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Program Barriers Addressed

Feedstock Integration

Ft-A. Resource Availability and Cost: The lack of credible data on price, location, quality and quantity of biomass creates uncertainty for investors and developers of emerging biorefinery technologies. In addition to a lack of information regarding national cellulosic biomass production, current estimates of feedstock resources are limited in scope, and do not consider how major technological advantages in production technologies will impact biomass availability. Due to the diversity and wide distribution of biomass feedstock resources, a regional approach is required to complete a more detailed assessment of the resources initially identified in the Billion Ton study. Feedstock supply is a significant cost component of bio-based fuels, products, and power.

Ft-B. Sustainable Production: Existing data on the environmental effects of feedstock production and residue collection are not adequate to support lifecycle analysis of biorefinery systems. The lack of information and decision support tools to predict effects of residue removal as a function of soil type, and the lack of a selective harvest technology that can evenly remove only desired portions of the residue make it difficult to assure that residue biomass will be collected in a sustainable manner. Until the residue issue is addressed, particularly with regard to corn stover, deployment of the Agricultural Residue pathway will be severely constrained. The production and use of perennial energy crops also raise a number of sustainability questions (such as water and fertilizer inputs, establishment and harvesting impacts on soil, etc.) that have not been comprehensively addressed.

Ft-C. Crop Genetics: Current crops and potential new crops require improvement to achieve the production potential estimates of the billion ton vision. There is inadequate information on plant biochemistry as well as insufficient genomic and metabolic data on many potential biomass crops. Genetic modification of energy crops for improved characteristics may create risks to native populations of related species, and any modification of commodity crops to improve residue characteristics may affect grain values.

Ft-D. Sustainable Harvest: Current crop harvesting machinery is unable to selectively harvest desired components of biomass and address the soil carbon and erosion sustainability constraints. Biomass variability places high demand and functional requirements on biomass harvesting equipment. Current systems cannot meet the capacity, efficiency, or delivered price requirements of large cellulosic biorefineries, nor can they effectively deal with the large biomass yields per acre of potential new biomass feedstock crops. In addition, feedstock specifications and standards against which to engineer harvest equipment, technologies, and methods, do not currently exist

Ft-G. Feedstock Quality and Monitoring: Physical, chemical, microbiological, and post-harvest physiological variations in feedstocks arising from differences in variety, geographical location, and harvest methods are not well understood. Passive, noninvasive analytical tools and sensors for rapid and/or real-time compositional and conversion efficiency measurements for cellulosic feedstocks are needed. In addition, processor standards and specifications for feedstocks are not currently available.

Ft-H. Storage Systems: Engineering analysis of unconventional storage methods, including centralized versus distributed systems, is needed to define storage requirements. Key elements requiring better understanding include in storage biomass losses, infrastructure for packaged (i.e., bale, silage wrap, etc.) and bulk stored biomass, storage bulk density, and post-harvest physiology of storage systems. These storage elements need to be understood as a function of feedstock source, biomass moisture, climate, storage time, and cost. Stored biomass that is or becomes wet is susceptible to spoilage, rotting, spontaneous combustion, and odor problems, therefore, the impact of these post-harvest physiological processes must be controlled to the benefit of biorefining processes.

Ft-J. Biomass Material Properties: Data on biomass quality and physical property characteristics for optimum conversion are limited. Information on functional moisture relations on quality and physical properties of biomass as affected by crop variability and climatic conditions during harvest and post-harvest operations is incomplete. Methods and instruments for measuring physical and biomechanical properties of biomass are lacking.

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

Ft-L. Biomass Material Handling and Transportation: The capital and operating costs for the existing package-based (i.e., bales, modules, pellets, etc.) equipment and facilities are not cost effective. The low density and fibrous nature of cellulosic biomass make it difficult and costly to collect, handle and transport. Present methodologies for collecting, storage handling, transport, and in-biorefinery handling of the biomass are too costly and inefficient for handling million ton quantities of biomass in a manner compliant with the efficiency and permitting requirements of cellulosic biorefineries.

Ft-M. Overall Integration: Existing biomass collection, handling, and transport systems are not designed for the large-scale needs of integrated biorefineries. Feedstock logistics infrastructure has not been defined for various locations, climates, feedstocks, storage methods, etc. The lack of experience with integrating time-sensitive collection, storage, transportation and delivery operations to ensure year-round supply of large amounts of biorefinery feedstock is a barrier to widespread implementation of biorefinery technology. The lack of data on variability of biomass resources and how this variability affects shelf life and processing yields are further barriers. In addition, it may be possible to better integrate one or more aspect of the feedstock supply system either alone or in combination with biorefinery operations. The lack of a quantitative analysis that assesses the benefits and drawbacks of these potential integration options is a potential barrier to cost savings and biorefinery efficiency improvement.

Biochemical Conversion

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

Bt-B. Biomass Variability: The characteristics of biomass can vary widely in terms of physical and chemical composition, size, shape, moisture content, and bulk density. These variations can make it difficult (or costly) to supply biorefineries with feedstocks of consistent, acceptable quality year-round, and also feedstock variability affects overall conversion rate and product yield of biomass conversion processes.

Bt-C. Biomass Recalcitrance: Lignocellulosic biomass feedstocks are naturally resistant to chemical and/or biological degradation. The fundamental role of biomass structure and composition and the critical physical and chemical properties that determine the susceptibility of cellulosic substrates to hydrolysis are not well understood. This lack of understanding of the root causes of the recalcitrance of biomass limits the ability to focus efforts to improve the cost-effectiveness and efficiency of pretreatment and other fractionation processes.

Bt-D. Pretreatment Chemistry: Thermochemical prehydrolysis of biomass, typically referred to as pretreatment, is required to break down the structure of biomass and increase its susceptibility to subsequent enzymatic hydrolysis by cellulase enzymes. The critical physical and chemical properties that determine the susceptibility of cellulosic substrates to hydrolysis and the role that lignin and other pretreatment products play in impeding access to cellulose are not well enough understood. Continued significant cost reductions in pretreatment technologies via improved sugar yields and quality require developing a better understanding of pretreatment process chemistries, including the kinetics of hemicellulose and cellulose hydrolysis.

Bt-E. Pretreatment Costs: Pretreatment reactors typically require expensive materials of construction to resist acid or alkali attack at elevated temperatures. In addition, the impact of reaction configuration and reactor design on thermochemical cellulose prehydrolysis is not well understood. Developing lower-cost pretreatments depends on the ability to process the biomass in reactors designed for maximum solid levels and fabricated out of cost-effective materials.

Bt-F. Cellulase Enzyme Production Cost: Cellulase enzymes remain a significant portion of the projected production cost of sugars from cellulosic biomass. Cost-effective enzyme production technologies are not currently available, although significant progress has been made through concerted efforts with industrial enzyme producers.

Bt-G. Cellulase Enzyme Loading: Reducing the cost of enzymatic hydrolysis depends on identifying more efficient enzyme preparations and enzyme hydrolysis regimes that permit more cost-effective and lower ratios of enzyme to substrate to be used.

Bt-H. Enzyme Biochemistry: Currently available enzymes do not exhibit the high thermostability and substantial resistance to sugar end-product inhibition. Developing enzymes that enable low-cost enzymatic hydrolysis technology requires more understanding of the fundamental mechanisms underlying the biochemistry of enzymatic cellulose hydrolysis, including the impact of biomass structure on enzymatic cellulose decrystallization. Additional efforts aimed at understanding the role of cellulases and their interaction not only with cellulose but also the process environment is needed to affect further reductions in cellulase cost.

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

Bt-J. Fuels Organism Development: Fermentation organisms used today have not been optimized for production of liquid fuels (ethanol, butanol and other alcohols) from the sugar mixture in the hydrolyzate broth produced during biomass pretreatment and enzymatic hydrolysis. For example, current organisms are not capable of utilizing the five-carbon sugar components, xylose and arabinose, in the biomass hydrolyzate as efficiently as glucose. In addition, impurities generated during pretreatment inhibit the organism, resulting in slow fermentations and incomplete utilization of sugars; this can lead to the need for costly purification. Improvements in fermentative organisms to perform in hydrolysate broths can significantly lower capital costs.

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

Bt-L. Biochemical/Thermochemical Processing Integration: Integration of the entire biorefinery is the final conversion barrier and overcoming it will require successful integration at the interfaces between the biochemical and thermochemical processes. For example, the lignin residue can be used as a feedstock for syngas or bio-oil production and for subsequent conversion to combined heat and power, fuels, or chemicals. Without planned and managed integration, the complete picture of biomass conversion to fuels and chemicals will not be clear enough to attract potential developers because the risks of commercialization will be too high for financiers. As conversion technologies mature, higher levels of integration will be feasible and second generation biorefineries are envisioned to be closely coupled biochemical / thermochemical facilities enabling the most efficient use of a wide range of feedstocks.

Thermochemical Conversion

Tt-A. Feeding Dry Biomass: In the near term, there are no significant barriers to feeding and handling dry wood or agricultural residues in atmospheric systems provided they are of a relatively uniform particle size. In the longer term, there is a need for improvements in the processing and feeding of dry biomass including densification and removal of problematic chemical contaminants (e.g. alkali species). Demonstrating reliable feeding of dry biomass into pressurized systems is also needed.

Tt-B. Feeding or Drying Wet Biorefinery Streams: There is a need to understand the costs and trade-off of drying or feeding wet biorefinery residues such as wet lignin-rich fermentation residues. Innovative dryer designs capable of utilizing low-value process heat will be important to the integrated biorefinery.

Tt-C. Gasification of Wood, Biorefinery Residue Streams and Low Sugar Content Biomass: There is a need to understand the fuel chemistry and physical handling properties of other biomass feedstocks, minor byproducts and co-products, and biorefinery residual solids. This includes developing an understanding of gasification options and their chemistries for materials including wood, spent pulping liquors, agricultural residues that are high in minerals, high-lignin feedstocks and residues, and high-moisture organic residues.

Tt-E. Pyrolysis of Biomass: Development of new methods to control the pyrolytic pathways to bio-oil intermediates in order to increase product yield and recovery is needed. These product quality improvements are important to achieving the stability specifications of the resulting bio-oil and may also result in more favorable chemistry for processing in conventional petroleum refineries. New methods to clean and stabilize the bio-oil intermediate are also needed to ensure the product is compatible with refining technology. These advances include improved hydrotreating catalysts and techniques for processing the bio-oil.

Tt.-F. Syngas Cleanup and Conditioning: There is a near-term need for gas cleaning and conditioning technology that can cost-effectively remove contaminants such as tar, particulates, alkali, and sulfur. The interactions between the catalysts used for gas cleanup and conditioning, and the gasification conditions and feedstock are not well understood. These interactions require careful attention to trace contaminants.

Tt-G. Fuels Catalyst Development: Gasification Route – The production of mixed alcohols from syngas has been known since the beginning of the last century; however, the commercial success of mixed alcohol synthesis has been limited by poor selectivity and low product yields. Improved catalysts with increased productivity and selectivity to higher alcohols are required to enable viable capital and operating costs.

Pyrolysis Route – The pyrolysis of biomass has been studied for some time, however, additional improvements in pyrolytic processing with or without catalysts to yield higher quality bio-oil will help reduce upgrading costs and allow for greater commercial viability. Furthermore, the development of robust catalysts for the upgrading of pyrolysis oil in production of liquid transportation fuels is also important to the economic viability of the process. The catalysts must afford high selectivity to the desired end product, be robust with respect to the pyrolysis oil impurities, and have high conversion rates and long lifetimes. Improvement to the robustness of hydrocracking catalysts for producing hydrocarbon biofuels via pyrolysis is also needed.

Tt-H. Validation of Syngas Quality: Syngas quality specifications for production of liquid fuel products like methanol/dimethyl ether (MeOH/DME), mixed alcohols and hydrocarbon liquids are reasonably well known. However, validation that syngas from biomass can meet the rigorous quality specification needed for the production of liquid fuels via catalytic synthesis is still needed.
Tt-I. Sensors and Controls: Effective process control will be needed to maintain plant performance and regulate emissions at target levels with varying load, fuel properties, and atmospheric conditions. Commercial control systems need to be developed for thermochemical processes and systems.

Integrated Biorefineries

Im-A. Inadequate Supply Chain Infrastructure: The uncertainty of a sustainable supply chain and the associated risk are major barriers to procuring capital for start-up biorefineries. The lack of operating biorefineries to create the demand for biomass exacerbates the problem. Once demand is established, the infrastructure will grow. Producing and delivering bioenergy products in large volumes will require dramatic capital investments throughout the supply chain—from feedstock production and transport through conversion processing and product delivery.
Im-B. Agricultural Sector-Wide Paradigm Shift: Energy production from biomass on a large scale will require careful evaluation of U.S. agricultural resources and logistics, as these will likely require a series of major system changes that will take time to implement. Current harvesting, storage, and transportation systems are inadequate for processing and distributing biomass on the scale needed to support dramatically larger volumes of biofuels production.
Im-C. Lack of understanding of environmental/ energy tradeoffs: A systematic evaluation of the impact on the environment and food supply for humans and animals of expanded biofuels production and use is lacking. Analytical tools to facilitate consistent evaluation of energy benefits and greenhouse gas emission impacts of all potential biofuels feedstock and production processes is needed.

Im-D. High Risk of Large Capital Investments: Once emerging biomass technologies have been developed and tested, they must be commercially deployed. Financial barriers are the most challenging aspect of technology deployment. Capital costs for commercially viable facilities are relatively high, and securing capital for unproven technology can be extremely difficult. For private investors to confidently finance biomass technology, the technology must be fully demonstrated as technically and commercially competent. Government assistance at the demonstration stage to accelerate proof of performance is critical to successful deployment.

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

Im-F. Cost of Production: An overarching market barrier for biomass technologies is the inability to compete, in most applications, with fossil energy supplies and their established supporting facilities and infrastructure. Uncertainties in fossil energy price and supply continue to exert upward pressure on the price of petroleum-derived fuels and products. Nevertheless, reductions in production costs along the biomass supply chain are needed to make bio-based fuels and products competitive in these markets.

It-A. End-to-End Process Integration: Successful advances in biochemical processes and the biorefinery concept are co-dependent. This biorefinery concept encompasses a wide range of technical issues related to collecting, storing, transporting, and processing diverse feedstocks, as well as the complexity of integrating several innovative process steps, thus entailing considerable technical risk. The challenge of feed-to-product process integration is crucial, as it impacts both performance and profitability.

It-B. Commercial-Scale Demonstration Facilities: As with all new process technologies, demonstrating sustained integrated performance that meets technical, environmental and safety requirements at sufficiently large scale is an essential step toward commercialization. Demonstration facilities that are capable of testing and validating new technologies and integrated systems are critical to successful commercial deployment. Additionally, increased understanding of these combined systems will result in the optimization of process configurations. Integrating new bioenergy processes with existing biorefineries, while improving the efficiency of all biorefineries, are two critical areas of focus for the platform.

It-C. Risk of Pioneer Technology: The first biorefineries will incorporate a variety of new technologies. The number of new process steps implemented in a demonstration project has been shown to be a strong predictor of future performance shortfalls. Heat and mass balances, and their implications, are not likely to be well understood in regard to new technologies. In addition, the impact of unanticipated buildup of impurities in process streams that can result in abrasion and corrosion of plant equipment and deactivation of process catalysts is not well understood.

It-D. Sensors and Controls: Effective process control will be needed to maintain plant performance and emissions at target levels because of variability in processing conditions, load, feedstock and intermediate stream properties. Development of new sensors and analytical instruments is needed to optimize control systems for biochemical and thermochemical systems. There are several key technical barriers to consider, including the lack of real-time sensors for measuring feedstock moisture and composition, the need for better tools to analyze various process streams, and the lack of process control systems for reactor systems and subsystems.

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

Biofuels Distribution and End Use

Dm-A. Lack of Biofuels Distribution Infrastructure: The lack of infrastructure to transport, store and dispense biofuels puts biofuels at a disadvantage compared to conventional fuels that already have mature infrastructure. Today's biofuels distribution infrastructure, which includes about 1,000 E85 fueling stations, is concentrated in the Midwest, near the feedstocks (corn and soybeans) and ethanol and biodiesel production facilities. To contribute significantly to the 20 in 10 volumetric goal, expansion beyond this region of the country will be required.

Dm-B. Availability of Biofuels-Compatible Vehicles: About six million ethanol FFVs have been manufactured for the U.S. market, at a price competitive with conventional vehicles. However, at this time, only a limited number of vehicle model/fuel type combinations exist. In addition, most FFVs on the road today use less than 4 gallons of E85 per year due to the limited number of E85 pumps across the U.S.

Dm-C. Industry and Consumer Acceptance and Awareness: To be successful in the marketplace, biomass-derived products must perform at the same level or better than the existing fossil-energy-based products. Industry partners and consumers must believe in the quality, value and safety of biomass-derived products and their benefits.

Dt-A. Ethanol Pipeline Distribution Issues: Ethanol is a stronger solvent than the petroleum products moved via pipeline today. Consequently, ethanol will remove water, rust, gums and other contaminants from the existing petroleum pipeline distribution system. This downgrades the value of the delivered ethanol and adds back-end costs to restore the fuel to meet specifications. Construction of new dedicated ethanol pipelines are limited by the high cost of capital investment, insufficient ethanol supplies, materials compatibility issues, technologies that can measure quality in real time, and existing right-of-way agreements.

Dt-B. Limited Information Available for Developing Codes and Standards: National organizations that develop codes and standards recognize that additional date is required to integrate biofuels into the model codes for infrastructure construction. Thousands of local code jurisdictions in the U.S. adopt and modify these model codes for use in their jurisdictions. At this time, insufficient technical information hinders revision of various codes and standards in support of the quickly accelerating biofuels industry. Lack of codes as well as costly project permitting processes can stymie the introduction of new technologies, including infrastructure, into the marketplace.

Dt-C. Materials Compatibility Issues of Alcohol Fuels: Alcohol fuels and alcohol fuel blends require components throughout the infrastructure system (e.g., fuel storage, pipes and piping, and on-board vehicle systems) that are compatible with the higher electrical conductivity and solubility of the fuel. Higher cost materials, including stainless steel, lined fiberglass tanks, and mild steel with epoxy coatings, are often required to ensure compatibility and mitigate risk of decay or failure.

Dt-D. Increased Evaporative Hydrocarbon Emissions of Ethanol Blends: Adding ethanol to gasoline increases the fuel volatility, as measured by its Reid vapor pressure (RVP). The higher RVP results in higher evaporative hydrocarbon emissions from ethanol blends than from straight gasoline. Ethanol in gasoline also increases the permeability of plastic on-board fuel tanks, which in turn contributes to increased evaporative emissions.

Dt-E. Ethanol Blend Vehicle Fuel Economy: Since ethanol has a lower heating value than gasoline (83,000 Btu/gal for E85 vs. 113,500 Btu/gal for gasoline), E85 delivers a lower fuel economy when compared to gasoline on a gallon by gallon basis. Lower fuel economy can be counteracted by optimizing the engine design to take advantage of the higher octane rating of E85 (98 for E85 vs. 87 for gasoline).

Sustainability

St-A. Scientific Consensus on Bioenergy Sustainability. There is no scientific consensus on the meaning of sustainability and key elements surrounding how bioenergy sustainability should be measured (such as definitions, approaches, system boundaries, and time horizons).

St-B. Consistent, Defensible Message on Bioenergy Sustainability. The prevalence of misrepresentations of the impacts of bioenergy – including assumptions and modeling that lack empirical underpinnings – creates confusion about the benefits of bioenergy production and leaves the industry vulnerable to criticism.

St-C. Sustainability Data across the Supply Chain. A fundamental hurdle is the lack of data by which to evaluate sustainability along the supply chain and compare impacts of one pathway to another. The lack of adequate, accessible, temporal and spatial data for measuring sustainability criteria hinders other critical activities such as establishing baselines, determining targets for improvement, recommending best practices, and evaluating tradeoffs.

St-D. Indicators and Methodology for Evaluating Sustainability. There are few operationally practical and effective methods to develop metrics, define baselines, set targets, and conduct life-cycle assessments to determine the impacts of bioenergy relative to other energy alternatives.

St-E. Best Practices for Sustainable Bioenergy Production. Because bioenergy production is relatively new, no "best practices" are defined for each component of the bioenergy supply chain.

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

St-G. Representation of Land Use. The inability of existing data sources to capture the actual state of the landscape, a poor understanding of the processes that drive land-use change (LUC), and the lack of knowledge about the environmental and social consequences of LUC associated with bioenergy production, have undermined efforts to assess the environmental and social effects of bioenergy.

Algae

Al-A. Algae Production

Al-B. Algal Fuel Production

1. Wet Mill Improvements Pathway	
Milestone #	**Milestone Title**
M.1	***Complete systems level demonstration and validation of technologies to improve corn wet mill facilities using corn grain feedstock***
M.1.1	Demonstrate and validate economical residual starch conversion in a wet mill
M.1.1.1	Convert residual starch in fiber stream to EtOH
M.1.1.2	Evaluate new feed product
M.1.1.3	Validate integrated process at pilot scale
M.1.1.4	Validate new process in wet mill
M.1.2	Demonstrate and validate economical fiber conversion to C5 and/or mixed C5/C6 sugars in a wet mill (residual starch also expected to be converted during fiber processing)
M.1.2.1	Solubilize hemicellulose in fiber to C5 sugars
M.1.2.2	Hydrolyze cellulose to C6 Sugar
M.1.2.3	Validate integrated process at pilot scale
M.1.2.4	Evaluate new feed product
M.1.2.5	Validate new process in wet mill
M.1.3	Demonstrate and validate economical conversion of mixed sugars to ethanol in a wet mill
M.1.3.1	Convert released sugars to ethanol
M.1.3.2	Validate integrated process at pilot scale
M.1.3.3	Validate new process in wet mill
M.1.4	Demonstrate and validate economical new products from C5 or mixed C5/C6 sugars in a wet mill
M.1.4.1	Convert released C5 sugars to products
M.1.4.2	Convert C5 sugars to building block chemicals
M.1.4.3	Convert mixed sugars to products
M.1.4.4	Convert mixed sugars to building block chemicals
M.1.4.5	Convert building block chemicals to products
M.1.4.6	Demonstrate product separation and recovery specification
M.1.4.10	Validate integrated process at pilot scale
M.1.4.11	Validate new process in wet mill
M.1.5	Demonstrate and validate economical new products from C6 sugars in a wet mill
M.1.5.1	Convert C6 sugars to products
M.1.5.2	Convert C6 sugars to building block chemicals
M.1.5.3	Convert building block chemicals to products
M.1.5.4	Demonstrate product separation and recovery specification
M.1.5.5	Validate integrated process at pilot scale
M.1.5.6	Validate new process in wet mill
M.1.6	Demonstrate and validate economical new products from corn-derived oils in a wet mill
M.1.6.1	Convert corn derived oils to products
M.1.6.2	Demonstrate product separation and recovery specification
M.1.6.3	Validate integrated process at pilot scale
M.1.6.4	Validate new process in wet mill
2. Dry Mill Improvements Pathway	
Milestone #	**Milestone Title**
M.2	***Complete systems level demonstration and validation of technologies to improve corn dry mill facilities using corn (or other) grain feedstock***

M.2.1	Demonstrate and validate economical residual starch conversion in a dry mill
M.2.1.1	Conversion of residual starch to glucose
M.2.1.2	Evaluate new feed product
M.2.1.3	Conversion of converted glucose to ethanol
M.2.1.4	Validate integrated process in a dry mill
M.2.2	Demonstrate and validate economical fiber conversion in a dry mill (residual starch also expected to be converted during fiber processing)
M.2.2.1	Convert fiber to monomer sugars
M.2.2.2	Evaluate new feed product
M.2.2.3	Validate integrated process at pilot scale
M.2.2.4	Validate new process in dry mill
M.2.3	Demonstrate and validate economical conversion of mixed sugars to ethanol in a dry mill
M.2.3.2	Convert released sugars to ethanol
M.2.3.4	Validate integrated process at pilot scale
M.2.3.5	Validate new process in dry mill
MI.1	Demonstrate and validate economical corn fiber-to-ethanol in a dry mill.
M.2.4	Demonstrate and validate economical conversion of mixed sugars to products in a dry mill
M.2.4.1	Conversion targets from C6 sugars to building blocks
M.2.4.2	Conversion targets from building blocks to products
M.2.4.3	Demonstrate product separation and recovery specification
M.2.4.4	Validate integrated process at pilot scale
M.2.4.5	Validate new process in dry mill
M.2.5	Demonstrate and validate economical new products from C6 sugars in a dry mill
M.2.5.1	Conversion targets from C6 sugars to building blocks
M.2.5.2	Conversion targets from building blocks to products
M.2.5.3	Product separation specification
M.2.5.4	Validate integrated process at pilot scale
M.2.5.5	Validate new process in dry mill
M.2.6	Demonstrate and validate economical front end fractionation processes in a dry mill
M.2.6.1	Derive additional value added products from front end fractionation
M.2.6.2	Evaluate new feed coproducts
M.2.6.3	Validate integrated process at pilot scale
M.2.6.4	Validate new process in dry mill
M.2.7	Investigate alternate sources for dry mill heat and power
M.2.7.1	Thermochemical processing of fiber stream to heat, power
M.2.7.2	Thermochemical processing of residues (i.e. corn stover) to heat, power
M.2.7.3	Validate integrated process at pilot scale
M.2.7.4	Validate new process in dry mill
3. Oil Mill Improvements Pathway	
Milestone #	**Milestone Title**
M.3	***Complete systems level demonstration and validation of technologies to improve oil processing mill facilities***
M.3.1	Demonstrate and validate economical and sustainable new oil crop production for production of biodiesel and other renewable diesel alternatives
M.3.1.1	Demonstrate sustainable agronomic practices
M.3.1.2	Demonstrate oil crop harvesting

M.3.1.3	Demonstrate oil crop storage
M.3.1.4	Demonstrate oil crop transportation
M.3.1.5	Demonstrate quality and quantity of oil crop available
M.3.1.6	Validate integrated oil crop logistics at pilot scale
M.3.1.7	Validate integrated oil crop logistics at demonstration scale
M.3.2	Demonstrate and validate economical new products from glycerol in a natural oil processing facility
M.3.2.1	Convert glycerol to products
M.3.2.2	Recover new products
M.3.2.3	Validate integrated process at pilot scale
M.3.2.4	Validate integrated process in natural oil processing facility
M.3.3	Demonstrate and validate economical new fuels from oils in natural oil processing facility
M.3.3.1	Convert oil to fuels
M.3.3.2	Recover fuels
M.3.3.3	Validate integrated process at pilot scale
M.3.3.4	Validate integrated process in natural oil processing facility
M.3.4	Demonstrate and validate economical new products from oils in natural oil processing facility
M.3.4.1	Convert oil to products
M.3.4.2	Convert oils to building block chemicals
M.3.4.3	Convert building block chemicals to products
M.3.4.4	Recover new products
M.3.4.5	Validate integrated process at pilot scale
M.3.4.6	Validate integrated process in natural oil processing facility
M.3.5	Demonstrate and validate economical cleanup of waste fats and greases for fuel production
M.3.5.1	Validate cleanup performance
M.3.5.2	Validate integrated cleanup at pilot scale
M.3.5.3	Validate integrated process in natural oil processing facility
4. Agricultural Residue Processing Pathway	
Milestone #	**Milestone Title**
M.4	***Complete systems level demonstration and validation of all key technologies to utilize agricultural residue feedstocks in existing or new facilities***
M.4.1	Demonstrate and validate integrated corn stover harvesting logistics
M.4.1.1	Demonstrate sustainable corn agronomic practices that account for corn stover harvesting
M.4.1.2	Demonstrate wet and dry corn stover harvesting
M.4.1.3	Demonstrate wet and dry corn stover storage
M.4.1.4	Demonstrate wet and dry corn stover transportation
M.4.1.5	Demonstrate wet and dry quality and quantity of corn stover available
M.4.1.6	Demonstrate corn stover preprocessing benefits
M.4.1.7	Validate integrated corn stover logistics in prototype equipment
M.4.1.8	Validate integrated corn stover logistics at demonstration scale
M.4.2	Demonstrate and validate integrated wheat straw harvesting logistics
M.4.2.1	Demonstrate sustainable wheat agronomic practices that account for wheat straw harvesting
M.4.2.2	Demonstrate wet and dry wheat straw harvesting
M.4.2.3	Demonstrate wet and dry wheat straw storage
M.4.2.4	Demonstrate wet and dry wheat straw transportation

M.4.2.5	Demonstrate wet and dry quality and quantity of wheat straw available
M.4.2.6	Demonstrate wheat straw preprocessing benefits
M.4.2.7	Validate integrated wheat straw logistics in prototype equipment
M.4.2.8	Validate integrated wheat straw logistics at demonstration scale
M.4.3	Demonsrate and validate integrated rice straw harvesting logistics
M.4.3.1	Demonstrate sustainable rice agronomic practices that account for rice straw harvesting
M.4.3.2	Demonstrate wet and dry rice straw harvesting
M.4.3.3	Demonstrate wet and dry rice straw storage
M.4.3.4	Demonstrate wet and dry rice straw transportation
M.4.3.5	Demonstrate wet and dry quality and quantity of rice straw available
M.4.3.6	Demonstrate rice straw preprocessing benefits
M.4.3.7	Validate integrated rice straw logistics in prototype equipment
M.4.3.8	Validate integrated rice straw logistics at demonstration scale
M.4.4	Feedstock FlexIbility and Availability via Blending Depot or Elevator
M.4.4.1	To be determined
M.4.5	Demonstrate and validate ag residue fractionation to produce mixed, dilute biomass sugars
M.4.5.1	Validate cellulase enzyme cost
M.4.5.2	Validate pretreatment technology cost
M.4.5.3	Demonstrate ability to economically satisfy internal heat and power demands
M.4.5.4	Validate capital cost
M.4.5.5	Validate integrated pretreatment and enzymatic hydrolysis at pilot scale
M.4.5.6	Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale
M.4.5.7	Validate feed flexibility in integrated system
M.4.6	Demonstrate and validate ethanol from 5 biomass sugars
M.4.6.1	Validate fermentation of all 5 sugars to produce ethanol
M.4.6.2	Optimize ethanol separation
M.4.6.3	Optimize integrated production of ethanol from sugars at pilot scale
M.4.6.4	Optimize integrated production of ethanol from sugars at demonstration scale
M.4.7	Demonstrate and validate chemical building blocks, chemicals or materials from 5 biomass sugars
M.4.7.1	Optimize chemical building blocks production
M.4.7.2	Optimize high value chemical production
M.4.7.3	Optimize product separation
M.4.7.4	Optimize integrated production of product(s) from sugars at pilot scale
M.4.7.5	Optimize integrated production of product(s)from sugars at demonstration scale
M.4.8	Demonstrate and validate high value chemical and material products from lignin intermediates
M.4.8.1	Demonstrate high value chemical/material production from lignin
M.4.8.2	Validate product separation
M.4.8.3	Validate integrated production of product(s)from lignin at pilot scale
M.4.8.4	Validate integrated production of product(s)from lignin at demonstration scale
M.4.9	Demonstrate and validate fuel products from lignin intermediates
M.4.9.1	Demonstrate direct fuel production from lignin
M.4.9.2	Validate fuel product separation
M.4.9.3	Validate integrated production of fuel(s)from lignin at pilot scale
M.4.9.4	Validate integrated production of fuels(s)from lignin at demonstration scale

M.4.10	Demonstrate and validate combined heat and power from lignin intermediates/residues
M.4.10.1	Demonstrate combined heat and power production from lignin
M.4.10.2	Validate integrated production of heat and power from lignin at pilot scale
M.4.10.3	Validate integrated production of heat and power from lignin at demonstration scale
M.4.11	Demonstrate and validate lignin gasification to produce syngas
M.4.11.1	Validate feeder system performance
M.4.11.2	Validate gasification performance
M.4.11.3	Validate gas cleanup performance
M.4.11.4	Validate capital costs
M.4.11.5	Validate integrated gasification and gas cleanup at pilot scale
M.4.11.6	Validate integrated gasification and gas cleanupat demonstration scale
M.4.12	Demonstrate and validate biomass gasification to produce syngas
M.4.12.1	Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems
M.4.12.2	Validate gasification performance
M.4.12.3	Validate gas cleanup performance
M.4.12.4	Validate capital costs
M.4.12.5	Validate integrated gasification and gas cleanup at pilot scale
M.4.12.6	Validate integrated gasification and gas cleanupat demonstration scale
M.4.12.7	Validate feed flexibility in integrated system
M.4.13	Demonstrate and validate ethanol from mixed alcohols using lignin or biomass derived syngas
M.4.13.1	Demonstrate ethanol production from mixed alcohols
M.4.13.2	Validate ethanol separation
M.4.13.3	Validate integrated production of ethanol from syngas at pilot scale
M.4.13.4	Validate integrated production of ethanol from syngas at demonstration scale
MT.19	Validate integrated corn stover/wheat straw-to-ethanol (via gasification) pilot operation.
M.4.14	Demonstrate and validate hydrogen production from lignin or biomass derived syngas
M.4.14.1	Demonstrate optimized hydrogen production from syngas
M.4.14.2	Validate hydrogen separation/recovery
M.4.14.3	Validate integrated production of hydrogen from syngas at pilot scale
M.4.14.4	Validate integrated production of hydrogen from syngas at demonstration scale
M.4.15	Demonstrate and validate combined heat and power production from lignin or biomass derived syngas
M.4.15.1	Demonstrate combined heat and power production from syngas
M.4.15.2	Validate integrated production of heat and power from syngas at pilot scale
M.4.15.3	Validate integrated production of heat and power from syngas at demonstration scale
M.4.16	Demonstrate and validate non-ethanol fuels from lignin or biomass derived syngas
M.4.16.1	Demonstrate non-ethanol fuel production from lignin or biomass-derived syngas
M.4.16.2	Validate non-ethanol fuel separation
M.4.16.3	Validate integrated production of non-ethanol fuels from syngas at pilot scale
M.4.16.4	Validate integrated production of non-ethanol fuels from syngas at demonstration scale
M.4.17	Demonstrate and validate product(s) from lignin or biomass derived syngas
M.4.17.1	Demonstrate high value chemical/material production (C3-C5 alcohols) from syngas
M.4.17.2	Validate product(s) separation
M.4.17.3	Validate integrated production of product(s) from syngas at pilot scale
M.4.17.4	Validate integrated production of product(s) from syngas at demonstration scale

M.4.18	Demonstrate and validate non-ethanol fuels from 5 biomass sugars that are econonomically viable
M.4.18.1	Validate fermentation of all 5 sugars to produce non-ethanol fuels
M.4.18.2	Optimize non-ethanol fuel separation
M.4.18.3	Optimize integrated production of non-ethanol fuels from sugars at pilot scale
M.4.18.4	Optimize integrated production of non-ethanol fuel from sugars at demonstration scale
M.4.19	Demonstrate and validate biomass pyrolysis to produce pyrolysis oil intermediate
M.4.19.1	Validate feeder systems to reliably feed solid biomass to pyrolysis reactor high pressure (30 bar) systems
M.4.19.2	Validate pyrolysis performance
M.4.19.3	Validate pyrolysis oil cleanup performance
M.4.19.4	Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount
M.4.19.5	Validate integrated pyrolysis and pyrolysis oil cleanup at pilot scale
M.4.19.6	Validate integrated pyrolysis and pyrolysis oil cleanup at demonstration scale
M.4.19.7	Validate feed flexibility in integrated system
M.4.20	Demonstrate and validate fuels from pyrolysis oil intermediate
M.4.20.1	Demonstrate fuel production from pyrolysis oil intermediate
M.4.20.2	Validate fuel separation
M.4.20.3	Validate integrated production of fuels from pyrolysis oil at pilot scale
M.4.20.4	Validate integrated production of fuels from pyrolysis oil at demonstration scale
M.4.21	Demonstrate and validate high value chemical and material products from pyrolysis oil intermediates
M.4.21.1	Demonstrate high value chemical/material production from pyrolysis oil
M.4.21.2	Validate product separation
M.4.21.3	Validate integrated production of product(s)from pyrolysis oil at pilot scale
M.4.21.4	Validate integrated production of product(s)from pyrolysis oil at demonstration scale
5. Perennial Crop Processing Pathway Milestones	
Milestone #	**Milestone Title**
M.5	***Complete systems level demonstration and validation of all key technologies to utilize perennial crops in existing or new facilities***
M.5.1	Demonstrate and validate integrated switchgrass production and harvesting logistics
M.5.1.1	Demonstrate sustainable switchgrass agronomic practices
M.5.1.2	Demonstrate wet and dry switchgrass harvesting
M.5.1.3	Demonstrate wet and dry switchgrass storage
M.5.1.4	Demonstrate wet and dry switchgrass transportation
M.5.1.5	Demonstrate quality and quantity of switchgrass available
M.5.1.6	Demonstrate switchgrass prepprocessing benefits
M.5.1.7	Validate integrated switchgrass logistics in prototype equipment
M.5.1.8	Validate integrated switchgrass logistics at demonstration scale
M.5.2	Demonstrate and validate integrated woody crop harvesting logistics
M.5.2.1	Demonstrate sustainable woody crop agronomic practices
M.5.2.2	Demonstrate woody crop harvesting
M.5.2.3	Demonstrate woody crop storage
M.5.2.4	Demonstrate woody crop transportation
M.5.2.5	Demonstrate quality and quantity of woody crops available
M.5.2.6	Demonstrate woody crop preprocessing benefits
M.5.2.7	Validate integrated woody crop logistics in prototype equipment
M.5.2.8	Validate integrated woody crop logistics at demonstration scale

M.5.3	Feedstock FlexIbility and Availability via Blending Depot or Elevator
M.5.3.1	To be determined
M.5.4	Demonstrate and validate switchgrass fractionation to produce mixed biomass sugars
M.5.4.1	Validate cellulase enzyme cost
M.5.4.2	Validate pretreatment technology cost
M.5.4.3	Demonstrate ability to economically satisfy internal heat and power demands
M.5.4.4	Validate capital cost
M.5.4.5	Validate integrated pretreatment and enzymatic hydrolysis at pilot scale
M.5.4.6	Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale
M.5.4.7	Validate feed flexibility in integrated system
M.5.5	Demonstrate and validate woody crop fractionation to produce mixed, dilute biomass sugars
M.5.5.1	Validate cellulase enzyme cost
M.5.5.2	Validate pretreatment technology cost
M.5.5.3	Demonstrate ability to economically satisfy internal heat and power demands
M.5.5.4	Valicate capital cost
M.5.5.5	Validate integrated pretreatment and enzymatic hydrolysis at pilot scale
M.5.5.6	Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale
M.5.5.7	Validate feed flexibility in integrated system
M.5.6	Demonstrate and validate ethanol from 5 biomass sugars
M.5.6.1	Validate ethanol production
M.5.6.2	Validate ethanol separation/recovery
M.5.6.3	Validate integrated production of product(s)from sugars at pilot scale
M.5.6.4	Validate integrated production of product(s)from sugars at demonstration scale
M.5.7	Demonstrate and validate products from 5 biomass sugars
M.5.7.1	Validate chemical building blocks production
M.5.7.2	Validate high value chemical production
M.5.7.3	Validate product separation
M.5.7.4	Validate integrated production of product(s)from sugars at pilot scale
M.5.7.5	Validate integrated production of product(s)from sugars at demonstration scale
M.5.8	Demonstrate and validate high value chemical and material products from lignin intermediates
M.5.8.1	Demonstrate high value chemical/material production from lignin
M.5.8.2	Validate product separation
M.5.8.3	Validate integrated production of product(s)from lignin at pilot scale
M.5.8.4	Validate integrated production of product(s)from lignin at demonstration scale
M.5.9	Demonstrate and validate fuel products from lignin intermediates
M.5.9.1	Demonstrate direct fuel production from lignin
M.5.9.2	Validate fuel product separation
M.5.9.3	Validate integrated production of fuel(s)from lignin at pilot scale
M.5.9.4	Validate integrated production of fuels(s)from lignin at demonstration scale
M.5.10	Demonstrate and validate combined heat and power from lignin intermediates/residues
M.5.10.1	Demonstrate combined heat and power production from lignin
M.5.10.2	Validate integrated production of heat and power from lignin at pilot scale
M.5.10.3	Validate integrated production of heat and power from lignin at demonstration scale
M.5.11	Demonstrate and validate lignin gasification to produce syngas

M.5.11.1	Validate feeder system performance
M.5.11.2	Validate gasification performance
M.5.11.3	Validate gas cleanup performance
M.5.11.4	Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount
M.5.11.5	Validate integrated gasification and gas cleanup at pilot scale
M.5.11.6	Validate integrated gasification and gas cleanup at demonstration scale
M.5.12	Demonstrate and validate biomass gasification to produce syngas
M.5.12.1	Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems
M.5.12.2	Validate gasification performance
M.5.12.3	Validate gas cleanup performance
M.5.12.4	Validate capital costs
M.5.12.5	Validate integrated gasification and gas cleanup at pilot scale
M.5.12.6	Validate integrated gasification and gas cleanupat demonstration scale
M.5.12.7	Validate feed flexibility in integrated system
M.5.13	Demonstrate and validate ethanol from mixed alcohols using lignin or biomass derived syngas
M.5.13.1	Demonstrate ethanol production from mixed alcohols
M.5.13.2	Validate ethanol separation
M.5.13.3	Validate integrated production of ethanol from syngas at pilot scale
M.5.13.4	Validate integrated production of ethanol from syngas at demonstration scale
M.5.14	Demonstrate and validate hydrogen production from lignin or biomass derived syngas
M.5.14.1	Demonstrate optimized hydrogen production from syngas
M.5.14.2	Validate hydrogen separation/recovery
M.5.14.3	Validate integrated production of hydrogen from syngas at pilot scale
M.5.14.4	Validate integrated production of hydrogen from syngas at demonstration scale
M.5.15	Demonstrate and validate combined heat and power production from lignin or biomass derived syngas
M.5.15.1	Demonstrate combined heat and power production from syngas
M.5.15.2	Validate integrated production of heat and power from syngas at pilot scale
M.5.15.3	Validate integrated production of heat and power from syngas at demonstration scale
M.5.16	Demonstrate and validate non-ethanol fuels from lignin or biomass derived syngas
M.5.16.1	Demonstrate non-ethanol fuel production from lignin or biomass-derived syngas
M.5.16.2	Validate non-ethanol fuel separation
M.5.16.3	Validate integrated production of non-ethanol fuels from syngas at pilot scale
M.5.16.4	Validate integrated production of non-ethanol fuels from syngas at demonstration scale
M.5.17	Demonstrate and validate product(s) from lignin or biomass derived syngas
M.5.17.1	Demonstrate high value chemical/material production (C3-C5 alcohols) from syngas
M.5.17.2	Validate product(s) separation
M.5.17.3	Validate integrated production of product(s) from syngas at pilot scale
M.5.17.4	Validate integrated production of product(s) from syngas at demonstration scale
M.5.18	Demonstrate and validate non-ethanol fuels from 5 biomass sugars that are econonomically viable
M.5.18.1	Validate fermentation of all 5 sugars to produce non-ethanol fuels
M.5.18.2	Optimize non-ethanol fuel separation
M.5.18.3	Optimize integrated production of non-ethanol fuels from sugars at pilot scale
M.5.18.4	Optimize integrated production of non-ethanol fuel from sugars at demonstration scale
M.5.19	Demonstrate and validate biomass pyrolysis to produce pyrolysis oil intermediate

M.5.19.1	Validate feeder systems to reliably feed solid biomass to pyrolysis reactor high pressure (30 bar) systems
M.5.19.2	Validate pyrolysis performance
M.5.19.3	Validate pyrolysis oil cleanup performance
M.5.19.4	Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount
M.5.19.5	Validate integrated pyrolysis and pyrolysis oil cleanup at pilot scale
M.5.19.6	Validate integrated pyrolysis and pyrolysis oil cleanup at demonstration scale
M.5.19.7	Validate feed flexibility in integrated system
M.5.20	Demonstrate and validate fuels from pyrolysis oil intermediate
M.5.20.1	Demonstrate fuel production from pyrolysis oil intermediate
M.5.20.2	Validate fuel separation
M.5.20.3	Validate integrated production of fuels from pyrolysis oil at pilot scale
M.5.20.4	Validate integrated production of fuels from pyrolysis oil at demonstration scale
M.5.21	Demonstrate and validate high value chemical and material products from pyrolysis oil intermediates
M.5.21.1	Demonstrate high value chemical/material production from pyrolysis oil
M.5.21.2	Validate product separation
M.5.21.3	Validate integrated production of product(s)from pyrolysis oil at pilot scale
M.5.21.4	Validate integrated production of product(s)from pyrolysis oil at demonstration scale
6. Forest Resources Processing	
Milestone #	**Milestone Title**
M.6	***Complete systems level demonstration and validation of technologies to improve pulp and paper mill facilities and/or produce additional products (fuels, chemicals and /or power) from wood feedstock in a pulp and paper mill environment***
M.6.1	Demonstrate and validate integrated logging residue and forest thinnings collection and logistics
M.6.1.1	Demonstrate sustainable logging practices
M.6.1.2	Demonstrate logging residue collection
M.6.1.3	Demonstrate forest thinnings collection
M.6.1.4	Demonstrate logging residue and forest thinnings transportation
M.6.1.5	Demonstrate quality and quantity of logging residue and forest thinnings available
M.6.1.6	Demonstrate logging residue and forest thinnings preprocessing benefits
M.6.1.7	Validate integrated logging residue and forest thinnings logistics in prototype equipment
M.6.1.8	Validate integrated logging residue and forest thinnings logistics at demonstration scale
M.6.2	Demonstrate and validate integrated fuel treatment biomass collection and logistics
M.6.2.1	Demonstrate fuel treatment biomass collection
M.6.2.2	Demonstrate fuel treatment biomass storage
M.6.2.3	Demonstrate fuel treatment biomass transportation
M.6.2.4	Demonstrate fuel treatment biomass quality and quantity of available
M.6.2.5	Demonstrate fuel treatment biomass preprocessing benefits
M.6.2.6	Validate integrated fuel treatment biomass logistics in prototype equipment
M.6.2.7	Validate integrated fuel treatment biomass logistics at demonstration scale
M.6.3	Demonstrate and validate forest resources fractionation to produce mixed, dilute biomass sugars
M.6.3.1	Validate cellulase enzyme cost
M.6.3.2	Validate pretreatment technology cost
M.6.3.3	Demonstrate ability to economically satisfy internal heat and power demands
M.6.3.4	Validate capital cost
M.6.3.5	Validate integrated pretreatment and enzymatic hydrolysis at pilot scale

M.6.3.6	Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale
M.6.3.7	Validate feed flexibility in integrated system
M.6.4	Demonstrate and validate ethanol from 5 biomass sugars
M.6.4.1	Validate fermentation of all 5 sugars to produce ethanol
M.6.4.2	Optimize ethanol separation
M.6.4.3	Optimize integrated production of ethanol from sugars at pilot scale
M.6.4.4	Optimize integrated production of ethanol from sugars at demonstration scale
M.6.5	Demonstrate and validate non-ethanol fuels from 5 biomass sugars
M.6.5.1	Validate fermentation of all 5 sugars to produce non-ethanol fuels
M.6.5.2	Optimize fuel separation
M.6.5.3	Optimize integrated production of non-ethanol fuels from sugars at pilot scale
M.6.5.4	Optimize integrated production of non-ethanol fuels from sugars at demonstration scale
M.6.6	Demonstrate and validate chemical building blocks, chemicals or materials from 5 biomass sugars
M.6.6.1	Optimize chemical building blocks production
M.6.6.2	Optimize high value chemical production
M.6.6.3	Optimize product separation
M.6.6.4	Optimize integrated production of product(s) from sugars at pilot scale
M.6.6.5	Optimize integrated production of product(s) from sugars at demonstration scale
M.6.7	Demonstrate and validate fuel products from lignin intermediates
M.6.7.1	Demonstrate direct fuel production from lignin
M.6.7.2	Validate fuel product separation
M.6.7.3	Validate integrated production of fuel(s) from lignin at pilot scale
M.6.7.4	Validate integrated production of fuels(s) from lignin at demonstration scale
M.6.8	Demonstrate and validate high value chemical and material products from lignin intermediates
M.6.8.1	Demonstrate high value chemical/material production from lignin
M.6.8.2	Validate product separation
M.6.8.3	Validate integrated production of product(s) from lignin at pilot scale
M.6.8.4	Validate integrated production of product(s) from lignin at demonstration scale
M.6.9	Demonstrate and validate combined heat and power from lignin intermediates/residues
M 6.9.1	Demonstrate combined heat and power production from lignin
M 6.9.2	Validate integrated production of heat and power from lignin at pilot scale
M 6.9.3	Validate integrated production of heat and power from lignin at demonstration scale
M 6.10	Demonstrate and validate lignin gasification to produce syngas
M 6.10.1	Validate feeder system performance
M 6.10.2	Validate gasification performance
M 6.10.3	Validate gas cleanup performance
M 6.10.4	Validate capital cost
M 6.10.5	Validate integrated gasification and gas cleanup at pilot scale
M 6.10.6	Validate integrated gasification and gas cleanup at demonstration scale
M 6.11	Demonstrate and validate cost-effective biomass gasification of wood, forest residues and other process residues and synthesis gas cleanup in a forest resources mill environment
M 6.11.1	Develop cost effective gasification designs for syngas production at appropriate scale
M 6.11.2	Validate feeder system performance to reliably feed solids to high pressure (30 bar) systems)
M 6.11.3	Validate gasification performance

M 6.11.4	Validate cost-effective gas cleanup performance
M 6.11.5	Validate integrated biomass gasification and syngas cleanup process at pilot scale
M 6.11.6	Validate integrated biomass gasification and syngas cleanup process in a forest resources mill environment
	Validate feed flexibility in integrated system
M 6.12	Demonstrate and validate production of ethanol from syngas in a forest resources mill environment
M 6.12.1	Produce mixed alcohols from syngas
M 6.12.2	Recover ethanol fuel product
M 6.12.3	Validate integrated process at pilot scale
M 6.12.4	Validate new process in a forest resources mill environment
M 6.13	Demonstrate and validate production of non-ethanol fuels from syngas in a forest resources mill environment
M 6.13.1	Produce non-ethanol fuel from biomass syngas
M 6.13.2	Recover fuel product
M 6.13.3	Validate integrated process at pilot scale
M 6.13.4	Validate new process in a forest resources mill environment
M 6.14	Demonstrate and validate hydrogen production from lignin or biomass derived syngas forest resources mill environment
M 6.14.1	Demonstrate optimized hydrogen production from syngas
M 6.14.2	Validate hydrogen separation/recovery
M 6.14.3	Validate integrated production of hydrogen from syngas at pilot scale
M 6.14.4	Validate integrated production of hydrogen from syngas at demonstration scale
M 6.15	Demonstrate and validate product(s) from lignin or biomass derived syngas forest resources mill environment
M 6.15.1	Demonstrate high value chemical/material productionfrom syngas
M 6.15.2	Validate product(s) separation
M 6.15.3	Validate integrated production of product(s) from syngas at pilot scale
M 6.15.4	Validate integrated production of product(s) from syngas at demonstration scale
M 6.16	Demonstrate and validate syngas utilization for combined heat and power in a forest resources mill environment
M 6.16.1	Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment
M 6.16.2	Validate CHP from syngas and/or direct use of sygas in process equipment
M 6.16.3	Validate integrated process at pilot scale
M 6.16.4	Validate new process in a forest resources mill environment
M 6.17	Demonstrate and validate bio-oil production to a stable intermediate forest resources mill environment
M 6.17.1	Validate bio-oil production
M 6.17.2	Validate bio-oil inermediate recovery
M 6.17.3	Validate integrated process for producing bio-oil at pilot scale
M 6.17.4	Demonstrate and validate new process in a forest resources mill environment
M 6.17.5	Validate feed flexibility in integrated system
M 6.18.	Achieve cost-effective conversion bio-oil intermediate into product(s) in a forest resources mill environment
M 6.18.1	Validate production of products from bio-oil
M 6.18.2	Validate bio-oil product(s) recovery
M 6.18.3	Validate integrated process for producing bio-oil product at pilot scale
M 6.18.4	Validate integrated process in a forest resources mill environment
M 6.19.	Achieve cost-effective conversion bio-oil intermediate into product(s) in a forest resources mill environment
M 6.19.1	Validate production of products from bio-oil
M 6.19.2	Validate bio-oil product(s) recovery
M 6.19.3	Validate integrated process for producing bio-oil product at pilot scale

M 6.19.4	Validate integrated process in a forest resources mill environment
M 6.20	Demonstrate and validate cost-effective extraction of C5 and C6 sugars from hemicellulose upstream of the pulp digestor in a pulp mill without negatively impacting paper quality
M 6.20.1	Meet yield target for C5 and C6 sugars without negatively impacting paper quality
M 6.20.2	Meet sugar upgrading requirements
M 6.20.3	Meet targets for recovery of other intermediates
M 6.20.4	Validate integrated sugar extraction process at pilot scale
M 6.20.5	Validate sugar extraction process in pulp and paper mill
M 6.21	Demonstrate and validate reliable and economic gasification of spent pulping liquor, recycle liquor causticization, chemical recovery and gas cleanup in a pulp mill
M 6.21.1	Validate reliable and economic performance of gasification of spent pulping liquor
M 6.21.2	Validate cost effective causticization and return Na based pulping chemicals
M 6.21.3	Validate advantages of co-gasification of spent pulping liquors and other forms of biomass (woody, recycle paper streams, and bio-oil)
M 6.21.4	Validate process chemical recovery from spent pulping liquor syngas
M 6.21.5	Validategas cleanup technologies on spent pulping liquor syngas
M 6.21.6	Validate integrated black liquor gasification, causticization, chemical recovery and gas cleanup process at pilot scale
M 6.21.7	Validate integrated black liquor gasification, causticization, chemical recovery and gas cleanup process in pulp and paper mill
7. Waste Processing Pathway	
Milestone #	**Milestone Title**
M.7	***Complete systems level demonstration and validation of technologies to process waste biomass streams to produce fuels, chemicals and /or power.***
M.7.1	Demonstrate and validate fractionation of carbohydrate rich waste streams to produce mixed, dilute biomass sugars
M.7.1.1	Validate cellulase enzyme cost
M.7.1.2	Validate pretreatment technology cost
M.7.1.3	Demonstrate ability to economically satisfy internal heat and power demands
M.7.1.4	Validate capital cost
M.7.1.5	Validate integrated pretreatment and enzymatic hydrolysis at pilot scale
M.7.1.6	Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale
M.7.1.7	Validate feed flexibility in integrated system
M.7.2	Demonstrate and validate ethanol from 5 biomass sugars
M.7.2.1	Validate fermentation of all 5 sugars to produce ethanol
M.7.2.2	Optimize ethanol separation
M.7.2.3	Optimize integrated production of ethanol from sugars at pilot scale
M.7.2.4	Optimize integrated production of ethanol from sugars at demonstration scale
M.7.3	Demonstrate and validate non-ethanol fuels from 5 biomass sugars
M.7.3.1	Validate fermentation of all 5 sugars to produce non-ethanol fuels
M.7.3.2	Optimize non-ethanol fuel separation
M.7.3.3	Optimize integrated production of non-ethanol fuels from sugars at pilot scale
M.7.3.4	Optimize integrated production of non-ethanol fuel from sugars at demonstration scale
M.7.4	Demonstrate and validate chemical building blocks, chemicals or materials from 5 biomass sugars
M.7.4.1	Optimize chemical building blocks production
M.7.4.2	Optimize high value chemical production
M.7.4.3	Optimize product separation
M.7.4.4	Optimize integrated production of product(s)from sugars at pilot scale

M.7.4.5	Optimize integrated production of product(s)from sugars at demonstration scale
M.7.6	Demonstrate and validate high value chemical and material products from lignin intermediates
M.7.6.1	Demonstrate high value chemical/material production from lignin
M.7.6.2	Validate product separation
M.7.6.3	Validate integrated production of product(s)from lignin at pilot scale
M.7.6.4	Validate integrated production of product(s)from lignin at demonstration scale
M.7.5	Demonstrate and validate fuel products from lignin intermediates
M.7.5.1	Demonstrate direct fuel production from lignin
M.7.5.2	Validate fuel product separation
M.7.5.3	Validate integrated production of fuel(s)from lignin at pilot scale
M.7.5.4	Validate integrated production of fuels(s)from lignin at demonstration scale
M.7.7	Demonstrate and validate combined heat and power from lignin intermediates/residues
M.7.7.1	Demonstrate combined heat and power production from lignin
M.7.7.2	Validate integrated production of heat and power from lignin at pilot scale
M.7.7.3	Validate integrated production of heat and power from lignin at demonstration scale
M.7.8	Demonstrate and validate lignin gasification to produce syngas
M.7.8.1	Validate feeder system performance
M.7.8.2	Validate gasification performance
M.7.8.3	Validate gas cleanup performance
M.7.8.4	Validate capital costs
M.7.8.5	Validate integrated gasification and gas cleanup at pilot scale
M.7.8.6	Validate integrated gasification and gas cleanupat demonstration scale
M.7.9	Demonstrate and validate waste biomass gasification to produce syngas
M.7.9.1	Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems
M.7.9.2	Validate gasification performance
M.7.9.3	Validate gas cleanup performance
M.7.9.4	Validate capital costs
M.7.9.5	Validate integrated gasification and gas cleanup at pilot scale
M.7.9.6	Validate integrated gasification and gas cleanupat demonstration scale
M.7.9.7	Validate feed flexibility in integrated system
M.7.10	Demonstrate and validate ethanol from mixed alcohols using lignin or waste biomass derived syngas
M.7.10.1	Demonstrate ethanol production from mixed alcohols
M.7.10.2	Validate ethanol separation
M.7.10.3	Validate integrated production of ethanol from syngas at pilot scale
M.7.10.4	Validate integrated production of ethanol from syngas at demonstration scale
M.7.11	Demonstrate and validate non-ethanol fuels from lignin or waste biomass derived syngas
M.7.11.1	Demonstrate non-ethanol fuel production from lignin or biomass-derived syngas
M.7.11.2	Validate non-ethanol fuel separation
M.7.11.3	Validate integrated production of non-ethanol fuels from syngas at pilot scale
M.7.11.4	Validate integrated production of non-ethanol fuels from syngas at demonstration scale
M.7.12	Demonstrate and validate hydrogen production from lignin or waste biomass derived syngas
M.7.12.1	Demonstrate optimized hydrogen production from syngas
M.7.12.2	Validate hydrogen separation/recovery
M.7.12.3	Validate integrated production of hydrogen from syngas at pilot scale

M.7.12.4	Validate integrated production of hydrogen from syngas at demonstration scale
M.7.13	Demonstrate and validate product(s) from lignin or waste biomass derived syngas
M.7.13.1	Demonstrate high value chemical/material production from syngas
M.7.13.2	Validate product(s) separation
M.7.13.3	Validate integrated production of product(s) from syngas at pilot scale
M.7.13.4	Validate integrated production of product(s) from syngas at demonstration scale
M.7.14	Demonstrate and validate combined heat and power production from lignin or waste biomass derived syngas
M.7.14.1	Demonstrate combined heat and power production from syngas
M.7.14.2	Validate integrated production of heat and power from syngas at pilot scale
M.7.14.3	Validate integrated production of heat and power from syngas at demonstration scale
M.7.15	Demonstrate and validate waste biomass pyrolysis to produce pyrolysis oil intermediate
M.7.15.1	Validate feeder systems to reliably feed solid biomass to pyrolysis reactor high pressure (30 bar) systems
M.7.15.2	Validate pyrolysis performance
M.7.15.3	Validate pyrolysis oil cleanup performance
M.7.15.4	Validate capital costs
M.7.15.5	Validate integrated pyrolysis and pyrolysis oil cleanup at pilot scale
M.7.15.6	Validate integrated pyrolysis and pyrolysis oil cleanup at demonstration scale
M.7.15.7	Validate feed flexibility in integrated system
M.7.16	Demonstrate and validate fuels from pyrolysis oil intermediate
M.7.16.1	Demonstrate fuel production from pyrolysis oil intermediate
M.7.16.2	Validate fuel separation
M.7.16.3	Validate integrated production of fuels from pyrolysis oil at pilot scale
M.7.16.4	Validate integrated production of fuels from pyrolysis oil at demonstration scale
M.7.17	Demonstrate and validate high value chemical and material products from pyrolysis oil intermediates
M.7.17.1	Demonstrate high value chemical/material production from pyrolysis oil
M.7.17.2	Validate product separation
M.7.17.3	Validate integrated production of product(s)from pyrolysis oil at pilot scale
M.7.17.4	Validate integrated production of product(s)from pyrolysis oil at demonstration scale
8. Algae Pathway	
M.8	
M.8.1	Algal feedstock production
M.8.1.1	Development of technically viable, sustainable and cost effective algae production
M.8.2	Algal conversion technologies
M.8.2.1	Development of technically viable, sustainable and cost effective fuel production from algae

Technology Readiness Levels

Identifier	*Description*	*Example*	*Output*
TRL-1	**Basic principles observed and reported:** This is lowest level of technology readiness. Scientific research begins with a systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications or products in mind. The knowledge or understanding will later be translated into applied research and development.	An example might include studies of a technology's basic properties.	Published papers, new innovations
TRL-2	**Technology concept and/or application formulated:** Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Practical application invented. Research to improve feasibility.	Examples are still limited to analytical studies.	Published papers, patents, preliminary investigation
TRL-3	**Analytical and experimental critical function and/or characteristic proof of concept:** Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.	Examples include components that are not yet integrated or representative.	Patents, prototypes of various unit operations built
TRL-4	**Component and/or breadboard validation in laboratory environment:** Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system.	Examples include integration of "ad hoc" hardware in the laboratory.	Patents, integrated prototypes, informs engineering scale designs, possible application of Stage Gate Processing.
TRL-5	**Component and/or breadboard validation in relevant environment:** Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.	Examples include "high fidelity" laboratory integration of components.	Integrated prototypes at bench scale, informs pilot plant designs, IP owned or licensed, initiation of Stage Gate Process/tracking.
TRL-6	**System/subsystem model or prototype demonstration in a relevant environment:** Representative model or prototype system, which is well beyond that of TRL-5, is tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness.	Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.	Integrated prototypes at pilot scale, informs demonstration scale designs. Progress through the Stage Gate Process.
TRL-7	**System prototype demonstration in a operational environment:** This represents a major step up from TRL-6. It requires the demonstration of an actual system prototype in an operational environment, such as in a light duty vehicle on the road.	Examples include testing at demonstration scale in simulated operational environment.	Integrated prototypes at the demonstration scale, informs commercial scale designs.
TRL-8	**Full Scale demonstration in a operational environment:** Completed and qualified through test and demonstration. The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of the true system development.	Examples include developmental testing and evaluation of the system with actual feedstocks through commissioning.	Integrated prototypes at the commercial scale. Operational procedures that are nearly complete.

Definitions:

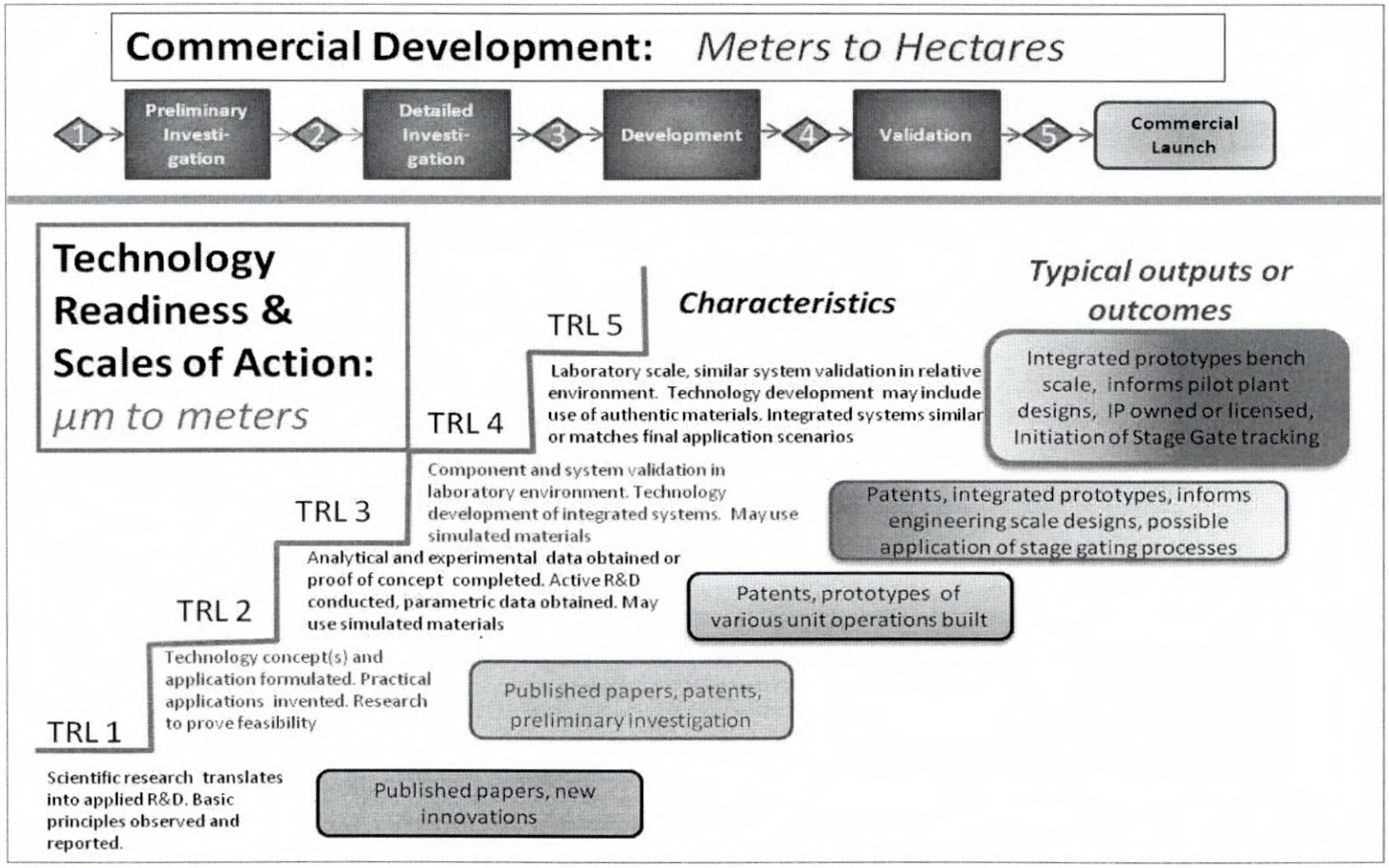
BREADBOARD: Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. These tools are typically configured for laboratory use to demonstrate technical principles of immediate interest. These may resemble final system/subsystem in function only.

"HIGH FIDELITY": Addresses form, fit and function. High-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

"LOW FIDELITY": A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low fidelity assessments are used to provide trend analysis.

MODEL: A functional form of a system generally reduced in scale, near or at operational specification. Models will be sufficiently developed to allow demonstration of the technical and operational capabilities required of the final system.

OPERATIONAL ENVIRONMENT: Environment that addresses all of the operational requirements and specifications required of the final system to include platform/packaging.
PROTOTYPE: The first early representation of the system that offers the expected functionality and performance expected of the final implementation. Prototypes will be sufficiently developed to allow demonstration of the technical and operational capabilities required of the final system.
RELEVANT ENVIRONMENT: Testing environment that simulates the key aspects of the operational environment.
SIMULATED OPERATIONAL ENVIRONMENTAL: Either 1) a real environment that can simulate all of the operational requirements and specifications required of the final system, or 2) a simulated environment that allows for testing of a virtual prototype; used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.



STRIPES 'ASSISTANCE AGREEMENT' (COVER PAGE) TEMPLATE LANGUAGE FOR NEW AWARDS AND AWARD MODIFICATIONS

MODIFICATIONS:

The purpose of this modification is to move tasks from Budget Period 2 into Budget Period 1. Accordingly the following changes are made:

1) Delete and replace the Terms and Conditions to incorporate the following changes:
   a. Delete and replace the "Award Project Period and Budget Periods" provision;
   b. Delete and replace the "Cost Sharing" provision;
   c. Delete and replace the "Funding of Budget Periods" provision;
   d. Delete and replace the "National Environmental Policy Act (NEPA) Requirements" provision;
   e. Add the "Reporting Subawards and Executive Compensation" provision; and
   f. Add the "Central Contractor Registration and Universal Identifier Requirements" provision;

2) Delete and replace the Statement of Project Objectives (Attachment 2);

3) Delete and replace the Budget Information, SF-424A (Attachment 4); and

4) Grant and No Cost Time Extension, specifically to extend the end of Budget Period 1 from 03/31/2011 to 09/30/2011.

All other terms and conditions remain unchanged.

In Block 7 of the Assistance Agreement, the Period of Performance reflects the beginning of the Project Period through the end of the current Budget Period, shown as 01/29/2010 through 09/30/2011. For multiple Budget Periods, see Special Terms and Conditions, Provision 4, "Award Project Period and Budget Periods."

The total amounts reflected in Blocks 12 and 13 of the Assistance Agreement do not include the Federally Funded Research and Development Center (FFRDC) funding amount of $424,480, which will be funded directly.

DOE Award Administrator: Molly Hames
E-mail: molly.hames@go.doe.gov
Phone: 303-275-4864

DOE Project Officer: Christy Sterner
E-mail: christy.sterner@go.doe.gov
Phone: 303-275-4720

Recipient Business Officer: Katie McFadden
E-mail: Katie.McFadden@Algenolbiofuels.com
Phone: 239-498-2000

Recipient Principal Investigator: Craig Smith
E-mail: craig.smith@algenolbiofuels.com

Phone: 239-498-2000