

# PROGRAMMATIC EVALUATION AND RESPONSE

## BIOENERGY TECHNOLOGIES OFFICE PROGRAMMATIC EVALUATION

*Prepared by the Bioenergy Technologies Office  
2017 Peer Review Steering Committee*

The Bioenergy Technologies Office (BETO or the Office) has a critical role in fostering the innovation required for an energy future for the United States that will enhance energy independence, drive new economic activity and job creation, and bring environmental and social sustainability for future generations. Technology development and the creation of new forms of industry are inherently risky endeavors. Borne by any one sector or market participant, these risks can be too large to bear, and progress will be slow or non-existent. Risk sharing between public and private interests is necessary to defray exposure and promote investment. Risk sharing is also appropriate, as the benefits of clean energy technologies are not compartmentalized to any one participant.

Economic benefits flow to a broad range of industries, such as agriculture, forestry, transportation and logistics, engineering, construction, and energy. Indirect economic benefits, such as job creation, enhanced gross domestic product, and a greater tax base, flow to the public. Enhanced energy security and environmental improvements are benefits to the nation broadly. In these challenging federal budget conditions, the Peer Review Steering Committee strongly recommends that continued risk and benefit sharing between industry and government be pursued.

The members of the Steering Committee wish to thank the BETO for the opportunity to view the breadth of BETO's research portfolio and provide our feedback and comments. It is highly encouraging that the Office values transparency and actively solicits the input of

external reviews in such a rigorous manner. It is also encouraging that, in looking back at the 2015 Peer Review, so many of the recommendations therein have been acted upon in the last 2 years. The launch of the new consortia is a notable example of responsiveness that should be applauded.

### BETO Portfolio: Overall Assessment

The comments that follow are in reference to the BETO portfolio, as presented during the Project Peer Review meeting. However, there are some projects and activities for which BETO is a leader or participant that were not covered by this review. These include the Biomass Research and Development Initiative, Small Business Grants, Defense Production Act, and other efforts. It would be helpful for future review efforts if BETO could outline their entire portfolio for the reviewers and Steering Committee. We understand that, even as it stands, this review was very large, and these other projects are not generally solely associated with BETO, so it could be appropriate that they were not reviewed here. However, they should be summarized to illustrate how they fill potential gaps left in the traditional BETO portfolio we did review. We understand that this puts an additional burden on the review organizers because the size of the review, but leave it as a challenge to the Office to include this information such that the entire effort is understood.

### BETO Portfolio: Strengths

#### Program Management

At the highest level, the program management approach that has been imposed throughout the BETO portfolio is commendable in driving structured, disciplined execution. Stage gates and go/no-go decision points are planned for each process, although there still is some work to do in ensuring that all parties understand and adhere to the process requirements and definitions.

During the Project Peer Review, numerous project principal investigators (PIs) pointed to go/no-go points that were simply treated as tracking milestones. A more widely understood programmatic rigor will ensure an efficient use of BETO resources, allowing reallocation from underperforming projects.

### **Consortia**

The launch of a range of new consortia—the Chemical Catalysis for Bioenergy Consortium (ChemCatBio), Consortium for Computational Physics and Chemistry, Feedstock-Conversion Interface Consortium (FCIC), Agile Biomanufacturing Foundry, Separations Consortium, etc.—is a welcome move to enhance collaboration amongst national laboratories and between the laboratories and industry and to cut across divisions within BETO technical areas. It is appreciated that some consortia are targeting near-term industry challenges, especially in the case of FCIC.

### **Greater Integration across Technology Areas**

The realignment of what were formerly separate technology areas (Thermochemical Conversion, Biochemical Conversion) and the addition of a new conversion focus (Waste to Energy) all under a single name, management structure, and thrust is a welcome move to break down barriers in a broad area where there are no clear technical dividing lines. Hybrid or unorthodox conversion approaches will face less chance of exclusion, and lessons learned will be more easily shared. This is a sound improvement in portfolio management structure.

### **Staff Continuity**

The 2015 Peer Review noted a risk to the Office in terms of staff retention versus turnover. Institutional memory, strong networks, and deep subject matter expertise are all important facets of a strong, technically focused organization. The Steering Committee was pleased to see so many familiar faces in 2017. Senior management of the Office is commended for their efforts to retain and develop key staff members, leading to strong programmatic and knowledge continuity.

## **BETO Portfolio: Weaknesses**

### **Interaction with Industry**

In the introduction of this section, the appropriateness of risk sharing between government and industry was emphasized. If these two partners are to be efficient in moving together towards the mutual goal of building the bioeconomy, close coordination is necessary. Overall, the Office appears to be highly cognizant of the need to interact strongly with industry. Efforts to reach out to industry through requests for information and workshops, to include external advisory boards in the establishment of new consortia, and to incentivize industry project participation through appropriate levels of cost-share requirements are all positive. However, there is an opportunity to improve the level of interaction with industry.

Of note is the perception that annual operating plan (AOP)–funded projects often lack the level of coordination and interaction with industry that is needed to ensure relevant outcomes. PIs need to understand industry issues, and those inputs need to help the decision-making process, not just in the creation of projects, but during their execution. PIs need to work with industry in real time to help optimize project outcomes when choices are made at interim gates or decision points. The addition of industry oversight or formalized advisory positions for AOP projects may be advisable. One particular area that might benefit from this type of coordination is the development of products from lignin. Two or three full-scale facilities are now producing hundreds of tons of lignin daily, and some are burning it for energy. Because this material is not a pure substance and is highly dependent on the up-stream process, utilization of this real-world material in the U.S. Department of Energy’s (DOE’s) development efforts might be well-accepted by the companies now producing it.

BETO should encourage industry to use DOE-funded testbeds and user facilities (e.g., Algae Testbed Public–Private Partnership, National Renewable Energy Laboratory’s Thermochemical Users Facility), both to lever-

age the sunk cost and to ensure that comparisons, to the extent practical, are done using a standard context.

It's not just one way—the Steering Committee appreciates that industry is not always open to involvement, due to concerns with intellectual property protections, lack of bandwidth, or other priorities. Nevertheless, a strong effort by BETO is needed to ramp up the level of interaction and proactively encourage industry to become involved where appropriate. BETO should specifically examine the technical, policy, legal, and other types of barriers to greater industry engagement and, if possible, address those barriers.

### **Portfolio Focus for Near-Term Success**

Some members of the Steering Committee feel that BETO would improve its impact and overall success towards its mission focusing more on research directions that will enable near-term success. Without making tough decisions about diverting resources towards those near-term wins, the whole advanced bioeconomy may be at risk of stalling out at a pre-commercial stage as capital markets grow impatient and seek returns in other, more mature clean-tech sectors. This line of thinking would encourage a more venture capital financing approach to project solicitation and selection, where commercial outcomes are weighted relatively strongly. In an uncertain budgetary environment, it is critically important to demonstrate successes, impacts, and the return on investment for public funding of BETO. Near-term success may be the most important factor in ensuring longer-term support for the Office. In addition to project selection for the near-term portfolio, aggressive project management to ensure accountability and outcomes is important.

### **Innovation Pipeline**

Many of the near-term technologies are inhibited by unanswered research questions that can only be addressed through research at lower technology readiness levels (TRLs). Therefore, even while focusing on near-term “wins,” BETO must ensure that it does not cut itself off from the flow of innovative new technology approaches

and novel research directions. The Steering Committee believes that investment in activities across the TRL spectrum is essential to leveraging innovations in bioenergy, with continued emphasis on commercial viability.

Notwithstanding previous comments around staff continuity, one suggestion is to establish a rotation of external staff or advisors to the Office. Such an effort could be undertaken even while maintaining a steady core, and this would assist in fostering the inflow of novel thinking and experiences.

### **International Engagement**

The Office, as part of the federal government, is rightly focused on spurring domestic innovation for the benefit of the American people. However, the Office takes perhaps too narrow of a focus by limiting projects to be almost entirely domestic in scope (with one or two notable exceptions). Enhanced international collaboration would provide a great ability to access world-leading expertise and innovation and potential funding leverage opportunities. BETO funds need not leave the borders of the United States to spur such collaboration. A good example of this kind of international collaboration is the European Union–Brazil coordinated research call on biofuels (part of the Horizon 2020 Programme), where each “nation” funds research within their own borders, but trans-Atlantic project teams collaborate towards common research goals.

## **BETO Project Impacts**

### **Project Impact: Support of Advanced Bioenergy Industry**

There is significant uncertainty in how impactful the current project portfolio will be in advancing the bioeconomy. Such uncertainty is simply part and parcel of managing research and development (R&D) portfolios.

The Steering Committee in large part defers to the individual technology area Review Panels for the judgment at the project level. However, at the highest portfolio level, what is missing from the Steering Committee's

perspective is the Office's overall assessment of portfolio risk. If the objective is to promote the bioeconomy, then investments and *investment strategies* that do not move the needle towards that objective should be identified as risks. A formal, quantitative approach to assessing, managing, and mitigating risks across the portfolio would be a welcome addition.

That said, risk management at the project level has shown solid improvement in the last 2 years. The stage-gate approach to project management is excellent, and the increased emphasis on validating the technology baseline included at the proposal stage for new projects, right at the outset, will ensure that precious BETO resources are not wasted on attempting to build new technologies on a shaky foundation.

### Project Impact: Novel and Innovative Projects

BETO has consistently demonstrated willingness to make changes to its project portfolio to reflect changes in bioenergy trends and technology. After multiple decades of correctly emphasizing cellulosic ethanol as the best way to leverage existing industrial involvement in starch ethanol production and logistics to help industry move to utilize cellulosic feedstocks for renewable fuels, BETO has been able to successfully shift the emphasis to areas that can help this nascent industry continue to grow. A shift to focus on drop-in hydrocarbon fuels is an excellent example of a major strategic change that tracks industry thinking. Additionally, a focus on value-added products will help enhance the return on investment of these first cellulosic conversion plants.

While cellulose to ethanol was an obvious choice for the first fuel to be produced and, therefore, to be supported by BETO, going to next level with other fuels and products is much more challenging for a government organization such as BETO. While everyone can agree that this direction is needed, the specific path is most

likely unknown to BETO. Past studies like the *Top Value-Added Chemicals from Biomass*<sup>41</sup> can be extremely valuable to industry in looking for chemicals of interest that they might be able to derive from biomass. However, most likely it will be the specific commercial developer that will say fuel X or product Y is for the target. Until those types of analyses and input are made by those who will eventually commercialize, BETO could be spending money on the wrong technologies. BETO must be driven by industrial interest. BETO should conduct studies and analyses, even to the point of illustrating scenarios that could have compelling economics to potentially interested firms. Without industrial input guiding deeper development needs, doing fundamental research to show that some of these pathways could be feasible and even economically interesting is as far as BETO should go. Much interaction between possible technology adopters and BETO on what fuel or product to investigate is paramount. BETO's role should be one of making suggestions with the least investment until a pathway of interest is known. The Office is beginning to show signs of extending past that shift to investigate the potential for leveraging properties of non-drop-in fuels that may provide performance or operational benefits. This is a cutting-edge application and an exemplar of novel thinking, but it is not clear that it is what industry will embrace.

However, there is an operational challenge to BETO always being on the forefront of innovation. The program life cycle includes the following phases: (1) request for information, (2) workshop, (3) solicitation, (4) review of proposals, (5) award, (6) technology validation, and (7) execution. With this extensive process, there is no practical way to avoid a lag between the spark of novelty and it lighting a fire in practice. Additionally, once contracts are established there is a necessary lock-in, until certain deliverables or go/no-go points are reached. These factors are unavoidable when managing research

<sup>41</sup> J. E. Holladay, J. F. White, J. J. Bozell, and D. Johnson, *Top Value-Added Chemicals from Biomass, Volume II—Results of Screening for Potential Candidates from Biorefinery Lignin* (Richland, WA: Pacific Northwest National Laboratory, 2007), PNNL-16983, <http://www.pnl.gov/publications/abstracts.asp?report=230923>.



portfolios, and therefore the Office should not be faulted for at times lagging the latest in industry thinking.

However, earlier comments on the Innovation Pipeline and Interaction with Industry provide some guidance for how BETO can best be connected to external sources of fresh thinking.

### Project Impact: Alignment with Private-Sector Investments

The level of private-sector support for bioeconomy technologies is primarily driven by the activity of entrepreneurs and the interests of financiers, such as venture capitalists and strategic investors. Entrepreneurs are highly driven by strong vision, but they are often so focused on pushing their particular technology to market that they may miss some key factor or adjacency that will prevent or inhibit their success. Providers of capital are often uninterested in the particulars or details of a technology and only seek to maximize and accelerate the gaining of a profitable return. In neither of those cases do the actors at play have the totality of vision that BETO does, nor do they have the patience for success that a public body such as the Office should.

Therefore, although BETO may provide support to technologies that the private sector is not currently supporting, that could often be explained because the private sector simply has not considered the need for that technology yet or does not have a long enough window for their investments to provide a return. The government, and specifically BETO, is the correct entity to more aggressively invest in lower-maturity technologies with more uncertain chances of success and longer timelines to market. While it makes sense for BETO to support technologies that the private sector is not actively investing in, these new technologies still need to be areas where there is a high confidence that—when brought to a high enough maturity level (TRL) by BETO—there will be an interest by the private sector (through market analyses, engineering analysis, economic analysis, and consultations with potential commercial adopters/inves-

tors). This is a challenging task, and BETO must be diligent to do the homework and keep the portfolio focused on the most prospective options across the technology landscape.

Given this difference between the public and private sectors, the Office's approach to require cost share from industrial partners, with 20% cost share for lower TRL scales, and 50% for Demonstration and Market Transformation (DMT)-type projects makes a lot of sense. A cost share of 50% from a private partner is significant for an unproven technology and really shows that the partner is committed to a successful outcome and isn't just "exploring" the space. As a technology gets closer to market, the risks for the private sector come down, and therefore, a greater share of the investment coming from the industry partners is a suitable approach.

## Technology Area Assessments

### Feedstock Supply and Logistics

The Feedstock Supply and Logistics component of the BETO portfolio is clearly at a transition point. The Panel appreciates the value of projects such as the Regional Feedstock Logistics and the High Tonnage projects. There is a sense that key feedstock logistics objectives have been explored, technology has been developed, and feasible solutions have been developed. BETO has documented nationally relevant feedstock productivity potential for major bioenergy crops. New, optimized logistics systems have been demonstrated that define the potential for cost reduction and performance improvement in logistics. However, relatively few of these advances have been commercialized at this point because of the lack of conversion facilities and markets. The consensus view is that Feedstock Supply and Logistics efforts should shift to addressing near-term issues, such as feedstock handling, quality measurement, and storage. Further refinement of analysis, forecasting, and prototype systems will have limited value at this point.

One area that could benefit from further technical development is the general depot concept. This has been analyzed, promoted, and incorporated into many BETO projects. However, a commercially relevant scale biorefinery depot system has not been tested. There could be value in evaluating the depot concept at some scale.

### Feedstock-Conversion Interface Consortium

The development of the FCIC is an exciting opportunity. There is clear understanding that this interface is the crux of many issues in biorefinery performance. Better integration and system optimization should occur through these projects. In particular, the Panel highlighted the potential of integrated measurement technologies and quality metrics that apply across the supply chain. New innovations in sensing and smart control systems can be pursued. The Panel looks forward to tracking progress of the FCIC over the next review period.

### Thermochemical Conversion R&D

The Thermochemical Conversion portfolio, as one of the larger technology areas by both funding and number of products, supports a wide range of projects and varying stages of maturity. The overall portfolio is maturing smoothly, and shifts in focus over the past few review cycles appear to have occurred without disruption. In fact, the program management appears to have taken advantage of lessons learned from previous projects and synergies from co-occurring ones.

The Panel's review of this technology area is exceptionally insightful and has a range of suggestions for refocusing efforts. The Steering Committee reinforces the Panel's comments regarding the challenge of utilizing technologies that convert whole biomass into an intermediate product with an overly broad distribution of chemical constituents and then attempting to hydro-treat that intermediate en masse to hydrocarbons. There is a need to focus on separations to narrow product distributions and identify value-added applications or novel product types based on the unique reactivities and functionalities of biobased molecules.

Earlier, we lauded the combination of thermochemical, biochemical, and waste-to-energy work into a single "Conversion" technology area, a move that should break down silos and enhance cooperation and synergy. There is clearly an opportunity to leverage the body of work accomplished in the Biochemical Conversion Area in relation to separations, either to use as a pretreatment or fractionation of biomass before the application of thermochemical techniques or to assist in separating thermochemically derived intermediates.

### Advanced Algal Systems

The Advanced Algal Systems portfolio has made strong progress since the last review, increasing the depth of knowledge in cultivation and yield improvements, while also expanding into areas such as marine strains, enhancing growth using carbon dioxide streams, and increasing the overall commercial viability of algae via high-value co-products.

Advanced Algal Systems is arguably the technical area associated with the greatest amount of commercial risk, particularly given the difficulties moving from bench scale to commercialization. Therefore, future efforts should prioritize the challenges of larger-scale ponds over controlled bench-scale experiments that do not accurately reflect real-world conditions. Projects led by the national laboratories continue to provide high value, producing long-term data and experimental platforms that are leveraged throughout the industry.

Operational costs continue to be one of the largest hurdles for a viable algal industry. While the focus of BETO is energy production, the only realistic pathway to a viable algal-based bioenergy industry is through creating high-value co-products. In addition, co-products that are unique to algae and present a significant market advantage, rather than those that compete with existing markets, should be prioritized. Continued emphasis on improved yield quantity and quality is also necessary to achieve necessary cost reductions. BETO also needs to continue progress to standardize reporting

and methods of calculating key parameters for easier comparison among projects.

With respect to commercial markets, the Panel suggested greater emphasis on industrial collaboration with those who may be integrating fuel intermediates or market co-products to ensure that products meet commercial needs. Similarly, moving toward dynamic market analysis for co-products is necessary to understand the impact on markets as production of co-products scale to ensure a viable path to commercialization.

### Biochemical Conversion R&D

BETO put a stake in the ground and challenged the projects to demonstrate (verify) production of hydrocarbon fuels at \$3.00/gasoline gallon equivalent by 2022. The entire research team is utilizing this goal and evaluating individual project techno-economic analyses (TEAs) to meet this goal. The program is using a diversity of project approaches to accomplish this goal and will likely have to down-select to the most promising approaches in the near future. In the past, a goal encompassing cellulosic ethanol was a logical first choice, as ethanol was already in large production from starch and was an accepted fuel in the overall fuel logistics. The choice of the most appropriate hydrocarbon fuel must include input from the market, those that are most likely to actually produce it and make its production successful. BETO must constantly obtain feedback and concerns from probable first adopters through whatever means appropriate.

The most successful projects are the core and consortia projects, which have an impact across BETO and industry at large. Development of new standard procedures makes relevant benchmarking and comparison possible. In the case of Analytical Methods Development and Support, the impact extends industry-wide. Analytical Methods Development and Support has the respect, reputation, and track record of delivering solutions that industry, government, and all concerned have accepted. The need for the type of work that Analytical Methods

Development and Support does has not diminished with past successes, but has only expanded as new areas of research and industrial need are highlighted by an emphasis on new processing routes. Other consortia, to the extent that they have strong voices from industry, have the potential to bring the wide array of expertise across the laboratories to play on the most important problems.

The renewed focus on making chemical products in parallel to fuel is critical and will play a major role in developing a strong biorefining industry. Progress is being made in lignin conversion research, which is addressing BETO's focus on co-products as an economic necessity. And while there are at least two very large-scale operating biorefineries in the United States, neither biorefinery's lignin seemed to be a focus of this research. The choice of adipic acid from lignin seems arbitrary. While it may be an excellent target, there are many structures that meet the selection criteria. It may be counterproductive and premature to pre-identify a specific structure before there is an understanding of the selective transformation of something as complex as lignin. See earlier general comments on how BETO should decide what products to do fundamental research and support work on.

The Review Panel suggested that projects could benefit from more consistent use of TEA, and BETO responded that they are working on a "quick turnaround TEA tool." This was informally suggested to BETO during the 2015 review with little result. It is a very difficult task to develop something that will be both "quick" and "useful." If it is not useful, its development could be a waste of resources. BETO should seek corporate examples (and/or assistance) in how this might be done.

### Waste to Energy

The Waste-to-Energy (WTE) Technology Area is a new and welcome addition to BETO's portfolio. Impressively, the area launched as the result of a Small Business Innovation Research solicitation, and it now includes several innovative projects aimed at developing a fea-

sible WTE sector. Biobased WTE is a broadly exciting, popular concept for many reasons—de-coupling the bioenergy sector from land use is a very powerful idea; finding better uses for municipal solid waste (over landfills) is universally favored; and waste feedstocks are already distributed, free, and otherwise pose a problem to businesses and communities. Developing promising technologies to harness energy from biobased community waste streams would have high impact to the national bioeconomy and energy mix, and this is an appropriate focus for BETO and its national laboratory partners.

BETO’s work to develop biogas resources is particularly relevant, as there is high interest among multi-sector end users in renewable natural gas. Projects aiming to increase biogas production and utilization should remain an important area of emphasis. Developing scalable biogas reactors and addressing barriers to pipeline injection of biogenic methane would greatly advance the state of WTE technology and help spur private investment considerably.

Beyond DOE’s WTE conversion science and pathway development work, feasible approaches for mobilizing distributed wastes (municipal solid waste, food wastes, sludge)—including logistics/handling and development and demonstration of small-scale localized refining technologies—are critically needed. Further improved modeling to provide a deeper understanding of waste feedstock resource availability and infrastructure needs at the regional and local levels would be very impactful.

BETO’s project work in the WTE Technology Area thus far is highly complementary and supportive to both private-sector efforts and work by other federal agency partners to realize a robust, domestic WTE industry.

## Analysis and Sustainability

### *Including the Billion-Ton Study series*

The fact that sustainability and strategic analysis is an integral part of BETO’s programming illustrates an understanding of the pulse of future industry. This

broad work of sustainability analysis will only become increasingly more important as our world searches for everything from better adaptation tools in the face of climate change, to local communities striving to reach their sustainability goals. A project recommendation for this department is to create a standardization tool that could compare these domestic bioenergy fuel types to traditional fossil fuels. While acknowledging the inherent complexity of analysis across these fields, further movement towards standardization may allow the public a better way to assess the pros and cons of different technologies. Just as differing levels of LEED certification in buildings have created a standard that is readily recognized in the construction industry, so too could creating and marketing a sustainability standard in fuels frame up the benefits of bioenergy fuels nicely.

The public is becoming increasingly aware of the “well to wheel” issues with fuels and this could greatly enhance the reputation and use of the products created with biotechnologies. This standardization could also help to integrate the goals of the sustainability and strategic analysis team across the many platforms of biotechnologies advanced within BETO, as this measurement would be consistent and could be referenced throughout the development of each fuel type - be it algal or feedstocks or waste.

While the various models and analyses used to understand the sustainability of a fuel are very complex, a tool that simplifies this information greatly – like the platinum, gold, and silver levels of LEED (Leadership in Energy and Environmental Design) or a report card type style grading system – could allow the public to feel like they can make an informed decision without being a scientist themselves. Another example of this nature of simplification is the manner of presentation the Intergovernmental Panel on Climate Change uses in their reports. They aim to help policymakers grasp both the qualitative and quantitative probability of climate change outcomes in terms of likelihood.



Simplification matters. It could aid in the adoption of these fuels. If, for example, an algal fuel gets an “A” in the air pollution metric and natural gas gets a “C,” this is meaningful to the average person. By increasing the comprehension of the tangible benefits of biotechnology fuel products in the eyes of the public, we increase their marketability.

The measuring of “well-to-wheel” environmental impacts, such as life-cycle land use, water use, and air pollution/emissions, would be critical sustainability metrics from such a tool. They would create a more complete environmental impact picture and enable people to make an “apples-to-apples” comparison with fossil fuels. Of further interest to these stakeholders, and one that may leverage the value of these domestically produced fuels, is the inclusion of metrics such as job creation and national economic benefit.

If BETO were to create and promote such a standardization tool, it could greatly serve both the individual fuel technologies created, as well as the BETO program as a whole. Such a tool could provide a platform to dispel myths, such as the notion that feedstock fuels are utilizing potential food sources. Lastly, it could provide a means to better promote and communicate the great achievements reported in the *2016 Billion-Ton Report*. A standardization tool could create a bridge to not only educate stakeholders on the value of BETO’s work, but help them to feel invested in this important research. In the current political climate, this may be particularly important.

### Demonstration and Market Transformation/ Advanced Development and Optimization

In the end-to-end development of bioeconomy technologies, this particular area is perhaps the most challenging from a portfolio management perspective. The investments needed are large; the timelines for projects to be developed and deployed are long; the number of projects that can be funded are low; and, therefore, the risks to the Office are high. However, we would like to

emphasize that the rewards are even higher, for when a DMT project is a success, it is a success not just for the whole technology area, but also for BETO and for the American public too. The successful demonstration of technology at scale is an absolute necessity to allow capital markets to open up for project developers once technology risk is sufficiently reduced. The significance of the Office’s dedicated and patient efforts in assisting the establishment of the POET demonstration cannot be understated.

Given the critical function that DMT performs, the current state of the DMT portfolio seems somewhat disproportionately low. There are few projects, and a low allocation of the overall budget, although the new funding opportunity announcements in this technology area are a welcome addition and should hopefully provide better budgetary balance.

Previous high-investment DMT projects that have not resulted in successful long-term operations at scale are an unfortunate reality that should not be ignored. However, it is clear that lessons have been learned from these experiences. The new emphasis on up-front validation of background technology brought into large projects is an excellent project management practice, and one that should help avoid misallocating time and money on technologies that are not ready for this scale-up stage.

One suggested area that DMT resources could be deployed into is addressing non-capital-intensive market barriers, such as fuel technical or regulatory qualification. These barriers are certainly perceived as risks by investors, but they are areas that are more inexpensively mitigated than technology scaling risks are.

One opportunity to capture value from previous DMT investments is ensuring that Independent Project Analysis Inc.’s involvement in the large cellulosic ethanol projects is fully leveraged. Independent Project Analysis’ initial review of projects was mandated by BETO. Part of Independent Project Analysis’ operating procedure is to “close-out” each capital project that they

review with an analysis of how the project performed. Independent Project Analysis then utilizes that data (without specific reference to the originating company) in their future project evaluations. This is extremely useful, as most large industrial corporations (e.g., Dow, DuPont, others) require that all of their major capital projects have a favorable Independent Project Analysis review prior to authorization of funds. This additional data from these cellulosic projects will not only inform BETO, but also help future capital deployments in cellulosic feedstocks.

### Co-Optimization of Fuels and Engines

The Co-Optimizations of Fuels and Engines (Co-Optima) Technology Area and initiative has developed rapidly since the previous Peer Review. The effort is well-organized, clearly focused, and leverages broad expertise across the DOE laboratory complex and both BETO and the Vehicle Technologies Office. To date, the Co-Optima team has conducted an extensive and rigorous potential blendstock screening process, narrowing over 300 candidate blendstocks down to four. This is a major milestone that has substantially contributed to the state of knowledge on co-optimization technology in a relatively short period of time.

The promise of fuel and engine co-optimization is significant; the potential for widespread deployment of drop-in biofuel blends across a large, fuel-efficient, internal-combustion-engine vehicle fleet merits committed DOE investment. This approach innovates beyond the existing model of flex-fuel vehicle and E85 deployment, which has been limited by the E10 blend wall and infrastructure availability. E85's impact on fuel economy is also a deterrent to consumer acceptance as neat ethanol has approximately 30% less energy than gasoline. To the extent that drop-in biofuel blends and efficient, co-optimized engines may alleviate all of these barriers, the Co-Optima initiative offers a novel pathway for transportation sector bioenergy use.

It is well-known that technology development alone will not necessarily spur broad adoption of new fuels and vehicle technologies. This has been seen with other alternative fuel platforms, such as compressed natural gas—which has also developed its own vehicle and fueling systems yet has had a much less robust adoption than hoped, in spite of incentives. Thus, the market transformation activity area is critical to BETO's Co-Optima work to help ensure that typical deployment barriers—such as materials compatibility, infrastructure, and regulatory impediments—are addressed along the development pathway and in close coordination with vehicle original equipment manufacturers, fuel suppliers, fuel retailers, and federal and state regulators (such as the U.S. Environmental Protection Agency and the California Air Resources Board).

BETO should expand the initiative's focus to be more inclusive of medium- and heavy-duty vehicles. A competitively priced, sustainable drop-in biofuel could carve a huge niche in the medium- and heavy-duty fuels market. States like California are strongly embracing renewable diesel, which has shown negligible negative impacts on vehicles or infrastructure. However, its use remains dependent on state credits (where available) to reduce cost barriers. An increased economic benefit through engine optimization and improved fuel economy could counter biofuel cost premiums, particularly in non-incentivized states. Tesla and others are developing heavy-duty electric trucks; however, liquid (diesel) fuel is poised to remain dominant in the trucking industry. There is substantially less potential sway towards electrification among the medium- and heavy-duty vehicle segment than there is in the light-duty vehicle segment, further underscoring its prime relevance to BETO. A sustainable drop-in fuel that proves reliable under various conditions could revolutionize long hauling, as all viable alternatives require costly changes to equipment and/or infrastructure.

## Biofuels in Defense and Aviation

Although not a technology area specifically reviewed, BETO's work related to biofuels in defense and aviation warrants comment. The selection of these two key markets for drop-in distillates fuels is a wise choice. Energy security concerns and a lack of carbon-free propulsion technologies for airplanes and certain military vehicles make end users for renewable jet fuel and diesel uniquely motivated and engaged in assisting the development of these fuel technologies. The continued push from commercial aviation concerns to develop a carbon-reduction scheme at the international level via the International Civil Aviation Organization is a further driver for low-carbon fuels. Additionally, the U.S. Department of Defense's and the U.S. Department of Agriculture's (USDA's) cooperation with BETO for the Defense Production Act (DPA) program is a real strength.

The initial round of DPA awardees appear to be making steady, if somewhat slow, progress towards the construction of their facilities. It is absolutely critical that there is success for at least one of these projects in deployment and commercial production. The level of public and industry support and investment in these projects means that much is at stake, and continued access to support from these kinds of sources would be threatened by an inability to deliver on commitments. The Office is encouraged to seek ways to help these projects succeed outside simply providing the committed funding, potentially by making connections between other portfolio projects with relevance to the DPA projects.

The new round of DPA funding is an excellent addition to the portfolio, and the Steering Committee appreciates that a broader set of technologies are eligible for inclusion than in the first round. The timeframes of project development and deployment are long, and it is a wise modification to allow fuel technologies to be proposed that do not yet have ASTM certification but that do have a viable path towards certification.

Outside the DPA program, there is a range of projects across BETO's portfolio that is relevant to the drop-in distillate fuel markets. One general suggestion for setting milestones and goals for these projects is to not overly emphasize that fuel production technologies should make a perfect jet fuel, for example, at the bench or pilot scale. It is far more important to be able to produce a fuel-like product that is affordable than to produce a perfect fit-for-purpose fuel that is unaffordable. Blending, and fuel finishing techniques from traditional refineries, allows some flexibility to still produce an on-spec fuel blend from an initial product that does not necessarily look like a jet fuel mixture.

The Steering Committee commends BETO's role in the development of the *Federal Alternative Jet Fuel Research and Development Strategy* that was published in 2016. This document is a model of interagency cooperation, both in its preparation and in the vision that it shares across a wide range of federal stakeholders. Such a considered and detailed R&D strategy should be a guide to BETO's continued engagement in this technology area.

## BETO Portfolio Impacts

### Portfolio Impact: Advancing Domestic Resources for a Thriving Bioeconomy

The work of BETO is central to the development of the U.S. bioeconomy. The history of investments, the breadth of technologies supported, the depth to which R&D and analysis are funded by the Office are all major contributors to where the United States is today—as a global leader in the development and deployment of bioenergy and bioproduct technologies. The current portfolio builds on the wealth of knowledge and expertise previously fostered, and it is well-positioned to significantly contribute to commercial success for bioeconomy technologies.

## Portfolio Impact: Areas of Improvement

There was discussion at the Review Panel and Steering Committee levels about the challenges of developing economical approaches to produce drop-in hydrocarbon fuels from lignocellulosics. Techno-economically, this outcome has remained challenging, and sustained low petroleum prices only serve to amplify the challenge. Biological feedstocks are rich in highly oxygenated molecules with interesting functionalities and reactivity that could possibly provide a platform for producing energy-carrying fuel molecules that do not simply displace petroleum with a functionally equivalent biobased fuel; instead, these energy-carrying fuel molecules could be a fuel with operational and energetic improvements over the fossil-fuel performance baseline.

This concept is behind the establishment of the fuel and engine co-optimization thrust, which is a commendable and innovative direction for the Office to take. These efforts should be encouraged, and possibly expanded upon, translating these efforts into those transportation markets not yet included in the Co-Optima initiative, such as heavy-duty ground transportation and aviation fuels.

DMT efforts are currently not as strongly supported as in the past. This is a particularly challenging phase of technology development and deployment, and it is particularly challenging to support, as the costs are high and timelines are long. On balance, however, the current allocation of portfolio resources into DMT is somewhat on the low side, even with the newly awarded projects that are commencing this year.

## Portfolio Impact: Gaps

In the current political and social climate, the issue of jobs in the energy sector is a hot-button topic. To counter misperceptions that supporting clean energy automatically eliminates jobs, BETO is encouraged to spotlight and strengthen efforts directed at workforce development. Currently, there is a thrust of the Communications

portfolio that targets these ends, and there is also one project in the Advanced Algal Systems Technology Area that is developing post-secondary curricula. There is a need for a more robust effort in promoting workforce development. While there was strong agreement within the Steering Committee that workforce development is a critical need for the bioenergy industry, it is less clear that BETO should take the lead in developing and supporting these programs. The primary competency of BETO is encouraging technological innovation. Therefore, collaboration with other agencies and educational consortia that have the appropriate capacity and experience to build workforce development programming is encouraged.

## Portfolio Impact: Supply Chain Focus

The bioenergy supply chain is a closely coupled system, and it is nearly impossible to choose the “chicken or the egg.” BETO’s approach to addressing cost reduction and performance improvement across the whole supply chain is commendable. The new consortia, like the FCIC, recognize that cost and performance must be optimized at the whole scale, not individual components. It is commendable that the Office is tracking and managing portfolio progress from that crosscutting portfolio perspective. That said, the new emphasis on defining “value proposition” and in developing bio-co-products to fully utilize the feedstock stream seems to offer the greatest potential to make a transformative leap for the bioeconomy.

## Strategic Plan for a Thriving and Sustainable Bioeconomy

The 2016 *Strategic Plan for a Thriving and Sustainable Bioeconomy* (2016 Strategic Plan) is an outstanding document that provides clarity of purpose and clear guidance for all stages, and timeframes, of planning. Further, it provides an excellent set of success indicators and milestones for the Office to track progress. It appears that this plan is motivating action within



the Office administration, as it informs the *Multi-Year Program Plan* and the AOPs. What is not clear, however, is how well the plan is understood by the broader BETO community. During the Project Peer Review, the Steering Committee perceived that a number of project PIs did not fully understand the greater context in which their work should be understood. Greater internal communication will help project leaders recognize their part in the whole.

The 2016 Strategic Plan's milestones are rightly focused on the actions and future successes of the Office. However, the goals of the Office, and the likelihood of achieving them, in large part rely on external factors, notably the actions of industry participants in the bioeconomy and the development and dynamics of markets for bio-derived products and energy. Therefore, including some predictions or projections about how various components and markets of the bioeconomy will develop over time would be a helpful augmentation to the 2016 Strategic Plan.

The "Billion-Ton" efforts are a real strength. The reports convincingly articulate the vision for how the nation's biomass resources can be mobilized in support of the Office's goals. For many broader stakeholders in the bioeconomy realm, lingering doubts about the materiality of a biobased economy should be put to rest by these analyses, provided they are well-promoted. The clear statement of the significant opportunity ahead is a strong motivator.

### 2016 Strategic Plan: Gaps

The 2016 Strategic Plan correctly acknowledges the importance of biobased products as key "stepping stones" on the journey towards large-scale, cost-competitive bioenergy. Many offer a more near-term commercialization success opportunity than bioenergy products, and success in one area of the bioeconomy will help maintain interest and investment from those who hold financial and political capital. However, not all bioproducts are going to equally enable BETO's overall

mission. The Office has studied the most important biobased product opportunities, hosting a workshop on the topic in 2015 and publishing a series of excellent, detailed reports that reveal market sizes, pricing dynamics, and details of incumbent technologies. The logical next step, but one that apparently has not been taken yet, is integrating this information to articulate a projection of the development over time of these technologies and the markets they unlock, satisfy, and potentially saturate. This would be very important for helping the Office prioritize investments in the bioproducts area. Absent such a view, BETO risks too broad a set of investments and may sub-optimize outcomes by investing in bioproduct technologies that will not be impactful on the Office's larger bioeconomy development objectives.

Additionally, there is a near-term challenge to strike the right balance between bioproducts and energy. BETO's mission is energy. However, for the reasons outlined above, there is a need to focus on bioproducts due to cost challenges, but they must always be tied to enabling bioenergy production. If BETO has to justify all projects as relating to energy, and yet prolonged low fossil fuel prices make competing with traditional energy products too difficult, then the Office risks being perceived as not attaining its mission. Currently, the drivers for a low-carbon energy future are weak, and until they re-strengthen (which we believe they will), it will be difficult to justify continued investment in what may be a marginally viable bio-industry. Two possible mitigations are to either (1) relax any required link to bioenergy and allow pure bioproduct technology investment that may lead to standalone profitability, or (2) invest in research projects on energy future scenarios to better inform the *Multi-Year Program Plan* and/or Strategic Plans.

The 2016 Strategic Plan lays out a strong case for the benefits of expanding stakeholder engagement and collaboration. In the following sections, the Steering Committee presents their views on the effectiveness of the Office's efforts in acting upon the plan.

## Technologies and Market Trends

### Recommendations: Responding to Emerging Technologies

BETO has done a thorough job in understanding, and shaping, the range of biomass-related technologies that may contribute to the Office's goals. If there are any potential disruptors to those goals, from a technology perspective, they would most likely come from adjacent sectors, such as energy, transportation, or agriculture.

With what appears to be a relatively stable and significant ongoing shale gas production sector, low natural gas prices and opportunities for stranded natural gas utilization are likely to foster technological innovation in this space. Novel approaches to conversion of natural gas into a range of platform chemicals, or upgrading to liquid fuels, could potentially undercut the markets that BETO's portfolio targets. To mitigate against this risk, intelligence on this technology field will be key. BETO would be well-served to make strong outreach efforts to stakeholders in the natural gas field to gain an enhanced understanding of who is developing what—to best be positioned to understand which product markets may be targeted and, therefore, where BETO may need to shift its investments.

In the transportation sector, one key technology is driving disruptive change. Electrification of light passenger vehicles is well underway and, in combination with demographic and behavioral changes, presents a scenario in which there is potential for dramatic reduction in demand for light-vehicle liquid fuels—in the United States, primarily gasoline. This presents a challenge to major aspects of the Office's Conversion portfolio that target cellulosic feedstocks with pyrolytic or liquefaction technologies. Absent significant and costly hydro-treating, the fuel products of these pathways contain a large proportion of molecules in the gasoline range. Directly mitigating against this risk will be difficult for the Office.

The Steering Committee does not suggest that pyrolytic or liquefaction-type pathways should be deemphasized, as they are some of the most promising for actually reaching the cost/volume targets BETO has set for any liquid fuels. However, recognition that, even against a backdrop of projected continuing low crude prices, the crack spread between gasoline and distillates is likely to continue to increase may be leveraged as an opportunity. A surfeit of low-cost gasoline-range aromatics, whether petro- or bio-derived, could be considered feedstock for combining or reacting with other bio-derived molecules to generate fuel molecules in the diesel or jet range. An additional mitigation against these liquid fuel markets trends is to continue building upon (1) the already established focus on aviation fuels, (2) the recent inclusion of marine fuels focus, and (3) continued emphasis on heavy-vehicle diesel targets. The end users in these markets are all increasingly focused on lowering their carbon footprints, even while their opportunities to electrify are limited.

### Recommendations: Responding to Market Trends

Despite short-term ebbs and flows of political will, over time and increasingly global, national, and local regulations are pushing towards imposing a cost on carbon emissions. The development of carbon markets to satisfy these regulatory requirements is a market trend with a significant probability to impact on BETO's goals. Increasing demand for carbon credits will push the effective cost of those credits upwards, and where regulatory schemes account for life-cycle carbon emissions savings of fuels and energy, this trend will assist in closing the techno-economic gap between cost of production and price in the market.

Technologies that capture atmospheric or waste carbon and fix or sequester that carbon into long-lived products or applications, such as biochar (which increases soil carbon in the long term), are going to provide an increasingly valuable opportunity as carbon regulations tighten. The Office should consider the implications of

different scenarios for carbon pricing into their strategic planning process. The Analysis and Sustainability portfolio tools for life-cycle analysis will be valuable.

More widespread adoption and deployment of renewable electricity production appears to have driven power markets to an inflection point. If current trends continue, it appears plausible that low-carbon electricity at very low costs may be a real future for the United States. Very-low-cost electricity could impact the Office's goals in two key ways. Firstly, electrolytic generation of hydrogen may provide a low-carbon source of this key input into the bioeconomy. Secondly, various forms of "electro-fuels" technologies may become increasingly feasible under this scenario. BETO should engage with colleagues in other DOE offices that invest in these technology areas to better understand the latest technology and how it may impact BETO's goals.

## Budget Priorities

In the allocation of budgetary resources that is under the Office's control, the relative spending on each technology area of the portfolio is mostly appropriate to the level of need and impact for each area.

### Budget Priorities: Future Focus

To the degree possible given congressional mandates, a reduction in the spending on Advanced Algae Systems relative to other areas would be appropriate. Algae technologies are no doubt an important component of the future bioeconomy, but in balance, the impact of BETO investment to date in this space is not in proportion to budgetary allocation. On the other hand, WTE is a highly promising technology area with an appropriate focus on low-cost and environmentally problematic feedstocks, yet it receives a disproportionately small allocation of the budget.

As mentioned earlier, risk sharing at the demonstration stage is an absolutely critical function of the Office, and therefore the Office should consider increasing the allocation to DMT projects.

Given that near-term budgets are likely to be smaller than in the past, it may be wise for BETO to focus on the technology areas that have already been identified and continue to push for results from the existing set of investments rather than spreading focus, and funding, any more thinly.

## Collaboration and Partnerships

### Technology Area Coordination

Efforts to enhance integration across the technology areas are evident. Breaking down the barrier between Biochemical Conversion and Thermochemical Conversion is a great example—enhancing cross-communication and collaboration between these disciplines will be important to ensure that opportunities for hybrid pathways and leveraging expertise, capabilities, or facilities will be strengthened. The planning and organization of the Office's efforts demonstrates a strong grasp of holistic system thinking, which is so important for maximizing outcomes in an emerging sector of such complexity. The Analysis and Sustainability team is a crucial link across the rest of the portfolio. Their efforts in integrating the findings, developments, and work of the different technology areas provides the overall high-level context in which the PIs or technology managers can see how they impact that bigger picture; their work can also help in decision making by providing a framework for understanding impacts.

Also important for cross-office coordination is the new efforts with Co-Optima, FCIC, ChemCatBio, etc. that bring together experts and capabilities from different technology areas to work on focused new opportunities. These efforts act as a bridge that will strengthen relationships and mutual recognition of capabilities in a way that is highly likely to organically lead to additional collaborations and innovations in areas adjacent to the near-term focus.

## Technology Area Knowledge Sharing

On the positive side, the launch of the FCIC is a clear example of lessons learned being fed back into the Office's plans. The challenges uncovered as previous rounds of large DMT projects struggled during commissioning gave a clear signal that concerted effort at the refinery throat was needed. The stakes in such large projects are clearly high, and therefore, acting on those challenges was easily and clearly identified as a priority. However, there may be a gap in identifying and communicating lessons learned at the smaller scales of R&D—bench and pilot projects.

It is a widespread challenge shared across almost all scientific endeavors that failure, missteps, and research dead ends are not communicated—only successes are. This situation naturally leads to different researchers repeating, quietly, the same mistakes that others have made before them. There is no reason to believe that BETO is an exception to this rule, although the strong staff continuity and active engagement of technology managers may partially obviate the issue through a consistency in oversight. BETO could go further, though, by actively drawing out from researchers their challenges and missteps. A card from the deck of Silicon Valley may be appropriate—developing a culture where failure is not a bad thing; in fact, it is something to be, if not celebrated, at least widely discussed to avoid similar dead ends in the future.

## DOE Coordination

The launch of the Co-Optima program is an excellent example of the value of coordination across different offices within DOE. There may also be advantages in collaboration between BETO and the Fuel Cell Technologies Office, given their coverage of hydrogen production and distribution efforts for DOE. Hydrogen is, of course, a key input to almost all advanced biofuel technologies, and better understanding of the future opportunities and dynamics in the hydrogen marketplace, both renewable and fossil-derived, will help BETO better understand the biofuel future.

The Steering Committee is not aware of any formal collaboration between BETO and the Advanced Manufacturing Office (AMO). Given the latter's mission, it seems likely that there could be areas in which collaboration would be fruitful, especially as the advanced bioeconomy moves out of the laboratory and into deployment. Advances in catalysis, process control, automation, and combined heat and power are all relevant to scaling up bioenergy technologies. Opportunities for fruitful collaboration will increase as the bioeconomy matures.

More broadly within DOE, continuing and enhancing cooperation with the Advanced Research Projects Agency – Energy (ARPA-E) is important. BETO and ARPA-E are highly complementary and should share a vision for the longer-term development of bioeconomy-relevant technologies. Given the staff continuity and depth of knowledge within BETO and the rotating expertise of program managers in ARPA-E, simply enhancing communication lines between the offices would be mutually beneficial in sparking innovative ideas and transferring deep knowledge.

## Interagency Coordination

The remits of other U.S. government agencies, such as USDA, the U.S. Environmental Protection Agency, and the U.S. Department of Transportation, are intrinsically connected to BETO's work. Coordination with these agencies is vitally important to ensure that BETO's goals are successfully achieved. Continued and enhanced dialogue is important; aligned visions for the future and plans for the near term are important to amplify the efforts of each agency towards common goals. A benefit of enhanced dialogue would be encouraging greater levels of “co-ownership” of the bioeconomy, building a stronger coalition of agency stakeholders.

A model for interagency coordination on bioenergy development is the Commercial Aviation Alternative Fuels Initiative, a public-private partnership of aviation stakeholders who are aligned around efforts to commercialize sustainable jet fuels. The Commercial Aviation



Alternative Fuels Initiative is co-sponsored by the Federal Aviation Administration and several aviation trade organizations, with non-dues-paying membership of approximately 450 organizations and 800 stakeholders. Importantly, representatives from a range of relevant U.S. federal agencies participate in coordination calls monthly, sharing information amongst themselves and with and from industry stakeholders.

Clearly, USDA is the agency with the greatest alignment of mission in building a biobased economy for America's future. BETO's vehicles of collaboration with USDA are naturally the strongest of any, in regard to other federal agencies. Coordination of mission is important as there is potential for both redundant action and gaps in the overall plan, where roles and responsibilities are not clear. The Biomass Research and Development Board is an appropriate venue to coordinate between these two agencies and with the other agency participants, but there are some areas of overlap outside the remit of that board (crop statistics, tracking of rural

economies, etc.). Continued close coordination between USDA and DOE is a clear need.

## Stakeholder Coordination

BETO workshops are an excellent "on-ramp" for new ideas, industry input, and stakeholder engagement. They form an important foundation for seeking early feedback on concepts for new programs or funding opportunity announcements, and they should certainly be continued as a best practice within the Office.

The consortia have less of a track record on which to judge their effectiveness, but they have been established with a mission to coordinate and collaborate on focused research areas. In order to ensure that mission is met, the consortia management will need to be diligent to remain open to interaction outside each consortium's core working team, proactively engage industry partners and advisory board representatives, and promote the work of the consortia outside of BETO.

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## BETO PROGRAMMATIC RESPONSE

*Prepared by BETO leadership*

### Introduction

BETO leadership would like to thank the Steering Committee for its work, technical support, and critical insights throughout the implementation of the 2017 Project Peer Review and Program Management Review. The Office appreciates all of the feedback provided and is encouraged by the Committee's support for many of BETO's current research activities and plans for future directions.

This section represents BETO's response to the Steering Committee's final report. BETO will work with the program and technology managers to implement a number of the recommendations and address many of

the Committee's concerns in the coming years. BETO will consider these in developing and implementing a coordinated framework for managing its portfolio based on systematically investigating, evaluating, and selecting the most promising opportunities across a wide range of emerging technologies and TRLs. This approach will support a diverse portfolio in applied R&D, enabling industry to identify promising targets for scale-up and demonstration with increasing integration and complexity.

Going forward, the Office will emphasize early-stage applied R&D to strengthen the body of knowledge enabling industry to demonstrate and deploy sustainable bioenergy technologies capable of producing price-competitive biofuels from non-food sources of biomass, such as wastes, agricultural residues, and energy crops (e.g., switchgrass and algae). Research focus areas will include the following: detailed understanding and opti-

mization of the physics and chemistry of each preprocessing step of highly variable biomass; identification and molecular characterization of high-performing algal strains; and development of engineered organisms and novel catalysts.

As described in the Office’s 2016 Strategic Plan, BETO’s primary focus will be on R&D to produce “drop-in” biofuels that are compatible with existing fueling infrastructure and vehicles across a range of transportation modes, including renewable gasoline, diesel, and jet fuels. The Office will also support early-stage R&D on converting biomass into high-value, renewable chemicals and products that can enhance the economics of biofuel production and improve energy security by displacing demand for oil imports and supplementing U.S. exports. Also, in collaboration with the Vehicle Technologies Office, BETO will continue the Co-Optima initiative to enable the development of biobased fuels and additives that have the potential to realize up to 15% fuel economy gain when blended with petroleum and used in high-efficiency engines.

## Steering Committee Recommendations Overview

The Steering Committee provided specific recommendations, such as launching consortia to enhance collaboration between the national laboratories and industry, enhancing cross-discipline collaboration and communication, and retaining and developing staff. We agree with these suggestions and appreciate that others are noticing the strength of the BETO team. The Agile Biomanufacturing Foundry and ChemCatBio Consortia have gotten off to a good start and will continue to focus on overcoming conversion efficiency barriers. The FCIC represents BETO’s newest cross-discipline collaboration that will focus on increased, robust conversion yields.

### BETO Portfolio Recommendations

The Steering Committee has made several recommendations for the BETO project portfolio, including

improving industry engagement, diversifying the project portfolio, focusing on medium- and heavy-duty vehicles and aviation jet fuel, and capitalizing on oxygenated molecules in biomass.

### Industry Engagement

BETO has a long history of public-private partnerships that have enabled collaboration with industry. However, with compressed budgets, the BETO team agrees with the Steering Committee that industrial engagement is more important than ever. To this end, BETO is employing additional mechanisms to work towards improving and expanding collaboration with industry, including leveraging cooperative R&D agreements, such as the creative cooperative R&D agreements administered through our consortia. For example, BETO is working through the Energy Materials Network to develop targeted consortia led by the national laboratories that integrate all phases of R&D, from discovery through optimization, and facilitate industry access to multiple national laboratories’ capabilities. The overall goal is to accelerate material development cycles and to enable U.S. manufacturers to deliver innovative, made-in-America products to the world market. Another example of BETO’s industry engagement efforts is the ChemCatBio Consortium, which continually engages with industry to advance common needs.

The consortia employ a laboratory call process that enables working with industry as well. This provides access to the entire distribution of world-class experts and to the national laboratory capabilities. By working together and serving as a singular point, focused on targeted topics, more efficient solutions to applied R&D problems can be employed. Additionally, advisory boards provide input on what efforts might best be tackled by industry, academia, or the laboratories; this supports more efficient use of funds and will continue.

As part of BETO’s industry engagement strategy, the Peer Review Steering Committee specifically pointed out the usefulness of industrial input in working with lignin because there are now a few companies out there

producing and using lignin for combustion and other products. We agree that with these commercial sources of lignin, these companies are gaining scale-up experience and will likely want to pursue higher-value products for this complex molecule. Our work in this area is seeing breakthroughs in utilizing lignin for higher-value products, and this represents a key strategy to derive greater value from biomass.

### **Portfolio Diversity**

In terms of portfolio diversity, one of the recommendations is to engage in early TRL work, and investment in activities across the TRL spectrum is essential to leveraging innovations in bioenergy. BETO supports innovative solutions and appreciates the recommendation to continue to engage stakeholders to capture the latest thinkers in rapidly evolving research areas. BETO agrees that it is crucial to keep a steady flow of new ideas coming into the technology pipeline and to underscore the most promising ideas with strong, early R&D.

Another recommendation was to seek near-term wins. While one can define a project's success by whether it reaches its ultimate goal—for example, an IBR reaching its design production capacity of 20 million gallons per year—BETO thinks there are opportunities to look at successes along the way. The Steering Committee's point is well-taken, and accordingly, BETO needs to adjust what is considered a success at different stages along the research development pipeline. BETO approaches this by collecting success stories throughout a project's lifetime to share the latest breakthroughs throughout the bioenergy sector and assist with justification for continued funding. The Steering Committee's recommendation that BETO consider utilizing a venture capital approach to funding is interesting and will be considered. Focusing constrained funding on a near-term, highly visible wins could improve overall public opinion of the value and impact of a growing bioeconomy. Such near-term opportunities with strong stakeholder support include renewable jet fuel for aviation and WTE approaches, both of which are in the current portfolio.

### **Medium-Duty, Heavy-Duty, and Aviation Jet Fuel**

The Peer Review Steering Committee suggests that BETO focus on medium- and heavy-duty vehicle fuel, as well as aviation jet fuel. BETO recognizes that distillates are a significant opportunity. BETO has incorporated sessions on marine fuels in its July 2017 conference—Bioeconomy 2017: Domestic Resources for a Vibrant Future—to keep the discussion relevant. The Office has also been actively engaging with renewable aviation fuels, with many projects focused on this nearer-term opportunity.

### **Oxygenated Molecules in Biomass**

The Steering Committee also recommended that BETO capitalize on oxygenated molecules found in biomass. There was some discussion on the appropriate timing to move towards products to leverage the strengths of biomass. BETO agrees that biological feedstocks are rich in highly oxygenated molecules with functionalities and reactivity that could provide a platform for producing energy-carrying fuel molecules that do not simply displace petroleum with a functionally equivalent biobased fuel—but could instead be a fuel with operational and energetic improvements over the fossil-fuel performance baseline.

BETO believes that our Co-Optima efforts are expanding the group of molecules derived from biomass that can enhance the performance of fuels. BETO will continue to support collaborative R&D with BETO's Vehicles Technologies Office within Co-Optima to develop biobased fuels and additives with the potential to enable an up to 15% fuel economy gain when blended with petroleum and used in high-efficiency engines. BETO is beginning to gather stakeholder input to answer the question, "How do we capture the rich functionality in oxygenated species that are present in the polymers we start with?"

### **Advancing the Bioeconomy**

With respect to BETO's work to advance the bioeconomy, the Steering Committee recommended collaborations with others to build a bioenergy workforce. BETO

is taking a leadership role in the Biomass Research and Development Board's Bioeconomy Initiative, which brings together multiple agencies with roles in advancing the bioeconomy. Workforce development is a recurring theme within the industry development, and joint efforts with USDA, the National Science Foundation, and others to find creative solutions to developing a workforce is a key component of the Bioeconomy Initiative.

The Steering Committee felt that DMT efforts are currently not as strongly supported as in the past and recommended more funding. This will likely be a challenge with the anticipated budget constraints going forward. As previously mentioned in this report, the DMT Program has recently been renamed the Advanced Development and Optimization (ADO) Program. BETO continues to look at the opportunity to inform the new administration, Congress, and Office of Management and Budget about the value of investing to advance to pilot-, engineering-, demonstration-, and pioneer-scale projects.

Prior to scale-up and integration, there is enormous technology uncertainty, and it is a vital role of government to reduce this technology uncertainty through strong R&D. BETO promotes pilot and engineering scales as the first significant integration of a biomass processing system. As such, a key driving force for the bioenergy R&D pipeline is uncovering the barriers that need to be studied and become visible at larger scale. Bioenergy production requires significant integration of unit operations, such as feedstock handling. Pilot-scale processes are typically facilities or projects that do not operate for gain and operate at a loss. These systems are highly specialized, capital expenditure-intensive, and operate solely in a campaign mode. Due to the cost and technology uncertainty, small- and medium-sized companies will not be able to invest in critical pilot-scale testing, and strong technologies are being shelved due to lack of funds and a lack of appetite for both risk and technology uncertainty. Consequently, there is a lot of innovation that will be lost if government agencies are not encouraged to continue collaborating with businesses on pilot-scale projects.

## Strategic Plan for a Thriving Sustainable Bioeconomy

The 2016 Strategic Plan, which BETO published in December of 2016, provides the framework to realize DOE-BETO's mission to research and develop transformative, revolutionary, sustainable bioenergy technologies for a prosperous nation. The Steering Committee made two primary recommendations with respect to BETO's strategy: (1) prioritization of bioproduct investments in the near and long term, and (2) improved communication of the 2016 Strategic Plan.

There are sensitivities around prioritizing bioproducts investment in the near and long term. Questions related to which co-products are a priority, the size of the market, and scalability with fuels need to be considered. Often the earliest-stage TRLs supporting biomass conversion can allow for a bioproducts or fuels approach, but as you get to development, the paths diverge somewhat.

BETO is working to increase use of available TEA tools and to apply them to bioproducts development. The scalability of singular products into multiple markets, and multiple derivative products derived from a platform intermediate into adjacent markets, are important strategies to explore as co-products scale up with biofuels, and there are some necessary down-selections that will be enforced with or without budgetary constraints. Regardless, multiple markets are beneficial to diversify market risk and to promote investments. BETO agrees with the Steering Committee that the products must integrate with fuel and energy future scenarios.

The Steering Committee also recommended better communication of the recent BETO 2016 Strategic Plan. Additionally, the Steering Committee suggested that BETO increase promotion of *The Billion Ton Bioeconomy Initiative: Challenges and Opportunities*<sup>42</sup> report, which was published in November 2016. These documents are sources of both internal objectives and interagency communication. BETO is working to educate DOE leadership and administration of the value of the bioeconomy, and these documents serve as important tools



for this education. BETO will look for ways to amplify the dissemination of these documents to the external stakeholder community.

## Technology and Market Trends

BETO recognizes that the energy sector requires adaptability to technological innovation, changing market dynamics, and policy impacts. The development of the bioeconomy depends upon generating both market pull and market push to effectively establish a functioning supply chain. The Peer Review Steering Committee identified two opportunities for improvement in technology and market trends, including the incorporation of carbon pricing scenarios within strategic planning exercises and collaboration with other DOE offices on R&D for using surplus renewable electricity.

BETO agrees with the recommendation to consider different carbon pricing scenarios. When coupled with a sensitivity analysis, BETO life-cycle assessments and TEAs could provide the opportunity to examine different carbon pricing scenarios. BETO does not conduct policy analysis but can look at different scenarios and assess the sensitivities of different policy options in terms of economic and environmental impacts.

Collaboration with other DOE offices on R&D for using surplus renewable electricity was discussed at the Office-sponsored Bioeconomy 2017 conference. The Office has conducted R&D related to leveraging renewable electricity. In addition, BETO agrees that enhancing the level of interaction and cooperation with ARPA-E is important. BETO has previously shared information, including TEAs of electro-fuels, with ARPA-E, which had funding under its electro-fuels program. This recommendation also relates to the Algae Cultivation for Carbon Capture and Utilization Workshop that BETO hosted in May 2017, as well as the Engineered Carbon Reduction Listening Day hosted in July 2017. These events gathered stakeholder input through facilitated

discussions focused on innovative technologies and business strategies for growing algae on waste carbon dioxide resources and for creating tools that leverage renewable power to manage carbon and create advanced bioproduct pathways for new economic opportunities.

## Budget Priorities

In terms of budget priorities, the Steering Committee highlighted the significant funding levels allocated to the Advanced Algal Systems Program and the low levels of funding allocated to the WTE and DMT (now ADO) Programs. The Committee recommended placing an emphasis on getting results from existing investments, rather than spreading funding too thinly.

With respect to the funding for Advanced Algal Systems, this research has significant support from Congress. BETO agrees that WTE is a very promising area. Congress also has demonstrated support for this research. There are a lot of other agencies that are doing WTE, all with distinct roles. BETO has conducted several workshops on this topic and is working to identify the unique aspects for BETO in WTE that align with BETO's distinct expertise. The Office has also been very strategic in using the Small Business Innovative Research program to explore WTE and has awarded several small business projects through Phase I and Phase II efforts in this area. BETO is leveraging strategic use of these projects to seed distinct, innovative R&D as BETO grows its WTE Program.

BETO agrees with the Steering Committee that DMT, now ADO, is a critical function not just to the Office, but to the bioenergy sector, as pilot- and engineering-scale work drives research in new directions. BETO also agrees with the recommendation to place emphasis on getting results from existing investments rather than spreading funding too thinly. The recent fiscal year 2018 budget request scenario development gave BETO the opportunity to look at this area with a fresh perspective and prioritize

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<sup>42</sup> Biomass Research and Development Board (BRDI), *The Billion Ton Bioeconomy Initiative: Challenges and Opportunities* (BRDI, November 2016), [https://biomassboard.gov/pdfs/the\\_bioeconomy\\_initiative.pdf](https://biomassboard.gov/pdfs/the_bioeconomy_initiative.pdf).

or rethink the portfolio. There is no room for spreading the funding too thinly under budgetary constraints.

There needs to be a portfolio balance between existing and emerging projects. The question BETO is trying to answer is, “How does the Office attain a balance of continually achieving near- and mid-term results, on one hand, while looking at earlier research on the other hand?” BETO thinks this can be an opportunity for education as BETO has a great pipeline already that can be leveraged for some time. BETO is building on prior investments and utilizing the results as we go forward. For example, BETO has analyzed the projects funded over the last 10 years and tried to capture the results and assess the benefits realized, lessons learned, and ripple effects of investments made; this extends into areas beyond the immediate research, development, and demonstration goal of specific biofuel technologies projects.

### Collaborations and Partnerships

In the area of collaborations and partnerships, the Steering Committee recommended that BETO increase its coordination with DOE Office of Energy Efficiency and Renewable Energy offices, including the Fuel Cell Technologies Office, AMO, and ARPA-E. Additionally, the Committee recommended expanding federal agency coordination within the Biomass R&D Board.

There are potential opportunities to learn about renewable hydrogen production and distribution efforts from the Fuel Cell Technologies Office. BETO has been using the Fuel Cell Technologies Office as a knowledge resource and is pleased to see that their big initiative on moving towards renewable hydrogen is cost-competitive with steam methane reforming. BETO is also beginning to see promising scenarios with the distributed production of hydrogen, which will be highly beneficial to distributed bioenergy production technology.

There is also potential for increased collaboration with AMO on deploying advanced technologies within the emerging bioeconomy, particularly catalysis, process control automation, and process intensification technologies.

BETO currently interacts with AMO on process intensification, separations, and products. Members of BETO are involved in advisory boards for the Rapid Advancement in Process Intensification Deployment Manufacturing Institute. On separations, there is a large effort at AMO that BETO is following, and the Office is leveraging AMO’s R&D progress while focusing on the separation challenges that are very specific to bioenergy challenges. BETO thinks process intensification is absolutely vital, and distributed bioenergy technologies will only have cost-effective modular systems with breakthroughs in process identification. While BETO believes our connectivity with AMO has improved recently, there is further room to improve.

The Committee recommends capitalizing on complementary efforts of ARPA-E and on their projects, such as leveraging electro-fuels. There is a very good relationship already and BETO currently participates in a joint quarterly with ARPA-E and Office of Science leadership. BETO is beginning to see a transition in ARPA-E’s innovative research projects successfully competing and being awarded funding in BETO’s more applied portfolio.

The Steering Committee felt the scope of the Biomass R&D Board should be expanded for additional coordination between the two agencies (DOE and USDA). In the past 2 years, the two agencies have exchanged staff on detail assignments and have held summits with DOE and USDA laboratories. BETO values knowing about USDA capabilities and is working to ensuring that laboratory efforts can be more synergistic and avoid any duplication of effort. The Biomass R&D Board is currently composed of members from DOE, USDA, the U.S. Department of the Interior, the U.S. Department of Transportation, the U.S. Department of Defense, the U.S. Environmental Protection Agency, the National Science Foundation, and the Office of Science and Technology Policy. Previously, other agencies that are not part of the eight have been invited, as needed, to come into the Biomass R&D Board on different topics. That is something BETO can look at again and use as appropriate in the future to expand the number of agencies actively coordinating across the bioeconomy.



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