Request for Information (RFI) DE-FOA-0001481:

Understanding Scale-up and Operational Challenges for Integrated Biorefinery Optimization

DATE: March 11, 2016

SUBJECT: Request for Information (RFI)

Description

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE) Bioenergy Technologies Office (BETO) seeks feedback from industry, academia, research laboratories, government agencies, and other stakeholders on issues related to "challenges encountered with the successful scale-up and reliable operation of integrated biorefinery plants (IBRs)." Specifically, BETO seeks information that will help it understand additional areas of research, capabilities, and yet to be addressed barriers and opportunities for stakeholder engagement pertaining to technology development and engineering solutions for the reliable operation of IBRs to produce biofuels, biochemicals and bioproducts.

BETO seeks information on all IBR processes and technologies, including any and all systems processes, technologies, methods and equipment employed to convert woody biomass, agricultural residues, dedicated energy crops, algae, municipal solid waste (MSW), sludge from wastewater treatment plants, and wet solids, into biofuels, biochemicals, and bioproducts. BETO seeks information on technical challenges that have hindered, or could in the future hinder, the achievement of reliable continuous operations. BETO is particularly interested in receiving stakeholder input on production systems expected to be in the range of feedstock throughput of 1 DTPD (Dry Tonne per Day) to 1,000 DTPD to:

1. Understand scale-up and mitigate operational risks and challenges for integrated biorefinery plants;
2. Develop robust handling of variable solid materials (dry and wet feedstocks, and/or residual solids remaining in the process)and investigate reactor feed systems operating under vacuum or at positive pressures;

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3. Improve pre-processing methodologies to transform diverse types of feedstocks into homogeneous, standardized intermediates;
4. Advance process intensification focused on simplification (such as reduction in number of process steps); enable reliable, robust continuous operations; increase selectivity and enable hybrid separations; cost reduction through innovative fabrication and construction methods (for example, modularization of systems); and/or efficient water management techniques;
5. Address unique process issues (for example, the need to remove oxygen and lignin to facilitate efficient processing of feedstocks into products, the need to remove natural or derivatized contaminants), and pathways including
    i. biological;
    ii. thermochemical;
    iii. catalytic
    iv. biochemical;
    v. algae; and
    vi. hybrid pathways; and
6. Develop strategies to reduce Capital Expense (CapEx) costs by reducing technical risks and ensuring minimum modifications during different phases of the execution (for example, construction, commissioning, operations, etc.) of biorefinery projects.

Background

BETO is one of ten technology development offices within EERE, and it supports EERE's efforts to expand the adoption of sustainable, domestically powered transportation alternatives and to stimulate the growth of a thriving domestic clean energy manufacturing industry.

BETO's mission is to develop and transform renewable biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower through targeted research, development, and demonstration of technologies that will enable operational integrated biorefineries supported through public and private partnerships. BETO is working to enable sustainable, nationwide production of biofuels that:

1) Are compatible with today's transportation infrastructure,
2) Reduce greenhouse gas emissions relative to petroleum-derived fuels, and
3) Can displace a share of petroleum-derived fuels to reduce U.S. dependence on foreign oil.

BETO's Demonstration and Market Transformation (DMT) Program has supported more than 35 pilot and demonstration facilities throughout the Program's history. These investments have

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allowed industry partners to integrate unit operations, validate techno-economic assessments, and prove a variety of technologies at scales enabling a path to commercialization.

BETO is cognizant of the fact that the bioenergy industry is in its early developmental stage and would require patience and support from the government and stakeholders alike to transform this industry from concept to successful commercialization. Validating performance at integrated pilot-scale, demonstration-scale, and pioneer-scale is essential to de-risk technology and enable financing that will catalyze the transition to large-scale production of renewable biofuels and bioproducts.

Even with years of continuous investments by BETO to de-risk the first-of-kind technologies, there are still numerous challenges that need to be addressed in order to achieve reliable and continuous operation of biorefineries that effectively compete with the refining and petrochemical industry. As a result, there are only a few integrated biorefineries in the early stages of commissioning, startup, and/or commercial production, and a wider deployment of highly-efficient integrated biorefinery facilities is still a goal yet to be realized. This is caused by a variety of non-technical and technical barriers. Many of the challenges are related to the complexity and variability of feedstocks, difficulties encountered with handling of solids in the production process, recalcitrance of feedstocks to efficiently convert into products, inhomogeneity of intermediates causing non-uniform heat and mass transfer during the manufacturing processes, complex multi-step separation and purification steps, difficulties in translating bench and pilot learnings to the next scale-up such as demonstration or pioneer commercial level, and non-competitive cost of goods due to higher capital and operational expenses. While this information and insight is important, it only represents the collective learnings of those projects that received federal financial assistance from DOE. DOE seeks information from a larger stakeholder community including private sector, universities, research laboratories and IBR projects funded by other federal funding agencies, to understand their detailed opinions and perspectives.

There are many factors that contribute to the biorefinery inefficiencies, reliability issues and the high cost associated with production of biofuels for example, feedstock cost and conversion are directly affected by individual process steps (biomass harvest and collection, handling, transportation, storage, and processing practices into feedstock), and by feedstock quality characteristics (ash content and constituent fractions, carbohydrates/structural sugars, moisture content, particle size and morphology, and soil and other contaminants). In addition, the feedstock cost and the conversion yield are the key parameters affecting both the biofuel selling price and the overall sustainability of biofuel production (Inmann D, Nagle N, Jacobson J, Searcy E, Ray A, 2010).

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Further challenges illustrating the inadequate feedstock handling and characterization and its impact on conversion processes are presented below:

- Additional operational costs of the biorefinery at its reduced pretreatment efficacy, increased wear in handling and feeding systems, increased downtime for equipment maintenance, increased corrosivity of pyrolysis oil, slagging and fouling in boilers and gasifiers, and resultant accumulation as a waste stream that requires additional disposal (Weiss ND, Farmer JD, Schell DJ, 2010) due to the presence of biomass ash and soil contamination. The increased disposal cost could potentially increase the cost of biofuel production (Kenney KL, Smith WA, Gresham GL, Westover TL, 2013). Possible solutions could be introduced via operational improvements during the biomass harvesting, and by feedstock processing technologies.
- Changes in biomass compositional stability such as those caused by biomass exposure to moisture and its degradation due to microbes, and ease of loss of carbohydrates during storage.
- Baled biomass stored outdoors is susceptible to dry matter loss, which does not occur uniformly among all of the measured biomass constituents, but occurs preferentially to water-soluble components and the structural components of hemicellulose and cellulose (Kenney KL, Smith WA, Gresham GL, Westover TL, 2013). The variability in carbohydrates content can have significant implications in biofuel yield and economics. The compositional variability could potentially reduce cellulosic ethanol yields by more than 30 gallons per dry ton. The carbohydrate content, moisture of a feedstock material and reduced variability can be achieved by formulation (blending) technology (Kenney KL, Smith WA, Gresham GL, Westover TL, 2013).
- Particle morphology – sizes, shapes and densities, and variability - can significantly affect performance in both handling systems and conversion processes, thus, physical properties of the biomass bulk solids are important for both biochemical and thermochemical processes (Bitra VSP, Womac AR, Chevanan N et al., 2009), (Igathinathane C, Womac AR, Sokhansanj S, Narayan S, 2009), (Mani S, Tabil LG, Sokhansanj S., 2004) and have an impact on manufacturing costs and GHG emissions. Often particle size specification is based on the screen size of a laboratory mill, rather than a thorough classification of particle size distribution.

Sufficient emphasis on variation in feedstock quality and specifications is lacking and is mainly driven by developers' use of "pristine" feedstock composed of clean, homogeneous biomass (for example, debarked wood from a single species in the case of woody biomass). Some that have scaled up to pilot-scale operations that require larger quantities of feedstock have experienced vast differences between pristine and "field-run" feedstocks (Humbird DA, Davis R, Tao L et al., 2011). Lack of understanding of biomass characteristics in relationship to the conversion technology's feedstock quality requirements results in missing conversion targets and substantial

increases in manufacturing costs. The consistent feedstock quality and homogeneity are critical for the stable and efficient biorefinery operations (Kenney KL, Smith WA, Gresham GL, Westover TL, 2013).

Addressing the previously mentioned challenges will help to improve the quality of feedstock, reliability of operations, and thereby increase the performance efficiencies of biorefineries.

Purpose: The purpose of this RFI is to solicit information from industry, academia, research laboratories, government agencies, and other stakeholders about "challenges encountered with the successful scale-up and reliable operation of integrated biorefinery plants (IBRs)." Specifically, this RFI will help BETO understand potential areas of research, capabilities, barriers and opportunities for stakeholder engagement pertaining to technology development and engineering solutions for the reliable operation of integrated biorefineries to produce biofuels, biochemicals and bioproducts. This is solely a request for information and not a Funding Opportunity Announcement (FOA). EERE is not accepting applications.

Disclaimer and Important Notes

This RFI is not a Funding Opportunity Announcement (FOA); therefore, EERE is not accepting applications at this time. EERE may issue a FOA in the future based on or related to the content and responses to this RFI; however, EERE may also elect not to issue a FOA. There is no guarantee that a FOA will be issued as a result of this RFI. Responding to this RFI does not provide any advantage or disadvantage to potential applicants if EERE chooses to issue a FOA regarding the subject matter. If a FOA is subsequently issued, final details, including the anticipated award size, quantity, and timing of EERE funded awards, will be subject to Congressional appropriations and direction.

Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. EERE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. EERE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that EERE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

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Proprietary Information

Because information received in response to this RFI may be used to structure future programs and FOAs and/or otherwise be made available to the public, **respondents are strongly advised to NOT include any information in their responses that might be considered business sensitive, proprietary, or otherwise confidential.** If, however, a respondent chooses to submit business sensitive, proprietary, or otherwise confidential information, it must be clearly and conspicuously marked as such in the response.

Responses containing confidential, proprietary, or privileged information must be conspicuously marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Federal Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

If your response contains confidential, proprietary, or privileged information, you must include a cover sheet marked as follows identifying the specific pages containing confidential, proprietary, or privileged information:

> **Notice of Restriction on Disclosure and Use of Data:**
>
> Pages of this response may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for the purposes described in this RFI DE-FOA-0001481. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

In addition, (1) the header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure" and (2) every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

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Evaluation and Administration by Federal and Non-Federal Personnel

Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to EERE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

Request for Information Categories and Questions

Category 1: Understanding scale-up, integration and mitigation of operational risks, and challenges for integrated biorefinery plants (hereafter "Understanding Scale-up and Operational Challenges for Integrated Biorefineries) (up to 5 page limit on responses including 1 page with the flow diagram where possible).

BETO wants to identify additional areas of research and development that industry, universities and other stakeholders are interested in collaborating on to address challenges faced by the developing bioenergy industry related to scale-up and mitigation of operational risks, and challenges for integrated biorefinery plants. Please consider addressing the following issue areas:

1) Provide information about your current activities that focus on scale-up and operating challenges, including the equipment and/or capabilities that could support the different steps of biorefinery operations such as solids handling (including feedstocks fed to the process and residual solids remaining in the process), feeding to reactors, overcoming the recalcitrance exhibited by feedstocks, handling of internal and external constituents (such as ash, sand, minerals, silica, non-carbohydrate matter, etc.), robust feedstock handling to enable conversion, efficient deconstruction of biomass, conversion into products, separation and purification of feeds, intermediates and products, and handling of waste (including solids, liquids and gaseous) streams. Include information on challenges that have been encountered in your implementation, methods employed to overcome specific challenges and those that remain acting as barriers to attaining reliable continuous operations.
2) Provide information regarding potential new activities that could address existing scale-up, reduction of technical risk, reduction of capital expenses through simplification of the

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process, additional work to identify and develop robust process control, and operational challenges for integrated biorefineries systems. In your response describe how interested parties could collaborate with BETO in addressing relevant technical barriers.

3) Provide input about what you perceive to be the most critical technology gaps that must be overcome to achieve success with improved scale-up for biorefineries.
4) Provide input as to how you define scale-up requirements and specifications.
5) Provide input regarding areas in need of additional research and/or development relative to scale-up approaches.
6) Provide recommendations regarding how testing protocols should be defined and assessed for successful scale-up outcomes (such as number of hours of operations, inclusion of recycle streams, integrated runs, emulation of wide variations of the process inputs that reflect an IBR that could be deployed across the U.S. etc.).

Category 2: Robust handling of solid materials (dry and wet feedstocks, and/or residual solids remaining in the process) and feeding systems to reactors operating under vacuum or at positive pressures (up to 5 page limit on responses including 1 page with the flow diagram where possible).

As a result of past interactions with and learnings from biorefinery stakeholders, BETO recognizes the following major barriers to achieving reliable operations with solids handling systems:

- Impact of the duration of feedstock storage and environmental conditions on biomass properties;
- Lack of understanding and availability of information on biomass and feedstock properties for use in equipment design;
- Operational challenges with wet and/or dry feedstocks;
- Ability to feed reliably at pressures (and/or vacuum) under continuous operations;
- Understanding the material flow properties and related challenges such as bridging, plugging; especially the similarities as well as differences between wood chips and other feedstocks such as corn stover, switchgrass, bagasse, etc.;
- Removal of feedstock impurities and potential requirements for washing of feedstocks to improve the reliability of the performance of equipment (for example, sand, rocks, metals, etc.);
- Efficient separation of residual solids remaining in the process (for example, lignin, ash, minerals, etc.) and further utilization (for example, valorization of lignin);

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- Wear and tear on equipment, slugging and fouling of the equipment, and quenching of the catalyst;
- Selection of proper material of construction of equipment and ancillary systems such as seals, filters, gaskets, etc. to improve their reliability of performance and duration of service;
- Required capital expenses (CapEx) for solids handling and feeding systems; and
- Current lack of codes and standards for the storage and processing stages of biofuels conversion (for example, fire hazards due to fine dust).

In light of the issues highlighted above, BETO seeks input in response to the following questions and/or issues:

1) Are there additional design and operational challenges that should be considered in addition to those mentioned above? If so, please describe.
2) Please comment on potential technical risks and the ways on how to mitigate these risks.
3) Are you aware of any innovative designs for feedstock handling systems that could be optimized to reliably feed a variety of real-world feedstocks? If yes, please describe.
4) What is the best strategy for transitioning new feedstock handling systems to the marketplace? When and how should research be shared with industry or partners?
5) Can successful operational experiences and learnings from another industry, for example, the pulp and paper industry with respect to feed handling and ancillary systems be transferred to biorefineries using woody and non-woody biomass as feedstocks?
6) What design and equipment specification guidelines can be utilized for applications to convert heterogeneous feedstocks into biofuels and bioproducts?
7) How to effectively control particle size distribution to achieve robust feeding and maximize product conversion yield?
8) What screening methods are available to help insure selection of proper materials of construction of equipment and ancillary systems?
9) Please provide information on technologies and methodologies from other applications, such as mineral processing or concrete pumping that could be deployed for the handling and conveying of biomass.

Category 3: Pre-processing methodologies to transform diverse types of feedstocks into homogeneous intermediates (up to 5 page limit on responses including 1 page with the flow diagram where possible).

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Through past stakeholder engagement activities, BETO recognizes the following barriers during pre-processing steps that hinder further downstream processing effectiveness:

- Bale to bale variations in composition (for example, switchgrass feedstock), compositional variation within a bale, feedstock impurities;
- Feedstock degradation during collection in the field, transportation and storage;
- Moisture content and its impact on handling and degradation of quality;
- Effects of particle size distribution and its effect on heat and mass transfer operations during processing; and
- Implementation of purification steps during the pre-processing.

BETO asks for feedback in the following two areas:

1) Are there modifications to existing pre-processing steps that should be considered? If so, please describe and include any impacts on techno-economics and green-house gas (GHG) reductions.
2) Are you aware of any innovative pre-processing designs that could be optimized to ensure the homogenous feedstock with uniform heat and mass transfer? If yes, please describe.

Category 4: Advancing process intensification focused on simplification, enabling reliable continuous operations; increasing selectivity and enabling hybrid separations; cost reduction through innovative fabrication and construction methods; and efficient water management techniques (up to 5 page limit on responses including 1 page with the flow diagram where possible).

BETO recognizes current barriers to process intensification including:

- Batch processes versus continuous processes;
- Effects on product yields due to reaction selectivity and separations processes;
- Reduction of the number of side products through increased selectivity, removal of contaminants or precursors to side products
- Complexity introduced due to multiple number of process steps; and
- Efficient water management techniques through water recycle and usage minimization.

In light of the barriers highlighted above, BETO seeks input in response to the following questions and/or issues:

1) What are the additional process intensification steps that should be considered? Please describe.

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2) What process steps would you simplify and reduce? How much would they reduce the current capital costs, energy consumption, and risk for construction and scale-up of biorefineries?
3) How would you make current process steps more flexible to available feedstocks and overall market conditions? Please describe.
4) Are you aware of any continuous processes (including continuous fermentation) that were implemented in biorefineries? If yes, please describe.
5) Describe modular continuous processes that have been implemented for validation of new/enhanced reactor and separation technologies; and new automation technology and components generated through manufacturing techniques.
6) How would you simplify current process steps utilized within separation and purification operations?
7) How would you improve current water management systems and wastewater treatment methods?

Category 5: Addressing unique process issues and pathways including: i) biological; ii) thermochemical; iii) catalytic; iv) biochemical; v) algae; and vi) hybrid pathways (up to 5 page limit on responses including 1 page with the flow diagram where possible).

Through past stakeholder engagement activities, BETO recognizes the need for the removal of oxygen and lignin to produce drop-in biofuels and further utilization of lignin and other co-products to improve process economics. Please consider addressing the following question areas:

1) What do you perceive as the most critical technology challenges and gaps that must be overcome to achieve success for the most efficient removal of oxygen, lignin, and effective conversion of the oxygen and aromatic functionalities into products that leverage the molecular groups in biomass positively?
2) How can lignin and other current waste streams be further utilized and converted into higher value products (higher value would be conversion of an expense into a revenue or higher value than burning the organic stream)?
3) Where do you see major gaps and inefficiencies in biological, thermochemical, catalytic, biochemical, algae and/or hybrid conversion pathways? How would you address these inefficiencies?

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Category 6: Strategies to reduce capital expense (CapEx) costs of biorefinery projects (up to 5 page limit on responses including 1 page with the flow diagram where possible).

Through past stakeholder engagement activities, BETO recognizes the following major barriers that contribute to the significant CapEx costs:

- Technical barriers such as end-to-end process integration, risk of first-of-a-kind technology, technical risk of scaling, cost of production due to higher capital as well as operation costs, and operational challenges due to requirements for robust handling solid biomass feedstocks; and
- Market challenges and barriers such as inadequate supply chain infrastructure, offtake agreements, biofuels distribution infrastructure, codes, standards and approval for use, lack of acceptance and awareness of biofuels.

Please consider addressing the following issue areas:

1) Provide recommendations on ways to reduce the CapEx and improve biorefineries' economic competitiveness with respect to fossil fuels facilities, infrastructure and current energy supplies?
2) Provide recommendations to aid in reducing the current high CapEx and OpEx of the pioneer commercial plants.
3) Provide recommendations on strategies to reduce CapEx costs by minimizing design changes and system modifications during different phases of the execution of biorefinery projects (for example, construction, commissioning, operations, etc.)
4) Provide recommendations to aid in speeding-up the de-risking of the biorefinery technologies with and/or without government involvement.
5) Provide recommendations to aid in ensuring the most efficient transfer of the learnings from the demonstration plant to pioneer commercial plant to n^{th} plant (for example, up to first five commercial plants) that would minimize/eliminate design modifications.
6) Provide recommendations to aid in achieving predictable commissioning and start-up of biorefineries.
7) Provide recommendations for creating greater overall effectiveness using vendor involvement during the design phase.
8) Provide recommendations for creating a well-trained labor force for biorefinery projects.

Request for Information Response Guidelines

Responses to this RFI must be submitted electronically to IBRSynthesisRFI@ee.doe.gov no later than 5:00pm (ET) on April 6, 2016. Responses must be provided as attachments to an email. It is

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recommended that attachments with file sizes exceeding 25MB be compressed (i.e., zipped) to ensure message delivery. Responses must be provided as a Microsoft Word (.docx) attachment to the email, and no more than 5 pages in length, 12 point font, 1 inch margins. Only electronic responses will be accepted.

Please specify the Category and Sub-Category (e.g., Category 6, Sub-Category 3) that you are responding to. Respondents may answer as many or as few questions as they wish. If you wish to provide input to more than one category of interest, you should submit a separate response for each category. Each such response must not exceed 5 pages in length. If, for example, you respond to questions under two different categories (e.g., Category 1 and Category 3), you may submit a separate 5-page response for each category (for a total of 10 pages).

EERE will not respond to individual submissions or publish publicly a compendium of responses. A response to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

Respondents are requested to provide the following information at the start of their response to this RFI:

- Company / institution name;
- Company / institution contact;
- Contact's address, phone number, and e-mail address.
- Stakeholder group(s) your response reflects (include all that apply from list below):
    - Academia
    - Research laboratory
    - Government
    - Industry
    - Other (Please specify)

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