# Biomass Research & Development Initiative

# Technical Advisory Committee

**2013 Grand Challenge**

## Problem Statement

The primary obstacle to producing advanced biofuels and bioproducts from cellulosic feedstocks is the lack of cost competitiveness when compared with petroleum's cost of production. This lack of cost competitiveness is the main reason for the lack of adoption by consumers.

## The Grand Challenge

**Replace fossil carbon with renewable carbon in transportation fuels and related products:** Rapidly expand the emerging biofuels and bioproducts industries, achieving 30% penetration of biomass carbon into the U.S. transportation market by 2030 in a sustainable and cost-effective manner to create jobs, reduce greenhouse gas impacts, and enhance national security.



Additional outcomes will include the following:

- Enhanced economic development by increasing direct and indirect jobs from 152,000 in 2012 (Bio-ERA Report) to more than 1 million by 2022. By 2030, with 45 billion gallons of fuel made with renewable carbon introduced into the biofuel industry, the direct and indirect economic impact should exceed 5 million jobs. Incentives need to guide such developments to provide opportunities for disadvantaged and minority populations.
- A cost-effective energy supply that is synergistic with existing fossil-based markets.
- Enhanced economic, environment, and social sustainability.
- Improved national energy security and decreased dependence of national defense on foreign energy supplies.

## Barriers to Rapid Adoption of Biobased Fuels and Products

There are three main barriers that restrict our ability to achieve the goals set forth in the Grand Challenge.

- First, biomass as the source of low-cost renewable carbon feedstock for conversion to fuels adds significant complexity for the agricultural industry.
- Second, conversion technologies for production of fuel from cellulosic feedstocks suffer from high energy requirements and low productivity (yield and rate of production), as well as high capital expenditures per gallon, which results in conversion technologies that are unable to achieve reinvestment economics.
- Third, lack of an updated distribution infrastructure and other market incentives directly impacts the adoption of the new fuel products by consumers.

*A. Low-Cost Biomass and Renewable Carbon Feedstock for Conversion to Fuels*

Widespread, sustainable, affordable, commercial-scale biomass feedstocks is the nation's first key enabler to achieving significant bioenergy and bioproducts production for the United States' "all-of-the-above" energy strategy, and it also supports the White House's "National Bioeconomy Blueprint." The U.S. Department of Energy's 2005 Billion-Ton Study and the recent 2011 update[1] provide sound evidence that production of significant quantities of feedstocks is feasible and can be sustainable. Nevertheless, a continuous increase of accessing and utilizing these feedstocks will transform American agriculture. To put this transformation into perspective, an annual use of 1 billion tons of biomass by 2030 represents the output of a new agricultural system that is 20% larger than the current 800 million tons of all annual agricultural products, including hay and pasture. Major hurdles to near-term use of such biomass quantities that impact production volume, cost, distribution, and adoption of the final product include the following:

- Concerns around sustainable (environmental, social, and economic) development.
    - Can the current agricultural system supply bioenergy feedstocks at scale without causing chronic market shocks for food, feed, and fiber production?
- Matching supply and demand of both feedstock and biobased products in a nascent industry requires robust and cost-effective conversion technologies.
    - Scale up of production capability and utilization of biomass in products are linked to each other and to the technological ability and market incentive of fuel manufacturers to convert these feedstocks into products. This means that the new industry's conversion technology, as well as the market supply and demand for products, will limit expanded feedstock production. The consumer demand equation represents a "market-pull" incentive to manufacturers to conduct research and development (R&D) for lower costs and thus develop a sustainable business model.
- Adoption in the farming community and response to economic opportunities.
    - To achieve grower acceptance, engagement, and production leading to supply chain maturity, applicable feedstocks will need similar support that is available for existing agricultural technologies in the areas of research and education, commercial enablement, and policy support programs. Examples include feedstock development; feedstock logistics and transportation infrastructure; grower acceptance, education, and extension; production risk mitigation; and sustainability.



Despite the perceived ample availability of biomass, the feedstock supply has costly detriments. Biomass has low density, is usually widely distributed, and has relatively low economic value. The low densities and widely distributed nature adds cost to harvest, collection, and transportation and presents logistical challenges to entraining these feedstocks into the biofuels supply chain. Differences among species, phenotypes, and conditions during growth, harvest, and storage result in feedstocks with profound

[1] U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

variability in cellulose, hemicelluloses, and lignin concentrations—all of which have a major impact on net energy use and productivity of conversion.

Economic barriers, in addition to debate on policy frameworks—such as the Renewable Fuel Standard (RFS)—and lack of confidence in a long-term stable policy for other bioproducts are restricting capital investment in new cellulosic conversion facilities. Therefore, it is necessary to demonstrate technology performance and the sustainable economics of the business model for renewable fuels to investors in order to justify capital investment in biorefineries. To ensure that biofuels have impact, it is critical to implement new enabling technologies that significantly reduce capital costs and operating expenses.

<u>Potential Solutions</u>**:**

1. Accelerate deployment of feedstock from existing, aggregated waste streams:
    - Agricultural, forestry, silviculture residues, and processing wastes
    - Livestock manure
    - Municipal solid waste (MSW)
    - Food industry and animal processing wastes
    - Oil derived from the corn ethanol industry
    - Industrial wastes.



2. Develop new farming systems to provide feedstocks sustainably from agriculture through adoption of technologies and best practices that maximize production on current acres. With current technologies under development, the corn seed industry fully expects to achieve a national average corn harvest of 300 bushels per acre by 2030. Increasing the harvest from existing acres could span agronomic solutions such as intercropping and dual cropping; new approaches to plant breeding; genetic engineering; and innovative land-use strategies, including algal farms. Farming systems that provide multiple harvests per growing season would maximize productivity on existing agricultural land and add many "virtual acres" for biomass production, effectively reducing the distributed nature of feedstock production.

3. Invest in research, innovation, technology, and infrastructural advances to enable distributed industries to evolve and become less distributed and more efficient. Despite increases in agricultural yields through conventional inputs such as fertilizer, and unconventional inputs through technology development, the greatest hurdle remaining is the logistics of delivering feedstocks to biorefineries. Creating a network of collection points within 10–20 miles of production fields would not be used for long-term storage, but would be used as sites for feedstock receiving, segregation, and pre-shipment processing. Feasibility of the collection-point model resides in the ability to provide value to the conversion industry through densification, pretreatment, or initial processing of feedstocks. Examples include pelleting, fiber expansion, gasification, or production of pyrolysis oil.

4. Create industry standards for feedstock composition and consistency. Creating feedstock collection and processing sites is the precursor to developing robust bioprocessing technologies that can accommodate the variability of feedstocks. All bioprocessing industries could greatly benefit from coordinated standardization of feedstock composition. As with other agricultural

processing industries, you could develop feedstock consistency through technologies that process or blend a variety of feedstock sources.

### *B. Highly Productive Conversion Technologies that Demonstrate Reinvestment Economics*

Biomass conversion plants require substantially higher capital expenditure per gallon capacity than starch/sugar ethanol plants or biodiesel plants because biomass processing is more complex and entails a greater number of unit operations than conventional biofuel facilities. The typical solution to high capital cost is to increase scale by building larger facilities. In the case of biomass processing plants and biorefineries, the costs of transporting biomass greater distances rises rapidly and can render any savings from reduced per gallon capital expenditures as unfeasible. Further, higher capital costs increase perceived project risk and reduce the likelihood of obtaining investment funding.

There is still a significant need for R&D in biofuels and bioproducts facilities. Priority should go to technology investments that can significantly reduce the capital and operating costs of advanced biofuels and biochemicals. This should include funding additional basic research, targeted research on specific elements of processes, and programs that address operational issues of early pilot and/or demonstration facilities.



Additional needs include development of technologies that have economics for early-stage plants that attract capital investment for subsequent expansion of similarly designed facilities. This targeted government investment in R&D and process optimization (in addition to stable and supportive policy) will enable the new industry to grow and prosper successfully.

<u>Potential Solutions</u>**:**

Discovery of solutions will require additional R&D in technology areas that allow significant reductions in the capital and operating costs of producing advanced biofuels and bioproducts. Research investments should be pursued that can demonstrate a capital and/or operating improvement that will allow the displacement of oil on a cost-competitive basis, including a reasonable return on capital. Research in the following areas within the conversion sector will help to address barriers:

*Pretreatment:*

Pretreatment technologies need improvement to provide efficient conversion of the feedstock into a higher concentration of sugars derived from a process with relatively low capital costs, and that minimize degradation of sugars and create inhibitory by-products.

*Fermentation:*

Capital costs for industrial fermentation of structural carbohydrates are excessive relative to capital costs for first-generation ethanol, biodiesel, and petrochemically derived chemicals. Fermentation needs to be viable in low-cost simple tanks with minimal aeration instead of highly specialized fermentation vessels.

Organisms need further improvement to handle a wider variety of feedstock hydrolysates, to utilize a variety of sugar types (i.e., glucose, sucrose, xylose, arabinose, etc.), and to be more robust to impurities in the hydrolysate.

*Thermochemical Catalysis:*

Compared to the knowledge that exists for converting petrochemical feedstocks, there is not a solid understanding of catalytic conversion of biomass feedstocks. There is a lack of knowledge about how reactions occur on the surface of catalysts and how to limit the fouling and deactivation caused by impurities—regardless of whether the catalysis is based on deoxygenation, hydrogenation, hydrogenolysis, decarbonylation, or other chemistries. Biomass conversion systems are also more complex because of the predominance of water in the process systems. The attraction of these processes is that lignin can be utilized in addition to other feedstock components. There is warrant for expanded research to better link biomass processing with petrochemical processing.

*Separations:*



Separation processes are particularly difficult and costly because of the high amounts of water involved in biomass systems. Product concentrations in the hydrolysate are often lower than in petroleum systems. There is a need to develop new membrane technologies, novel molecular recognition systems, or other recovery strategies to significantly reduce capital and operating costs.

### *C. Market Incentives, Updated Distribution Infrastructure, and Consumer Adoption*

The major barrier of translating new biomass technologies to the marketplace is the absence of a reliable and sufficient market price for the fuel products. Traditional fuel prices are based on the market price of petroleum, which currently is 3–10 times its cost of production. Because crude oil producers have room to cut prices and remain profitable, today's fuel price is a "moving target." The result is a volatile market dynamic for biofuels that renders the new industry uncompetitive.

<u>Potential Solutions</u>:

*Market Incentives:*

From a non-technical perspective, there is a need to make long-term commitments to policies to encourage use of renewable materials for the production of both biofuels and biochemicals. The capital markets require confidence that the policy will be in place long enough to ensure reasonable return on capital investments.

*Distribution Infrastructure:*

Recent advancements in biomass conversion technologies must be directed at accessing established feedstocks. Bench scale is needed to establish robust conversion technologies prior to deploying these technologies at large scale. From an engineering perspective, integrating unit operations is a challenge, especially since the scaling factor of one unit is substantially different. It is common to see a limit to unit size of biological operations that is different from the scalability of machinery. New early stage R&D can facilitate creation of new unit operation modules, but latter stage development must address integration of all elements of the process. Early stage R&D will need clear and compelling logic and analysis to elucidate how each part will successfully integrate into a whole process.

The intermediate infrastructure between feedstock production and conversion processing is widely recognized as an essential element of the value chain. This essential infrastructure must create value for both the upstream feedstock element and the downstream conversion sector. In order to better utilize low-cost waste streams, logistics and conversion processes need to become more robust in order to handle the diversity that is inherent to biomass feedstocks. Specific needs include the following:

- Matching of the most appropriate conversion technologies to available amounts of waste streams
- Limited research on preprocessing of waste materials
- Inefficient handling of MSW
- Feedstock specifications by conversion facilities are not standardized
- Reticence on the part of concerned citizens over the change in use of waste streams and the conversion processes in which they will be used.

| | Near Term | Mid Term | Long Term |
|---|---|---|---|
| **Policy** | • Create a floor price for biofuels<br>• RFS goals must encourage use of renewable materials | | |
| **Feedstocks** | **During the next five years, access 200 million tons of aggregated low-cost feedstocks. Examples include MSW, woody residues, industry wastes, manures, etc.**<br>• Determine technology readiness levels for low-cost feedstocks and develop strategies<br>• Early use of non-conventional feedstocks<br>• Leverage first-generation production for second-generation systems<br>• Expand acreage and seed development of novel crops<br>• Develop agricultural system models and analytics that provide for decision support on societal issues | **During the next 5–10 years, access 600 million tons of feedstocks. Bring ag-derived feedstock online through new farming systems technologies and intensify feedstock production**<br>• Optimize existing production acreage, or "added virtual acres"<br>• Implement broad-based crop rotations that are synergistic with food crop production<br>• Access mature agricultural residues and processing wastes<br>• Access silviculture production resources | **Beyond the next 10 years, access 1 billion tons of feedstocks annually**<br>• Access purpose-grown feedstock crops resulting from modern plant breeding and genetics R&D<br>• Link feedstock resources to the correct conversion process, including biobased products and biochemicals<br>• Implement algae-based production systems |
| **Conversion** | **Capture the successes of previously funded R&D projects**<br>• Ensure that current integrated biorefineries are completed and begin production<br>• Capture lessons learned from terminated integrated biorefineries in order to provide insight and keep future paths moving toward technical breakthroughs and commercialization goals<br>• Ensure that knowledge is shared among federal agencies and transferred to industry<br>• Enable more demonstrations and pilot projects through science-based competitive processes<br>• Establish policy to provide a "floor" for stability in biofuels prices compared to petroleum<br>• Support research on specialty and high-value co-products derived from biomass to enable the production of fuels<br>• Support research on novel separations technology to help lower capital costs | **Commence a national effort on next-generation biofuels**<br>• Develop new technologies that focus on enabling new molecules; conversion technologies focused on hydrocarbons, such as biobased diesel and jet fuel. Refine thermochemical catalysis, metabolic engineering/synthetic biology, and separations technologies. Develop fuels that are compatible with the existing delivery infrastructure<br>• Facilitate research on separations and other core processes that would reach several technologies, have a significant impact on the industry, and improve yields<br>• Optimize the loan guarantee process to realistically recognize risk of new biofuels/bioproducts plants<br>• Support implementation of distributed facilities to perform preliminary processing with final conversion conducted at larger, more centralized refining facilities. This should reduce both capital and operating costs | |
| **Infrastructure/ Logistics** | **Establish industry standards for feedstock characterization**<br>• Review existing relevant research and specification limits of existing supply chains<br>• Implement systems R&D programs to optimize the mass and energy balances of the complete supply chain while capturing maximum efficiencies throughout; *replacing the whole barrel while using the whole plant*<br>• Conduct feasibility analyses between large centralized biorefineries and distributed pretreatment facilities | **Demonstrate numerous feedstock supply chains that correspond to feedstock development goals**<br>• Solicit proposals to integrate biomass producers, communities, facility operators, equipment manufacturers, transporters, and end users. Establish multiple examples of functioning supply chains, which represent real-world examples of collecting, preprocessing, and shipping biomass to the various end users that facilitate the nation in meeting the Grand Challenge | **Aggregate, process, blend, and store feedstocks in order to "Use the Whole Plant"**<br>• Establish processes to efficiently deconstruct, increase energy density, remove oxygen, improve handling, and stabilize during storage<br>• Develop processes to improve handling and storage at the refinery<br>• Demonstrate improved separation processes in order to "Replace the Whole Barrel"<br>• Demonstrate improved distribution logistics of conversion products and co-products, including distribution of drop-in fuels that consist of molecules similar to petroleum-derived fuels, as well as products that do not have petroleum counterparts |

## Action Items for Potential Solutions:

The following are more detailed action items over the short, mid, and long term to implement the potential solutions described above.

### *Policy*

Short Term:

Establish a reasonable "floor price" for renewable fuels.

- Establish a national policy that creates a floor price for biofuels. Under the policy's guidelines, there will be no support given if market prices remain above the floor; however, there will be support provided if prices drop below a "reasonable" floor price.

### *Feedstocks*

Short Term:

During the next five years, access 200 million tons of aggregated low-cost feedstocks. Examples include MSW, woody residues, industry wastes, manures, etc.



- Conduct workshops to determine technology readiness levels for low-cost feedstocks and develop strategies.
- Early use of non-conventional feedstocks (waste streams) to drive down costs of conversion technologies and processes.
- Leverage first-generation production assets for second-generation systems (for instance, leverage corn ethanol facilities to implement cellulosic ethanol production).
- Expand acreage and seed development of novel crops.
- Develop farming system models and analytics that provide for decision support on societal issues (e.g., food versus non-food feedstocks, land-use change, carbon footprint, etc.).

Mid Term:

During the next 5–10 years, access 600 million tons of feedstocks. Bring ag-derived feedstocks online through new farming systems technologies and intensified feedstock production.

- Optimize existing production acreage, or "added virtual acres."
- Implement broad-based crop rotations that are synergistic with food crop production.
- Access mature agricultural residues and processing wastes.
- Access silviculture production resources.

Long Term:

Beyond the next 10 years, access 1 billion tons of feedstocks annually.

- Access purpose-grown feedstock crops resulting from modern plant breeding and genetics R&D.
- Link feedstock resources to the correct conversion process, including biobased products and biochemicals.

- Implement algae-based production systems.

### *Conversion*

Short Term:

Capture the successes of previously funded R&D projects.

- Ensure that current integrated biorefineries are completed and begin production.
- Objectively capture lessons learned from terminated integrated biorefineries in order to provide insight and keep future paths moving toward technical breakthroughs and commercialization goals.
- Ensure that knowledge is shared among federal agencies and transferred to industry.
- Enable more demonstrations and pilot projects through science-based competitive processes.
- Establish policy to provide a "floor" for stability in biofuels prices compared to petroleum.
- Support research on specialty and high-value co-products derived from biomass to enable the production of fuels.
- Support research on novel separations technology to help lower capital costs.



Mid and Long Term:

Commence a national effort on next-generation biofuels.

- Develop new technologies that focus on enabling new molecules; conversion technologies focused on hydrocarbons, such as biobased diesel and jet fuels. Refine thermochemical catalysis, metabolic engineering and synthetic biology, and separations technologies. Develop fuels that are compatible with the existing delivery infrastructure.[t]
- Facilitate research on separations and other core processes that would reach several technologies, have a significant impact on the industry, and improve yields.
- Optimize loan guarantee processes to realistically recognize risk of new biofuels/bioproducts plants.
- Support implementation of distributed facilities to perform preliminary processing with final conversion conducted at larger, more centralized refining facilities. This should reduce both capital and operating costs.

### *Infrastructure and Logistics*

Short Term:

Establish industry standards for feedstock characterization.

- Review existing relevant research and specification limits of existing supply chains.
- Implement systems R&D programs to optimize the mass and energy balances of the complete supply chain while capturing maximum efficiencies throughout; *replacing the whole barrel while using the whole plant*.
- Conduct feasibility analyses between large centralized biorefineries and distributed pretreatment facilities.

Mid Term:

Demonstrate numerous feedstock supply chains that correspond to feedstock development goals (discussed above in the feedstock section).

- Solicit proposals to integrate biomass producers, communities, facility operators, equipment manufacturers, transporters, and end users. Establish multiple examples of functioning supply chains, which represent real-world examples of collecting, preprocessing, and shipping biomass to the various end users that facilitate the nation in meeting the Grand Challenge.

Long Term:

Aggregate, process, blend, and store feedstocks in order to “Use the Whole Plant.”

- Establish processes to efficiently deconstruct, increase energy density, remove oxygen, improve handling, and stabilize during storage.
- Develop processes to improve handling and storage at the refinery.
- Demonstrate improved separation processes in order to “Replace the Whole Barrel.”
- Demonstrate improved distribution logistics of conversion products and co-products, including distribution of drop-in fuels that consist of molecules similar to petroleum-derived fuels, as well as products that do not have petroleum counterparts.