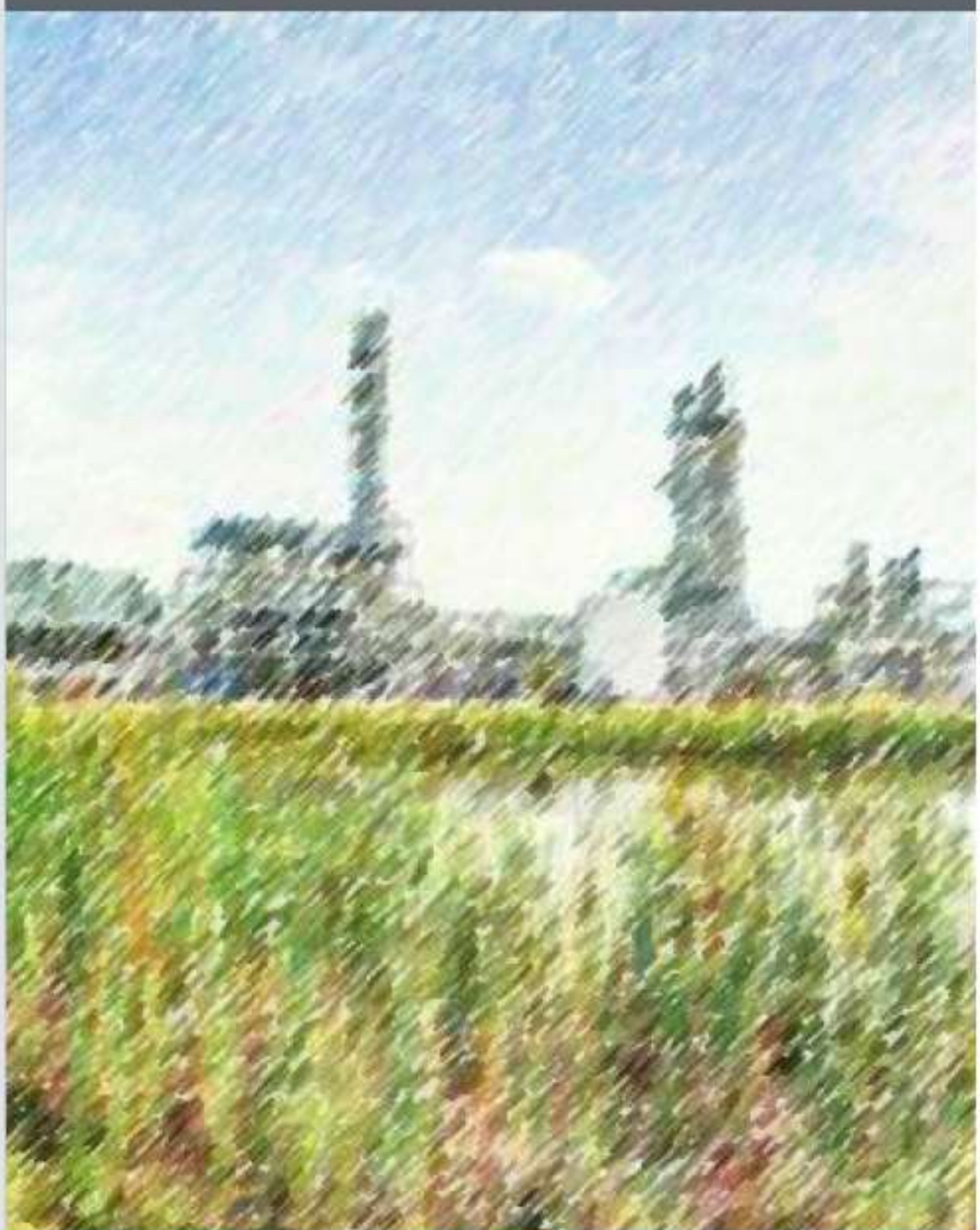
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOENERGY TECHNOLOGIES OFFICE

Demonstration and Deployment Strategy Workshop: Summary

May 2014



Demonstration and Deployment Strategy Workshop: Summary

May 2014

Workshop and report sponsored by the

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Bioenergy Technologies Office
Demonstration and Deployment Team

Prepared by

Energetics Incorporated

Preface

This report is based on the proceedings of the U.S. Department of Energy's Bioenergy Technologies Office (BETO) Demonstration and Deployment (D&D) Strategy Workshop, held on March 12–13, 2014, at Argonne National Laboratory. The workshop gathered stakeholders from industry, academia, national laboratories, and government to discuss the issues and potential for demonstration and deployment activities to pave the way for large-scale production of cost-competitive, renewable fuels from biomass resources. The ideas provided here represent a snapshot of the perspectives and ideas generated by the discrete set of participants in attendance at the workshop.

Acknowledgements

Special thanks are extended to the workshop plenary speakers in helping to frame this workshop: Anthony Crooks, PhD, U.S. Department of Agriculture; Angela Foster-Rice, United Airlines; Kevin A. Gray, PhD, Beta Renewables; Jennifer Holmgren, LanzaTech; Sharyn Lie, U.S. Environmental Protection Agency; Jonathan Male, BETO; Ron Meeusen, Cultivian Sandbox Ventures, LLC; Hans van der Sluis, POET-DSM Advanced Biofuels; Jim Spaeth, BETO; and Travis Tempel, BETO.

BETO gratefully acknowledges the valuable ideas and insights contributed by all of the stakeholders who participated in the D&D Strategy Workshop. The willingness of these experts to share their time and knowledge has helped to identify and better define current and emerging opportunities to expedite the demonstration and deployment of innovative technologies for sustainably producing a suite of advanced biofuels and bioproducts. These individuals are listed in Appendix A.

Workshop planning and execution and the preparation of this report were conducted under the direction of Jim Spaeth and Travis Tempel, with significant contributions from others in BETO and Energetics Incorporated.

Cover

Original photo provided courtesy of INEOS BIO.

Contents

Executive Summary

To accelerate the commercial production of drop-in hydrocarbon fuels from biomass, the Bioenergy Technologies Office (BETO) in the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) held a strategy workshop at Argonne National Laboratory on March 12–13, 2014. The workshop brought together a broad spectrum of experts from industry, academia, national laboratories, and government to discuss the technical and economic barriers impeding the demonstration and deployment of technologies for the commercial production of drop-in hydrocarbon fuels and products. The wealth of information generated at the workshop will inform BETO's strategic planning and prioritization efforts. As summarized and grouped thematically in Table ES-1, workshop participants identified key barriers, as well as activities to address those barriers.

Working in five parallel breakout sessions, workshop participants prioritized 25 advancement activities that could accelerate the commercialization of drop-in hydrocarbon fuels. These technical groups ultimately placed priority on a number of activities in common, suggesting the potential for broad appeal across the sector. Four recurring themes echoed across the groups:

- **Creation of Test Facilities:** A truly versatile test facility, while challenging to set up and finance, would expedite technology validation efforts.
- **Feedstock Handling:** Improved equipment for feedstock handling could resolve issues that often lead to biorefinery failure.
- **Economic Value:** Bioproducts—and the versatility they provide—could improve the economics of biorefineries.
- **Partnering Efforts:** Partnering is always a critical need; technical experts in diverse fields are needed to design, build, and operate a successful biorefinery.

These industry opinions on mechanisms for advancing biofuels provide valuable insights into activities that could potentially help realize the commercial potential of drop-in hydrocarbon biofuels.

Table ES-1.1: Key Barriers and Activities to the Development and Demonstration of Critical Technologies

Barrier	Advancement Activity	Group
Standards Development and Market Analysis		
Lack of widely available, reliable, comprehensive, and transparent information on costs and conversion efficiencies at each stage of the supply chain	Publish estimated costs and conversion efficiencies by feedstock and conversion process each year.	F
Overly optimistic evaluations that set unrealistically high targets and expectations for pioneer plants	Establish a new standard to guide the critical review of technical and economic metrics.	BC
Lack of useable and enforceable metrics for assessing the industrial robustness of organisms, enzymes, and processes for biochemical conversion	Develop metrics to indicate the technological robustness of organisms, enzymes, and processes.	BC
Inconsistent techno-economic modeling results due to different assumptions and methodologies	Standardize analytics for techno-economic and process modeling.	TC B
Facilities / Test Beds		
Technical and economic challenges of separations	Demonstrate separations technologies at pilot and demonstration scales.	P
Prohibitive cost for a single entity to produce large volumes (i.e., >1000 gallons) of biofuel	Create a Cross-Platform Development Incubator	BC
Lack of validated catalyst performance data to feed into the technical and economic models that guide future engineering design for technology scale-up and demonstration	Conduct preliminary pilot-scale testing to measure the performance of catalysts.	TC A
Limited number, range, and industry awareness of facilities for pilot-scale thermochemical testing and development; lack of demonstration-scale user facilities and consistent, adequate support for pilot facilities	Use the convening power of DOE to form partnerships to develop the technology, further develop existing pilot facilities, and expand them into demonstration-scale user facilities.	TC A
Need to test and validate the economic viability of a fully integrated plant operation, from feedstock to end products	Establish Plant Integration facility for users to demonstrate acceptable plant uptime, product quality and yield, and operating costs.	TC B
Difficulties in validating catalyst performance (yield, selectivity, lifetime) in converting biomass to intermediates and in upgrading those intermediates to "whole barrel" replacement hydrocarbons	Provide facility or facilities for demonstrating catalyst manufacturing and evaluating catalyst performance at scale.	TC B
Feedstock Handling		
Challenges in scaling up technologies without adversely affecting feedstock cost, the availability and reliability of supply, and consistent quality	Develop and demonstrate advanced logistics systems for biomass feedstocks.	F
Lack of operational flexibility to accommodate feedstock variability	Design robust processes to transform diverse biomass resources into homogeneous intermediates, enabling component separation for further processing.	P
Lack of feedstock-flexible processing and handling systems, especially at pilot or larger scale	Develop more versatile feedstock handling systems at pilot scale and larger.	TC B

Barrier	Advancement Activity	Group
Equipment Development		
Lack of simple, timely, accurate instruments to verify biomass quality specifications at points of collection, consolidation, delivery, or storage	Develop fast, simple, and inexpensive devices/measures to accurately determine feedstock quality.	F
Lack of biorefinery plant infrastructure (i.e., pumps, heat exchangers, etc.)	Clarify an infrastructure procurement strategy for biorefineries (e.g., a Green Manhattan Effort).	P
Current processing units that are not optimized for the bioenergy industry	Conduct value engineering on specific unit operations.	P
High cost of biorefinery infrastructure, particularly for creation of new processes	Build on the existing ethanol infrastructure.	BC
Outreach and Partnering Efforts		
Uncoordinated development and commercialization efforts along the feedstock supply chain	Engage a broader spectrum of biomass feedstock development stakeholders to accelerate progress.	F
Difficulty in identifying compatible partners and thermochemical technologies	Develop a database of thermochemical technologies (by feedstock, process, and product) to enable assembly of field and patent data from federally funded projects.	TC A
Lack of connection among catalyst manufacturers, process inventors, and developers in DOE-funded programs; high financial and technical risks for all parties on a team	Encourage and support collaborative efforts to scale up catalyst production and piloting.	TC A
"Gaps" or areas of lower competency/resources present in most organizations for moving new technology into integrated commercialization (D&D)	Establish best practices in partnering or gap filling to bolster experience, expertise, finances, etc. (including foreign entities).	TC B
Economic Value		
Overwhelming nature of the vast array of options for chemicals that can be produced from biomass	Target specific platform chemical intermediates that could collectively substitute for the whole barrel.	P
Low-value end use for significant portion of the feedstocks that move through the supply chain	Add value to the rest of a bale, specifically lignin conversion.	P
Economic limitations of producing a single product	Co-produce multiple bioproducts to enhance economic stability.	BC
Funding Support		
Limited funding and construction of commercial-scale facilities	Underwrite activities to bolster investor confidence and market pull; validate the technical and economic performance of these technologies with a focus on the end customer.	BC

BC: Biochemical Conversion; F: Feedstock; P: Products; TC A: Thermochemical Conversion A; TC B: Thermochemical Conversion B

1. Introduction

Displacing conventional jet fuel, diesel, and gasoline with renewable fuels will require the production of bio-based molecules that are equivalent in performance to the petroleum-based molecules they are designed to replace. Domestic production of drop-in hydrocarbon fuels that can directly substitute for conventional transportation fuels will deliver a wealth of benefits, including economic growth, energy security, reduced greenhouse gas emissions, and positive impacts on sustainability and the environment.

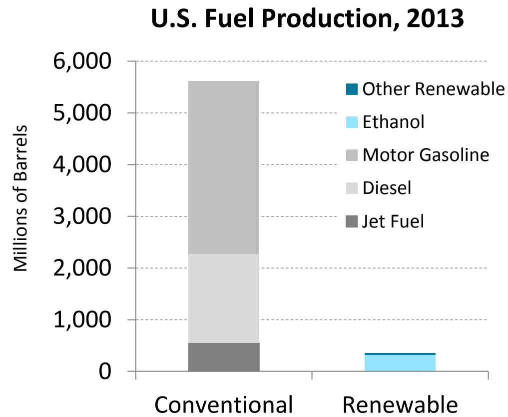


Figure 1.1: 2013 U.S. fuel production

Source: [EIA Petroleum & Other Liquids, Supply and Disposition]

While domestic biofuels make up less than 6% of today's market (Figure 1.1), the U.S. bioindustry is on the verge of developing and deploying novel technologies that will give the country a cleaner and more sustainable source of transportation fuel. As the private sector embarks on the commercial-scale production of cellulosic ethanol, the Bioenergy Technologies Office (BETO) in the Office of Energy Efficiency and Renewable Energy (EERE) at the U.S. Department of Energy (DOE) continues to support those efforts and seeks to catalyze progress in the nation's domestic capability to produce cost-competitive, drop-in hydrocarbon fuels from biomass. The objectives of BETO's Demonstration and Deployment (D&D) team are to demonstrate novel technologies for various conversion pathways at progressively larger scales and to validate the associated cost and performance data. The D&D team helps span the gap from research and development to commercial production, reducing technology and investment risk. In pursuit of these objectives, BETO provides cost-shared funding for the construction of biorefineries at the pilot, demonstration, and pioneer scales.

DOE currently provides cost-shared support for 12 pilot, 4 demonstration, and 4 pioneer-scale integrated biorefineries. Using a range of feedstocks and conversion technologies, these facilities are pushing biofuels along the development curve toward cost parity with traditional petroleum fuels. Derisking these technologies helps them navigate the treacherous "valley of death" that often prevents promising laboratory technologies from advancing to commercialization. Federal support for these plants and the broader bioeconomy is essential to successfully achieve widespread commercialization of these innovative technologies.

After validating the modeled cost target for cellulosic ethanol in 2012, BETO has been able to prioritize work on drop-in hydrocarbon fuels, and the D&D team has begun to more narrowly focus on the barriers that prevent the commercial deployment of these production technologies. To better understand these barriers and challenges, the D&D team convened a Strategy Workshop on March 12–13, 2014, at Argonne National Laboratory. At the workshop, stakeholders from industry, academia, national laboratories, and government gathered to discuss the issues and potential paths forward to sustainable, cost-competitive fuels from non-food biomass resources.

This report summarizes the workshop results, which will provide useful input as BETO identifies, evaluates, and prioritizes the demonstration and deployment efforts needed to achieve affordable, scalable, and sustainable production of hydrocarbon biofuels. This report is not designed to comprehensively cover all of the relevant issues but merely to summarize the innovative ideas generated by those in attendance at the workshop. These results are presented within four technical areas:

- **Feedstocks:** Commercial-scale feedstock choice, growth, collection, transport, and processing
- **Products:** Conversion pathways ending in products other than fuels (technology agnostic)

- **Fuels via Biochemical Conversion:** Enzymatic conversion pathways to fuels (most likely in a bioreactor)
- **Fuels via Thermochemical Conversion:** Inorganic catalytic conversion pathway to fuels *(discussed in parallel by two separate breakout groups).*

1.1 Non-Technical Barriers

Aside from technical challenges, the accelerated commercialization of biomass and biofuels faces significant non-technical barriers. These barriers fit into three main categories: regulation, finance, and education. While these issues fall outside the traditional scope of BETO activities, they constitute significant barriers and should be addressed in tandem with the technical issues.

Regulatory

Regulatory barriers can actively hinder the deployment of biofuels and bioproducts. Petroleum-derived fuels continue to dominate the supply chain, even with the Renewable Fuels Standard (RFS) driving the creation of a more sustainable fuel supply. Petroleum-based fuels involve a fairly predictable and established set of refining operations, processes, and systems, and an effective structure has evolved to regulate this mature industry. Biofuels production, in contrast, involves significantly more varied feedstocks, suppliers, pathways, and sustainability issues. Effective regulation of this emerging industry must necessarily reflect the dynamic and innovative nature of biofuels processing—or it will impede progress. Improved rules implementation and approval pathways focused on application-specific validation could expedite market entry of novel transportation biofuels.

Regulations need to interpret sustainability more broadly to include the use of traditional waste streams as feedstocks. Biorefineries today can receive Renewable Identification Number (RIN) credits (or the like) for corn stover but not for diverting organic waste from landfills, including municipal solid waste. Simple regulatory changes are needed to reflect the large number of feedstocks and pathways that biorefineries may employ to sustainably produce a diverse slate of renewable products that support national goals for energy and the environment. Given the large capital and operating expenses incurred in running an integrated biorefinery, the legislative environment also needs to provide better policy direction and investor certainty. A more responsive regulatory environment and clear prioritization of fuels or pathways would better inform industry decisions and expedite commercialization.

The wider marketplace needs to be better educated about biofuels. Genetically modified organisms represent novel and promising feedstocks, which could be tailored for use in conversion pathways. This approach could potentially raise yields and lower costs, yet the costly approval process imposed by current regulations constrains deployment.

Biofuels receive significant pushback from the petroleum industry. Although biofuels are direct competitors to this long-established market, many producers target refinery integration as a mutually beneficial strategy. While biofuels regulation must recognize existing biases, they must also avoid worsening relationships between these two industries, which could discourage potential collaborations and ultimately delay deployment of biofuels.

Economic

Financial issues continue to impede the construction of large demonstration and pioneer-scale biorefineries. These plants require large capital investments and are not expected to break even for years, even with favorable economic conditions. Loan guarantees and tax incentives are helpful, but some impose onerous requirements, such as high cost share or 30% mandated contingency funds. Often, these mechanisms result in funding pathways that are inappropriate for start-ups or smaller companies.

As in the petrochemicals industry, large plant size appears to be a requisite for profitability, so the scale of plant operations continues to dominate plant economics. Nonetheless, innovative thinking could yield smaller, modular systems that could be produced and deployed in larger numbers to achieve economies of scale while exploiting geographically dispersed biomass. Potentially, such systems would require significantly smaller total investment and may avoid many of the difficulties inherent in financing larger, more expensive projects.

Many financial institutions need to balance the large capital expenses and long payback periods of biorefineries with certainty about future production levels and market demand. The inability of many biorefineries to arrange long-term contracts for either supply or offtake increases the financial risk and may discourage decision makers in financial institutions from providing financing for biorefineries. Biorefineries need a buyer like the U.S. military, which has both a long-term interest in the space and the long-term vision to commercialize biofuels.

Governmental support has been critical in helping the domestic bioindustry reach its current state, and high levels of federal funding will continue to drive this technology toward commercial self-sustainability. Additional economic barriers include high feedstock costs and the need to create market pull.

Education

Educational needs fall into two main categories: educating the general public and developing the STEM workforce. The American public values sustainability, and the biofuels industry needs to align its messaging with this priority value. A strong and effective public education campaign can help to create market pull, educate lawmakers, and ultimately drive the industry forward. Educating the consumer accelerates development in this industry and helps bring affordable, sustainable biofuels to commercialization.

The lack of an available STEM workforce presents a barrier to the construction of new biorefineries. While qualified individuals exist, manufacturers value their skills highly and few are unemployed. The siting of plants close to biomass sources, consumers, and qualified plant operators remains a non-trivial issue, especially while shale continues to bolster demand by the traditional chemicals sector.

2. Feedstocks

2.1 Overview

Commercial-scale biorefineries face numerous technical challenges in consistently getting the right quantity and quality of affordable biomass feedstocks to the plant gate. While some feedstocks can be handled by commercial logistics systems (e.g., white wood pellets or MSW), new and emerging crops under consideration as future feedstocks may pose logistical challenges. Successful commercialization of integrated biorefineries will require that feedstocks be developed in tandem with the logistics for handling them.

The lack of feedstock specifications and wide variability in the characteristics of biomass feedstock are among the most significant feedstock-related challenges. Producers need feedstock specifications to better understand biorefinery requirements and the characteristics of feedstocks that are important for processing. Biorefineries need an ample supply of feedstocks that are of consistent quality—every day of the year. Lack of blending capabilities and difficulties in processing multiple feedstocks intensify the challenges presented by feedstock variability.

Another major barrier is feedstock cost, which is exacerbated by the high cost of transporting bulky, but not energy dense biomass. The lack of an agreed-upon definition for sustainability presents yet another barrier for both producers and refiners. Further down the line, lignin is seen as a feedstock with high potential, but the lack of cost-effective conversion technologies for lignin restricts its use and limits resource efficiency.

Development and demonstration of advanced logistics systems will help to address the cost, availability, reliability, and consistency of feedstock supply. A two-pronged approach is proposed: (1) identify and develop innovative approaches to improve feedstock supply systems and (2) demonstrate and optimize commercial-ready equipment in functioning logistics systems. Integrated feedstock supply systems could be demonstrated in existing biomass markets, such as animal feed and heat/power markets—even if these markets are seen as competitors for biomass feedstocks in the near term. This approach will help to make feedstock systems deployment-ready when biorefineries need them.

Data needs related to feedstock quality vary by feedstock and by process. Feedstock characteristics needing quantification may include ash, moisture, carbohydrates, metals, ammonia, pH, and lignin. High priority should be placed on developing fast, simple, mobile, and inexpensive devices to measure feedstock quality. Successful development of these devices will require collaboration among suppliers, buyers, and OEMs.

Solutions to feedstock technologies call for enhanced collaboration among all stakeholders. The various government agencies that work on feedstock issues—such as BETO, the DOE Office of Science, U.S. Department of Agriculture (USDA), and Environmental Protection Agency (EPA)—could actively share information on their projects, objectives, barriers, and solutions. A “clearinghouse” could provide information on ongoing projects and provide information on where to find experts or specialized expertise. An interagency working group could coordinate federally funded work on feedstock issues.

One barrier impeding bioindustry development is the lack of widely available, reliable, comprehensive, and transparent information about the costs and conversion efficiencies of various technologies and feedstocks. When asked, everyone’s technology is “close to commercial.” A public reference for benchmarking and evaluating the various technologies and conversion pathways could help all stakeholders make better decisions. To create this reference, a team of subject matter experts, industry stakeholders, government representatives, and academics needs to objectively identify the relevant models of feedstock supply chains and processes. A single web portal could share this information and the assumptions used in the analysis. A public reference of this type will help to identify the top R&D challenges and opportunities and encourage investment in the most promising technologies.

2.2 Technical Barriers

Feedstock-related technical barriers to the deployment of commercial biorefineries are ranked by priority in Table 2.1. Non-technical barriers (policy and financing) are addressed above in Section 1.1. The highest-priority technical barriers are related to the diverse physical qualities and quantities of feedstocks and the equipment and systems to handle them.

Table 2.1: Feedstock-Related Technical Barriers to Wider Deployment of Commercial Biorefineries

Physical Feedstock Quantities	
High Priority	• Lack of specifications ●●●●●●●●●●
Medium Priority	• Consistent process-specific quality over 365 days. Performance of mixtures. ●●●●● • Biomass variability at plant gate with respect to quality and amount ●●●● • Blending capability for consistency, material handling, cost control, and sourcing of feedstock ●●●●
Low Priority	• Dry matter loss ●●
Equipment and Systems	
High Priority	• Lignin: Lack of cost-effective conversion technology to obtain “lean/cleaner” lignin for upgrading this feedstock to higher-value chemicals ●●●●●●●●●
Medium Priority	• Cost: Transportation of low-value feedstock; preprocesses at local supply point ●●●●●
Low Priority	• Transporting biomass – locate smaller refineries closer to fields ●●● • Shipping density ●●● • Processes/technologies to actively/cost effectively manage variability and uncertainty ●●●
Market Information	
High Priority	• Cost of feedstock ●●●●●●●
Medium Priority	• Uncertainty of biomass production each year ●●●●
Low Priority	• Lack of common contract terms for new feedstocks ●
Analysis	
Low Priority	• Limited funding for new RD&D on improving biomass feedstock logistics limits the rate of proven advancements ●●● • Need reliable data on which feedstocks are closest to commercialization ●● • Lack of long term breeding support for many biomass crops ●● • Life cycle analysis is complex and contentious ●● • Verifiable chain of custody technologies, procedure, and methodology ●●

● = 1 priority vote

2.3 Priorities for Advancement Activities

Advancement activities to address key barriers to the demonstration and deployment of drop-in hydrocarbon biofuels fit within four priority activities. These activities are listed below and described in more detail in Appendix D, Tables D-1.1 through D-1.4.

RD&D Priorities

- **Develop and demonstrate advanced logistics systems for biomass feedstocks:** Accelerate the development of feedstock supply systems (i.e., test them in cattle feed and biopower/combined heat and power [CHP] markets) to achieve cost, availability/reliability, and consistency (quality) targets in parallel with the development of biorefineries, so that these systems will be ready for deployment when needed by the biorefineries. *12 votes*
- **Develop fast, simple, and inexpensive devices/measures to accurately determine feedstock quality:** Develop instruments that can adapt to particular operations and are fast, reliable, mobile, low in cost, widely available, attachable to farm equipment, easy to use, and able to wirelessly transmit results/readings. *10 votes*

Analysis and Outreach Priorities

- **Publish estimated costs and conversion efficiencies by feedstock and conversion process each year:** Provide public references for benchmarking, conversion economics, investment decisions, and R&D targets so that private companies can elaborate on them. *6 votes*
- **Engage a broader spectrum of biomass feedstock development stakeholders to accelerate progress:** Develop a more integrated way to engage stakeholders (representing basic research through agronomic development) to facilitate rapid deployment of the feedstock supply chain for biorefinery projects. *5 votes*

3. Products

3.1 Overview

Bioproducts other than fuels can improve the economic viability of biorefineries, regardless of the conversion pathway used. Bioproduct processing technologies that are ready for validation include syngas conversion, Fischer-Tropsch, esterification, reactive distillation, fermentation, pyrolysis, thermo catalysis, and advanced separation analytics. Although some of these technologies may be entering commercial application (some internationally), more demonstration and deployment activities are needed to help these technologies advance to market. In some cases, more testing or validation is needed to prove the benefits of scale up, system integration, operational robustness, and associated lifecycle emissions, such as GHG reduction.

Some of the barriers to successful scale-up of these technologies are non-technical in nature, such as limited workforce and education resources, cost parity with current products, and biomass acquisition costs. Technical solutions could potentially address some of these non-technical barriers (e.g., increasing theoretical yields could drive down costs to establish pricing parity). Major technical barriers include the lack of conversion equipment at the appropriate scale, the lack of distributed production technologies, the amount of energy required for processing (lack of low-energy separation alternatives), the high cost of water separation, downstream logistics, and the need to integrate unit operations for biofuels and biochemicals. Measurement barriers include the lack of metrics for product chemicals and the time and expense involved in testing products and developing these testing procedures.

Several activities to address these barriers closely align with BETO capabilities. A promising strategy is to target the economic production of specific platform chemical intermediates that, collectively, can replace the whole barrel. BETO has historically focused on fuels, but expanding the slate of biorefinery products will help to overcome some significant barriers; even today's chemical industry could not function without co-products. This activity, potentially sponsored by DOE, may involve pairing research technologies with existing pilot plants. Better defining this focus on intermediate products to replace the whole barrel will also help meet deployment targets, assuming the presence of consistent policy to stimulate private investment.

The most technically challenging and expensive aspect of bioprocessing often involves process and water separations technologies. BETO could accelerate progress by supporting the demonstration and deployment of economically and environmentally optimized, integrated separations systems for processing diverse feedstocks into bio-based products. Analyses could evaluate dilute aqueous systems, dilute organic systems, chemical and physical properties of biomaterials, gross separations vs. polishing, and more. Promising separations innovations could be demonstrated at the optimum scale for the technology. BETO's efforts in this area could produce a useful matrix of the separations technologies appropriate for various products or intermediates.

The economics of bioprocessing can improve significantly by "using the whole bale." A significant portion of the feedstock traveling through today's supply chain has a low-value end use; less than the entire bale is currently used to produce fermentable sugars. Further D&D for lignin conversion technologies will add value to the rest of the bale, beyond its heat content. Techno-economic analysis will help to identify barriers. Key needs include a framework and comprehensive report on the technical barriers and economic feasibility of various lignin conversion pathways. Such a publication could specify the contaminant tolerances and other relevant technical details of each conversion process (e.g., pyrolysis, gasification).

Increased awareness and education will assist in establishing broader support for and coordination of efforts to develop the bioproducts platform. Elevated consumer awareness will help to create market pull. A marketing campaign, for example, could expand today's niche demand for environmentally friendly products to a broader consumer market that understands the diverse benefits of bioproducts (e.g., American grown). Improved dialogue between those setting agendas and those acting on agendas could increase government recognition of the value of byproducts. This improved understanding, in turn, could lead to clear RD&D priorities, consistent choices by all market participants, and a robust infrastructure procurement strategy—amounting to a "Green Manhattan Project." Ideally, this effort will create long-term tax incentives and consistent regulatory and permitting practices that favor a clear commercialization pathway for bioproducts.

Feedstock variability and biorefinery flexibility are crucial issues. A bale of corn stover alone can possess widely variable characteristics that are only multiplied by geographic diversity, seasonal changes, and distributed operating locations. Other feedstocks similarly introduce a myriad of potential variations. Well-designed technologies could handle such feedstock variability on the processing end. Such a robust, multi-feedstock process could also alleviate a bad feedstock year for any one bioproduct. The desired outcome to this feedstock variability challenge is a standardized design case for a biomass-to-intermediate process that accommodates widely variable feedstocks and the associated handling and recovery systems to feed material into the standardized design. A necessary first step in this effort is to demonstrate the robust co-feeding capability and techno-economic evaluation of the technology design.

Finally, the capital and operational costs of producing bioproducts will decrease as individual unit processes improve in performance and efficiency. Specific unit operations require value engineering and optimization for the bioenergy industry. To remove bottlenecks in downstream processing, DOE support can help to identify unit operations requiring optimization. As an actionable activity, this group recommends that unit operations be compared to process models (comparing performance and cost-effectiveness of technologies for separation, etc.), to identify candidate operations for further research and development.

3.2 Technical Barriers

Technical barriers to a broader slate of bioproducts from commercial biorefineries are ranked by priority in Table 3.1. Non-technical barriers in the areas of policy and economics are discussed above in Section 1.1. The highest-priority technical barriers for bioproducts focus on economics, educational limitations, and product quality/ specifications.

Table 3.1: Technical Barriers to the Demonstration and Deployment of a Broad Slate of Biorefinery Products

Economics	
High Priority	• Economics ●●●●●●●●●●●●●
Medium Priority	• Biomass acquisition cost ●●●●● • Commodity fuel markets vs. high-value chemical opportunities ●●●●● • Lengthy time to commercialization ●●●●
Low Priority	• Missing integrated supply of value ●●●
Educational Limitations	
High Priority	• Lack of BETO/EERE metrics focused on product chemicals (government education component) ●●●●●●●●● • Government and public perception ●●●●●●●●
Low Priority	• Education and resources around picking the "correct" fuel ●● • Lack of training and STEM education ●

Product Quality/ Specifications	
High Priority	• Expense and time required for product testing/qualifications (need innovation and standard revision) ●●●●●●●●●●●
Low Priority	• Setting and meeting product quality specifications, (e.g., jet fuel) ●
Logistics	
Medium Priority	• Distribution supply chain logistics downstream ●●●●● • Feedstock logistics ●●●●
Low Priority	• Lack of organized chain of commerce (field-to-wheels players) ●●●
Scale of Technology	
Medium Priority	• Paradigm shift from centralized to distributed production ●●●●●
Low Priority	• Availability of conversion equipment at "biomass scale" [modularity] ●●●
Process Limitations	
Medium Priority	• Limitations in downstream processing (e.g., water and product separation, fermentation) technologies and cost ●●●●●● • High energy input requirements for energy output, comparatively ●●●●●● • Cost-competitive reduced energy separations technologies ●●●●●
Low Priority	• Lack of integration between processes for biofuels and biochemicals hindering cost effectiveness ●

● = 1 priority vote

3.3 Priorities for Advancement Activities

Six advancement activities could address priority barriers to the demonstration and deployment of bioproducts produced in tandem with drop-in hydrocarbon biofuels. These activities are introduced below and further described in Appendix D, Tables D-2.1 through D-2.6.

RD&D Priorities

- **Demonstrate separations technologies at pilot and demonstration scales:** Demonstrate and deploy economically and environmentally optimized, integrated separations systems for processing a variety of feedstocks into bio-based products. *10 votes*

- **Design robust processes to transform diverse biomass resources into homogeneous intermediates, enabling component separation for further processing:** Minimize raw material costs for a wide range of locations (opportunistic acquisition); enhance ability to operate year round; lower raw material storage and handling costs; and gain ability to tailor separation ratios to maximize plant revenues. *7 votes*

- **Conduct value engineering on specific unit operations:** Decrease capital and operational costs by increasing the performance capability and efficiency of individual units; develop standard performance metrics and accompanying analytical techniques for each unit operation. *8 votes*
- **Add value to the rest of a bale, specifically lignin conversion:** Enable economical production of high-value, lignin-based products to improve the profitability of biorefineries that can sell low-cost alternative fuels (lower CAPEX). *9 votes*

Analysis and Outreach Priorities

- **Clarify an infrastructure procurement strategy for biorefineries (e.g., a Green Manhattan Project Effort):** Provide a combination of tax incentives and regulatory and permitting practices that favor this "Green Manhattan Project" and prioritize consistent choices by all market participants without forcing them. *8 votes*
- **Target specific platform chemical intermediates that could collectively substitute for the whole barrel:** Sharpen the RD&D focus to help meet deployment targets for replacing the whole barrel. Consistent policy on this will stimulate private investment. *17 votes*

4. Fuels via Biochemical Conversion

4.1 Overview

Barriers affecting biochemical conversion begin with the delivery of feedstock to the biorefinery and continue through shipping of the blend stock or drop-in fuel. A range of relevant technologies, many of which are close to commercialization, are now ready for technology validation. These include the catalytic conversion of lignin to fuel and bioreactors with immobilized bacteria and enzymes.

Issues impeding the commercialization of biochemical conversion processes for hydrocarbon fuels include investor confidence and market pull, technology robustness, feedstock flexibility, co-products, and the availability of technical information. Funding for commercialization is hard to obtain if investors cannot trust market assessments. Investors will be more willing to back a technology that has received a realistic and independent evaluation. The robustness of a process is also an issue—commercial deployment depends on the extent to which organisms can survive a range of operating conditions. Conversion processes will need to accommodate a range of feedstocks and wide variations in feedstock quality. In addition, the lack of co-products may threaten the economic viability of a biorefinery. Broader advancement of the technology is inhibited by both siloed technology development and inadequate information sharing.

To secure a commercial pathway for hydrocarbon fuels produced via biochemical conversion, BETO could underwrite the technical and economic validation of new technologies. This activity will bolster investor confidence by providing an "insurance fund" to address market acceptance. Credible metrics and evaluations are essential. Investors need concrete and credible information to make investment decisions. Overly optimistic evaluations have eroded investor confidence and reduced the credibility of information about a technology. BETO could help establish a new standard that provides a realistic view of the current state of technology and its future prospects (subject to broad industry review) and make sure that its reports reflect real-world yields and costs.

To address the lack of co-products, a single plant could house a small scale production demonstration facility showcasing output flexibility between fuel and co-products manufacturing. BETO could support the development of multiple-product processes on a scalable platform. This approach could bolster investor confidence by demonstrating an accelerated commercial pathway and providing product samples that are cost competitive in the market.

Finally, to break down the silos that hinder development and advancement, BETO could bring interested parties together. Specifically, BETO could facilitate partnering between lab developers and engineering firms to accelerate commercialization. BETO could also help create a development campus that co-locates developers of multiple technologies and serves as a cross-platform incubator. This activity could leverage common infrastructure and reduce costs.

4.2 Technical Barriers

A priority ranking of the technical barriers to increased commercial biochemical conversion of biomass to fuels is presented in Table 4.1. Non-technical barriers in the areas of policy and economics are discussed above in Section 1.1. The highest-priority technical barriers to biochemical conversion technologies focus on robustness, investor confidence, and market pull.

Table 4.1: Technical Barriers to Wider Deployment of Biochemical Conversion Technologies for Advanced Biofuels

Robustness	
High Priority	• Industrial/robustness of organisms and enzymes used in bioreactors ●●●●●●●
Medium Priority	• Process robustness ●●●●●●
Low Priority	• Process flexibility to handle feedstocks of diverse chemical composition/structure ●● • Hydrogenation product creation ●● • "Clean" sugars → cost of cleanup ● • Lack of stable feedstock yield and the supporting strategic research plan ● • Lack of reliable feedstocks, interruptions in scaling ●
Investor Confidence and Market Pull	
High Priority	• Lack of critical, realistic evaluation of technology processes. Impact: makes number of granters more cautious/skeptical ●●●●●●●●●●
Medium Priority	• Confidence in technology → derisking → investment interest ●●●● • Challenge of finding partners at all stages of supply chain ●●● • Biomass sugar as new commodity product ●●●●
Low Priority	• Lack of firm contracts for products ●
Regulatory/Standards and Consistency Specifications	
Medium Priority	• Water ●●●●●●
Low Priority	• Volume requirements for certification ●
Lack of Co-products	
Medium Priority	• Co-products should be added into the biofuel process economics ●●●● • Lignin to fuels ●●●●
Low Priority	• Lack of complete biomass usage, (e.g., lignin waste usage) ●● • Lack of co-products with cellulosics ●
Carbon and Energy Efficiency	
Medium Priority	• Lack of carbon and energy efficiency cost ●●●●●●
Discrete vs. Continuous	
Low Priority	• Take the technology to the biomass. Impact: new market ●● • Feasible apparatus for distributed applications of process—small scale at many sites → progression blocked ●●
Silos	
Medium Priority	• Silos → resource limitation. Need to partner and collaborate smartly ●●●●●●

● = 1 priority vote

4.3 Priorities for Advancement Activities

A broad discussion of the barriers to biochemical conversion technologies for drop-in hydrocarbon biofuels led to the identification of six priority activities. These activities are described below and in more detail in Appendix D, Tables D-3.1 through D-3.6.

RD&D Priorities

- **Create a cross-platform development incubator:** Set up an incubator that facilitates partnerships and leverages existing infrastructure. *4 votes*
- **Build on the existing ethanol infrastructure:** Establish a commodity sugar platform to reduce risk for new biofuel production; leverage existing know-how to create new market opportunities for ethanol (corn ethanol industry); use CO_2 and lignin to produce new fuels. *5 votes*
- **Co-produce multiple bioproducts to enhance economic stability:** Provide DOE support for technology development of co-products along with biofuel production on a "scalable" platform in order to demonstrate economic viability; secure investor(s) by demonstrating accelerated commercial pathway and providing product samples that show cost competitiveness in the market. *5 votes*
- **Underwrite activities to bolster investor confidence and market pull; validate the technical and economic performance of these technologies with a focus on the end customer:** Create a model for successfully deploying technology in the market. *10 votes*

Analysis and Outreach Priorities

- **Establish a new standard to guide the critical review of technical and economic metrics:** DOE/BETO needs to set a standard for critical review of the current state of technology and abandon "nth Plant" economics. This will help to allocate resources where they can make the greatest economic impact. DOE could fund an EPC (engineering, procurement, and construction) consortium to evaluate processes. *4 votes*
- **Develop metrics to indicate the technological robustness of organisms, enzymes, and processes:** End point metrics and validation protocols for robustness. *4 votes*

5. Fuels via Thermochemical Conversion: Group A

5.1 Overview

Many of the common barriers to the development and deployment of thermochemical conversion technologies could be addressed by the formation of large, interdisciplinary teams or cooperative partnerships that possess complementary expertise in all facets of the production pathway, from biomass acquisition to conversion into fuel and distribution by market participants. DOE and other government agencies have and will continue to play a key role in bringing these multidisciplinary groups together to apply their distinct core competencies and ultimately commercialize hydrocarbon biofuels. Collaborative activities that address key technical challenges could help achieve many shared goals in this field.

Beyond the known regulatory and financing issues, major technical barriers to the commercial deployment of drop-in hydrocarbon biofuels run the gamut from feedstock quality verification through technical certification of the fuel products. These technical barriers include short catalyst lifetimes, poor catalyst performance in syngas clean up and conversion, catalyst tolerance of impurities, failure of modeling software, need for large economies of scale (from a feedstock and capital perspective), feedstock handling, sourcing feedstocks of sufficient quality, fuel market acceptance criteria, and a general lack of operational knowledge of unit operations (see Table 5-1).

A cross-cutting knowledge database could be developed and would prove valuable in addressing many of these D&D issues. The goal of this database would be to accelerate development by leveraging lessons learned and knowledge gained through past projects. Even failures can be useful and instructive. Moving forward, researchers will face many potential pathways; eliminating those that are dead ends could expedite progress. This database would collect relevant experiences, allowing experts and the broader private sector to contribute their knowledge and insight. It would contain information about past ideas, projects, and possibly even the people responsible—helping to form the aforementioned partnerships key to D&D efforts. Although DOE and other government agencies have a long history of operating in this space, establishing database protocols is not a simple task. A complex balance will need to be struck between the open flow of information and the protection of business-sensitive data. Ultimately, this database could lead to widespread deployment and commercial growth. While admittedly difficult to implement, a smartly run knowledge database could underlie and support all D&D efforts.

Multi-disciplinary teams are needed specifically to address some of the key barriers surrounding catalysts. These teams would consist of the catalyst inventors, process engineers, and the companies that can mass produce the catalysts. Eventually, these entities are brought together on a project, but if BETO encourages their close interaction from the outset, many preventable issues could be avoided. In the future, after a number of successful collaborations, BETO would be able to readily identify potential partners to help the technology inventors advance their technology to commercial scale.

An integrated pilot-scale facility can be developed to validate technical data on catalysts for use in modeling larger scales and to enable construction of these larger plants. This data is critical to modeling and road mapping efforts. The development of a standardized pilot-scale testing facility would inform technologists, policy makers, and financiers about the technology. Such a facility could potentially lead to toll manufacturing as a commercialization method. This method obviates the vertical integration of biorefineries, instead allowing them to collect a flat fee per unit of product produced. Logistics and marketing would be handled by companies with expertise in the space, allowing biorefinery operators to focus on their core competency.

More broadly, a versatile user facility could be developed to validate scale-up activities. Regional facilities could leverage the purchase of both common and regional feedstock specific equipment. They would help subsidize development efforts and attract significant operational expertise. These pilot plant user facilities would validate technology for the developer, financiers, and partners, ultimately reducing risk and increasing the likelihood of future successful commercialization efforts. This demonstration-scale partnership would have a plug-and-play aspect, whereby the technology developer would only need to provide equipment based on their technology, enabling a streamlined start up process.

5.2 Technical Barriers

Technical barriers to the increased thermochemical conversion of biomass to fuels in commercial biorefineries are ranked by priority in Table 5.1. Non-technical barriers in the areas of policy and economics are discussed above in Section 1.1. The highest-priority technical barriers are concerned with catalysts, conversion issues, and feedstock quality.

Table 5.1: Technical Barriers to Wide Deployment of Thermochemical Conversion Technologies for Advanced Biofuels

Catalyst and Conversion Issues	
High Priority	• Catalyst lifetime ●●●●●●●●
Medium Priority	• Syngas clean up and quality across different feedstocks ●●●● • Catalyst tolerance ●●● • Ability to co-process high oxygen-content feed at high ratios with hydrocarbon feed without fouling or phase separation ●●● • Higher carbon efficiency and yield ●●●● • Catalyst cost ●●●
Low Priority	• Optimized biomass particle size for maximum yield and minimum energy loss ●● • Catalyst recovery – Recovery of a liquid-phase catalyst ●
Feedstock Quality	
High Priority	• Biomass feeder scale-up challenges [capacity of feeders] ●●●●●●●
Equipment Issues	
Medium Priority	• Verify modeling of reactors to build better reactors ●●●●
Low Priority	• Bio-oil (solvents) vs. materials (metals and polymers) compatibility/life ● • Data does not scale. Transferring scale (i.e., transfer between lab and pilot, and finding transfer function) ●
Feedstock Quantity	
Medium Priority	• Economic viability: drive toward smaller scale (modular) ●●●●●
Product Quality/Requirements	
Medium Priority	• Technical certification of the fuel ●●●●● • Requirements for production volumes for certification ●●● • Bio-oil quality requirements/specs for refining integration ●●●

Infrastructure	
Medium Priority	• H_2 demand/utilization ●●●
Low Priority	• Supply chain development ●● • Refinery integration – co-processing and distribution. Value chain integration ●● • Biomass densification and upgrading – pretreatment ●
Waste Handling	
Low Priority	• Solid waste from pyrolysis and gasification – usage, reusability, disposal ●● • Pyrolysis wastewater recycle reuse ●● • Pyrolysis waste water characterization and treatment ●
Miscellaneous	
Low Priority	• Improved speed and reliability of trace contaminant analysis at TRL 5 and up ●● • Flexibility in product slate: fuels versus biochemicals (overlapping barrier) ● • Feasibility of funding transition beyond lab technology readiness level 4/5 ●

● = 1 priority vote

5.3 Priorities for Advancement Activities

Advancement activities to address the key barriers to thermochemical processing of biomass into drop-in hydrocarbon biofuels fall within four priority topic areas. These topics are described below and in more detail in Appendix D, Tables D-4.1 through D-4.4.

RD&D Priorities

- **Conduct preliminary pilot-scale testing to measure the performance of catalysts:** Technically feasible and economically viable (attractive) processes recommended for scale-up to demonstration. Catalyst performance is documented and validated for commercial catalyst production throughout the path to toll manufacturing. If integrated, pilot-scale testing is successful, it serves as a stage gate to future (unsolicited) funding for demonstrations. *8 votes*
- **Encourage and support collaborative efforts to scale catalyst production and piloting:** New catalysts will be scaled up by manufacturers and tested at pilot scale for yield and lifetime. *13 votes*
- **Use the convening power of DOE to form technology development partnerships, further develop existing pilot facilities, and expand them into demonstration-scale user facilities:** Identify pilot plant user group facilities and coordinate research activities, reducing the risk for capital investors. Establish demonstration-scale user facilities, possibly by region or biomass type, that would leverage commonly needed equipment, such as water treatment or feed system operations. This should be done with private technology under development at reasonable cost. *18 votes*

Analysis and Outreach Priorities

- **Develop a database of thermochemical technologies (by feedstock, process, and product) to enable assembly of field and patent data from federally funded projects:** Data gathered will support sharing lessons learned within the thermochemical working group to prevent "reinventing the wheel." This will benefit biorefinery deployment by accelerating the discovery of compatible partners and technologies. *10 votes*

6. Fuels via Thermochemical Conversion: Group B

6.1 Overview

Thermochemical conversion technologies can be categorized according to the fundamental fuel processing routes: pyrolysis, gasification, and other. The latter category includes such routes as hybrid thermochemical and biochemical processing, conversion of woody biomass to carbon, and conversion of ethanol to gasoline. Priority barriers to the increased deployment of thermochemical conversion technologies for biofuels include gas clean-up issues; the reliability and interoperability of unit operations; feedstock handling issues; catalyst development; economies of scale; intermediate handling; the unavailability of inexpensive renewable hydrogen (H_2), and federal business processes.

Exploration of these barriers reveals promising opportunities to facilitate advancements. Potential activities include efforts to improve or address (1) plant integration; (2) catalyst [development] issues; (3) feedstocks; (4) analytics to support scale-up demonstrations; (5) federal business processes; and (6) partnering (including foreign entities).

BETO could expedite progress by expanding its support for the integration of thermochemical biomass conversion technologies at various scales. Operating integrated thermochemical technologies for an appropriate number of hours will generate the data and information needed to reduce technical and investment risk and foster increased support from the financial community.

Accelerating the development of catalysts will require an increase in catalyst manufacturing and demonstration activities at scale. Pilot- and commercial-scale catalyst manufacturing efforts are needed to move catalyst technologies from the lab bench to market. Support is also needed to test catalyst performance over the long term in realistic environments and to optimize catalysts, manufacturing processes and operations, and catalyst use.

Feedstock concerns focus on the lack of flexible processing systems and the inadequacy of current handling systems for loading biomass into thermochemical reactors, especially at the pilot scale or larger. All projects need systems that can handle biomass variations (e.g., in terms of shape/aspect ratio, grindability, density, contaminants, abrasiveness, moisture content, and ash [elemental components and volume]), yet no such systems/equipment are available. The federal government has an appropriate role in characterizing (as a baseline) existing feedstock systems (preprocessing, feeder) and in providing focused funding for improving system performance in this area. In addition, simulations and system studies are needed to identify the most efficient ways to use natural gas to supplement biomass or to improve conversion chemistry and/or heat integration. Other important needs are to characterize the materials of construction in existing processing plants (up to the reactor) and to collect/maintain information on problems or lessons learned with feedstock handling systems.

To assist new scale-up and demonstration efforts, improved system analytics could address the current inconsistencies in thermochemical processing technologies. In particular, the development of standards for techno-economic and process modeling could yield significant benefits for funded projects—avoiding the inconsistent results obtained when a variety of assumptions and methodologies are used. Examples from other DOE programs include Fuel Cell Technologies' H2A model and Fossil Energy's bituminous coal model.

The business processes of federal agencies (DOE, USDA, and EPA) can constitute a serious non-technical barrier. For example, the loan guarantee program is difficult to navigate, some projects present foreign investment strategies that do not fit federal guidelines, and standard industrial financing practices are often inconsistent with federal requirements. Improved federal business processes and best practices could help federal agencies keep pace with fast-moving changes in the business world and stay on the cutting edge of technology innovation. In general, federal business processes should be streamlined as necessary or appropriate to align with the needs of the financial investment community, global business, and industry.

Success in the D&D Program requires the forging of strong partnerships and the development of large, interrelated teams with expertise in all facets of the biomass-to-biofuel supply chain. In evaluating proposals, DOE should give positive weighting to entities that strengthen competencies by forming partnerships, including partnerships with foreign firms—if that is the most effective way to acquire the best practices and/or financial support needed to lower project risks. Agencies could expedite D&D progress by revising application processes, exercising due diligence to identify gaps in applicant competencies, providing a global "dating service" for qualifying partners, and developing a library/clearinghouse to avoid redundancies in funded work.

6.2 Technical Barriers

Technical barriers to the increased thermochemical conversion of biomass to fuels in commercial biorefineries are ranked by priority in Table 6.1. Non-technical barriers in the areas of policy and economics are discussed above in Section 1.1. The highest-priority technical barriers to thermochemical conversion technologies are concerned with catalyst development, feedstock handling, the reliability and operability of unit operations, and gas clean-up.

Table 6.1: Technical Barriers to Wide Deployment of Thermochemical Conversion Technologies for Advanced Biofuels

Reliability and Operability of Unit Operations	
High Priority	• Reliability or availability of operating unit ●●●●●●●●●●●●●●●
Medium Priority	• Plant integration ●●●●●
Gas Clean-Up	
High Priority	• Ultra-hot syngas filtration ●●●●●●●●●
Medium Priority	• Tar handling ●●●●●●● • Gasification – Syngas cleanup for downstream catalytic processes ●●●●●●
Catalyst Development	
High Priority	• Catalyst robustness and stability: longevity cap ex and p ex ●●●●●●●●●●●
Feedstock Handling	
High Priority	• Feedstock handling system into gasifier/pyrolyzer ●●●●●●●●●●●●●●●
Intermediate Handling	
Medium Priority	• Stability-storage and corrosivity—material of construction compatible with HC's phase separation ●●●●●●●

Economies of Scale	
Medium Priority	• Economics of scale ●●●●●●●●
Availability of Cheap H_2 (Renewable)	
Medium Priority	• Cheap H_2 for onsite upgrade ●●●●●●
Miscellaneous	
Low Priority	• Feedstock flexibility ● • Ash considerations with catalytic processing ●● • Feedstock aggregation ● • P/G cost effective delivered biomass availability ● • Standardized, reviewed, third party techno-economic analysis-across platform ●● • Concerns about complications of woody feedstocks/feedstock neutrality debate ● • Gasification; depends on type of gasifier, ash or slag variability, fusion temperature ● • Syngas to "whole barrel" drop-in product slate at reasonable cost ● • Understanding of co-processing of renewable and fossil intermediates ●● • Water cleanup carbons contaminant removal ●●● • Gasification feedstock quality for consistent handling ●●●

● = 1 priority vote

6.3 Priorities for Advancement Activities

A broad discussion of advancement activities needed to address barriers to the thermochemical conversion of biomass into drop-in hydrocarbon fuels resulted in five priority topic areas. These topics are described below and in more detail in Appendix D, Tables D-5.1 through D-5.5.

RD&D Priorities

- **Develop more versatile feedstock handling systems at pilot scale and larger:** Strategies to ensure that the plant can operate at capacity, regardless of perturbances in the biomass (supply or physical/chemical characteristics). These strategies should consider new and better hardware, systems configuration, feedstock preprocessing, and/or procurement of better feedstock (including natural gas and coal as supplemental feeds). *8 votes*
- **Provide facility or facilities for demonstrating catalyst manufacturing processes and evaluating catalyst performance at scale:** Validation of demonstration-scale performance (yield, selectivity, and lifetime) allowing/enabling financing of commercial plant. *8 votes*
- **Establish plant integration facility for users to demonstrate acceptable plant uptime, product quality and yield, and operating cost:** Lower the risk of integrated plant operation so that investor funding becomes available for commercial deployment; investor funding is critical for initial deployment of multiple plants prior to large-scale commercialization. *14 votes*

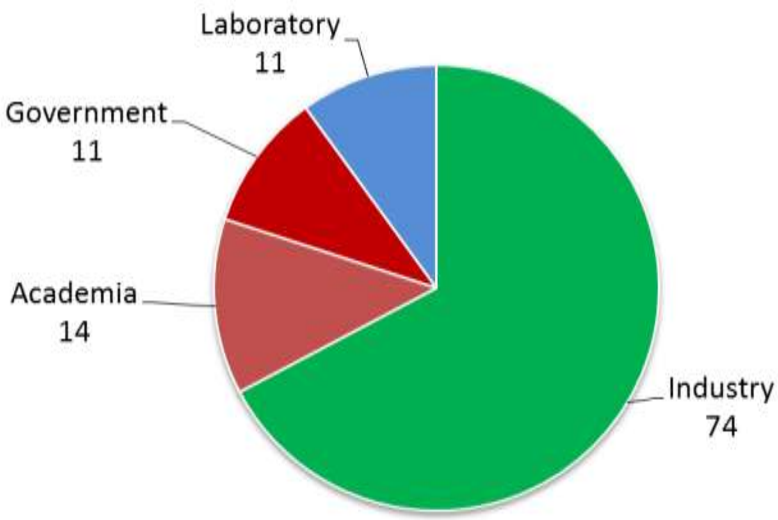
Analysis and Outreach Priorities

- **Establish best practices in partnering or gap filling to bolster experience, expertise, finances, etc. (including foreign entities):** In evaluations for funding, DOE should give positive weighting to entities that source needed competencies from others by partnering, including outside the United States, if that is where best practices and/or financial support is most available; objective is to de-risk the development. *5 votes*

- **Standardize analytics for techno-economic and process modeling:** Better and consistent analytics will lower risks—both technical and economic—for project deployment; analytics would include standardized and consistent techno-economic analysis as well as process simulation and design. *5 votes*

Appendix A: Attendee List

Breakdown by Affiliation: 110 Participants



Attendee List

First Name	Last Name	Affiliation
Zia	Abdullah	Battelle Memorial Institute
John	Aikens	Proterro
Masood	Akhtar	Bioenergy Deployment Consortium
Thomas	Amidon	SUNY-College of Environmental Science and Forestry
Amar	Anumakonda	UOP LLC, A Honeywell International Company
Rahul	Basu	DSM Bio-based Products & Services
Michael	Bernstein*	BCS, Incorporated
Wes	Bolsen	Cool Planet
Charles	Bowman	BCLF Corporation
Richard	Brotzman	Argonne National Laboratory
Craig	Brown	Catchlight Energy LLC
Robert	Brown	Iowa State University
Sabine	Brueske*	Energetics Incorporated
Bruce	Bryan	Gas Technology Institute
Marie	Burkland	BP
Vann	Bush	Gas Technology Institute
Ronald	Cascone	Nexant, Inc.
Mike	Castle	Strategic Solutions, LLC
Kevin	Comer	Antares Group Inc.

Anthony	Crooks+	U.S. Department of Agriculture, Rural Development
Dan	Cummings	INEOS Bio
David	Dayton	RTI International
Dan	Derr	Logos Technologies
Richard	Doctor	E3Tec Services, LLC
Chris	Doherty	TRI, Inc.
Glenn	Doyle	U.S. Department of Energy, BETO
Jennifer	Dunn	Argonne National Laboratory
Jeffrey	Elam	Argonne National Laboratory
Christian	Escher	Husky Energy
Sidney	Firstman	ReGen Technology
Aaron	Fisher*	Energetics Incorporated
Gary	Folkert	Cargill
Jeff	Fornero	Glucan Biorenewables
Angela	Foster-Rice+	United Airlines
Anthe	George	Sandia National Laboratories
Josh	Gesick	NREL
Paul	Gilna	Oak Ridge National Laboratory
David	Glass	Joule Unlimited Technologies, Inc.
Paul	Grabowski	U.S. Department of Energy, BETO
Kevin	Gray+	BetaRenewables
William	Gruber	United Financial of Illinois, Inc.
Susan	Hager	Myriant Corporation
Fred	Hansen*	Energetics Incorporated
Donald	Hanson	Argonne National Laboratory
Alice	Havill	LanzaTech Inc
Paul	Henkel	DH Consulting
Jenny	Herzfeld*	Energetics Incorporated
Richard	Hess	Idaho National Laboratory
Stephen	Hockett	U.S. Department of Energy, BETO
Jennifer	Holmgren+	LanzaTech Inc
John	Howard III	Coronal LLC
George	Huff	BP
Lonnie	Ingram	University of Florida
Douglas	Jack	Sundrop Fuels Inc.
Jeremy	Javers	ICM, Inc.
Edward	Kalebich	Sustainable Solutions 4E and QEST
Lisa	Kamke	Virent, Inc.
Kef	Kasdin	Proterro, Inc.
Stephen	Kelley	IBSS – NCSU
George	Kervitsky*	BCS, Incorporated
Jason	Kester	Southern Ohio Port Authority
Gozdem	Kilaz	Purdue University

Keith	Kittrell	KSE, Inc
Rick	Knight	Gas Technology Institute
Aspi	Kolah	Michigan State University
Stephen	Korstad	Coronal LLC
Caroline	Kramer*	Energetics Incorporated
Theodore	Krause	Argonne National Laboratory
Jason	Kwiatkowski	DSM
Shawn	Lapean	United Financial of Illinois, Inc.
Markus	Lesemann	RTI International
Elliott	Levine	U.S. Department of Energy, BETO
Sharyn	Lie+	U.S. Environmental Protection Agency, Climate Econ
Yupo	Lin	Argonne National Laboratory
Christopher	Lindsey	Antares Group Inc.
Alex	Macleod	Natural Resources Canada
Tommi	Makila*	Energetics Incorporated
Jonathan	Male+	U.S. Department of Energy, BETO
Terry	Marker	Gas Technology Institute
Ronald	Meeusen+	Cultivian Sandbox Ventures, LLC
Loula	Merkel	Coskata
Landon	Miller	Aemerge
Liz	Moore~	U.S. Department of Energy, BETO
Scott	Morgan*	Energetics Incorporated
Quang	Nguyen	Abengoa Bioenergy
Kevin	O'Brien	Illinois Sustainable Technology Center
Norm	Olson	Iowa Energy Center
George	Parks	FuelScience LLC
Kendra	Parlock	W.R. Grace
Hemant	Pendse	University of Maine
Chris	Perkins	Sundrop Fuels Inc.
Monica	Peterlinz	DSM
Mark	Petri	Iowa Energy Center
Craig	Raddatz	United Financial of Illinois, Inc.
Douglas	Rivers	ICM, Inc.
Michael	Roberts	Gas Technology Institute
Luis	Rodriguez	Illinois Sustainable Technology Center
Bob	Rozmiarek	Virent, Inc.
Kelly	Russell	INEOS Bio
Richard	Simmons	Purdue University
Samir	Sofer	ReGen Technology
Colin	South	Novogy Inc.
James	Spaeth~+	U.S. Department of Energy, BETO
Bret	Strogen	DoD/Office of Operational Energy
Kimberly	Swanson	

Satish	Tamhankar	Linde LLC
Yannick	Tamm*	Energetics Incorporated
Travis	Tempel~+	U.S. Department of Energy, BETO
Melissa	Tiedeman >	SRA International
Maobing	Tu	Auburn University
Meltem	Urgun-Demirtas	Argonne National Laboratory
Austin	Vaillancourt	Southern Research Institute
Hans	van der Sluis+	POET-DSM
Michael	Vevera	Mercurius Biorefining
Paul	Weider	Shell International E&P
Paul	Wever	Chip Energy Inc.
Lysle	Whitmer	Iowa State University, BioEconomy Institute
Eric	Wind	Tyton BioEnergy Systems
Arthur	Wiselogel	CNJV
Elizabeth	Woods	Virent, Inc.
Patrick	Woolcock	Southern Research Institute
Mark	Wright	Iowa State University
May	Wu	Argonne National Laboratory
Bin	Yang	Washington State University
Jeffrey	Yingling	BCLF Corporation
Joshua	Yuan	Texas A&M Agrilife Synthetic and Systems Biology Innovation Hub
Kelly	Zering	North Carolina State University
Jenn	ZiBerna >	SRA International

* Facilitator + Speaker ~ Organizer > Support Staff

Appendix B: Acronyms

BC	Biochemical conversion
BETO	Bioenergy Technologies Office (EERE/DOE)
CHP	Combined heat and power
DOE	U.S. Department of Energy
D&D	Demonstration and deployment
EERE	Office of Energy Efficiency and Renewable Energy (DOE)
EPA	Environmental Protection Agency
FOA	Funding Opportunity Announcement
gge	Gallons of gas equivalent
GHG	Greenhouse gas
IBR	Integrated biorefineries
MSW	Municipal solid waste
R&D	Research and development
RD&D	Research, development, and demonstration
RFI	Request for Information
RFS	Renewable Fuels Standard
RIN	Renewable Identification Number
STEM	Science, Technology, Engineering, and Mathematics
TC	Thermochemical conversion
TRL	Technology readiness level
USDA	U.S. Department of Agriculture

Appendix C: Meeting Agenda

Wednesday, March 12, 2014	
Time	**Activity** ☐ = auditorium ☐ = breakout rooms
7:30-8:30 am	Registration and Coffee *(APS Conference Center)*
8:30 am	**Welcome and Opening Remarks**
8:45 am	**Bioenergy Technologies Office, Program Overview** ■ Jonathan Male, Director, BETO: BETO Overview ■ Jim Spaeth, Demonstration and Deployment Program Manager, BETO: Successful IBR Demonstration: Lessons Learned, Challenges, and Future Needs ■ Travis Tempel, Technology Manager, BETO: Request for Information Results
9:45 am	**Discussion Panel: Strategic Partnerships and Financing** Moderator: Jim Spaeth ■ Kevin A. Gray, PhD, Vice President, Beta Renewables ■ Ron Meeusen, Managing Partner, Cultivian Sandbox Ventures, LLC ■ Hans van der Sluis, Joint Venture Director, POET-DSM Advanced Biofuels
10:45 am	Break
11:00 am	**Discussion Panel: D&D Industry Drivers** Moderator: Travis Tempel ■ Anthony Crooks, PhD, Renewable Energy Policy Specialist, USDA Rural Development ■ Sharyn Lie, Director, U.S. EPA Climate Economics and Modeling Center ■ Angela Foster-Rice, Managing Director Environmental Affairs & Sustainability, United Airlines
12:00 pm	**Charge to Breakouts**
12:15 pm	Lunch *(Gallery—Deli Buffet)*
1:15 pm	**Breakout Session I : State of Technology and Testing/Demonstration Needs** Five Breakout Groups: ▪ Feedstocks ▪ Products ▪ Fuels via Biochemical Conversion ▪ Fuels via Thermochemical Conversion, TC Group A ▪ Fuels via Thermochemical Conversion, TC Group B
2:15 pm	**Breakout Session II: Major Barriers to Advancement** *(same groups)*
3:15 pm	Break
3:30 pm	**Breakout Session III: Advancement Activities** *(same groups)*
4:25 pm	Transition to Main Room

4:35 pm	**Breakout Session Day 1 Reports**
5:00 pm	Adjourn Day 1

Thursday, March 13, 2014	
Time	**Activity** = auditorium = breakout rooms
Starting 7:00am, pick up every 10 minutes	Shuttle Bus Transportation -- Argonne Guest House to Advanced Photon Source (APS) Conference Center
7:15-8:15 am	Networking and Coffee
8:15 am	**Welcome Back**
8:30 am	**Keynote Presentation** ■ Jennifer Holmgren, Chief Executive Officer of LanzaTech
9:05 am	Transition to Breakouts
9:15 am	**Breakout Session III Continued: Advancement Activities** *(same groups)*
10:15 am	**Breakout Session IV: Advancement Activity Action Plans** *(same groups)*
12:00 pm	Lunch and Networking *(Gallery—Boxed Lunch)*
1:00 pm	**Breakout Session Day 2 Reports, Action Plans and Q&A**
2:15 pm	**Closing Comments and Next Steps**
2:30 pm	Adjourn Workshop

Appendix D: Advancement Activities

Feedstocks

D-1.1: Publish Estimated Costs and Conversion Efficiencies by Feedstock and Conversion Process Each Year

D-1.2: Develop Fast, Simple, and Inexpensive Devices/Measures To Accurately Determine Feedstock Quality

D-1.3: Engage a Broader Spectrum of Biomass Feedstock Development Stakeholders To Accelerate Progress

D-1.4: Develop and Demonstrate Advanced Logistics Systems for Biomass Feedstocks

Products

D-2.1: Target Specific Platform Chemical Intermediates that Could Collectively Substitute for the Whole Barrel

D-2.2: Design Robust Processes To Transform Diverse Biomass Resources into Homogenous Intermediates, Enabling Component Separation for Further Processing

D-2.3: Clarify an Infrastructure Procurement Strategy for Biorefineries

D-2.4: Demonstrate Separation Technologies at Pilot and Demonstration Scales

D-2.5: Conduct Value Engineering on Specific Unit Operations

D-2.6: Add Value to the Rest of the Bale, Specifically (Convert) Lignin

Fuels via Biochemical Conversion

D-3.1: Underwrite Activities To Bolster Investor Confidence and Market Pull; Validate the Technical and Economic Performance of These Technologies with a Focus on the End Customer

D-3.2: Establish a New Standard To Guide the Critical Review of Technical and Economic Metrics

D-3.3: Co-Produce Multiple Bioproducts To Enhance Economic Stability

D-3.4: Create a Cross-Platform Development Incubator

D-3.5: Build on the Existing Ethanol Infrastructure

D-3.6: Develop Metrics To Indicate the Technological Robustness of Organisms, Enzymes, and Processes

Fuels via Thermochemical Conversion

D-4.1: Develop a Database of Thermochemical Technologies To Enable Assembly of Field and Patent Data from Federally Funded Projects

D-4.2: Encourage and Support Collaborative Efforts To Scale Up Catalyst Production and Piloting

D-4.3: Conduct Preliminary Pilot-Scale Testing To Measure the Performance of Catalysts

D-4.4: Use the Convening Power of DOE To Form Technology Development Partnerships, Further Develop Existing Pilot Facilities, and Expand Them into Demonstration-Scale User Facilities

D-5.1: Establish Best Practices Partnering To Fill Gaps in Experience, Expertise, and Finances

D-5.2: Develop More Versatile Feedstock Handling Systems at Pilot Scale and Larger

D-5.3: Establish Plant Integration User Facility for Demonstrating finAcceptable Plant Uptime, Product Quality, Yield, and Operating Costs

D-5.4: Provide Facility or Facilities for Demonstrating Catalyst Manufacturing and Evaluating Catalyst Performance at Scale

D-5.5: Standardize Analytics for Techno-Economic and and Process Modeling

TABLE D-1.1 (FEEDSTOCKS): PUBLISH ESTIMATED COSTS AND CONVERSION EFFICIENCIES BY FEEDSTOCK AND CONVERSION PROCESS EACH YEAR

Summary of Recommendation: Address lack of reliable, comprehensive, transparent, widely available information on costs and conversion efficiencies at each stage of the supply chain.

Desired Outcome: Provide public references for benchmarking, conversion economics, investment decisions, and R&D targets so that private companies can elaborate on them.

Action Plan Steps

Near Term (0–3 years)

- Assemble a team of subject matter experts, industry stakeholders, and representatives of government and academia to identify objective, relevant models of supply chains for a given end-product.
- Create a single web portal for sharing the information and relevant assumptions (e.g., link to the Knowledge Discovery Framework [KDF]).

Longer Term (3+ years)

- Fund the program
- Maintain staff
- Continuously improve the models
- Validate the data and methods on an ongoing basis/publish methodology document
- Commission studies on emerging feedstocks, products, and markets

Interim Milestones and Results

Near Term (0–3 years)

- Identify entity to manage the program
- Identify models
- Circulate methodology for review by stakeholders (public comment period)
- Agree on a methodology
- Integrate with EIA, USDA, and other existing databases

Longer Term (3+ years)

- Routine updating
- Recurring validation of results
- Periodic reporting of trends or changes in costs, efficiencies, and top opportunities and challenges—with links to existing product price reports

Metrics

Near Term (0–3 years)

- Team assembled
- Program manager appointed
- Funding received
- Team met
- Model and methodology accepted
- Results published

Longer Term (3+ years)

- Models and results updated every two years
- Additional process models published (on feedstocks, logistics, conversion and product markets, prices)
- Conduct annual situation and outlook meeting

TABLE D-1.2 (FEEDSTOCKS): DEVELOP FAST, SIMPLE, AND INEXPENSIVE DEVICES/MEASURES TO ACCURATELY DETERMINE FEEDSTOCK QUALITY

Summary of Recommendation: Critical barriers: For all market participants in the biomass supply chain (regardless of the feedstock being sold), the quality specifications are not readily understood by both parties. Simple, timely, verifiable instruments are not available for use at points of collection, consolidation, delivery, or storage. [All-Customer Examples: Ash, moisture, carbohydrates, metals, ammonia, chrome, pH, lignin. Specific-Customer Examples: Lipid content, water, metal, (solution, cl) at all points of collection to delivery].

Desired Outcome: Instruments that can adapt to particular operations and are fast, reliable, mobile, low-cost, widely available, attachable to farm equipment, easy to use, and able to wirelessly transmit results/readings.

Action Plan Steps

Near Term (0–3 years)

- Participant agreement (suppliers and buyers)
- Develop a list of desirable specifications for each feedstock and technology (conversion)
- For each property find proxy/surrogate that can be tested easily and in a timely manner
- Set a standard specification (e.g., ASTM)
- Survey technology that can be quickly adopted
- Make sure the OEMs buy in
- Demonstrate biomass of a given specification or quality in a pilot or commercial operation, (e.g., agricultural residue)

Longer Term (3+ years)

- Identify real time, cost effective, and scalable solutions
- Develop national database for most common feedstocks
- Identify best management practices throughout supply chain
- Manufacturers expand tolerances to increase feedstock volume
- Increase efficiency of collection to meet the specifications

Interim Milestones and Results

Near Term (0–3 years)

- Lists of feedstock specs: 6 months
- Lists of proxy tests: 1 year
- Develop standard specs: 1 year
- Survey results of current technology that can be adopted: 1.5 years
- Sign up OEM to perform demo: 2 years
- Demo results: 3 years

Longer Term (3+ years)

- Cost effective solutions
- Establishment of a regional or national database
- Extensive education on best practices
- Expanded specs from users
- Improved collection/storage methods

Metrics

Near Term (0–3 years)

- Number of participants (buyer and supplier) collaborating
- A joint specification
- Validated standard test method
- Number of OEMs signed up
- Number of demos

Longer Term (3+ years)

- Price of instruments
- Number of feedstock analyses/specs
- Number of farmers/suppliers adopting best the practice
- New, more tolerant feedstock specs
- Improvement in quality of delivered feedstocks

TABLE D-1.3 (FEEDSTOCKS): ENGAGE A BROADER SPECTRUM OF BIOMASS FEEDSTOCK DEVELOPMENT STAKEHOLDERS TO ACCELERATE PROGRESS

Summary of Recommendation: Coordinate development of feedstocks with input from multiple sectors, including basic research through agronomic development to commercialization. DOE should serve as a nexus to engage stakeholders and broaden their participation in planning and developing a reliable feedstock supply chain

Desired Outcome: Develop a more integrated way to engage stakeholders to facilitate rapid deployment of the feedstock supply chain for biorefinery projects.

Action Plan Steps

Near Term (0–3 years)

- Convene a workshop (similar to this one) that brings together other stakeholders (e.g., DOE Office of Science, USDA, EPA) to better inform BETO on feedstock objectives, barriers, and solutions
- Develop, publish, and maintain a "clearing house" of information on:
  - What research is ongoing
  - Who the experts are
  - Other D&D activities, etc.
- Establish an interagency working group across all relevant agencies and R&D organizations

Longer Term (3+ years)

Interim Milestones and Results

Near Term (0–3 years)

- Publish outcomes of the workshop
- Release version 1.0 of website with details
- Select working group expert members

Longer Term (3+ years)

Metrics

Near Term (0–3 years)

- Number of attendees
- Number of feedstocks evaluated
- Date released

Longer Term (3+ years)

TABLE D-1.4 (FEEDSTOCKS): DEVELOP AND DEMONSTRATE ADVANCED LOGISTICS SYSTEMS FOR BIOMASS FEEDSTOCKS

Summary of Recommendation: Critical Barriers: Feedstock cost, the availability and reliability of supply, and consistency of feedstock quality; the approach is two-pronged:

1. Incubation to identify, discover, & develop new approaches to supply feedstocks in the context of the critical barriers
2. Demonstration and optimization of near-term, commercial-ready equipment assembled in functioning logistic systems

Desired Outcome: Increase the rate of developing feedstock supply systems that can achieve cost, availability/ reliability and consistency (quality) in parallel (i.e., cattle feed and biopower/CHP markets) with the development of biorefineries, so the system is deployment-ready when the biorefinery is ready

Action Plan Steps

Near Term (0–3 years)

- Integrated feedstock supply system demonstrations for existing biomass markets (i.e., animal feed, heat/power, etc.)
- Identify and qualify acceptable markets for demonstrations at various scales
- Quantify costs and opportunities to improve cost/quality at the demonstration scale
- Identify "commercial ready" equipment/systems that can reliably supply the off-take market
- Issue Incubator FOA for innovative feedstock supply processes and equipment

Longer Term (3+ years)

- Demonstrate "Advanced" supply designs for existing biomass markets and identify available biorefinery opportunities
- Develop and support advances in manufacturing of new technologies, processes, and equipment for supply systems
- Develop the new support services industry for feedstock data collection, analysis, and quality assessment
- Continue incubator activities for debugging advanced systems

Interim Milestones and Results

Near Term (0–3 years)

- Identify end users and off-take requirements
- Initiate demonstration/deployment feedstock supply projects
- Establish framework to collect and report project performance data for modeling/analysis
- Qualify the biomass off-take market as to be used by biorefineries
- Use of niche demonstration experiences to identify innovations and targets for development

Longer Term (3+ years)

- Integration of biorefineries into off-take markets
- Refine/modify specifications to meet biorefinery requirements at scale
- Achieve full biorefinery supply scale

Metrics

Near Term (0–3 years)

- Cost of supply system
- Reliability of system
- Quality of product supplied

Longer Term (3+ years)

- Same as left only with advanced system that are better, faster, cheaper

Table D-2.1 (Products): Target Specific Platform Chemical Intermediates That Could Collectively Substitute for the Whole Barrel

Summary of Recommendation: To focus chemicals from biomass on a shorter list of target products (primary fuel, co-products) that can replace the whole barrel. Co-products drive economics and need acute focus.

Desired Outcome: Better defined focus will help us to meet deployment targets for replacing the whole barrel. Consistent policy on this will stimulate private investment.

Action Plan Steps

Near Term (0–3 years)

- Determine specific chemicals to produce based on sound techno-economic analysis and current state of technology.
- Pair research with existing pilots to demonstrate integrated operations

Longer Term (3+ years)

- Hold course on 0–3-year focus
- Incentivize the build-out

Interim Milestones and Results

Near Term (0–3 years)

- Prioritize list and strategy to get there
- From the list, identify technologies that should be moved to demonstrations
- Identify and publicize the available sites
- Define process for companies to interact, leading to demonstrations

Longer Term (3+ years)

- Write policy that is stable through multiple administrations

Metrics

Near Term (0–3 years)

- Set a date for producing a documented list
- Set a date for tech ID
- Set a date for others as well
- Determine when the entire process should be completed (through the first round of demonstrations)

Longer Term (3+ years)

- Are we still focused and building out in 3+ years?

Table D-2.2 (Products): Design Robust Processes To Transform Diverse Biomass Resources into Homogeneous Intermediates, Enabling Component Separation for Further Processing

Summary of Recommendation: *Barrier:* Lack of operational flexibility to accommodate feedstock variability. *Approach:* Design robust processes that can process a wide range (composition and form) of biomass resources and transform them into homogeneous intermediates, enabling component separation for further downstream processing.

Desired Outcome: Minimize raw material costs for a wide range of locations (opportunistic acquisition), enhance ability to operate year round, lower raw material storage and handling costs, gain ability to tailor separation ratios to maximize plant revenues.

Action Plan Steps

Near Term (0–3 years)

- A: Develop and issue an RFP to demonstrate process robustness across a wide range of biomass
- B: Fund a demonstration of co-feeding of alternative feedstock (e.g., corn stover and wood chips)
- C: Conduct techno-economic evaluation on the process economics of co-feeding in a wide variety of areas
- D: Document the effectiveness of biomass handling systems for each type of biomass

Longer Term (3+ years)

- I: Publish a standardized design case for a biomass-to-intermediate process that accommodates wide variability in feedstocks
- II: Engineer biomass handling and recovery systems to feed material into the standardized design. Design would adapt to site-specific feedstock availabilities
- III: Publish regional market assessments of product needs vs. biomass availability

Interim Milestones and Results

Near Term (0–3 years)

- A: Document the range of biomass alternatives that are acceptable for intermediate production
- B: Demonstrate co-feeding is possible (e.g., the equipment works)
- C1: Clarify the economic importance of multi-feedstock operation
- C2: Identify the economic opportunity of co-feeding versus alternating, single-feedstock operation
- D: Produce reports on handling systems

Longer Term (3+ years)

- I: Validated design to handle a wide range of feedstocks
- II: Validated design for material receiving and reactor insertion
- III: Documented regional markets and defined opportunities

Metrics

Near Term (0–3 years)

- A1: Acceptable composition range (chemistry)
- A2: Acceptable composition form (density/particle size)
- A3: Biomass-to-intermediate yield per bone dry mass
- B1: Product output co-feeding intermediate yields > 95% similar to single-biomass feeding
- C1: Production cost of intermediate defined for a variety of regions
- C2: Determine the cost differential for intermediate production
- D1: Identify cost per ton

Longer Term (3+ years)

- I: Unit cost to process biomass
- II: Unit cost, reliability and availability of biomass preparation and reactor injection
- III: Market volumes and prices recorded and published with comparison to biomass processing costs to identify plant investment opportunities

TABLE D-2.3 (PRODUCTS): CLARIFY AN INFRASTRUCTURE PROCUREMENT STRATEGY FOR BIOREFINERIES (E.G., A GREEN MANHATTAN EFFORTS FOCUS)

Summary of Recommendation: Meeting the 2022 goal of 16 billion gallons per year of cellulosic biofuels will require about 530 30-million-gallons-per-year plants; A) Current feedstock collection and consolidation companies and equipment are insufficiently mechanized and organized; B) Basic materials suppliers and sub-systems are currently insufficiently organized to build this number of plants within the context of the rest of the U.S. industrial base; C) No defined, one-condition regulatory structure (standards, buyer and user incentives) currently exists to support this volume of bio-fuels production. Thus, we need a plan ("a **Green Manhattan Project**") focused on incentives that prioritize consistent choices and capital allocations over a longer time horizon.

Desired Outcome: A combination of tax incentives and regulatory and permitting practices that favor this "Green Manhattan Project" and prioritize consistent choices by all market participants—without forcing them.

Action Plan Steps

Near Term (0–3 years)

- 1: Realistically survey inventories of available technologies, companies, and capacities that address A, B, and C (above)
- 2: Develop SWOTs (strengths, weaknesses, opportunities, and threats) for A, B, and C and facts required to support decisions
- 3: Develop tax incentive programs that induce choices without forcing (market-driven choices, not selecting winners and losers)
- Fund (1) and (2): subsidize as necessary the development of some elements across A, B, and C

Longer Term (3+ years)

- Adjust incentives slowly and carefully where choice disincentives materially distort other Title 3 efforts

Interim Milestones and Results

Near Term (0–3 years)

- 1: a) Understand the necessary conditions to get this "Green Manhattan Project" qualified as a Title III project
  b) Get it qualified as a Title III project
- 2: Create the facts needed to determine and justify a program of tax incentives that "induce" priorities and choices across A, B, and C
- 3: Refine research objectives and project scope to increase "speed, breadth, and depth" of the program

Longer Term (3+ years)

- Minimized market distortions, studies, and adjusted incentives

Metrics

Near Term (0–3 years)

- 1: Phase-gated plan and results
- 2: Phase–gated plan and results
- 3: Actions

Longer Term (3+ years)

- Cost of elements across A, B and C

TABLE D-2.4 (PRODUCTS): DEMONSTRATE SEPARATION TECHNOLOGIES AT PILOT AND DEMONSTRATION SCALES

Summary of Recommendation: Separations are often the most technically challenging and expensive aspects of bioprocessing

Desired Outcome: Demonstrate and deploy economically and environmentally optimized, integrated separations systems for processing a variety of feedstocks into bio-based products.

Action Plan Steps

Near Term (0–3 years)

- Identify available separations technologies and the attributes of analysis [for dilute aqueous systems, dilute organic systems, chemical and physical properties of biomaterials, gross separations vs. polishing, etc.].
- Develop models/explore reactive separations
- Propose innovations to improve existing separations technologies
- Establish optimum scale of the technology
- Demonstrate attractive innovations; champion systems

Longer Term (3+ years)

- Validate models based on demonstration data; demonstrate predictability and batch vs. continuous
- Develop new separations systems
- Demonstrate more reactive separations (process intensifications)
- Demonstrate continuous processes

Interim Milestones and Results

Near Term (0–3 years)

- Benchmark current technologies
- Selection of widely applicable baseline for techno-economic analysis (TEA), life-cycle assessment (LCA), and financial models allowing for comparisons between products and processes
- Develop matrix of technologies vs. product or intermediate
- Evaluate scalability, select champion systems
- Operational data/control wide

Longer Term (3+ years)

- Articulated model options
- Prototypes/pilots/demonstrations with improved energy efficiency
- Established best practices (e.g., metal ions from water)

Metrics

Near Term (0–3 years)

- Efficiency, yield, cost (price), purity
- Interferences
- Scale factor
- Energy efficiency
- Demonstrate process in control reporting

Longer Term (3+ years)

- Capital cost
- Batch vs. continuous
- Preventative maintenance cycle

TABLE D-2.5 (PRODUCTS): CONDUCT VALUE ENGINEERING ON SPECIFIC UNIT OPERATIONS

Summary of Recommendation: Barrier: Current process units are not optimized for the bioenergy industry. Approach: Decrease capital and operational costs and increase robustness through unit operations by the use of equipment specifically tailored to the process.

Desired Outcome: Decreased capital and operational costs due to the increased performance capability and efficiency of individual units. Development of standard performance metrics and accompanying analytical techniques for each unit operation (e.g., NREL, LOPs)

Action Plan Steps

Near Term (0–3 years)

- Test unit operations to provide a basis for comparing unit performance of model systems (comparing performance and cost-effectiveness of technologies for separation, etc.)
- Establish clear accounting of the impacts of upstream process conditions on downstream performance and product quality
- Develop prototype equipment that is specifically designed to address troubling or limiting unit operations

Longer Term (3+ years)

- Extend testing results to larger systems for continuous improvement
- Create a center of excellence for optimizing unit operations

Interim Milestones and Results

Near Term (0–3 years)

- Report on energy and material balances, capital cost, and maintenance
- List identifying “high intensity” unit operation in current processes

Longer Term (3+ years)

- Define categories for centers for excellence

Metrics

Near Term (0–3 years)

- Standard report at defined frequency to measure pre-determined metrics
- Standard analytic procedures for measuring performance
- Measures of operational robustness (cost, maintenance, uptime)

Longer Term (3+ years)

- Implementation schedule with specific and measurable items

Table D-2.6 (Products): Add Value to the Rest of the Bale, Specifically Lignin Conversion

Summary of Recommendation: Conduct R&D on lignin conversion technologies so that a significant portion of feedstock moving through the supply chain will no longer have a low-value end use (i.e., "deadweight").

Desired Outcome: Enable economical production of high-value lignin-based products to improve the profitability of biorefineries that can sell low-cost alternative fuels (lower CAPEX).

Action Plan Steps

Near Term (0–3 years)

- Improve technologies for the separation and clean-up/pretreatment of lignin
- Demonstrate pyrolysis and gasification units for lignin at TRL 7
- Identify limitations to lignin conversion routes that are near commercial
- Conduct comprehensive analysis of lignin conversion technologies (including TRL level)
- Create standard specifications for lignin that can be converted into high-value products
- Conduct techno-economic analyses of lignin conversion pathways
- Make selling lignin to current users (power plants, pellet plants) a focus of implementation in the near term and allow it to stay within the boundary

Longer Term (3+ years)

- Assess carbon and energy performance of various lignin pathways
- Develop robust catalyst(s) to convert lignin to high-value products
- Identify key limitations of scaling up lignin conversion processes
- Pilot lignin-based products in intended applications

Interim Milestones and Results

Near Term (0–3 years)

- Demonstrate separation technologies to meet specifications
- Demonstrate pyrolysis and gasification of lignin and assess product quality
- Produce framework and comprehensive report on technical barriers, economic feasibility of lignin conversion pathways
- Publish specifications (e.g., tolerances of various contaminants) needed for each conversion processes
- Develop preliminary techno-economic analysis (TEA) model for multiple pathways

Longer Term (3+ years)

- Expand TEA to include carbon and energy
- Identify viable catalyst(s)
- Develop comprehensive list of limitations to scale up in plant
- Utilize half of lignin in biofuel industry for a higher-value purpose

Metrics

Near Term (0–3 years)

- Identify pathway(s) to double the current value of lignin (i.e., as a boiler feedstock)
- Characterize quality of lignin input, product output, conversion efficiency for x hours and value
- Publish report that clearly identifies technical barriers to multiple pathways with publicly available TEA model

Longer Term (3+ years)

- Catalyst lifetime of 1000 hours
- Lignin is a value-added product for biorefineries contributing to success/profitability
- (Economy-wide) Estimate market size and potential metrics for lignin-derived products
- (Unit) Measure value and volume of lignin-derived product from demonstration unit

TABLE D-3.1 (FUELS VIA BC): UNDERWRITE ACTIVITIES TO BOLSTER INVESTOR CONFIDENCE AND MARKET PULL; VALIDATE THE TECHNICAL AND ECONOMIC PERFORMANCE OF THESE TECHNOLOGIES WITH A FOCUS ON THE END CUSTOMER

Summary of Recommendation: The critical barrier to commercialization of new technologies is lack of investor confidence and lack of market pull for the technology. DOE BETO can support new technologies by underwriting the technical and economic validation of these technologies with an emphasis on end customer requirements.

Desired Outcome: Creating a model for success tech to market deployment.

Action Plan Steps

Near Term (0–3 years)

- 1. Hold meeting to obtain input from market stakeholders (buyers and sellers) on specific needs and hurdles (technical/regulatory/ economic) that can be overcome
- 1a. Use stakeholder input as a match-making tool to link buyers and sellers (e.g., matching interface)
- 2. Structure a program that takes existing grant funding and re-deploys it as an “insurance fund” to directly address market acceptance and investor confidence; this leverages existing funding for broader use (e.g., 5x nominal grant $ value)
- Promulgate RFP and select awardees for “insurance policy”
- Commercial (FOA) transactions performed under insurance fund

Longer Term (3+ years)

- If model works, then funding is available for subsequent FOAs after a defined time period. Reassess available funds and repeat FOA process for new technologies

Interim Milestones and Results

Near Term (0–3 years)

- 1. Stakeholder meeting in the next month
- 2. Issue FOA in October
- 3. Select awardees by March 2015
- 4. By March 2017 have commercial volumes of high-quality, cost-effective hydrocarbon biofuels

----

- 1. Obtain sufficient feedback
- 1a. Establish collaborations via interface
- 2. Write and issue FOA; 2a. Develop risk metrics for projects and to size program
- 3. Select and award
- 4. Volume flowing

Longer Term (3+ years)

- Assess number of new commercial relationships and transactions
- Count # of pathways funded

Metrics

Near Term (0–3 years)

- Number of stakeholders
- Number of applications
- Number of awardees
- Volume of biofuels

Longer Term (3+ years)

- Metrics
  - Biofuels commercially sold
  - Efficiency of $ deployed (lost)

TABLE D-3.2 (FUELS VIA BC): ESTABLISH A NEW STANDARD TO GUIDE THE CRITICAL REVIEW OF TECHNICAL AND ECONOMIC METRICS

Summary of Recommendation: Overly optimistic evaluations erode investor confidence. A realistic evaluation will better allocate limited resources. Additionally, the performance matrix must include the energy-water-food nexus.

Desired Outcome: DOE/BETO needs to set a standard for critical review of the current state of technology and abandon "Nth Plant" economics. This will help to allocate resources where they can make the greatest economic impact. DOE could fund an EPC (engineering, procurement, and construction) consortium to evaluate processes.

Action Plan Steps

Near Term (0–3 years)

- Re-do NREL/BETO cellulosic ethanol report to reflect real-world values and costs: "A critical re-evaluation of current and near-term cellulosic ethanol processes."
- Conduct a critical evaluation that is not unduly optimistic.
- Develop operability metrics and evaluation methods – "What impacts robustness."
- Publish and expand on IBR "lessons learned" with specific examples.

Longer Term (3+ years)

- Create an EPC (engineering, procurement, and construction) consortium/database for critically validated and accepted industry standards
- A standard list of operability concerns and solutions

Interim Milestones and Results

Near Term (0–3 years)

- List of economic gaps between current economic assessments and Nth plant economics
- Industry forum – members of industry judge the evaluation to be credible

Longer Term (3+ years)

- Standard equipment lists and line ups for comparison purposes

Metrics

Near Term (0–3 years)

- How do you develop a metric for reality? (industry perspective)
- Elimination of disincentives for technologies that because of real world limitations do not meet overly optimistic metrics

Longer Term (3+ years)

- Have a "gold standard" of evaluation metrics that investors can trust. Provide confidence for investors.

TABLE D-3.3 (FUELS VIA BC): CO-PRODUCE MULTIPLE BIOPRODUCTS TO ENHANCE ECONOMIC STABILITY

Summary of Recommendation: Economic limitations of a single-product line; co-production of multiple bioproducts to enhance economic stability.

Desired Outcome: DOE supports technology development of co-products along with biofuel production on a "scalable" platform to demonstrate economic viability. Secure investor(s) by demonstrating accelerated commercial pathway and providing product samples that show cost competitiveness in the market.

Action Plan Steps

Near Term (0–3 years)

- Fund potential teams to participate in developing multiple-product processes (new grand ideas).
- Create consortium of manufacturers, suppliers, and users to help support multiple product development. It will provide advice and may bring potential financial support.

Longer Term (3+ years)

- Support industrial sector to install technology demonstration at existing manufacturing sites.
- Support large-volume product to validate potential consumer market.

Interim Milestones and Results

Near Term (0–3 years)

- Establish TRL 6 technology and process pathways.
- Industrial groups adapt new technologies for producing multiple co-products

Longer Term (3+ years)

- Prove economic viability by industrials.
- Secure market distribution pathway.

Metrics

Near Term (0–3 years)

- Demonstration of TRL 6 technology and process with TEA
- Number of partnerships by industrials

Longer Term (3+ years)

- Commercial distribution of end products

TABLE D-3.4 (FUELS VIA BC): CREATE A CROSS-PLATFORM DEVELOPMENT INCUBATOR

Summary of Recommendation: Large volumes (e.g., >1000 gals.) are cost-prohibitive for a single entity to produce; large volumes require partnering and access to appropriate intermediates or processing technologies/operations.

Desired Outcome: Incubator that facilitates partnerships and leverages existing infrastructure

Action Plan Steps

Near Term (0–3 years)

- Identify intermediates and existing process technology capabilities
- Set aside funding for supplemental operations for 5 years
- Assess location (entirely co-located vs. separate); greenfield and brownfield; and access to feedstocks
- Establish framework for creating incubators: matchmaking, published list of capabilities (joint centers for scale-up)
- Solicit users for incubator
- Determine general features needed in an incubator that will inform site selection: onsite technical support, nearby companies, environmental permitting and feedstock offtake/ intake agreement availability

Longer Term (3+ years)

- Ongoing operations to support supplemented activities
- Support continuous improvement of site; fund modifications and operations
- Maintain flexibility to repurpose as needs change
- Assess technologies; hold review by cross-functional team
- Benchmark facility to gauge relevance
- Expand/facilitate additional interest in product samples

Interim Milestones and Results

Near Term (0–3 years)

- List of capabilities
- Framework for centers
- Locations
- Funding
- Users/"Customers" lined up
- Framework for managing IP across participants

Longer Term (3+ years)

- One successful incubator (assess for feasibility of expansion
- Production volume target

Metrics

Near Term (0–3 years)

- Degree of flexibility
- Number of potential users
- Framework/charter
- Diversity of partners

Longer Term (3+ years)

- Number of graduated technologies
- Sustainable utilization (preferred growth
- Hours of operation
- Percentage of asset utilization
- Number of parties served (tech developers, customers/end-users)

TABLE D-3.5 (FUELS VIA BC): BUILD ON THE EXISTING ETHANOL INFRASTRUCTURE

Summary of Recommendation: Develop cellulosic sugars as a commodity, catalytic upgrading of ethanol; synergistic/co-development of other hydrocarbons. Identify and develop co-products.

Desired Outcome: Commodity sugar platform to reduce risk for new biofuel production. Leverage existing know-how to create new market opportunities for ethanol (corn ethanol industry). Use CO_2 and lignin to produce new fuels.

Action Plan Steps

Near Term (0–3 years)

- Incentive to reduce risk for new users/adopters for higher-value fuels and chemicals
- Loan guarantees/limited tax credits
- Process warranty (partial)/floor product price
- Develop economic feasibility of catalytic upgrading
- Fund at $10 MM over 3 years
- Define lignin value for fuels, fibers, other co-products
- Fund at $10 MM over 3 years

Longer Term (3+ years)

- Two platforms
  - Ethanol to fuels + chemicals
  - Sugars to fuels + chemicals
- Replace the whole barrel

Interim Milestones and Results

Near Term (0–3 years)

- Develop 10 sugar facility projects
- New products
  - Capex/Opex sugar production
  - Capex/Opex "bioprocess" production or catalytic production

Longer Term (3+ years)

- Deploy 3-5 facilities
- Integrate catalytic upgrading and co-products as feasible
- Develop fuels and fibers as market products

Metrics

Near Term (0–3 years)

- Evaluate project feasibility
- Petroleum displaced
- Carbon yield increase
- Energy balance

Longer Term (3+ years)

- Facilities developed
- Reduced complexity
- Measure plant start to full operation
- Volume to value of products
- Price to value
- Potential to expand
- Compare capital and operating expenditures (Capex/Opex)

TABLE D-3.6 (FUELS VIA BC): DEVELOP METRICS TO INDICATE THE TECHNOLOGICAL ROBUSTNESS OF ORGANISMS, ENZYMES, AND PROCESSES

Summary of Recommendation: Lack of useable and enforceable metrics for industrial robustness of organisms, enzymes, and processes

Desired Outcome: End-point metrics and validation protocols for robustness

Action Plan Steps

Near Term (0–3 years)

- Support development and demonstration of technologies that improve project robustness
- Assess performance of organisms under process contaminant loading typically seen in industrial fermentation
- Evaluate performance of enzyme systems under "dirty" process conditions
- Ensure plant-wide modeling of reliability using industry specific data (mean time between failures, etc.)

Longer Term (3+ years)

- Support technology for genetic stability in genetically modified organisms
- Develop new platforms operating over broader process environment (temperature, pH, shear stress)
- Establish tolerance to inhibitors to reduce upstream costs and increase robustness
- Minimize by-product fermentation by organisms and enzymes

Interim Milestones and Results

Near Term (0–3 years)

- Share lessons learned on industrial robustness in previous IBRs
- Publish roadmap for key technology targets

Longer Term (3+ years)

- Publish database of performance of key technologies
- Incorporate metrics into plant reliability modeling

Metrics

Near Term (0–3 years)

- Consistent process yield under expected range of operating conditions and catalyst (enzyme) lifetime

Longer Term (3+ years)

- Tolerable operating range

TABLE D-4.1 (FUELS VIA TC A): DEVELOP A DATABASE OF THERMOCHEMICAL TECHNOLOGIES (BY FEEDSTOCK, PROCESS, AND PRODUCT) TO ENABLE ASSEMBLY OF FIELD AND PATENT DATA FROM FEDERALLY FUNDED PROJECTS

Summary of Recommendation: Compatible partners and thermochemical technologies can be difficult to find. Develop a "KDF" database of thermochemical technologies (targeted to different feedstocks, processes, and products) that assembles field and patent data from DOE-funded projects and funding agencies.

Desired Outcome: Data gathered will support sharing lessons learned within the thermochemical working group to prevent "reinventing the wheel." This will benefit biorefinery deployment by accelerating the discovery of compatible partners and technologies.

Action Plan Steps

Near Term (0–3 years)

- Scope out data collection and work plan
- Identify working group
- Populate database with publically available data related to thermochemical data
- Identify data sources
- Analyze data gathered to provide guidance
- Secure federal funding over five years
- Provide secure access to the online database

Longer Term (3+ years)

- Expand database to other BETO technologies (biochemical conversion, hybrids, etc.)
- Continue to update existing records
- Continue to add features and improve usability
- Host workshops with modeling groups to present the data

Interim Milestones and Results

Near Term (0–3 years)

- Assembled database
- Assembled working group
- Major pathways incorporated
- Interim report peer reviewed
- Identified hosting space/group
- Online database rollout

Longer Term (3+ years)

- Meeting with groups representing other platforms in BETO
- Database expanded to other platforms
- Second version released
- National workshop hosted

Metrics

Near Term (0–3 years)

- Positive response from working group
- Number of database pathways incorporated
- Database access records

Longer Term (3+ years)

- Number of data base records and technologies expanded
- Database access records

TABLE D-4.2 (FUELS VIA TC A): ENCOURAGE AND SUPPORT COLLABORATIVE EFFORTS TO SCALE UP CATALYST PRODUCTION AND PILOTING

Summary of Recommendation: Lack of connection among catalyst manufacturers, process inventors, and developers in DOE-funded programs; high financial and technical risks for all parties on a team. Approach: Encourage collaborative teams that enable catalyst developers to make meaningful contributions.

Desired Outcome: New catalysts will be scaled up by manufacturers and tested at pilot scale for yield and lifetime.

Action Plan Steps

Near Term (0–3 years)

- BETO should issue FOAs requiring that proposed teams include
  - Catalyst inventors/developers (may be the same organization as below)
  - Catalyst manufacturer with proven ability to scale up (may be same organization as above)
  - End user who can develop the technology (process using the catalyst) at pilot scale and beyond
- Project management structure should enable catalyst manufacturer to be a service provider (minimize onerous accounting audits and reporting)

Longer Term (3+ years)

- Develop a “stable” of industrial catalyst manufacturers similar to EERE’s “SSL” (solid state lighting) Program

Interim Milestones and Results

Near Term (0–3 years)

- Produce minimum quantity (e.g., 10–1000 kg) at designated final particle size
- Demonstrate stable, continuous operation of catalyst in pilot (or larger-scale) process
- Viable catalyst cost and total process operating cost

Longer Term (3+ years)

- List/database of participating/approved catalyst manufacturers and process operators (catalyst users)

Metrics

Near Term (0–3 years)

- Quantity (mass or volume) of catalyst
- Hours on stream at or above required productivity
- Total cost of production (e.g., \$/gallon)

Longer Term (3+ years)

- Number of participants
- Time to market
- Percentage of projects reaching a certain TRL level

Table D-4.3 (Fuels via TC A): Conduct Preliminary Pilot-Scale Testing To Measure the Performance of Catalysts

Summary of Recommendation: A variety of thermochemical pathways has been identified to help BETO achieve the $3/gge by 2017 target. These TC processes all require catalysts for conversion to liquids or upgrading intermediates to fuel. Integrated pilot-scale testing of catalyst performance is paramount for collecting reliable engineering data to validate technical and economic models to guide future engineering design for scale-up and demonstration.

Desired Outcome: Technically feasible and economically viable (attractive) processes recommended for scale-up to demonstration. Catalyst performance is documented and validated for commercial catalyst production → path to toll manufacturing. If integrated pilot-scale testing is successful, it serves as a stage gate to future (unsolicited) funding for demonstration.

Action Plan Steps

Near Term (0–3 years)

- RFI to identify suitable facilities for pilot-scale catalyst testing (Regional Centers?)
- Validate/identify catalyst performance metrics, i.e., change in activity/time (equilibrium catalyst performance), catalyst lifetime needs (how long should a catalyst last?)
- Catalyst manufacturers provide >100 kg of catalyst for pilot-scale consortium?
- Define catalyst regeneration needs and replacement rates

Longer Term (3+ years)

- Long-duration, continuous pilot operation to resolve reliability, operability, and maintenance issues for scale up
  - Public-private partnerships or consortia
  - Involve state agencies?

Interim Milestones and Results

Near Term (0–3 years)

- Regional facilities for developing consortia for pilot testing
- Less than 10% change in activity for 100 hours at pilot scale
- Convene a working group or consortium of catalyst vendors/developers/manufacturers

Longer Term (3+ years)

- Fixed bed catalyst replacement life at least one year
- Fluid bed catalyst replacement rates are economically viable

Metrics

Near Term (0–3 years)

- Catalyst cost and activity support $3/gge modeled target for biofuel production
- Minimum duration of 1,000 hours (at least 200 continuous)

Longer Term (3+ years)

- Commercially relevant time on-stream (e.g., 4,000 hours) for future demonstrations
  - 1,000 hours continuous
  - 4,000 hours max
- 90% capacity factor for pilot operation
- Modeled biofuel production of $3/gge

TABLE D-4.4 (FUELS VIA TC A): USE THE CONVENING POWER OF DOE TO FORM PARTNERSHIPS TO DEVELOP THE TECHNOLOGY, FURTHER DEVELOP EXISTING PILOT FACILITIES, AND EXPAND THEM INTO DEMONSTRATION-SCALE USER FACILITIES

Summary of Recommendation: The several facilities capable of pilot-scale thermochemical testing and development are poorly identified and stop at the pilot scale as they receive sporadic and meager support. DOE is in a unique position to foster partnerships for developing the technology, developing these user facilities, and expanding them into demonstration-scale user facilities.

Desired Outcome: Identify these pilot plant user group facilities and coordinate research activities → reduce risk for capital investors. Establish demonstration-scale user facilities, possibly by region or biomass type, that would leverage commonly needed equipment, such as water treatment or feed system operations. This should be done with private technology under development at reasonable cost.

Action Plan Steps

Near Term (0–3 years)

- Pilot plant identification for project coordination
  - Establish a working group within DOE to coordinate pilot plant activities
- Identify early-stage adopters of the demonstration facilities
  - Issue FOA
- Identify site(s) that may take advantage of distressed assets or brownfield to reduce capital costs of demo user facility
  - Site identification needs to address "feedstock" type (crop residue vs. wood wastes vs. MSW vs. other)
  - Start building facility within three years

Longer Term (3+ years)

- Construct and begin operation of several regional demo sites
- Advertise success stories broadly!
- Produce certification volumes of fuels across technology platforms

Interim Milestones and Results

Near Term (0–3 years)

- Establish working group within DOE to coordinate pilot plant activities
- Release FOA
- Form team to support demo-scale front-end engineering and design and specification
- Break ground on demonstration facility site(s)

Longer Term (3+ years)

- Publish success stories
- Commercialize technologies that graduated from pilot through demo sites into commercial
- Meet RFS targets
- Improve capital efficiency
  - Lower IRR (internal rate of return)

Metrics

Near Term (0–3 years)

- Established facilities officially recognized and documented with the DOE with list of capabilities
- Queue of users identified for both pilot and demo scale facilities
- Percentage construction progress completed on demonstration facility

Longer Term (3+ years)

- Capital efficiency
- RFS target production

TABLE D-5.1 (FUELS VIA TC B): ESTABLISH BEST PRACTICES IN PARTNERING OR GAP FILLING TO BOLSTER EXPERIENCE, EXPERTISE, FINANCES, ETC. (INCLUDING FOREIGN PARTNERSHIPS)

Summary of Recommendation: Every organization has some "gaps" (areas of lower competency or resources) for moving new technology into integrated commercialization (D&D).

Desired Outcome: In evaluating projects for funding, DOE should add positive weighting to entities that gain needed competencies by obtaining partners, including non-U.S. groups—if that is where best practices and/or financial support is most available; the objective is to de-risk the development.

Action Plan Steps

Near Term (0–3 years)

- Reconsider/re-design:
  - Application processes and criteria for funding
  - Due diligence on applicants to determine if gaps in competencies exist create risks to moving forward
  - Ability to find and qualify partners globally ("dating service")
- Publicize that this is now DOE policy
- Assure that new partners are truly committed

Longer Term (3+ years)

- Create library/clearinghouse of (non-proprietary) best practices
- Establish institutes (e.g., PSRI, FRI) that are focused on expanding know-how in generic technologies relevant to biomass

Interim Milestones and Results

Near Term (0–3 years)

- Application processes and criteria are changed by 2015
- Partner "dating service" established by 2015
- Publicity on policy rolled out in 2015
- Workshop for lessons learned in partnering

Longer Term (3+ years)

Metrics

Near Term (0–3 years)

- Assess extent to which funding applications received by 2015 have filled all gaps in competency and cost share internally or via partners (count number of non-U.S. partners)
- How many inquiries are made? How many partnerships established?
-

Longer Term (3+ years)

TABLE D-5.2 (FUELS VIA TC B): DEVELOP MORE VERSATILE FEEDSTOCK HANDLING SYSTEMS AT PILOT SCALE AND LARGER

Summary of Recommendation: Lack of feedstock-flexible processing and handling systems, especially at pilot or larger scale. These systems need to handle differences in seasons, shape/aspect ratio; grindability; density; contaminants; abrasiveness; moisture content, ash (elemental components and volume); Inability to incorporate (optimally) natural gas into a biorefinery.

Desired Outcome: Strategies to ensure that the plant can operate at capacity, regardless of biomass perturbances (supply or physical/chemical characteristics). These strategies should consider: new/better hardware, systems configuration, feedstock preprocessing, and/or procurement of better feedstocks (including natural gas and coal as supplemental feeds).

Action Plan Steps

Near Term (0–3 years)

- Identify and characterize (baseline) existing feedstock systems (preprocessing, feeder). Provide funds for feeder supplier to measure/monitor their system performance.
- Conduct simulations/system studies to identify optimal use of natural gas to supplement biomass and/or improve conversion chemistry and/or heat integration.
- Define lifetime (benchmark) of currently used materials of construction everywhere in the plant up to the reactor.

Longer Term (3+ years)

Interim Milestones and Results

Near Term (0–3 years)

- Identify the aspects that affect feeder performance
- Obtain data on various feeder systems
- Completion of X cases, implications of scaling

Longer Term (3+ years)

Metrics

Near Term (0–3 years)

- Flow rates, bulk density, “flowability,” energy usage, time on-stream
- Economics and LCA for various configurations
- Corrosion rates, abrasion rates

Longer Term (3+ years)

TABLE D-5.3 (FUELS VIA TC B): ESTABLISH PLANT INTEGRATION USER FACILITY FOR DEMONSTRATING ACCEPTABLE PLANT UPTIME, PRODUCT QUALITY, YIELD, AND OPERATING COSTS

Summary of Recommendation: Testing and validation of an economically viable, fully integrated plant-operation, from feedstock to end products. Demonstration of acceptable plant uptime, product quality and yield, and operating cost.

Desired Outcome: De-risk integrated plant operation so that investor funding becomes available for commercial deployment. Investor funding is critical for initial deployment of multiple plants prior to large-scale commercialization.

Action Plan Steps

Near Term (0–3 years)

- Set TRL standards applicable to individual unit ops as a screening criteria for plant integration FOA
- Establish minimum funding level for a D&D project
- Establish an integrated, proven plant design matrix to justify integrated demonstration trials
- Verify economic viability on a standardized basis
- Design and construct full demonstration unit

Longer Term (3+ years)

Interim Milestones and Results

Near Term (0–3 years)

- Set acceptable TRL level on each unit
- Demonstrate robust, proven model with sufficient data to validate cost basis
- Demonstrated economics on DOE standard, *pro forma*

Longer Term (3+ years)

Metrics

Near Term (0–3 years)

- Demonstration in integrated plant of:
  - 1,000 hours, availability 90%
  - 5,000 hours, > 90%
  - 8,000 hours, > 95%
- Yield and quality meets *pro forma* assumptions

Longer Term (3+ years)

Table D-5.4 (Fuels via TC B): Provide Facility or Facilities for Demonstrating Catalyst Manufacturing and Evaluating Catalyst Performance at Scale

Summary of Recommendation: Critical Barrier: Demonstration- scale (low risk to commercial scale) confirmation of catalyst performance (yield, selectivity, lifetime) in converting biomass to intermediates and upgrading those intermediates to "whole barrel" replacement hydrocarbons. Financial support for capital and operating costs of this demo-scale confirmation of manufacturing operations.

Desired Outcome: Validation of demonstration-scale performance (yield, selectivity, service lifetime, allowing/enabling financing of commercial plant

Action Plan Steps

Near Term (0–3 years)

- Provide funding support for pilot- and/or commercial-scale catalyst manufacture.
- Provide funding support for translational activities from bench to industrial commercial scale.
- Provide funding support for demonstration-scale confirmation of pre-commercial catalyst and process configuration for biomass to intermediates and/or intermediates to hydrocarbons.
- Provide funding support for long-term performance testing in a relevant environment.

Longer Term (3+ years)

- Optimize the catalyst and catalyst manufacturing.
- Optimize the process (reactor throughput, etc.):
  - Optimize operations (start-up, regeneration)
- Develop commercial arrangements with catalyst manufacturer(s).

Interim Milestones and Results

Near Term (0–3 years)

- Catalyst production at sufficient scale for pilot with commercial methods
- Commercial-scale catalyst production
- Developed catalyst cost (commercially relevant) feed package for demonstration plant
- Catalyst performance meets economic targets

Longer Term (3+ years)

- Commercial-scale catalyst production
- Fully developed cost and pricing for commercial catalyst
- Optimized start-up and operations plan
- Signed commercial catalyst agreement
- Approval of performance by independent engineers

Metrics

Near Term (0–3 years)

- Catalyst produced and provided
- Cost estimates developed
- Catalyst performance metrics met:
  - Yield
  - Selectivity
  - Lifetime

Longer Term (3+ years)

- Commercial supply agreement/general market supply

TABLE D-5.5 (FUELS VIA TC B): STANDARDIZE ANALYTICS FOR TECHNO-ECONOMIC AND PROCESS MODELING

Summary of Recommendation: Technoeconomic modeling results may be inconsistent due to different assumptions and methodologies. DOE should facilitate the development of standards for techno-economic and process modeling. Examples that might serve as models for BETO include the DOE Fuel Cell Technologies Office's H2A model and Fossil Energy's bituminous coal model.

Desired Outcome: Better and consistent analytics will lower risks—both technical and economic—for project deployment. Analytics would include standardized and consistent technoeconomic analysis as well as process simulation and design.

Action Plan Steps

Near Term (0–3 years)

- Engage stakeholders (industry; engineering, procurement, and construction [EPC] contractors; etc.) to establish critical parameters and methodologies.
- Develop methodology and tools using National Laboratories, outside contractors, universities, etc. Involve DOE system modelers to insure compatibility across offices.
- Validate methodology and tools using existing projects and obtain buy-in from stakeholders.
- Train program managers, grant recipients, and other stakeholders on models and tools.
- Require use of DOE standard analysis methods for all grant and loan respondents and recipients.

Longer Term (3+ years)

- Update and revise model periodically to accommodate new technologies and projects.
- Incorporate feedback from users.

Interim Milestones and Results

Near Term (0–3 years)

- Workshop and subsequent reporting
- Report describing methodologies and tools
- Workshop held
- Revision of DOE reporting requirements.

Longer Term (3+ years)

- Model updates issued

Metrics

Near Term (0–3 years)

- Degree of participation of various stakeholders in planning workshop
- Issuance of draft model and methodology
- Buy-in of stakeholders
- Final model/methodology approval
- Prediction of economics and performance

Longer Term (3+ years)

- Improved prediction of economics and performance

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

For more information, visit:
biofuels.energy.gov

DOE/EE-1104 • May 2014