- Complete outreach efforts focused on the R&D success of meeting cellulosic ethanol cost targets by 2013
- Complete outreach efforts focused on new Office technologies, pathways, and directions by 2014
- Complete outreach efforts focused on the GHG emission reductions resulting from biomass-based alternative fuels by 2014

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

Research and Development
Feedstocks
Terrestrial Feedstocks
Resource Assessment
▪ Identify environmental criteria (soil health and air quality) and establish a methodology for incorporation into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways by 2013
▪ Integrate environmental and feedstock quality criteria into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways by 2014
▪ Produce a fully integrated assessment of the potentially available feedstock supplies under specified criteria and conditions by 2016
Logistics
▪ Deliver feedstock supply and logistics design cases achieving the 2017 goal of delivering feedstock to the conversion reactor throat at required specifications at or below $80/DT $2011 by 2013
▪ Evaluate advanced herbaceous and woody biomass preprocessing systems against conversion performance criteria by 2015
▪ Validate fully integrated advanced feedstock logistics systems that accept a broad range of herbaceous and woody biomass resources at field-scale by 2017
Algal Feedstocks
▪ Establish cost goals and technical targets for one alternate algal system and complete techno-economic analysis for one additional algal-production-to-finished-fuel technology pathway, including feasibility and trade-off analysis with higher value co-products by 2013
▪ Demonstrate at a non-integrated process development unit scale, algal productivity of 20 gallons per square meter per day AFDW (corresponding to 1,500 gallons of processed oil or equivalent biofuel intermediate per acre per year) by 2014
▪ Demonstrate at non-integrated process development unit scale, an open cultivation system design without use of traditional plastic liners and with integrated nutrient and water recycling that demonstrates algal productivity of 25 gallons per square meter per day AFDW (corresponding to 2,500 gallons processed oil or equivalent biofuel intermediate per acre per year) by 2018
▪ Validate an algal feedstock logistics system that can efficiently process more than 800 gallons of harvested algae per minute by 2018
▪ Validate algal productivity of greater than 5,200 gallons biofuel intermediate per acre per year by 2022
Conversion
Biological and Chemical Conversion R&D
▪ Establish out-year cost goals and technical targets for biologically derived hydrocarbon fuels based on techno-economic analysis for at least one technology pathway by 2013
▪ 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)—to be set in 2013—by 2017
Bio-Oil Pathways R&D
▪ Define requirements for characterizing heating oil from biomass and establish an R&D strategy by 2013
▪ Establish out-year (2017, 2022) cost goals and technical targets based on completed techno-economic analysis for two additional bio-oils technology pathways by 2014
▪ Validate bench scale, semi-integrated conversion processes for a “high impact” biomass feedstock to renewable gasoline or diesel via a direct liquefaction conversion process with bio-oil processing to a finished fuel at a scale sufficient enough for transfer to pilot-scale operation to support the 2017 targets by 2015
▪ Validate fully integrated, pilot scale conversion processes for a “high impact” biomass feedstock to renewable gasoline or diesel via direct liquefaction conversion process with bio-oil processing to a finished fuel by 2017
Gaseous Intermediates Conversion R&D
▪ Establish out-year cost goals and technical targets, based on completed techno-economic analysis, for at least one gaseous intermediate conversion to hydrocarbon fuels pathway by 2014

▪ Validate integrated conversion process for woody biomass to renewable gasoline or diesel via conversion of gaseous intermediates at a scale sufficient enough for transfer to pilot-scale operation by 2022

Demonstration and Deployment
Integrated Biorefineries
▪ Validate a total annual production capacity of 80 million gallons of advanced biofuels by 2014
▪ Mature technology plant model will be validated for cost of ethanol production based on actual integrated biorefinery project performance data and compared to the target of $2.15/gallon ethanol ($2007) by 2017
Cross-Cutting
Sustainability
Analysis
▪ Evaluate and compare the sustainability of biofuels produced from agricultural residues, energy crops, forest resources pathways, and algae by 2017
▪ Evaluate and compare the sustainability of biofuel production pathways by 2022
Pilot and Demonstration
▪ Demonstrate sustainable production of biofuel from agricultural residues at pilot scale, including all sustainability categories by 2015
▪ Demonstrate sustainable production of biofuel from woody or herbaceous energy crops at pilot scale, including all sustainability categories by 2017
▪ Demonstrate sustainable biofuel production from cellulosic and algal feedstocks by 2022
Best Practices Deployment
▪ Implement best practices for all sustainability categories for a sustainable integrated biomass-to-biofuel process for agricultural residue by 2017
▪ Implement best practices for all sustainability categories for a sustainable integrated biomass to bioenergy process for energy crops (woody or herbaceous), forest resources, and algae by 2022
Strategic Analysis
▪ Select and complete techno-economic modeling and set goals and targets for at least two hydrocarbon pathways by 2013
▪ Select and complete techno-economic modeling and set goals and targets for at least two additional hydrocarbon pathways by 2014
▪ Validate 2017 hydrocarbon pathway performance targets by 2017
Strategic Communications
▪ Complete outreach efforts focused on the R&D success of meeting cellulosic ethanol cost targets by 2013
▪ Complete outreach efforts focused on new Office technologies, pathways, and directions by 2014
▪ Complete outreach efforts focused on the greenhouse gas emission reductions resulting from biomass-based alternative fuels by 2014
<u>Demonstration</u>: At pilot scale and beyond, verify that the unit operations operate as designed and meet the complete set of performance metrics (individually and as an integrated system)
<u>Validation</u>: At pilot scale and beyond, ensure the process/system meets desired expectations/original intent. Validation goes beyond just meeting all of the performance metrics; it is an assessment of whether the system actually fulfills/completes a portion of the Office effort so that the Office can move on to the next priority

Section 2: Office Technology Research, Development, Demonstration, and Deployment Plan

The Bioenergy Technologies Office's research, development, demonstration and deployment (RDD&D) efforts are organized around three key technical and three key cross-cutting elements (Figure 2-1). The first two technical elements—Feedstock Supply R&D and Conversion R&D—primarily focus on research and development. The third technical area—Demonstration and Deployment—focuses on Integrated Biorefineries and Distribution Infrastructure. The cross-cutting elements—sustainability, strategic analysis, and strategic communications—focus on addressing barriers that could impede adoption of biomass technologies. This organization of the work allows the Office to allocate resources for pre-commercial technology development, as well as for demonstration and deployment of technologies across the biomass-to-bioenergy supply chain.

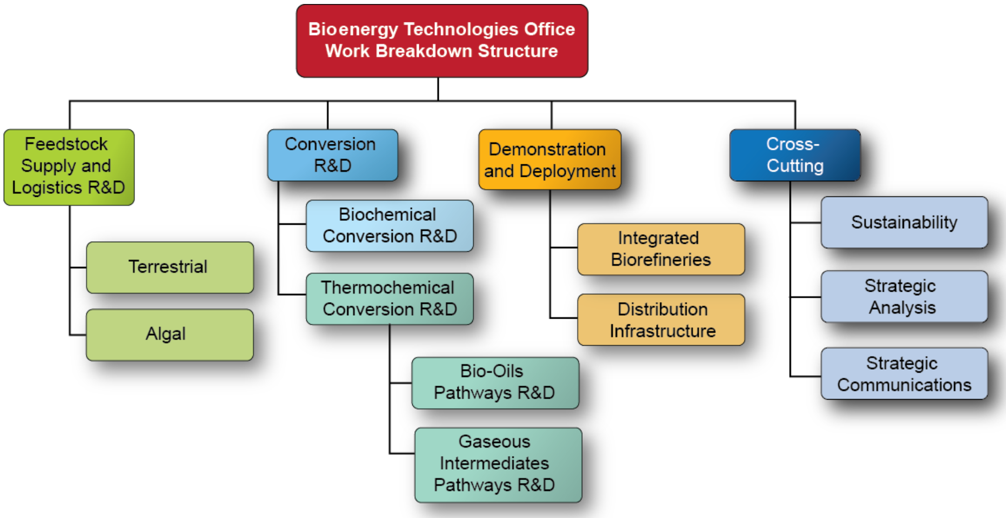

Figure 2-1: Bioenergy Technologies Office Work Breakdown Structure (Technical Elements Only)

Office Work Breakdown Structure

Research and Development (R&D)

The R&D activities sponsored by the Office are focused on addressing technical barriers, providing engineering solutions, and developing the scientific and engineering underpinnings of a bioenergy industry. Near- to mid-term applied R&D is focused on moving current feedstock and conversion technologies from concept to bench to integrated pilot scale. The goal of longer-term R&D is to develop basic knowledge of biomass, biological systems, and biochemical and thermochemical conversion processes. This knowledge can ultimately be used to develop new or improved technologies that increase conversion efficiency and/or reduce conversion cost. Bioenergy Technologies Office-funded R&D is performed by national laboratories, industry, and universities.

The Office R&D includes two technical elements:

- **Feedstock Supply and Logistics R&D** is focused on developing sustainable technologies to provide a reliable, affordable, and sustainable biomass supply to enable a nascent and growing bioenergy industry. This R&D is focused on two areas— terrestrial and algal feedstocks. R&D for development and production of terrestrial biomass feedstocks is led by the U.S. Department of Agriculture (USDA) in partnership with the Department of Energy (DOE) and other federal agencies, and coordinated through the Biomass R&D Board established by EPAct 2005. The DOE Bioenergy Technologies Office's primary focus in this area is on feedstock resource assessment and feedstock logistics (i.e., harvesting, storage, preprocessing, and transportation). R&D for the algal feedstocks area is led by DOE and includes resource assessment, strain improvement, efficient cultivation systems, harvest/dewatering, and feedstocks preprocessing (i.e., intermediate production and stabilization). (For details, see Section 2.1.)

- **Conversion R&D** is focused on developing commercially viable technologies to convert terrestrial and algal feedstocks into liquid fuels, as well as bioproducts and biopower. Biochemical Conversion R&D efforts focus on pathways producing sugars, other carbohydrate intermediates, and lignins from biomass and converting those intermediates into fuels, chemical intermediates, or products. Thermochemical Conversion R&D is focused on pathways producing vapor, oil, and gaseous intermediates from biomass and converting these intermediates into fuels, chemical intermediates, products, and/or power. (For details, see Section 2.2.)

Technology Demonstration and Deployment

The Bioenergy Technologies Office's demonstration and deployment activities focus on integrated biorefinery (IBR) applications and biofuel distribution infrastructure and end use. IBR activities address problems encountered in the so-called "Valley of Death" between pilot-scale and commercial-scale deployment.

For biofuels, the goal of demonstration and deployment activities is to develop emerging conversion technologies beyond bench scale to pre-commercial demonstration scale, culminating in the construction of pioneer biofuels production plants by industry. The Office is also working with other federal agencies to facilitate the introduction and expansion of biofuels distribution infrastructure and biofuels-compatible vehicles across the United States into the marketplace. These demonstration and deployment efforts directly align with the biomass-to-bioenergy supply chain, as illustrated in Figure 2-2.

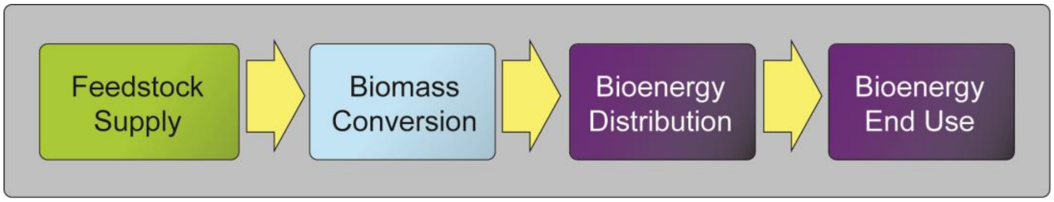

Figure 2-2: Scope of Office's Demonstration and Deployment Efforts

The ultimate technology demonstration and deployment goal is to develop the supporting infrastructure needed to enable a fully developed, operational, and sustainable biomass-to-bioenergy value chain in the United States. Demonstration and deployment is conducted via Office partnerships with industry and other key stakeholders and includes two technical elements:

- **Integrated Biorefinery** activities focus on demonstration and deployment of integrated conversion processes at a scale sufficient to demonstrate and validate commercially acceptable cost and performance targets. These efforts are industry-led, cost-shared, competitively awarded projects. Intellectual property and geographic and market factors will determine the feedstock and conversion technology options that industry will choose to demonstrate and commercialize. Government cost share of biorefinery development is essential due to the high technical and financial risk. The Office will fund a number of pilot-scale, demonstration-scale, and commercial-scale biofuel production facilities over the next five years (see Section 2.3.1).

- **Biofuels Distribution Infrastructure and End Use** activities focus on coordinating with other federal agencies to develop the required biofuels distribution and end use infrastructure. These activities include evaluating the performance, material compatibility, and environmental, health, and safety impacts of advanced biofuels and biofuel blends (see Section 2.3.2).

Cross-Cutting Activities

- **Sustainability** activities focus on developing the resources, technologies, and systems needed to grow a biomass energy industry in a way that protects our environment. While petroleum displacement is at the core of the Office's mission, improving long-term sustainability is increasingly important. The existing and emerging bioenergy industry, which includes such diverse sectors as agriculture, waste management, and automobile manufacturing, will need to invest in systems based on economic viability and market needs, while also addressing the more overarching concerns such as food security and environmental sustainability. To that end, the Bioenergy Technologies Office is working to articulate the challenges related to sustainable bioenergy production and partnering with other agencies to address these challenges through basic and applied research and analysis (see Section 2.4).

- **Strategic Analysis** includes a broad spectrum of cross-cutting analyses to support programmatic decision making, demonstrate progress toward goals, and direct research activities. Programmatic analysis helps frame the overall Office goals and priorities and covers issues that impact all technology areas, such as life-cycle assessment of GHG emissions from bioenergy. Technical area analysis helps to monitor Office accomplishments in each technology area. Continued public/private partnerships with the biomass scientific community and multi-lab coordination efforts will help ensure that the analysis results from the Office are transparent, transferable, and comparable (see Section 2.5).

- **Strategic Communications** focuses on identifying and addressing non-technical and market barriers to bioenergy adoption and utilization in an effort to reach full-scale market penetration. It fosters awareness and acceptance by engaging a range of stakeholders in meaningful collaborations, promoting Office accomplishments, and increasing consumer acceptance. Strategic Communications activities include distributing information to stakeholders and conveying key Office goals, priorities, activities, and accomplishments (see Section 2.6).

The Office's Biorefinery Pathways Framework

The biorefinery pathways framework integrates efforts among the technical elements and aligns with the major bioenergy industry market segments. Figure 2-2 shows the relationship between Office elements. Figure 2-3 shows the relationships between the biorefinery pathways currently supported by the Office in terms of feedstocks, conversion processes, and products. The Bioenergy Technologies Office's pathways framework highlights the Office's current priority feedstock pathways to biofuel production—Agricultural Residue Processing, Energy Crops, Forest Resources, Waste, and Algae pathways—as well as its current priority technology pathways to biofuel production—biochemical conversion, direct liquefaction, and indirect liquefaction.

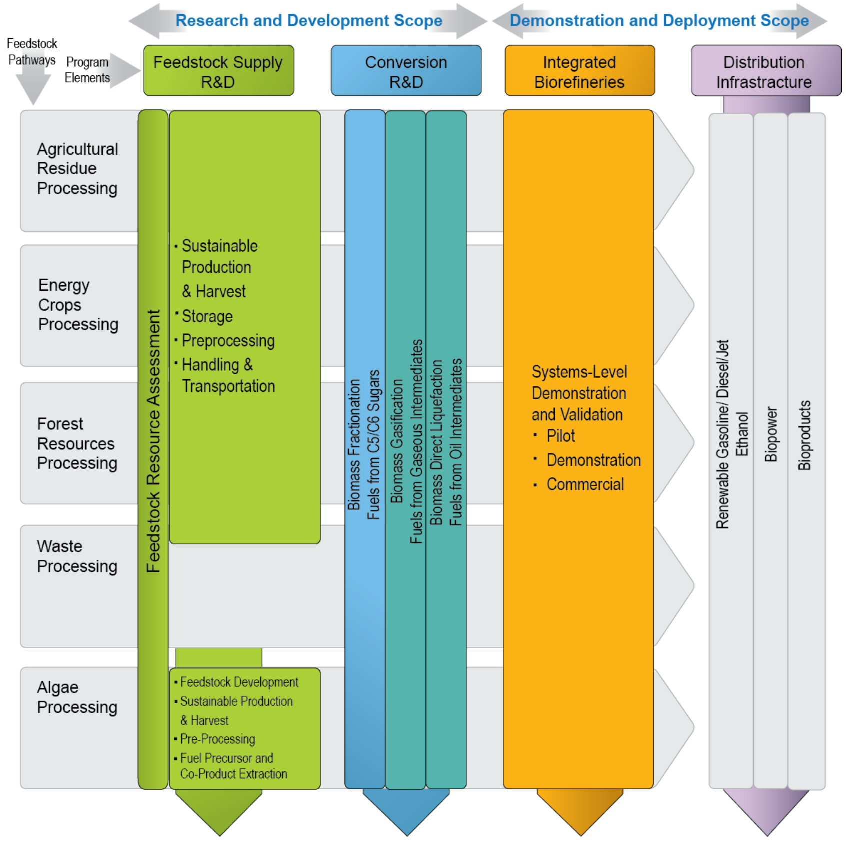

Figure 2-3: Office Technical Element Links to Biorefinery Pathway Framework

The Office uses the biorefinery pathway framework to identify priorities and balance the RDD&D activities that are expected to have the greatest impact on achieving Office goals. Figure 2-3 shows the Office integration of R&D and demonstration and deployment of integrated biorefineries that will use the broad range of biomass feedstocks and leverage the know-how, capabilities, and infrastructure of the existing bioenergy industry.

Premises for Office's Biorefinery Pathway Framework

The Office biorefinery pathway framework has developed over time to support the following needs:

- Recognize the diversity of feedstocks and the need to address substrate-specific issues from production through conversion

- Highlight the need for integration between the feedstock production, feedstock logistics, and conversion elements in the biomass supply chain
- Identify the complete set of technologies required, up to and including those in the biorefinery, as well as the connections or interfaces between the individual technology parts, especially those from fundamentally different technical areas or disciplines
- Clarify how new technologies could fit into the existing bioenergy industry market segments (e.g., corn ethanol, pulp, and paper mills)
- Identify current and future synergies within existing bioenergy industry market segments
- Envision the transition from today's bioenergy industry to the future.

The biorefinery pathways were charted in a manner so that they would relate to specific portions of the resource base identified in the *Billion-Ton Study*[1] and the *Billion-Ton Update*[2] and either:

(1) Represent existing segments of today's bioindustry, where possible; and/or
(2) Accommodate potential major future bioindustry market segments where envisioned.

Additionally, the pathways were designed keeping the following factors in mind:

- Specific enough to enable
  - – Creation of detailed RDD&D plans by giving technical context to performance metrics and cost targets
  - – Tracking of technological status and progress toward commercialization
- Flexible enough to be able to include new ideas and approaches as they are identified
- Generic enough so that combinations of pathways or pathway segments could be used to describe biorefineries
- Detailed enough with multiple levels of detail so that information could be rolled up or disaggregated depending on the need.

Pathway Links to the Biomass Resource Base

Linking the biorefinery pathways to a biomass resource base bounds the total bioenergy potential from each source and helps to clearly identify and prioritize the necessary R&D associated with feedstock production and logistics. The resource base also guides prioritization so that the Office can focus on the feedstocks with the greatest impact on its goals.

The *Billion-Ton Update* describes the potential terrestrial biomass supply that could be generated from U.S. agricultural and non-federal forestlands, as well as secondary and tertiary residues. The majority of the types of biomass resources described in the study are included as feedstocks to one of the pathways shown in Figure 2-4. This figure shows categories of feedstocks that led to pathway definitions. However, there are some portions of the biomass resource base, such as animal manures, that do not currently have corresponding pathways defined in detail. These portions do not currently represent a significant segment of the overall Office investment and are covered by other federal efforts (most notably USDA and EPA). Biomass from non-terrestrial

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[1] Robert Perlack, Lynn Wright, et al, "Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," DOE/USDA, DOE/GO-102005-2135 (2005), http://feedstockreview.ornl.gov/pdf/billion_ton_vision.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.

sources—such as algae—were also not included in the *Billion-Ton Update*. Efforts to define this potential biomass resource base are ongoing.

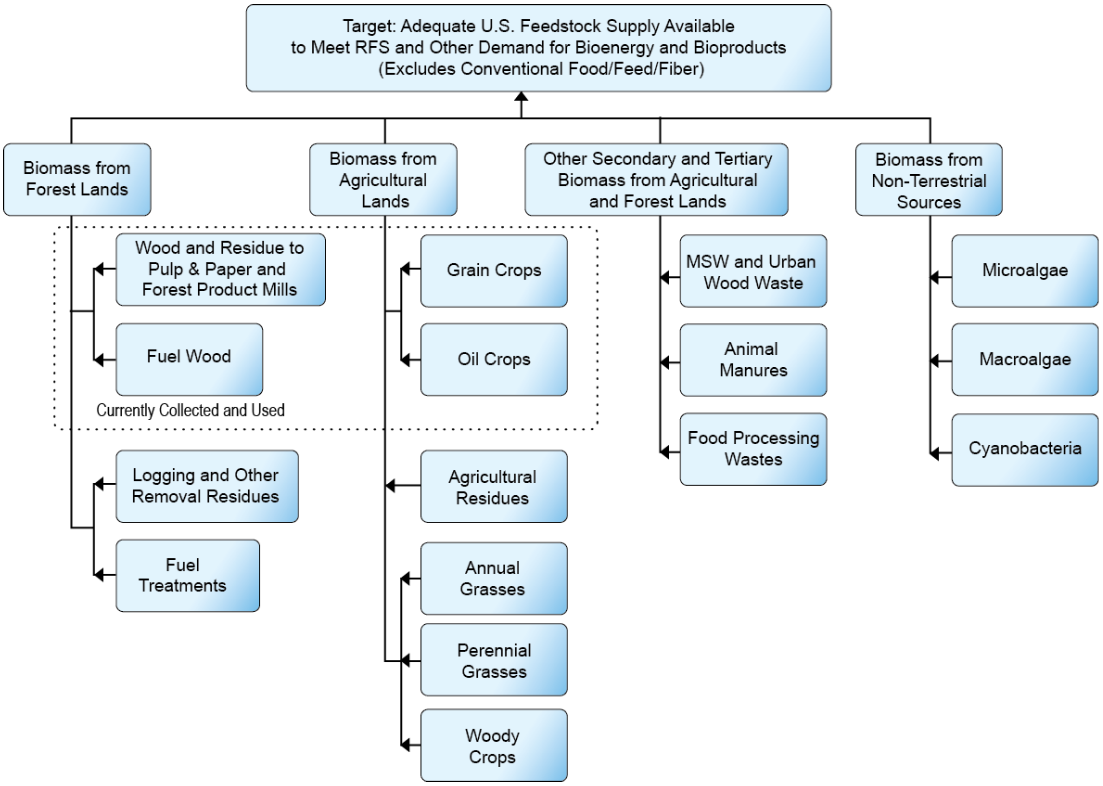

Figure 2-4: Biomass Resource Categories

Pathway Links to Bioenergy Industry Market Segments – Current and Future

The existing bioenergy industry provides opportunities for public/private partnerships to integrate and demonstrate new conversion technologies in existing commercial plants where the feedstock and infrastructure exist that could support a build out of additional capacity (e.g., corn wet and dry grind mills, pulp and paper mills). These biorefinery pathways provide nearer-term opportunities to help address Office goals. Efforts along these pathways serve a twofold purpose. The first benefit is the acceleration of technology deployment since the use of existing infrastructure with a readily available, captive, and low-cost feedstock lowers both the capital and operating cost, as well as associated risk. The second benefit is a reduction in the time it takes to build stand-alone plants. Integrating new technology into existing plants improves yield, efficiency, and profitability of the existing operation, while increasing the likelihood of obtaining commercial financing to enable the expansion of the domestic biofuels industry.

Agricultural residue, forest resources, energy crop, and algae pathways require significant R&D in the areas of feedstock production, feedstock logistics, and conversion technologies. While development time is longer for these options, their potential impact on displacing imported petroleum by producing biofuels is significantly larger.

Office Element Discussion

The remainder of Section 2 details plans for each Office element:

Feedstock Supply....................................Section 2.1
Conversion..Section 2.2
Demonstration and Deployment ....Section 2.3
Sustainability ....Section 2.4
Strategic Analysis ....Section 2.5
Strategic Communications.......................Section 2.6

Each element discussion is organized as follows:

- Brief overview of the element process concept and its interfaces with other elements of the Office (in the context of the biomass-to-bioenergy supply chain)
- Element strategic goal, as derived from the Office strategic goals
- Element performance goals, as derived from the Office performance goals
- Technical and market challenges and barriers
- Strategies for overcoming barriers, the basis for element work breakdown structures (tasks and activities with links to barriers)
- Prioritization, milestones, and timelines.

2.1 Feedstock Supply and Logistics Research and Development

Future growth of the U.S. bioenergy industry will depend on the cost, quality, and quantity of biomass available to biorefineries. As the starting material for biomass-to-biofuels, bioproducts, and biopower value chains, a sufficient and secure supply of affordable, high-quality feedstocks is a critical step in accomplishing Office goals and enabling a biomass conversion industry. Therefore, Feedstock Supply and Logistics R&D relates directly to, and strongly influences, all of the downstream elements of the Office's portfolio and their respective goals and objectives.

Feedstock Supply and Logistics R&D includes two broad types of feedstocks: terrestrial feedstocks (i.e., agricultural residues, forest resources, and dedicated energy crops); and algal feedstocks. It encompasses three primary research areas: sustainable feedstock production (which includes resource assessment); feedstock logistics; and algae and advanced feedstocks. All of the activities in these areas are directed at reducing the delivered cost of feedstock, improving and preserving the quality of harvested feedstock, and/or expanding the volume of feedstock materials accessible to the bioenergy industry.

The Office anticipates that the USDA will lead the federal government's lignocellulosic feedstock production efforts, in accordance with the February 3, 2010, White House release of "Growing America's Fuel."[3] The Office will work with USDA to align and leverage progress made by USDA and others into the Office's strategy for supporting the development of a robust and sustainable bioenergy industry in the United States. The Office also anticipates playing a leading role in the federal government's algae feedstock development and production efforts.

New strain development and optimization of culture conditions are key activities in the algae feedstock production area. Algae production systems cover the entire variety of alternatives, including open-ponds, closed photobioreactors, attached growth systems, and macroalgae cultivation systems. Algal feedstock logistics technologies include neutral lipid extraction, hydrothermal liquefaction of whole algal biomass, and innovative pathways that circumvent current dewatering paradigms via extracellular secretion. Heterotrophic algal fermentations strategies are discussed in the Biochemical Conversion R&D section of the MYPP (Section 2.2.1).

The Office coordinates with DOE's Office of Science (SC) on advanced feedstock development R&D via the Joint Genome Institute under the Genomes-to-Life Program; the SC and USDA's National Institute on Food and Agriculture (NIFA) annual solicitation on feedstock genomics; the SC Bioenergy Research Centers; the SC Energy Frontier Science Centers; the USDA-Agricultural and Food Research Institute's Regional Bioenergy Coordinated Agricultural Program (CAP); the USDA-Agricultural Research Services' Bioenergy Program (National Program #213) with its regional Biomass Research Centers and the Bioenergy & Energy Alternatives Program (National Program #307); and DOE and NIFA's annual joint solicitation under the Biomass Research and Development Initiative.

Terrestrial Feedstocks Supply System

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[3] For more information, see http://www.whitehouse.gov/sites/default/files/rss_viewer/growing_americas_fuels.pdf.

The conceptual flow diagram shown in Figure 2-5 outlines the main elements of the terrestrial feedstock supply system. Process details are available in the most recent roadmap document.[4]

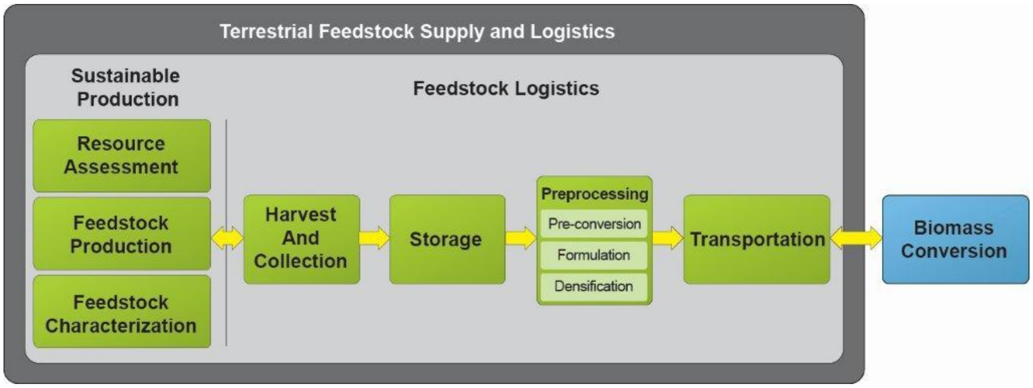

Figure 2-5: Feedstocks Supply Flow Diagram

Sustainable Production: Sustainable production R&D activities are focused on getting affordable, abundant, and high-quality biomass materials into the feedstock supply chain. There are three primary activities associated with sustainable production.

- **Resource Assessment:** Bioenergy Technologies Office feedstock resource assessment activities include compiling current and future projections of the geographic location, price, quality, and environmental sustainability of accessing existing and potential future feedstock resources. Resource assessment activities provide critical data layers for establishing and measuring progress toward Office goals.[5]

- **Feedstock Production:** Feedstock production addresses all the steps required to sustainably produce terrestrial biomass feedstocks to the point when they are ready to be collected or harvested.

- **Feedstock Characterization:** Biomass quality is a critical aspect of a biomass-to-biofuels supply chain. The physical properties of biomass directly influence efficiency of transport systems, as well as the ease with which it can be conveyed into the conversion process reactor throat. Biomass chemical composition relates directly to potential product yield in a conversion process. Other properties of biomass can influence actual process yield and kinetics as well. The Office's feedstock characterization activity is developing analytical methods to measure biomass quality characteristics for a variety of crops. The Biomass R&D Library has also been created and will be maintained to provide critical biomass quality data and physical samples to the emerging industry and broader research community.

Feedstocks Logistics: Feedstock logistics refers to the supply chain operations that must take place after the feedstock is produced, but before the biomass is converted into fuels, products, or

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[4] Janet Cushman, James Easterly, J. Richard Hess, et al, "Roadmap for Agricultural Biomass Feedstock Supply in the United States," Idaho National Laboratory, DOE/NE-ID-11129 (2003), http://www.inl.gov/technicalpublications/Documents/3323197.pdf.

[5] Perlack, Stokes, et al, "U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.

power. Activities in this area are primarily focused on how to most efficiently and cheaply harvest and transport high-quality biomass from a variety of crops to biorefinery end users. These unit operations include feedstock harvest and collection, storage, handling, preprocessing, and transportation to the biorefinery.

> **Harvest and Collection:** Harvesting operations represent the interface between feedstock production and biomass conversion processes, and therefore serve a critical role in maximizing the entry of high-quality biomass resources into the bioenergy system, while simultaneously ensuring the sustainability of the production system. Cost-effective, sustainable biomass harvest and collection operations gather high-quality biomass from the field or forest. Harvest timing can be impacted by the growing season of a primary crop (e.g., grain) and/or weather conditions that may constrain the harvest window. Harvest timing and strategy may also affect composition and structural features of herbaceous and woody feedstocks.
>
> **Storage:** Seasonally available herbaceous and woody feedstocks must be cost-effectively and sustainably stockpiled and held at optimal moisture content to maintain quality characteristics over time, while minimizing degradation and physical loss of material, to provide a reliable year-round biomass resource to biorefineries. Inventory management procedures that monitor important quality attributes of the variety of feedstocks anticipated will facilitate the practicality of longer storage times and help to maintain superior downstream processing performance characteristics.
>
> **Handling:** Cost-effective handling of biomass feedstocks on an industrial scale requires high-volume, high through-put systems, which can be challenged by the low density, non-uniform physical and chemical characteristics of raw biomass feedstocks. Highly efficient, large volume handling systems currently exist for a variety of solid, liquid, and gaseous materials. Converting raw biomass into infrastructure compatible materials within the logistics system can leverage the existing handling infrastructure and help to reduce feedstock cost.
>
> **Preprocessing:** Preprocessing turns raw biomass into stable, standardized, flowable solid or liquid feedstocks with characteristics similar to grains, flours, and slurried or liquid materials. Preprocessed feedstocks will be more efficiently delivered to an end user if they are compatible with existing (or emerging) handling, transportation, and storage infrastructure. Preprocessing treatments are designed to upgrade biomass for longer-term storability, durability, and performance in handling, efficient transport and conversion operations. Preprocessing treatments also convert raw biomass into more consistent feedstocks that routinely achieve reliable performance in conversion processes. Preprocessing steps include preconversion, formulation, and densification. Any or all of these steps could potentially occur at any point in the supply chain, from harvesting to insertion into the conversion reactor.

- *Preconversion* includes mechanical, thermal, and chemical processes that upgrade the physical and/or chemical characteristics of harvested biomass*:*
    - Mechanical preconversion includes size reduction and fractional deconstruction utilizing a variety of existing milling and separations

    technologies to selectively format raw biomass to achieve desired physical and/or chemical characteristics.
    - Thermal preconversion technologies, such as drying, deep drying, and torrefaction, increase material stability in storage through moisture content reduction, which increases the energy density of the material and may also improve biomass performance throughout the value chain.
    - Chemical preconversion technologies, such as leaching or washing, ammonia treatment, and dilute-acid treatment, upgrade biomass quality by reducing ash content and/or recalcitrance to cell wall deconstruction in downstream operations.
- *Formulation:* Feedstock quality and performance in handling and conversion operations can be upgraded by combining biomass types with different chemical and physical characteristics. Blending and aggregation are examples of formulation processes. Formulation strategies can mitigate inherent variability in raw biomass characteristics, producing feedstocks that dampen wide performance variations in biomass handling operations and in conversion process yield and/or kinetics. Therefore, formulation strategies can create opportunities for additional biomass resources to enter the supply chain.
- *Densification:* Densification processes increase the bulk and energy density of raw biomass, impart longer-term stability to biomass feedstocks relative to raw biomass through an intrinsic ability to exclude water and create feedstocks that are compatible with existing solids and liquids handling infrastructures. Size reduction, compaction, extrusion, forging, agglomeration, and thermal treatments are examples of processes that produce dense, solid feedstocks. In addition, pyrolysis is a thermochemical process that produces an energy densified feedstock in liquid form. The liquid state of the feedstock enables alternative storage, handling and transport strategies. More details about pyrolysis pathways can be found in Section 2.2.

Transportation: Biomass may be transported between field or forest and conversion facility by truck, train, or barge using existing transportation infrastructure. Optimization of container volumes and dimensions designed for moving biomass feedstocks that simultaneously reach both weight and volume limits would increase efficiencies in the feedstock supply chain and therefore decrease delivered feedstock cost. Existing transportation infrastructure demonstrates these efficiencies, and preprocessing raw biomass to feedstocks with infrastructure compatible material characteristics can leverage key components of the existing infrastructure.

The cost, quality, and volume of biomass feedstocks required by the emerging biorefining industry will be addressed through transition from conventional agriculture and forestry biomass supply systems to more advanced, purpose-designed systems in the 2013 to 2017 timeframe.[6] Conventional supply systems address critical logistics challenges, such as efficiency/capacity of equipment, dry matter losses, and the operational window for gathering material. Conventional systems, however, are limited in their ability to preserve or upgrade feedstock quality, and to

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[6] J. Richard Hess, Christopher Wright, et al. "Uniform-Format Solid Feedstock Supply System: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass," Idaho National Laboratory, INL/EXT-08-14752 (2009), www.inl.gov/bioenergy/uniform-feedstock.

access diverse and distributed resources across the nation. The introduction of advanced preprocessing operations within conventional supply systems will be required to meet 2017 Office goals. Specific R&D focus will be given to blending and formulation operations that will be critical to achieving feedstock cost, quality, and volume targets in support of Office goals.

R&D efforts will also continue to develop advanced, infrastructure compatible feedstocks that provide a commodity-based, specification-driven system. This system, called the Advanced Uniform-Format feedstock supply system, resembles the grain commodity system, which serves as a model for biomass quality and performance in the supply chain, as well as a variety of conversion processes. This allows subsequent supply system infrastructure to be similar for a broad range of biomass resources, while enabling biomass commodities to have predictable physical and chemical characteristics, to be storable over fairly long periods of time, to be transportable over relatively long distances, and to enable many end uses.

Algae Feedstocks Supply Systems

Establishing a conceptual model that encompasses the many algae biofuel pathways under development requires granularity that is not compatible with establishing a design basis that can be used in detailed systems engineering-based cost projections. The conceptual model presented here encompasses many, but not all, possible algae systems and is particularly well suited for expounding on the design basis pathway used in establishing the cost projections presented later in this section. The intent in presenting this conceptual model is not to limit the field, but to establish a common baseline and set the groundwork for considering alternative and innovative models. The conceptual flow diagram in Figure 2-6 outlines main elements of a generalized algae feedstock supply system. A range of alternative processes are discussed in the *National Algal Biofuels Technology Roadmap.*[7]

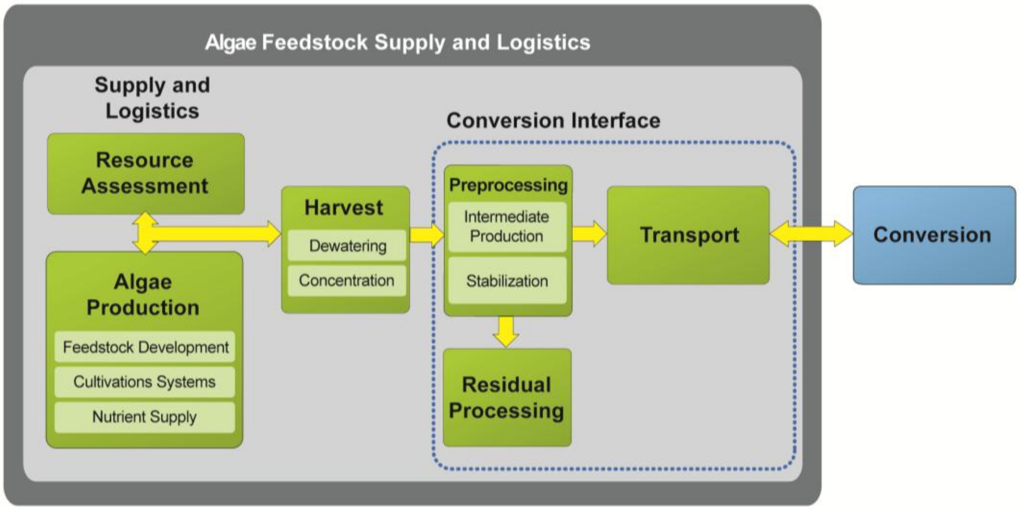

Figure 2-6: Algae Feedstock Supply Flow Diagram

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[7] U.S. Department of Energy, *National Algal Biofuels Technology Roadmap* (2010), Washington: Government Printing Office, http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf.

Supply and Logistics: Supply includes resource assessment and feedstock production. Feedstock logistics primarily includes the harvest steps of dewatering and concentration.

> **Resource Assessment:** Bioenergy Technologies Office algal feedstock resource assessment activities include identification of the geographic location, price, and environmental sustainability of accessing existing and potential future feedstock resource, as well as projecting future supply availability and prices. Algal feedstock resources include sufficient solar isolation, available non-arable land, non-potable water, waste nutrient streams, waste $C0_2$, and supporting transport infrastructure to access downstream conversion processing.
>
> **Feedstock Production:** Production of algal feedstock refers to the cultivation of both micro and macro alga, as well as cyanobacteria. Cultivation strategies rely on strain prospecting and isolation to identify types of algae with desirable growth properties; biological improvement such as breeding, modification, and genetic engineering; cultivation strategies such as crop protection, water and nutrient management, light optimization, temperature management, and seasonal succession; and cultivation infrastructure engineering to maximize biomass yields while minimizing land, capital, and operating costs. Examples of algae cultivation systems include, but are not limited to, open mixed ponds, attached growth systems, and closed photobioreactors. Cultivation systems must optimize light supply, materials cost, and operability while maximizing productivity. Nutrient supply encompasses feeding of both micro and macro nutrients as well as CO_2 and recycled harvest water.
>
> **Harvest:** Harvesting operations are the interface with feedstock production and have a critical role in maximizing biomass resources entering the bioenergy system while ensuring sustainability of the production system. Harvest operations may be continuous or take place daily/weekly. Harvest timing throughout the growth cycle may affect composition and structural features of algal feedstocks. To minimize water consumption, water must be recycled to the cultivation system after harvest. Macroalgae and attached growth systems that cultivate multi-cellular algae do not require the same dewatering intensity.
>
> - *Dewatering*: Microalgae and cyanobacteria cultivated in water grow at low concentrations. Dewatering technology exists in waste water treatment and the mining industry to isolate solids from high-volume, low-concentration effluents, but these existing technologies can be too energy, capital, and reagent use intensive for use in algal biofuels .
> - *Concentration*: Dewatered algal biomass may still be too dilute for effective preprocessing. Concentration technology is needed to boost algal biomass slurry concentration to at least 15%–20% solids to be efficiently preprocessed; the final target will be dictated by the preprocessing interface. Centrifugation is typically used for concentrations, but as in dewatering, innovative adaptations, and new technologies are needed to cut energy and capital costs.

Conversion Interface: Conversion Interface steps include the preprocessing required to produce clean, energy-dense, stable, and transportable feedstock suitable for further refining as well as transportation and residual processing.

Preprocessing: Algae preprocessing refers to technologies for the on-farm production of transportable intermediate products from the harvested algal biomass. Preprocessed algal biofuel intermediates should be energy dense and compatible with existing handling, transporting, and storage infrastructure. Preprocessing may improve the algal biomass for longer-term storability, handling, and transport, as well as prepare the raw material for efficient conversion. In this conceptual model, algal preprocessing steps include:

- *Intermediate Production*: Intermediate production is defined as the deconstruction and/or processing of algal biomass into products such as, but not limited to, extracted lipids and lipid extracted biomass, or hydrothermally liquefied biomass. Maximizing throughput and efficiency while producing both energy-dense biofuel intermediates and useful remaining biomass are key objectives for intermediate production technology. Technologies may involve drying and pressing, homogenization and solvent extraction, thermal "pre-conversion" processes, or other technologies. Regardless of which technology, the interface between feedstock characterization and downstream product requirements will play a role in determining appropriate intermediate production technology, e.g., a biofuel process requiring neutral lipids will need an intermediate stream of polar solvent extracted lipids. More details on liquefaction pathways are available in Section 2.2.2.
- *Stabilization*: The stability of intermediate products is an important consideration, particularly in this conceptual model, where the biofuel intermediate is transported offsite to a refinery for further upgrading.

Transportation: Algal biofuel intermediate products may be transported using existing transportation infrastructure.

Residual Processing: Residual processing can provide valuable nutrient and power recycling back to cultivation systems. Components of algae biomass not sent for conversion to biofuel or recycled can be converted to valuable co-product streams.

The conceptual model of the algae feedstock supply system is based on literature, bench, and development unit efforts undertaken since 2009. Uniform specifications are not established and will require a harmonized approach to integrating resource assessment, life-cycle analysis, techno-economics, and close coordination with the conversion interface.

2.1.1 Feedstock Support of Office Strategic Goals

The Bioenergy Technologies Office's overarching strategic goal is to *develop commercially viable biomass utilization technologies to enable the sustainable, nationwide production of advanced biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry supporting the EISA goal of 36 bgy of renewable transportation fuels by 2022.*

Large volumes of biomass feedstocks are essential to achieving Office goals. The cost, quality, and quantity of feedstock available at any given time will therefore determine the maximum amount of biofuels that can be produced economically. The Feedstock Supply and Logistics strategic goal is to *develop sustainable technologies to provide a secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry, in partnership with USDA and other key stakeholders.* The ultimate outcome (2030 and beyond) of Feedstock Supply and Logistics R&D is technology and methods that can supply over 1 billion tons per year of biomass feedstocks in a sustainable and cost-effective manner.

Feedstock Supply and Logistics R&D directly addresses and supports assessment, production, harvesting, storage, preprocessing, and delivery of feedstocks for the Agricultural Residues, Energy Crops, Forest Resources, and Algae-based conversion pathways.

2.1.2 Feedstock Support of Office Performance Goals

2.1.2.1 Terrestrial Feedstocks Performance Goals & milestones

Feedstock Supply and Logistics R&D currently has two performance goals.

- The feedstock resource assessment goal is to establish geographic, economic, quality, and environmental criteria under which 155 million dry tons (DT) per year would be feasible by 2017.[8]
- The feedstock logistics goal is to develop and demonstrate feedstock supply and logistics systems that can deliver feedstock to the conversion reactor throat at required conversion specifications at or below $80/DT ($2011) by 2017. Cost-saving and process-improving technologies will be developed within each stage of the feedstock supply chain in order to achieve this goal.

The specific **resource assessment milestones** under investigation are:

- By 2013, identify environmental criteria (soil health and air quality) and establish a methodology for incorporation into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways.
- By 2014, integrate environmental and feedstock quality criteria into biomass supply assessments for agricultural residues, energy crops, and forest resources pathways.
- By 2016, produce a fully integrated assessment of potentially available feedstock supplies under specified criteria and conditions.

The specific **feedstock logistics milestones** under investigation are:

- By 2013, deliver feedstock supply and logistics design cases achieving the 2017 goal of delivering feedstock to the conversion reactor throat at required specifications at or below $80/DT ($2011).
- By 2015, evaluate advanced herbaceous and woody biomass preprocessing systems against conversion performance criteria.
- By 2017, validate a fully integrated advanced feedstock logistics system that accepts a broad range of herbaceous and woody biomass resources at field scale.

2.1.2.2 Algae Feedstocks Performance Goals and Milestones

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[8] Table B-1 in Appendix B.

Feedstocks Supply and Logistics algae feedstocks performance goals are based on an open-pond, neutral lipid extraction followed by offsite hydrotreating to renewable diesel, as is described in detail in a recent technical report.[9] The harmonized model underlying the design basis is an integration of three individual models on resource assessment,[10] techno-economics,[11] and life-cycle analysis[12] developed and published prior to the convening of the Harmonization Workshop that brought the model developers together with external principal investigators and stakeholders to refine assumptions and parameters for a conservative integrated baseline. Alternative designs continue to be evaluated and will be incorporated into the Office's strategic plans.

The performance goal for algal resource assessment is:

- By 2013 (Q4), establish feedstock resource assessment models with geographic, economic, quality, and environmental criteria under which sustainable algal resource supply can be identified to support cultivation of 1 million metric tons ash free dry weight algae biomass by 2017 and 20 million metric tons ash free dry weight (AFDW) by 2022.

The feedstock supply and logistics performance goal is to increase the projected productivity of large-scale algae cultivation and preprocessing while maximizing efficiency of water, land, nutrient, and power use to supply a stable biofuel intermediate for conversion to advanced biofuels.

- By 2022, validate the potential for algae supply and logistics systems to produce 5,200 gallons oil (or equivalent biofuel intermediate) per acre of cultivation per year, achieving a modeled nth plant minimum selling price of $3.27/GGE ($2011) of raw biofuel intermediate.

The above goal and the technical parameters used in the 2022 projection are illustrated in Appendix B, Table B-4. The $3.27/gallon feedstock price corresponds to a projected $3.73/GGE ($2011) of renewable diesel minimum fuel selling price.

Performance milestones for algae feedstocks supply and logistics are:

- By 2013 (Q4), establish cost goals and technical targets for one alternate algal system and complete techno-economic analysis for one additional algal-production-to-finished-fuel technology pathway, including feasibility and trade-off analysis with higher value coproducts.
- By 2014 (Q4), demonstrate at a non-integrated process development unit scale, algal productivity of 20 grams per square meter per day ash-free dry weight (AFDW)

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[9] Ryan Davis, Daniel Fishman, Edward Frank, et al, "Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model," Argonne National Laboratory, ANL/ESDA/12-4 (2012), http://greet.es.anl.gov/publication-algae-harmonization-2012.

[10] Mark Wigmosta, Andre Coleman, Richard Skaggs, et al, "National Microalgae Biofuel Production Potential and Resource Demand." *Water Resources Research* 47 (2011).

[11] Ryan Davis, et al, "Techno-Economic Analysis of Autotrophic Microalgae for Fuel Production," *Applied Energy* 88 (2011): 3524-3531.

[12] Edward Frank, Jeongwoo Han, et al, "Methane and Nitrous Oxide Emissions Affect the Life-Cycle Analysis of Algal Biofuels," *Environmental Research Letters* 7 (2012).

(corresponding to 1,500 gallons of processed oil or equivalent biofuel intermediate per acre per year).

- By 2018 (Q4), demonstrate at non-integrated process development unit scale, an open cultivation system design without use of traditional plastic liners and with integrated nutrient and water recycling that demonstrates algal productivity of 25 g per square meter per day AFDW (corresponding to 2,500 gallons processed oil or equivalent biofuel intermediate per acre per year).
- By 2018 (Q4), validate an algal feedstock logistics system that can efficiently process more than 800 gallons of harvested algae per minute.
- By 2022 (Q4), validate algal productivity of greater than 5,200 gallons biofuel intermediate per acre per year.

2.1.3 Feedstock Technical Challenges and Barriers

Feedstock Supply Technical Barriers

Ft-A. Feedstock Availability and Cost: The lack of credible data on price, location, environmental sustainability, quality, and quantity of available biomass feedstocks creates uncertainty for investors and developers of emerging biorefinery technologies. Estimates of current and potential feedstock resources are limited in scope and do not consider how major advances in production technologies and supply chain strategies will impact future biomass availability, cost, and quality. Established feedstock production history is required to assure investors/funding sources that the feedstock supply risk is sufficiently low. Reliable, consistent feedstock supply is needed to reduce financial, technical, and operational risk to a biorefinery and its financial partners.

Ft-B. Sustainable Production: Existing data on the productivity and environmental effects of energy crop production and biomass collection systems are not adequate to support life-cycle analysis of biorefinery systems. A number of sustainability questions (such as water and fertilizer inputs, establishment and harvesting impacts on soil, etc.) have not been comprehensively addressed. New production technologies for feedstock systems such as algae are also required to address cost, productivity, and sustainability issues.

Ft-C. Feedstock Genetics and Development: The productivity and robustness of algae and terrestrial feedstock crops used for biofuel production could be improved by selection, screening, breeding, and/or genetic engineering. This will require extensive ecological, genetic, and biochemical information, which is currently lacking for most algal species and the majority of non-domesticated terrestrial energy crops. Any genetically modified organisms deployed commercially will also require prior deregulation by the appropriate federal, state and local government agencies. The Bioenergy Technologies Office does not anticipate sponsoring efforts in the area of terrestrial crop variety development or development of best management practices for energy cropping systems, as this work will be pursued by USDA.

Feedstock Logistics Technical Barriers

Ft-D. Sustainable Harvesting: Current crop harvesting machinery is unable to selectively harvest preferred components of cellulosic biomass and address the soil carbon and erosion sustainability constraints. Biomass variability places high demand and functional requirements on biomass harvesting equipment. Current systems cannot meet the capacity, efficiency, or delivered price requirements of large cellulosic biorefineries, nor can they effectively cope with the exceptionally high biomass yields per acre of which potential new biomass feedstock crops are capable. Also, in the case of algal biomass, current harvesting and dewatering technologies are costly and energy- and resource-intensive.

Ft-G. Feedstock Quality and Monitoring: Physical, chemical, microbiological, and post-harvest physiological variations in feedstocks arising from differences in genetics, degree of crop maturity, geographical location, and harvest methods are not well understood. This variability presents significant cost and performance risks for bioenergy systems. Processing standards and specifications for cellulosic feedstocks are not currently developed to the same level as for existing commodities that have achieved mature commercial status. The quality characteristics of cellulosic biomass feedstocks are more variable than for grain, due to the wide genetic diversity of these undomesticated crops. Grain-fed biorefineries rely on fairly consistent feedstock composition parameters to achieve expected performance targets. A better understanding is needed of the effects of wide variability in feedstock characteristics on biorefinery operations and performance.

Ft-H. Biomass Storage Systems: Characterization and analysis of different storage methods and strategies are needed to better define storage requirements, so as to preserve harvested biomass and maintain its potential product yield over time. Storage strategies need to be understood as a function of feedstock source, biomass moisture, climate, storage method, storage time, and cost. Stored biomass that is or becomes wet is susceptible to spoilage, rotting, spontaneous combustion, and odor problems. Therefore, the impacts of these post-harvest processes must be controlled to benefit biorefining processes and ensure a consistent, high-quality feedstock supply.

Ft-J. Biomass Material Properties: Data on biomass quality and physical property characteristics in relation to conversion process performance characteristics are extremely limited. Methods and instruments for measuring physical and biomechanical properties of biomass are lacking. Information on moisture effects on quality and physical properties of biomass as affected by feedstock variability and climatic conditions is incomplete.

Ft-K. Biomass Physical State Alteration: The initial sizing and grinding of cellulosic biomass affects efficiencies and quality of all the downstream operations, yet little information exists on these operations with respect to the multiplicity of cellulosic biomass resources and biomass format requirements for biorefining. New technologies and equipment are required to process biomass between the field and conversion facilities. The harvest season for most crop-based cellulosic biomass is short, especially in northern climates, thus requiring preprocessing systems that facilitate stable biomass storage, densification, and blending to ensure year-round feedstock supply for the biorefinery.

Ft-L. Biomass Material Handling and Transportation: The capital and operating costs for the existing package-based equipment and facilities for handling cellulosic biomass are not cost-effective. The low density and fibrous nature of cellulosic biomass make it difficult and costly to collect, handle, and transport. For algal biomass, there is a need for characterization and analysis of collection, handling, and transportation systems.

Ft-M. Overall Integration and Scale-Up: Existing biomass harvesting, collection, storage, handling, and transport systems are not designed for the large-scale needs of integrated biorefineries. Feedstock logistics infrastructure has not been defined for the potential variety of locations, climates, feedstocks, storage methods, etc. Integrating time-sensitive collection, storage, and delivery operations to ensure year-round supply of large amounts of consistent, high-quality biomass feedstocks is a barrier to widespread implementation of sustainable biorefineries, due to lack of experience. Securing feedstock within these constraints is critical to reducing feedstock supply risk, therein reducing technical and operational risks of the biorefinery. The lack of understanding of the variability of biomass resources, as well as how variability affects shelf life and processing yields present additional barriers. Integration of one or more aspects of the feedstock supply system—either alone or in combination with biorefinery operations—should lead to net gains in efficiency. Further, the lack of analysis quantifying the relative benefits and drawbacks of potential integration options is a barrier to cost savings, biorefinery efficiency improvement, and reduction of technical risk. There is also significant potential for systems integration and optimization with current algal production and logistics systems. New technologies, engineering designs, and siting strategies are required to develop more efficient ways to use resources and energy in these systems for sustainable biofuels production.

Ft-N. Algal Feedstock Processing: After cultivation and harvesting of algal feedstocks, algal biomass may require processing or fractionation into lipids, carbohydrates, and/or proteins before these individual components can be converted or further processed into the desired fuel or product. Current technologies for algal fractionation and product extraction are not commercially viable, scalable, or sustainable. Options to circumvent or improve these processes exist; for example, conversion of whole algal biomass or secretion or direct production of the desired fuel or product in culture can be used, but little data exists on the cost, sustainability, and efficiency of these processes.

2.1.4 Feedstock Supply R&D Approach for Overcoming Challenges and Barriers

The R&D approach for overcoming feedstock supply challenges and barriers is outlined in its work breakdown structure (WBS) organized around five key activities, as shown in Figure 2-7. The current terrestrial feedstock supply R&D efforts are focused on: assessing current and potential sustainable biomass feedstock supplies in all U.S. counties and corresponding costs; establishing a baseline for lignocellulosic feedstock productivity and environmental sustainability across all regions of the United States; improving the capacity and efficiency of feedstock harvesting, handling, collection, preprocessing, storage, and transportation; conserving harvested biomass; and controlling stability and maintaining feedstock quality throughout the logistics system operations with conversion input specifications clearly in mind. Office funded feedstock logistics R&D activities are performed by national laboratories, universities, industry, consortia, and a variety of state and regional partners.

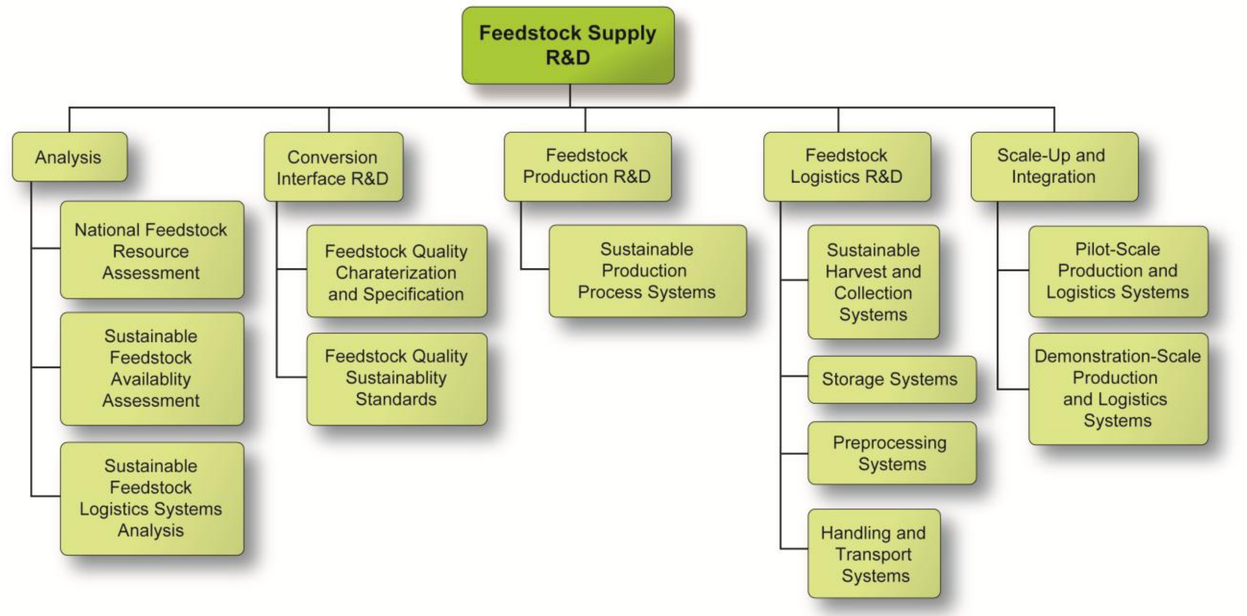

Figure 2-7: Feedstocks Supply R&D Work Breakdown Structure

The R&D approach of each WBS activity is described below, while Table 2-1 summarizes each activity's work as it relates to specific barriers and biorefinery pathways.

Analysis and Sustainability

The primary area of work within analysis and sustainability is resource assessment, which includes establishing an inventory of national feedstock resource potential and assessing environmentally sustainable feedstock availability now and in the future. A revised resource assessment[13] was released in 2011, which included updated biomass feedstock supply curves that incorporate county-level and environmental sustainability data under several technology development scenarios. These supply curves will be updated as projections of technology and underlying market conditions evolve and will be maintained in a publicly accessible Web-based Geographical Information Systems database. Analysis also includes developing design cases and state of technology (SOT) assessments for cost-effective, sustainable, and reliable delivery of cellulosic biomass resources to end-use facilities and of the production and processing of algal feedstocks. Algal resource assessments to examine algal biomass production potential are also underway.[14] Planned R&D analysis activities for algal feedstocks and processing systems include techno-economic and life-cycle analyses for multiple algal biomass production and processing scenarios.

Conversion Interface R&D

Efficient and effective linkage between feedstock supply and conversion processes is critical to facilitate the functioning of the entire value chain. The conversion interface area primarily addresses the effect of feedstock logistics operations on conversion technology performance

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[13] Perlack, Stokes, et al, "U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.
[14] Wigmosta, Coleman, Skaggs, et al, "National Microalgae Biofuel Production Potential and Resource Demand."

characteristics by correlating feedstock quality parameters with conversion performance metrics. These efforts will help to delineate conversion process input specifications such that process economic targets can be achieved. Specific activities include the collection and organization of feedstock samples gathered from the Regional Feedstock Partnership trials and other partners for characterization of chemical and physical properties, as well as conversion performance characteristics. This enables the correlation of those two data to better understand the relationships, if any, among genetic, crop production, chemical composition, and conversion performance factors. This data is shared with the feedstock producer from whom the sample was collected, as well as with conversion R&D researchers.

Feedstock Production RD&D

The primary focus of feedstock production research, development, and deployment (RD&D) is developing sustainable feedstock production processes, systems, and standards.

Office efforts to overcome feedstock production barriers and optimize lignocellulosic feedstock production regionally are implemented through the Regional Biomass Energy Feedstock Partnerships (Partnership) in conjunction with the Sun Grant Initiative, many land grant universities, the national laboratories, and USDA's Agricultural Research Service. The Partnership is dedicated to improving the assessment and sustainable production of feedstocks in each of the five Sun Grant regions. It does this by working to establish a productivity baseline for dedicated herbaceous energy crops (such as sorghum, switchgrass, energycane, and Miscanthus), short-rotation woody crops (such as hybrid poplar and willow), and agricultural residues (such as corn stover and wheat straw) through a series of multi-year replicated field trials across wide geographical ranges. Select trial sites are also collecting environmental sustainability data such as soil carbon, water use, and GHG emissions, as well as establishing biomass sample and data collection methods that facilitate coordination with USDA Research Centers and SC Research Centers.

The Bioenergy Technologies Office also directly supports R&D of algal feedstocks and issues related to the sustainable production of algae-derived biofuels with the goal of creating abundant, cost-effective, and sustainable algae biomass supplies in the United States. Algal feedstock R&D focuses on algal genetics, strain development, and algal cultivation strategies. These efforts will also factor into the economic and environmental sustainability of various routes and technologies to produce algal biofuels and bioproducts.

Feedstock Logistics RD&D

The Office's feedstock logistics RD&D is focused on developing supply and logistics supply chain systems, technologies, and processes that reduce the delivered cost of feedstock, maintain and/or improve the quality of feedstock, and increase the volume of high-quality biomass that can be delivered as feedstock to biorefineries. The near-term focus of R&D includes continued improvement of lower cost conventional systems, while increasing the amount of feedstock that can meet minimum-quality specifications for a variety of biomass conversion processes to provide lowest cost feedstocks to meet the near-term needs of pioneer biorefineries. Other work with a longer time horizon will address the RD&D needs to meet quality and volume requirements associated with a growing biorefinery industry and the envisioned commoditization of the biomass feedstock supply system.

Longer-term focused efforts on the advanced preprocessing strategy consider how to develop active quality controls that ensure high-quality delivered feedstock and convert raw biomass into engineered infrastructure compatible feedstocks, while minimizing costs and maximizing conversion performance characteristics.

As illustrated in Figure 2-8, the advanced processing strategy is envisioned to draw in presently inaccessible and/or underused resources via local biomass preprocessing depots that format biomass into a stable, bulk, densified, and flowable material. The formatted biomass is transported to a network of supply terminals where the material is consistently blended to the specification required by the biorefinery conversion process (note that feedstock specifications will likely differ depending upon the conversion process). The advanced processing strategy design incrementally incorporates design improvements as the industry matures, providing a progressively improved series of feedstock supply system designs that couple to, and build from, current systems and address science and engineering constraints that have been identified by rigorous sensitivity analyses as having the greatest impact on feedstock supply system efficiencies and costs. Implementing a commodity-based feedstock supply system not only reduces risk to the biorefinery and producer, but also promotes cropping options beyond local markets, which in turn promotes crop diversity and enhances crop rotation options for individual producers.

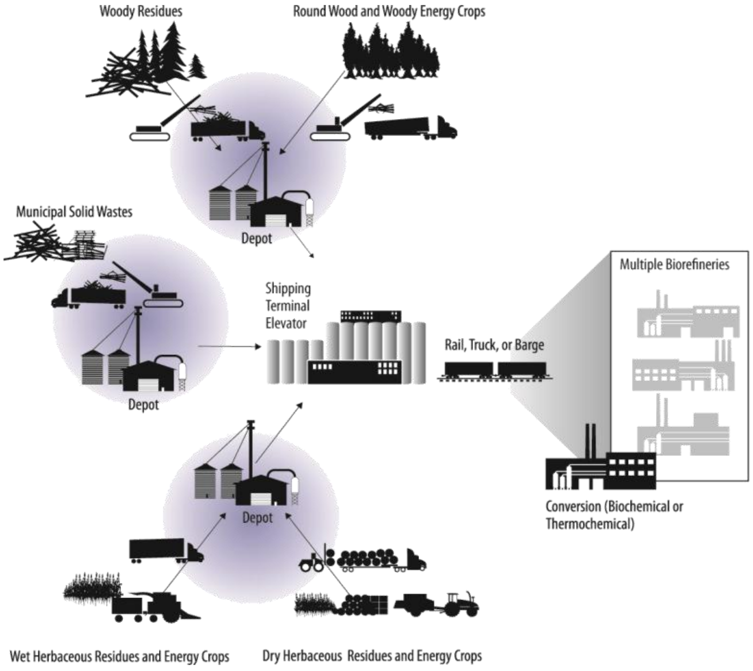

Figure 2-8: The Advanced Feedstock Processing Supply System

Scale-Up and Integration

Scale-up and integration activities, which are part of the advanced processing strategy system outlined above, address feedstock production and feedstock logistics systems at scales equivalent to those addressed by the Office’s Integrated Biorefinery Technology Area, namely pilot and demonstration scale.

Table 2-1: Feedstock Supply R&D Activity Summary

***Goal**: Develop sustainable technologies to provide a secure, reliable, affordable, and sustainable biomass feedstock supply for the U.S. bioenergy industry, in partnership with USDA and other key stakeholders.*

WBS Element	Description	FY 2012 Performers	Barrier(s) Addressed	Pathway(s) Addressed
Analysis and Sustainability	Analyze availability, cost, and sustainability of feedstocks, and feedstocks production and logistics systems: • Inventory national feedstock resources by identifying, quantifying, and geo-spatially analyzing total available feedstock volume, cost, and type by location at a county level of resolution • Assess sustainable feedstock availability at a county level • Assess sustainable feedstock logistics supply systems and design biomass supply systems that are commercially viable and meet supply requirements • Assess the supply potential for cyanobacteria, microalgae, and macroalgae-based production systems • Assess multiple algae production and processing systems for commercial viability and sustainability.	Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Sandia National Laboratory (SNL), Sun Grant Regional Feedstock Partnership, National Alliance for Advanced Biofuels and Bioproducts (NAABB), The National Academies/National Research Council	Ft-A: Feedstock Availability & Cost Ft- B: Sustainable Production Ft- D: Sustainable Harvesting Ft-G: Feedstock Quality and Monitoring Ft-H: Storage Systems Ft-J: Material Properties Ft-K: Physical State Alteration Ft-L: Material Handling and Transportation Ft-M: Integration and Scale-Up Ft-N: Algal Feedstock Processing	Agricultural Residue Processing Energy Crops Processing Forest Resources Processing Algae Processing
Conversion Interface and Technologies	Identify key feedstock characteristics and standards for/from conversion processes: • Characterize feedstock composition and determine physical properties and chemical composition for biochemical and thermochemical conversion.	INL, NREL, ORNL, PNNL Sun Grant Regional Feedstock Partnership, NAABB	Ft-B: Sustainable Production Ft-J: Material Properties	
Feedstock Production RD&D	Develop feedstocks, sustainable agronomic practices, and feedstocks production processes and systems: • Develop sustainable production processes/systems to increase yield and lower cost • Develop and test feedstock production standards • Discover, breed, or engineer algae strains that are productive and robust.	INL, ORNL, PNNL, LANL, Sun Grant Regional Feedstock Partnership, NAABB Montana State University, Utah State University, CABComm, ATP3	Ft-A: Feedstock Availability & Cost Ft-B: Sustainable Production Ft-C: Feedstock Genetics and Development	
Feedstock Logistics RD&D	Develop, test, and demonstrate sustainable feedstocks logistics systems: • Develop sustainable harvest and collection systems with improved efficiency, reduced costs, and increased biomass tonnages • Develop feedstock storage systems that meet year-round facility supply needs • Develop preprocessing systems to improve bulk density and meet conversion/IBR requirements (e.g., water, ash and carbohydrate content) • Develop blending/formulation strategies/algorithms to satisfy the input specification requirements of biorefinery processes. • Develop handling and transportation methods and systems • Develop algal processing systems.	INL, ORNL, NREL, NAABB, ATP3	Ft-D: Sustainable Harvesting Ft-G: Feedstock Quality and Monitoring Ft-H: Storage Systems Ft-J: Material Properties Ft-K: Physical State Alteration Ft-L: Material Handling and Transportation Ft-M: Integration and Scale-Up Ft-N: Algal Feedstock Processing	
Scale-Up and Integration	Complete systems-level demonstration and validation of all key technologies to utilize feedstocks in existing or new facilities: • Demonstrate/validate pilot-scale integrated feedstock production and logistics systems • Demonstrate/validate demonstration-scale integrated feedstock production and logistics systems.	Genera Energy, LLC, Agco,Inc., Auburn University, State University of New York, FDC Enterprises, Inc., INL, ORNL, University of Tennessee, ATP3	Ft-A: Feedstock Availability and Cost Ft-B: Sustainable Production Ft-M: Overall Integration and Scale-up	

2.1.5 Prioritizing Feedstock Supply R&D Barriers

In order to achieve the Feedstock Supply and Logistics R&D goal of developing sustainable technologies to provide a secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry, all of the challenges and barriers identified need to be addressed and the issues solved. However, the following four issues are critical and will be emphasized within the technology area's efforts:

- Incorporate sustainability and feedstock supply risk into the assessment of current and future biomass resource quantities, prices, and characteristics
- Develop baseline productivity for major feedstocks on a regional and sustainable basis
- Develop feedstock materials to meet stability, density, flowability, and quality targets associated with a uniform-format feedstock supply chain
- Develop commercial-scale biomass supply systems by increasing capacity and efficiency of associated unit operations.

Figures 2-9 and 2-10 illustrate how the Feedstock Technology Area utilizes analysis to prioritize efforts in overcoming technical barriers. Figure 2-9 shows the projected biomass feedstock demand required to meet EISA and biopower needs and is further detailed in Appendix B-1. Through 2012, the demand for cellulosic feedstocks was projected to be limited and thus grower payments were based on the projected minimum production cost for niche feedstocks (see Appendix B-2). By 2017, the demand for cellulosic feedstocks is expected to expand to address EISA and biopower demands, and the grower payment is expected to rise in order to draw the required amount of feedstock into the bioenergy marketplace.

Figure 2-2 shows projected feedstock availability by category of feedstocks required to satisfy projected demand from EISA and biopower. Appendix B-2 also shows how increased overall demand is linked to increases in grower payment and production of new feedstocks such as herbaceous energy crops.[15]

Grower payments are those made to feedstock producers over and above the costs incurred for harvest, collection, storage, preprocessing, and transport. The Office models the grower payment based on anticipated feedstock demand (as described above). The estimated grower payment is a national market price that would provide the grower a competitive profit for the use of the land or is sufficient, in the case of residues, to induce the grower to allow the residue to be harvested. As larger quantities of biomass feedstocks are required, the grower payment increases. For crop residues, the grower payment covers the environmental value of the residue removed (e.g., nutrients and organic matter), as well as profit. For woody residues, these payments cover the value of the residue. For dedicated energy crops, grower payments cover pre-harvest machine costs, variable inputs such as fertilizers and seed, and amortized establishment costs for perennial crops, which do not typically reach mature yields until at least the third growing season. The payments must also reflect what profit the land could produce if planted with other crops. Other factors also affect grower payments, such as profits to growers for investment returns and risk

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[15] Perlack, Stokes, et al, "U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.

taking, alternative financial arrangements (e.g., cooperatives), fixed pricing mechanisms, shared-equity arrangements between growers and processors, and other competitive uses.

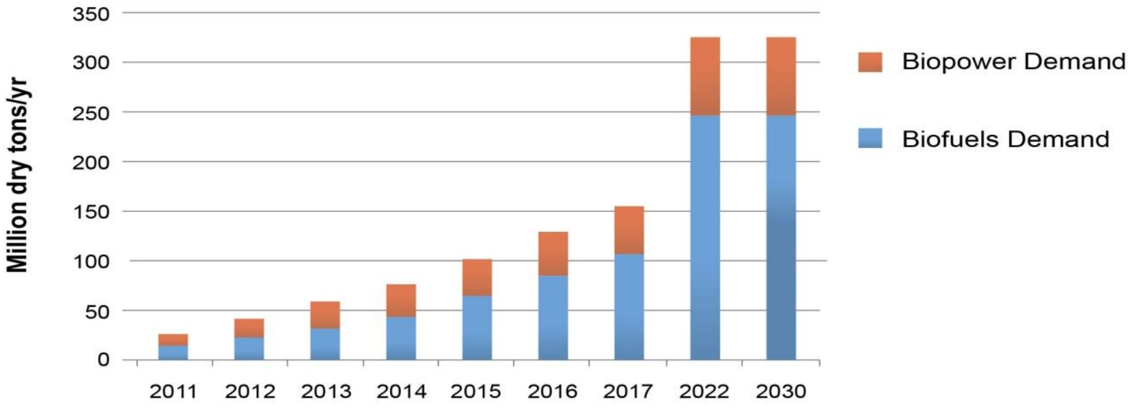

Figure 2-9: Projected Feedstock Demand Based on EISA and EIA Biopower Projections[16]

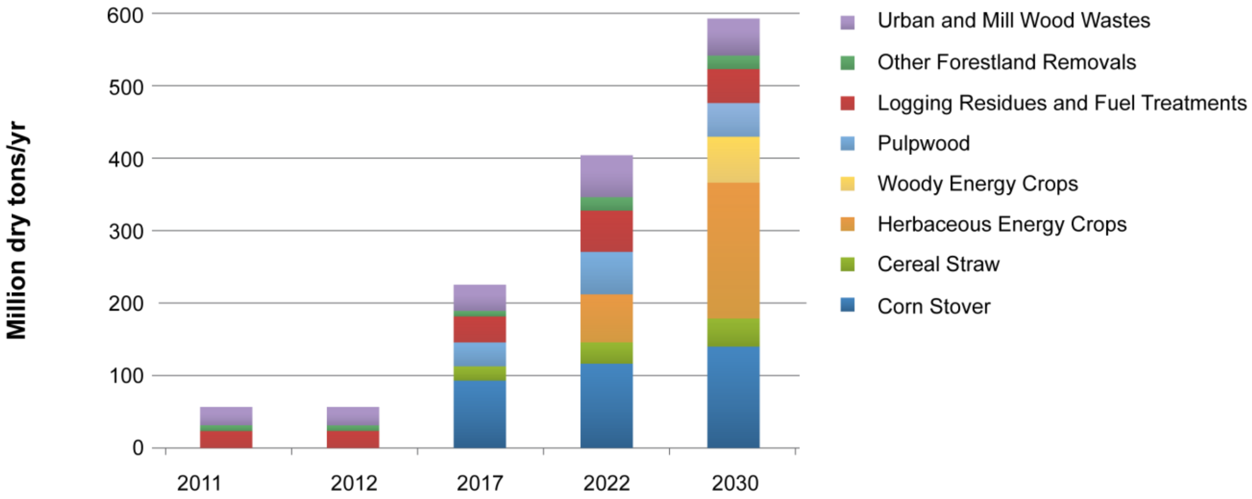

Figure 2-10: Projected Feedstock Availability at Specified Minimum Grower Payments[17]

Figure 2-11 and Table 2-2 show the magnitude of the potential reduction in the logistics costs for a pyrolysis process. Detailed information on the technical performance targets that form the basis for the conceptual logistics system designs and cost estimates are provided in Appendix B, Table B-3[18]. These targets are for the current baseline concept for collection, storage, preprocessing, transportation, and delivery to conversion plant gate.

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[16] Appendix B-1

[17] Appendix B-2, 2011 and 2012 volumes projected at minimum grower payment needed to meet RFS & EISA

[18] Searcy, Hess, Wright, et al, "State of Technology Assessment of Costs of Southern Pine for FY12 – Pyrolysis," Idaho National Laboratory, INL/MIS-11-20887 (2011).

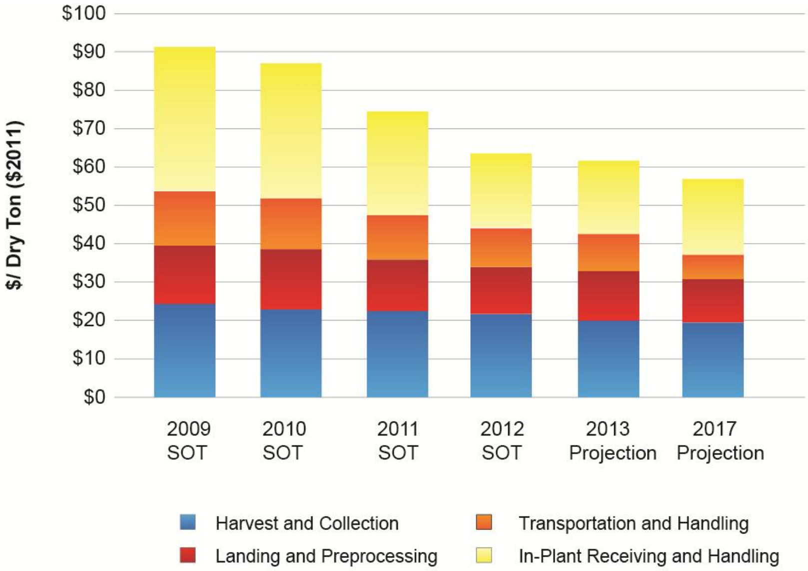

Figure 2-11: Feedstock Logistics Costs for Pyrolysis

Table 2-2: Feedstock Logistics Costs for Pyrolysis

2011 Dollars	2009 SOT	2010 SOT	2011 SOT	2012 SOT	2013 Projection	2017 Projection
Total Feedstock Logistics, $/DT	**$90.90**	**$86.94**	**$74.55**	**$63.69**	**$61.85**	**$54.50**
Harvest and Collection	$24.89	$23.77	$23.15	$22.24	$20.70	$19.53
Storage and Queuing	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Landing and Preprocessing	$15.18	$15.18	$13.60	$12.17	$13.08	$11.73
Transportation and Handling	$13.95	$13.39	$11.15	$10.28	$9.50	$6.37
In-Plant Receiving and Preprocessing	$36.88	$34.60	$26.65	$19.00	$18.58	$16.88
Total Feedstocks Logistics $/gal total fuel	**$1.25**	**$1.19**	**$1.02**	**$0.86**	**$0.74**	**$0.51**
Harvest and Collection	$0.34	$0.33	$0.32	$0.30	$0.25	$0.18
Storage and Queuing	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Landing and Preprocessing	$0.21	$0.21	$0.19	$0.16	$0.16	$0.11
Transportation and Handling	$0.19	$0.18	$0.15	$0.14	$0.11	$0.06
In-Plant Receiving and Preprocessing	$0.51	$0.47	$0.37	$0.26	$0.22	$0.16
Gallons total fuel/Dry Ton	73	73	73	74	84	106

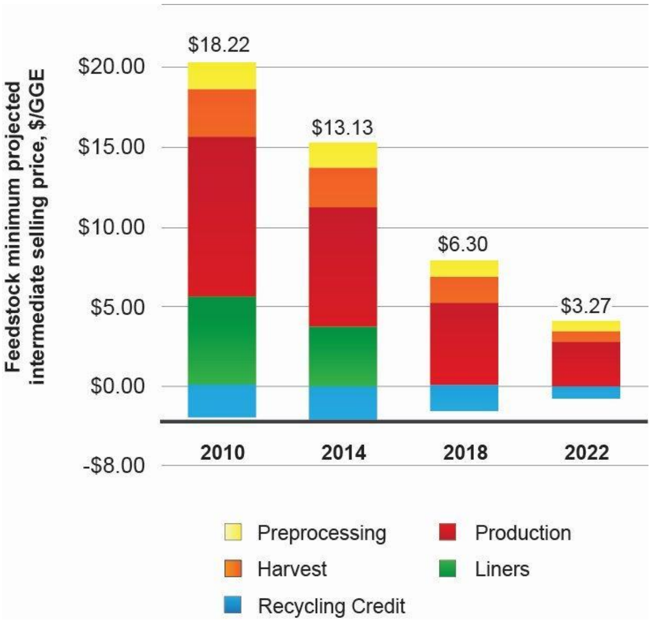

Figure 2-12: Algae Feedstock Production and Logistics Costs

Table 2-3: Algae Production and Logistics Costs for Lipid Extraction and Upgrading ($2011)

$2011		**2010 SOT**	**2014 Projection**		**2018 Projection**	**2022 Target**
Total Algal Feedstock Cost	**$ / GGE Algal Oil**	**$18.22**	**$13.13**		**$6.30**	**$3.27**
Production Cost	$ / GGE Algal Oil	**$15.60**	**$11.18**		**$5.17**	**$2.63**
Harvest Cost	$ / GGE Algal Oil	**$2.99**	**$2.52**		**$1.65**	**$0.67**
Preprocessing Cost	$ / GGE Algal Oil	**$1.72**	**$1.56**		**$1.11**	**$0.77**
Recycle Credit	$ / GGE Algal Oil	**-$2.08**	**-$2.14**		**-$1.63**	**-$0.80**

Figure 2-12 and Table 2-3 show projected minimum intermediate prices based on the technical projections described in Appendix B-4.[19] The projections show that the greatest opportunity to reduce costs is in the production systems. This is expected to be achieved through improved biomass yield and reduced cultivation capital costs (by eliminating plastic pond liners). Significant cost improvements are also projected in feedstock harvest and preprocessing. Also shown explicitly is the value of the recycling credit achieved from processing the residual biomass via anaerobic digestion to produce on-site power and recover nitrogen and phosphorus. Diverting the residual biomass to other uses would eliminate the recycling credit.

Conversion of extracted algal lipid to renewable diesel is not a part of this figure. Conversion of extracted algal lipids is projected to add between $0.50–$1.00 per gallon of renewable diesel; the projected 2022 minimum fuel selling price (MFSP) for renewable diesel from algal lipids is $3.73/GGE ($2011).

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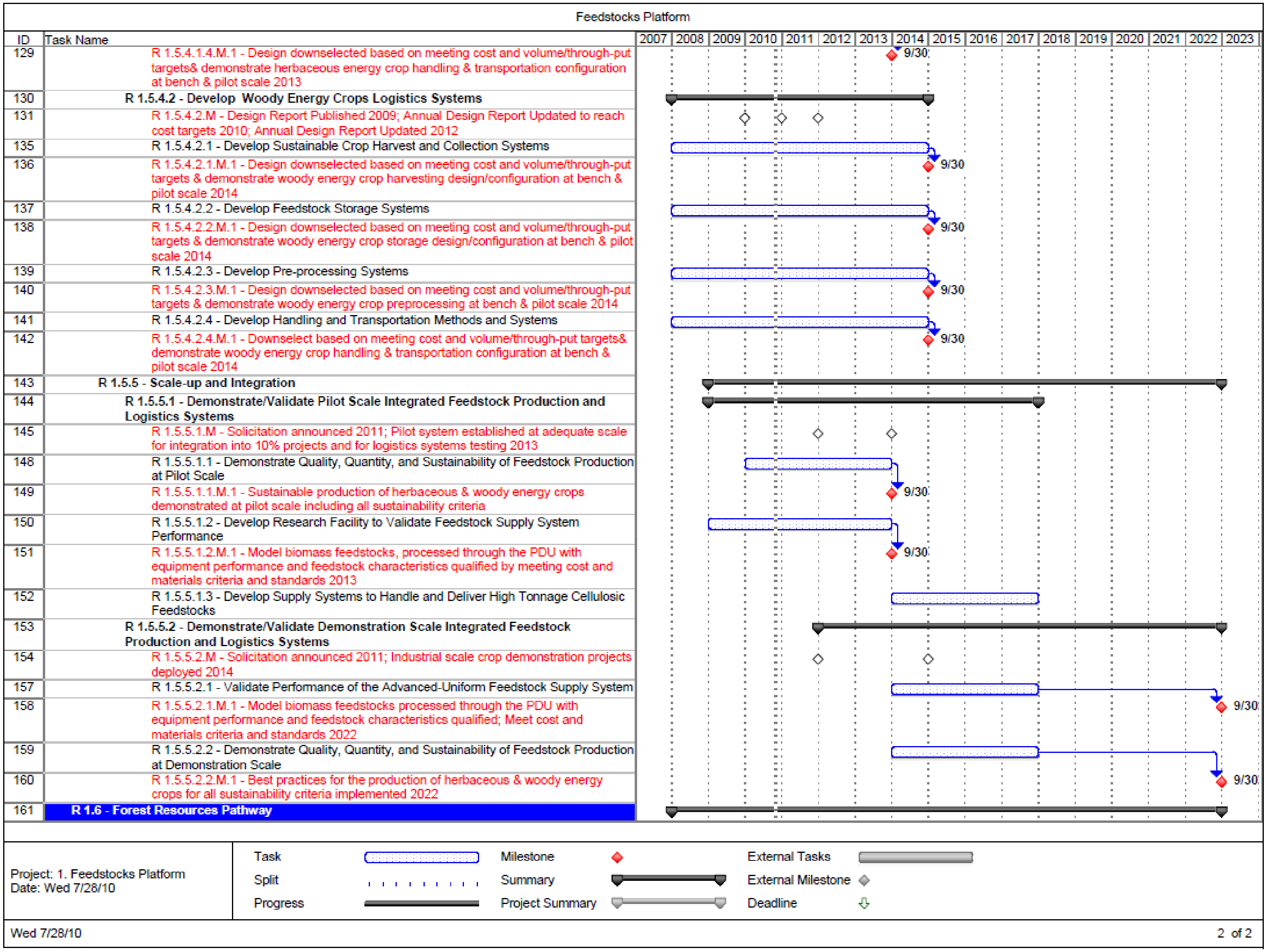
[19] Davis, Fishman, Frank, et al, “Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model.”

2.1.6 Feedstock Platform Milestones and Decision Points

The key Feedstock Technology Area milestones, inputs/outputs, and decision points to complete the tasks described in Section 2.1.4 are summarized in the chart in Figure 2-13

Figure 2-13: Feedstock Supply R&D Gantt Chart



Feedstocks Platform

ID	Task Name
129	R 1.5.4.1.4.M.1 - Design downselected based on meeting cost and volume/through-put targets& demonstrate herbaceous energy crop handling & transportation configuration at bench & pilot scale 2013
130	**R 1.5.4.2 - Develop Woody Energy Crops Logistics Systems**
131	R 1.5.4.2.M - Design Report Published 2009; Annual Design Report Updated to reach cost targets 2010; Annual Design Report Updated 2012
135	R 1.5.4.2.1 - Develop Sustainable Crop Harvest and Collection Systems
136	R 1.5.4.2.1.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate woody energy crop harvesting design/configuration at bench & pilot scale 2014
137	R 1.5.4.2.2 - Develop Feedstock Storage Systems
138	R 1.5.4.2.2.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate woody energy crop storage design/configuration at bench & pilot scale 2014
139	R 1.5.4.2.3 - Develop Pre-processing Systems
140	R 1.5.4.2.3.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate woody energy crop preprocessing at bench & pilot scale 2014
141	R 1.5.4.2.4 - Develop Handling and Transportation Methods and Systems
142	R 1.5.4.2.4.M.1 - Downselect based on meeting cost and volume/through-put targets& demonstrate woody energy crop handling & transportation configuration at bench & pilot scale 2014
143	**R 1.5.5 - Scale-up and Integration**
144	**R 1.5.5.1 - Demonstrate/Validate Pilot Scale Integrated Feedstock Production and Logistics Systems**
145	R 1.5.5.1.M - Solicitation announced 2011; Pilot system established at adequate scale for integration into 10% projects and for logistics systems testing 2013
148	R 1.5.5.1.1 - Demonstrate Quality, Quantity, and Sustainability of Feedstock Production at Pilot Scale
149	R 1.5.5.1.1.M.1 - Sustainable production of herbaceous & woody energy crops demonstrated at pilot scale including all sustainability criteria
150	R 1.5.5.1.2 - Develop Research Facility to Validate Feedstock Supply System Performance
151	R 1.5.5.1.2.M.1 - Model biomass feedstocks, processed through the PDU with equipment performance and feedstock characteristics qualified by meeting cost and materials criteria and standards 2013
152	R 1.5.5.1.3 - Develop Supply Systems to Handle and Deliver High Tonnage Cellulosic Feedstocks
153	**R 1.5.5.2 - Demonstrate/Validate Demonstration Scale Integrated Feedstock Production and Logistics Systems**
154	R 1.5.5.2.M - Solicitation announced 2011; Industrial scale crop demonstration projects deployed 2014
157	R 1.5.5.2.1 - Validate Performance of the Advanced-Uniform Feedstock Supply System
158	R 1.5.5.2.1.M.1 - Model biomass feedstocks processed through the PDU with equipment performance and feedstock characteristics qualified; Meet cost and materials criteria and standards 2022
159	R 1.5.5.2.2 - Demonstrate Quality, Quantity, and Sustainability of Feedstock Production at Demonstration Scale
160	R 1.5.5.2.2.M.1 - Best practices for the production of herbaceous & woody energy crops for all sustainability criteria implemented 2022
161	**R 1.6 - Forest Resources Pathway**

Project: 1. Feedstocks Platform
Date: Wed 7/28/10

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

Wed 7/28/10

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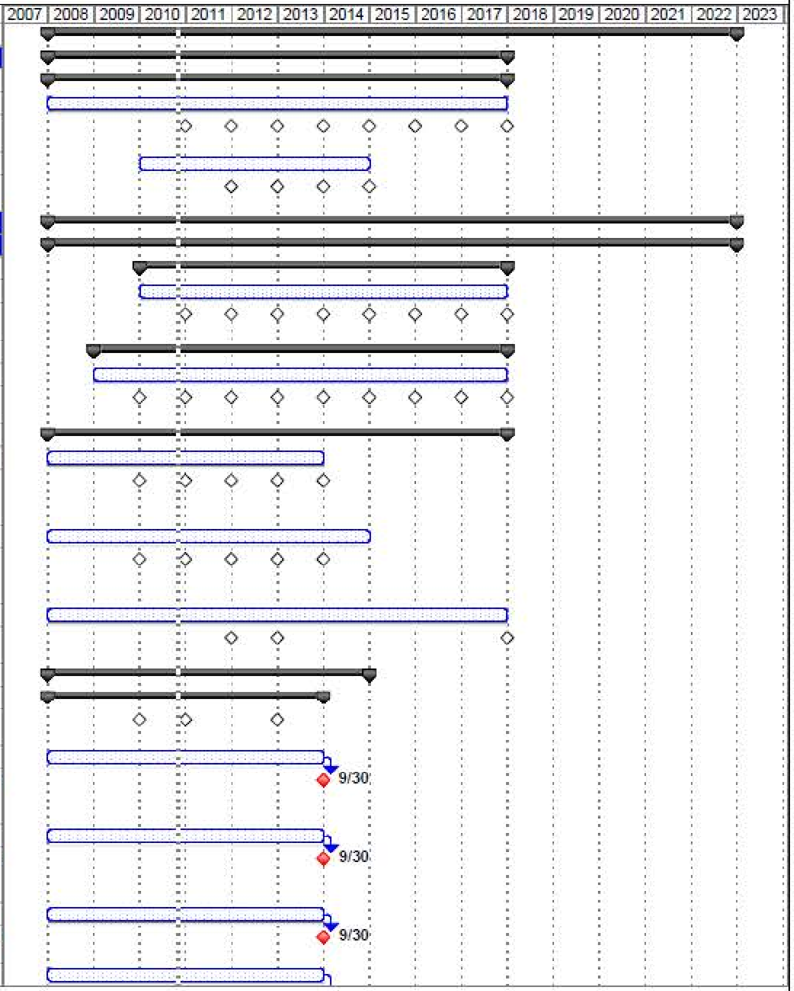
Feedstocks Platform

ID	Task Name
1	**R 1 - Feedstock Supply R&D**
2	**R 1.0. - All Pathways**
3	**R 1.0.1 - Analysis**
4	R 1.0.1.1 - Inventory National Feedstock Resources
5	R 1.0.1.1.M - Billion Ton Update (including industry high-yield scenario) published 2010; Regional supply curves / scenarios produced each year 2011- 2017
14	R 1.0.1.2 - Assess Sustainable Feedstock Availability
15	R 1.0.1.2.M - Annual updated addendum to regional feedstock supply curves with environmental impact published - 2011 through 2014
20	**R 1.4 - Agricultural Residues Pathway**
72	**R 1.5 - Energy Crops Pathway**
73	**R 1.5.1 - Analysis**
74	R 1.5.1.1 - Assess Sustainable Feedstock Logistics Supply Systems
75	R 1.5.1.1.M - IBSAL & SOT models integrated to allow the development and analysis of feedstock supply systems 2010; Develop annual SOT - 2010 - 2017
84	**R 1.5.2 - Conversion Interface**
85	R 1.5.2.1 - Characterize Feedstock Composition
86	R 1.5.2.1.M - Library and database complete 2009; Library of feedstock samples and analysis results compiled 2010 - 2017
96	**R 1.5.3 - Feedstock Production RD&D**
97	R 1.5.3.1 - Develop Sustainable Herbaceous Energy Crops Production Processes/Systems
98	R 1.5.3.1.M - Regional trials established 2009; Trial results incorporated into KDF 2009-13; Baseline and targets established for priority crops 2012; Final assessment of varieties / crops completed by region 2013
104	R 1.5.3.2 - Develop Sustainable Woody Energy Crops Production Processes/Systems
105	R 1.5.3.2.M - Regional trials established 2009; Trial results incorporated into KDF 2009-13; Baseline and targets established for priority crops 2012; Final assessment of varieties / crops completed by region 2013
111	R 1.5.3.3 - Develop and Test Feedstock Production Standards
112	R 1.5.3.3.M - Cost and sustainability criteria set 2011; Indicators selected 2012; Standards published 2017
116	**R 1.5.4 - Feedstock Logistics RD&D**
117	**R 1.5.4.1 - Develop Herbaceous Energy Crops Logistics Systems**
118	R 1.5.4.1.M - Design Report Published 2009; Annual Design Report Updated to reach cost targets 2010; Annual Design Report Updated 2012
122	R 1.5.4.1.1 - Develop Sustainable Crop Harvest and Collection Systems
123	R 1.5.4.1.1.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate herbaceous energy crop harvesting design/configuration at bench & pilot scale 2013
124	R 1.5.4.1.2 - Develop Feedstock Storage Systems
125	R 1.5.4.1.2.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate herbaceous energy crop storage design/configuration at bench & pilot scale 2013
126	R 1.5.4.1.3 - Develop Pre-processing Systems
127	R 1.5.4.1.3.M.1 - Design downselected based on meeting cost and volume/through-put targets & demonstrate energy crop preprocessing at bench & pilot scale 2013
128	R 1.5.4.1.4 - Develop Handling and Transportation Methods and Systems



Project: 1. Feedstocks Platform
Date: Wed 7/28/10

Task	▭	Milestone	◆	External Tasks	▬
Split	⋯	Summary	▬	External Milestone	◇
Progress	▬	Project Summary	▬	Deadline	⇩

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2.2 Conversion Research and Development

The strategic goal of Conversion R&D is to *develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible liquid transportation fuels, as well as bioproducts or chemical intermediates and biopower*. Biomass resource diversity results in a need to develop multiple conversion technologies that can efficiently deal with the broad range of physical and chemical characteristics of various feedstocks. Investing in multiple conversion technologies also reduces the risk that any specific technology fails to reach commercial viability. The Office divides its Conversion R&D efforts into: Biochemical Conversion R&D, which focuses on pathways using sugars, other carbohydrates, and lignin intermediates and Thermochemical Conversion R&D, which focuses on pathways using bio-oil and gaseous intermediates. These focus areas are shown in Figure 2-14. Within each area, there are many possible variations, but the main differences are in the intermediate building blocks produced and the primary catalytic system employed.

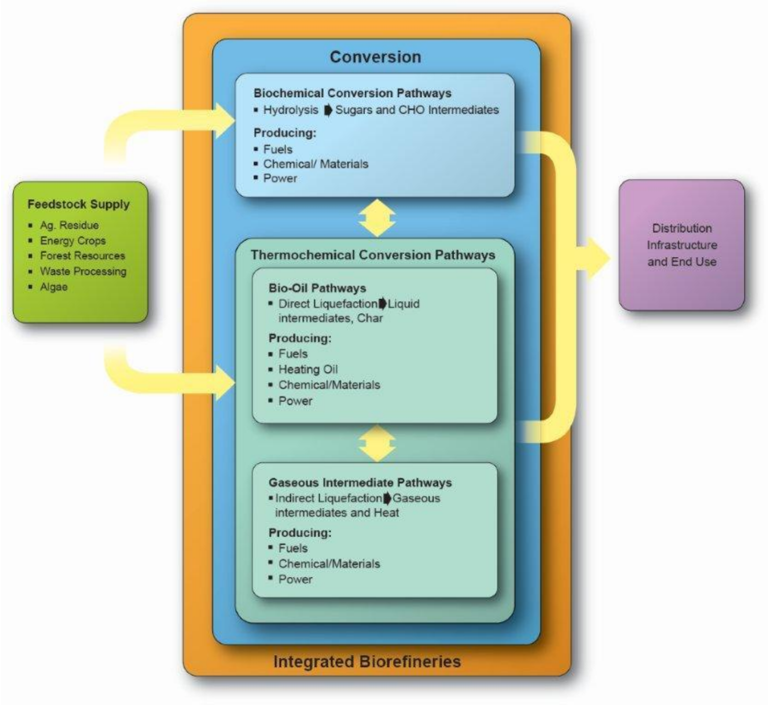

Figure 2-14: Conversion Routes for Biomass to Bioenergy

While the Office addresses the Conversion R&D needs through three separate technology areas defined around their primary intermediate product—sugars, bio-oils, and syngas—it is envisioned that the combined use of technologies from multiple areas offers the greatest opportunity for optimizing biomass conversion into a variety of different fuels, chemicals, and energy products. The early years of the industry may not see such complex biorefineries, but complexity may be added as technologies evolve over time.

The Office also actively pursues R&D in technology areas that do not fit neatly into the three intermediate pathways. This includes work on emerging technology including efforts in waste to energy, synthetic biology, and hybrid technology pathways.

2.2.1 Biochemical Conversion Research and Development

Biochemical Conversion R&D is focused on reducing the cost of converting lignocellulosic biomass to mixed, dilute sugars and other processable intermediates, and further conversion of these chemical intermediates to liquid transportation fuels or other bioproducts. Other processable intermediates that may be produced include oligomeric sugars and lignin. Biochemical conversion uses biocatalysts, usually including enzymes and microorganisms, in addition to physical forces and chemical catalysts, to convert the carbohydrate portion of the biomass cell walls (i.e., hemicellulose and cellulose) into an intermediate sugar stream. The biomass sugars act as intermediate building blocks, which are then biologically or chemically converted to various liquid fuels and other products. Biological conversion processes typically utilize organisms such as yeast, filamentous fungi, bacteria, or algae with optimized metabolic pathways to convert intermediate products (sugars) via a fermentation process. Alternatively, chemical conversion employs catalysts to drive the reactions from sugars to specific product suites. The remaining lignin portion of the biomass can be used to produce heat and power via combustion or to produce additional fuels and chemicals via a thermochemical route.

Building on the successful development of biochemical conversion processes to cellulosic ethanol, the Office is investigating a broad range of biological and chemical conversion routes to advanced biofuels. Reaching 2022 volumetric goals will require technologies that can convert biomass to fuels at high efficiencies or specificities and/or accept lower quality, but potentially lower cost biomass, thereby allowing access to a larger biomass supply. Biochemical conversion routes may also be able to leverage existing investment in biorefinery infrastructure, such as corn wet mills, thereby reducing capital costs.

Biochemical Conversion R&D also includes feedstock/conversion interfaces focused at improving overall cost effectiveness and productivity to enable larger sources of feedstocks to be used in producing fuels and chemicals via a biological, chemical, or hybrid routes.

Biochemical Conversion Unit Operations

The conceptual block flow diagram in Figure 2-15 outlines the main technologies or unit operations of the biological and chemical biomass-to-fuel process. There are multiple routes to fuels and chemicals, as shown in the various feedstock pathways in Appendix A. New routes to other advanced biofuels can be analogous to the Office's published design case for cellulosic ethanol,[20] with the addition of appropriate fermentative organisms and modifications to the product upgrading and recovery processes. In addition, the bioindustry has recently developed innovative approaches including non-fermentative routes that chemically or catalytically convert processable intermediates into fuel and chemical products. This approach is depicted in the diagram as the "Chemical Processing" block, which parallels the "Biological Processing" block.

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[20] D. Humbird, R. Davis, et al, "Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover," National Renewable Energy Laboratory, NREL TP-510-47763 (2011), http://www.nrel.gov/biomass/pdfs/47764.pdf.

The block diagram depicts a high-level view of the primary units of operations. Specific process operation conditions, and inputs and outputs within and between each unit vary in practice; these process variations can impact the key performance outcomes (titer, rate, and yield), which determine economic viability when the process is scaled up. The following descriptions highlight issues in each key process step.

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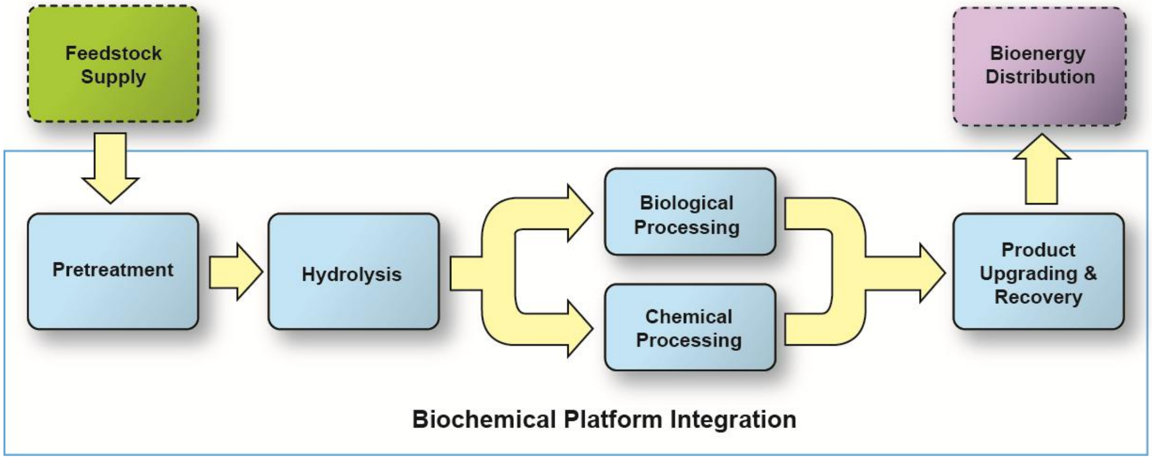

Figure 2-15: Generalized Biochemical Conversion Route for Biomass to Biofuels

Pretreatment: In this step, biomass feedstock undergoes a process to mechanically or chemically fractionate the lignocellulosic complex into soluble and insoluble components. Soluble components include mixtures of five- and six-carbon sugars (xylose, arabinose, mannose, galactose, and glucose) and soluble oligomers of sugars. Insoluble components include oligomers of sugars, cellulosic polymers, and lignin (and anything else that may be linked to those insoluble constituents). Depending on the exact chemistry chosen for this step, variable amounts of the biomass may be solubilized. The main purpose of this step is to open up the physical structure of the plant cell walls to permit access by subsequently added enzymes. The more open structure of the resulting insoluble material makes the remaining carbohydrate polymers more accessible for hydrolytic conversion to soluble sugars by enzymes or chemicals. Depending on the process, low or high molecular weight lignin is produced. The specific mix of sugars and oligomers released depends on the feedstock used and the pretreatment technology employed.

Conditioning: In some process configurations, the pretreated material goes through a hydrolysate conditioning and/or neutralization process to adjust the pH of the biomass slurry and remove undesirable byproducts from pretreatment that are toxic to the downstream fermenting organism. In some cases, this step and hydrolysis, the next step, are combined into a single process.

Hydrolysis: In hydrolysis, the pretreated material, with the remaining solid carbohydrate fraction, primarily cellulose, is hydrolyzed, releasing primarily the readily fermentable sugar, glucose. This can be done with enzymes such as cellulases or using strong acids. Addition of other enzymes in this step, such as xylanases, may allow for less severe pretreatment conditions, potentially resulting in a reduced overall pretreatment and hydrolysis cost. Depending on the process design, enzymatic hydrolysis requires several hours to several days, after which the mixture of sugars and any unreacted cellulose is transferred to the fermenter. Currently processes use purchased enzymes or enzymes manufactured on site, based on the economics of the specific process. Some processes combine the hydrolysis and fermentation steps (i.e., simultaneous saccharification and fermentation [SSF]). For technologies using strong acids, acid recovery is important for the economics to be viable.

Biological Processing: Currently, the most common approach to biological processing is to employ a fermentation step, wherein an inoculum of a fermenting organism is added to the biomass hydrolysates. Fermentation of all sugars is then carried out while continuing to utilize the enzymes for further glucose production from any remaining solid cellulose. After a few days of continued saccharification and fermentation, nearly all of the sugars are converted to biofuels or other chemicals of interest. The resulting aqueous mixture or two phase broth is sent to product recovery.

Chemical Processing: Chemical or catalytic conversion can be used in place of, or in addition to, fermentation to convert the hydrolysis products, such as sugars, alcohols, or a variety of other stable oxygenates, to a desired end product. The addition of a catalyst makes the reaction less energy intensive, thus making the entire process more energy efficient. However, different reactions achieve different yields and intermediates, while targeting different end fuels and chemicals, so the research is aimed at identifying optimal combinations with respect to process efficiency, feedstock utilization, cost, sustainability, finished product characteristics, and anticipated market demands.

Product Upgrading and Recovery: Product upgrading and recovery varies based on the type of conversion used and the type of product generated, but in general, involves any biological and chemical transformations, distillation or other separation and recovery method, and some cleanup processes to separate the fuel from the water and residual solids. Residual solids are composed primarily of lignin, which can be burned for combined heat and power generation, chemically converted to intermediate chemicals, or also converted to synthesis gas or pyrolysis oil intermediates for other uses.

Biochemical Conversion Interfaces

Feedstock Logistics Interface: A feedstock supply chain will need to be capable of providing preprocessed feedstock materials that meet the input requirements (composition, size, handling characteristics, density, etc.) established by a baseline biochemical conversion process configuration. These input requirements are expected to vary, depending on the process configuration. Close coordination between Feedstock Supply and Logistics R&D (see Section 2.1) and Biochemical Conversion R&D is necessary to ensure that the feedstock and the conversion process are optimized in relation to each other such that feedstock materials of sufficient quantity and quality are readily available for the lowest overall cost and highest conversion efficiency.

Biofuels Distribution Interface: The next step in the biomass-to-biofuels supply chain is the biofuels distribution step. Biofuels leaving a biorefinery must meet all applicable federal, state, and local codes and standards. As the Office broadens its Biochemical Conversion R&D

portfolio from ethanol to include infrastructure-compatible hydrocarbons, close coordination with traditional petroleum refiners will be essential to ensure desired product quality characteristics are met.

2.2.1.1 Biochemical Conversion R&D Support of Office Strategic Goals

The Biochemical Conversion Area's strategic goal is to *develop commercially viable technologies for converting biomass feedstocks via biochemical routes into energy dense, fungible liquid transportation fuels, as well as bioproducts or chemical intermediates, and bioenergy*.

The R&D portfolio directly addresses and supports development of technologies necessary for producing fuels and bioproducts from high impact feedstocks, including herbaceous, woody, and algal feedstocks, as well as from MSW.

2.2.1.2 Biochemical Conversion R&D Support of Office Performance Goals

The overall near-term performance goal of Biochemical Conversion R&D is to reduce the estimated mature technology processing cost[21] for converting cellulosic feedstocks to hydrocarbon fuels via biochemical pathway:

- By 2022, achieve the overall Office performance cost goal of $3 per gallon of gasoline equivalent ($2011) based on data at the integrated pilot scale.

The current performance milestones for the technology area in the near term are:

- By 2013, establish out-year cost goals and technical targets for biologically derived hydrocarbon fuels based on techno-economic analysis for at least 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 bench-scale to measure progress against an interim modeled cost goal (nth plant, $2011), to be set in 2013.

Preliminary analyses suggest that achievement of Office cost goals will require economic contributions from co-product development in addition to technological advancements from R&D for biofuels.

2.2.1.3 Biochemical Conversion Challenges and Barriers

Inherent to Biomass Utilization

Bt-B. Biomass Variability: The characteristics of biomass feedstock materials can vary widely in terms of physical parameters (size, shape, bulk density, etc.) and chemical composition, (moisture, ash, carbohydrate, lignin, Btu content, etc.). These variations can make it difficult (or costly) to reliably supply biorefineries with feedstocks of consistent, acceptable quality year-

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[21] Estimated mature technology processing cost means that capital and operating costs are assumed to be for an "nth plant" where several plants have been built and are operating successfully, so additional costs for risk financing, longer startups, under performance, and other costs associated with pioneer plants are not included.

round. Additionally, feedstock variability can affect overall conversion process performance parameters, including conversion rate and product yield, which directly impacts profitability.

Bt-C. Biomass Recalcitrance: Lignocellulosic biomass feedstocks are naturally resistant to chemical and/or biological degradation. The fundamental role that cell wall architecture and composition play in determining its resistance to decomposition is not well understood. This knowledge gap partially limits the ability to direct efforts to improve the cost-effectiveness and efficiency of pretreatment and other fractionation and conversion processes.

Technical R&D Barriers to Processing Biomass

Bt-A. Biomass Fractionation: Fractionation can be used to increase the value of the individual components in biomass prior to their subsequent conversion to products. Currently, the interactions between chemical, biological, solvation (ability to go into solution), and mechanical processes that ultimately allow biomass to be more efficiently fractionated into high-purity components prior to conversion are insufficiently understood or simply too costly to implement commercially.

Bt-D. Pretreatment Processing: Chemical, mechanical, and/or thermal pretreatments can be employed to alter the structure of biomass to increase the efficiency of subsequent cell wall carbohydrate polymer hydrolysis or to carbohydrate intermediates. The resulting lignin and degradation products can inhibit the downstream processing steps following pretreatment; therefore, optimal process parameters need to be developed to minimize production of these inhibitors and maximize production of the desired intermediates.

Bt-E. Pretreatment Costs: Pretreatment reactors typically require expensive construction materials to resist acid or alkali attack at elevated temperatures and pressures. In addition, the impact of reactor configuration and reactor design on chemical cellulose prehydrolysis is not well understood. Developing lower-cost pretreatment depends on the ability to process the biomass in reactors fabricated from cost-effective materials, designed for maximum biomass solids content, and compatible with process conditions.

Bt-F. Cellulase Enzyme Production Cost: Cellulase enzymes remain a significant portion of the projected production cost of converting sugars from cellulosic biomass. Significant progress has been made through targeted public and private R&D efforts, however, the cost and efficiency of enzyme production continues to impact the economics of an integrated process. Unique proteins that target deconstruction of residual substrates need to be identified in order to augment process yields, and the production strains for these enzymes need to be optimized for commercial production.

Bt-G. Cellulase Enzyme Loading: Reducing the cost of enzymatic hydrolysis depends on identifying more efficient enzyme preparations and hydrolysis parameters that enable cost-effective release of sugars. The target is to reduce the ratio of enzyme protein mass required to solubilize the substrate (i.e., increased specific activity). In addition, commercially available enzymes are not sufficiently thermostable and also suffer from substantial sugar end-product inhibition. Developing enzymes that enable low-cost enzymatic hydrolysis technology requires a better understanding of the fundamental mechanisms underlying the biochemistry of enzymatic cellulose hydrolysis, including the impact of biomass architecture on the ability of enzymes to decrystallize cellulose during hydrolysis. Additional efforts aimed at understanding both the interaction of cellulases with biomass substrates and the optimal molecular-level hydrolysis environment are needed to achieve the targeted specific activity improvements that can further inform solicitations and further reduce cellulase cost.

Bt-I. Cleanup/Separation: Sugar solutions resulting from pretreatment and hydrolysis contain a mixture of sugars and non-sugar components. Potential impurities include acetic acid released during hemicellulose hydrolysis, lignin-derived phenolics solubilized during pretreatment, inorganic acids or alkalis, other compounds introduced during pretreatment, various salts, and hexose and pentose sugar degradation or transglycosylation products. The presence of some of the non-sugar components can inhibit downstream biological and chemical catalysts. Low-cost purification technologies need to be developed that can remove impurities from hydrolysates and provide concentrated, clean sugar feedstocks to manufacture biofuels and biobased products.

Bt-J. Catalyst Development: There is a need for efficient biological and chemical catalysts that can transform the sugar mixture and other hydrolysates components into advanced biofuels, bioproducts, and fuel intermediates. Improvement in the productivity, efficiency, and robustness of catalysts (bacterial, fungal, algal, or chemical) and their ability to perform utilizing hydrolysate or synthesis gas can lead to significantly lower capital and operating costs.

Bt-K. Biochemical Conversion Process Integration: Process integration remains a key technical barrier hindering development and deployment of biochemical conversion technologies. These conversion technologies currently present large scale-up risks given the lack of high-quality performance data on integrated processes carried out at the high solids conditions required for commercially viable industrial operations. The effect of feed and process variations throughout the process must be understood to ensure efficient operations and profitability. Process integration work is essential for characterizing the complex interactions that exist between many of the processing steps, including identifying unrecognized separation requirements, minimizing waste streams, addressing bottlenecks and knowledge gaps, and generating the integrated performance data necessary to develop predictive mathematical models that can guide process optimization and scale-up.

Bt-L. Biochemical/Thermochemical Interface: Hybrid technologies combine the best features and advantages of biochemical conversion unit operations with those of thermochemical conversion unit operations, while addressing some existing limitations found in each straight conversion route. For example, syngas fermentation technologies can pair up the specificity and efficiencies of conversion microorganisms with the relatively uniform intermediate from biomass gasification. Achieving successful hybrid conversion biorefineries will require identifying and resolving the challenges that exist at the interfaces between the biochemical and thermochemical processes. Without detailed analysis, characterization, and strategic integration of operations across these interfaces, the risks of commercialization will remain too high for financiers. As these hybrid conversion technologies mature, the understanding of system trade-offs and achieving optimal overall system operations will be feasible and may allow for the use of a wider range of feedstocks in producing desired fuels and chemicals.

2.2.1.4 Biochemical Conversion R&D Approach for Overcoming Challenges and Barriers

The approach for overcoming biomass conversion technical challenges and barriers is outlined in Figure 2-16.

Current efforts are focused on overcoming the recalcitrance of biomass; validating advanced conversion enhancements such as increased solids loadings, improved separation, and milder process conditions; developing more robust conversion mechanisms such as fermentation and catalysis; and integrating conversion technologies with upstream feedstock collection/transport processes. Research addressing the key technical barriers is performed by national laboratories, industry, universities, and multi-disciplinary consortia. Relevance of the R&D portfolio to industrial and commercial applications will be ensured via project stage gate and biennial portfolio reviews with a panel of external experts, partnering with industry as appropriate, and patenting and publishing the results.

The R&D approach of each group of activities is described below, while Table 2-4 summarizes each activity element's work as it relates to specific barriers and biorefinery pathways.

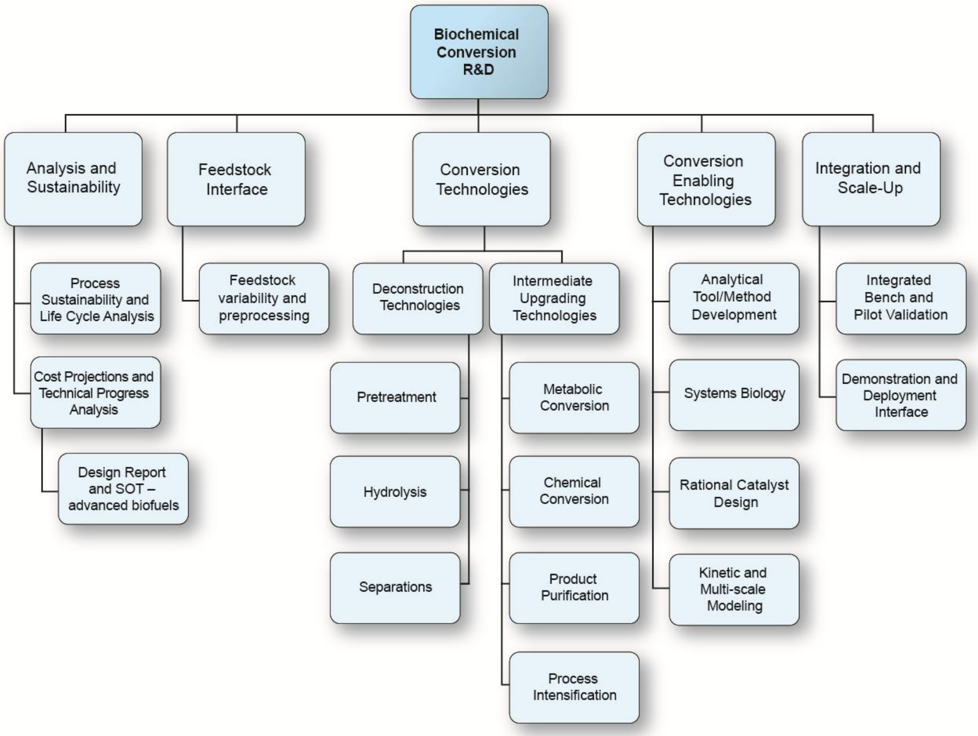

Figure 2-16: Work Breakdown Structure for Biochemical Conversion R&D

Analysis and Sustainability

Analysis and sustainability activities play a critical role in investigating the potential of new conversion methods, establishing baselines, developing targets, and monitoring progress of the research portfolio. Techno-economic modeling activities have been used to develop technical and related cost targets by unit operation. The resulting models can be utilized to determine the impact of process trade-offs (both economic and technical), as well as define the current state of technology. Additionally, life-cycle analysis is used to assess the sustainability and identify additional R&D for development of efficient and environmentally benign conversion processes.

Feedstock Interface

Establishing the impact of, and requirements for, feedstock assembly processes to feed bioconversion processes are necessary for the development of biorefineries. Linking feedstock harvest, collection, and transport processes with conversion processes allows for the evaluation of technology options and trade-offs on both sides of the processing interface, ensuring a fully integrated process from stump to fuel. Activities will develop cost and quality specifications for feedstock assembly technologies that are compatible with the biochemical conversion technologies. Additionally, the Office is investigating the development of preprocessing techniques and simultaneously assessing the impact on conversion efficiency when such preprocessed feedstocks are introduced into a process.

Conversion Technologies

Overcoming the barriers associated with high capital and operating costs and sub-optimal process yields is the key to developing an integrated biochemical conversion process. The investigation and evaluation of pretreatment approaches are aimed at reducing the cost of pretreatment and increasing the digestibility of residual cellulose and hemicellulose in pretreated biomass. Fundamental and applied research is focused on improving the existing enzyme cocktails and fermentation organisms, expanding the knowledge of new organisms/catalysts, and developing advanced technologies to overcome the key rate-limiting steps in the conversion of biomass to advanced biofuels and products.

Conversion Enabling Technologies

The biorefinery of the future will require efficient and highly productive biological and non-biological catalysts for biofuel production. Optimizing the hydrolytic enzymes or a platform microorganism requires a fundamental understanding of the biological processes governing gene expression, protein folding, modification, and secretion, the flux of metabolic pathways, and the metabolite transport. In addition, a fundamental understanding of the factors and causes underlying the recalcitrance of biomass to biochemical degradation is needed to make feedstock processing more specific and less costly. The development of tools such as molecular modeling and cell wall microscopy will enable a more complete understanding of biomass structure and the most appropriate methods to deconstruct cell walls into processable components.[22] Other approaches, such as systems and synthetic biology, will be examined for their ability to make potential transformational, not incremental, changes in conversion technology efficiency and costs. For chemical and inorganic catalyst development, catalyst inactivation and support structures need to be understood on a mechanistic level to enable rational designs that enhance catalyst productivity and specificity. The further development and implementation of new technologies like kinetic and multi-scale modeling that advance the state-of-the art will also be sought to enable conversion enhancing parameters that positively impact yields and costs.

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[22] Shishir Chundawat, Greg Beckham, et al, “Deconstruction of Lignocellulosic Biomass to Fuels and Chemicals,” The Annual Review of Chemical and Biomolecular Engineering 2 (2011): 121-1435, http://www.annualreviews.org/doi/abs/10.1146/annurev-chembioeng-061010-114205.

Integration and Scale-Up

Investigating pretreatment and enzymatic hydrolysis technologies together with downstream synthesis can help identify the issues and opportunities for integration. Integration of biomass process steps in Process Demonstration Units and other user facilities can improve overall efficiency, reduce costs, and is a necessary precursor for scale-up activities. In addition, the effect of feed and process variations throughout the process must be understood to ensure robust, efficient biorefineries that produce fuels and products on a consistently cost-effective basis. Lessons learned from these activities will be shared with the biochemical conversion-related integrated biorefineries to promote technology transfer.

Table 2-4: Biochemical Conversion R&D Activity Summary

***Goal**: Develop commercially viable technologies for converting biomass feedstocks via biochemical routes into energy dense, fungible, liquid transportation fuels, as well as bioproducts, other chemical intermediates, and bioenergy*

WBS Element	Description	FY12 Performer(s)	Barrier(s) Addressed	Pathway(s) Addressed
Analysis and Sustainability	Develop integrated conversion process designs, assess techno-economic feasibility and progress, and evaluate sustainability/life-cycle impacts • Current to biochemical processes and alternatives • Biochemical and hybrid processes for advanced biofuels.	NREL, PNNL	Bt-K: Biological Process Integration	Agricultural Residue Processing Energy Crops Processing Forest Resources Processing Waste Processing Algae Processing
Feedstock Interface and Technologies	Develop feedstock specifications and processing systems that accommodate feedstock variability and optimize conversion processes • Validate the impacts of feedstock variability and preprocessing on biochemical conversion processes.	INL, NREL	Ft-J: Biomass Materials Properties Ft-M: Overall Integration, Bt-B: Biomass Variability Bt-G: Cellulase Enzyme Loading	
Conversion Interface and Technologies	R&D on the most promising technology routes based on life-cycle analyses (environmental and techno-economic) and preliminary investigation into new emerging routes • Reduce the current cost of biochemical conversion processes through R&D in pretreatment, fermentation, chemical processing, purification, and alternative/combined processes • Identify technically feasible next generation biochemical conversion processes including optimizing the integration between biochemical and thermochemical processes.	NREL, PNNL, ANL, ORNL, INL, Genomatica, Virent, Virdia, MBI, TEES	Bt-A: Biomass Fractionation Bt-B: Biomass Variability Bt-C: Biomass Recalcitrance Bt-D: Pretreatment Chemistry Bt-E: Pretreatment Costs Bt-G: Cellulase Enzyme Loading Bt-I: Cleanup/Separation Bt-J: Catalyst Development Bt-K: Biological Process Integration Bt-L: Biochemical/Thermochemical Processing Integration	
Conversion Enabling Technologies	Enhance existing enabling technologies, investigate promising improvements in non-route-specific unit operations, and develop non-route-specific conversion technologies • Develop new analytical methods and tools to enhance understanding of basic mechanisms in biomass conversion • Engage applied systems biology applications to address biochemical conversion-specific needs including new synthetic biological approaches that bring transformational improvements in conversion technologies.	NREL, PNNL	Bt-C: Biomass Recalcitrance Bt-J. Catalyst Development	
Scale-Up and Integration	Integrate unit operations and scale-up to reduce cost of sustainable biomass conversion to fuels • Integrate current biochemical conversion process unit operations • Fully integrate emerging biochemical conversion process unit operations to advanced biofuels • Identify needs of IBR projects and provide limited unit-operations-focused R&D to enable successful performance.	NREL, ANL, Virdia, Virent	Bt-K: Biological Process Integration Bt-L: Biochemical/ Thermochemical Processing Integration	

2.2.1.5 Prioritizing Biochemical Conversion Barriers

In order to achieve the Biochemical Conversion R&D goals, all of the challenges and barriers need to be addressed. However, the following issues are critical and will be emphasized within near- to mid-term Biochemical Conversion R&D efforts:

- Developing innovative approaches to biomass deconstruction that lower the cost of sugars and other intermediates
- Lowering/stabilizing enzyme costs
- Enabling high performance separations technologies
- Moving beyond fermentation-to-ethanol technologies by developing fermentative organisms, catalysts, and other hybrid biochemical conversion routes.

Although each of the deconstruction and conversion components of both the microbial and catalytic conversion pathways are still being evaluated in terms of costs and sustainability indicators, Table 2-5 shows example metrics against which Biochemical Conversion R&D results may be reported anticipating some of the technical barriers identified in the forthcoming report from the Conversion Technologies for Advanced Biofuels workshop.[23] The Office will also leverage findings from the updated 2011 Biochemical Design Report,[24] which incorporated developments in conversion and process integration research over the last decade and updated equipment and raw materials costs. Beyond 2017, the identification of new conversion options and tools from enabling research are expected to lead to a series of generations of improved technologies that will be developed, demonstrated, and ultimately deployed.

Table 2-5: Biochemical Conversion R&D Barrier Areas and Example Metrics

Barrier Area	Example Metrics (Change over Base SOT)
Deconstruction	
Pretreatment	Increase solids loading by x%
Hydrolysis	Increase yields of xylose by x%
Separations	Demonstrate a low-cost separation of monomeric sugars from hydrolysates at x scale
Intermediates Upgrading	
Metabolic Conversion	Improve the rate of biological conversion efficiency of cellulosic sugars to hydrocarbon fuels by engineering more active forms of sugar transporters in x production organism
Chemical Conversion	Improve the chemical conversion efficiency of cellulosic sugars to hydrocarbon fuels by improving catalyst specificity
Product Purification	Enhance the recovery of x fuel product from x% to y%
Process Intensification	Reduce the number of unit operations by combining hydrolysis with fermentation

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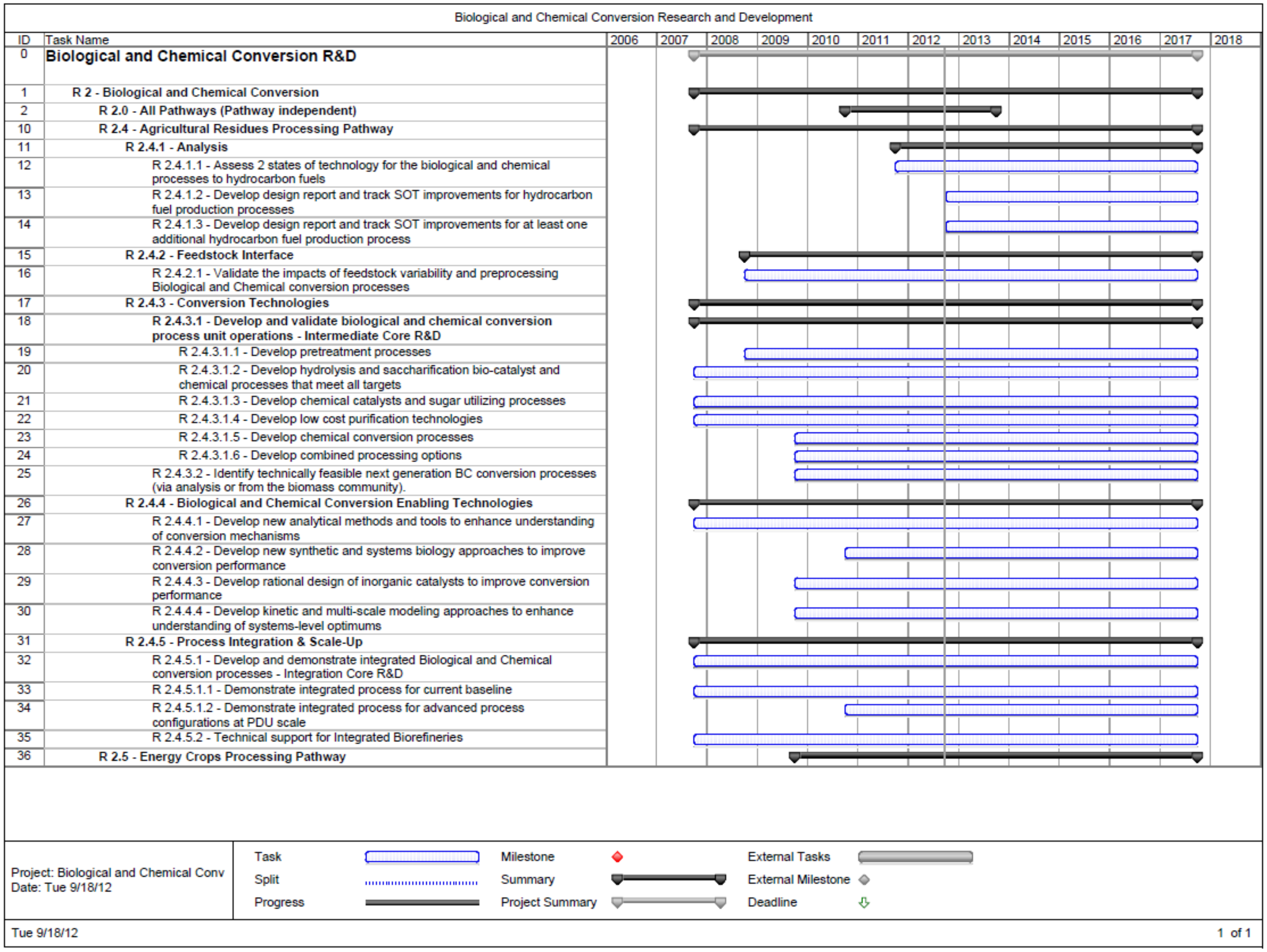
[23] U.S. Department of Energy, Conversion Technologies for Advanced Biofuels Workshop Report, 2013, Washington: Government Printing Office, Manuscript in preparation.

[24] Humbird, Davis, et al, "Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover."

2.2.1.6 Biochemical Conversion R&D Milestones and Decision Points

High-level Biochemical Conversion R&D tasks are summarized in Figure 2-17. A detailed overview of milestones, inputs/outputs, and decision points to complete these tasks will be included in a later edition.

Figure 2-17: Biochemical Conversion R&D Gantt



Biological and Chemical Conversion Research and Development

ID	Task Name
0	**Biological and Chemical Conversion R&D**
1	**R 2 - Biological and Chemical Conversion**
2	**R 2.0 - All Pathways (Pathway independent)**
10	**R 2.4 - Agricultural Residues Processing Pathway**
11	**R 2.4.1 - Analysis**
12	R 2.4.1.1 - Assess 2 states of technology for the biological and chemical processes to hydrocarbon fuels
13	R 2.4.1.2 - Develop design report and track SOT improvements for hydrocarbon fuel production processes
14	R 2.4.1.3 - Develop design report and track SOT improvements for at least one additional hydrocarbon fuel production process
15	**R 2.4.2 - Feedstock Interface**
16	R 2.4.2.1 - Validate the impacts of feedstock variability and preprocessing Biological and Chemical conversion processes
17	**R 2.4.3 - Conversion Technologies**
18	**R 2.4.3.1 - Develop and validate biological and chemical conversion process unit operations - Intermediate Core R&D**
19	R 2.4.3.1.1 - Develop pretreatment processes
20	R 2.4.3.1.2 - Develop hydrolysis and saccharification bio-catalyst and chemical processes that meet all targets
21	R 2.4.3.1.3 - Develop chemical catalysts and sugar utilizing processes
22	R 2.4.3.1.4 - Develop low cost purification technologies
23	R 2.4.3.1.5 - Develop chemical conversion processes
24	R 2.4.3.1.6 - Develop combined processing options
25	R 2.4.3.2 - Identify technically feasible next generation BC conversion processes (via analysis or from the biomass community).
26	**R 2.4.4 - Biological and Chemical Conversion Enabling Technologies**
27	R 2.4.4.1 - Develop new analytical methods and tools to enhance understanding of conversion mechanisms
28	R 2.4.4.2 - Develop new synthetic and systems biology approaches to improve conversion performance
29	R 2.4.4.3 - Develop rational design of inorganic catalysts to improve conversion performance
30	R 2.4.4.4 - Develop kinetic and multi-scale modeling approaches to enhance understanding of systems-level optimums
31	**R 2.4.5 - Process Integration & Scale-Up**
32	R 2.4.5.1 - Develop and demonstrate integrated Biological and Chemical conversion processes - Integration Core R&D
33	R 2.4.5.1.1 - Demonstrate integrated process for current baseline
34	R 2.4.5.1.2 - Demonstrate integrated process for advanced process configurations at PDU scale
35	R 2.4.5.2 - Technical support for Integrated Biorefineries
36	**R 2.5 - Energy Crops Processing Pathway**

Project: Biological and Chemical Conv
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2.2.2 Thermochemical Conversion Research & Development

Conversion R&D on thermochemical conversion technologies is grouped around two major areas, Bio-Oil Pathways R&D and Gaseous Intermediate Pathways R&D.

2.2.2.1 Bio-Oil Pathways Research & Development

Research and development of bio-oil pathways focuses on technology to convert biomass to fuels (including transportation fuels and heating oils), chemicals, and power via direct liquefaction-based processes, such as fast pyrolysis, catalytic fast pyrolysis (ex-situ and in-situ), hydrothermal liquefaction, solvent liquefaction, hydropyrolysis, and other alternative processes. Process intermediates from liquefaction technologies primarily include bio-oil (a liquid product from pyrolysis or liquefaction), bio-char (a solid product from liquefaction or gasification), and gases that may be used as fuel gas or for reforming. Bio-oil intermediates may be upgraded to products such as renewable gasoline, renewable diesel, renewable jet fuel, heating oil, chemical products, or high-purity hydrogen, or even used directly for heat and power generation. R&D efforts focus on direct liquefaction-based processes, as well as the upgrading of bio-oil intermediates, to produce direct substitutes for fossil-fuel-based intermediates and products that are compatible with existing fossil fuel processing and distribution infrastructure.

Bio-oil pathways have the potential to maximize biomass resource utilization to produce biofuels because they can convert biomass resources with high lignin fractions such as woody feedstocks and the lignin-rich non-fermentable residues from biochemical conversion processes, as well as algae-based feedstock at high-moisture contents. Advanced conversion technology scenarios rely on considerable liquid fuel yield per ton of biomass and enable higher overall energy efficiencies by allowing integration of high-efficiency heat and power production systems.

Bio-Oil Pathways Conversion Processing Steps

A simple bio-oil pathway for converting biomass to transportation fuels such as renewable gasoline, jet fuel, and diesel, or to power applications such as heating/fuel oil is shown in Figure 2-18 below. Process details for producing renewable gasoline and diesel from woody biomass via fast pyrolysis with bio-oil stabilization and upgrading are available in a 2009 design report.[25]

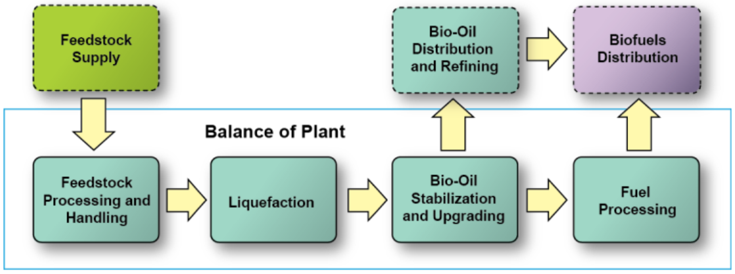

Figure 2-18: Bio-Oil Pathways Route for Biomass to Biofuels

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[25] SB Jones, C Valkenburg, CW Walton, et al, "Production of Gasoline and Diesel from Biomass Via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case," Pacific Northwest National Laboratory, PNNL-18284 (2009), http://www.pnl.gov/main/publications/external/technical_reports/pnnl-18284.pdf.

Feed Processing and Handling: The feedstock interface for the bio-oil pathway addresses the main biomass properties that affect the long-term technical and economic success of liquefaction conversion processes: moisture content, elemental composition, impurity concentrations, particle size, particle porosity, and ash content. High moisture and ash content reduce the usable fraction of delivered biomass. Most liquefaction processes require dry feedstocks, while hydrothermal and solvent liquefaction approaches can use biomass at high moisture percentages, such as algae.

Liquefaction: Liquefaction is the thermal or chemical decomposition of biomass to produce a bio-oil intermediate. Fast pyrolysis is typically performed at 400°C –550°C and atmospheric pressure and produces primarily liquid products together with some gases and bio-char. Catalytic fast pyrolysis employs a catalyst to produce a bio-oil with lower oxygen content than conventional fast pyrolysis bio-oil. Other liquefaction technologies include hydropyrolysis, hydrothermal liquefaction, and solvent liquefaction. Each technology produces bio-oils with varying characteristics and properties for oxygen content, water content, or viscosity that depend on the processing conditions.

Bio-Oil Stabilization and Upgrading: Bio-oil stabilization and upgrading involves mitigating reactive compounds to improve storage and handling properties. This encompasses the removal of water, char, and ash particulates, and destabilizing components such as metals and oxygenated species. Hydroprocessing and similar thermal-catalytic processing techniques reduce the total oxygen and acid content, thereby increasing stability. This processing is required before a bio-oil intermediate can be processed under conventional hydroprocessing conditions (e.g., high temperature/pressure) in a stand-alone biorefinery or before it can become a suitable feedstock for a petroleum refinery.

Fuel Processing: Hydroprocessing converts the stabilized bio-oil to hydrocarbons by eliminating oxygen. After such processing, the total fuel may be separated into renewable gasoline, jet fuel, diesel, or co-products, such as heating oil, using conventional technologies such as those employed by petroleum refiners. The hydroprocessing and separation of fuel cuts may leverage the economies of scale and the capital investments of the petroleum industry.

Balance of Plant: This encompasses the entire site and significant contributions are derived from the hydrogen generation and air- and water-operation. Cost reductions are attained through more efficient hydrogen usage and better usage of power, water, and process recycle streams.

Bio-Oil Pathways R&D Interfaces

Feedstock Supply Interface: Feedstock Supply R&D provides preprocessed feedstocks that meet the requirements (composition, quality, size, moisture content, etc.) as defined by the specific liquefaction conversion process at the biorefinery. Close coordination between Feedstock Logistics and Bio-Oil Pathways R&D is required to supply adequate feedstock in an appropriate quality and form to the biorefinery.

Bio-Oil Distribution and Refining: Two distribution options are being explored for the bio-oil pathway. One involves upgrading bio-oil for distribution to fuel markets. Under this scenario, bio-oil may be upgraded to a blendstock within a fully integrated biorefinery, or stabilized bio-oil may be produced at several locations then transported to a centralized upgrading facility for blendstock production and distribution to fuel markets. This is commonly referred to as a “hub and spoke” model, and it allows biofuel producers to take advantage of economies of scale for the centralized upgrading facility. The other option involves producing a bio-oil intermediate to be used as a petroleum refinery feedstock, leveraging existing infrastructure. Bio-Oil Pathways R&D provides information about the physiochemical properties, reactivities, and compatibilities of intermediates to petroleum refineries. Understanding and specifying bio-oil intermediate requirements for use in petroleum refineries and the limitations of the distribution infrastructure are critical.

Biofuels Distribution Infrastructure Interface: The next step in the biomass-to-biofuels supply chain is the distribution of the biofuels produced. The biofuel may be produced as a tradable intermediate bio-oil (for centralized refining such as a petroleum refinery feedstock) or as a fully finished, fungible fuel distributed through the market as a blend stock. Bio-Oil Pathways R&D provides information about bio-oil intermediates and biofuels compatibility with the existing petroleum infrastructure and fuels, as described above in Bio-Oil Distribution and Refining. Understanding miscibility and behavior of biofuels with existing petroleum-derived fuels and fuel handling systems/engines is particularly critical.

2.2.2.1.1 Bio-Oil Pathways R&D Support of Office Strategic Goals

The Bio-Oil Pathways R&D strategic goal is to *develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible liquid fuels, such as renewable gasoline, jet fuel, and diesel, bioproducts and chemical intermediates, and bioenergy.*

Bio-Oils Pathways R&D directly addresses and supports production of fuels from forest resources, energy crops, agricultural residues, dry sorted MSW, and other lignocellulosic feedstocks. The Office is also currently examining the use of bio-oil conversion technologies for the conversion of algae and algal oils to fuels. It also indirectly supports the production of bioproducts, such as chemicals and power, from these feedstocks. Bio-oil conversion technologies provide options for improving the economic viability of the developing bioenergy industry by their ability to convert whole biomass as well as the fractions of biomass resources that are not amenable to biological conversion technologies (e.g., lignin-rich process residues and other low-carbohydrate feedstock or process intermediates).

2.2.2.1.2 Bio-Oil Pathways R&D Support of Office Performance Goals

The Bio-Oil Pathways R&D performance cost goal, currently corresponding to a fast pyrolysis processing route, is to reduce the estimated mature technology processing cost for converting cellulosic feedstocks to advanced biofuels.

- By 2017, achieve a conversion cost of $1.83 per gallon of total blendstock ($1.73 /GGE, $2011) via a bio-oil pathway.

The above goal is based on a 2009 Design Case for fast pyrolysis of woody biomass to produce a combined gasoline and diesel blendstock, illustrated in Appendix B, Table B-7.[26] Additional techno-economic analyses are being performed to more accurately reflect the Office's diverse R&D portfolio that includes other direct liquefaction technologies (such as catalytic fast pyrolysis, hydrothermal liquefaction, solvent liquefaction, hydropyroylsis, etc.) with bio-oil processing schemes. The results of the techno-economic analysis will inform the selection of new design cases establishing out-year performance goals. These additional design cases will be peer reviewed and made public.

Performance milestones for the bio-oil pathways under investigation are as follows:

- By 2013, (Q4), define requirements for characterizing heating oil from biomass and establish an R&D strategy.
- By 2014 (Q4) establish out-year (2017, 2022) cost goals and technical targets based on completed techno-economic analysis for two additional bio-oils technology pathways.
- By 2015, (Q4), validate bench scale, semi-integrated conversion processes for a "high impact" biomass feedstock to renewable gasoline or diesel via a direct liquefaction conversion process with bio-oil processing to a finished fuel at a scale sufficient enough for transfer to pilot-scale operation to support the 2017 targets.
- By 2017, (Q4), validate fully integrated, pilot scale conversion processes for a "high impact" biomass feedstock to renewable gasoline or diesel via a direct liquefaction conversion process with bio-oil processing to a finished fuel.

2.2.2.1.3 Bio-Oil Pathways R&D Technical Challenges and Barriers

Tt-A. Feeding Dry Biomass: For dry biomass, improved processes are needed to produce feedstocks with quality specifications optimized for conversion technologies. Investigating a range of feedstock formats, such as those produced by densification, that enables access to larger volumes of feedstock supply and improves logistics costs on a national scale is also critical. Additionally, evaluating the performance of these feedstock formats in high pressure feed systems is imperative to reducing technical risks to commercial scale-up.

Tt-B. Feeding or Drying Wet Biomass: Understanding the costs and trade-offs for drying or feeding wet biomass feedstock or wet lignin-rich fermentation residues into reactor systems is important. Innovative dryer designs capable of utilizing low-value process heat will be essential for industry to meet techno-economics for commercial scale-up.

Tt-E. Liquefaction of Biomass and Bio-Oil Stabilization: The liquefaction of biomass has been studied for some time; however, the resulting bio-oil is unstable and highly reactive. Improvements in processing—with or without catalysts—are needed to yield higher quality bio-oil that will lower subsequent upgrading costs that allows for greater commercial viability. New methods and catalysts to clean and stabilize the bio-oil are needed to ensure the product is less reactive and stable; these advances include improved catalysts for deoxygenation and techniques for removal of solids from bio-oil.

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[26] Ibid.

Tt-G. Fuel Synthesis and Upgrading: Hydroprocessing catalysts that are highly selective to desired end products and stable in the presence of impurities are coveted. Bio-oils are known to have deleterious effects on catalysts after minimal processing. Therefore, it is important to develop catalysts with long steady-state operability while maintaining high product yields. The development of catalysts for upgrading and hydrotreating bio-oils to produce liquid transportation fuels is vital for the success of these processes. Bio-oils may be upgraded to different levels, allowing several entry points to a petroleum refinery.

Tt-I. Sensors and Controls: Effective process control will be needed to maintain plant performance and regulate emissions at target levels with varying load, fuel properties, and atmospheric conditions. Commercial control systems need to be developed and tested for thermochemical processes and systems.

Tt-K. Bio-Oil Pathways Process Integration: Bio-oil conversion process integration currently presents large scale-up risks because of a lack of high-quality controlled process data on integrated systems over extended periods of time that would be required of industrial scale operations. The effect of feed and process variations must be understood to ensure efficient and reliable biorefinery operations. Process integration work is essential for characterizing the complex interactions that exist between many of the processing steps, identifying impacts of trace components on catalytic and thermal systems, and enabling the generation of predictive engineering models that can guide process optimization and scale up.

2.2.2.1.4 Bio-Oil Pathways R&D Approach for Overcoming Challenges and Barriers

The Bio-Oil Pathways R&D approach for overcoming the above mentioned technical challenges and barriers is outlined in the WBS shown in Figure 2-19. Bio-Oil Pathways R&D is organized around five key areas: Analysis and Sustainability, Feedstock Interface, Conversion Technologies, Conversion Enabling Technologies, and Integration and Scale-Up.

The Office currently has R&D investments in multiple biomass liquefaction conversion processes and bio-oil processing technologies for the production of renewable gasoline, diesel, and jet fuel, as well as co-products such as chemicals and power (i.e. heating oil). The Office's current design case for a bio-oil pathway is based on fast pyrolysis of woody feedstocks to support the 2017 goal.

R&D to overcome the related challenges and barriers are performed by national laboratories, industry, non-profits, and universities. The National Advanced Biofuels Consortium (NABC) and National Alliance for Advanced Biofuels and Bio-Products (NAABB) established under ARRA are also conducting bio-oil conversion research and development. The National Renewable Energy Laboratory (NREL) and Pacific Northwest National Lab (PNNL) have various thermochemical processing user facilities that enable the Office to conduct integrated bench and pilot scale testing on bio-oil production and upgrading to validate the cost projections in the design case and update the state of technology accordingly.

The Bio-Oil Pathways R&D WBS illustrated in Figure 2-19 is described below. Table 2-6 summarizes each task element's work as it relates to specific R&D barriers and biorefinery pathways.

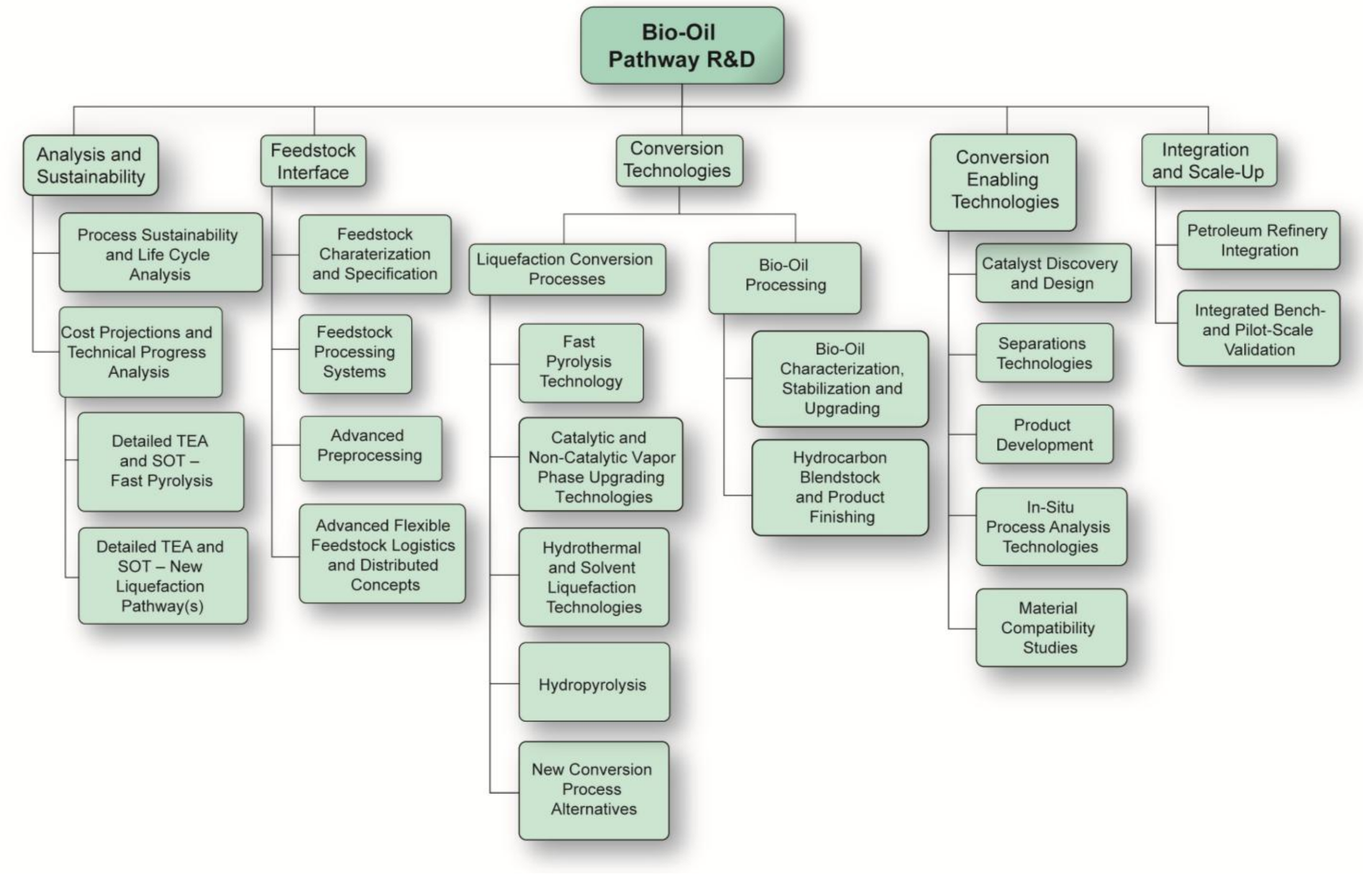

Figure 2-19: Work Breakdown Structure for Bio-Oil Pathways R&D

Analysis and Sustainability (Barriers St-C, St-D, Tt-K)

Modeled, integrated conversion process designs are developed to assess techno-economic feasibility and progress, evaluate life-cycle impacts, and improve sustainability of each feasible bio-oil pathway. Experimental data are obtained from DOE-funded R&D projects (including the national laboratory user facilities) and publicly available sources to monitor progress against cost projections and direct future research efforts. Techno-economic and process data from integration and scale-up efforts can be used to validate existing models, inform state of technology updates, and verify the accuracy of modeled cost projections.

Feedstock Interface (Barriers Tt-A, Tt-B)

For biorefineries, it is important that feedstock specifications be met while feedstock processing requirements are minimized to reduce costs. Specifically, the key challenges will be to efficiently transport and handle biomass as well as economically preprocess biomass to the required moisture content, ash content, and particle size to enable process optimization. One strategy to address this problem involves assessing the utility of densified feedstock for optimizing bio-oil production and upgrading processes to finished fuels. This requires balancing the cost of plant-gate feedstock with the handling and preprocessing required for reliable and sustainable operation. Research activities also encompass handling, processing, and feeding that occur within the biorefinery plant boundaries. Relevant feedstock interface R&D for the production of biofuels may also be utilized by biopower technologies.

Conversion Technologies (Barriers Tt-E, Tt-G,)
Research and development for liquefaction technologies includes processing techniques such as fast pyrolysis, catalytic fast pyrolysis, vapor phase upgrading, hydropyrolysis, and solvent liquefaction technologies (such as hydrothermal liquefaction). Research needs in bio-oil processing encompass improving yields and bio-oil quality, mitigating destabilizing components, catalytic deoxygenation of bio-oils, corrosion and material compatibility studies, and development of catalysts for hydroprocessing to produce bio-oil intermediates suitable for petroleum refinery feedstocks or to yield finished hydrocarbon biofuels. For these technologies, processes for recovering carbon and/or hydrogen from aqueous and/or gas phase streams are being developed to maximize energy efficiency.

Conversion Enabling Technologies (Barriers Tt-E, Tt-G)
The need to develop the next generation of catalysts for conversion of biomass and conditioning of bio-oils is critical in the advancement of biomass processing technologies. Understanding and more accurately measuring catalyst activities, selectivities and deactivation processes, and gaining insights into the synergistic roles of elemental species within the active catalytic sites will enable development of new processes that are more energy, carbon, and cost-efficient. These mechanisms will be informed using tools developed by DOE’s Office of Science and leveraged for catalyst development and techno-economic analysis needs.

Integration & Scale-Up (Barriers Tt-A, Tt-B, Tt-E, Tt-G, Tt-I, Tt-K)
Integration and scale-up efforts enable validation of processes economics (at a relevant scale) and verify Office targets. Validation of integrated processes is essential in order to identify potential process and scale-up challenges at the earlier (and less expensive) stages of R&D, therein reducing commercialization risks. If these potential problems are not corrected or remain unidentified, it is unlikely that a future commercial plant will achieve profitability. Immediate goals include demonstrating that improved liquefaction conversion technologies and upgrading processes for bio-oils are cost competitive with their petroleum based-counterparts. The Office leverages industry feedback to understand emerging issues and R&D opportunities. Bio-Oil Pathways R&D also supports the Office’s Demonstration and Deployment Technology Area by identifying emerging integrated biorefinery projects and synergistic R&D.

Table 2-6: Bio-Oil Pathways R&D Activity Summary

<u>Goal</u>*: *Develop competitively viable technologies for converting biomass feedstocks into energy dense, fungible liquid fuels, such as renewable gasoline, renewable jet fuel, and renewable diesel, bioproducts and chemical intermediates, and bioenergy .

WBS Element	Description	FY2012 Performer	Barrier(s) Addressed	Pathway(s) Addressed
Analysis and Sustainability	Develop integrated conversion process designs, assess techno-economic feasibility and progress, and evaluate sustainability / life-cycle impacts • Fast pyrolysis conversion pathway • Catalytic fast pyrolysis pathway • Hydrothermal liquefaction, Solvent liquefaction pathways • Hydropyrolysis pathway • New conversion process pathways.	NREL, PNNL	St-C: Sustainability Data St-D: Sustainability Indicators and Methodology Tt-K: Bio-Oil Process Integration	Agricultural Residue Processing Energy Crops Processing Forest Resources Algae Processing Waste Processing
Feedstock Interface and Technologies	Develop feedstock specifications and processing systems that accommodate feedstock variability and optimize conversion processes • Mechanically, and chemically characterize the feedstocks and develop optimal feedstock and blending specifications • Develop feedstock processing systems for optimal yields and selectivity.	INL, ORNL	St-C: Sustainability Data Tt-A: Feeding Dry Biomass Tt-B: Feeding or Drying Wet Biomass	
Conversion Interface and Technologies	Research and development into most promising technology pathways based on techno-economic analysis and preliminary investigation into new emerging routes • Develop fast pyrolysis conversion processes including pyrolysis oil upgrading and stabilizing and fuel processing systems • Develop catalytic fast pyrolysis and hydropyrolysis conversion processes • Develop hydrothermal and solvent liquefaction conversion processes.	NREL, PNNL, Iowa State University, Research Triangle Institute, Virent, University of Massachusetts Amherst, GTI, W.R. Grace, NABC, NAABB	St-C: Sustainability Data Tt-G: Catalyst Development Tt-H: Validation of 2017 Cost Target Tt-I: Sensors and Controls Tt-E: Pyrolysis of Biomass and Bio-Oil Stabilization	
Conversion Enabling Technologies	Enhance existing enabling technologies, investigate non-route-specific promising unit operations improvements and develop non-route-specific conversion technologies • Develop catalysis technologies for improved catalyst lifetime and function • Investigate and develop pretreatment enhancement to downstream yields. • Develop reforming processes for recovering carbon and/or hydrogen from aqueous phase streams • Understand corrosion mechanisms and eliminate problematic molecular functionality • Products development.	NREL, PNNL, ORNL, GTI, W.R. Grace, Research Triangle Institute, DOE's Office of Science	Tt-E: Pyrolysis of Biomass and Bio-Oil Stabilization Tt-G: Catalyst Development Tt-I: Sensors and Controls	
Scale-Up and Integration	Integrate unit operations and scale up to reduce cost of sustainable biomass conversion to fuels • Fully integrate liquefaction to bio-oil-to-fuel system • Fully integrate other emerging thermochemical process alternatives • Identify needs of IBR projects and provide limited unit operations focused R&D to enable successful performance.	NREL, PNNL, RTI, GTI, UOP, Avello	Tt-A: Feeding Dry Biomass Tt-B: Feeding or Drying Wet Biomass Tt-E; Pyrolysis of Biomass and Bio-Oil Stabilization Tt-G: Catalyst Development Tt-H: Validation of 2017 Cost Target Tt-I: Sensors and Controls Tt-K: Bio-Oil Process Integration	

2.2.2.1.5 Prioritizing Bio-Oil Pathways R&D Barriers

The Bio-Oil Pathways R&D has prioritized its efforts in overcoming technical barriers based on techno-economic analysis and stakeholder workshops, such as the Conversion Technologies for Advanced Biofuels.[27] In order to achieve the Bio-Oil Pathway's conversion goals, all of the challenges and barriers need to be addressed. However, the following three high-impact research areas with engineering and/or catalysts as critical aspects to R&D success are:

- Quality of bio-oil intermediates
- Hydrothermally stable catalysis and/or processing of bio-oils
- Maximizing carbon utilization (e.g., recovery/conversion of carbon from aqueous phases).

The design case analysis results for a bio-oil pathway utilizing fast pyrolysis of woody biomass, followed by hydroprocessing, are illustrated below in Figure 2-20 and Table 2-7.[28]

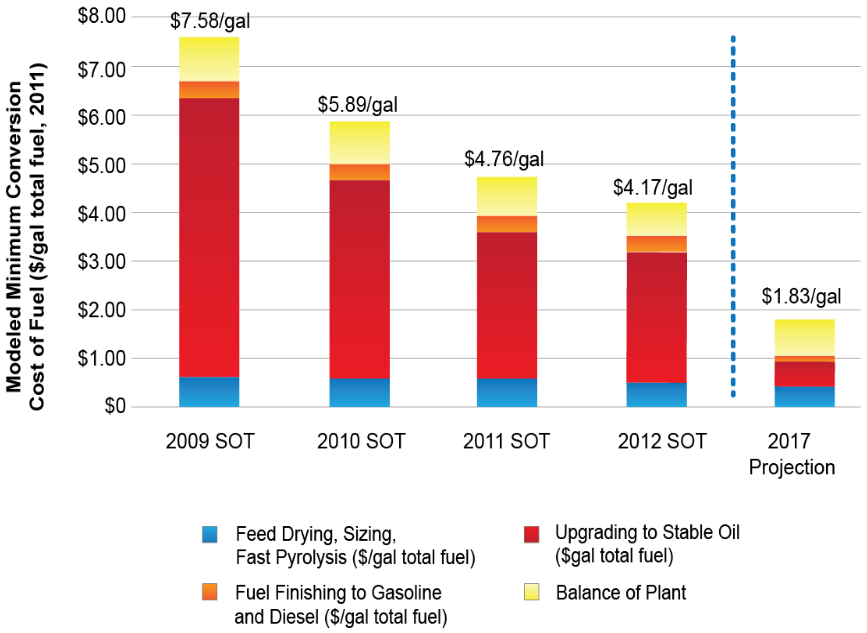

Figure 2-20: Conversion of Woody Feedstocks to Renewable Gasoline and Diesel Blend Stocks via Fast Pyrolysis

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[27] U.S. Department of Energy, *Conversion Technologies for Advanced Biofuels Workshop Report*.

[28] Jones, Valkenburg, Walton, et al, "Production of Gasoline and Diesel from Biomass Via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case."

Table 2-7: Conversion of Woody Feedstocks to Renewable Gasoline and Diesel Blend Stocks via Fast Pyrolysis

2011 Dollars	2009 SOT	2010 SOT	2011 SOT	2012 SOT	2017 Projection
Conversion Contribution ($/gal gasoline)	**$7.55**	**$5.86**	**$4.73**	**$4.15**	**$1.83**
Conversion Contribution ($/gal diesel)	**$7.61**	**$5.92**	**$4.78**	**$4.20**	**$1.83**
Conversion Contribution ($/GGE total fuel)	**$7.19**	**$5.59**	**$4.51**	**$3.95**	**$1.73**
Fast Pyrolysis ($/gal total fuel)	$0.62	$0.61	$0.60	$0.50	$0.39
Upgrading to Stable Oil ($/gal total fuel)	$5.70	$4.05	$3.00	$2.69	$0.55
Fuel Finishing to Gasoline and Diesel ($/gal total fuel)	$0.35	$0.34	$0.33	$0.33	$0.13
Balance of Plant ($/gal total fuel)	$0.91	$0.89	$0.83	$0.66	$0.75

Figure 2-20 shows that a total potential reduction of 75% can be achieved with improvements in all four areas. R&D activities are focused to impact this cost. In 2013, the fast pyrolysis design case is being re-examined to ensure the optimal cost-, carbon-, and energy-efficiency; early results suggest that the fast pyrolysis cost goals may increase. In addition to fast pyrolysis, other bio-oil pathways will be examined as design case options.

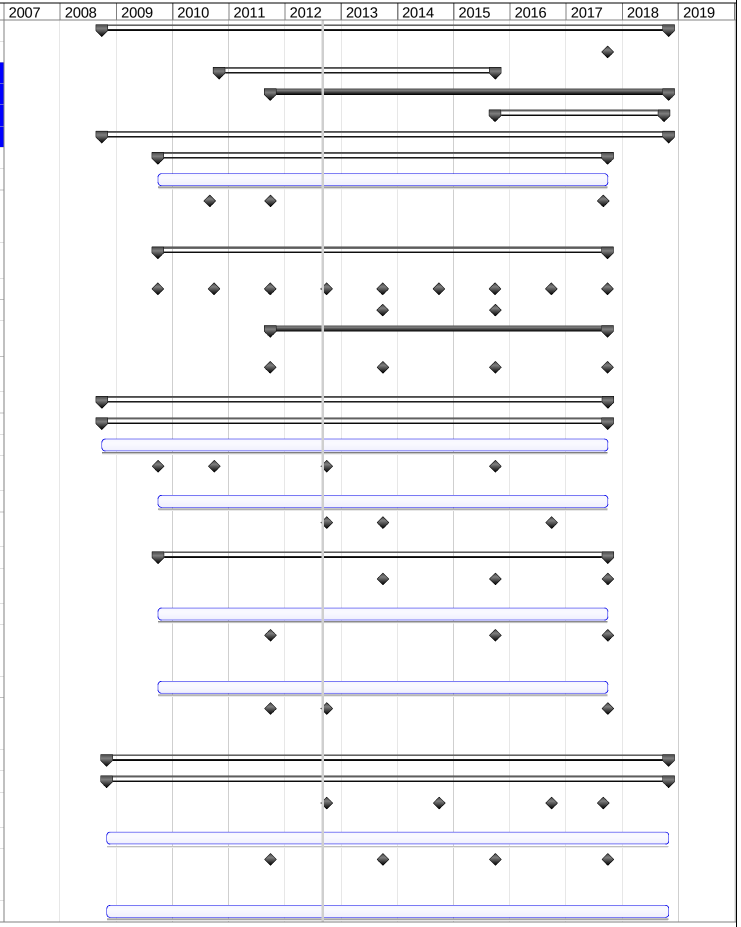
Current state of technology projections are based on pyrolysis of woody feedstocks, bio-oil stabilization, and fuel finishing to gasoline and diesel. The projections are modeled production costs at 2,000 DT feedstock/day of an n^{th} plant using the available literature data and experimental data from PNNL for bench-scale fast pyrolysis and subsequent hydrotreating R&D. Initial summary information on the technical performance projections for the pyrolysis conversion system design is provided in Appendix B, Table B-5.

2.2.2.1.6 Bio-Oil Pathways R&D Milestones and Decision Points

The key Bio-Oil Pathways R&D milestones, inputs/outputs, and decision points to complete the tasks described in Section 2.2.2.1.4 are summarized in the chart in Figure 2-21. Figure 2-21 will be updated in the next MYPP revision to more accurately reflect other liquefaction technologies currently in the Office’s R&D portfolio in addition to fast pyrolysis, such as fast catalytic pyrolysis (ex-situ and in-situ), hydrothermal and solvent liquefaction, hydropyrolysis, and other new conversion processes as shown in Figure 2-19.

Figure 2-21: Bio-Oil Pathways R&D Gantt

Bio-Oils Pathway RFri 8/31/12



ID	Task Name
1	**R 3 - Bio-oil Pathways R&D**
2	R 3.M.1 - 2017: Achieve conversion cost of $.156/gallon of total blendstock ($1.47/GGE) (2007$).
4	**R 3.0 - All Pathways (Pathway independent)**
15	**R 3.4 - Agricultural Residues**
124	**R 3.5 - Energy Crops (Herbaceous)**
200	**R 3.6 - Forest Resource Processing Pathway**
201	**R 3.6.1 - Analysis**
202	R 3.6.1.1 - Assess bo-oil pathways sustainability
203	R 3.6.1.1 M - 2010: Develop sustainability metrics. 2011: Assess process design sustainability. 2017: Assess fuel production LCA and sustainability relative to 932 projects data
207	**R 3.6.1.3 - Develop design report and track SOT improvements for Pyrolysis Conversion Route**
208	R 3.6.1.3.M.1 - Annual SOT report delivered annually 2009-2017
218	R 3.6.1.3.M.2 - 2013: Updated design reports. 2015 Updated Design Reports
221	**R 3.6.1.4 - Develop design report and track SOT improvements for new/emerging Bio-oil Pathways processes**
222	R 3.6.1.4.M.1 - 2011: Cost, energy and atom efficiencies of new concepts presented as needed on a comparable basis. 2013: Updated. 2015: Updated. 2017: Updated.
227	**R 3.6.2 - Feedstock-Bio-oil Pathways Interface**
228	**R 3.6.2.1 - Develop Feedstock Characterization Specifications**
229	R 3.6.2.1.2 - Develop feedstock specific specifications for pyrolysis
230	R 3.6.2.1.2.M.1 - 2009: initial database of specifications developed for pyrolysis. 2010: Woody feedstocks report published. 2012: Specifications updated for pyrolysis.
235	R 3.6.2.1.3 - Develop specifications for new emerging conversion processes.
236	R 3.6.2.1.3.M.1 - 2012: Specifications developed for hydrothermal liquefaction. 2013: specifications for aqueous phase reforming.
240	**R 3.6.2.2 - Develop Feedstock Processing Systems**
241	R 3.6.2.2.M.1 - 2013: Process sustainability assessed. 2015: Process sustainability assessed. 2017: Process sustainability assessed.
245	R 3.6.2.2.1 - Develop feedstock processing for wet biomass
246	R 3.6.2.2.1.M.1 - 2011: Feedstock composition specifications compiled. 2013: Design feeding system for wet conversion system. 2017: bench scale optimization of wet woody biomass processing.
250	R 3.6.2.2.2 - Develop dry biomass feedstock processing
251	R 3.6.2.2.2.M.1 - 2011: Feedstock composition specifications compiled. 2012 Feedstock process and delivery system designed. 2017: Feedstock processing and delivery system for pyrolysis reactors built and demonstrated.
255	**R 3.6.3 - Conversion Technologies**
256	**R 3.6.3.2 - Develop Pyrolysis Conversion Processes**
257	R 3.6.3.2.M.1 - 2012, 2014, 2016: Sustainaiblity of process assessed. 2017: Fast pyrolysis conversion of woody feedstocks to drop in fuels optimized.
262	R 3.6.3.2.1 - Develop Fast Pyrolysis Technology
263	R 3.6.3.2.1.M.1 - 2011: Baseline engineering model developed. 2013: PDU process validated. 2015: stabilization with acceptable catalyst. 2017: Integrated and optimized system demonstrated at PDU scale.
268	R 3.6.3.2.2 - Develop cleanup & conditioning processes (upgrading and stabilizing)

Project: Bio-Oils Pathway RFri 8/31/12
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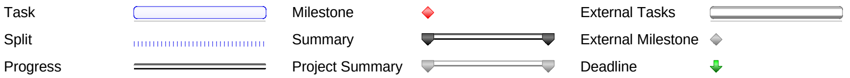

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Bio-Oils Pathway RFri 8/31/12

ID	Task Name
1	**R 3 - Bio-oil Pathways R&D**
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124	**R 3.5 - Energy Crops (Herbaceous)**
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207	**R 3.6.1.3 - Develop design report and track SOT improvements for Pyrolysis Conversion Route**
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221	**R 3.6.1.4 - Develop design report and track SOT improvements for new/emerging Bio-oil Pathways processes**
222	R 3.6.1.4.M.1 - 2011: Cost, energy and atom efficiencies of new concepts presented as needed on a comparable basis. 2013: Updated. 2015: Updated. 2017: Updated.
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235	R 3.6.2.1.3 - Develop specifications for new emerging conversion processes.
236	R 3.6.2.1.3.M.1 - 2012: Specifications developed for hydrothermal liquefaction. 2013: specifications for aqueous phase reforming.
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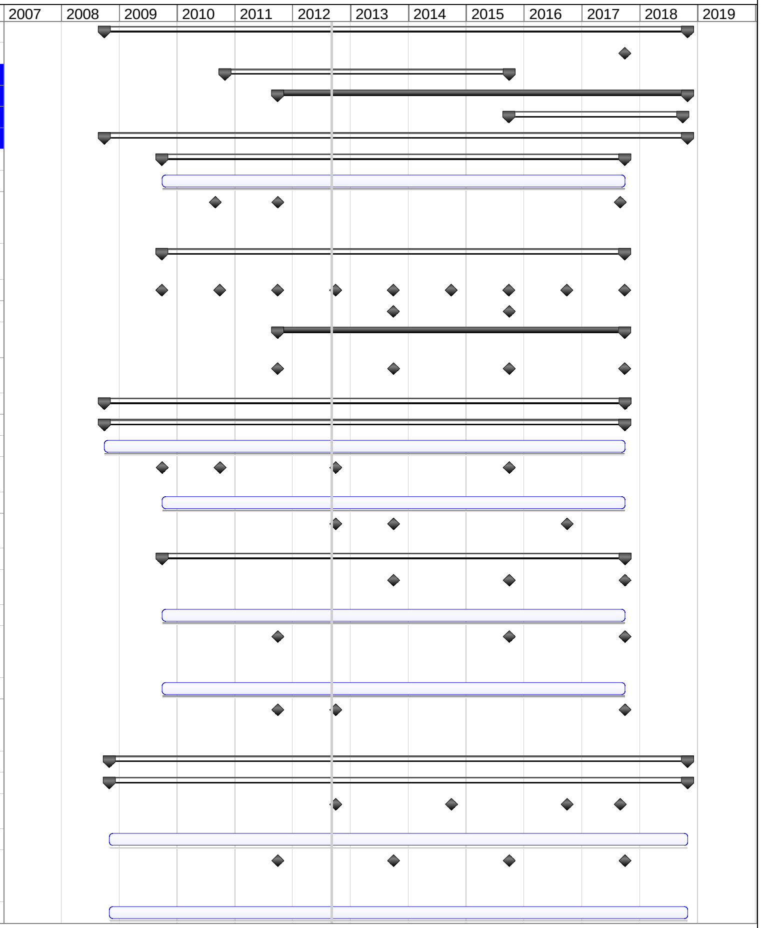
268	R 3.6.3.2.2 - Develop cleanup & conditioning processes (upgrading and stabilizing)



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Task	▭	Milestone	◆	External Tasks	▭
Split	┆┆┆┆┆┆	Summary	▬	External Milestone	◇
Progress	▬	Project Summary	▬	Deadline	⇩

2.2.2.2 Gaseous Intermediate Pathways Research & Development

The Bioenergy Technologies Office's Gaseous Intermediate Pathways (indirect liquefaction) R&D focuses on developing technology that converts biomass to a gaseous intermediate (e.g., synthesis gas, synthetic natural gas), or other intermediates for the production of fuels, chemicals, and power. Synthesis gas (primarily hydrogen and carbon monoxide) is generated via gasification of biomass or MSW. Synthetic natural gas (primarily methane) is generated by processes such as catalytic hydrothermal gasification or anaerobic digestion. Synthetic natural gas may also be obtained from landfill gas. Each of these gaseous intermediates may be further converted to fuels or chemicals via biological and/or catalytic processes.

Gaseous Intermediate Conversion Process Description

A simplified gaseous intermediate process flow to convert biomass to biofuels is shown in Figure 2-22. This biomass indirect liquefaction process encompasses various methods to produce a high-quality gaseous intermediate that is suitable for upgrading to liquid fuels or chemical products. While further R&D is needed for several of the process steps, the Office will focus efforts on those that have the highest impact (as appropriations allow). Each process block is discussed below.

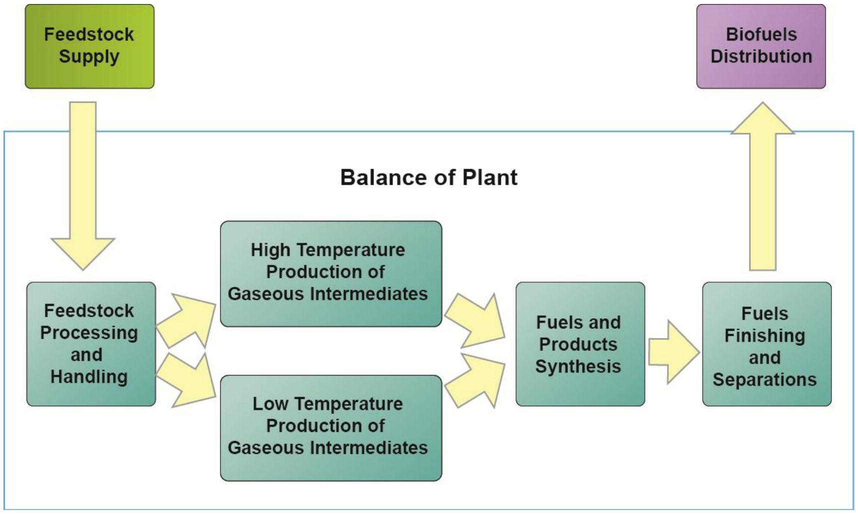

Figure 2-22: Gaseous Intermediate Route for Biomass to Biofuels

Feed Processing and Handling: Cost and quality of biomass feedstock can greatly affect the economics and quality of the gaseous intermediates and the final fuel or product. The feedstock interface examines and optimizes the main biomass properties that affect the long-term technical and economic success of a gaseous intermediate conversion process: moisture content, fixed carbon and volatiles content, impurity concentrations, and ash content. For example, high moisture and ash content reduce the usable fraction of delivered biomass in high-temperature gaseous intermediate conversion processes. Solids concentration, pH, and feedstock composition can affect the efficiency of low-temperature gaseous intermediate conversion processes.

High-Temperature Production of Gaseous Intermediates: Clean gaseous intermediates are produced by deconstructing biomass (e.g., gasification, catalytic gasification,) followed by gas clean up and conditioning. As an example, biomass gasification is a high-temperature conversion process that begins with the rapid thermal decomposition of a lignocellulosic feedstock. This is followed by partial oxidation or reforming of the biomass with a gasifying agent—usually air, oxygen, or steam—to yield raw syngas. This all occurs within the same reactor within seconds. The raw gas composition and quality are dependent on a range of factors, including feedstock composition, type of gasification reactor, gasification agents, stoichiometry, temperature, pressure, and the presence or lack of catalysts. Gas cleanup is the removal of contaminants from biomass-derived synthesis gas. It involves an integrated multi-step approach that varies depending on the intended end use of the product gas. However, gas cleanup normally entails removing or reforming tars and acid gas, ammonia scrubbing, capturing alkali metal, and removing particulates. Typical gas conditioning steps include sulfur polishing (to reduce levels of hydrogen sulfide to acceptable amounts for fuel synthesis) and water-gas shift (to adjust the final hydrogen-carbon monoxide ratio for optimized fuel synthesis).

Low-Temperature Production of Gaseous Intermediates: Low-temperature gaseous intermediate conversion processes include biological (e.g., landfill gas, anaerobic digestion) and catalytic deconstruction processes. While the deconstruction mechanisms may differ widely, many low-temperature deconstruction processes yield lower BTU (compared to natural gas) synthesis gas or methane, in addition to low concentrations of other gases such as carbon monoxide and carbon dioxide. As with high-temperature production of gaseous intermediates, some gas cleanup and conditioning may be required for catalytic or biological synthesis of fuels and products. Catalytic hydrothermal gasification, applicable to a wide range of organic-in-water mixtures, is a useful means to recover the energy value of the organics as a fuel gas and allows for reuse of the water and dissolved nutrients. It is an energy-efficient process that can be used with various wet biomass feedstocks and byproduct aqueous stream from biomass conversion processes.

Fuels Synthesis: Clean gaseous intermediates may be converted to fuels via biological organisms (e.g., syngas fermentation) or catalytic processes (e.g., Fischer-Tropsch synthesis). The production of fungible liquid transportation fuels from these intermediates also yields high-value biobased byproducts and chemicals. Since catalytic fuel synthesis is typically exothermic, heat recovery is essential to maximize the process efficiency.

Balance of Plant: Balance of plant encompasses the entire site and its need for integrated and effective energy, heat, steam, and water usage. Pinch analysis is used to analyze the energy network of the process and optimize energy integration of the process. Cost reductions are attained through better usage of the waste heat stream.

Gaseous Intermediates Conversion Interfaces

Feedstock Interface: Feedstock Logistics R&D provides preprocessed feedstock that meets the requirements (composition, quality, size, moisture content, etc.), as defined by the specific gaseous intermediate conversion process configuration. Close coordination between Feedstock Logistics and Gaseous Intermediate Pathways R&D is required to supply adequate feedstock in an appropriate quality and form to the biorefinery.

Biofuels Distribution Infrastructure Interface: The next step in the biomass-to-biofuels supply chain is the distribution of the biofuels produced. Gaseous Intermediates Pathway R&D provides information about physical properties, reactivities, and compatibilities of intermediates and biofuels to the Distribution Infrastructure and End Use Technology Area, while working to understand and specify requirements and limitations of distribution infrastructure and end use on the biofuels and intermediates being developed.

2.2.2.2.1 Gaseous Intermediate Pathways R&D Support of Office Strategic Goals

The Gaseous Intermediate Pathways R&D strategic goal is to *develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible liquid fuels, such as, renewable gasoline, jet fuel, and diesel, bioproducts and chemical intermediates, and bioenergy.*

Gaseous Intermediate Pathways R&D directly addresses and supports the production of fuels from forest resources, organic fraction of MSW, energy crops, algae, and agricultural residue. It also indirectly supports the production of bioproducts. Gaseous intermediates conversion technologies provide options for improving the economic viability of the developing bioenergy industry because they can convert whole biomass, as well as the fractions of the biomass resources that are not amenable to biochemical conversion technologies (e.g., lignin-rich process residues and other low-carbohydrate feedstocks or process intermediates).

2.2.2.2.2 Gaseous Intermediate Pathways R&D Support of Office Performance Goals

The Gaseous Intermediate Pathways R&D overall performance goal is to reduce the estimated mature technology processing cost[29] for converting cellulosic feedstocks to advanced biofuels:

- By 2022, achieve the overall Office performance cost goal of $3/GGE ($2011) via catalytic upgrading of biomass synthesis gas to gasoline and diesel range hydrocarbons.

Milestones towards accomplishment of those performance goals include:

- By 2014, (Q4), establish out-year cost goals and technical targets, based on completed techno-economic analysis, for at least one gaseous intermediate conversion to hydrocarbon fuels pathway.
- By 2022, (Q4), validate integrated conversion process for woody biomass to renewable gasoline or diesel via conversion of gaseous intermediates at a scale sufficient enough for transfer to pilot-scale operation.

2.2.2.2.3 Gaseous Intermediate Pathways R&D Technical Challenges and Barriers

Gt-A. Feeding Dry Biomass: There is a significant need for improvements in the processing and feeding of dry biomass including densification, logistics of handling, development of specifications, and removal of problematic chemical contaminants. Demonstrating reliable feeding of dry biomass into pressurized systems is also needed.

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[29] Estimated mature technology processing cost means that the modeled capital and operating costs are assumed to be for an “nth plant” where several plants have been built and are operating successfully so that additional costs for risk financing, longer startups and under performance, and other costs associated with pioneer plants are not included

Gt-B. Feeding or Drying Wet Biomass: Better understanding of the costs and trade-offs for drying or feeding wet biomass feedstocks, algal feedstocks, or wet lignin-rich fermentation residues is needed. Innovative dryer designs capable of utilizing low-value process heat will be important to the integrated biorefinery.

Gt-C. High-Temperature Gas Production from Biomass: Better understanding of the chemistry and physical handling properties of biomass feedstocks, minor byproducts and co-products, and biorefinery residual solids is needed. This includes developing an understanding of gasification options and their chemistries for materials including wood, energy crops, sorted MSW, agricultural residues high in minerals and lignin, and high-moisture organic residues. Gas production from high-moisture feedstocks brings in another set of barriers including organics, nutrient, and mineral recovery and energy efficiency optimization.

Gt-D. Low-Temperature Production of Gaseous Intermediates: Low-temperature gaseous intermediate conversion processes include biological (e.g., landfill gas, anaerobic digestion) and catalytic deconstruction processes. Since many low-temperature deconstruction processes yield lower BTU (compared to natural gas) synthesis gas or methane, as well as other gases such as carbon monoxide and carbon dioxide, further exploration of the chemistry and physical handling properties of biomass feedstocks, minor byproducts and co-products, and biorefinery residual solids is needed. This includes developing an understanding of hydrothermal gasification and anaerobic digestion options and their chemistries for materials including wood, energy crops, sorted MSW, agricultural residues high in minerals and lignin, and high-moisture organic residues. Gas production from high-moisture feedstocks introduces barriers including organics, nutrient and mineral recovery and energy efficiency optimization. While the deconstruction mechanisms may differ widely, as with-high temperature production of gaseous intermediates, some understanding the needs for gas cleanup and conditioning will be a requirement for catalytic or biological synthesis of fuels and products.

Gt.-F. Gas Cleanup and Conditioning: There is a near-term need for gas cleaning and conditioning catalysts and technology that can cost-effectively remove contaminants such as tars, particulates, alkali, and sulfur. The interactions between the catalysts used for gas cleanup and conditioning, and the gasification conditions and feedstock are not well understood. These interactions require careful attention to trace contaminants and are important for efficient cleanup and conditioning of syngas in conjunction with optimal lifetimes of the catalyst(s).

Gt-G. Fuel Synthesis and Upgrading:
The commercial success of mixed alcohol synthesis or hydrocarbon liquids has been limited by poor selectivity and low product yields. More robust catalysts with increased productivity and selectivity with a biomass feedstock, together with extended lifetimes, are required to enable viable capital and operating costs.

Gt-H. Validation of Syngas Quality: Syngas quality specifications for production of liquid fuel products like methanol/dimethyl ether, mixed alcohols, and hydrocarbon liquids are reasonably well known. However, validation that syngas from biomass can meet the rigorous quality specifications needed for the production of liquid fuels via catalytic synthesis is still needed.

Gt-I. Sensors and Controls: Effective process control will be needed to maintain plant performance and regulate emissions at target levels with varying load, fuel properties, and atmospheric conditions. Commercial control systems need to be developed and tested for gaseous intermediates processes and systems.

Gt-K. Gaseous Intermediates Process Integration: Gaseous intermediates conversion technologies process integration currently presents large scale-up risks because of a lack of high-quality controlled process data on integrated systems over extended periods of time that would be required of industrial operations. The effect of feed and process variations throughout the process must be understood to ensure robust and efficient operation of biorefineries. Process integration work is essential for characterizing the complex interactions that exist between many of the processing steps; identifying impacts of trace components on catalytic and thermal systems; and enabling the generation of predictive engineering models that can guide process optimization and scale up.

2.2.2.2.4 Gaseous Intermediate Pathways R&D Approach for Overcoming Challenges and Barriers

The Gaseous Intermediate Pathways R&D approach to overcome the above mentioned technical challenges and barriers is outlined in its WBS shown in Figure 2-23. Gaseous Intermediate Pathways R&D is organized around five key areas: Analysis and Sustainability, Feedstock Interface, Conversion Technologies, Conversion Enabling Technologies, and Integration and Scale-Up.

Near-term R&D efforts focus on gasification of woody biomass to biofuels, however, agricultural residues, dry sorted MSW, and later, energy crops, will also be examined. Additional feedstocks, and feedstock densification strategies that are amenable for the production of renewable gasoline, diesel, and jet fuel will also be examined. Research is performed by national laboratories, industry, and universities, as well as in the National Advanced Biofuels Consortium. The DOE, via their national laboratories, has Process Development Units that are able to be utilized in the R&D.

The Gaseous Intermediates R&D WBS illustrated in Figure 2-23 is described below. Table 2-8 summarizes each task element's work as it relates to specific R&D barriers and biorefinery pathways.

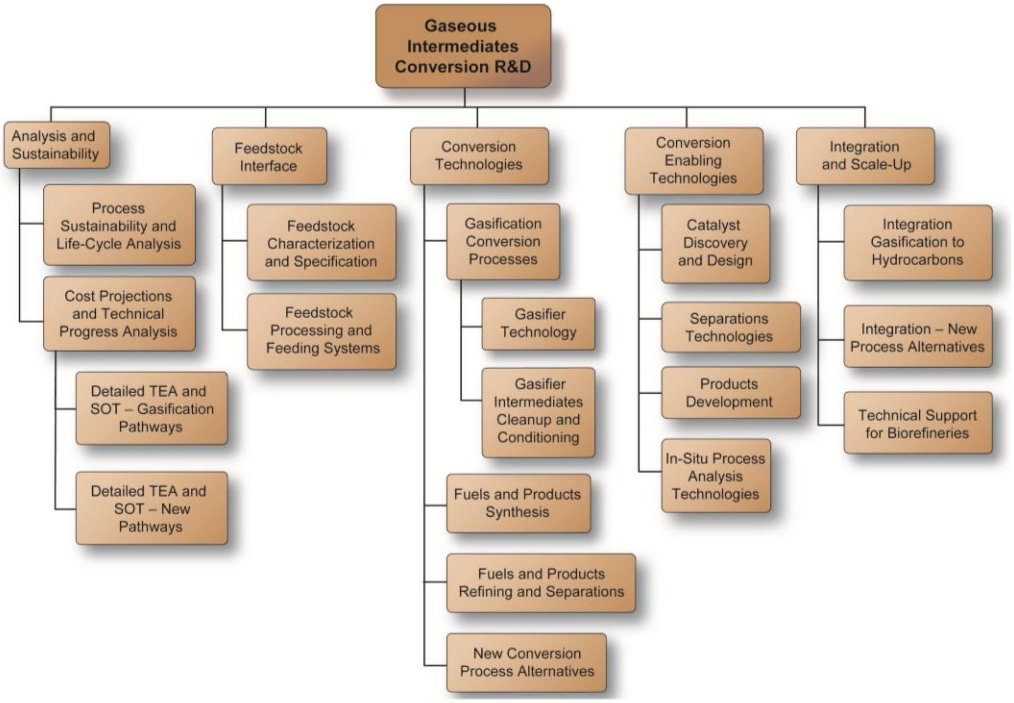

Figure 2-23: Work Breakdown Structure for Gaseous Intermediate Pathways R&D

Analysis and Sustainability (Barriers St-C, St-D, Gt-K)

Modeled, integrated conversion process designs will be developed to assess techno-economic feasibility and progress, evaluate life-cycle impacts, and improve sustainability of each feasible gaseous intermediate conversion route yielding biofuels. Experimental data are obtained from DOE funded R&D projects (including the national laboratory user facilities) and publicly available sources to monitor progress against cost projections and direct future research efforts. Techno-economic and process data from integration and scale-up efforts can be used to validate existing models, inform state of technology updates, and verify the accuracy of modeled cost projections.

Feedstock Interface (Barriers Gt-A, Gt-B)

Meeting biomass feedstock specifications, while minimizing costs, is absolutely necessary for the production of any biofuel. Specifically, the key challenges in high-temperature gaseous conversion will be to efficiently transport and handle a high-moisture-content material, economically dry biomass to less than 30 wt% moisture content, and reduce ash content of the feedstock. This requires balancing the cost of plant-gate feedstock with the handling and processing required for reliable operation. Research activities also encompass handling, processing, and feeding that occur within the biorefinery plant boundaries. Relevant feedstock interface R&D for the production of biofuels may also be utilized by biopower technologies.

Conversion Technologies (Barriers Gt-C, Gt-F, Gt-G)

In order to fully realize the benefits of an integrated biorefinery, robust and cost-effective biomass thermal conversion processes are under development that can convert a variety of biomass materials to suitable clean and high-quality intermediates for subsequent conversion to biofuels or biopower. Maintenance of catalyst activity is key with feedstocks containing sulfur or mineral content. R&D is also needed on recovery and recycling of nutrients in the aqueous stream, preparation and pumping of wet biomass feedstocks, and validation of cost-effective applications of catalytic hydrothermal gasification. R&D on pretreatment and conversion processes from other Gaseous Intermediate Pathways may also be further developed for use with biopower technologies.

Conversion Enabling Technologies (Barriers Gt-C, Gt-F, Gt-G)
The need to develop the next generation of catalysts for conversion and conditioning of both biomass and intermediates and subsequent synthesis of biofuels is critical in the advancement of biomass processing technology. Advancing both the measurement and understanding of catalyst activities, selectivities, and deactivation processes, and gaining insights into the synergistic roles of elemental species within the active catalytic sites will enable development of new processes that are more energy-, carbon- and cost-efficient. Complementary to the enabling technology of catalysis are advances in the biomass pretreatment technologies that will improve feedstock logistics and the accessibility of the biomass molecular moieties to subsequent conversion processes. Advanced pretreatment will enable greater yield and quality of biomass intermediates and biofuels, and thus improve energy efficiency.

Integration & Scale-Up (Barriers Gt-A, Gt-B, Gt-C, Gt-F, Gt-G, Gt-H, Gt-I, Gt-K)
Investigating gaseous intermediates conversion technologies together with downstream fuel synthesis identifies the issues and opportunities in integration and scale-up. In addition, the effect of feed and process variations throughout the process must be understood to ensure robust, optimally controlled, efficient biorefineries. Immediate goals include demonstrating that improved tar cracking and reforming catalysts have opportunities for process intensification and utilizing the synergies between synthesis gas conditioning and fuel synthesis for a pathway with reduced cost and risk of gasification-based process technology. Process intensification and advanced process control can drive the economics by significantly reducing capital and operating costs, thus minimizing the overall production costs. As gaseous intermediates conversion technologies get proven, findings are communicated for integration into new and existing biorefineries. The Office leverages industry feedback to understand emerging issues and R&D opportunities, while also supporting the Office’s Integrated Biorefineries Technology Area by identifying needs for integrated projects and providing synergistic R&D that is limited to unit operations.

Table 2-8: Gaseous Intermediate Pathways R&D Activity Summary

***Goal*: Develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible, liquid fuels, such as renewable gasoline, renewable jet fuel, and renewable diesel, bioproducts and chemical intermediates, and bioenergy.**

WBS Element	Description	FY2012 Performer	Barrier(s) Addressed	Pathway(s) Addressed
Analysis and Sustainability	Develop integrated conversion process designs, assess techno-economic feasibility and progress, and evaluate sustainability / life-cycle impacts • Gasification to hydrocarbon fuels conversion route • New conversion process alternatives.	NREL, PNNL	St-C: Sustainability Data St-D: Sustainability Indicators and Methodology Gt-K Gaseous Intermediates Process Integration	Agricultural Residue Processing Energy Crops Processing Forest Resources Processing Algae Processing Waste Processing
Feedstock Interface and Technologies	Develop feedstock specifications and processing systems that accommodate feedstock variability and optimize conversion processes • Mechanically and chemically characterize the feedstocks and develop optimal feedstock and blending specifications • Develop feedstock processing systems for optimal yields and selectivity.	INL, ORNL	Gt-A: Feeding Dry Biomass Gt-B: Feeding or Drying Wet Biomass	
Conversion Interface and Technologies	Research and develop the most promising technology routes based on techno-economic analysis and preliminary investigation into new emerging routes • Develop gasification to hydrocarbon fuels conversion processes including gasifier technology, syngas cleaning and conditioning, and fuel synthesis systems • Develop new conversion process alternatives such as wet gasification, anaerobic digestion, • Develop conversion to products.	NREL , PNNL, Emery Energy Company, Iowa State University, Research Triangle Institute, Southern Research Institute, NABC	Gt-C: Gasification of Biomass Gt-F: Syngas Cleanup and Conditioning Gt-G: Fuels Catalyst Development Gt-H: Validation of Syngas Quality Gt-I: Sensors and Controls	
Conversion Enabling Technologies	Enhance existing enabling technologies, investigate non-route-specific promising unit operations improvements, and develop non-route-specific conversion technologies • Develop catalyst technologies for conversion beyond ethanol to improve catalyst life and function • Investigate and develop pretreatment enhancement to downstream yields.	NREL, Emery Energy Company, Iowa State University, Research Triangle Institute, Southern Research Institute	Gt-F: Syngas Cleanup and Conditioning Gt-G: Fuels Catalyst Development Gt-I: Sensors and Controls	
Scale-Up and Integration	Integrate unit operations and scale-up to reduce cost of sustainable biomass conversion to fuels • Integrate gasification to hydrocarbon fuels unit operations • Fully integrate other emerging gaseous intermediates process alternatives • Identify needs of IBR projects and provide limited unit operations focused R&D to enable successful performance.	NREL, PNNL	Gt-A: Feeding Dry Biomass Gt-B: Feeding or Drying Wet Biomass Gt-C: Gasification of Biomass Gt-F: Syngas Cleanup and Conditioning Gt-G: Fuels Catalyst Development Gt-H: Validation of Syngas Quality Gt-I: Sensors and Controls Gt-K: Gaseous Intermediates Process Integration	

2.2.2.2.5 Prioritizing Gaseous Intermediate Pathways R&D Barriers

In order to achieve the Gaseous Intermediate Pathways R&D goals, all of the challenges and barriers need to be addressed. However, the three high-impact research areas that are critical to R&D success are:

- Quality of gaseous intermediates (e.g., synthesis gas)
- Fuels synthesis from syngas
- Reactor process optimization.

The Gaseous Intermediate Pathways Technology Area will prioritize its R&D efforts in overcoming technical barriers based on techno-economic analysis. The following technical targets in Table 2-9 are proposed to enable the achievement of cost goals given in Section 2.2.2.2.2.

Table 2-9 Preliminary Technical Targets[30] for Gaseous Intermediate Pathways R&D

Metric	Target*	Timeframe
Mixed oxygenate production, gal/dry ton wood	100	2022
CO conversion, % to HC liquids	90	2022
Hydrocarbon fuel volume yield, gal/dry ton wood	60	2022
Co-product yield, lb/lb wood	0.2	2022
Total catalyst cost for intermediate product, ($/lb)	22.50	2022
Total target product yield (e.g., gasoline blendstock), gal/dry ton wood	>60	2022

2.2.2.2.6 Gaseous Intermediate Pathways R&D Milestones and Decision Points

The key Gaseous Intermediate Pathways R&D milestones, inputs/outputs, and decision points to complete the tasks described in Section 2.2.2.2.4 are summarized in the chart in Figure 2-24.

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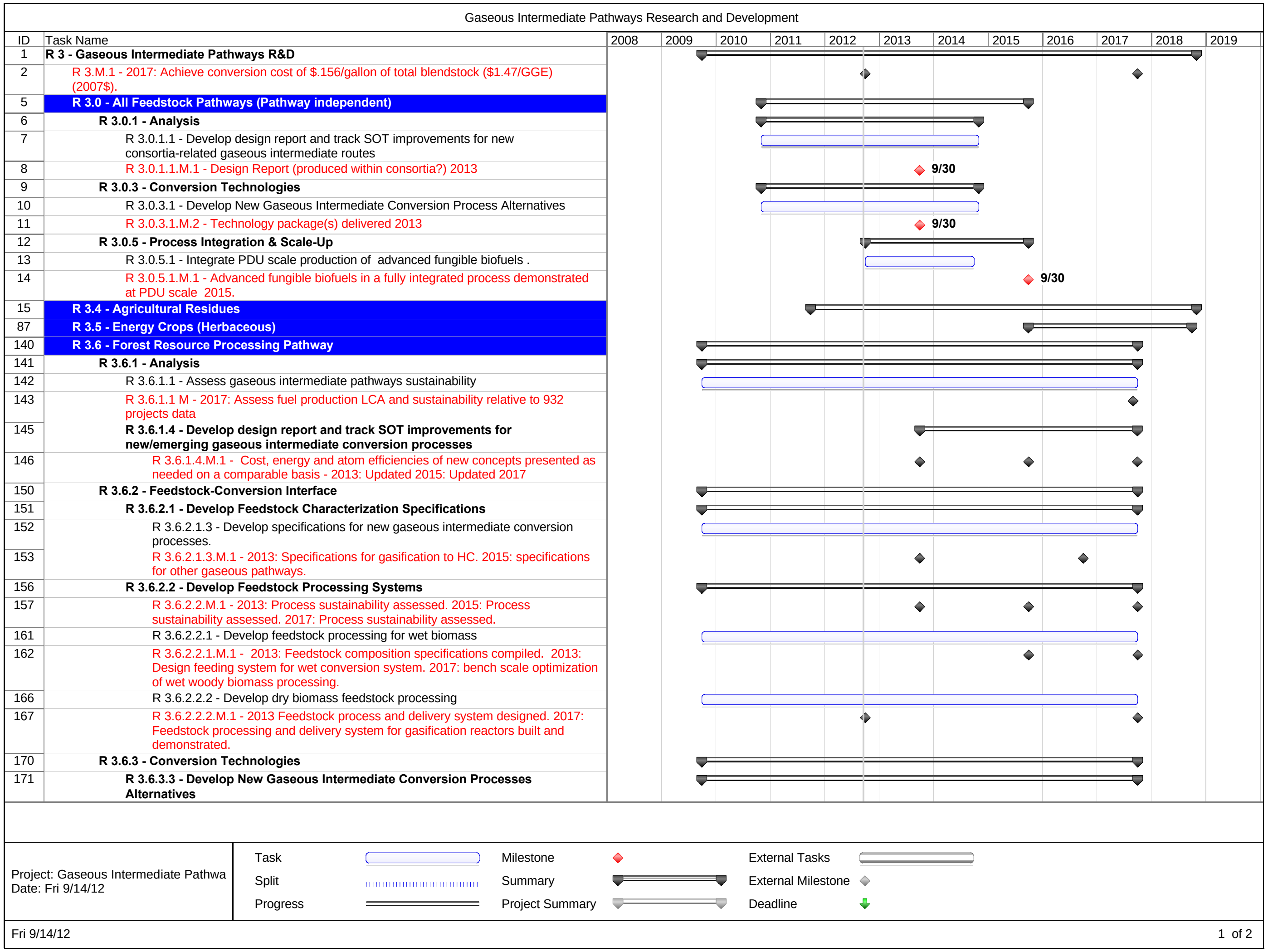
[30] Pending completed techno-economic analysis and design case development

Figure 2-24: Gaseous Intermediate Pathways R&D Gantt



Gaseous Intermediate Pathways Research and Development

ID	Task Name
1	**R 3 - Gaseous Intermediate Pathways R&D**
2	R 3.M.1 - 2017: Achieve conversion cost of $.156/gallon of total blendstock ($1.47/GGE) (2007$).
5	**R 3.0 - All Feedstock Pathways (Pathway independent)**
6	**R 3.0.1 - Analysis**
7	R 3.0.1.1 - Develop design report and track SOT improvements for new consortia-related gaseous intermediate routes
8	R 3.0.1.1.M.1 - Design Report (produced within consortia?) 2013
9	**R 3.0.3 - Conversion Technologies**
10	R 3.0.3.1 - Develop New Gaseous Intermediate Conversion Process Alternatives
11	R 3.0.3.1.M.2 - Technology package(s) delivered 2013
12	**R 3.0.5 - Process Integration & Scale-Up**
13	R 3.0.5.1 - Integrate PDU scale production of advanced fungible biofuels .
14	R 3.0.5.1.M.1 - Advanced fungible biofuels in a fully integrated process demonstrated at PDU scale 2015.
15	**R 3.4 - Agricultural Residues**
87	**R 3.5 - Energy Crops (Herbaceous)**
140	**R 3.6 - Forest Resource Processing Pathway**
141	**R 3.6.1 - Analysis**
142	R 3.6.1.1 - Assess gaseous intermediate pathways sustainability
143	R 3.6.1.1 M - 2017: Assess fuel production LCA and sustainability relative to 932 projects data
145	**R 3.6.1.4 - Develop design report and track SOT improvements for new/emerging gaseous intermediate conversion processes**
146	R 3.6.1.4.M.1 - Cost, energy and atom efficiencies of new concepts presented as needed on a comparable basis - 2013: Updated 2015: Updated 2017
150	**R 3.6.2 - Feedstock-Conversion Interface**
151	**R 3.6.2.1 - Develop Feedstock Characterization Specifications**
152	R 3.6.2.1.3 - Develop specifications for new gaseous intermediate conversion processes.
153	R 3.6.2.1.3.M.1 - 2013: Specifications for gasification to HC. 2015: specifications for other gaseous pathways.
156	**R 3.6.2.2 - Develop Feedstock Processing Systems**
157	R 3.6.2.2.M.1 - 2013: Process sustainability assessed. 2015: Process sustainability assessed. 2017: Process sustainability assessed.
161	R 3.6.2.2.1 - Develop feedstock processing for wet biomass
162	R 3.6.2.2.1.M.1 - 2013: Feedstock composition specifications compiled. 2013: Design feeding system for wet conversion system. 2017: bench scale optimization of wet woody biomass processing.
166	R 3.6.2.2.2 - Develop dry biomass feedstock processing
167	R 3.6.2.2.2.M.1 - 2013 Feedstock process and delivery system designed. 2017: Feedstock processing and delivery system for gasification reactors built and demonstrated.
170	**R 3.6.3 - Conversion Technologies**
171	**R 3.6.3.3 - Develop New Gaseous Intermediate Conversion Processes Alternatives**

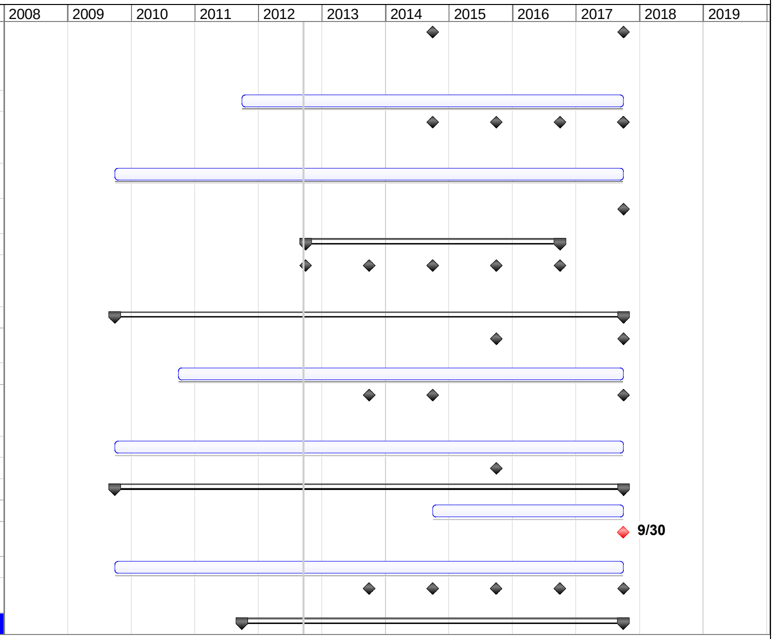
Project: Gaseous Intermediate Pathwa
Date: Fri 9/14/12

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

Fri 9/14/12 1 of 2

Gaseous Intermediate Pathways Research and Development

ID	Task Name
172	R 3.6.3.3.M.1 - 2014: Next wave of gaseous intermediate conversion technologies of wet feedstocks optimized in order to determine traction. 2017: gasification of biomass to ethanol R&D leveraged to develop process for gasification to drop in fuels.
175	R 3.6.3.3.1 - Develop Gasification to other fuels
176	R 3.6.3.3.1.M.1 - 2014: Complete models. 2015 Optimize MTG, MTO, and DME. 2016: Complete models. 2017: Gasification to other fuels optimized, contaminants reduced, and 1000 hours demonstrated.
183	R 3.6.3.3.2 - Identify other technically feasible next generation gaseous intermediate conversion processes
184	R 3.6.3.3.2.M.1 - 2017: Fully integrated and optimized system to produce drop in fuels demonstrated at PDU scale for new conversion process.
186	**R 3.6.3.4 - Gaseous Intermediate Conversion to Products**
187	R 3.6.3.4.M.1 - 2013: Higher value for lignin residues demonstrated. 2015: high-value derivatives commercialized. 2012,2014, 2016: process sustainability assessed.
194	**R 3.6.4 - Conversion Enabling Technologies**
195	R 3.6.4.M.1 -2015: Promising pretreatment/extraction processes determined. 2017: Next generation of catalysts for drop in fuels developed.
198	R 3.6.4.1 - Develop catalyst technologies
199	R 3.6.4.1.M.1 - 2013: Proof-of-prinicple data, next generation of catalysts developed. 2014: Industry buy-in and competitive funds obtained for scale-up. 2017: Process sustainability assessed.
204	R 3.6.4.2 - Investigate advanced pretreatments
205	R 3.6.4.2.M.1 - 2015: Go/No Go decisiosn for new processes.
207	**R 3.6.5 - Process Integration & Scale-Up**
208	R 3.6.5.3 - Fully integrate other emerging gaseous intermediate process alternatives
209	R 3.6.5.3.M.1 - Fully integrated and optimized system to produce drop in fuels demonstrated at PDU scale 2017
210	R 3.6.5.4 - Technical support for Integrated Biorefineries
211	R 3.6.5.4.M.1 - 2013: IBR needs/Issues & work scope needs identified. 2014: Support plan developed. 2015: Plan reviewed. 2016: Plan reviewed. 2017: Plan reviewed.
217	**R 3.7 - Waste Processing**



Project: Gaseous Intermediate Pathwa
Date: Fri 9/14/12

Task		Milestone	◆	External Tasks	
Split		Summary		External Milestone	◆
Progress		Project Summary		Deadline	⇩

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2.3 Demonstration and Deployment

2.3.1 Integrated Biorefineries

The role of the Integrated Biorefineries (IBR) Technology Area is to demonstrate and validate cost and performance data for various biofuel conversion pathways through building and operation of pilot-, demonstration- and commercial-scale integrated biorefineries by public/private partnerships. IBR is focused on resolving key issues involved in the scale-up of IBR systems. These projects will help overcome barriers and promote commercial acceptance, ultimately reducing the risk for private-sector financing of follow-on plants.

IBR's activities contribute to all of the biorefinery pathways. The Bioenergy Technologies Office is committed to completing the construction and operation of pilot-, demonstration- and first-of-a-kind commercial-scale projects that convert biomass into advanced biofuels. The cost-shared partnerships are essential to bridging the "valley of death" between R&D and commercial deployment of renewable biofuels technologies.

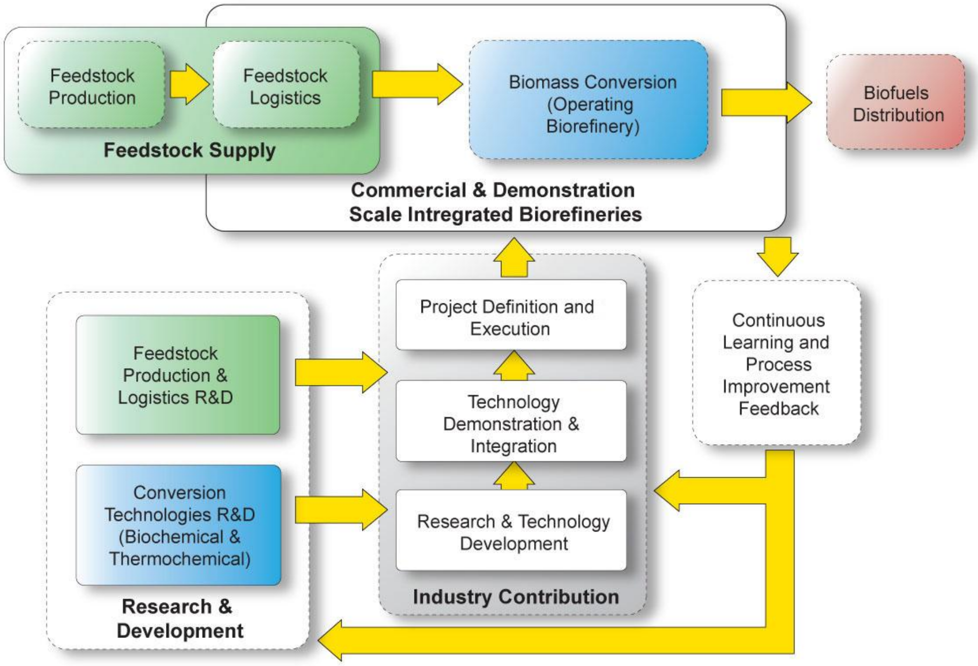

Figure 2-25: Integrated Biorefineries Technology Area Scope and Connection to R&D Efforts

Integrated Biorefinery Stages of Development

The stages described below outline the various activities involved in biorefinery development and project management of the IBR projects (Figure 2-25).

Scales of Biorefinery Development

Technology integration and validation at the pilot scale verifies the performance of the given suite of technologies from both a technical and an economic perspective. Integrated pilot-scale validation is essential in identifying flaws that must be corrected for a successful commercial launch. If these potential problems are not corrected or remain unidentified, it is unlikely that a plant will achieve its design capacity, operability factor, and/or profitability. Integrated pilot testing is also instrumental in generating the performance data and equipment specifications required to design a demonstration-scale facility. Successful integrated piloting will strengthen projects in their later demonstration stages and encourage private investment.

Technology validation at the demonstration scale verifies the performance of the given suite of technologies from both a technical and an economic perspective, at a scale sufficient to provide the performance data and equipment specifications required to design a commercial-scale facility. A demonstration-scale facility is generally considered to be between one-fiftieth and one-tenth of the scale of the envisioned commercial facility. Technology validation at the demonstration scale confirms that industrial-scale components can be incorporated into a complete system and that system performance and operational requirements meet design specifications. To determine if a project is ready for demonstration scale, integrated pilot testing of all critical process steps must be successfully completed.

First commercial-scale deployment refers to a first-of-a-kind or “beta” commercial facility. The successful design, construction, and operation of a first-of-a-kind commercial facility is dependent on the prior development of a functional, fractional-scale demonstration plant that can generate the performance data and equipment specifications required to design a full-scale commercial facility. To determine if a project is ready for scale-up to commercial operation, integrated pilot- and demonstration-scale data should be analyzed. Once there is a commercial-scale facility that achieves design specifications and positive cash flow, the technology application can be replicated.

These follow-on plants would be eligible for traditional project financing from investment bankers.

Integrated Biorefinery Project Management Activities

Project definition includes developing a detailed facility design, coupled with mass and energy balances that identify technical uncertainties or issues that have not been resolved. In these cases, additional R&D and piloting may be required before the project can continue. Facility permitting is a long, iterative process and should be initiated during this stage.

Project execution includes facility construction, precommissioning, commissioning, and performance acceptance testing at the pilot, demonstration, and commercial scale. Some design flaws may not be identified until startup, which can lead to a wide range of training, equipment, or design issues. The overall duration of construction, commissioning, and startup is tied to the scale and complexity of the facility design, and in certain cases, may last several years. Failure to get through the commissioning and subsequent performance acceptance tests in a timely fashion may result in project failure. The availability of integrated pilot performance data, combined with properly executed process design and facility engineering, can help reduce risk and increase the likelihood of success.

Project Management Plans enable the Bioenergy Technologies Office to monitor the implementation of IBR projects. The Project Management Plan (PMP) includes the development of a “baseline” scope, budget, and schedule that meets the following criteria:

- Demonstrates appropriate project management practices will be fully integrated with financial and business systems to measure project progress and enhance the probability of successful completion
- Demonstrates the identification and consideration of risk, and the use of effective risk management and change control systems that will be put into full effect very early in the project and used to mitigate impacts
- Demonstrates a comprehensive plan to address all environmental, health, safety, permitting, and compliance concerns.

The Office draws on independent engineers, financial analysts, project officers, and other advisors to review proposed PMPs, including scope, schedule, and budget, and the reasonableness and readiness of the projects. The Office also utilizes a “stage-gate” process, combined with comprehensive annual project reviews and/or go/no-go decisions, to evaluate the status of the projects against the original baseline.

In order to minimize risk within the current portfolio, the Office employs a risk management approach to assess each project. This evaluation serves to identify areas of risk that may require further attention before projects begin and uses a methodology to ensure that projects progress as expected.

Integrated Biorefinery Interfaces with R&D

The Office’s R&D is focused on developing the scientific and engineering underpinnings of a bioenergy industry by understanding technical barriers and providing process and engineering solutions. The IBR public/private partnerships offer a unique opportunity to validate technologies at scale and leverage additional assets to resolve the underlying technical problems.

The product of these partnerships is primarily operational data, which the Office will use to validate the cost and performance of the respective technology. The partnerships must report on technical progress including process flow diagrams, mass and energy balances, and process performance parameters by unit operation. They also provide financial data including pro forma and actual capital and operating costs. Sustainability metrics associated with the facility or system will also be collected.

The data from the IBR partnerships is evaluated and used as input to Office portfolios and strategic planning.

Feedstock R&D

A biorefinery must operate with predictable efficiency; therefore, plant operations are dependent on a continuous, consistent feedstock supply to achieve their commercial targets. Feedstock cost, availability, variability, quality control, and storage are all parameters that affect the economics of the plant.

Biochemical Conversion R&D

The development of advanced biochemical conversion technology performance and cost targets must be accomplished to achieve broad deployment and full commercialization of the IBR model. Through the implementation of the necessary technological advances, cellulosic feedstock conversion processes have the potential to achieve similar investment returns as conventional grain-based processes. The integration of cellulosic conversion technologies in conventional biofuels production operations will likely have a synergistic effect and lower the entry cost of cellulosic biofuels, improving the bottom line of the conventional commercial operations.

Thermochemical Conversion R&D

The development of advanced thermochemical conversion technology performance and cost targets must be accomplished to achieve broad deployment and full commercialization of the IBR model. Advances in various thermochemical biorefinery technologies must be made to increase feedstock flexibility, diversify biofuel product options, and maximize plant performance economics.

Although thermochemical and biochemical conversions are treated as separate topics, a number of technology applications will employ components from both conversion technology areas to optimize yield, productivity, and efficiency.

2.3.1.1 Integrated Biorefineries Support of Office Strategic Goals

IBR projects are the mechanism used by the Office to validate its technology goal: to develop and deploy sustainable, commercially viable biomass conversion technologies to produce biofuels that support meeting EISA RFS targets.

The IBR Technology Area's strategic goal is to *demonstrate and validate integrated technologies to achieve commercially acceptable performance and pro forma cost targets*. This goal is best accomplished through public/private partnerships.

The IBR Technology Area directly addresses and supports all feedstock and conversion pathways as shown in Figure 2-26.

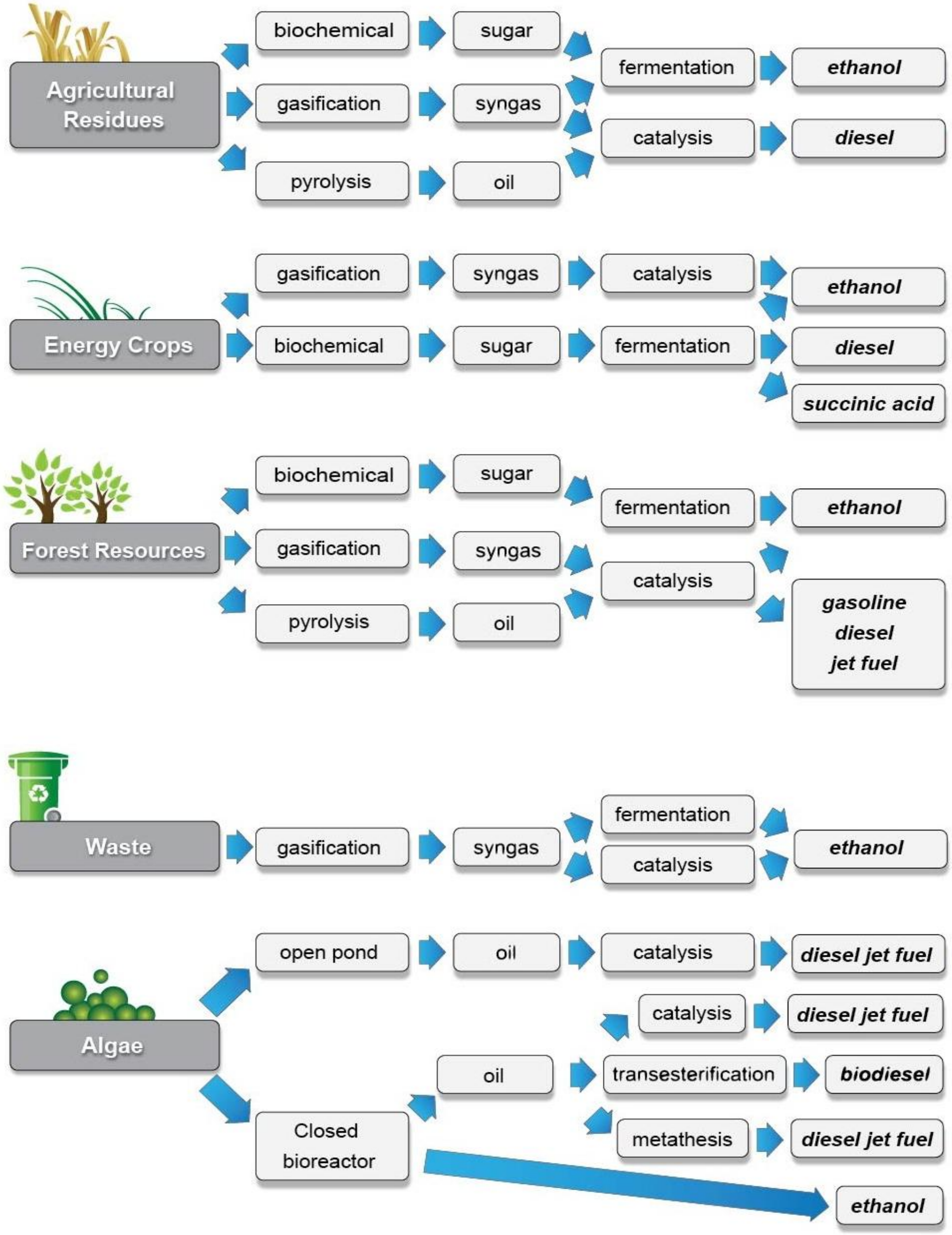

Figure 2-26: Current Integrated Biorefineries Project Pathways

2.3.1.2 Integrated Biorefineries Support of Office Performance Goals

The 2017 performance goal of the IBR Technology Area is to validate a mature technology plant model[31] cost of ethanol production, based on actual IBR project plant performance data and compared to the target of $2.15/gallon ethanol ($2007). [32] The 2014 performance goal is to validate a total annual production capacity of 80 million gallons of advanced biofuels.

The final intent is for the six commercial-scale facilities to be techno-economically viable, ongoing production facilities that contribute to meeting the RFS targets. The pilot- and demonstration-scale projects may not be economically viable for ongoing biofuel production at their respective scales. Rather, at the pilot and demonstration scale, these IBR projects will generate at least 1,000 hours of continuous operational data that support the design of a techno-economically viable commercial-scale facility. Pilot- and demonstration-scale facilities can also help identify additional barriers that need to be addressed through further R&D to enable viable commercial production stage.

The percentage contribution of each project toward the 2014 advanced biofuels volumetric performance goal for the feedstock pathways currently under investigation is shown in Table 2-10.

Table 2-10: Estimated Project Contribution for 2014 Biofuel Production Capacity Goal

Project	Percent of 2014 Production Capacity	Conversion Route	Feedstock
Abengoa	31%	Biochemical	Agricultural Residue
Poet	31%	Biochemical	Agricultural Residue
Mascoma	25%	Biochemical	Forest Resources
Ineos New Planet Bioenergy	10%	Thermochemical/Biochemical Hybrid	Green Waste & MSW
Verenium	2%	Biochemical	Agricultural Residue
Sapphire	1%	Biochemical	Algal Oil

Table 2-11 shows how the 29 competitively selected IBR projects in which the Office has invested are distributed by scale, feedstock type, and fuel type.

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[31] The modeled cost refers to the use of models to project the cost such as those defined in recent design reports

[32] The ethanol production cost targets are estimated mature technology processing costs which means that the capital and operating costs are assumed to be for an "nth plant" where several plants have been built and are operating successfully so that additional costs for risk financing, longer startups, under performance, and other costs associated with first-of-a-kind plants are not included.

- Hess, Wright, et al. "Uniform-Format Solid Feedstock Supply System: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass."
- Humbird, Davis, et al, "Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol: Dilute Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover."

Table 2-11: Competitively Selected Integrated Biorefinery Projects by Feedstock and Fuel Type

Pathway/Feedstock	Agricultural Residues	Energy Crops	Forest Resources	Waste Processing	Algae Processing	Ethanol/ Other Alcohols	FT Liquids/ Renewable Hydrocarbon	Products	Total
Total	6	5	12	2	4	17	11	1	29
Integrated Biorefinery Deployment	6	5	11	2	3	17	9	1	27
Pilot	3	3	4		2	6	6		12
Demonstration	1	2	3	2	1	6	2	1	9
Commercial	2		4			5	1		6
Continued Technology Development			1		1		2		2

2.3.1.3 Integrated Biorefineries Challenges and Barriers

Market Challenges and Barriers

Im-A. Inadequate Supply Chain Infrastructure: The lack of commoditized feedstocks and feedstock infrastructure increases the uncertainty associated with a sustainable feedstock supply chain. Variable composition, geographical diversity, and diverse physical characteristics increase the radius of collection, and therefore, the delivered cost of feedstock. Once demand is established, the infrastructure is expected to grow accordingly. Producing and delivering commoditized feedstock in sufficient volume to support a commercial advanced biofuels industry will require incentive programs to stimulate the large capital investments needed for production, preprocessing, storage, and transport to commodity markets.

Im-B. Agricultural Sector-Wide Paradigm Shift: Energy production from biomass on a scale sufficient to meet EISA RFS goals, or those of a future Renewable Portfolio Standard (RPS), will require a series of major system changes that will take time to implement. Current harvesting, storage, and transportation systems are inadequate for processing and distributing biomass on the scale needed to support dramatically larger volumes of biofuels production.

Im-C. Lack of Understanding of Environmental/Energy Tradeoffs: A systematic evaluation of the impact of expanded biofuels production on the environment and food supply for humans and animals is insufficient. Sufficient data needs to be generated from various operational facility 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 production 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 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 50% reduction in GHG emissions. The EPA has established the methodology for evaluating these impacts for some pathways.

Im-D. High Risk of Large Capital Investments: Once emerging biomass technologies have been developed and tested, they must be commercially deployed. Financial barriers are the most challenging aspect of technology deployment. Capital costs for commercially viable facilities are relatively high, and securing capital for an unproven technology is extremely difficult. Lenders are hesitant to provide debt financing for first-of-a-kind commercial facilities where the process performance cannot be adequately guaranteed. For private investors to have the confidence to invest equity in biomass technology applications, the technology must be fully demonstrated and validated at commercial scale. Government assistance to validate proof of performance at the pilot, demonstration, and first-of-a-kind commercial scales is critical to successful deployment. Potentially the most significant challenge for debt financing of first-of-a-kind commercial facilities is the lack of long-term, consistent federal policies. Lenders will not consider federal incentives and subsidies as income in the consideration of loan applications because these financial support mechanisms are prone to discontinuation or reduction as political priorities change between administrations.

Im-E. Lack of Industry Standards and Regulations: The lack of local, state, and federal regulations, as well as inconsistency among existing regulations, constrains development of the biomass industry. The long lead times associated with developing and understanding new and revised regulations for technology can delay or stifle commercialization and deployment. Consistent standards and sampling methods are lacking for feedstock supply and infrastructure, as well as for biofuel products and the associated distribution infrastructure.

Im-F. Cost of Production: An overarching market barrier for biomass technologies is the inability to compete, in most applications, with fossil energy supplies and their established supporting facilities and infrastructure. Uncertainties in fossil energy price and supply continue to exert upward pressure on the price of petroleum-derived fuels and products. Nevertheless, reductions in production costs along the entire biomass supply chain—including feedstock supply, conversion processes, and product distribution—are needed to make advanced biofuels and bioproducts competitive with petroleum-derived analogs.

Im-G. Off-take Agreements: Production costs, as well as therefore selling price and profits, of commodity fuels and chemicals based on crude oil are dependent on a fluctuating market. Generally these companies offer products on a contract basis, but also sell on the spot to the market to generate the greatest return on investment. Off-take agreements can often take the form of fixed price contracts for 1–2 years followed by contracts fixed to a specific index, such as the Chicago Board of Trade pricing. The producer then must adjust their *pro forma* accounting and variable cost structure to account for such market fluctuations. Another challenge with fuel offtake agreements is that the industry standard is 1–2 years, in contrast to the term of debt financing, which can range from 7–15 years or longer. The providers of long-term debt generally require the duration of the offtake agreement to match the tenor of the loan, which is a difficult challenge when the product selling price is dependent on a fluctuating market.

Technical Challenges/Barriers

It-A. End-to-End Process Integration: Successful deployment of the biorefinery business model is dependent on advances in biochemical and thermochemical biomass conversion process technologies. The biorefinery concept encompasses a wide range of technical issues related to collecting, storing, transporting, and processing diverse feedstocks, as well as the complexity of integrating new and unproven process steps. The demonstration and validation of total process integration, from feedstock production to end-product distribution, is crucial as it impacts both performance and profitability.

It-B. Demonstration-Scale Facilities: As with all new process technologies, demonstrating sustained integrated performance that meets technical, environmental, and safety requirements at a sufficiently large scale is an essential step toward commercialization. Demonstration-scale facilities that are capable of validating new integrated process technologies and generating the process performance parameters and equipment specifications for commercial-scale plant design are critical to successful commercial deployment. Additionally, increased understanding of the performance of integrated systems at demonstration scale will result in the optimization of process design configurations for commercial-scale facilities. A significant challenge for establishing demonstration-scale facilities is that they add several years to the timeline of commercialization. They are also a costly but necessary asset that is not designed to generate revenue. For these reasons, technology developers, project developers, and venture capitalists generally seek to short-circuit this vital step, leading to a higher degree of risk and failure for the first-of-a-kind commercial facilities that attempt to go straight from pilot to production.

It-C. Risk of First-of-a-Kind Technology: The first biorefineries will incorporate a variety of new technologies. The number and complexity of new process steps implemented in pilot- and demonstration-scale projects has been shown to be a strong predictor of future commercial performance shortfalls. Heat and mass balances, along with their implications, are not likely to be well understood with regard to new technologies. In addition, the unanticipated buildup of impurities in process recycle streams can result in degradation of chemical performance, abrasion and corrosion of plant equipment, and deactivation of process catalysts.

It-E. Engineering Modeling Tools: The current level of understanding regarding fuels chemistry is insufficient for optimization, scale-up, and commercialization. In order to better understand how fuel chemistry affects commercial viability, rigorous computational fluid dynamic models are needed. Engineering modeling tools are also needed to address heat integration issues.

2.3.1.4 Integrated Biorefineries Approach for Overcoming Challenges and Barriers

The Office’s efforts to overcome the challenges and barriers associated with the IBR Technology Area are organized around five pathways (see Appendix A for a description of the Office’s strategy framework of biorefinery pathways) as illustrated in Figure 2-27. Each pathway includes the following activities:

- Deployment: includes all of the major IBR projects
- Technical assistance: covers smaller R&D projects that are identified by the IBR team, industry partners, and stakeholders as critical to improving existing biorefinery operations
- Technical analysis: includes a broad range of technical, economic, and environmental topics and is used to assess the individual progress of the IBR projects, as well as the

collective status and progress of the bioindustry.

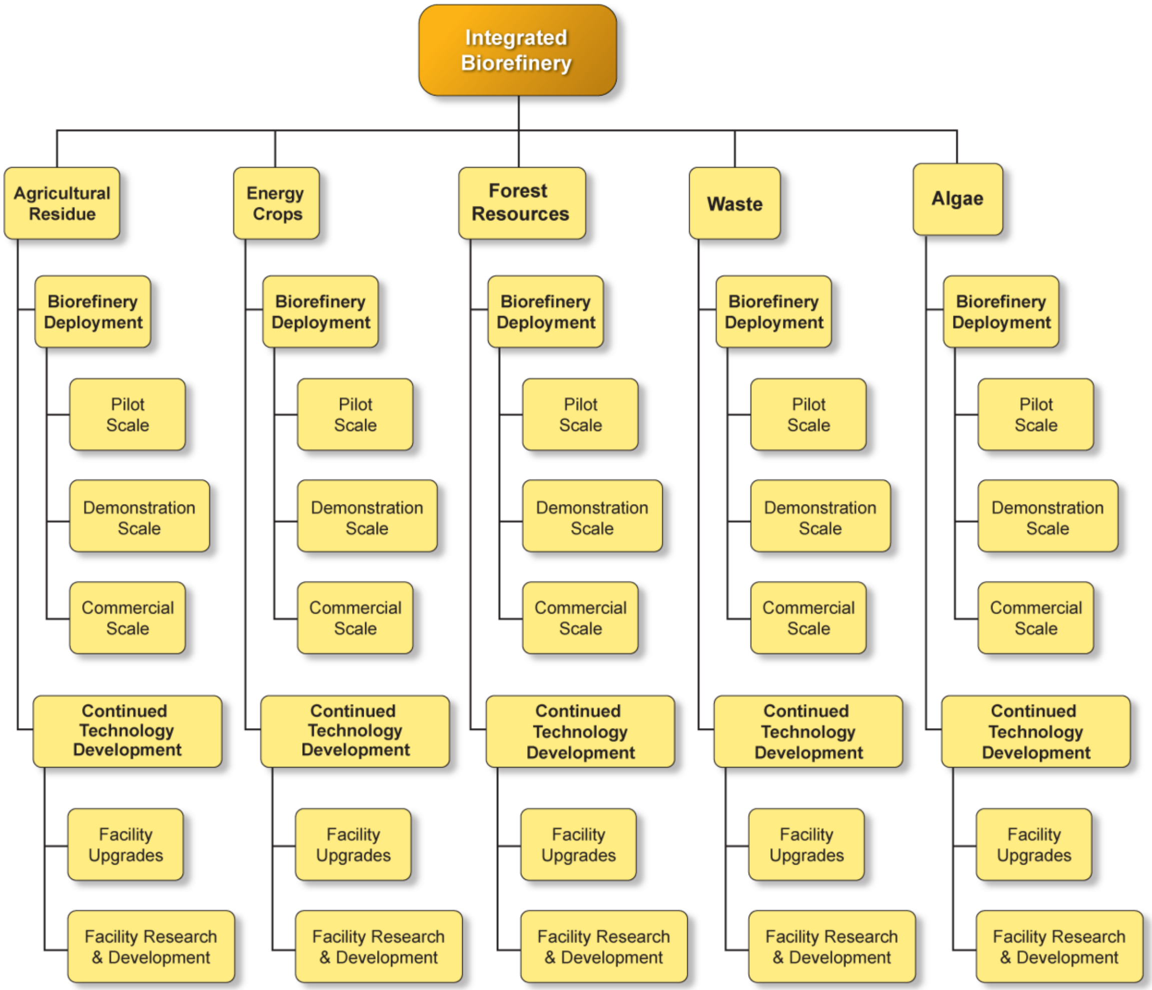


Figure 2-27: Integrated Biorefineries Work Breakdown Structure

Agricultural Residue Processing Pathway

The objective is to develop and demonstrate commercially viable processes and systems to convert residues from current agricultural production activities to biofuels and bioproducts. Both biochemical and thermochemical conversion technologies, individually or in combination, are being used to produce ethanol, green diesel, and chemical intermediates. Using existing agricultural residues is seen as the primary strategy to bridge the gap between near-term niche, low-cost biomass supplies, and long-term, high-volume dedicated energy crops.

Energy Crops Processing Pathway

The objective for this pathway is to develop and demonstrate commercially viable processes and systems to convert dedicated energy crops to biofuels and bioproducts, which is the foundation of the long-term strategy for petroleum displacement. Conversion technologies and processes for dedicated perennial feedstocks will build on the experience gained through processing agricultural and forest residues and process intermediates in commercial-scale facilities. Both biochemical and thermochemical conversion technologies are under evaluation.

Forest Resources Processing Pathway

The objectives of this pathway include the development and demonstration of the conversion of forest resources to biofuels, biopower, and bioproducts. When co-located with a pulp and paper facility, the addition of biofuel capabilities may also improve the economic efficiency of those existing operations. This pathway could include the conversion of underperforming pulp and paper mills into plants that produce biofuel, biopower, and bioproducts with no impact to paper quality.

Waste Processing Pathway

This pathway was added to the Office portfolio based on the quantity and availability of cellulosic wastes for biofuels production. The objective is to develop and demonstrate commercially viable processes to convert the cellulosic fractions of various waste streams to biofuels, biopower, and bioproducts. Feedstocks include sorted MSW, urban wood waste, and construction and demolition wastes.

Algal Processing Pathway

This pathway demonstrates the potential to mass-produce algae with high oil content and to reduce the cost of algae production to an acceptable level. The goal is low-cost algal oil production, which requires higher productivities and oil content than currently achievable. There is a need to isolate, screen, select, and test various algal strains in open ponds and enclosed bioreactors and to genetically enhance algal strains for higher oil content and overall productivity (i.e., both photosynthetic and heterotrophic productivity), as well as resistance to grazers, invasions, temperature, and other environmental factors.

The approaches for overcoming the barriers within each pathway, along with specific tasks/activities, are described in Table 2-12. Integration is the key component for successful development and deployment of a biorefinery. The Office's biorefinery industrial partnerships are each associated with a principal pathway, and most incorporate cross-cutting elements involving secondary, and in some cases tertiary, feedstocks and could therefore support multiple pathways.

Table 2-12: Integrated Biorefinery Activity Summary

***Goal:* Demonstrate and validate integrated technologies to achieve commercially acceptable performance and pro-forma cost targets**

WBS Element	Performer	Pathway(s) Addressed	Barrier(s) Addressed
Integrated Biorefinery Deployment and Portfolio Management			
Pilot Scale – Integrated unit operations to produce fuels, power, or products at the scale of at least 1 metric tonne.	ADM, Logos Technologies, Renewable Energy Institute International	Agricultural Residue Processing	Im-A: Inadequate Supply Chain Infrastructure Im-B: Agricultural Sector-Wide Paradigm Shift Im-C: Lack of Understanding of Environmental/ Energy Tradeoffs Im-D: High Risk of Large Capital Investments; It-A: End-to-End Process Integration It-B: Commercial-Scale Demonstration Facilities It-C: Risk of First-of-a-Kind Technology It-E: Engineering Modeling Tools St-C: Sustainability Data across Supply Chain
	ICM, Inc., Amyris Biotechnologies, Inc., ZeaChem, Inc.	Energy Crops Processing	
	American Process, Inc., Haldor Topsoe, Inc., UOP, LLC, ClearFuels Technology, Inc.	Forest Resources Processing	
	Algenol Biofuels, Solazyme, Inc.	Algae Processing	
Demonstration Scale – Integrated projects that convert at least 50 or 70 metric tonnes of biomass to biofuels, biopower, and/or bioproducts.	Verenium Biofuels Corp.	Agricultural Residue Processing	
	Myriant Technologies, Inc.	Energy Crops Processing	
	Red Shield Acquisition	Forest Resources Processing	
	Enerkem Corporation, INEOS	Waste Processing	
	Sapphire Energy, Inc.	Algae Processing	
Commercial Scale – Integrated commercial-scale projects that convert at least 700 metric tonnes of biomass to biofuels, biopower, and/or bioproducts, without government subsidies.	Abengoa Bioenergy LLC, POET	Agricultural Residue Processing	
	BlueFire Ethanol, Inc., Mascoma	Forest Resources Processing	
Continued Technology Development			
Identify opportunities for process optimization with the goal of reducing cost and increasing efficiency. Validate these improvements at existing pilot-, demonstration-, or commercial-scale facilities.	Gas Technology Institute	Forest Resources Processing	Im-A: Inadequate Supply Chain Infrastructure Im-C: Lack of Understanding of Environmental/ Energy Tradeoffs It-B: Commercial-Scale Demonstration Facilities It-E: Engineering Modeling Tools St-E: Best Practices for Sustainable Bioenergy Production
	Elevance Renewable Sciences	Algae Processing	

2.3.1.5 Prioritizing Integrated Biorefineries Barriers

The Bioenergy Technologies Office is developing a suite of technologies across the biorefinery pathways to enable a broad spectrum of biomass resources to be used in the production of a variety of biofuels.

2.3.1.6 Integrated Biorefineries Milestones and Decision Points

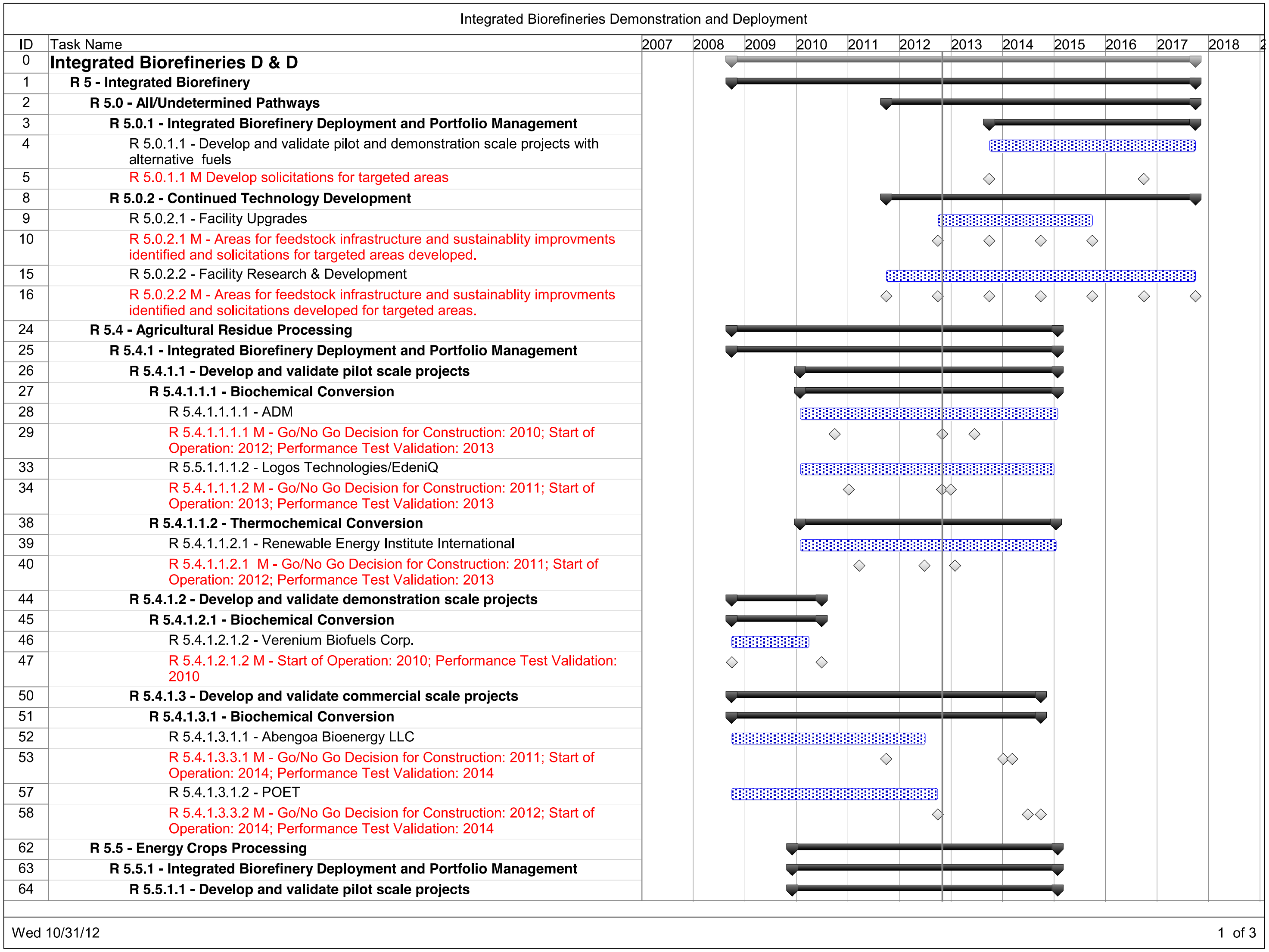
The key IBR milestones, inputs/outputs, and decision points to complete the tasks described in Section 2.3.1.4 are summarized in the chart in Figure 2-28.

Given the cost and technology maturity for the demonstration- and commercial-scale efforts, this work is conducted via competitively awarded cost-share agreements with industry. The targets/milestones listed in Figure 2-28 include the successful operation of integrated systems and validate performance metrics for each project. Milestones and go/no-go decisions track the progression from contract award to construction for start-up and operation of each pilot-, demonstration-, or commercial-scale biorefinery.

The following definitions apply to the milestones listed in Figure 2-28.

- **Demonstrate:** At pilot scale and beyond, verify that the unit operations operate as designed and meet the complete set of performance metrics (individually, and as an integrated system).
- **Validate:** At pilot scale and beyond, ensure the process/system meets desired expectations/original intent. Validation goes beyond just meeting all of the performance metrics; it is an assessment of whether the system actually fulfills/completes a portion of the Office effort, so that the Office can move on to the next priority.

Figure 2-28: Integrated Biorefineries Gantt Chart



Integrated Biorefineries Demonstration and Deployment

ID	Task Name
0	**Integrated Biorefineries D & D**
1	**R 5 - Integrated Biorefinery**
2	**R 5.0 - All/Undetermined Pathways**
3	**R 5.0.1 - Integrated Biorefinery Deployment and Portfolio Management**
4	R 5.0.1.1 - Develop and validate pilot and demonstration scale projects with alternative fuels
5	R 5.0.1.1 M Develop solicitations for targeted areas
8	**R 5.0.2 - Continued Technology Development**
9	R 5.0.2.1 - Facility Upgrades
10	R 5.0.2.1 M - Areas for feedstock infrastructure and sustainablity improvments identified and solicitations for targeted areas developed.
15	R 5.0.2.2 - Facility Research & Development
16	R 5.0.2.2 M - Areas for feedstock infrastructure and sustainablity improvments identified and solicitations developed for targeted areas.
24	**R 5.4 - Agricultural Residue Processing**
25	**R 5.4.1 - Integrated Biorefinery Deployment and Portfolio Management**
26	**R 5.4.1.1 - Develop and validate pilot scale projects**
27	**R 5.4.1.1.1 - Biochemical Conversion**
28	R 5.4.1.1.1.1 - ADM
29	R 5.4.1.1.1.1 M - Go/No Go Decision for Construction: 2010; Start of Operation: 2012; Performance Test Validation: 2013
33	R 5.5.1.1.1.2 - Logos Technologies/EdeniQ
34	R 5.4.1.1.1.2 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013
38	**R 5.4.1.1.2 - Thermochemical Conversion**
39	R 5.4.1.1.2.1 - Renewable Energy Institute International
40	R 5.4.1.1.2.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2012; Performance Test Validation: 2013
44	**R 5.4.1.2 - Develop and validate demonstration scale projects**
45	**R 5.4.1.2.1 - Biochemical Conversion**
46	R 5.4.1.2.1.2 - Verenium Biofuels Corp.
47	R 5.4.1.2.1.2 M - Start of Operation: 2010; Performance Test Validation: 2010
50	**R 5.4.1.3 - Develop and validate commercial scale projects**
51	**R 5.4.1.3.1 - Biochemical Conversion**
52	R 5.4.1.3.1.1 - Abengoa Bioenergy LLC
53	R 5.4.1.3.3.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2014; Performance Test Validation: 2014
57	R 5.4.1.3.1.2 - POET
58	R 5.4.1.3.3.2 M - Go/No Go Decision for Construction: 2012; Start of Operation: 2014; Performance Test Validation: 2014
62	**R 5.5 - Energy Crops Processing**
63	**R 5.5.1 - Integrated Biorefinery Deployment and Portfolio Management**
64	**R 5.5.1.1 - Develop and validate pilot scale projects**

Wed 10/31/12

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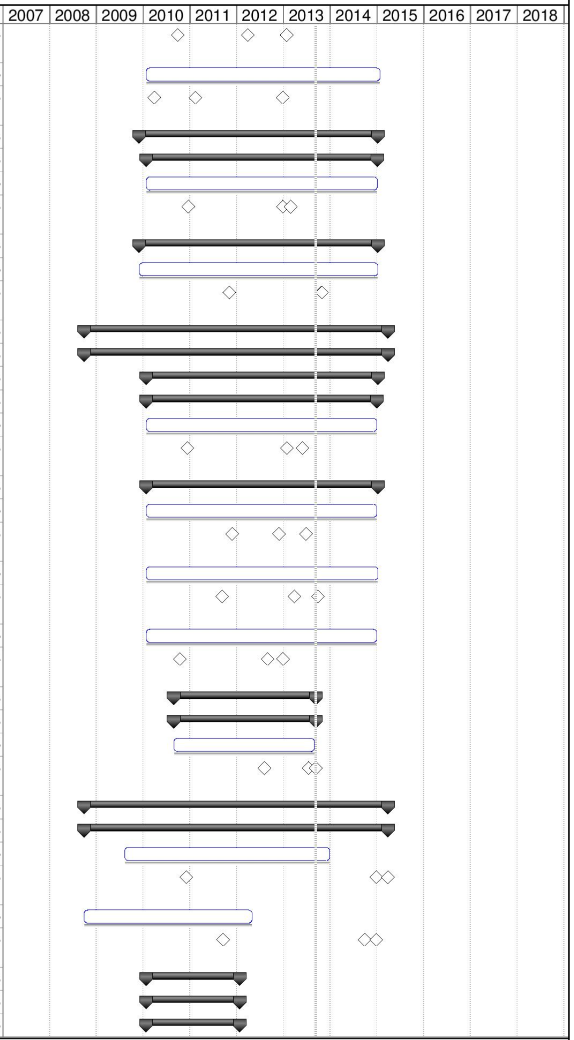
Integrated Biorefineries Demonstration and Deployment

ID	Task Name	Start	Finish	Duration
67	R 5.5.1.1.1 M - Go/No Go Decision for Construction: 2010; Start of Operation: 2012; Performance Test Validation: 2013	**Thu 9/30/10**	**Tue 1/29/13**	**127.86 mons**
71	R 5.5.1.1.2 - Amyris Biotechnologies, Inc.	##########	Tue 1/27/15	273.96 mons
72	R 5.5.1.1.2 M - Go/No Go Decision for Construction: 2010; Start of Operation: 2011; Performance Test Validation: 2013	**Thu 4/1/10**	**Sun 12/30/12**	**150.66 mons**
76	**R 5.5.1.2 - Develop and validate demonstration scale projects**	**Fri 12/4/09**	**Sat 1/10/15**	**279.51 mons**
77	**R 5.5.1.2.1 - Biochemical Conversion**	**##########**	**Tue 1/6/15**	**270.66 mons**
78	R 5.5.1.2.1 Myriant	##########	Tue 1/6/15	270.66 mons
79	R 5.5.1.2.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Thu 12/23/10**	**Fri 3/1/13**	**119.9 mons**
83	**R 5.5.1.2.2 - Hybrid/Other Conversion**	**Fri 12/4/09**	**Sat 1/10/15**	**279.51 mons**
84	R 5.5.1.2.2.1 - ZeaChem, Inc.	Fri 12/4/09	Sat 1/10/15	279.51 mons
85	R 5.5.1.2.2.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Mon 6/6/11**	**Thu 10/31/13**	**131.76 mons**
89	**R 5.6 - Forest Resources Processing**	**##########**	**Tue 3/31/15**	**355.95 mons**
90	**R 5.6.1 - Integrated Biorefinery Deployment and Portfolio Management**	**##########**	**Tue 3/31/15**	**355.95 mons**
91	**R 5.6.1.1 - Develop and validate pilot scale projects**	**##########**	**Sun 1/11/15**	**271.41 mons**
92	**R 5.6.1.1.1 - Biochemical Conversion**	**##########**	**Thu 1/1/15**	**269.91 mons**
93	R 5.6.1.1.1.1 - American Process, Inc	##########	Thu 1/1/15	269.91 mons
94	R 5.6.1.1.1.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Thu 12/16/10**	**Fri 5/31/13**	**134.6 mons**
98	**R 5.6.1.1.2 - Thermochemical Conversion**	**##########**	**Sun 1/11/15**	**271.41 mons**
99	R 5.6.1.1.2.1 - Haldor Topsoe, Inc.	##########	Thu 1/1/15	269.91 mons
100	R 5.6.1.1.2.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Fri 9/30/11**	**Sun 6/30/13**	**95.9 mons**
104	R 5.6.1.1.2.2 - UOP, LLC	##########	Sun 1/11/15	271.41 mons
105	R 5.6.1.1.2.2 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Mon 9/12/11**	**Mon 9/30/13**	**112.4 mons**
109	R 5.6.1.1.2.3 - ClearFuels Technology, Inc.	##########	Thu 1/1/15	269.91 mons
110	R 5.6.1.1.2.3 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2012; Performance Test Validation: 2013	**Mon 10/18/10**	**Mon 12/31/12**	**120.81 mons**
114	**R 5.6.1.2 - Develop and validate demonstration scale projects**	**Wed 9/1/10**	**Fri 9/13/13**	**166.26 mons**
115	**R 5.6.1.2.1 - Biochemical Conversion**	**Wed 9/1/10**	**Fri 9/13/13**	**166.26 mons**
116	R 5.6.1.2.1.2 - Red Shield Acquisition (RSA)	Wed 9/1/10	Sun 9/1/13	164.46 mons
117	R 5.6.1.2.1.2 M - Go/No Go Decision for Construction: 2012; Start of Operation: 2013; Performance Test Validation: 2013	**Wed 8/8/12**	**Fri 9/13/13**	**60.21 mons**
121	**R 5.6.1.3 - Develop and validate commercial scale projects**	**##########**	**Tue 3/31/15**	**355.95 mons**
122	**R 5.6.1.3.1 - Biochemical Conversion**	**##########**	**Tue 3/31/15**	**355.95 mons**
123	R 5.6.1.3.1.1 - BlueFire Ethanol, Inc.	##########	on 12/30/13	240.21 mons
124	R 5.6.1.3.1.1 M - Go/No Go Decision for Construction: 2010; Start of Operation: 2015; Performance Test Validation: 2015	**Tue 7/20/10**	**Tue 3/31/15**	**257.25 mons**
128	R 5.6.1.3.1.2 - Mascoma	##########	Wed 5/2/12	196.56 mons
129	R 5.6.1.3.1.2 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2014; Performance Test Validation: 2015	**Mon 9/19/11**	**Tue 12/30/14**	**179.76 mons**
133	**R 5.6.2 - Continued Technology Development**	**##########**	**Fri 1/27/12**	**109.56 mons**
134	**R 5.6.2.3 - Facility R&D Conversion Upgrades/Retrofits**	**##########**	**Fri 1/27/12**	**109.56 mons**
135	**R 5.6.2.3.2 - Thermochemical Conversion**	**##########**	**Fri 1/27/12**	**109.56 mons**



Project: Integrated Biorefineries D & D
Date: Thu 9/5/13

Task	▭	Milestone	◆	External Tasks	▬
Split	┈	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

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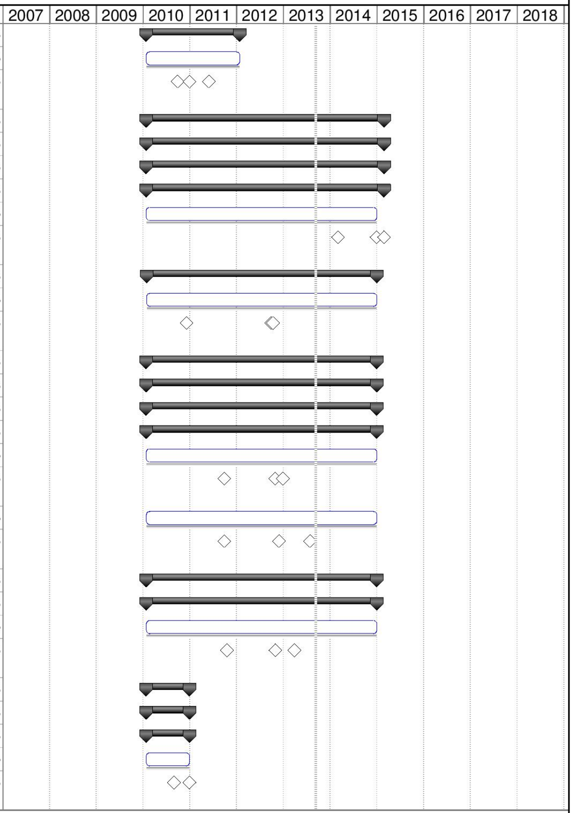
Integrated Biorefineries Demonstration and Deployment

ID	Task Name	Start	Finish	Duration
136	**R 5.6.2.3.2.1 - Preliminary Engineering Design of Projects**	**##########**	**Fri 1/27/12**	**109.56 mons**
137	R 5.6.2.3.2.1.1 - Gas Technology Institute	##########	Fri 1/27/12	109.55 mons
138	R 5.6.2.3.2.1.1 M - Go/No Go Decision for Construction: 2010; Start of Operation: 2011; Performance Test Validation:	**Wed 1/27/10**	**Wed 6/1/11**	**73.56 mons**
142	**R 5.7 - Waste Processing**	**##########**	**Sun 3/1/15**	**278.85 mons**
143	**R 5.7.1 - Integrated Biorefinery Deployment and Portfolio Management**	**##########**	**Sun 3/1/15**	**278.85 mons**
144	**R 5.7.1.2 - Develop and validate demonstration scale projects**	**##########**	**Sun 3/1/15**	**278.85 mons**
145	**R 5.7.1.2.2 - Thermochemical Conversion**	**##########**	**Sun 3/1/15**	**278.85 mons**
146	R 5.7.1.2.2.1 - Enerkem Corporation	##########	Thu 1/1/15	270.06 mons
147	R 5.7.1.2.2.1 M - Go/No Go Decision for Construction: 2013; Start of Operation: 2015; Performance Test Validation: 2015	**Fri 3/1/13**	**Sun 3/1/15**	**109.5 mons**
151	**R 5.7.1.2.3 - Hybrid/Other Conversion**	**##########**	**Thu 1/1/15**	**269.46 mons**
152	R 5.7.1.2.3.1 - INEOS	##########	Thu 1/1/15	269.46 mons
153	R 5.7.1.2.3.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2012; Performance Test Validation: 2013	**Fri 12/10/10**	**Mon 10/15/12**	**101.25 mons**
157	**R 5.8 - Algae Processing**	**##########**	**Thu 1/1/15**	**270.06 mons**
158	**R 5.8.1 - Integrated Biorefinery Deployment and Portfolio Management**	**##########**	**Thu 1/1/15**	**270.06 mons**
159	**R 5.8.1.1 - Develop and validate pilot scale projects**	**##########**	**Thu 1/1/15**	**270.06 mons**
160	**R 5.8.1.1.3 - Hybrid/Other Conversion**	**##########**	**Thu 1/1/15**	**270.06 mons**
161	R 5.8.1.1.3.1 - Algenol Biofuels	##########	Thu 1/1/15	270.06 mons
162	R 5.8.1.1.3.1 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2012; Performance Test Validation: 2013	**Fri 9/30/11**	**Mon 12/31/12**	**68.7 mons**
166	R 5.8.1.1.3.2 - Solazyme, Inc.	##########	Thu 1/1/15	269.91 mons
167	R 5.8.1.1.3.2 M - Go/No Go Decision for Construction: 2011; Start of Operation: 2013; Performance Test Validation: 2013	**Fri 9/30/11**	**Wed 7/31/13**	**100.5 mons**
171	**R 5.8.1.2 - Develop and validate demonstration scale projects**	**##########**	**Thu 1/1/15**	**269.91 mons**
172	**R 5.8.1.2.3 - Hybrid/Other Conversion**	**##########**	**Thu 1/1/15**	**269.91 mons**
173	R 5.8.1.2.3.1 - Sapphire Energy, Inc.	##########	Thu 1/1/15	269.91 mons
174	R 5.8.1.2.3.1 M - Go/No Go Decision for Construction: 2012; Start of Operation: 2012; Performance Test Validation: 2013	**Thu 10/20/11**	**Sat 3/30/13**	**79.11 mons**
178	**R 5.8.2 - Continued Technology Development**	**##########**	**Fri 12/31/10**	**50.76 mons**
179	**R 5.8.2.3 - Facility R&D Conversion Upgrades/Retrofits**	**##########**	**Fri 12/31/10**	**50.76 mons**
180	**R 5.8.2.3.3 - Hybrid/Other Conversion**	**##########**	**Fri 12/31/10**	**50.76 mons**
181	R 5.8.2.3.1.1 - Elevance Renewable Sciences	##########	Fri 12/31/10	50.76 mons
182	R 5.8.2.3.1.1 M Start of Operation: 2010; Performance Test Validation: 2010	**Wed 1/27/10**	**Fri 12/31/10**	**50.76 mons**



Project: Integrated Biorefineries D & D
Date: Thu 9/5/13

Task	▭	Milestone	◆	External Tasks	▬
Split	┈	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

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2.3.2 Biofuels Distribution Infrastructure and End Use

The Biofuels Distribution Infrastructure and End Use (Infrastructure) Technology Area is focused on facilitating the development of a safe and cost-effective biofuels delivery infrastructure (Figure 2-29), designed to meet the Office's strategic goals and the EISA RFS target for the use of 36 billion gallons of biofuels by 2022.

Today, the market for biofuels in the United States consists primarily of corn-starch-based ethanol. Of the nearly 14 billion gallons of ethanol produced in 2011, more than 99% was marketed as an E10 blend for use in conventional vehicles, with the remainder sold as E85 for use in FFVs.[33] Currently, over 95 % of gasoline in the United States contains up to 10% ethanol, which means that the market for E10 ethanol blends is approaching saturation, often referred to as the "blend wall." Beyond the blend wall, the market for ethanol could increase by expanding the use of E85 or other high-level blends in FFVs or through the use of intermediate ethanol blends (e.g., E15) in conventional vehicles.

The EERE Bioenergy Technologies Office and Vehicle Technologies Office funded research on the effects of intermediate ethanol blends on vehicle performance, materials compatibility, exhaust emissions, and other criteria. Using this and other research, the EPA issued a waiver in January 2011, which permits the sale of E15 for use in model year 2001 and newer vehicles. However, a number of political, regulatory, and liability issues will need to be addressed before widespread introduction of E15 into the market is possible.

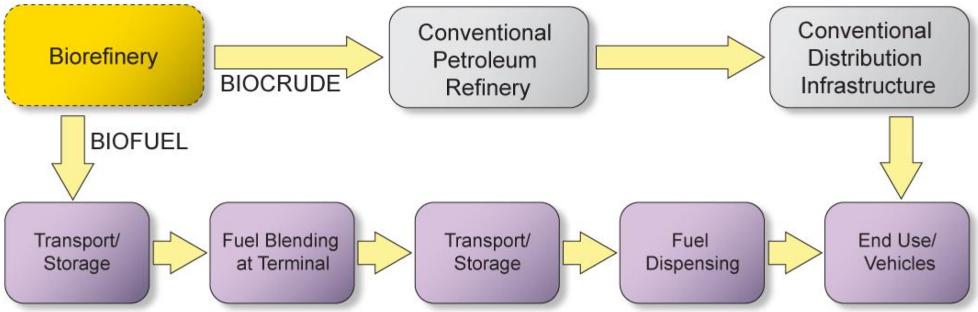

Figure 2-29: Distribution Infrastructure and End Use Flow Chart

A number of other biofuel technologies currently under development may alleviate some of the infrastructure challenges involved in distributing and using ethanol. Renewable hydrocarbon fuels (i.e., renewable gasoline, diesel, and jet fuel) are being developed and are expected to have chemical compositions virtually identical to their petroleum counterparts, and thus have the potential to be fully compatible and fungible with the existing petroleum infrastructure. Other advanced biofuels, such as biobutanol, may also be more compatible than ethanol with existing infrastructure and could have characteristics closer to conventional petroleum products.

Transportation and Storage: Petroleum fuels are transported predominantly through a network of pipelines from coastal production and import facilities to distribution terminals dispersed throughout the United States. Pipelines are generally the most efficient and cost-effective way to

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[33] "RFA: Ethanol Industry Statistics," Renewable Fuels Association, http://www.ethanolrfa.org/pages/statistics.

transport large volumes of liquid fuels over long distances. In general, trucks are only used to transport refined petroleum products from the distribution terminals to refueling stations, typically a distance of less than 50 miles.

In contrast, corn ethanol is produced primarily in the Midwest and distributed to major demand centers on the east and west coasts. Due to material compatibility and pipeline operational concerns, denatured ethanol (95% ethanol/5% gasoline) is generally transported by rail from biorefineries to existing petroleum terminals where it is blended with gasoline and then transported by truck to refueling stations. There has only been very limited pipeline transport of ethanol to date.

Advanced biofuels will likely utilize a wider variety of biomass resources, such as energy crops and woody residues, and cellulosic biorefineries are expected to be more widely distributed throughout the country. This could reduce some of the additional cost and logistical constraints involved in transporting biofuels from the Midwest. Renewable hydrocarbon biofuels are expected to be fungible with petroleum fuels, but further research, testing, and characterization will likely be required to validate these expectations. .Other advanced biofuel pathways involve the production of biocrudes, such as pyrolysis oil, which can serve as an intermediate precursor to renewable gasoline, diesel, and jet fuel. Transporting biocrudes may present unique challenges, while at the same time providing an opportunity to more easily resolve other feedstock logistics and infrastructure issues.

Fuel Dispensing and Vehicle End Use: All conventional highway vehicles manufactured since 1978 are certified to run on blends of ethanol up to E10. The recent waiver granted by EPA permits the use of blends up to E15, in vehicles model year 2001 and newer. Only certified FFVs are designed to run on higher-level ethanol blends, up to E85. Whereas E10 can be stored and dispensed in the same tanks and dispensers as gasoline, E85 requires a certified dispenser and separate storage tank, which together can cost over $60,000 to install at a refueling station. Currently, more than 8.6 million FFVs and nearly 2,500 E85 retail stations are in use in the United States.

2.3.2.1 Biofuels Distribution Infrastructure and End Use Support of Office Strategic Goals

The goal of the Infrastructure Technology Area is to *help create the conditions whereby all biofuels can safely, cost-effectively, and sustainably reach their market and be used by consumers as a replacement for petroleum fuels.*

The Infrastructure Technology Area helps coordinate the RDD&D activities within the Bioenergy Technologies Office with research activities among various federal agencies dealing with biofuels infrastructure issues. The Office also supports the development of geospatial tools, which can be used to evaluate the needs of biofuels distribution infrastructure. The Office also intends to examine and help facilitate testing and characterization of renewable hydrocarbon fuels and other advanced biofuels, as needed.

2.3.2.2 Biofuels Distribution Infrastructure Challenges and Barriers

Market Challenges and Barriers

Dm-A. Availability of Biofuels Distribution Infrastructure: The infrastructure required to distribute and dispense large volumes of ethanol will need to expand significantly to meet the EISA target for the use of 36 billion gallons of biofuels by 2022. Various challenges to expanding this infrastructure exist, depending on what percentage of the fuel is ethanol and what percentage can be integrated into the fuel supply as infrastructure compatible fuels. The market for higher level ethanol blends has been slow to develop and would require a dramatic expansion of E85 infrastructure and FFVs. Integrating larger volumes of E15 into the existing fuel supply will require overcoming a variety of political, legal, and logistical hurdles. In addition, transporting large volumes of ethanol from the MidWest to the East Coast and West Coast markets may impose significant constraints on the existing rail, barge, and highway network. Infrastructure compatible biofuels may also require distribution infrastructure investments, including new transportation systems, and east-west pipeline expansion.

Dm-D.[34] Market Uncertainty: There is uncertainty regarding the pace of development and commercialization of new biofuels technology. Additionally, there is uncertainty surrounding which types of biofuels will produced and at what volumes over the short and long term, adding risk to investment in biofuels infrastructure. Other factors, such as the price of oil, the pace of economic recovery, climate legislation, and other policy measures also complicate investment decisions.

Technical Challenges and Barriers

Dt-B. Codes, Standards, and Approval for Use: New biofuels and biofuel blends must comply with federal, state, and regional regulations before introduction to the market. The EPA plays a central role in approving new fuels for use; technical codes and standards are developed by organizations including the American Society for Testing and Materials International, American Petroleum Institute, and Underwriters Laboratory; and safety, health, and environmental standards are developed by the Occupational Safety and Health Administration, the U.S. Department of Homeland Security, and others. Codes and standards are adopted by state and local jurisdictions to ensure product safety and reliability and reduce liability. Limited data and technical information can delay approval for use and development of technical codes and standards for biofuels and related infrastructure components including pipelines, storage tanks, and dispensers. The approval process can take years and cost millions of dollars for fuels that are not substantially similar in composition to existing fuels.

Dt-C. Materials Compatibility: Ethanol and certain other biofuels and intermediates are not fully compatible with the existing petroleum delivery infrastructure. Ethanol can be corrosive toward soft metals and certain types of plastics, which can present a problem for some plastic hoses, gaskets, seals, and nozzles associated with distribution infrastructure and dispensers. Because ethanol is both a stronger solvent than petroleum and hygroscopic, it can dissolve hydrocarbon residue in pipelines and storage tanks and/or absorb water, resulting in fuel

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[34] Dm-B, Dm-E, Dt-A, Dt-D, and Dt-F were removed in the September 2012 update. Dm-C was removed in the November 2010 update.

contamination and off-spec material. There is also some concern that ethanol may lead to stress corrosion cracking, which would require technical mitigation. Raw pyrolysis-oil and biocrudes can also be highly corrosive toward distribution infrastructure components. While emerging renewable hydrocarbon biofuels are expected to be fully compatible with the existing petroleum infrastructure, this remains to be verified.

Dt-E. Fuel Economy Penalties: Some biofuels result in decreased fuel economy on a miles per gallon basis, relative to petroleum fuels. Ethanol has a lower energy density than gasoline, approximately 76,000 Btu per gallon of ethanol in comparison to 115,000 Btu per gallon of gasoline.[35] This means that E10 contains around 97%, and E85 around 71%, of the energy contained in gasoline. Fuel economy is dominated by energy content. However, the higher octane rating of ethanol—which is 115, compared to 85–88 for regular gasoline—may make up for some of ethanol's lower energy content. Actual differences in fuel economy are dependent on a variety of factors and will vary by biofuel type.

Dt-G. Vehicle and Engine Compatibility: Nearly all vehicles manufactured in the United States are certified to run on blends of up to 10% ethanol. Vehicles manufactured since 2001 are certified to run on blends of E15. Renewable hydrocarbon biofuels are not expected to have these compatibility issues, but will require testing and characterization for verification.

2.3.2.3 Biofuels Infrastructure Approach for Overcoming Challenges and Barriers

Achieving the goals of the Infrastructure Technology Area will require leveraging the resources of federal agencies, the national laboratories, and state and local governments, as well as partners in industry, academia, and other affiliated organizations. Several interagency collaborations will be used to coordinate assessments of biofuels infrastructure and to develop a coordinated approach to facilitating a resolution of these challenges. DOE and EPA will continue to collaborate on fuels testing, while DOE will partner with DOT to address biofuels transport and logistical issues, including assessing material issues with storage containers and pipelines. DOE will work with American Society for Testing and Materials International, American Petroleum Institute, the National Institute of Standards and Technology, and the Underwriters Laboratory to facilitate the establishment of specifications, codes, and standards.

Lastly, the Bioenergy Technologies Office will work closely with the Vehicle Technologies Office to build on the latter Office's efforts in developing and deploying alternative vehicle and fuel technologies through its Clean Cities Program and other avenues.

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[35] U.S. Department of Energy, *Annual Energy Outlook 2007: Biofuels in the U.S. Transportation Sector, Table 11* (2007), Washington: Government Printing Office, http://www.eia.doe.gov/oiaf/analysispaper/biomass.html.

2.4 Sustainability

Enabling long-term viability of bioenergy systems is a critical component of the Bioenergy Technologies Office's mission to reduce dependence on oil. The Office is focused on developing the resources, technologies, and systems needed to grow a biofuels industry in a way that protects natural resources and maximizes economic, social, and environmental benefits. To sustain operations into the future, the existing and emerging biofuels industry will need to invest in systems based not just on economic viability and market needs, but also on resource availability, food security, and environmental sustainability. To that end, the Office is articulating the challenges related to sustainable bioenergy production and use and working with partners to address these challenges through basic and applied research, analysis, and demonstration and deployment efforts. Furthermore, the Office's Sustainability Area is focused on leveraging emerging social and market drivers to develop innovative solutions that support the Office's goals of reducing the cost of producing advanced biofuels and enabling industry growth.

Executive Order 13514 (Federal Leadership in Environmental, Energy, and Economic Performance) provides the following definition for sustainability: "To create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations." Maintaining the services provided by natural resources, promoting economic development, and providing conditions that support human and societal health are all critical components of a sustainable bioenergy industry.

Figure 2-30 Bioenergy Technologies Office Sustainability Scope

Based on this mandate, the Office's sustainability efforts are organized around environmental, social, and economic dimensions—the three core aspects of sustainability (see Figure 2-30). With activities in all three areas, the Office can enhance sustainability along the entire biomass-to-bioenergy supply chain and enable a sustainable bioenergy industry over time (see Figure 2-31). The Sustainability Area supports cross-cutting activities relevant to multiple supply chain elements and also coordinates with each Office area to improve technology-specific sustainability.

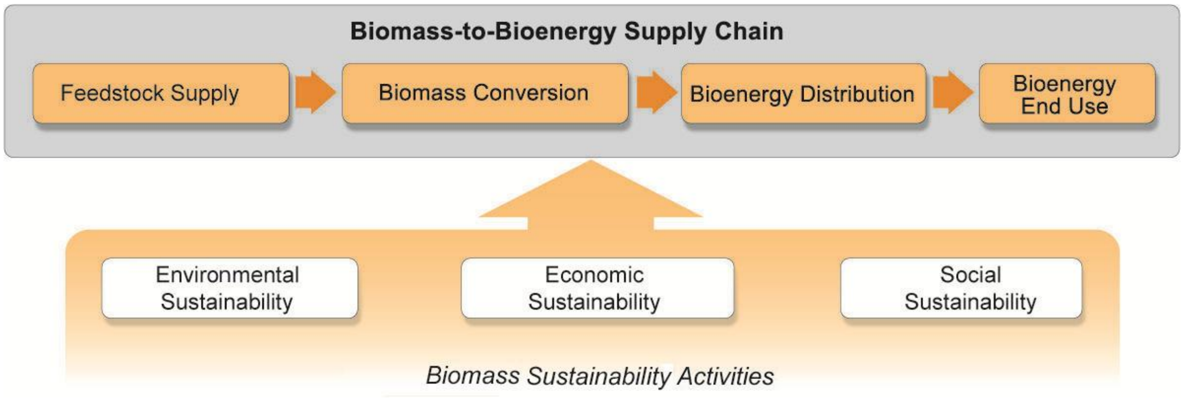


Figure 2-31: Sustainability Activities Crosscut All Biomass-to-Bioenergy Supply Chain Elements

Environmental Sustainability

Environmental sustainability activities are focused in several key areas. Certain environmental categories—such as soil quality and biological diversity—are most relevant for feedstock production, while others—such as water and air quality, as well as land use—should be monitored along the entire bioenergy supply chain. These categories and their associated objectives are:

- *Climate*: Increasing carbon sequestration and reducing GHG emissions associated with biofuel production and use
- *Soil quality and agronomics*: Maintaining or improving soil quality
- *Water quality and quantity*: Maintaining or improving water quality, reducing consumptive water use, and improving water-use efficiency
- *Air quality*: Maintaining or improving air quality
- *Biological diversity*: Conserving plant and animal diversity and protecting habitat and ecological systems
- *Land use*: Maintaining or improving land productivity, minimizing negative land-use change impacts, and promoting beneficial landscape design.

Economic Sustainability

The primary goal of the Office is to promote an economically viable bioenergy industry in the United States. Therefore, several economic sustainability categories are critical for measuring progress toward this goal. Beyond profitability, the Office also relies heavily on measurements of efficiency and productivity when assessing and documenting the state of technology for promising bioenergy pathways. Economic sustainability is deeply interwoven into the Office's cost target structure, and therefore, is not a separate focus of cross-cutting sustainability efforts. However, the interaction between economic sustainability and the other two components (social and environmental) is covered under system-level sustainability.

Social Sustainability

Social sustainability, an often overlooked component, is critical to ensure that the development of the bioenergy industry aligns with societal values and promotes social goals. For example, much of the recent support given to biofuels has focused on their ability to promote energy security through the reduction of U.S. dependence on foreign oil. While social sustainability is not necessarily core to the Bioenergy Technologies Office's mission and efforts, much of the Office's activities are intrinsically related to the social benefits of bioenergy. Impacts from the Office's efforts that are directly aligned with social sustainability are:

- *Social acceptability:* Improving public opinion, minimizing risks, maximizing transparency, and ensuring effective stakeholder participation
- *Social well-being:* Maintaining or improving prosperity, safety, health, and food security
- *Energy security and external trade:* Reducing dependence on foreign oil, increasing access to affordable energy, demonstrating a positive net energy balance relative to fossil fuels, and improving the balance of trade between imports and exports for energy-related materials
- *Rural development and workforce training*: Promoting rural livelihoods and ensuring a trained workforce to support the bioenergy industry.

System-Level Sustainability

System-level sustainability represents an explicit consideration of the relationship within and between the sustainability categories above. One example of system-level sustainability would be to optimize for both economic and environmental sustainability in order to find the most beneficial outcome.

In order to understand and address the environmental, social, and economic benefits and impacts of bioenergy production, the Bioenergy Technologies Office works closely with other federal agencies whose missions incorporate bioenergy. In particular, the Office partners closely with the USDA, EPA, and the U.S. Department of Transportation (DOT). The Office is also actively involved in international dialogue on sustainable bioenergy through the Global Bioenergy Partnership's Sustainability and Capacity Building Working Groups, the Roundtable on Sustainable Biofuels, the Council on Sustainable Biomass Production, and the International Organization for Standardization.

While other federal agencies have activities related to select focus areas along the supply chain, such as feedstock production within USDA, infrastructure and end use within DOT, or environmental impacts within EPA, the Bioenergy Technologies Office addresses the integration of all dimensions of sustainability and all supply chain components. The Office is focused on evaluating all that goes into sustaining an integrated biorefinery—feedstock production and logistics (sustainable supply), conversion unit operations, and infrastructure for the delivery of fuel, power, and products from the biorefinery facility to end use. Data integration is critical to proactively assessing and addressing the environmental, economic, and social impacts of the industry as a whole and for specific feedstock-to-energy pathways.

2.4.1 Sustainability Support of Office Strategic Goals

The Bioenergy Technologies Office's overarching strategic goal is to *develop commercially viable biomass utilization technologies to enable the sustainable, nationwide production of advanced biofuels that are compatible with today's transportation infrastructure and can displace a share of petroleum-derived fuels to reduce U.S. dependence on oil and encourage the creation of a new domestic bioenergy industry, supporting the EISA goal of 36 billion gallons per year of renewable transportation fuels by 2022*.

Sustainability is an integral part of the Bioenergy Technologies Office's vision and strategic goal. The Sustainability Technology Area's strategic goal is *to understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities.*

Sustainability Activities Interfaces
Sustainability activities interface with and impact all elements of the biomass-to-bioenergy supply chain and at each stage of the development of bioenergy.

2.4.2 Sustainability Support of Office Performance Goals

The overall performance goals for the Sustainability Technology Area are:

- By 2013, identify metrics and set targets for soil quality and air quality for agricultural residues, energy crops, and forest resources and at least one conversion pathway.
- By 2022, evaluate, quantify, and document sustainable integrated pilot-scale production of biofuels from agricultural residues, energy crops, forest resources, and algae.

The performance goals for the pathways under investigation are:

Analysis

- By 2017, evaluate and compare the sustainability of biofuels produced from agricultural residues, energy crops, forest resources, and algae.
- By 2022, evaluate and compare the sustainability of biofuel production pathways.

Pilot and Demonstration

- By 2015, demonstrate sustainable production of biofuel from agricultural residues at the pilot scale, including all sustainability categories.
- By 2017, demonstrate sustainable production of biofuel from woody or herbaceous energy crops at the pilot scale, including all sustainability categories.
- By 2022, demonstrate sustainable biofuel production from cellulosic and algal feedstocks.

Best Practices Deployment

- By 2017, implement best practices for all sustainability categories for a sustainable, integrated biomass-to-biofuel process for agricultural residues.

- By 2022, implement best practices for all sustainability categories for a sustainable integrated biomass to bioenergy process for energy crops (woody or herbaceous), forest resources, and algae.

2.4.3 Sustainability Technical Challenges and Barriers

St-A. Scientific Consensus on Bioenergy Sustainability: While there is agreement on the general definition of sustainability, there is no consensus on its specific definition and ways to quantitatively measure bioenergy sustainability (such as definitions, approaches, system boundaries, and time horizons).

St-B. Consistent and Evidence-Based Message on Bioenergy Sustainability: The prevalence of misrepresentations of the effects of bioenergy—including assumptions, scenarios, and model projections that lack empirical underpinnings—creates confusion about the benefits of bioenergy production and leaves the industry vulnerable to criticism.

St-C. Sustainability Data Across the Supply Chain: A fundamental hurdle to ensuring sustainable bioenergy production is the lack of data available to evaluate sustainability and to compare the sustainability of one biofuel or bioenergy pathway with another. The lack of adequate and accessible temporal and spatial data for measuring sustainability also hinders other critical activities, such as establishing baselines, determining targets for improvement, recommending best practices, and evaluating tradeoffs.

St-D. Implementing Indicators and Methodology for Evaluating and Improving Sustainability: Significant progress has been made on developing a science-based framework for assessing bioenergy sustainability through developing metrics, defining baselines, setting targets, and conducting life-cycle assessments to determine the impacts of bioenergy relative to other energy alternatives. The remaining challenge is to further refine and implement that framework and assess its effectiveness in evaluating and improving sustainability.

St-E. Best Practices and Systems for Sustainable Bioenergy Production: Because bioenergy production from cellulosic and algal feedstocks is relatively new, few “best practices” and sustainable systems are defined for all components of the bioenergy supply chain. Best practices must be developed and deployed, and their effectiveness demonstrated at progressively larger scales.

St-F. Systems Approach to Bioenergy Sustainability: The sustainability of the entire supply chain is not considered in current assessments of technical feasibility and economic optimization. No tools exist to allow researchers to consider the potential synergies and trade-offs among different goals (energy security, biodiversity protection, low-cost commodities), aspects of sustainability (environmental, economic, social), and bioenergy scenarios.

St-G. Representation of Land Use and Innovative Landscape Design: The limitations of existing data sources to capture the actual state of the landscape and an incomplete understanding of the processes that drive land-use change have undermined efforts to assess the environmental and social effects of bioenergy. Science-based strategies are needed for proactively designing landscapes to minimize negative land-use change impacts and maximize environmental benefits.

2.4.4 Sustainability Approach for Overcoming Challenges and Barriers

The approach for overcoming biomass sustainability technical challenges and barriers is outlined in the Sustainability Technology Area's WBS as shown in Figure 2-32. The WBS is organized around two areas: Sustainability Analysis and Sustainable System Design, with key subtasks as shown in Figure 2-34.

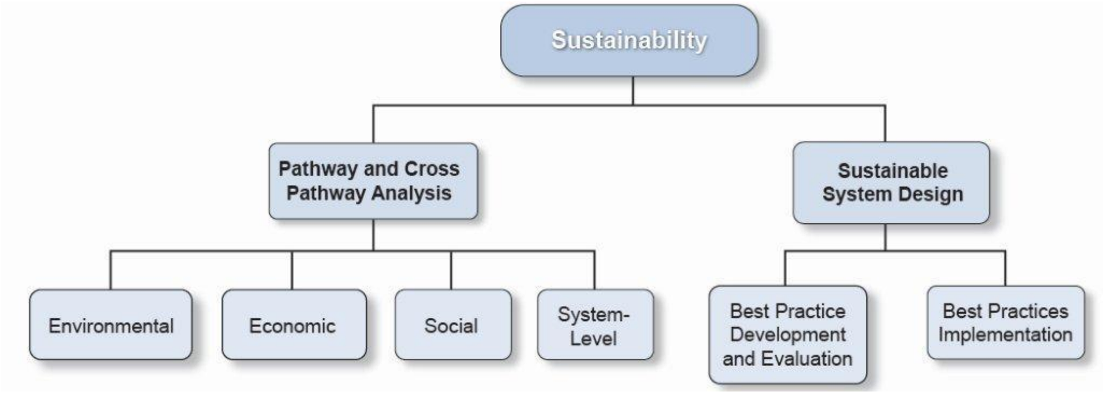


Figure 2-32: Work Breakdown Structure for Sustainability

The R&D approach of each Sustainability WBS task element is described below, while Table 2-13 summarizes each task element's work as it relates to specific sustainability barriers and biorefinery pathways.

Pathway and Cross-Pathway Analysis

Sustainability Analysis is focused on identifying sustainability indicators, establishing performance baselines and targets, identifying trends, and evaluating trade-offs and progress for technology pathways/routes across the entire supply chain—feedstocks, conversion, distribution, and end use. Environmental, social, and economic sustainability of all pathways will be considered, as well as integration across these aspects of sustainability to enable the comparison of various biorefinery pathways (referred to as "cross-pathway analysis"). For additional information on the evaluation of economic sustainability, see Section 2.7–Analysis.

Sustainable System Design and Best Practices

This area is focused on developing, evaluating, and supporting implementation of best practices based on monitoring, field and process data, and modeling results. This includes collaborating with relevant research and regulatory entities to identify and prevent negative consequences of emerging bioenergy technologies and feedstock varieties that might pose risks to ecological systems or human health. As best practices are developed and validated, they will be incorporated into the Office's technology evaluation approach and implemented in future funded RDD&D projects. Adoption of best practices will also be promoted through outreach and knowledge dissemination. The Office supports development of innovative, sustainability-focused solutions that reduce supply risks and the delivered cost of feedstock to biorefineries through highly integrated feedstock production system designs. The Office is also investigating and facilitating opportunities to reduce biofuel production costs by coupling conservation and environmental markets to biorefinery processes and feedstock supply systems.

Table 2-13: Sustainability Activity Summary

***Goal**: To understand and promote positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities.*

WBS Element	Description	FY 2012 Performer	Barrier(s) Addressed
Pathway & Cross-Pathway Sustainability Analysis	Identify indicators, establish baselines and targets, and assess progress for technology pathways/routes across the entire supply chain. Assess indicators for ease and cost of data collection, verification, and comparison, as well as effectiveness in reflecting the implications of different technologies on goals and priorities. Identify trends and evaluate trade-offs among different indicators and pathways. Test and validate hypotheses and calibrate models against relevant empirical data. Review objectives, indicators, and best practices in light of changing conditions, priorities, and new knowledge.	See below	See below
Environmental	Identify categories of environmental indicators that reflect goals and priorities to provide comparison among different technology options. Identify sustainability indicators and set baselines and targets for climate, water, land use, soil quality, and air quality.	ANL, INL, NREL, ORNL, PNNL, Regional Feedstock Partnerships	St-A: Scientific Convergence St-B: Consistent, Evidence-Based Message St-C: Sustainability Data Across the Supply Chain St-D: Indicators and Methodology St-G: Representation of Land Use
Social	Identify categories of social indicators that reflect goals and priorities and permit the comparisons across different technology options. Identify indicators for social acceptability, social well-being, energy security, external trade, and rural development.	ORNL	St-A: Scientific Consensus St-B: Consistent, Evidence-Based Message St-C: Sustainability Data Across the Supply Chain St-D: Indicators and Methodology
System-Level Sustainability	Identify categories of indicators that reflect goals and priorities for sustainability and permit the comparisons across different technology options. Evaluate categories using selection criteria for indicators. Assess utility of the indicators in terms of their effectiveness in reflecting the implications of different technologies on goals and priorities.	ANL, INL, NREL, ORNL, PNNL	St-A: Scientific Consensus St-B: Consistent, Evidence-Based Message St-C: Sustainability Data Across the Supply Chain St-D: Indicators and Methodology St-F: Systems Approach to Bioenergy Sustainability St-G: Representation of Land Use
Sustainable System Design	Develop, evaluate, and support implementation of best practices based on monitoring, field and process data, and modeling results.	Coordinated across Office projects	See below
Best Practices Development and Evaluation	Develop and evaluate best practices based on monitoring, field data, and modeling results. Compare practices with empirical data to support continuous improvement in sustainability.	Coordinated across Office projects	St-A: Scientific Consensus St-B: Consistent, Evidence-Based Message St-C: Sustainability Data Across the Supply Chain St-D: Indicators and Methodology St-E: Best Practices St-F: Systems Approach to Bioenergy Sustainability St-G: Representation of Land Use
Best Practices Implementation	Promote adoption of best practices.	Coordinated across Office projects	St-C: Sustainability Data Across the Supply Chain St-D: Indicators and Methodology St-E: Best Practices St-F: Systems Approach to Bioenergy Sustainability St-G: Representation of Land Use

2.4.5 Prioritizing Sustainability Barriers

To enable data-driven prioritization of its sustainability efforts, the Bioenergy Technologies Office developed a framework of tasks for each sustainability category (climate, soil quality, etc.), as illustrated in Figure 2-33. To assess and improve the sustainability of a particular bioenergy production pathway, tasks are being completed in each category for each relevant supply chain element. Sustainability Area goals have been set based on the maturity of each biorefinery pathway and anticipated technology development.

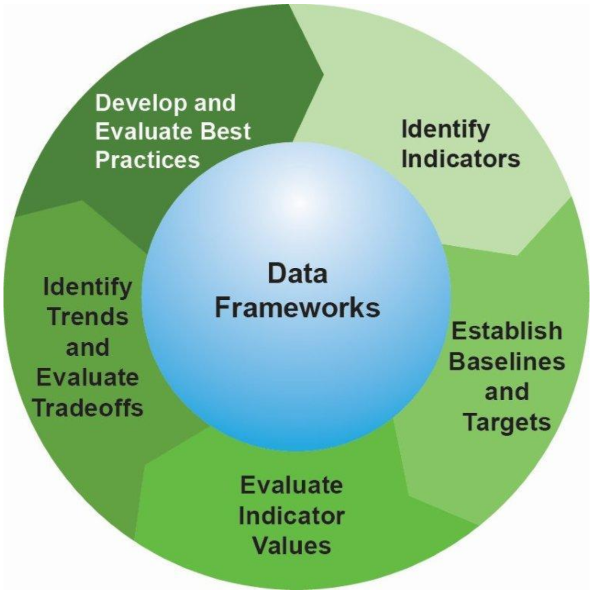


Figure 2-33 Sustainability Activities

Sustainability Activities for Each Biorefinery Pathway

The Office is working to define and implement principles of sustainability within the context of bioenergy production. Some of these principles, such as “biofuels should have a lower GHG impact than petroleum-based fuels,” are legislatively mandated (in this case by EISA), while in other cases they are not clearly defined. The main sustainability categories are:

- *Environmental Sustainability*: Climate, soil quality and agronomics, water quality and quantity, air quality, biological diversity, and land use
- *Economic Sustainability*: Efficiency, productivity, and profitability
- *Social Sustainability*: Social acceptability, social well-being, energy security, external trade, rural development, and workforce training.

Principles are being developed across these categories by which progress can be measured using indicators. Based on these associated indicators or metrics, best practices will be demonstrated as follows:

- **Evaluate and select appropriate indicators** based on sustainability goals and selection criteria (e.g., cost of data collection and verification, attribution, comparability across pathways, consistency across agencies, etc.). Assess utility in terms of indicator capacity to reflect implications of different technologies on sustainability goals and priorities.
- **Establish baseline and target conditions** consistent with the goals and scales (temporal and spatial) of effects to be measured. Develop scenarios for the evolution of supply,

demand, and consequences with and without Office interventions. Establish relevant sustainability targets for each selected indicator to reflect the changes that could be expected as a result of Office activities and investments.

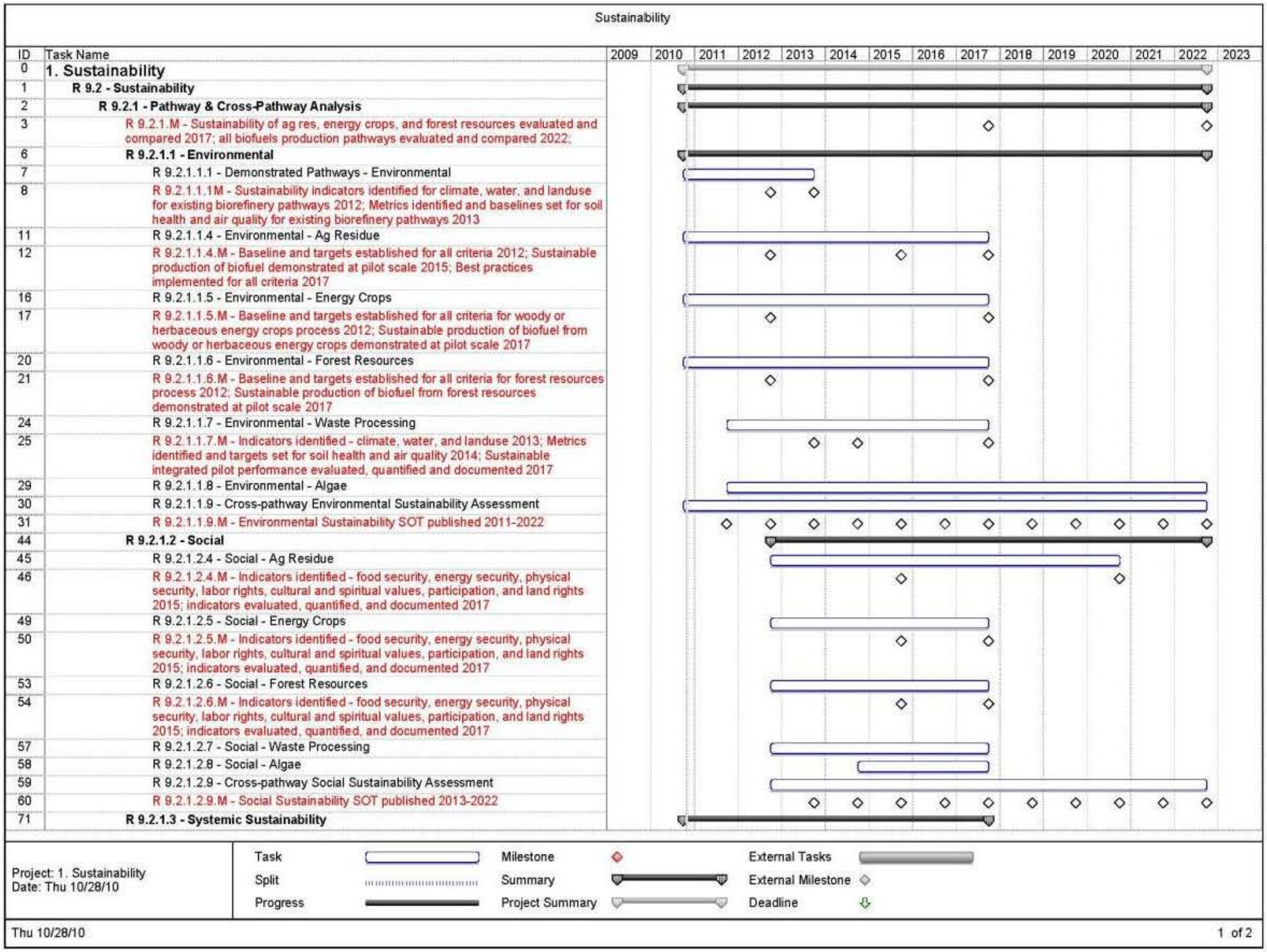
- **Evaluate indicator values** based on established monitoring protocols and considering relationships among each supply chain element and indicator. Document what is known and unknown about all factors that induce changes in indicator status. Document the presumed degree to which Office intervention can impact indicator values.
- **Identify trends and evaluate trade-offs** among different indicators and pathway elements. Test and validate hypotheses and calibrate models against relevant empirical data.
- **Develop and evaluate best practices based on monitoring, field data, and modeling results.** Compare practices with empirical data to support continuous improvement in sustainability. Review objectives, indicators, and best practices in light of changing conditions, priorities, and new knowledge.

Comparing new bioenergy technologies with current and evolving global bioenergy systems is an important element of the Sustainability Area’s activities. Such comparisons enable the Office to assess performance against benchmark systems from other major bioenergy-producing countries.

2.4.6 Sustainability Milestones and Decision Points

The key milestones, inputs/outputs, and decision points to complete the tasks described in Section 2.4.4 are summarized in the chart in Figure 2-34. The highest level milestones are the performance goals for the Sustainability Area. These performance goals represent the culmination of work from the collection of data at the bench and field scale to the pilot and demonstration scale; to the analysis and evaluation of baselines and targets; and eventually to the implementation of best practices in demonstration- and commercial-scale efforts.

Figure 2-34: Sustainability Gantt Chart



ID	Task Name
0	**1. Sustainability**
1	**R 9.2 - Sustainability**
2	**R 9.2.1 - Pathway & Cross-Pathway Analysis**
3	R 9.2.1.M - Sustainability of ag res, energy crops, and forest resources evaluated and compared 2017; all biofuels production pathways evaluated and compared 2022;
6	**R 9.2.1.1 - Environmental**
7	R 9.2.1.1.1 - Demonstrated Pathways - Environmental
8	R 9.2.1.1.1M - Sustainability indicators identified for climate, water, and landuse for existing biorefinery pathways 2012; Metrics identified and baselines set for soil health and air quality for existing biorefinery pathways 2013
11	R 9.2.1.1.4 - Environmental - Ag Residue
12	R 9.2.1.1.4.M - Baseline and targets established for all criteria 2012; Sustainable production of biofuel demonstrated at pilot scale 2015; Best practices implemented for all criteria 2017
16	R 9.2.1.1.5 - Environmental - Energy Crops
17	R 9.2.1.1.5.M - Baseline and targets established for all criteria for woody or herbaceous energy crops process 2012; Sustainable production of biofuel from woody or herbaceous energy crops demonstrated at pilot scale 2017
20	R 9.2.1.1.6 - Environmental - Forest Resources
21	R 9.2.1.1.6.M - Baseline and targets established for all criteria for forest resources process 2012; Sustainable production of biofuel from forest resources demonstrated at pilot scale 2017
24	R 9.2.1.1.7 - Environmental - Waste Processing
25	R 9.2.1.1.7.M - Indicators identified - climate, water, and landuse 2013; Metrics identified and targets set for soil health and air quality 2014; Sustainable integrated pilot performance evaluated, quantified and documented 2017
29	R 9.2.1.1.8 - Environmental - Algae
30	R 9.2.1.1.9 - Cross-pathway Environmental Sustainability Assessment
31	R 9.2.1.1.9.M - Environmental Sustainability SOT published 2011-2022
44	**R 9.2.1.2 - Social**
45	R 9.2.1.2.4 - Social - Ag Residue
46	R 9.2.1.2.4.M - Indicators identified - food security, energy security, physical security, labor rights, cultural and spiritual values, participation, and land rights 2015; indicators evaluated, quantified, and documented 2017
49	R 9.2.1.2.5 - Social - Energy Crops
50	R 9.2.1.2.5.M - Indicators identified - food security, energy security, physical security, labor rights, cultural and spiritual values, participation, and land rights 2015; indicators evaluated, quantified, and documented 2017
53	R 9.2.1.2.6 - Social - Forest Resources
54	R 9.2.1.2.6.M - Indicators identified - food security, energy security, physical security, labor rights, cultural and spiritual values, participation, and land rights 2015; indicators evaluated, quantified, and documented 2017
57	R 9.2.1.2.7 - Social - Waste Processing
58	R 9.2.1.2.8 - Social - Algae
59	R 9.2.1.2.9 - Cross-pathway Social Sustainability Assessment
60	R 9.2.1.2.9.M - Social Sustainability SOT published 2013-2022
71	**R 9.2.1.3 - Systemic Sustainability**

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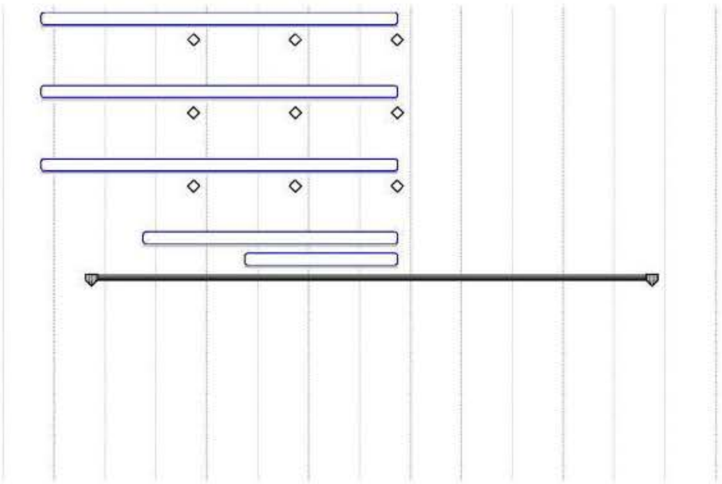
ID	Task Name
72	R 9.2.1.3.4 - Systemic Sustainability - Ag Residue
73	R 9.2.1.3.4.M - Indicators categorized against sustainability goals and priorities 2013; Indicators evaluated against selection criteria 2015; Indicators' reflection of sustainability of different technologies evaluated 2017
77	R 9.2.1.3.5 - Systemic Sustainability - Energy Crops
78	R 9.2.1.3.5.M - Indicators categorized against sustainability goals and priorities 2013; Indicators evaluated against selection criteria 2015; Indicators' reflection of sustainability of different technologies evaluated 2017
82	R 9.2.1.3.6 - Systemic Sustainability - Forest Resources
83	R 9.2.1.3.6.M - Indicators categorized against sustainability goals and priorities 2013; Indicators evaluated against selection criteria 2015; Indicators' reflection of sustainability of different technologies evaluated 2017
87	R 9.2.1.3.7 - Systemic Sustainability - Waste Processing
88	R 9.2.1.3.8 - Systemic Sustainability - Algae
89	**R 9.2.1.4 - Cross Pathway sustainability analysis**
90	R 9.2.1.4.M - Cross-pathway Systemic Sustainability SOT published 2011-2022
103	**R 9.2.2 - Sustainability Standards & Adoption**
104	R 9.2.2.1 - Document best practices
105	R 9.2.2.1.M - Best practices defined for feedstock production, collection, transport, processing and distribution of biofuel; Conditions tested for ag res 2017, energy crops
108	R 9.2.2.2 - Set standards / promote adoption of best practices
109	R 9.2.2.2.M - Targets developed for each type of indicator and feedstock type relative to the goals - ag residue 2017; forest resource 2022
112	R 9.2.2.2.M.3 - Standard information collection methods determined and sustainability effects assessed 2022



Project: 1. Sustainability
Date: Thu 10/28/10

Task	▭	Milestone	◆	External Tasks	▬
Split	⋯	Summary	▬	External Milestone	◇
Progress	▬	Project Summary	▬	Deadline	⇩

Thu 10/28/10

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2.5 Strategic Analysis

Strategic analysis helps determine overall Office goals and priorities and covers issues that cut across all technology areas. Technology-specific analysis activities contribute to engineering designs, set performance targets, and enable the Office to monitor progress toward goals. System-level analyses help the Office focus its technology development priorities and identify key drivers and hurdles for industry growth.

The Strategic Analysis Area plays four main roles in the Bioenergy Technologies Office's decision-making process:

1) Provides the analytical basis for Office planning and assessment of progress
2) Defines and validates performance targets for biomass technologies and systems
3) Conducts system-level policy, industry, and environmental analyses relevant to bioenergy
4) Reviews and evaluates external analysis and studies.

Maintaining these capabilities at the cutting edge is essential to ensure that the analysis provides the most efficient and complete answers to technology developers and Office management. Coordinated multi-lab efforts and continued partnerships with the biomass industry and scientific community help ensure that the analysis results from the Office are peer reviewed, transferable, and comparable.

Figure 2-35 shows how the Strategic Analysis Technology Area supports all elements of the biomass-to-bioenergy supply chain.

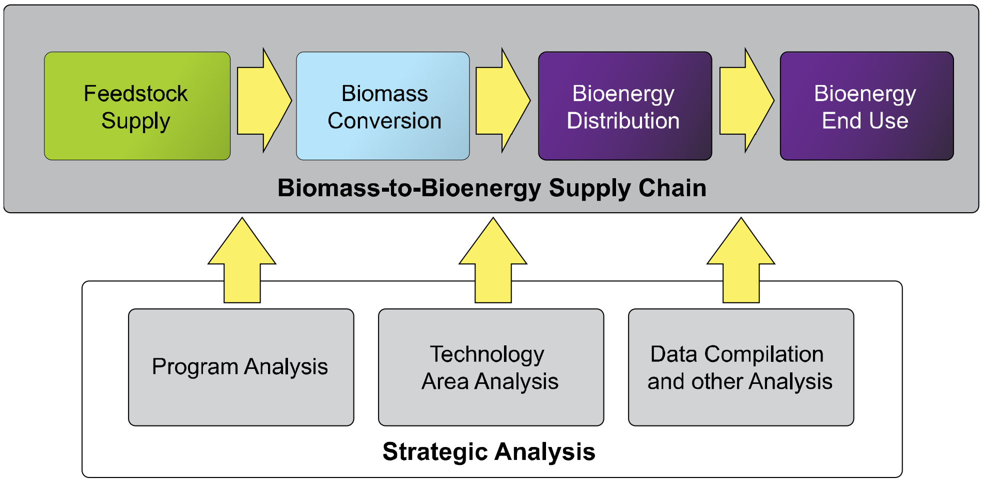

Figure 2-35: Strategic Analysis Supports the Entire Supply Chain

2.5.1 Strategic Analysis Support of Office Strategic Goals

Strategic Analysis' strategic goal is to *provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management.*

2.5.2 Strategic Analysis Support of Office Performance Goals

Strategic analysis activities support accomplishment of Office goals by:

- Ensuring high-quality, consistent, reproducible, peer-reviewed analyses
- Developing analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts
- Conveying the results of analytical activities to a wide audience, including DOE management, Congress, the White House, industry, and the general public.

Strategic analysis activities are ongoing; however, the following key milestones will provide the analytical basis for out-year targets and R&D activities for meeting those targets:

- By 2013, select, complete techno-economic modeling, and set goals and targets for at least two hydrocarbon pathways.
- By 2014, select, complete techno-economic modeling, and set goals and targets for at least two additional hydrocarbon pathways.
- By 2017, validate 2017 hydrocarbon pathway performance targets.

2.5.3 Strategic Analysis Challenges and Barriers

Several factors impact the understanding of key drivers and implications for developing and sustainably deploying new biomass technologies. These include the following challenges and barriers:

At-A. Lack of Comparable, Transparent, and Reproducible Analysis. Analysis results are strongly influenced by the datasets employed, as well as by the assumptions and guidelines established to frame the analysis. The lack of standardized datasets, assumptions, and guidelines makes results difficult to compare and integrate with the results of other analyses.

At-B. Limitations of Analytical Tools and Capabilities for System-Level Analysis. Current analysis tools and models are not sufficient in their current state to enable the understanding of broader bioenergy supply-chain-wide systems, linkages, and dependencies. Models need to be developed to understand these issues and their interactions. Improvements in component models and in linkages are necessary to make them more useful and consistent.

At-C. Inaccessibility and Unavailability of Data. Understanding the biomass-to-bioenergy supply chain and its economic, environmental, and other impacts requires complete and comparable data. Current data are difficult to find, access, compile, and analyze. Some data that are required to understand all relevant dimensions of bioenergy production and use are unavailable or nonexistent.

2.5.4 Strategic Analysis Approach for Overcoming Challenges and Barriers

Strategic Analysis activities are designed to support Office decision-making processes and track milestones. They validate decisions, ensure objective inputs, and respond to external recommendations. The WBS shown in Figure 2-36 shows the types of analysis activities undertaken by the Office. The descriptions below discuss the models and methods used for the various types of analysis conducted by national laboratories, universities, and within EERE.

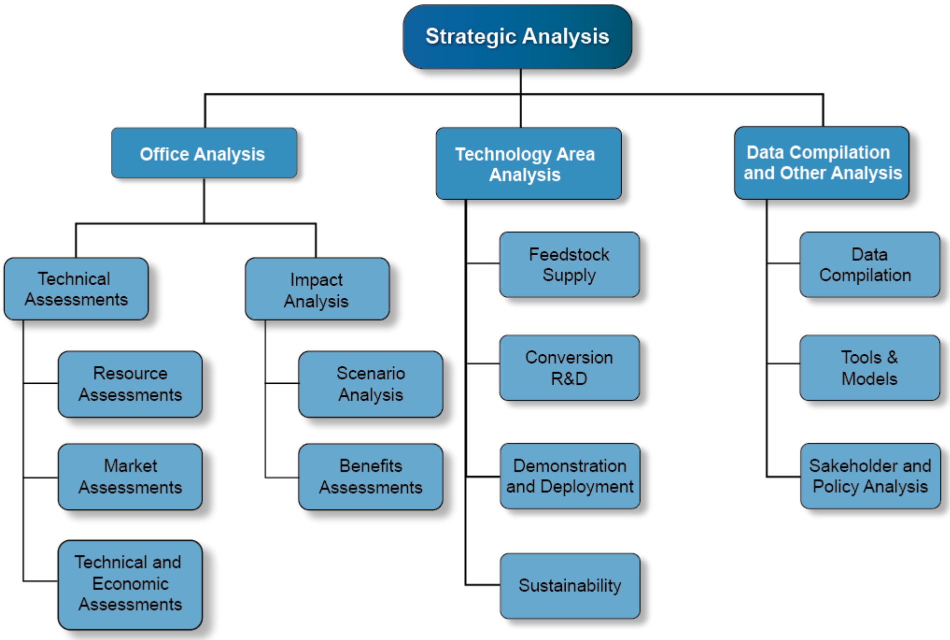

Figure 2-36: Strategic Analysis Work Breakdown Structure

Office Analysis

i) Technical Assessments

Resource Assessments: Feedstock supply resource assessments identify the geographic location, price, and environmental sustainability of accessing existing and potential future feedstock resources, as well as projecting future supply availability and prices. Strategic Analysis activities utilize these data to understand price effects of competition from various biomass utilization technologies (e.g., biofuel versus biopower), as well as to assess cross-technology impacts of feedstock cost, quantity, and quality.

***Market Assessment*:** Market assessment helps the Office focus its technology development priorities in the near, mid, and long term by analyzing the potential cost, commercialization time, and market demands for candidate biofuels, biopower, and bioproducts. This analysis draws on a broad range of other analyses, including fossil fuel cost projections; future energy demand forecasts; infrastructure assessments; state of biomass utilization technology development; national and local sustainability analysis; and consumer, economic, and policy scenarios. This analysis also helps identify current and future market attractiveness, gaps, strengths, and risks that may impact producer, investor, and consumer decision making.

Technical and Economic Assessment: The Office assesses the technical and economic viability of new processes and technologies, identifies the potential for cost reduction, assesses cross-pathway and cross-technology progress, and provides input into portfolio development and technology validation. Near-term efforts focus on development of a model that uses preset assumptions combined with user-generated inputs to analyze and compare various biofuels conversion and production technologies by modeling minimum selling prices at specified rates of return. Technology and economic analysis methods and tools used include unit operation design flow and information models, process design and modeling (e.g., Aspen Plus©[36]), capital costs (e.g., Aspen ICARUS[37]) and operating cost[38] determination, discounted cash flow analysis, and Monte Carlo sensitivity analysis/risk assessment (e.g., Crystal Ball[39]). The Office also assesses the potential cost reductions that can be achieved as the advanced biofuels industry develops and increases capacity beyond first-of-a-kind pioneer facilities. This ongoing analysis effort applies learning rates from relevant, more established industries to estimate the range of possible cost reductions as conversion technologies are commercialized and replicated.

ii) Impact Analyses

Scenario Analysis**:** Understanding the impacts of changes and development of various elements of the biomass-to-bioenergy supply chain is the key to informing technology portfolio planning and monitoring progress toward national goals. To help understand which supply chain modifications have the greatest potential to accelerate deployment of biofuels, the Office has supported development of the Biomass Scenario Model (BSM). The BSM is a systems dynamics model for conducting biofuels policy analysis through investigating the systemic effects, linkages, and dependencies across the biomass-to-biofuels supply chain. Figure 2-37 shows the conceptual structure of the model and an overview of the module for each supply chain component. The model considers pathways from starch, lignocellulosic, oilseed, and algal feedstocks to ethanol, butanol, gasoline, diesel, and aviation fuel.

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[36] Aspen Plus© is a process modeling tool for steady state simulation, design, performance monitoring, optimization and business planning widely used in the chemicals, specialty chemicals, petrochemicals and metallurgy industries. Information is available at http://www.aspentech.com/.

[37] For information, see http://www.aspentech.com.

[38] As an example, chemical supply costs are taken from *The Chemical Marketing Report* and labor costs from related industries such as corn ethanol production.

[39] For information, see http://www.decisioneering.com/.

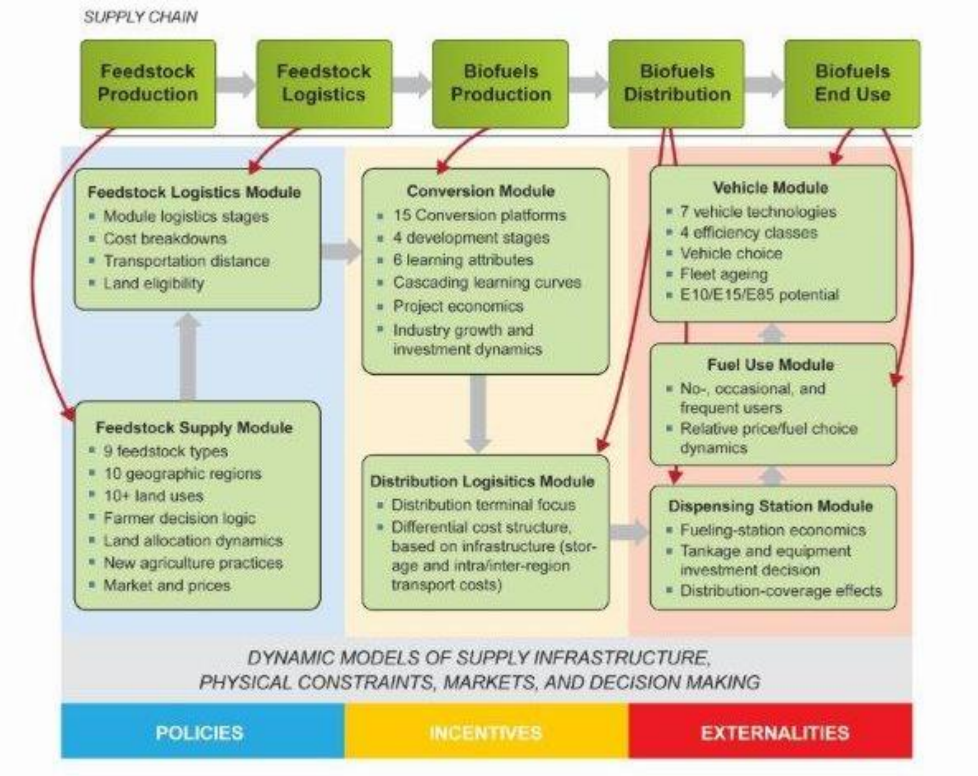

Figure 2-37: Conceptual Schematic of Biomass Scenario Model

Benefits Analysis**:** Benefits analysis helps the Office quantify and communicate the long-term benefits of biomass RD&D (e.g., imported oil displacement and GHG mitigation). The scenarios developed and the quantified costs and benefits are used to evaluate the most viable biomass utilization technologies and routes. Results are also used in cross-cutting benefits analysis and are a key input to EERE renewable technology portfolio decision making.

Technology Area Analysis

Feedstock Supply R&D

Feedstock supply R&D analysis includes resource assessments and feedstock logistics system technical and economic assessments. Resource assessments estimate the current and future quantity and location of biomass resources by county, state, and region within the United States. Additionally, resource analysis projects resource cost as a function of the amount available on a sustainable basis for utilization.[40] A variety of integrated modeling tools (e.g., Policy Analysis System or POLYSYS[41]) and databases are used to estimate sustainable feedstock supplies. Additionally, geographic information systems (GIS) modeling tools are used to map and analyze resource data.

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[40] Perlack, Wright, et al, “Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.”

[41] For information, see http://www.agpolicy.org/polysys.html.

Conversion R&D: Technical, economic, and environmental analyses of conversion technologies track research improvements and determine their contribution to reducing the cost of sustainably converting biomass feedstocks to fuels, power, and products; guide R&D by identifying areas of largest potential for cost reductions; and provide data to support deployment and transition analyses.

Demonstration and Deployment: The Office gathers technical and economic analyses from DOE-funded IBR projects. These operations data from first-of-a-kind pilot-, demonstration-, and commercial-scale plants allow the Office to monitor progress against Office goals, compare projected benefits of various biomass utilization technologies, and assess the current state-of-technology development. IBR projects also provide critical insights into the challenges associated with building first-of-a-kind plants. Additional deployment analyses help identify strategies for addressing distribution, infrastructure, and end-use issues.

Sustainability: The Strategic Analysis Technology Area supports Office sustainability efforts through developing and maintaining life-cycle and land-use change models to estimate the environmental impacts of biomass production and utilization technologies. This analysis is discussed in detail under Section 2.4, Sustainability. It is heavily reliant on the development of practical, scientifically based, verifiable, cost-effective indicators, metrics, and baselines, as outlined in that section.

Life-cycle analysis models identify and evaluate the emissions, resource consumption, and energy use of various processes, technologies, or systems[42,43,44,45,46,47] to help understand the full impacts of existing and developing technologies and prioritize efforts to mitigate negative effects. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation[48] (GREET) model is used to estimate fuel-cycle energy use and emissions associated with alternative transportation fuels and advanced vehicle technologies. Strategic Analysis supports updates and enhancements to the GREET model to continually reflect new and evolving bioenergy technologies.

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[42] May Wu, Ye Wu, and Michael Wang, "Mobility Chains Analysis of Technologies for Passenger Cars and Light-Duty Vehicles Fueled with Biofuels: Application of the GREET Model to the Role of Biomass in America's Energy Future (RBAEF) Project," Argonne National Laboratory, ANL/ESD/07-11 (2005), http://www.transportation.anl.gov/pdfs/TA/344.pdf.

[43] Norman Brinkman, Michael Wang, et al, "Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions," Argonne National Laboratory (2005), http://www.transportation.anl.gov/pdfs/TA/339.pdf.

[44] John Sheehan, Andy Aden, Keith Paustian, et al, "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol," *Journal of Industrial Ecology Special Issue on Biobased Products* 7 (2003): 117-146.

[45] Michael Wang, Chris Saricks, and Hanjie Lee, "Fuel-Cycle Energy and Emission Impacts of Ethanol-Diesel Blends in Urban Buses and Farming Tractors," Argonne National Laboratory (2003), http://www.transportation.anl.gov/pdfs/TA/280.pdf.

[46] Hosein Shapouri, James Duffield, and Michael Wang, "The Energy Balance of Corn Ethanol: An Update," Argonne National Laboratory (2002), http://www.transportation.anl.gov/pdfs/AF/265.pdf.

[47] John Sheehan, Vince Camobreco, James Duffield, et al, "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus," National Renewable Energy Laboratory, NREL/SR-580-24089 (1998), http://www.nrel.gov/docs/legosti/fy98/24089.pdf.

[48] For information, see http://greet.es.anl.gov/.

In addition to maintaining and enhancing the Global Trade Analysis Project (GTAP) model to more accurately reflect the direct and indirect effects of land-use change from the U.S. biofuels industry, Strategic Analysis supports efforts to better understand and characterize the complex drivers of land-use change and gather more accurate land-use data to feed into these analyses.

Extensive analysis is being conducted to address water quantity and quality issues related to feedstock growth and biofuels production, using the Soil and Water Analysis Tool model.

Data Compilation and Other Analysis

Data Compilation: Many disciplines and sectors are involved in bioenergy RDD&D. Developing, compiling, maintaining, and providing easy access to the best available, credible data, models, and visualization tools is critical to supporting sustainable commercialization of biomass utilization technologies. To serve this need, the Office developed the Bioenergy Knowledge Discovery Framework (KDF), a Web-based data repository, visualization tool, and library. The goal of the KDF is to facilitate planning, development, and management decisions by providing a means to synthesize, analyze, and visualize vast amounts of information in a relevant and succinct manner. The KDF’s GIS-based data analysis, mapping, and visualization components draw from dynamic and disparate databases of information to enable users to analyze economic, social, and environmental impacts of various biomass utilization technologies for biomass feedstocks, biorefineries, and infrastructure.

Tools and Methods: The Office supports the development and deployment of new analytical tools and methods and guides the selection of assumptions and methodologies to be used for all analyses to ensure consistency, transparency, and comparability of results.

Stakeholder and Policy Analysis: The Office provides ongoing analysis and policy support to other U.S. government agencies and legislative bodies. Emerging issues, interests, and trends raise new questions from a wide variety of stakeholders, including DOE senior management, members of Congress, other federal agencies, and state governments. Scholarly articles, popular media, and other broader forums are additional sources of questions for analysis.

Table 2-14: Strategic Analysis Activity Summary

<u>Goal</u>: Provide context and justification for decisions at all levels by establishing the basis of quantitative metrics, tracking progress toward goals, and informing portfolio planning and management

WBS Element	Description	FY 2012 Performer	Barrier(s) Addressed
Office Analysis			
Technical Assessments			
Resource Assessments	Assess terrestrial and algal feedstock resource constraints and availability.	ORNL, PNNL	At-A: Lack of Comparable, Transparent and Reproducible Analysis At-B: Limitations of Analytical Tools and Capabilities for System-Level Analysis At-C: Inaccessibility and Unavailability of Data.
Market Assessment	Determine the cost, timing, and market demands for candidate biofuels and biocrudes.	NREL	
Technical and Economic Feasibility Assessment	- Comparative technical and economic assessment of biofuels - Support of the Comprehensive Integration of Annual State of Technology (SOT) Assessment - Support feedstock-pathway-wide techno-economic analysis.	NREL, ORNL, INL, PNNL	
Impact Analysis			
Scenario Analysis	Assess impacts of changes and development of various elements of the biomass-to-bioenergy supply chain and identify impacts of supply chain modifications on deployment of biofuels.	NREL Systems Integration (SI)	
Benefits Assessment	Evaluate and document impact of biofuels on U.S. economies and environment.	NREL SI	
Risk Analysis	Identify, quantify, and evaluate uncertainty and risk of biofuels.	NREL SI	
Technology Area Analysis			
Feedstock Supply	- Assess quantity and associated costs of biomass resources - Develop feedstock logistics process design and monitor SOT progress toward targets.	ORNL, INL, PNNL	
Conversion R&D	Develop techno-economic process designs and monitor SOT development and progress toward targets.	NREL, PNNL	
Demonstration & Deployment	Technical and economic analysis of IBR projects - Compile operations data from pilot-, demonstration-, and commercial-scale plants - Assess the current state-of-technology development - Assess distribution infrastructure and end use issues.	See Demonstration & Deployment Section	
Sustainability	Develop and maintain models used to assess land use, GHG and life-cycle impacts and support overall Office sustainability analysis.	ANL, INL, ORNL, NREL	
Data Compilation and Other			
Data Compilation	Ensure results of analytical and research activities are available through the KDF.	ORNL	
Tools and Methods	- Develop new analytical tools and methods as needed to address emerging needs - Establish and maintain standardized assumptions and methods.	DOE	
Stakeholder, Policy, and International Analysis	- Evaluate and document impact/implications of U.S. biofuels legislation (Farm Bill, EPAct, EISA) - Conduct specified analyses to provide technical support to GFO (proposal evaluation), EPA, USDA, the California Air Resources Board, and other agencies.	ANL, ORNL, NREL	

2.6 Strategic Communications

The Office's Strategic Communications area is focused on identifying and addressing non-technical and market barriers to bioenergy adoption and utilization in an effort to reach full-scale market penetration. The activities performed in support of these efforts are geared toward fostering greater stakeholder, public, and Congressional awareness and acceptance of significantly increased production of sustainable biofuels, bioproducts, and bioenergy needed to replace the whole barrel of oil, which displaces petroleum products and reduces GHG emissions. Together, these reduce our dependence on foreign oil and secure our nation's economic and energy future. Accordingly, Strategic Communications engages a range of stakeholders in meaningful collaborations, promotes the accomplishments of R&D projects in first-of-a-kind technologies, increases consumer acceptance, and accelerates the expansion of bioenergy production and use.

Strategic Communications includes distributing technical and non-technical information to internal and external stakeholders through a number of channels, including traditional media, new and digital media, website content, and conferences and events. In addition to conveying key Office goals, priorities, activities, and accomplishments, Strategic Communications also focuses on creating and maintaining public awareness, as well as promoting bioenergy production and use.

The Bioenergy Technologies Office's target audiences include scientists, engineers, and researchers; industry; policymakers at all levels of government, including Members of Congress and their staffs. The target audience also includes the general American public, specifically educators and students, as well as members of rural and farming communities.

2.6.1 Strategic Communications Support of Office Strategic Goals

The Strategic Communications area's strategic goal is to support and enhance the Office's mission *by conducting strategic outreach that promotes the benefits of sustainable biomass and biofuels to the public and key stakeholders and highlights the role bioenergy plays in the creation of green jobs and energy security*.

2.6.2 Strategic Communications Support of Office Performance Goals

The performance goals for Strategic Communications are to achieve the following:

- Increase awareness and support of the Office's advanced biomass R&D and technical accomplishments, highlighting their role in achieving national energy independence goals.
    - By 2013, complete outreach efforts focused on the R&D success of meeting cellulosic ethanol cost targets.
    - By 2014, complete outreach efforts focused on new Office technologies, pathways, and directions.
- Educate audiences about the environmental benefits of biomass as a viable alternative to fossil fuels, as well as the potential for advanced biofuels to displace petroleum-based transportation fuels

- By the end of 2014, complete outreach efforts focused on the GHG emission reductions resulting from biomass-based alternative fuels.

2.6.3 Strategic Communications Challenges and Barriers

Accelerating the growth of the bioenergy economy requires addressing market barriers at local, state, and federal levels. Strategic Communications' activities are focused on addressing the following market challenges and barriers:

Ct-A. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel: To succeed in the marketplace, biomass-derived fuels and chemical products must perform as well as or better than comparable petroleum- and fossil-based products. Industry partners and consumers must believe in the quality, value, sustainability, and safety of biomass-derived products and their benefits, relative to the risks and uncertainties that widespread changes will likely bring. Compared with other renewable technologies, consumer acceptance and awareness of biofuels and Bioenergy Technologies are varied. Additionally, there is a well-organized and heavily funded campaign of misinformation about biofuels. Only trustworthy, accurate, and up-to-date information can refute these allegations and reassure the public that biofuels, bioproducts, and bioenergy benefit the environment, while not reducing food stocks supply or increasing the cost of food stocks.

Ct-B. Poorly Understood Role of Government versus the Role of Industry: Government-funded R&D focuses on a broad range of emerging technologies. This approach supports a diverse technology portfolio and identifies the most promising targets for industry to pursue in follow-on, industrial-scale demonstration and deployment. Through grants and partnerships with universities, national labs, and research groups, the Office helps support basic research that would be too risky for any one private entity to pursue, while advancing the state of technology for the entire biomass industry. Once a technology reaches maturity, private industry entities are better equipped to aid in deploying that technology to end users. Stakeholders and the general public often do not understand these distinct and necessary roles. For example, cellulosic ethanol is now near deployment, causing a shift in the Office's focus to less developed technologies, such as drop-in hydrocarbon biofuels. The Office will need to communicate this shift in focus to its audiences in a clear, transparent manner to avoid misconceptions about the success of cellulosic ethanol. Additionally, the Office must communicate its repositioning as a necessary step in the advancement of technology to meet national energy independence goals, including EISA goals, which will require a diverse array of bio-based fuels and products.

Ct-C. Inconsistent and Unpredictable Policy Landscape and Priorities: The Office continues to support new, emerging technologies throughout a constantly changing policy, tax, and economic landscape. Communicating these shifting priorities effectively and accurately is an ongoing challenge.

2.6.4 Strategic Communications Approach for Overcoming Challenges and Barriers

The approach for overcoming Strategic Communications challenges and barriers is outlined in Figure 2-38 and described below.

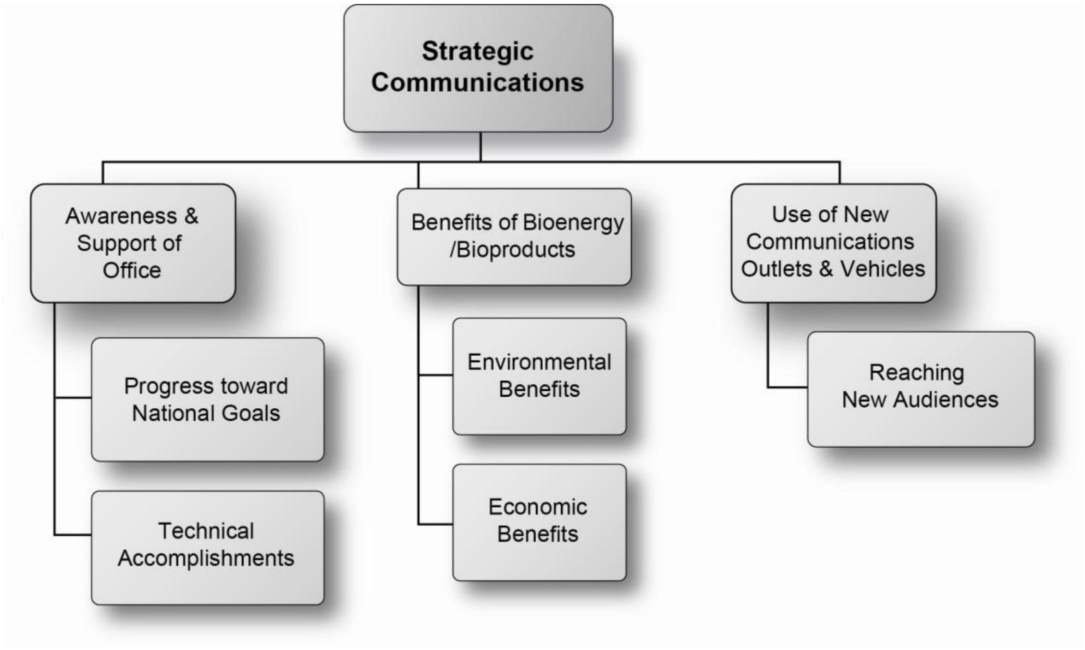


Figure 2-38: Strategic Communications Work Breakdown Structure

Awareness & Support of Office

This includes informing the public about Office accomplishments as well as new Office strategies and technologies, while calibrating expectations of near- and medium-term RDD&D achievements. Near-term activities in this area focus on promoting the Office's cellulosic ethanol R&D accomplishments, alongside the shift in focus to other infrastructure compatible fuels. Mid-term activities will highlight deployment and demonstration efforts as first-of-a-kind commercial biorefineries begin and continue production. Keeping lines of communication open through the GovDelivery listserv monthly news blast, the website, press releases and progress alerts, and other outreach vehicles will help disseminate this key messaging.

Benefits of Bioenergy Products/Bioproducts

These activities focus on deepening understanding of the environmental, economic, social, and energy security benefits of biofuels, biopower, and bioproducts. The continued use of regularly scheduled webinars, fact sheets and other publications, the annual Bioenergy Technologies Office conference, and speaking opportunities at industry and partner events will support these near and mid-term activities.

Use of New Communications Outlets and Vehicles

Alongside the use of traditional media, we have planned efforts for more effective utilization of electronic and social media to address challenges surrounding bioenergy and draw attention to positive perceptions, results, and accomplishments. Near-term efforts include strengthening communication of the Office's project portfolio through a Web-based, searchable library, and keeping lines of communication with key stakeholders open through the new Bioenergy Technologies Office Blog. Long-term efforts include the implementation of various new outlets for the dissemination of clear and consistent, targeted Office messaging that will increase the Office's reach beyond current stakeholders, while maintaining costs. These new outlets include increasing the use of new and social media and of third-party products, such as placing interviews with Office and lab personnel on targeted radio stations or publishing feature-length articles on Office activities and accomplishments in relevant technical and trade publications. Additionally, the Office will look into developing concepts for new media applications.

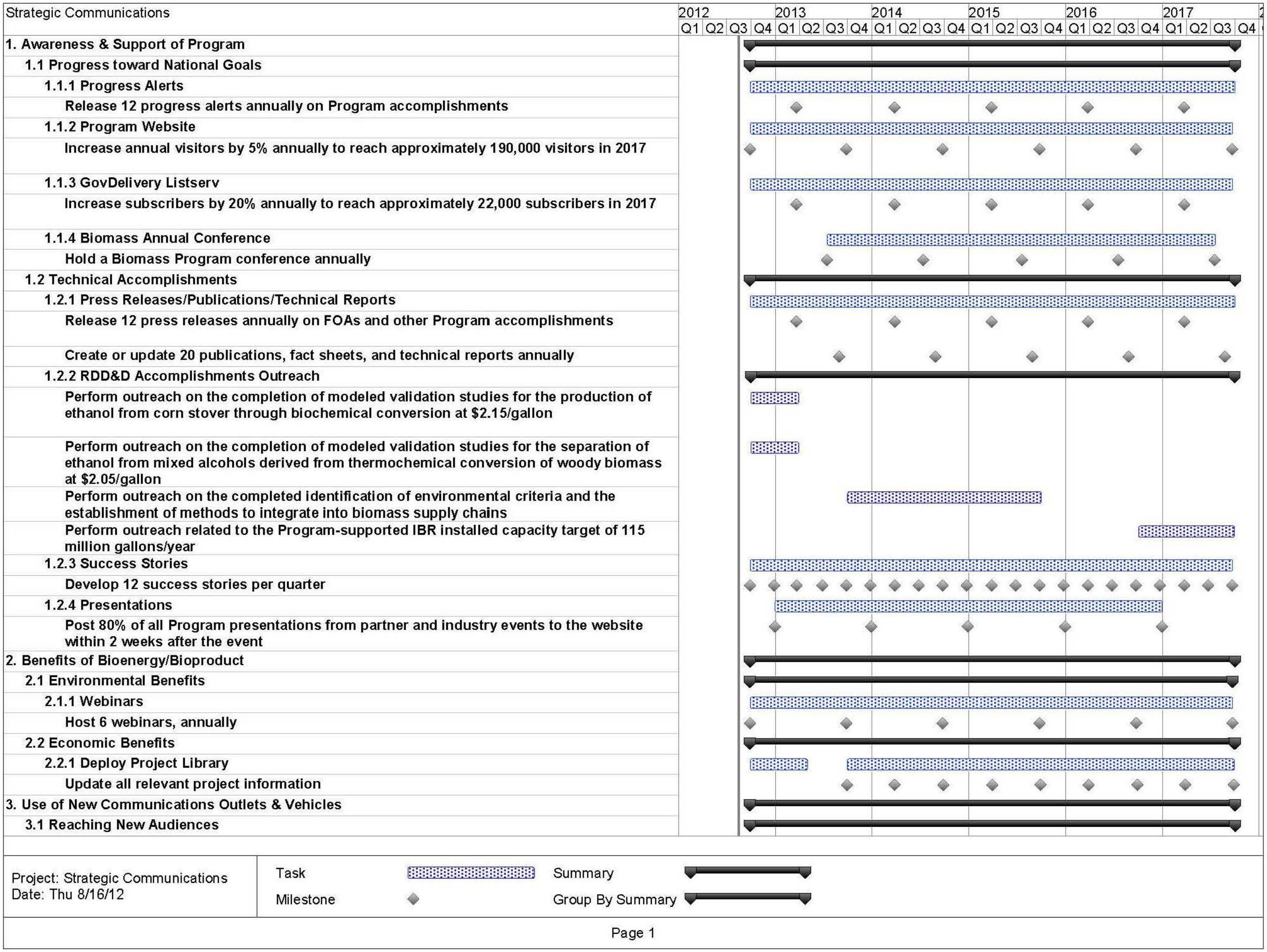
Activities for Strategic Communications are outlined in Table 2-15 and Figure 2-39.

Table 2-15: Strategic Communications Activity Summary

***Goal*: Support the Office's mission by conducting strategic outreach that promotes the benefits of sustainable biomass and biofuels to the public and key stakeholders and highlights the role bioenergy plays in the creation of green jobs and energy security.**

WBS Element	Description	FY 2013 Performer	Barrier(s) Addressed
Awareness & Support of Office	Use various media outlets to increase awareness and support of the Office's advanced biomass R&D and technical accomplishments.		
Progress Toward National Goals	Highlight the role the Office plays in achieving national goals, such as meeting EISA requirements for alternative fuels, creating new green jobs, and reducing the nation's dependence on foreign oil by replacing the whole barrel of petroleum-based fuels and products.	DOE	**Ct-A**. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel **Ct-B**. Poorly Understood Role of Government versus the Role of Industry
Technical Accomplishments	In 2013, Strategic Communications will focus on completing outreach efforts focused on the R&D success of meeting cellulosic ethanol targets. After these accomplishments are fully highlighted and explained to the public, outreach efforts will shift to highlighting other new technologies, pathways, and directions.	DOE	**Ct-A**. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel **Ct-B**. Poorly Understood Role of Government versus the Role of Industry
Benefit of Bioenergy/ Bioproducts	Use various media outlets to increase awareness about the benefits of bioenergy and bioproducts.		
Environmental Benefits	Educate audiences about the environmental benefits of biomass as a viable alternative to fossil fuels, such as outreach efforts focused on the GHG emission reductions resulting from biomass-based alternative fuels.	DOE	**Ct-A**. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel **Ct-C**. Inconsistent and Unpredictable Policy Landscape and Priorities are Inconsistent
Economic Benefits	Educate audiences about the economic benefits of a strong bioenergy industry, including the creation of new, green jobs.	DOE	**Ct-A**. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel
Use of New Communications Outlets & Vehicles	Implement new outlets for the dissemination of clear and consistent, targeted messaging that will increase the Office's reach beyond current stakeholders, while maintaining costs.		
Reaching New Audiences	New outlets that can be used to reach new audiences and targeted demographics include new and social media and third-party products, such as placing interviews with Office and lab personnel on targeted radio stations or publishing feature-length articles on Office activities and accomplishments in relevant technical and trade publications.	DOE	**Ct-A**. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative Fuel **Ct-B**. Poorly Understood Role of Government versus the Role of Industry

Figure 2-39: Strategic Communications Gantt Chart

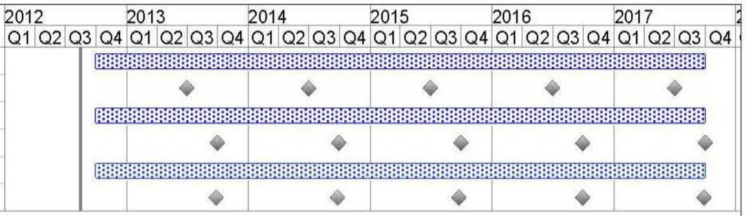


Strategic Communications

3.1.1 Videos and Multimedia
- **Create and upload 15 videos to YouTube annually**

3.1.2 Social Media
- **Post to social media profiles 12 times annually**

3.1.3 Biomass Program Blog
- **Update the Blog 12 times annually**



Project: Strategic Communications
Date: Thu 8/16/12

Task	▨	Summary	▬
Milestone	◆	Group By Summary	▬

Section 3: Office Portfolio Management

This section describes how the Department of Energy's (DOE) Bioenergy Technologies Office develops and manages its portfolio of research, development, demonstration, and deployment (RDD&D) activities. It identifies and relates different types of portfolio management activities, including portfolio decision making, analysis, and performance assessment.

Overview

The Bioenergy Technologies Office manages a diverse portfolio of technologies across the spectrum of applied RDD&D. Management of the Office's technology portfolio is a vital and demanding activity, made even more challenging by the fact that management of the portfolio must occur within the dynamic context of changing federal budgets and evolving administrative priorities.

To meet this challenge, the Office has developed a coordinated framework for managing its portfolio of RDD&D projects. The framework is based on systematically investigating, evaluating, and down-selecting the most promising opportunities across a diverse spectrum of emerging technologies and Technology Readiness Levels (Table 3-1). This approach is intended to support a diverse technological base in applied research and development (R&D), while identifying the most promising targets for follow-on industrial-scale demonstration and deployment. The RDD&D pipeline is shown diagrammatically in Figure 3-1.

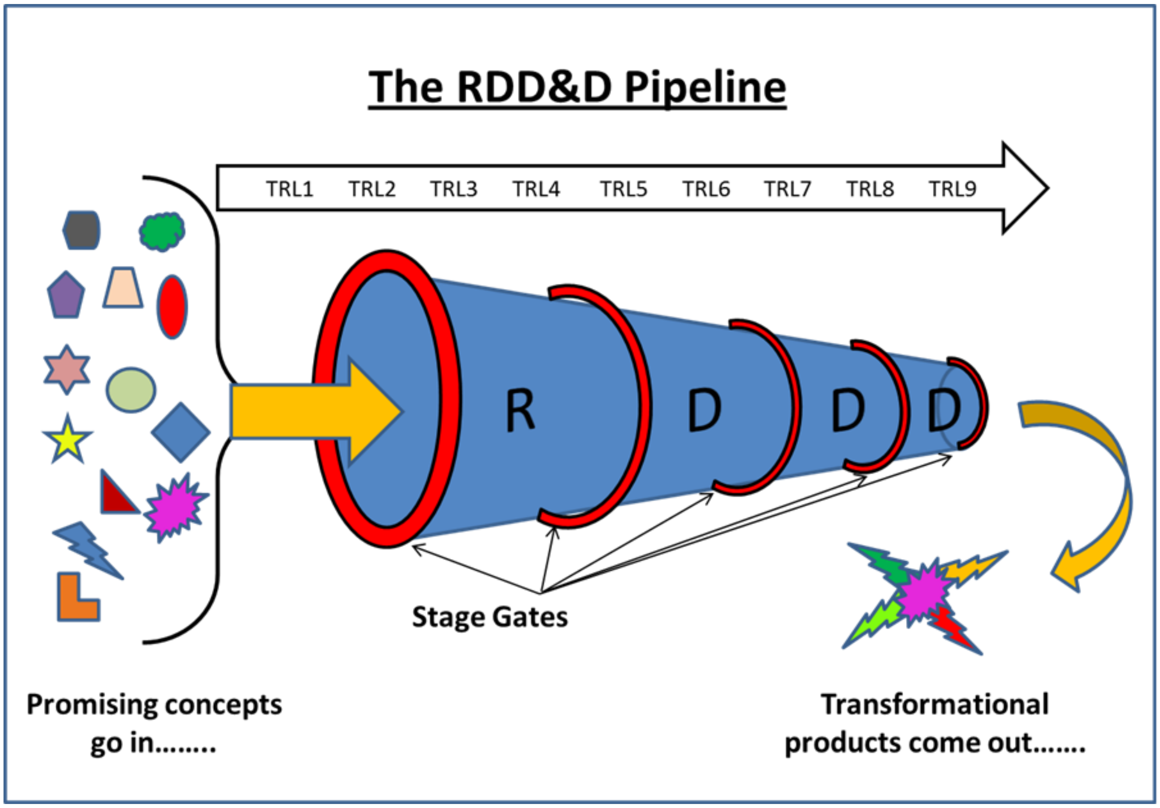


Figure 3-1: The RDD&D Pipeline

Table 3-1: Technology Readiness Level (TRL) Definitions

TRL 1	Basic Research: Initial scientific research begins. Basic principles are observed. Focus is on fundamental understanding of a material or process. Principles are qualitatively postulated and observed. Supporting information includes published research or other references that identify the principles that underlie the material process.
TRL 2	Applied Research: Once basic principles are observed, initial practical applications can be identified. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Potential of material or process to satisfy a technology need is confirmed. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from basic to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
TRL 3	Critical Function: Applied research continues and early stage development begins. Includes studies and initial laboratory measurements to validate analytical predictions of separate elements of the technology. Analytical studies and laboratory-scale studies are designed to physically validate the predictions of separate elements of the technology. Examples include components that are not yet integrated. Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical components. At TRL 3 experimental work is intended to verify that the concept works as expected. Components of the technology are validated, but there is no strong attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
TRL 4	Laboratory Testing/Validation of Alpha Prototype Component/Process: Design, development, and lab testing of technological components are performed. Results provide evidence that applicable component/process performance targets may be attainable based on projected or modeled systems. The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4–6 represent the bridge from scientific research to engineering, from development to demonstration. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on-hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function. The concept is there but the details of the unit process steps are not yet worked out. The goal of TRL 4 should be the narrowing of possible options in the complete system.
TRL 5	Laboratory Testing of Integrated/Semi-Integrated System: Component and/or process validation in relevant environment- (Beta prototype component level). The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical. Scientific risk should be retired at the end of TRL 5. Results presented should be statistically relevant.
TRL 6	Prototype System Verified: System/process prototype demonstration in an operational environment- (Beta prototype system level). Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include fabrication of the device on an engineering pilot line. Supporting information includes results from the engineering scale, testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the final system. For PV cell or module manufacturing, the system that is referred to is the manufacturing system and not the cell or module. The engineering pilot scale demonstration should be capable of performing all the functions that will be required of a full manufacturing system. The operating environment for the testing should closely represent the actual operating environment. Refinement of the cost model is expected at this stage based on new learning from the pilot line. The goal while in TRL 6 is to reduce engineering risk. Results presented should be statistically relevant.
TRL 7	Integrated Pilot System Demonstrated: System/process prototype demonstration in an operational environment-(integrated pilot system level).This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete. The goal of this stage is to retire engineering and manufacturing risk. To credibly achieve this goal and exit TRL 7, scale is required as many significant engineering and manufacturing issues can surface during the transition between TRL 6 and 7.
TRL 8	System Incorporated in Commercial Design: Actual system/process completed and qualified through test and demonstration-(Precommercial demonstration). The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include full scale volume manufacturing of commercial end product. True manufacturing costs will be determined and deltas to models will need to be highlighted and plans developed to address them. Product performance delta to plan needs to be highlighted and plans to close the gap will need to be developed.
TRL 9	System Proven and Ready for Full Commercial Deployment: Actual system proven through successful operations in operating environment, and ready for full commercial deployment. The technology is in its final form and operated under the full range of operating conditions. Examples include steady state 24/7 manufacturing meeting cost, yield, and output targets. Emphasis shifts toward statistical process control.

This approach has several distinct advantages:

- It ensures the Office will examine diverse feedstocks and conversion technologies for producing biofuels, biopower, and bioproducts
- It effectively links resources with the stages of technology readiness, from applied research through commercial deployment
- It successfully identifies gaps within the portfolio, as well as crucial linkages between the stages of RDD&D
- It is adequately flexible to accommodate new ideas and approaches as well as various combinations of feedstock and process in real biorefineries
- It incorporates a stage-gate process, which guarantees a series of periodical technology readiness reviews to help inform the down-selection process.

3.1 Office Portfolio Management Process

The Bioenergy Technologies Office manages its portfolio based on the approach recommended under the Office of Energy Efficiency and Renewable Energy (EERE) Program Management Initiative,[1] complemented with processes derived from classical systems engineering for managing technically complex programs. The five major steps in the Office portfolio management process are shown in Figure 3-2 and are described on the following pages.

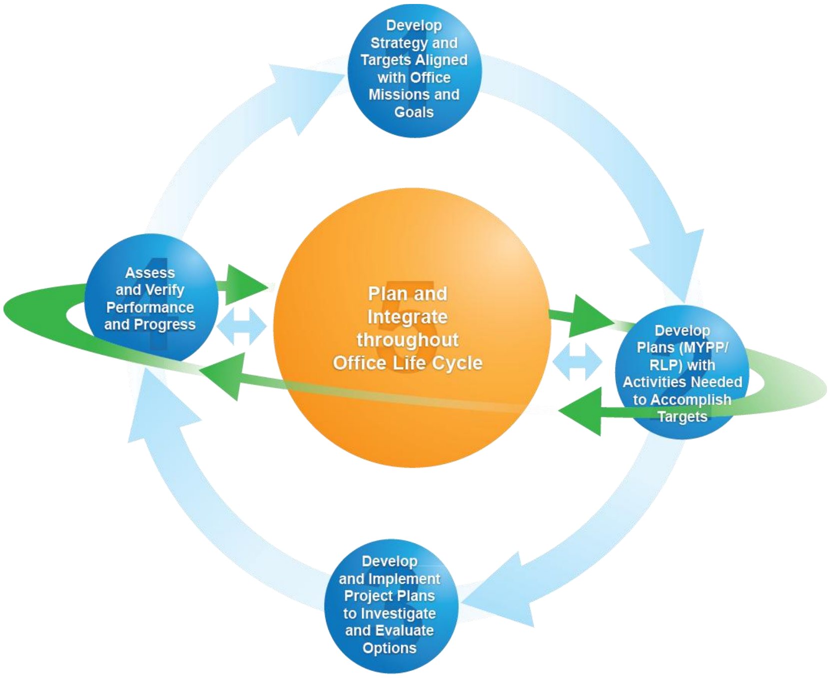


Figure 3-2: Office Portfolio Management Process

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[1] The EERE Program Management Initiative was launched in 2003 to address stakeholder expectations, the President's Management Agenda, DOE and EERE strategic plans, findings and recommendations by the National Academy of Public Administration, and the Government Performance and Results Act. Complete information is available at http://www1.eere.energy.gov/office_eere/bo_pmi.html.

Step 1: Develop Office Strategy and Targets Aligned with Office Mission and Goals.

Step 1 encompasses the process of developing the Office mission and goals (outlined in Section 1), both of which are developed from a combination of the Office's strategic goal hierarchy (Figure 1-5) based on national goals, administrative and legislative priorities, and DOE and EERE strategic goals and priorities, in alignment with the goals of other federal agencies.

The Office design and logic (Figure 1-7) detail how the mission and goals fit within the planning and budgetary framework of the Office. Combining the Office design and logic with an understanding of market needs and technical scenarios leads to the definition of Office targets that are consistent with government objectives. Targets are allocated to the Office elements responsible for managing and funding research related to the targets.

Portfolio decision making at the strategic level is based on three main criteria:

- Does the portfolio contain the correct elements across the RDD&D spectrum of activities to meet the technical and/or market targets required to achieve Office goals?
- Does the portfolio sponsor diverse technologies that can buy down the risk of producing competitively priced bioenergy?
- Does the portfolio support the establishment of the bioenergy industry in the United States?

Step 2: Develop Plans (MYPP/RLP) with Activities Needed to Accomplish Targets.

Step 2 guides how the Office develops its multi-year plan to outline the path to achieving the high-level Office technical and market targets defined in Step 1.

Each Office technical area has performance goals and barriers identified through internal evaluation and public/private collaborative meetings. To meet the Office's performance goals and address the associated barriers, each technical area develops a multi-year Resource Loaded Plan (RLP) that identifies the strategic activities and associated resources to achieve respective targets. Programmatic priorities to address the barriers are determined by balancing the needs and driving forces behind the emerging industry within the context of inherently governmental activities.

The RLPs for each technology area are then integrated into an Office-wide plan and evaluated for gaps and linkages. Gaps that are identified are addressed, while linkages between the technology areas are highlighted so that all parts of the supply chain are developed iteratively to comparable levels of maturity over time. The RLPs form the basis for activities described in the Multi-Year Program Plan (MYPP). The MYPP is designed to undergo review and be updated on a regular basis to incorporate technology advances, Office learning, and changes in direction and priority.

Step 3: Develop and Implement Project Plans to Investigate and Evaluate Options.

Step 3 involves developing individual Project Management Plans (PMPs) that are aligned with the MYPP and the technology area RLPs. The PMPs define the work selected to investigate and evaluate the chosen approaches for achieving the Office-level technical and market targets, as well as milestones in the MYPP.

Project development and analysis are used to define a portfolio of projects that, when combined, will most effectively achieve Office targets. Factors considered at the project level are similar to those considered at the Office level in Step 2 and include potential benefits, scope, cost, schedule, and risk. Also, like Step 2, this is an iterative process that weighs benefits against costs and risks; however, the emphasis stays on the specific projects under consideration and how they compare to each other, as well as their relevance to the Office. At the initiation of a project, a PMP is prepared to describe the entire project duration, with special attention to the activities planned for the year. PMPs are updated annually based on actual progress, results of interim stage-gate reviews, and updates to the Office MYPP.

Step 4: Assess and Verify Performance and Progress.

Step 4 involves a system of performance assessments held on multiple levels to monitor and evaluate performance and progress as the Office is implemented (described in detail in section 3.2). The Office evaluates project performance on a quarterly basis against baseline schedule, scope, and cost provided in the PMP. The Office's subprogram element peer reviews and an overall Office peer review are conducted biennially to provide decision making on future funding and direction. Stage-gate reviews are conducted at the individual project level to assess technical, economic, environmental, and market potential, as well as risk.

In large-scale demonstration projects and pioneer conversion facilities involving public/private partnerships, independent expert analysis, stage-gate decision making, and evaluation by the Office contribute to project risk assessments and go/no-go decisions.

Step 5: Plan and Integrate throughout the Office Life Cycle.

Step 5 includes cross-cutting technical and Office integration efforts designed to help Programand Project Managers strengthen their management approaches to ensure a coordinated R&D effort, in addition to a well-integrated approach to technology demonstration and deployment. The diversity of technology options in each supply chain element and the distribution from applied science through development to demonstration and deployment lead to significant decision-making challenges.

3.1.1 Portfolio Analysis and Management

Portfolio analysis is carried out to determine the optimum portfolio of technologies and projects to achieve the Office's performance and market targets. Factors considered include the level of benefits expected, scope, cost, schedule, and risk to realizing the Office benefits. This is an iterative process that weighs benefits against costs and risks, while taking into account the latest external information regarding market, technical status, and barriers. The process also incorporates the updated status of portfolio efforts based on verified, externally reviewed progress.

Portfolio management is not just a static annual activity, but rather is ongoing and synchronized to the budget cycle over several years. Each year, on a continuing basis, the Office re-evaluates its goals and barriers, technical and market targets, and portfolio of technologies across the RDD&D spectrum; the Office then uses that information to assess its progress. Every year, there is a new set of decisions associated with populating the RDD&D pipeline with new R&D projects, assessing the performance of ongoing development and demonstration projects, down-selecting—via the Stage-Gate process—the most promising projects, and ceasing to fund those projects that are not performing or otherwise failing to address the Office's goals.

The Bioenergy Technologies Office's efforts to improve its portfolio management, analysis, and assessment efforts are supported by the Biomass Systems Integration Office. The focus of systems integration analysis is to understand the complex interactions between new technologies, system costs, environmental impacts, societal impacts, system tradeoffs, and penetration into existing systems and markets. The goals of integrated baseline management are to provide and maintain the links between the Office's technical areas. Top-down technical baseline management evaluates the links between the mission and strategies, performance and goals, and milestones and decision points of the Office. Bottom-up programmatic baseline management evaluates the links of the scope, budget, and schedule of each individual project, as well as activities of the Office.

3.2 Performance Assessment

Performance assessment includes performance monitoring, as well as Office and project evaluation. It provides the means to measure relevant outputs and outcomes that aid the Office in re-evaluating its decisions, goals, and approaches and tracks the actual progress being made. By design, the assessment processes provide input on Office progress and effectiveness from other government agencies, stakeholders, and independent expert reviewers.

Table 3-2: Office and Project-Level Assessments that Support Decision-Making

Assessment Type		Assessment Synopsis	Documentation
Performance Monitoring	*External Monitoring*	DOE's Annual Performance Target Tracking System	Annual Performance Target Reports
	Internal Monitoring	EERE's Corporate Planning System (CPS)	CPS Database/Website
		Project Monitoring with Quarterly Reports	Project Management Database
		Office Monitoring with Integrated Baseline Update	CORE[2] Integrated Baseline Reports
Office Evaluation	*Peer Reviews*	Conducted by independent experts outside of the Office portfolio to assess quality, productivity, and accomplishments, as well as relevance of Office success to EERE strategic and Office goals; and management[3]	Public Summary Documents Including Office Response
	General Office Evaluation Studies	Conducted by independent external experts to examine process, quantify outcomes or impacts, identify market needs and baselines, or quantify cost-benefit measures as appropriate[4]	Public Reports and Documentation
Performance Monitoring and Office Evaluation	*Technical Office Reviews*	EERE Senior Management	EERE Internal
		Biomass R&D Technical Advisory Committee	Report to Congress (Including Office Response)
	Technical Project Reviews	Stage-Gate Reviews conducted by DOE only for public/private demonstration projects, DOE plus independent industry, academia, or other government for precompetitive R&D projects	Internal Reports for Public/Private Demonstration Projects and Public Information for Precompetitive R&D Projects

Performance Monitoring

External Performance Monitoring

The Office of Management and Budget monitors Office performance against technical Annual Performance Targets. Each office is responsible for establishing and monitoring quarterly milestones, as well as meeting Annual Performance Targets established in Congressional Budget Requests.

Internal Performance Monitoring

The Office utilizes the Corporate Planning System (CPS) to help formulate, justify, manage, and execute Congressional Budget Requests. CPS also serves as a management tool to enable prospective spend planning, project data collection, and portfolio performance assessment. The system stores project-level management data, such as scope, schedule, and cost to track progress against technical milestones.

Standardized processes used to monitor and manage the performance of the projects ("agreements" in CPS) include:

- PMPs are developed to provide details of work planned throughout the entire project duration, as well as to establish measures for evaluating performance. The plans include multi-year descriptions, milestones, schedules, and cost projections. The PMPs are updated annually.

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[2] CORE is a systems engineering software package.

[3] U.S. Department of Energy: Energy Efficiency and Renewable Energy, *Peer Review Guide* (2004), Washington: Government Printing Office, http://www1.eere.energy.gov/analysis/pdfs/2004peerreviewguide.pdf.

[4] U.S. Department of Energy: Energy Efficiency and Renewable Energy, *EERE Guide for Managing General Program Evaluation Studies: Getting the Information You Need* (2006), Washington: Government Printing Office, http://www1.eere.energy.gov/analysis/pdfs/evl_mg_app.pdf.

- Quarterly project progress reports are submitted by the funded organizations, outlining financial and technical status, identifying problem areas, and highlighting achievements. The Office performs a quarterly assessment of project progress against the planned scope and schedule and financial performance against the cost projection and documents the assessment in a quarterly management report.
- The performance of major demonstration and deployment projects is also monitored through comprehensive annual project reviews. The results of these reviews are used for Office portfolio management and Office planning.

With more than 150 projects in the Office portfolio, the project plan and progress information must be summarized and synthesized in order to evaluate overall Office performance in a meaningful way. The Office has implemented a systems engineering approach and established integrated technical plans across Office elements to achieve the Office's goals. The Office has also developed its integrated baseline, which links the technology-area-based project activities with resource-based milestones, illuminating gaps/issues in the current project portfolio and providing the foundation for data-driven decision-making by Office management.

The Office uses additional systems engineering approaches, including interface management, independent performance verification, and robust information management tools to monitor overall progress toward achieving technical goals. The integrated baseline is updated annually at a minimum, using project data and information. The updates monitor risks and identify critical technical gaps, cost overruns, and schedule slippages.

Office Evaluation

Peer Reviews

The Bioenergy Technologies Office uses an external peer review process to assess the performance of the technical elements, as well as the Office as a whole. The Office implements the peer review process through a combination of subprogram element technology area peer reviews and an overall Office peer review, which are conducted at least biennially. The emphasis of the Office peer review is on the MYPP and the portfolio as a whole to determine whether or not it is balanced, organized, and performing appropriately. In contrast, the emphasis of the subprogram technology area reviews is on the composition of projects that comprise the respective elements and whether or not those projects are performing appropriately and contributing to technology area goals.

The Office peer review evaluates the RDD&D contributions of the subprogram technology area elements toward the overall Office goals, as well as the processes, organization, management, and effectiveness of the Bioenergy Technologies Office. The review is led by an independent steering committee that selects independent experts to review both the Office and technical element or technology area portfolios. The results of the review provide the feedback on the performance of the Office and its portfolio, identifying opportunities for improved Office management, as well as gaps or imbalances in funding that need to be addressed. By addressing these gaps and imbalances, the Office will continue to stay focused on the highest priorities.

The subprogram technology area peer reviews are conducted prior to the Office review. Information and findings from the technology area peer reviews are incorporated into the comprehensive Office peer review process. The objectives of the subprogram technology area peer review meetings are:

- Review and evaluate RDD&D accomplishments and future plans of projects in a subprogram element following the process guidelines of the EERE Peer Review Guide and incorporating the project evaluation criteria used in the Office Stage-Gate Management Process[5]
- Define and communicate Office strategic and performance goals applicable to the projects in the technology area element
- Provide an opportunity for stakeholders and participants to learn about and provide feedback on the projects in the Office portfolio to help shape future efforts so that the highest priority work is identified and addressed
- Foster interactions among industry, universities, and national laboratories conducting the RDD&D, thereby facilitating technology transfer.

Technical experts from industry and academia are selected as reviewers based on their experience in various aspects of biomass technologies under review, including project finance, public policy, and infrastructure. The reviewers score and provide qualitative comments on RDD&D based on the presentations given at the meeting and the background information provided. The reviewers also are asked to identify specific strengths, weaknesses, technology transfer opportunities, and recommendations for modifying project scope.

The Office analyzes all of the information gathered at the review and develops appropriate responses to the findings for each project. This information, including the Office response, is documented and published in a review report that is made available to the public through the Office website.[6]

General Office Evaluation Studies

The Bioenergy Technologies Office sponsors several activities and processes that are aligned with the program evaluation studies described in the EERE Guide for Managing General Program Evaluation Studies. The Office is conducting general program evaluations based on this guide, including:

- Needs/Market Assessment Evaluations
- Outcome Evaluations
- Impact Evaluations
- Cost-Benefit Evaluations.

Needs/Market Assessment Evaluations**:** In the past several years, the Bioenergy Technologies Office has held a number of workshops in the past several years that have brought together stakeholders from federal and state government agencies, industry, academia, trade associations, and environmental organizations. These workshops identified the key needs and opportunities for biobased fuels, power, and products in the United States. Recent workshops have focused on feedstock supply, bioproducts, biopower, and algae.

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[5] "Stage Gate Management in the Biomass Program: Revision 2," Oak Ridge National Laboratory (2005), http://feedstockreview.ornl.gov/pdf/stage_gate_management_guide.pdf.

[6] The most recent Program Review Portal website can be found at: http://obpreview2011.govtools.us/.

Outcome, Impact, and Cost/Benefit Evaluations: These types of evaluations are carried out by the EERE Office of Planning Budget and Analysis and were described previously in the Benefits Analysis portion of Section 2.5.

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Performance Monitoring and Office Evaluation

Technical Office Reviews

The Bioenergy Technologies Office uses several forms of technical review to assess progress and promote Office and project improvement: The Biomass R&D Technical Advisory Committee Office reviews, EERE strategic office reviews, and technical project reviews according to the Bioenergy Technologies Office Stage-Gate management process.

The Biomass Technical Advisory Committee reviews the joint USDA/DOE Biomass R&D portfolio annually and provides advice to the Secretary of Energy and Secretary of Agriculture concerning the technical focus and direction of the portfolios. Periodic reports are submitted to Congress by the Committee.[7] Internally, DOE-EERE senior management holds periodic strategic office review meetings with the Bioenergy Technologies Office Director for various purposes, including preparation for Congressional budget submission and evaluation of strategic direction.

Technical Project Reviews

The Office also holds stage-gate reviews at the project level. The stage-gate process, as depicted in Figure 3-3, is an approach for making disciplined decisions about R&D that lead to focused process and/or product development efforts.[8] Specifically, the Office uses the stage-gate process to inform decisions regarding the following:

- Which projects to carry forward in the Office's technology portfolio
- The alignment of R&D project objectives with Office objectives and industry needs
- Distribution of Office funding across the spectrum of TRLs within the spectrum of RDD&D activities
- Guidance on project definition, including scope, quality, outputs, and integration
- Evaluation of projects for progress and alignment with the Office portfolio.

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[7] The most recent report, Annual Report to Congress on the Biomass Research and Development Initiative for 2006, can be accessed at: http://www.biomassboard.gov/pdfs/biomass_initiative_report_to_congress_fy_2006.pdf.

[8] "Stage Gate Management in the Biomass Program: Revision 2," Oak Ridge National Laboratory.

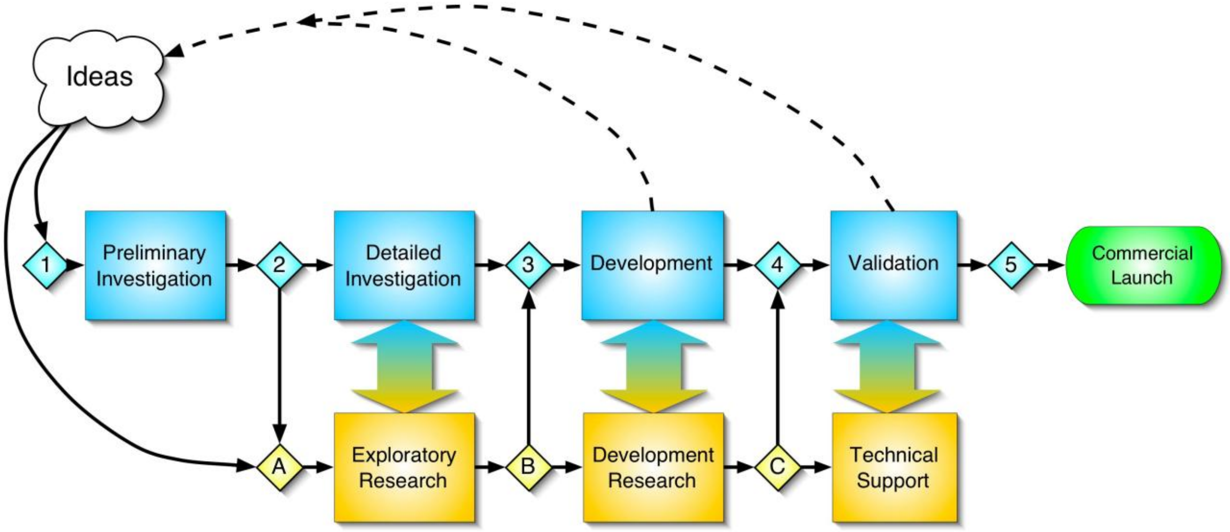

Figure 3-3: Bioenergy Technologies Office Stage-Gate Process

Stage-Gate Reviews: Each stage is preceded by a decision point or gate that must be passed through before work on the next stage can begin. Gate reviews are conducted by a combination of internal management and outside experts or the gate-keepers. The purpose of each gate is twofold: first, the project must demonstrate that it met the objectives identified in the previous gate and stage plan; and second, that it satisfies the criteria for the current gate. A set of seven types of criteria are used to judge a project at each gate:

- Strategic Fit
- Market/Customer
- Technical Feasibility and Risks
- Competitive Advantage
- Legal/Regulatory Compliance
- Critical Success Factors and Show Stoppers
- Plan to Proceed.

Specific criteria are different for each gate and become more rigorous as the project moves along the development pathway.

The possible outcomes of this portion of the review could be pass, recycle, hold, or stop. Passing implies that the goals for the previous stage were met, and everything looks good for authorization to proceed.

Recycling indicates that working longer in the current stage is justified—all goals have not been accomplished, but the project still has a high priority and potential looks promising.

Holding suspends a project because the need for it may have diminished or disappeared. There is an implication that the market demand could come back and the project could be resumed later.

Stopping a project might occur because the technology development is not progressing as it should, the market appears to have shifted permanently, the technology has become obsolete, or the economic advantage is no longer there. In this case, the best ideas from the project are salvaged, but the project is permanently halted.

The second half of the gate review takes place if the decision is made that the project “passes” the gate. The project leader must propose a project definition and preliminary plan for the next stage, including objectives, major milestones, high-level work breakdown structure, schedule, and resource requirements. The plan must be presented in sufficient detail for the reviewers to comment on the accomplishments necessary for the next stage, as well as the goals for completion of the next gate. Once the plan is accepted, the project can move to the next stage. Because the stakes get higher with each passing stage, the decision process becomes more complex and demanding. If the decision is made to “recycle” the project, the review panel will provide suggestions to the project leader on work that needs to be completed satisfactorily before the next gate review is held. In the case of a “hold” or “stop” decision, the plan to proceed is not needed.

An overview of the Bioenergy Technologies Office stage-gate process is available online at http://devafdc.nrel.gov/pdfs/9276.pdf. The stage-gate process is a key portfolio management tool because it integrates a number of challenging key decision areas, which include:

- Project selection and prioritization
- Resource allocation across projects
- Implementation of business strategy.

The gates and gate reviews allow the Office to filter poor performing or off-the-target projects and reallocate resources to the best projects and/or open the way for new projects to begin.

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Appendix A: Technology Pathway Structure

High-level block flow diagrams for each biorefinery pathway are presented in Figures A-1 through A-5. These diagrams show the current process (if it exists today) and current products including fuels, chemicals and power; options for improvements; and associated new products. *These diagrams are not intended to be all inclusive; many other viable processing options are possible.* These diagrams do not display options for pathways that are considered mature commercial technology.

The blocks and paths on the diagrams are coded as follows:

- 🟩 Feedstocks – Feedstocks R&D
- 🟦 Biochemical – Biochemical Conversion R&D
- 🟥 Thermochemical – Thermochemical Conversion R&D
- ▢ Bold blocks – Highest priorities
- ⬚ Dash blocks – Medium and low priorities
- ⟶ – New routes to biofuels, with the heavy lines indicating the highest priority routes
- Enabling Products – Potential new enabling non-fuel products
- ▢ OR → – Existing processing steps in current biorefineries

◇ – Indicates that an "option" exists on how to process the stream. The options must be evaluated and compared against each other to identify the best overall pathway configuration. For pathways representing existing industry segments, the options include the status quo. The options analysis may compare options that would take the full stream or fractions of the full stream. The ability to add and evaluate options within a pathway results in a flexible framework for considering innovative new ideas in the future.

The Office Work Breakdown Structure, shown in Table A-1, shows the necessary activities being pursued to address the critical RDD&D challenges in the biorefinery pathways. Priority feedstock pathways denoted in bold font represent the primary RDD&D focus of the specific activity.

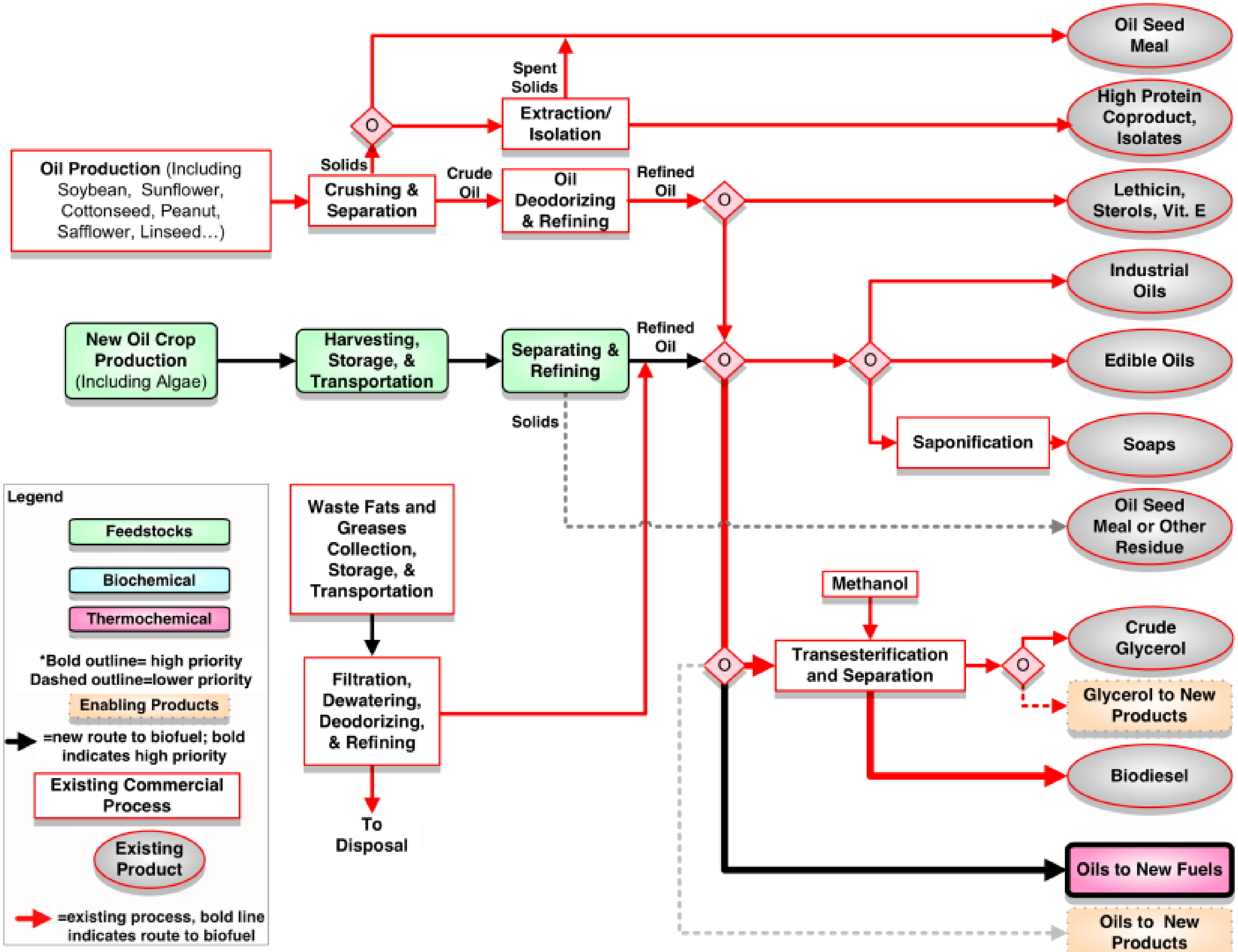

Figure A-1: Natural Oils Pathway

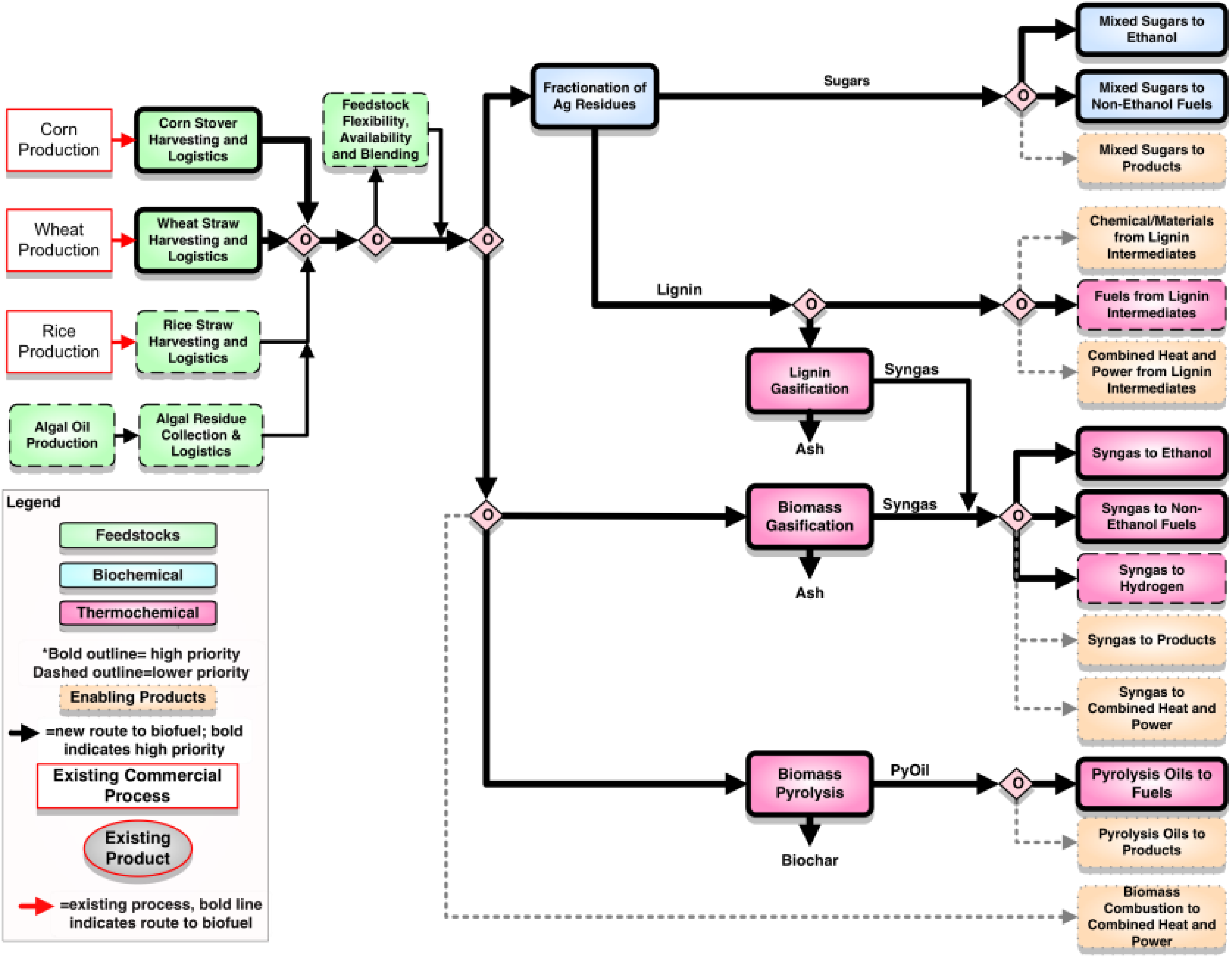

Figure A-2: Agricultural Residues Pathway

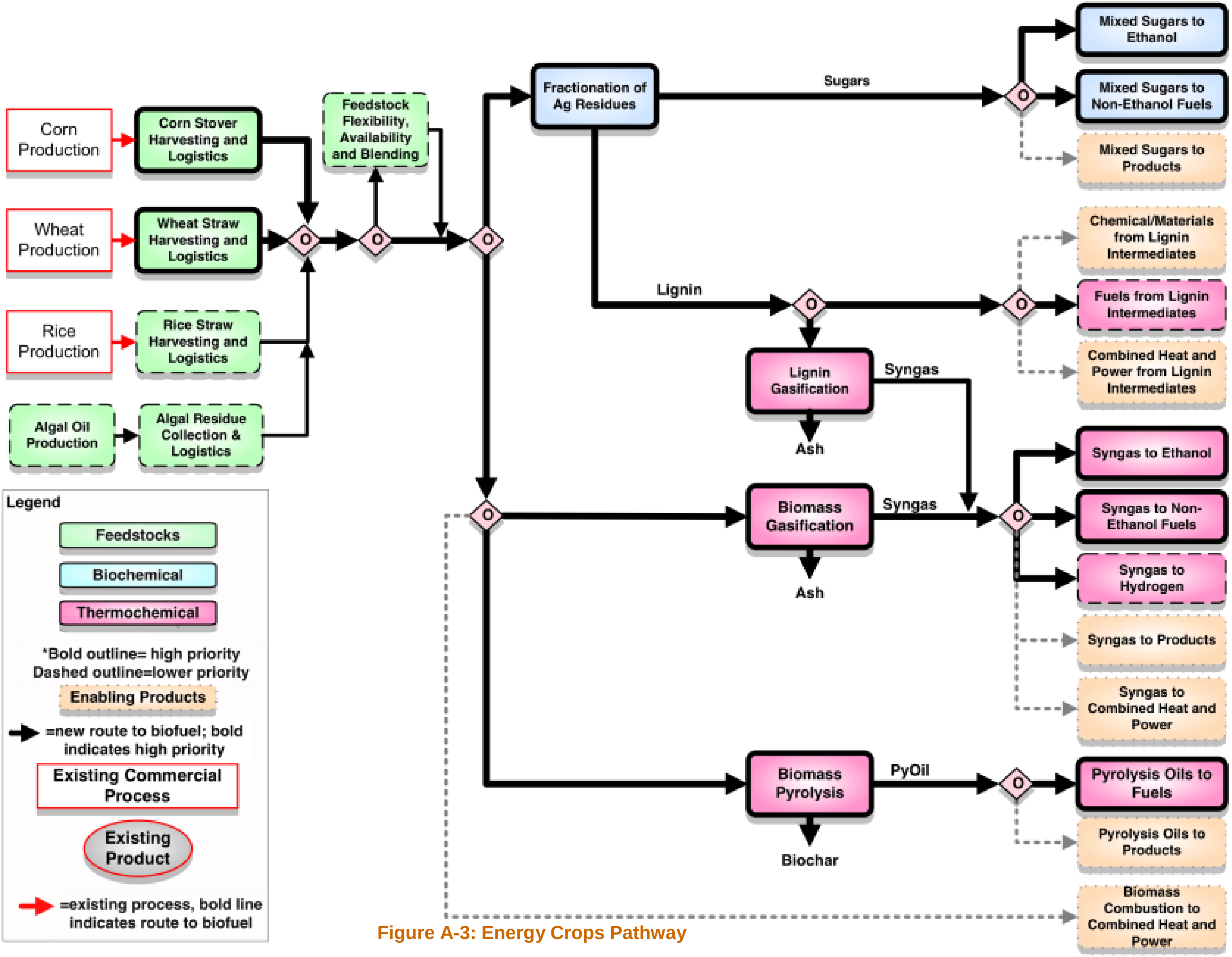

Figure A-3: Energy Crops Pathway

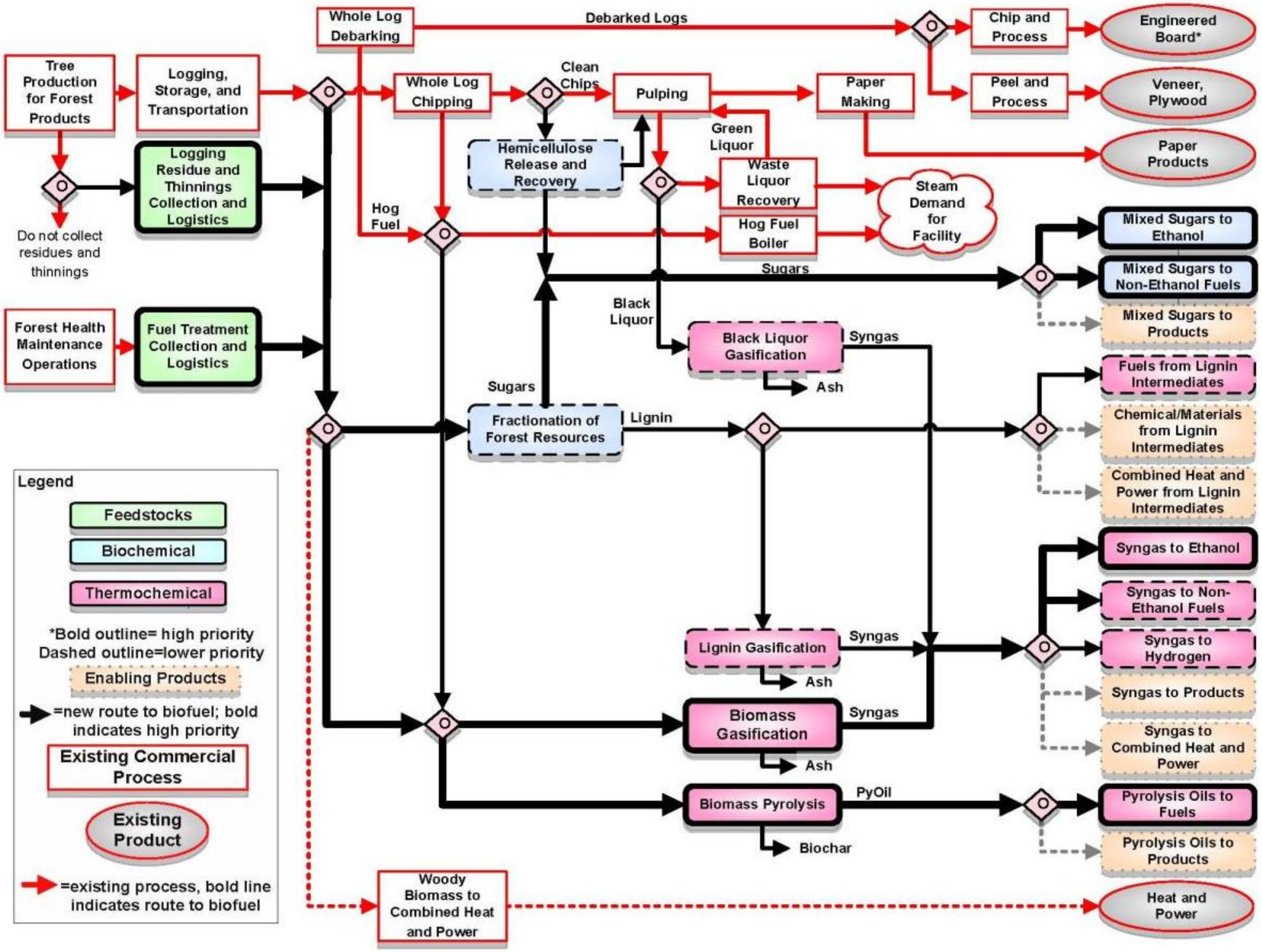

Figure A-4: Forest Resources Pathway

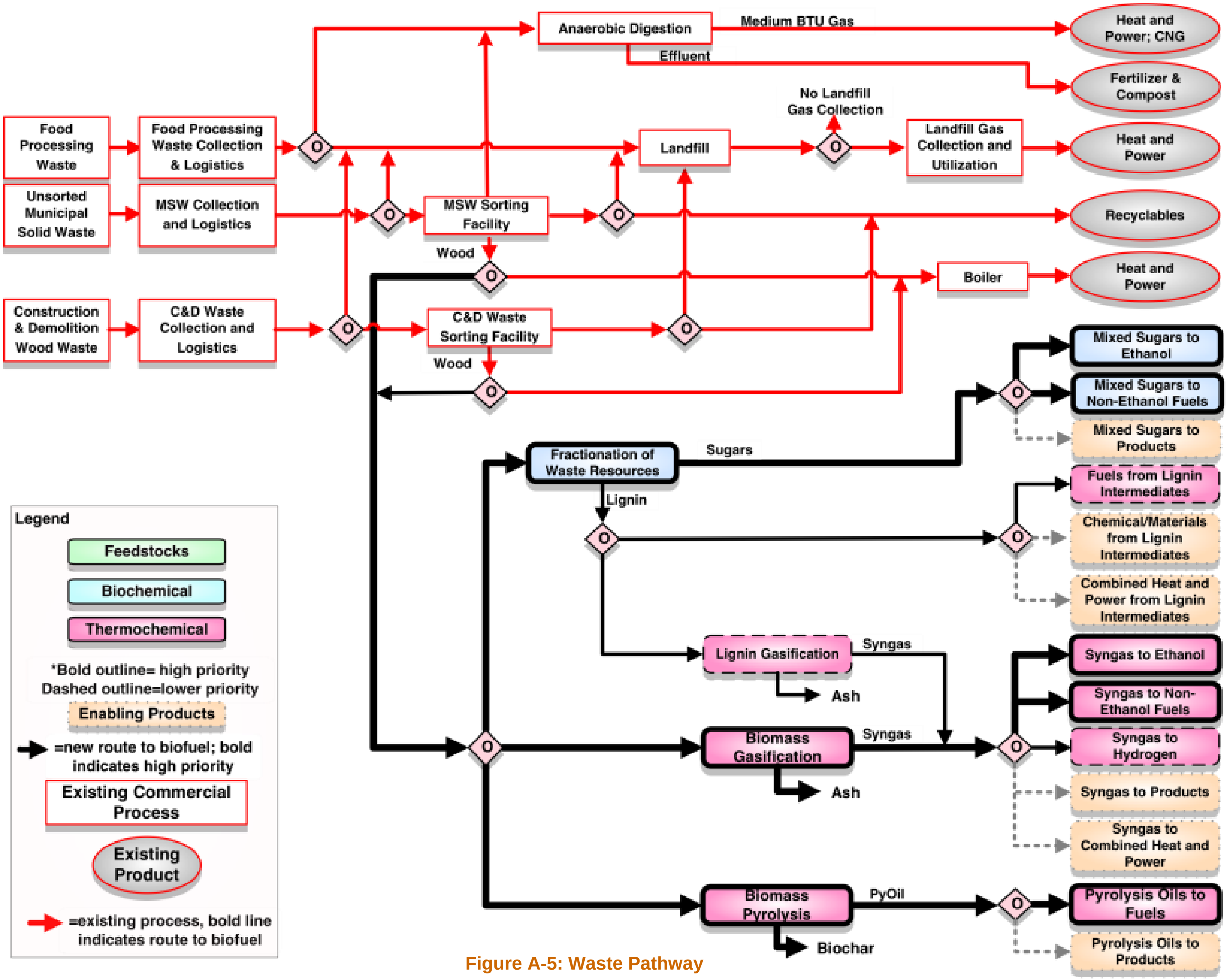

Figure A-5: Waste Pathway

Appendix B: Technical Projection Tables

Table B-1: Projected National Feedstock Demand from Biofuel and Biopower

	Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2022**	**2030**
EISA (BGY)	billion gallons/year	1	2	3	4	6	7	9	21	21
Biofuels Demand[1]	million tons/year	16	24	32	44	65	85	106	247	247
Biopower Demand[2]	million tons/year	10	20	27	32	38	44	49	78	78
National Feedstock Demand	million tons/year	**26**	**44**	**60**	**76**	**102**	**129**	**155**	**325**	**325**

[1] Biofuels demand calculated at 85 gallons/dry ton (DT)

[2] 2010 AEO Reference Case Table 16: Generation: Wood and biomass, net of generation from biofuels (Table 26) and pulp and paper (Table 36); 13,000 Btu/kWh; 16 million Btu/DT.

Table B-2: Projected Feedstock Supplies Available to Meet EISA RFS and Biopower Demand

				2011	2012	2017	2022	2030
National Feedstock Demand [1]			million dry tons/yr		**44**	**155**	**325**	**325**
Resource			2011$					
Agricultural Residues	**Corn Stover**	**Grower Payment**	$/dry ton	$24.77	$24.77	$32.15	$47.33	$47.33
		Supply at Grower Payment	million dry tons/yr	-[2]	-[2]	95	115	140
	Cereal Straw	**Grower Payment**	$/dry ton	$24.04	$24.04	$32.15	$40.38	$40.38
		Supply at Grower Payment	million dry tons/yr	-[2]	-[2]	17	30	40
Energy Crops	**Herbaceous Energy Crops**	**Grower Payment**	$/dry ton	$19.50	$19.50	$29.83	$43.65	$43.65
		Supply at Grower Payment	million dry tons/yr	-[2]	-[2]	3	65	184
	Woody Energy Crops	**Grower Payment**	$/dry ton	$23.19	$23.19	$41.54	$47.97	$47.97
		Supply at Grower Payment	million dry tons/yr	-[2]	-[2]	0	2	65
Forest Resources	**Pulpwood**	**Grower Payment**	$/dry ton	$16.02	$16.02	$26.25	$31.94	$31.94
		Supply at Grower Payment	million dry tons/yr	1	1	1	2	2
	Logging Residues and Fuel Treatments	**Grower Payment**	$/dry ton	$14.44	$14.44	$23.83	$41.43	$41.43
		Supply at Grower Payment	million dry tons/yr	22	22	33	57	48
	Other Forestland Removals	**Grower Payment**	$/dry ton	$14.44	$14.44	$33.63	$47.97	$47.97
		Supply at Grower Payment	million dry tons/yr	7	7	10	18	15
	Urban and Mill Wood Wastes	**Grower Payment**	$/dry ton	$14.44	$14.44	$33.63	$47.97	$47.97
		Supply at Grower Payment	million dry tons/yr	22	22	32	56	47
Total Feedstock Available			million dry tons/yr	52	52	192	345	540

[1] Biopower demand from Energy Information Administration, 2010. Annual Energy Outlook 2010. Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington D.C., p. 231. Biofuels demand from EISA @ 85 gal/dt.

[2] 2012 niche feedstocks expected to be available locally at the minimum procurement cost based on Billion-Ton Update net of harvest cost.

[3] Demand-based grower payment based on supply volume required to meet RFS requirement plus EIA biopower demand projection.

Table B-3: Technical Projections for Dry Woody Feedstocks Collection, Preprocessing, and Delivery to Pyrolysis Conversion Reactor Inlet*

Pyrolysis		**Woody Biomass: Purpose Grown 6-8" Trees**					
Process Concept: Feedstock Harvest through plant gate and insertion to Conversion Reactor Inlet	**Metric**	**2009 SOT**	**2010 SOT**	**2011 SOT**	**2012 SOT**	**2013 Projection**	**2017 Projection**
	Year $ basis	2011	2011	2011	2011	2011	2011
Pyrolysis							
Total Feedstock Logistics (Harvest through insertion to conversion reactor inlet)	***$/DM ton***	***$90.90***	***$86.94***	***$74.55***	***$63.69***	***$61.85***	***$54.50***
	$/gal (biofuel)	***$1.25***	***$1.19***	***$1.02***	***$0.86***	***$0.74***	***$0.51***
Total cost of feedstock logistics to plant gate	**$/DM ton**	**$54.02**	**$52.34**	**$47.90**	**$44.69**	**$43.27**	**$37.62**
Capital Cost Contribution	$/DM ton	$15.62	$15.12	$15.19	$14.51	$13.17	$11.37
Operating Cost Contribution	$/DM ton	$38.39	$37.22	$32.71	$30.18	$30.10	$26.25
Total cost of feedstock handling after plant gate	**$/DM ton**	**$36.88**	**$34.60**	**$26.65**	**$19.00**	**$18.58**	**$16.88**
Capital Cost Contribution	$/DM ton	$6.81	$6.25	$5.66	$2.96	$3.41	$3.10
Operating Cost Contribution	$/DM ton	$30.08	$28.35	$20.99	$16.04	$15.17	$13.78
Total cost of grower payment (see TB-1)	**$/DM ton**	**$16.02**	**$16.02**	**$16.02**	**$16.02**	**$26.25**	**$26.25**
Total Feedstock Cost Through Process Feed	**$/DM ton**	**$106.92**	**$102.96**	**$90.57**	**$79.71**	**$88.10**	**$80.75**
	$/gal (biofuel)	**$1.46**	**$1.41**	**$1.24**	**$1.08**	**$1.05**	**$0.76**
Harvest and Collection							
Total Cost Contribution	$/DM ton	$24.89	$23.77	$23.15	$22.24	$20.70	$19.53
Capital Cost Contribution	$/DM ton	$7.14	$6.70	$6.74	$6.64	$5.99	$5.66
Operating Cost Contribution	$/DM ton	$17.74	$17.08	$16.41	$15.60	$14.70	$13.87
Harvest Efficiency	%	65%	65%	80%	80%	81%	82%
Collection Efficiency	%	65%	75%	75%	75%	75%	75%
DM Density	lbs/ft3	10.0	10.0	10.0	10.0	10.0	10.0
Moisture Content	% (wet basis)	50%	50%	40%	40%	35%	30%
Storage and Queuing							
Total Cost Contribution	$/DM ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Capital Cost Contribution	$/DM ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operating Cost Contribution	$/DM ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Landing Preprocessing							
Total Cost Contribution	$/DM ton	$15.18	$15.18	$13.60	$12.17	$13.08	$11.73

Pyrolysis		**Woody Biomass: Purpose Grown 6-8" Trees**					
Process Concept: Feedstock Harvest through plant gate and insertion to Conversion Reactor Inlet	**Metric**	**2009 SOT**	**2010 SOT**	**2011 SOT**	**2012 SOT**	**2013 Projection**	**2017 Projection**
	Year $ basis	2011	2011	2011	2011	2011	2011
Capital Cost Contribution	$/DM ton	$3.91	$3.91	$4.68	$4.48	$4.01	$3.60
Operating Cost Contribution	$/DM ton	$11.27	$11.27	$8.92	$7.69	$9.07	$8.13
Chipper Efficiency	%	65%	65%	75%	75%	75%	78%
Chipper Capacity	DM ton/hour	22.0	22.0	24.0	28.0	28.0	28.0
DM Density	lbs/ft3	10.0	10.0	10.0	10.0	10.0	10.0
Particle Size	Inch	< 2	< 2	< 2	< 2	<0.5	<0.5
Moisture Content	%(wet basis)	50%	40%	40%	35%	35%	30%
Transportation and Handling							
Total Cost Contribution	$/DM ton	$13.95	$13.39	$11.15	$10.28	$9.50	$6.37
Capital Cost Contribution	$/DM ton	$4.58	$4.52	$3.77	$3.39	$3.17	$2.12
Operating Cost Contribution	$/DM ton	$9.37	$8.87	$7.38	$6.89	$6.33	$4.25
Average Transport Distance	miles	50	50	50	50	50	50
Moisture Content	% (wet basis)	50%	40%	40%	35%	35%	30%
In-Plant Receiving and Preprocessing							
Total Cost Contribution	$/DM ton	$36.88	$34.60	$26.65	$19.00	$18.58	$16.88
Capital Cost Contribution	$/DM ton	$6.81	$6.25	$5.66	$2.96	$3.41	$3.10
Operating Cost Contribution	$/DM ton	$30.08	$28.35	$20.99	$16.04	$15.17	$13.78
Particle Size, Plant Gate	Inch	< 2	< 2	< 2	< 2	<0.5	<0.5
Moisture Content, Plant Gate	% (wet basis)	50%	50%	40%	35%	35%	30%
Particle Size, Reactor Feed	Inch	0.08	0.08	0.08	0.08	0.16	0.16
Moisture Content, Reactor Feed	% (wet basis)	10%	10%	10%	10%	10%	10%
Ash Content	%	< 1	< 1	< 1	< 1	< 1	< 1

* Searcy, Hess, Wright, et al. “State of Technology Assessment of Costs of Southern Pine for FY12 – Pyrolysis.” Idaho National Laboratory. INL/MIS-11-20887. 2011.

Table B-4: Open Pond Algae Feedstock Supply and Logistics Key Process and Cost Metrics*

Algal Lipids					
Process Concept: Open Pond, wet solvent-based lipid extraction	**Metric**	**2010 SOT**	**2014 Projection**	**2018 Projection**	**2022 Projection**
Total Algal Feedstock Cost	$ / GGE Algal Oil	**$18.22**	**$13.13**	**$6.30**	**$3.27**
Production Cost	$ / GGE Algal Oil	**$15.60**	**$11.18**	**$5.17**	**$2.63**
Harvest Cost	$ / GGE Algal Oil	**$2.99**	**$2.52**	**$1.65**	**$0.67**
Preprocessing Cost	$ / GGE Algal Oil	**$1.72**	**$1.56**	**$1.11**	**$0.77**
Recycle Credit	$ /GGE Algal Oil	**-$2.08**	**-$2.14**	**-$1.63**	**-$0.80**
Production					
Total Cost Contribution	$/AFDW Ton	$916.2	$656.47	$384.48	$343.19
Capital Cost Contribution	$/AFDW Ton	$650.8	$436.34	$207.46	$174.54
Operating Cost Contribution	$/AFDW Ton	$265.3	$220.13	$177.02	$168.65
Algal productivity	g/m2/day	13.2	20	25	30
Lipid content	dry wt%	25%	25%	30%	50%
Pond size	acres	10,000	10,000	10,000	10,000
Operating days/year	days	330	330	330	330
Concentration at harvest	g/L	0.5	0.5	0.5	0.5
Dewatering Logistics					
Total Cost Contribution	$/AFDW Ton	$175.3	$148.27	$123.10	$87.21
Capital Cost Contribution	$/AFDW Ton	$71.57	$59.62	$47.28	$30.13
Operating Cost Contribution	$/AFDW Ton	$103.8	$88.65	$75.82	$57.08
Gross harvesting efficiency	%	77%	85%	90%	95%
Net harvesting efficiency	%	95%	95%	95%	95%
Final concentration	g/L	200	200	200	200
Harvesting Capex	$/MM gal per day	$169,0	$152,100	$126,750	$84,500
Harvesting Opex	$/MM gal from	$88	$79	$66	$44
Preprocessing					
Total Cost Contribution	$ / GGE Algal Oil	$1.72	$1.56	$1.11	$0.77
Capital Cost Contribution	$ / GGE Algal Oil	$0.88	$0.84	$0.58	$0.27
Operating Cost Contribution	$ / GGE Algal Oil	$0.84	$0.72	$0.53	$0.51
Net extraction efficiency	%	86%	86%	90%	95%
Flow rate	gal harvested	471	715	893	1071
Biofuel Intermediate Yield	gal intermediate /	1,047	1,586	2,490	5,257
Extraction CAPEX	$ / ton algal	$36,50	$32,850	$27,375	$18,250
Extraction OPEX	$ / ton algal	$12	$11	$9	$6
Recycle Credit					
Operating Cost Contribution	$/ GGE algal oil	-$2.08	-$2.14	-$1.63	-$0.80
N Recycle	mg / kg algae	57	57	57	57
P Recycle	mg / kg algae	4	4	4	4
CO_2 Recycle	g / g algae	0.71	0.71	0.64	0.39
Power Generation	kwh	13,248	20,074	22,592	16,536

* Davis, Ryan, Fishman, Daniel, Frank, Edward, et al. “Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model.” Argonne National Laboratory. ANL/ESDA/12-4. 2012. http://greet.es.anl.gov/publication-algae-harmonization-2012.

Table B-5: Unit Operation Cost Contribution Estimates (2011$) and Technical Projections for Conversion to Gasoline and Diesel

(Process Concept: Woody Energy Crop, Fast Pyrolysis, Bio-oil Upgrading, Fuel Finishing)

Processing Area Cost Contributions & Key Technical Parameters	**Metric**	**2009 SOT**	**2010 SOT**	**2011 SOT**	**2012 SOT**	**2013 Projection***	**2014 Projection**	**2015 Projection**	**2016 Projection**	**2017 Projection†**
Conversion Contribution	**$/gal gasoline**	$7.55	$5.86	$4.73	$4.15	$3.33	$2.82	$2.65	$2.12	$1.83
	$/gal diesel	$7.61	$5.92	$4.78	$4.20	$3.39	$2.88	$2.71	$2.18	$1.83
Conversion Contribution, combined fuel	**$/gge**	$7.19	$5.59	$4.51	$3.95	$3.18	$2.70	$2.54	$2.04	$1.73
Year $ basis		2011	2011	2011	2011	2011	2011	2011	2011	2011
Office Performance Goal	**$/gal**									**$3**
Minimum Gasoline Selling Price	$/gal gasoline	$9.01	$7.27	$5.97	$5.23	$4.36	$3.83	$3.57	$2.95	$2.59
Minimum Diesel Selling Price	$/gal diesel	$9.09	$7.35	$6.04	$5.29	$4.44	$3.91	$3.64	$3.03	$2.59
Production Gasoline + Diesel	mm gallons/yr	53	53	53	53	61	61	66	70	76
Yield (Gasoline + Diesel)	gal/ dry ton wood	73	73	73	74	84	84	91	98	106
Natural Gas Consumption	SCF/dry ton wood	1,160	1,160	1,040	901	1,820	1,820	2,300	2,700	3,120
Feedstock										
Total Cost Contribution	**$/gal total fuel**	**$1.46**	**$1.41**	**$1.24**	**$1.08**	**$1.05**	**$1.03**	**$0.93**	**$0.84**	**$0.76**
Capital Cost Contribution	$/gal total fuel	$0.31	$0.29	$0.29	$0.24	$0.20	$0.19	$0.17	$0.16	$0.14
Operating Cost Contribution	$/gal total fuel	$1.16	$1.12	$0.96	$0.84	$0.85	$0.83	$0.75	$0.68	$0.63
Feedstock Cost	$/dry US ton	$106.92	$102.96	$90.57	$79.71	$88.10	$86.26	$84.43	$82.59	$80.75
Energy Content (LHV, dry basis)	BTU/lb	7603	7603	7603	7603	7603	7603	7603	7603	7603
Fast Pyrolysis										
Total Cost Contribution	**$/gal total fuel**	**$0.62**	**$0.61**	**$0.60**	**$0.50**	**$0.51**	**$0.51**	**$0.47**	**$0.44**	**$0.39**
Capital Cost Contribution	$/gal total fuel	$0.38	$0.37	$0.36	$0.35	$0.30	$0.30	$0.28	$0.26	$0.24
Operating Cost Contribution	$/gal total fuel	$0.24	$0.24	$0.24	$0.15	$0.21	$0.21	$0.19	$0.18	$0.15
Feed Moisture Content to	%	10%	10%	10%	10%	10%	10%	10%	10%	10%

Processing Area Cost Contributions & Key Technical Parameters	Metric	2009 SOT	2010 SOT	2011 SOT	2012 SOT	2013 Projection*	2014 Projection	2015 Projection	2016 Projection	2017 Projection†
FP										
Number Fast Pyrolysis Units		1x2000 tpd no filter	1x2000 tpd no filter	1x2000 tpd w filter	1x2000 tpd w filter	1x2000 tpd w filter	1x2000 tpd w filter	1x2000 tpd w filter	1x2000 tpd w filter	1x2000 tpd w filter
Pyrolysis Oil Yield (dry)	lb/lb dry wood	0.60	0.60	0.60	0.60	0.62	0.62	0.63	0.64	0.65
Ash Content	ppm	<500	<500	<500	<500	<500	<500	<500	<500	<500
Char	ppm	<500	<500	<500	<500	<500	<500	<500	<500	<500
Corrosivity, TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Upgrading to Stable Oil via Multi-Step Hydrodeoxygenation										
Total Cost Contribution	**$/gal total fuel**	**$5.70**	**$4.05**	**$3.00**	**$2.69**	**$1.59**	**$1.09**	**$1.01**	**$0.56**	**$0.55**
Capital Cost Contribution	$/gal total fuel	$0.53	$0.51	$0.47	$0.72	$0.40	$0.39	$0.36	$0.22	$0.21
Operating Cost Contribution	$/gal total fuel	$5.18	$3.54	$2.52	$1.97	$1.19	$0.69	$0.64	$0.34	$0.34
Number of Parallel Hydrotreaters		2x100% w guard bed	2x100% w guard bed	2x100% no guard bed	2x100% no guard bed	2x100% no guard bed	2x100% no guard bed	2x100% no guard bed	1x100% no guard bed	1x100% no guard bed
Catalyst Life	operating days	14	21	30	40	60	120	120	329	329
Catalyst Regeneration Frequency	days	0	0	0	0	0	0	0	6	1
Catalyst Base		carbon	carbon	carbon	carbon	carbon	carbon	carbon	carbon	carbon
Stable Oil Yield	lb/lb dry FP oil	0.40	0.40	0.40	0.40	0.45	0.45	0.47	0.50	0.55
Corrosivity, TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Sulfur	ppm	<40	<40	<40	<40	<40	<30	<30	<20	<15
Nitrogen	ppm	<40	<40	<40	<40	<40	<40	<40	<40	<40
Chlorine	ppm	<50	<50	<50	<50	<50	<50	<50	<50	<50
Alkali Compounds	ppm	<10	<10	<10	<10	<10	<10	<10	<10	<10
Gasoline, Octane Number		~89	~89	~89	~89	~89	~89	~89	~89	~89
Diesel, Cetane Index		~32	~32	~32	~32	~32	~32	~32	~32	>40
Hydrogen Partial Pressure Reactor	psia	~1750	~1750	~1600	~1600	~1600	~1600	~1600	~1600	~1600
Fuel Finishing to Gasoline and Diesel via Hydrocracking and Distillation										
Total Cost Contribution	**$/gal total fuel**	**$0.35**	**$0.34**	**$0.33**	**$0.33**	**$0.31**	**$0.30**	**$0.29**	**$0.28**	**$0.13**
Capital Cost Contribution	$/gal total fuel	$0.25	$0.24	$0.24	$0.22	$0.22	$0.22	$0.21	$0.21	$0.08
Operating Cost	$/gal total fuel	$0.10	$0.10	$0.10	$0.10	$0.09	$0.09	$0.08	$0.07	$0.05

Processing Area Cost Contributions & Key Technical Parameters	**Metric**	**2009 SOT**	**2010 SOT**	**2011 SOT**	**2012 SOT**	**2013 Projection***	**2014 Projection**	**2015 Projection**	**2016 Projection**	**2017 Projection**[†]
Contribution										
Extent of Hydrocracking/treating		diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier	diesel and heavier
Balance of Plant: Hydrogen Generation & OSBL										
Total Cost Contribution	**$/gal total fuel**	**$0.91**	**$0.89**	**$0.83**	**$0.66**	**$0.95**	**$0.95**	**$0.91**	**$0.87**	**$0.75**
Capital Cost Contribution	$/gal total fuel	$0.46	$0.45	$0.42	$0.43	$0.36	$0.35	$0.33	$0.31	$0.25
Operating Cost Contribution	$/gal total fuel	$0.44	$0.44	$0.41	$0.23	$0.60	$0.60	$0.58	$0.57	$0.50
Models: Case References		2009 SOT-0912 HL	2010 SOT-0912 HL	2011 SOT-0912 HL	2012 SOT-0912 HL	2013 P-0912 HL	2014 P-0912 HL	2015 P-0912 HL	2016 P-0912 HL	2017 Design 0912 HL

Note: The table may contain very small (≤ $0.01) rounding errors due to the difference between the way that Microsoft Excel™ displays and calculates rounded values.

[*] The demarcation line between 2012 and 2013 indicates the design case update planned to incorporate findings from the NABC, the stabilization call, and future upgrading work

[†] Production of Gasoline and Diesel from Biomass Via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case", PNNL-18284, February 2009

Appendix C: Calculation Methodology for Cost Goals

The two primary goals of this appendix are to:

1) Summarize the bases for the Bioenergy Technologies Office's performance goal
2) Explain the general methodology used to develop the cost goals and projections and adjust them to different year dollars.

Table C-1 describes the primary documents—including the Multi-Year Program Plan (MYPP)[1]—that cover the evolution of technology design and cost projections for specific conversion concepts. Additional details for the technical performance targets and cost goals can be found in Appendix B.

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[1] U.S. Department of Energy: Office of the Biomass Program, *Multi-Year Program Plan 2007-2012* (2005), Washington: Government Printing Office.

Table C-1: Primary Source Documents for Office Cost Goals

Document	Design and Cost Information: Bases and Differences
2002 Corn Stover to Ethanol Design Report[2]	• Ethanol market target of $1.07/gal (2000$) to be competitive with corn ethanol. • First design report for an agricultural residue feedstock. • Assumed $30/ dry ton (DT) feedstock cost delivered to the plant in bales. • Detailed conversion plant process design, factored capital cost estimate, operating cost estimate, and discounted cash flow rate of return used to determine ethanol cost target. • Costs based on 2000 dollars.
2005 MYPP with Feedstock Logistics Estimates	• Ethanol cost target of $1.08/gal (2002 dollars) in 2020. • First Program plan with feedstock cost components identified. • Feedstock grower payment assumed at $10/ton, although it is understood that this is a point on the supply curve that would correspond to a relatively low level of available agricultural residue type feedstock. • Feedstock logistics estimated cost at $25/DT based on unit operations breakdown, including preprocessing and handling, with equipment and operations up to the pretreatment reactor throat. • Detailed conversion plant design virtually the same as in the 2002 design report, but excluded feedstock handling system equipment and operation, which is now included in feedstock logistics. Several additional minor modifications and corrections made to original design with no significant cost impact. • Conversion costs escalated to 2002 dollars.
2007 MYPP	• Cost target of ~ $1.30/gal (2007 dollars) in 2012. • Feedstock grower payment escalated to $13/ton, although it is still and assumed number and understood that it is a point on the supply curve that would correspond to a relatively low level of available agricultural residue type feedstock. • Feedstock logistics cost breakdown updated based on first detailed design report covering this portion of the supply chain. • Detailed conversion plant design virtually the same as used in the 2005 MYPP case. • All costs escalated to 2007 dollars.
2009 MYPP	• Program cost target of $1.76/gal (2007 dollars) in 2012 is based on the Energy Information Administration's (EIA's) reference case wholesale price of motor gasoline for 2012[3] and calculations to adjust for the energy density of ethanol relative to gasoline.[4] Program cost target of $1.76/gal (2007 dollars) in 2017 reflects the addition of new feedstocks, new conversion technologies, and new cellulosic biofuels in the Program portfolio. • Cost projection of $1.49/gal (2007 dollars) in 2012 for the Biochemical Conversion Platform projected nth plant ethanol cost.[5] • Introduction of first projection of woody feedstock costs. • Feedstock grower payment escalated to $15.90/ton, although it is still assumed and understood that it is a point on the supply curve that would correspond to a relatively low level of available agricultural residue type feedstock. • Thermochemical conversion model updated based on first detailed design report for gasification, synthesis gas clean up, and mixed alcohol synthesis. • Thermochemical conversion model included based on first design report for pyrolysis, pyrolysis -oil upgrading and stabilization, and fuel synthesis to gasoline/diesel blendstock. • All costs escalated to 2007 dollars using actual economic indices up to 2007. • Feedstock models significantly improved and refined which resulted in a price increase.

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[2] A. Aden, M. Ruth, et al, "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover," National Renewable Energy Laboratory, NREL/TP-510-32438 (2002), http://www1.eere.energy.gov/biomass/pdfs/32438.pdf.

[3] U.S. Department of Energy, *Annual Energy Outlook 2009: Table 112* (2009), Washington: Government Printing Office, http://www.eia.doe.gov/oiaf/archive/aeo09/supplement/suptab_112.xls.

[4] 0.67 gallon gasoline /gallon ethanol conversion factor

[5] S. Phillips, A. Aden, et al, "Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass," National Renewable Energy Laboratory, NREL/TP-510-41168 (2007), http://www.nrel.gov/docs/fy07osti/41168.pdf.

Document	Design and Cost Information: Bases and Differences
2010 MYPP	• Program performance goals are based on EIA's reference case wholesale price of motor gasoline. The 2012 goal is based on the EIA's pre-American Recovery and Reinvestment Act of 2009 (ARRA) reference case for gasoline.[6] The 2017 goals for gasoline, diesel, and jet are based on the EIA's post-ARRA reference case.[7] • Thermochemical conversion models updated based on first detailed design report for pyrolysis to hydrocarbon biofuels.[8]
2011 MYPP	• Thermochemical conversion models, including preliminary technical projections further detailed for pyrolysis to hydrocarbon fuels. • Updated financial assumptions for biochemical and gasification design cases. • Gasification to ethanol design case with cost target, projections, and back-cast state of technology (SOT) results updated for technology advancements and revised cost of capital equipment. • Biochemical Conversion R&D cost target projections revised for updated design case, including 'back-cast' SOT. Design cases and future projections are modeled production costs for a plant converting dry corn stover to ethanol at 2,000 DT feedstock per day, via dilute acid pretreatment, enzymatic hydrolysis, and ethanol fermentation and recovery, with lignin combustion for combined heat and power production. • Feedstock supply models updated providing assumed $23.50/DT grower payment for corn stover, and $15.20/DT grower payment for pulpwood for 2012. Woody feedstock logistics models updated to reflect all logistics handling to the reactor throat for thermochemical conversion.
2012 MYPP	• The Program's 2017 performance goals are based on EIA's reference case projections for the wholesale price of gasoline, diesel, and jet fuel.[9] • Updated financial assumptions and cost indexes for calculating cost goals.

Office's Performance Goal: Calculation Methodology

The Office's performance goals are based on commercial viability with fossil-based fuels, specifically the Energy Information Administration (EIA)'s oil price outlook for future motor gasoline, diesel, and jet wholesale prices. The underlying assumptions include the following:

- Refinery gate production cost of gasoline can be compared to the biorefinery production cost of biomass-based renewable gasoline and ethanol (adjusted for Btu content). Similarly, refinery gate production cost of diesel and jet fuel can be compared to the biorefinery production cost of biomass-based renewable diesel and jet fuel.
- Downstream distribution costs are excluded as are subsidies and tax incentives.

The historical crude oil prices and EIA projections are presented in Figure C-1.

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[6] U.S. Department of Energy, *Annual Energy Outlook 2009: Table 112* (2009), Washington: Government Printing Office, http://www.eia.doe.gov/oiaf/archive/aeo09/supplement/suptab_112.xls

[7] U.S. Department of Energy, *Annual Energy Outlook 2009 Updated Case with ARRA: Table 112* (2009), Washington: Government Printing Office, http://www.eia.doe.gov/oiaf/aeo/supplement/stimulus/arra/excel/suptab_112.xls.

[8] SB Jones, C Valkenburg, CW Walton, et al, "Production of Gasoline and Diesel from Biomass Via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case," Pacific Northwest National Laboratory, PNNL-18284 (2009), http://www.pnl.gov/main/publications/external/technical_reports/pnnl-18284.pdf.

[9] U.S. Department of Energy, *Annual Energy Outlook 2012: Table 131* (2012), Washington: Government Printing Office, http://www.eia.gov/oiaf/aeo/supplement/suptab_131.xlsx.

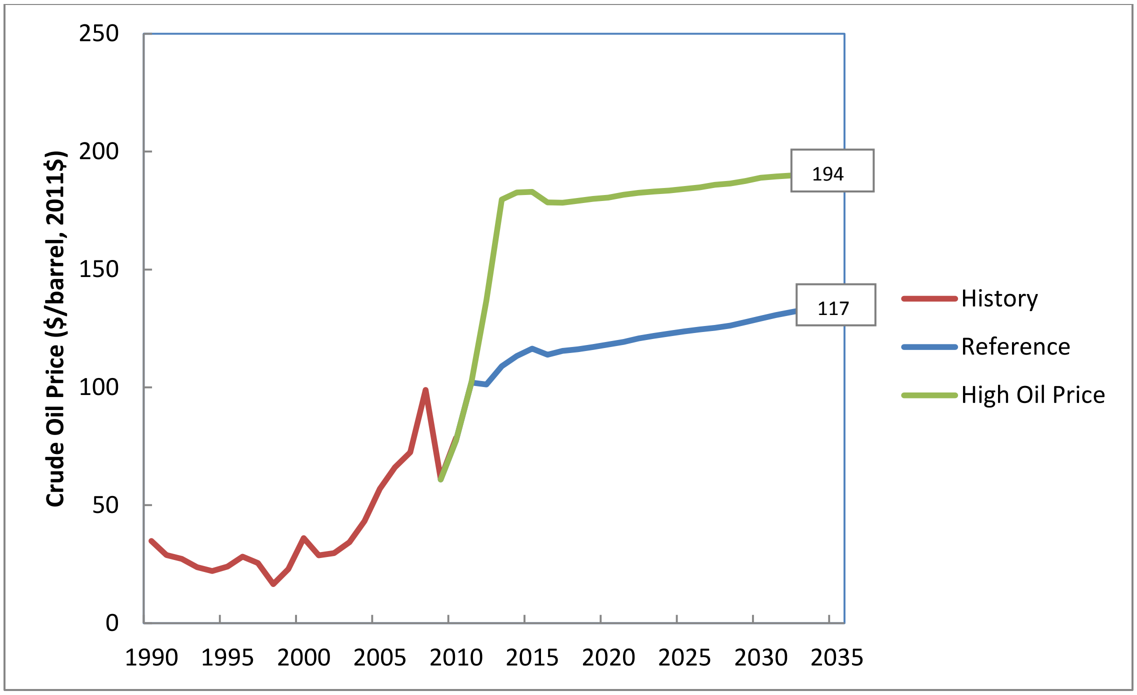

Figure C-1: EIA Projections for Crude Oil Prices[10]

The crude oil, gasoline, diesel, and jet prices for EIA's reference and high oil cases are summarized in Table C-2.

Table C-2: EIA Oil Price Forecasts

	Wholesale Prices in 2011$[11]	2017	2020	2022	2035
Reference Case[12]					
	Crude oil ($/barrel)	116	118	121	136
	Diesel ($/gallon)	3.31	3.42	3.49	3.95
	Jet ($/gallon)	3.29	3.39	3.45	3.93
	Gasoline ($/gallon)	3.11	3.21	3.25	3.59
High Oil Price Case[13]					
	Crude oil ($/barrel)	178	181	183	191
	Diesel ($/gallon)	4.71	4.68	4.80	4.95
	Jet ($/gallon)	4.75	4.67	4.80	5.00
	Gasoline ($/gallon)	4.63	4.63	4.64	4.60

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[10] Source: Energy Information Administration, Annual Energy Outlook 2012.

[11] Note: Fuel prices are reported in 2010$ in the Annual Energy Outlook 2012. They have been adjusted from 2010$ to 2011$ by using the GDP implicit price deflators (1.110 for 2010; 1.133 for 2011) obtained from the Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts.

[12] U.S. Department of Energy, *Annual Energy Outlook 2012: Table 131* (2012), Washington: Government Printing Office, http://www.eia.gov/oiaf/aeo/supplement/suptab_131.xlsx.

[13] U.S. Department of Energy, *Annual Energy Outlook 2012: High Oil Price Case, Table 70* (2012), Washington: Government Printing Office.

Table C-2 shows that the Office performance goal of producing biofuels at or less than $3/gallon by 2017 is consistent with the EIA projections for diesel, jet, and gasoline prices in the reference case.

Cost Goals and Projections

Table C-3 shows the cost breakdown of the projected cost goals for the fast pyrolysis pathway as a result of updating the dollar year from 2007 to 2011 and adjusting other key assumptions, as shown in Table C-4. The cost components are based on the first three major elements of the biomass-to-biofuels supply chain (feedstock production, feedstock logistics, and biomass conversion) and their associated sub-elements.

The costs for feedstock production are based on simulated feedstock supply curves developed and published in the *U.S. Billion Ton Update*.[14] This analysis projects feedstock production scenarios based on a series of factors that impact feedstock production decisions. The supply curves project the amount of feedstock produced at various market prices for each of several feedstock categories identified in Table B-2. The costs in Table B-2 represent the price points on the supply curves where sufficient feedstock is available to meet national goals. These price points are selected for the relevant feedstock resource categories used in calculating the system level cost goals.

The projected production cost goals represent mature technology processing costs, which means that the capital and operating costs are assumed to be for an “nth plant,” where several plants have been built and are operating successfully, no longer requiring increased costs for risk financing, longer startups, under performance, and other costs associated with pioneer plants.

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[14] 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.

Table C-3: Production Cost Breakdown by Supply Chain Element

Supply Chain Areas	Units	2009 Wood / Pyrolysis to Hydrocarbon Fuel Design Report	2012 MYPP 2017 Goals/Targets
Year $	Year	2007	2011
Feedstock Production			
Grower Payment	$/DT	$22.60	$26.25
Feedstock Logistics			
Harvest and Collection	$/DT	$18.75	$19.53
Storage and Queuing	$/DT	$0.00	$0.00
Landing Preprocessing	$/DT	$11.42	$11.73
Transportation and Handling	$/DT	$8.95	$6.37
Plant Receiving and In-Feed Preprocessing	$/DT	$17.65	16.88
Logistics Subtotal	**$/DT**	**$56.77**	**$54.50**
Feedstock Total	**$/DT**	**$79.37**	**$80.75**
Fuel Yield	Gal Gasoline +Diesel/ DT	106	106
Feedstock Production			
Grower Payment	$/gal total fuel	$0.21	$0.25
Feedstock Logistics			
Harvest and Collection	$/gal total fuel	$0.18	$0.18
Storage and Queuing	$/gal total fuel	$0.00	$0.00
Landing Preprocessing	$/gal total fuel	$0.11	$0.11
Transportation and Handling	$/gal total fuel	$0.08	$0.06
Plant Receiving and In-Feed Preprocessing	$/gal total fuel	$0.17	$0.16
Logistics Subtotal	$/gal total fuel	$0.54	$0.51
Feedstock Total	**$/gal total fuel**	**$0.75**	**$0.76**
Biomass Conversion			
Feedstock Drying, Sizing, Fast Pyrolysis	$/gal total Fuel	$0.34	$0.39
Upgrading to Stable Oil	$/gal total Fuel	$0.47	$0.55
Fuel Finishing to Gasoline and Diesel	$/gal total Fuel	$0.11	$0.13
Balance of Plant	$/gal total Fuel	$0.65	$0.75
Conversion Total	**$/gal** total **Fuel**	**$1.57**	**$1.83**
Fuel Production Total	***$/gal*** total ***Fuel***	***$2.32***	***$2.83***

Table C-4 outlines changes in the analysis assumptions for the fast pyrolysis pathway as well as design cases currently being developed.

Table C-4: 2012 Changes to Analysis Assumptions

	Prior Values	2012 Updated Values
% Equity / % Debt Financing	100%	40% / 60%
Loan Terms (% Rate, Term)	N/A	8%, 10 years
Discount Factor	10%	10%
Year-Dollars	2007 dollars	2011 dollars
Depreciation Method, Time	MACRS 7 years general plant 20 years steam/boiler	MACRS 7 years general plant 20 years steam/boiler
Cash Flow / Plant Life	20 years	30 years
Income Tax	39%	35%
On-Line Time	90%	90%
Indirect Costs (Contingency, Fees, etc.)	51% of total installed costs	60% of total direct costs*
Lang Factor	3.7	4.7 (fast pyrolysis case)

* Total direct costs include installed costs plus other direct costs (warehouse, additional piping, and site

General Cost Estimation Methodology

The Office uses consistent, rigorous engineering approaches for developing detailed process designs, simulation models, and cost estimates, which in turn are used to estimate the minimum selling price for a particular biofuel using a standard discounted cash flow rate of return calculation. The feedstock logistics element uses economic approaches to costing developed by the American Society of Agricultural and Biological Engineers. Details of the approaches and results of the technical and financial analyses are thoroughly documented in the Office's conceptual design reports[15] and are not included here. Instead a high-level general description of how costs are developed and escalated to different year dollars is provided below.

Cost estimate development is slightly different between the feedstock logistics and biomass conversion elements, but generally both elements include capital costs, costs for chemicals and other material, and labor costs. The indices for plant capital chemicals, and materials have increased significantly since 2003, while the labor index has shown a consistent if steady rise of about 2.5% per year.

The total project investment (based on total equipment cost), as well as variable and fixed operating costs, are developed first using the best available cost information. Cost information typically comes from a range of years, requiring all cost components to be adjusted to a common year. For the case shown in Appendix C, each cost component was adjusted based on the ratio of the 2007 index to the actual index for the particular cost component. The delivered feedstock

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[15] SB Jones, C Valkenburg, CW Walton, et al, "Production of Gasoline and Diesel from Biomass Via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case," Pacific Northwest National Laboratory, PNNL-18284 (2009), http://www.pnl.gov/main/publications/external/technical_reports/pnnl-18284.pdf.

cost was treated as an operating cost for the biomass conversion facility. With these costs, a discounted cash flow analysis of the conversion facility was carried out to determine the selling price of fuel when the net present value of the project is zero.

Total Project Investment Estimates and Cost Escalation

The Office design reports include detailed equipment lists with sizes and costs, and details on how the purchase costs of all equipment were determined. For the feedstock logistics element, some of the equipment, such as harvesters and trucks, do not require additional installation cost; however, other logistics equipment and the majority of the conversion facility equipment will be installed.

For the types of conceptual designs the Office carries out, a “factored” approach is used. Once the installed equipment cost has been determined from the purchased cost and the installation factor, it can be indexed to the project year being considered. The purchase cost of each piece of equipment has a year associated with it. The purchased cost year will be indexed to the year of interest using the Chemical Engineering Plant Cost Index.

Figure C-2 and Table C-5 show the historical values of the Index. Notice that the Index was relatively flat between 2000 and 2002 with less than a 0.4% increase, while there was a nearly 18% jump between 2002 and 2005. Changes in the plant cost indices can drive dramatic increases in equipment costs, which directly impact the total project capital investment.

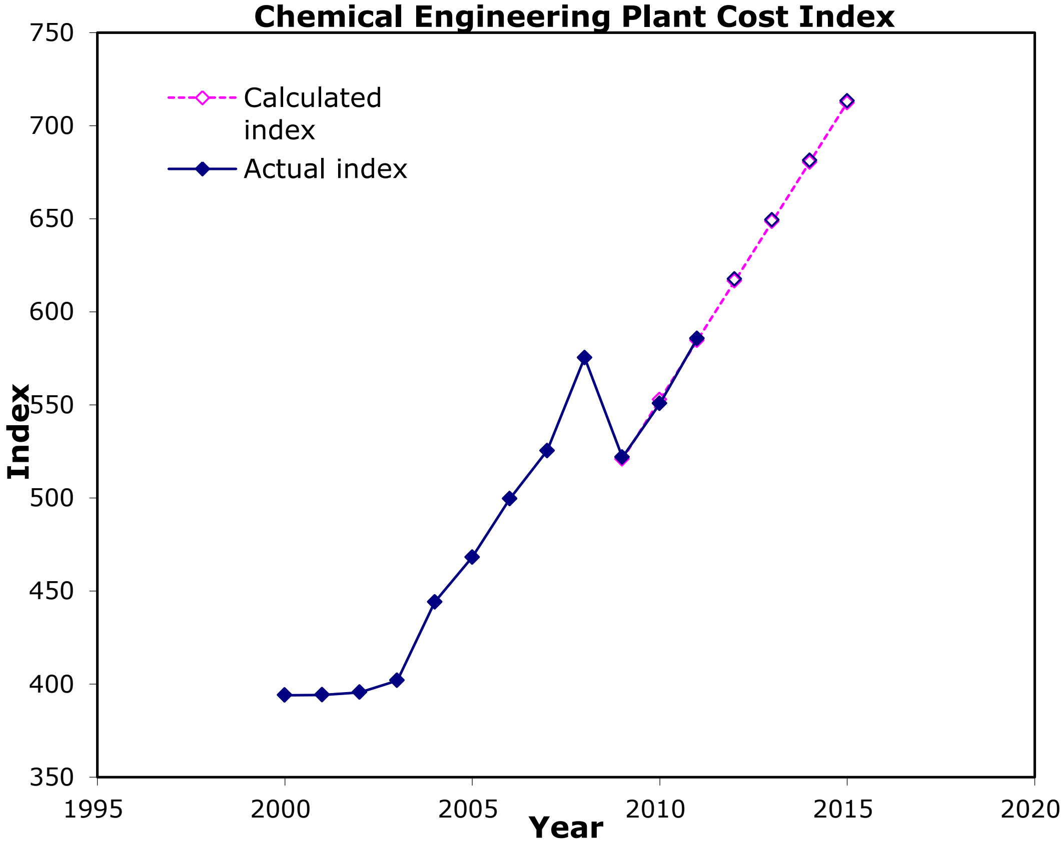

Figure C-2: Actual and Extrapolated Plant Cost Index (see Table C-5 for values)

Table C- 5: Plant Cost Indices

Source	Year	CE Annual Index	Calculated Index	Index Used in Calculations
(1)	2000	394.1		394.1
(2)	2001	394.3		394.3
(2)	2002	395.6		395.6
(3)	2003	402.0		402.0
(3)	2004	444.2		444.2
(3)	2005	468.2		468.2
(4)	2006	499.6		499.6
(4)	2007	525.4		525.4
(4)	2008	575.4		575.4
(4)	2009	521.9	520.9	521.9
(5)	2010	550.8	552.8	550.8
(5)	2011	585.7	584.7	585.7
	2012		616.6	617.6
	2013		648.5	649.5
	2014		680.4	681.4
	2015		712.3	713.3

Sources:

(1) Chemical Engineering Magazine, April, 2002

(2) Chemical Engineering Magazine, December, 2003

(3) Chemical Engineering Magazine, May 2005

(4) Chemical Engineering Magazine, April 2009

(5) Chemical Engineering Magazine, April 2012
Current indices @ http://www.che.com/ei

Any extrapolation of this data is extremely difficult. Trends prior to 2003 were nearly linear, followed by significant increases until an economic downturn in 2009. As additional data points become available, the extrapolation will be refined.

For equipment cost items in which actual cost records do not exist, a representative cost index is used. For example, the U.S. Department of Agriculture (USDA) publishes Prices Paid by Farmers indexes that are updated monthly. These indexes represent the average costs of inputs purchased by farmers and ranchers to produce agricultural commodities and a relative measure of historical costs. For machinery list prices, the Machinery Index was used. The Repairs Index was used for machinery repair and maintenance costs. These USDA indices were used for all machinery used in the feedstock supply system analysis, including harvest and collection machinery (combines, balers, tractors, etc.), loaders and transportation-related vehicles, grinders, and storage-related equipment and structures.

Operating Cost Estimates and Cost Escalation

For the different design cases, variable operating costs—which include fuel inputs, raw materials, waste handling charges, and byproduct credits—are incurred when the process is operating, and are a function of the process throughput rate. All raw material quantities used and wastes produced are determined as part of the detailed material and energy balances calculated for all the process steps. As with capital equipment, the costs for chemicals and materials are associated with a particular year. The U.S. Producer Price Index from SRI Consulting was used as the index for all chemicals and materials. Available data were regressed to a simple equation and used to extrapolate to future years, as shown in Figure C-3 and Table C-6.

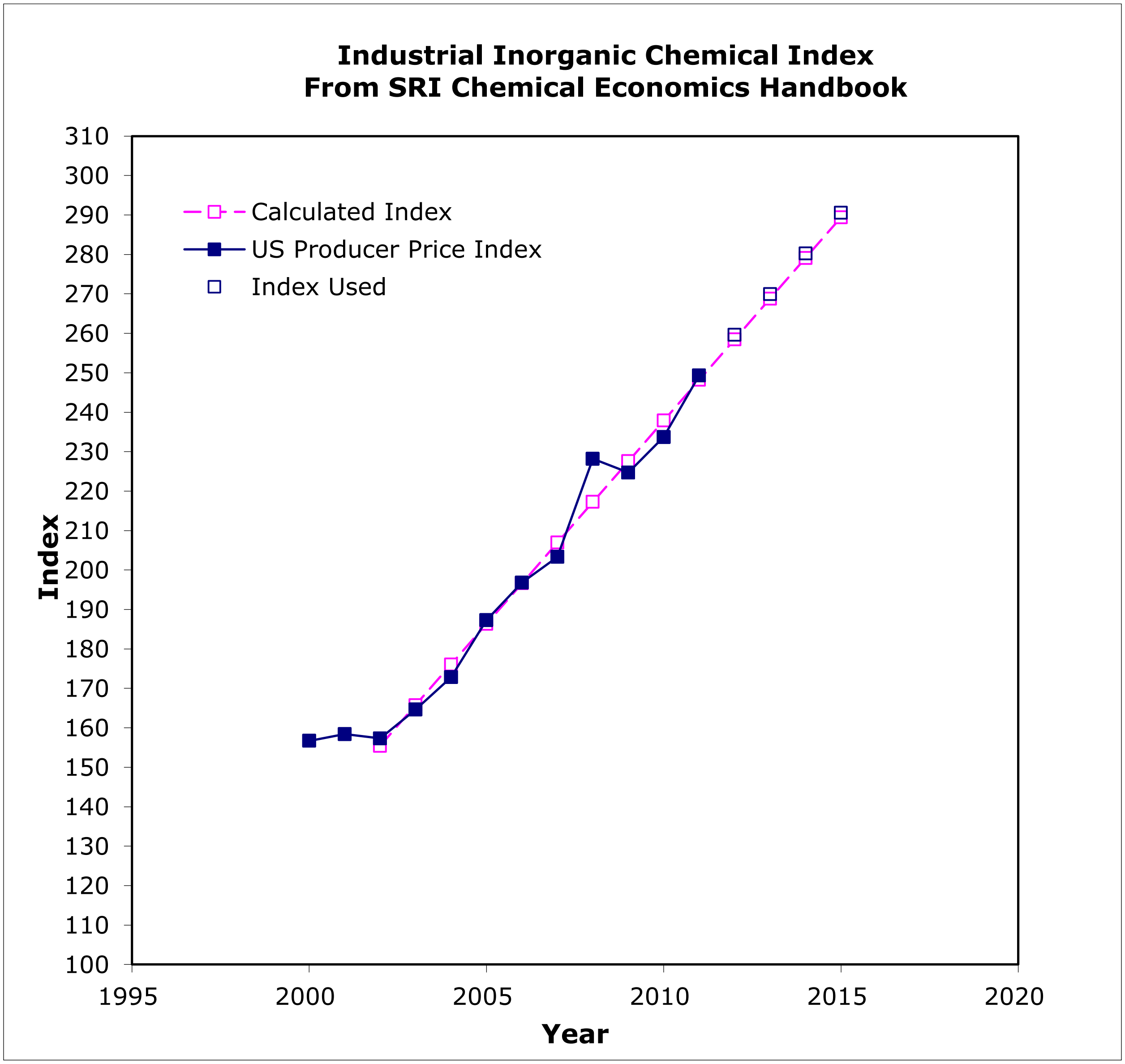

Figure C-3: Actual and Extrapolated Chemical Cost Index (see Table C-6 for values)

Table C-6: U.S. Producer Price Index – Total, Chemicals and Allied Products

Year	U.S. Producer Price Index	Calculated Index	Index Used
2000	156.7		156.7
2001	158.4		158.4
2002	157.3	155.4	157.3
2003	164.6	165.7	164.6
2004	172.8	176.0	172.8
2005	187.3	186.3	187.3
2006	196.8	196.6	196.8
2007	203.3	207.0	203.3
2008	228.2	217.3	228.2
2009	224.7	227.6	224.7
2010	233.7	237.9	233.7
2011	249.3	248.2	249.3
2012		258.5	259.6
2013		268.8	269.9
2014		279.1	280.2
2015		289.4	290.5

Source:
SRI International Chemical Economics Handbook,
Economic Environment of the Chemical Industry 2011.
Current indices @
https://www.sriconsulting.com/CEH/Private/EECI/EECI.pdf

Some types of labor, especially related to feedstock production and logistics are variable costs, while labor associated with the conversion facility are considered fixed operating costs.

Fixed operating costs are generally incurred fully, whether or not operations are running at full capacity. Various overhead items are considered fixed costs in addition to some types of labor. General overhead is generally a factor applied to the total salaries and covers items such as safety, general engineering, general plant maintenance, payroll overhead (including benefits), plant security, janitorial and similar services, phone, light, heat, and plant communications. Annual maintenance materials are generally estimated as a small percentage (e.g., 2%) of the total installed equipment cost. Insurance and taxes are generally estimated as a small percentage (e.g., 1.5%) of the total installed cost. The index to adjust labor costs is taken from the Bureau of Labor Statistics and is shown in Figure C-4 and Table C-7. The available data were regressed to a simple equation and the resulting regression equation used to extrapolate to future years.

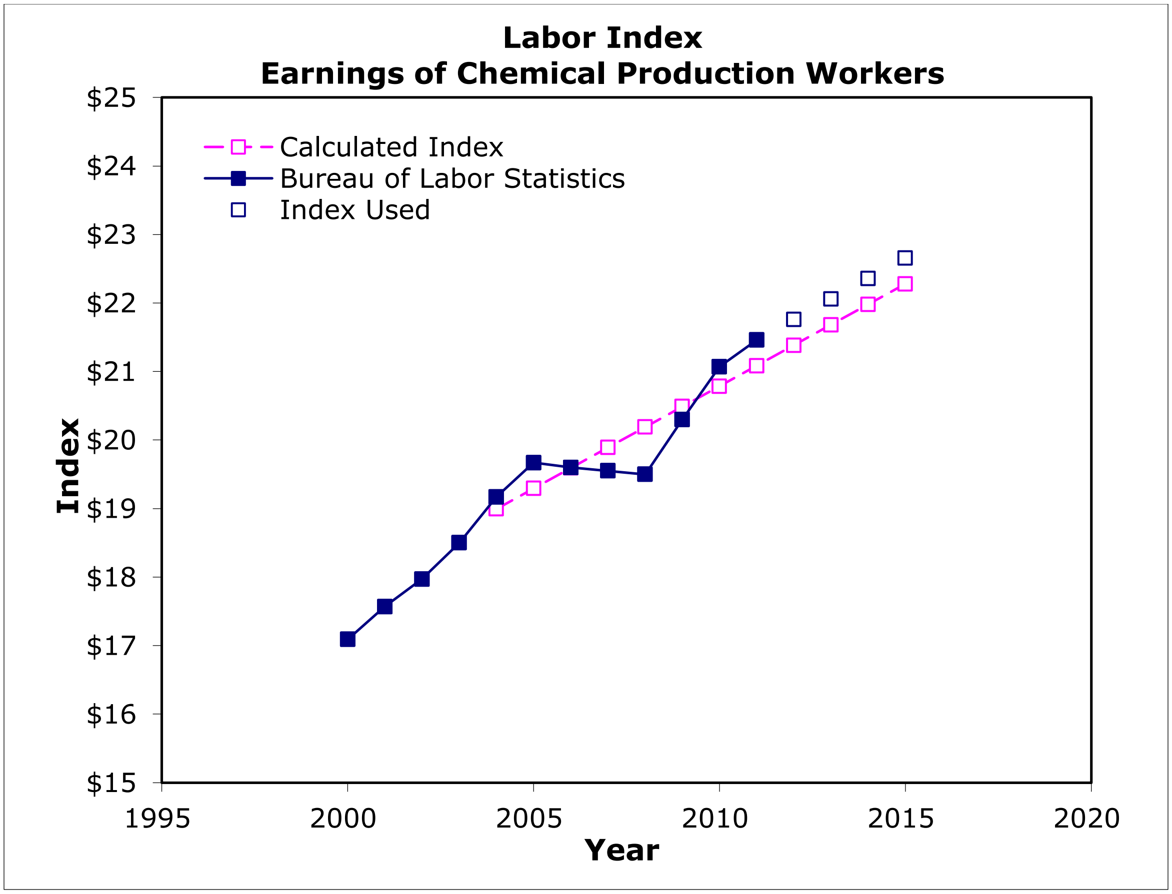

Figure C-4: Actual and Extrapolated Labor Cost Index (see Table C-7 for values)

Table C-7: Labor Index

Year	Reported	Calculated	Index Used
2000	17.09		17.09
2001	17.57		17.57
2002	17.97		17.97
2003	18.50		18.50
2004	19.17	19.00	19.17
2005	19.67	19.29	19.67
2006	19.60	19.59	19.60
2007	19.55	19.89	19.55
2008	19.50	20.19	19.50
2009	20.30	20.49	20.30
2010	21.07	20.79	21.07
2011	21.46	21.09	21.46
2012		21.38	21.76
2013		21.68	22.06
2014		21.98	22.36
2015		22.28	22.65

Source:
Bureau of Labor Statistics, Series ID: CEU3232500008
Chemicals Average Hourly Earnings of Production Workers
Current indices from http://data.bls.gov/cgi-bin/srgate

Discounted Cash Flow Analysis and the Selling Cost of Ethanol

Once the two major cost areas have been determined—(1) total project investment and (2) operating costs—a discounted cash flow analysis can be used to determine the minimum selling price per gallon of biofuel produced. The discounted cash flow analysis program iterates on the selling cost of the biofuel until the net present value of the project is zero. This analysis requires that the discount rate, depreciation method, income tax rates, plant life, and construction start-up duration be specified. The Office has developed a standard set of assumptions for use in the discounted cash flow analysis.

Appendix D: Matrix of Revisions

Section Name	Specific Reference	Revision	Version Change was Implemented
April 2011			
Section 1.4.3	Program Multi-Year Targets	Updated new platform cost targets	April 2011
Section 2.1 Feedstock Supply Research and Development	Text changes throughout, platform goals in section 2.1.2	Added information about the Advanced Uniform-Format feedstock supply system, updated resource assessment figures and text, and feedstock logistics tables and figures.	April 2011
Section 2.2.1	Biochemical Conversion R&D cost targets	Reflect updated 2012 technical and cost targets from updated 2012 design case	April 2011
Section 2.2.2	Thermochemical Conversion R&D cost targets (gasification)	Reflect updated 2012 technical and cost targets from updated gasification to ethanol design case.	April 2011
Appendix B	Appendix B Technical Target Tables	Updated all tables with new modeled feedstock grower payment and feedstock logistics and handling cost targets. Updated Biochem and gasification technical targets consistent with newly revised design cases.	April 2011
Appendix C	Cost Target calculations	Included description of changes to updated conversion R&D design cases	April 2011
November 2011			
Executive Summary & Section One	Program Multi-Year Strategic Goal and Program Performance Goal	Replaced “cost-competitive” with “commercially viable”	November 2011
Section 2.1 Feedstock Supply Research and Development & Appendix B	2017 Platform goals for ethanol routes	Removed 2017 goals and targets for ethanol based routes. Expanded description of feedstock preprocessing.	November 2011

Section Name	Specific Reference	Revision	Version Change was Implemented
Section 2.2.1.5 Prioritizing Biochemical Conversion Barriers & Appendix B	Figure 2-13, Biochemical Conversion of Corn Stover to Ethanol & Appendix Table B-6	Added 2011 State of Technology.	November 2011
April 2012			
Section 2.1.5; Section 2.2.2.5; Appendix B	2011 State of Technology figures	Replaced 2011 Projection with 2011 State of Technology Updates.	April 2012
Appendix B, Table B-2	Projected Feedstock Supplies Available to Meet EISA RFS and Biopower Demand	Correct erroneous supply and grower payment figures for Pulpwood and totals.	April 2012
November 2012			
All Sections	Throughout	Major and minor update to all sections with refocus on hydro-carbon fuel including split of thermochemical pathways, de-emphasis of biopower and distribution infrastructure and end use, and refocus on strategic communications. Update to 2011 dollars.	November 2012
Section 2.1 and Appendix Table B-3	Addition of Algae cost and technical targets	Expand descriptions of algal feedstocks. Add cost goals and technical targets	November 2012
April 2013			
Section 2.1.5; Section 2.2.2.1.5; Appendix Tables B-3 and B-5	2012 State of Technology figures	Replaced 2012 Projection with 2012 State of Technology Updates. Table B-5 corrected erroneous natural gas consumption.	May 2013

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