Bioeconomy Initiative Forum: Stakeholder Q&A with Bioeconomy Research & Development Board Members

Introduction

The *Bioeconomy Initiative Forum* took place virtually on September 15 and 16, 2020. On the first day of the event, 231 stakeholders attended and on the second day, 175 tuned in to the event programming. The event agenda and speaker biographies can be found online (hyperlink). This document summarizes the highlights of stakeholder question and answer sessions with Bioeconomy Research and Development (BR&D) Board Members (or their representatives).

Bioeconomy Initiative Forum attendees were asked to submit potential panel questions during registration and were given the opportunity to select the top five questions at the beginning of the Opening Reception each day. The topics selected for discussion for Day One included biofuels and bioproducts, scale-up challenges, environmental sustainability, biomass supply chain, and economics. The topics selected for day two included cost-competitive bioproducts, scaling transformative technologies, and CO_2 utilization and sequestration.

The Opening Reception on Day One focused on *Bioeconomy at Scale.* A welcoming address was provided by Scott Hutchins, Biomass BR&D Board Co-Chair and U.S. Department of Agriculture (USDA) Deputy Under Secretary, Research, Education, and Economics. The panel moderator was Operations Committee (OpsCo) member William Goldner (USDA) and panelists included Michael Berube (U.S. Department of Energy [DOE] Office of Energy Efficiency and Renewable Energy (EERE) Acting Deputy Assistant Secretary for Transportation and Acting Bioenergy Technologies Office [BETO] Director), Mark Brodziski (USDA Rural Development), and Bill Hohenstein (USDA Office of the Chief Economist).

The Day Two Opening Reception discussion covered the topic of *Technological Breakthroughs that Underpin the Bioeconomy.* A welcoming address was provided by Daniel Simmons, BR&D Board Co-Chair and Assistant Secretary for DOE's EERE at DOE. The moderator, Valerie Reed, OpsCo member and Deputy Director, BETO led the discussion among panelists Sharlene Weatherwax (DOE Office of Science, Gene Lester (USDA-Agricultural Research Service), and Richard Dickinson (National Science Foundation).

The commentary provided in these sessions has been edited for clarity and conciseness.

BIOECONOMY INITIATIVE

BR&D BIOMASS RESEARCH & DEVELOPMENT

Contents

Bioeconomy at Scale

Biofuels and Bioproducts

What roles do biomaterials and bioproducts have in growing the bioeconomy potential for biofuels?

Berube: DOE has a vision around developing cost-effective biofuels. We have made tremendous progress; next fiscal year we will be demonstrating a gasoline gallon equivalent (GGE) minimum fuel selling price (MFSP) down approximately 50% over the past five or so years. In order to reach our goal of $2.50/GGE, though, we know we will need bioproducts. Bioproducts are critically important to the economics of biofuels. Much like in petroleum today, the volume is the fuel-side (70% of every barrel goes to fuel) but the profit (around 30% of each barrel) comes from products. Products, like chemical intermediates, will need to have the first market pull which then translates to fuels. DOE is looking very carefully at balancing the short-term economic opportunity with bioproducts and the long-term incentivizing of biofuels.

Hohenstein: USDA has a great example of the importance of thinking about biorefining in a comprehensive way. Conventional ethanol production has several co-products, one of which is CO_2, which is historically thought of as low value. That changed this spring when CO_2 became a scare commodity and in high demand. This is an example of how something like that can change the economics for some plants, to turn things at the margin to make them successful. It reinforces the importance of thinking of all the products that come out of a refining effort and how to best market them.

Brodziski: Reflecting on the industry interest in financing programs around biorefinery start-up and scale-up, as to the type of product, it really needs to be an all of the above type approach. It is not just a

product, fuel, or chemical but a combination that is dependent upon the feedstock, available resources, assets, and market opportunities. We clearly see strong interest around biofuels from waste products, fertilizers, additives, and chemicals that ultimately support renewable fuels. Some of the technologies are focusing on solving problems like resolving waste materials within production agriculture; anaerobic digesters to solve the problems of waste rather than loading up soils with fertilizers; and use the materials for the production of biofuels, biogas, and other materials. Again, it needs to be an all of the above approach. There are some great opportunities with some of these technologies and stakeholder work going forward.

Scale-up Challenges

What scale-up challenges is your Office addressing individually and through coordination via the Bioeconomy Initiative?

Brodziski: The USDA Biorefinery Assistance Program has Loan Guarantees and is familiar with the critical challenges of scale-up. We focused on assisting projects through the buildup of a demonstration unit to the extent that the proposed technology can be moved to demonstration scale. Trying to utilize the full integrations of technologies and feedstocks as an intermediate to full scale production. We work closely with DOE BETO and NREL on technical reviews of project applications that we see to help with understanding the technology. We also look closely with our sister agencies, such as the Agricultural Research Service, for example, on research that can impact these challenges. Most recently, we have expanded our Memorandum of Understanding (MOU) with DOE—in addition to working together on the Biomass Research and Development Initiative—and we have a side MOU that covers all the other energy space and we've broadened that to include bioenergy. The BR&D Initiative does not have an interagency working group (IWG) on scale-up so we are engaged on this topic via the MOU.

Goldner: I would like to point out that USDA, DOE, and the other agencies have a series of activities looking at applied research, moving towards demonstration, and ultimately commercialization.

Berube: Scale-up is front and center to our thinking. DOE has a series of meetings called X-Labs and last year the focus was the Bioeconomy. One of the things we heard from industry leaders is that scale-up is a key challenge. There is a lot of great science developed but the question remains, "how do we take it to the next level?" At DOE we have 2 key initiatives: 1) Process development units at Lawrence Berkeley National Laboratory, Idaho National Laboratory, and National Renewable Energy Laboratory (NREL). We are working towards expanding the NREL demonstration unit pending appropriation of funding. 2) $30–$40 million per year of funding opportunities are aimed toward scale-up. Last year we spent $30 million for pre-pilot projects. Our goal is to have a series of pre-pilot, pilot, and demo scale projects, recognizing that there is realistically at least a 10-year cycle to develop technology to scale. We look forward to continuing that effort—and there is strong Congressional support to do so. How do we fund the right projects at the right time? In the past, we may have gone too fast or skipped steps and gotten burned; we have had companies receive funding that were not quite ready for scale-up. So now we are defining a clear set of criteria that establishes whether a technology and/or a company is ready for pilot or demo scale. I think if we as government agencies can collaborate on developing a gold standard then we can fund projects at whatever level they are ready for. As an example, last year we funded LanzaTech jet fuel at demonstration scale. Whereas other technologies may be ready at the pre-pilot or pilot scale. Let

us create a system that is flexible enough to fund the right projects at the right level at the right time. Making sure that they are technologically ready to enter that stage.

Goldner: One of the things that we have seen at USDA is the need for an assistance-based approach. When we look at the different research environments, we look at feedstock development, supply chain, and conversion technology but scale-up means putting these elements together. USDA has supported some larger projects which link an emerging technology, a conversion process, and a supply chain, which allows the project to assess risk among all of the supply chain areas linking up to the value proposition. This is an approach that USDA and DOE have taken and its key to what we do. As both Berube and Brodziski have stated, working with partners is critical. This is because we really need feedback loops, and we need to be relevant in terms of how we approach this.

Environmental Sustainability

What are potential environmental and social benefits that a bioeconomy at scale could deliver at local and national levels? How is the government encouraging that these benefits are delivered at scale both in their programs and in partnership with industry?

Hutchins: The environmental and social sustainability question is really central to a lot of the value that is created here. What we need to do is recognize that things such as the concept of sustainable agriculture really does have three legs on the stool. First of all, it has to be an economically viable enterprise – in our case, especially for the producers and growers. We also have to have the social acceptance. And of course, the environmental footprint. There are still a lot of people that think these three factors cannot co-exist, that you have to prioritize one or the other. What we are trying to do with our Ag Innovation is demonstrate that they can all coincide. I want to talk to the fact that we can get multi-use applications. We can find the biomass feedstocks that can create bioenergy such as jet fuel and also use that to be better stewards of the land, with considerations like soil health. Also, we can use bioproducts for feeds and other uses. The notion of addressing all three of these components together and ensuring that we hit all three of those levers – economic, social, and environmental – are central to a successful project. With any of three those missing, I do not think we can claim success or scale a project to where it needs to be.

Berube: I agree with Hutchins. You need to have balance between each of the three components of sustainability. If you do not have solutions that can meet peoples' needs and that you can actually get into the economy, then you will not be able to have sustainability in the long term. With respect to biofuels there is a broad range of opinions and data on the environmental sustainability question. From a DOE perspective, we look at a full life-cycle balance with everything we do. Within transportation, we spend a lot of time looking at emissions to compare between petroleum fuel, biobased, or electricity. In some sectors, such as aviation or long-haul trucking, they need a liquid fuel. If you want to find a low-carbon liquid fuel, we think the absolute most sustainable option is a biofuels-based approach. I think that there is growing recognition around this point. I think we need to make sure we are working on this across agencies and with others outside of government. We all need to be aligned on the measurements of life cycle impact including water, emissions, and energy-efficiency. The fact that it is complicated cannot stop us from trying. We just have to try harder and build broad based incentives that allow us to move forward.

Hohenstein: Our office does a tremendous amount of work on environmental accounting and assessing performance on an operational scale for technologies, processes, and approaches that are already widely adopted. I think that one misconception about biofuels is around the dichotomy between "conventional" and "advanced." We see that within conventional systems, there is a range of performance. And there has been tremendous improvements in environmental performance. When feedstocks are being produced more sustainably and there are improvements in agricultural production practices and in output per unit of input. Then, at the plant level, we are seeing changes in production, co-products being developed, combinations like the corn kernel fiber cellulosic pathway, there is a potential opportunity to improve the environmental performance of conventional systems.

Berube: This is a critical point. There has historically been this dichotomy between advanced and non-advanced. Technology changes over time, though, and there could be a lot of improvements made quickly – in terms of scale-up—if we put those definitions aside for a moment. If we focus on our fundamental objectives, we may find that the optimal solutions right now may involve a blurring of conventional and advanced approaches, at least in an intermediate timeframe.

Biomass Supply Chains

How can cost effective biomass supply chains be developed and costs controlled after an investment is made in a bioconversion plant?

Hohenstein: USDA spends a lot of time thinking about the importance of supply chains. In the context of biofuels, bioproducts, and bioenergy, there is a lot of potential to improve the sustainability of supply chains and to incorporate that into the value of the products that are being produced. That means assessing the environmental performance of feedstock production, looking at life cycle impacts—in terms of water quality or emissions or land use—and valuing the technologies and practices that have the best performance. We are seeing increased demand for products that are produced sustainably, and in some case, there are policies driving that. The renewable fuel standard is a relatively simple way of driving that – it has two classes, conventional and advanced. If you look at California and the Low Carbon Fuel Standard, they provide more gradations and include pathways for individual processes – where the value of the supply chain can be improved by demonstrating and documenting the environmental performance. There is a lot of potential here thinking about the supply chains and how to add value to co-products and also to environmental goods and services.

Berube: When I think about the supply chain question, especially the feedstock issue, our experience over the past five years so, where we have really had trouble is in getting the feedstocks from where they are grown to the biorefinery. There are two critical issues which aren't the highest tech but they require a lot of attention: 1) ensuring a consistent feedstock, and 2) low-density, unstable biomass feedstocks (solved by either densifying or stabilizing the feedstocks or by building biorefineries closer to the feedstocks). Over the next 5–10 years, we at DOE are focused on taking all of our great work to develop conversion technology to develop biofuels and bioproducts and get them to the point of cost-effective commercialization. In order to do this, we will need to address these issues related to supply chain and feedstocks. Something we are doing this year is investing $15 million this year at Idaho

National Laboratory for facilities that will be available for third-party use. If you have not worked with Idaho National Laboratory and are interested in feedstocks, definitely connect with them.

Economics

What economic and job analysis is performed to evaluate the potential of local, regional, and national bioeconomies? How can the U.S. government and industry collaborate to improve accuracy and timeliness of data & analysis?

Hohenstein: The USDA Agriculture Innovation Agenda was announced by the Secretary in February 2020. A component of this is the "scorecard." It's important to note that biofuels and bioenergy was one of the areas that we focused on within the Ag Innovation Agenda, as having potential to improve both environmental performance as well as the bottom line for farmers and the rural economy. We recognize that both are important. In order to be successful, we have had to assess where we are, set meaningful goals, and assess progress. One nice thing about biofuels relative to some of the other metrics that we are looking at is that we actually have quite good economics. We know that in terms of production of biofuels and bioenergy, there is still work to do on environmental performance. We need to work to assess the affects that various production processes have on the environment – both air quality and water quality. Then, we need to keep those statistics up to date. One of the metrics that we are using to measure joint productivity—between economic and environmental performance—where we are measuring output per unit of input, is a measure of production efficiency. I think this is where we will be heading in a lot of areas of environmental performance, especially those that also have a component of economic performance.

Hutchins: This question is very broad when we are talking about the bioeconomy. With regard to this subset, let us not lose sight of the fact that there are many other bio-based product areas that we are not really touching on today. We can think about biopharma, natural based products—many of which are used in agriculture. The bioeconomy is a very big organism. We often lose sight of this. In some regards, all of agriculture is in this space. So, the notion of how to do job analysis related to local, regional, and national bioeconomies will be specific to that particular level of the bioeconomy. It definitely needs to be done because it is part of the broader ecosystem.

Brodziski: Looking at the economics—at a project level it comes down to the mix of biorefinery products. We are working to advance some of our initiatives at a regional scale to consider what the type of feedstocks are available in that region, i.e., community assets. Beyond the project level, what are the assets in the broader region that can support a project and how can a project support the region's economy?

Technological Breakthroughs that Underpin the Bioeconomy

Cost-Competitive Bioproducts

What are your Offices doing to tackle the R&D challenges to developing cost-competitive bioproducts from biomass?

Simmons: One of the things we are doing is having a focus on performance-advantaged opportunities. On July 2, 2020 we announced seven projects totaling about $2 million to conduct R&D to accelerate the adoption of performance-advantaged biofuel blendstocks. That's one of the keys, there are certain things for which the bio-derived components perform at a higher level than something derived from petroleum. In that case, one of the things that we're doing is working with our Vehicle Technologies Office on a program called the Co-Optimization of Fuels & Engines. Working together with DOE BETO we look at how we can improve that co-optimization. Valerie, after the panel I would love to also hear your thoughts on this question.

Dickinson: The National Science Foundation (NSF), as many people know has a different mission that some of the other agencies on the panel. Funding research across all science and engineering, most of our core programs are organized around disciplines. For topics in this area and in other areas it is usually a matter of matching the fundamental research questions within that discipline and fitting that application to that phase. In my division we fund a lot of work in this area, mostly in the cellular and molecular bioengineering program. Some of the types of projects we've recently funded include the valorization of wastewater biomass to produce value-added chemicals and power, pyrolysis of biomass towards higher value products, biomass convergent technologies, and using biocatalysis. These are all in core programs and typically come in the form of unsolicited proposals that were four $100,000 single investigators, but we also have lots of opportunities for larger collaborative multidisciplinary projects that at the NSF we like to call convergence, which are big problems that require multidisciplinary teams. A benefit of NSF is that we have a spectrum of disciplines represented all the way from economics, behavioral science, physics, to engineering. One of the initiatives for these larger team projects is that we just awarded several projects in the area of future manufacturing, in which some of the subtopics are in biomanufacturing as well as ecomanufacturing. Just to highlight one as an example we funded a large scale project with Lawrence Berkley National Laboratory titled, "Digital White Manufacturing for the Circular Economy." The team is engineering organisms to synthesize monomers from biomass sugars to generate resins that are going to be used in 3D printing applications and that are easy to deep fry so we can recover the monomers for additional uses with the circular economy in mind. Another program that comes out of the Office of Engineering is a program called "Emerging Frontiers for Research and Innovation," which has published two topics every year for two consecutive years. The current topics are focused on end of life plastics and the other which is more relevant here is distributed chemical manufacturing, which is basically bringing the manufacturing to the feedstock. In the case of the distributed manufacturing project, we've funded the project from the University of Washington, called synthetic biology processing units for distributed manufacturing of high-value products. Another opportunity for research in this space is in our research centers, these are large centers typically around the order of $4–$5 million a year for up to 10 years. Lastly, let me just mention another program that provides opportunities for industry to collaborate with academic institutions, there's an industry and university collaborative research program called the Industry-University Research Partnerships (IUCRC), and one of their topics that was funded there recently was their center for advanced forestry systems and the other was their center for bioplastics and biocomposites. There are really a spectrum of opportunities that are covered in the fundamental research area of this space so NSF funds early-stage research with high risk and high rewards if anyone is interested.

Weatherwax: I think I'm going to highlight one thing that is really unique to DOE's Office of Science and that is our support for user facilities. These are facilities that we support and sustain and have

instrumentation, with a lot of high-tech tools and approaches manned by skilled technical staff. People apply to use them by bringing their ideas and one of the things that we think as being important to underpin when you're deciding what kind of bioproduct you could make is well, you know, what's already out there and what can I do to either prove or reinvent something. For example, our genomic sequencing facility, the Joint Genome Institute that we have at Lawrence Berkley National Laboratory, plays a big role. It will sequence all the genetics, complement of maybe a fungus that's going to break down biomass, or maybe a microbe that put together building blocks in different kinds of ways, or even higher plants or trees, to determine what exactly in their raw materials that you could break down and then transform into something that would be of a higher value or different value. These are examples of things where the community can get involved and that they can put proposals in and then the user facility will give them the data back and it is all in the public domain. This process makes it very democratized so everybody then can take a look at it and say, "oh I didn't realize that this microbe had the pathway to do this maybe what I'll do is add an extra pathway and now we can generate this new product." That is the kind of thing that we're hoping to facilitate. We also have facilities to analyze a product you've made, so characterization is a big key. We have light sources, neutron sources of synchrotrons all across the country, we have a cryo EM facility, we have real high-tech instrumentation at the environmental molecular science lab. These are places that you can actually bring your sample and then have it tested to see if it is what you think it is. Maybe you created a new enzyme and you don't know how to characterize it, and these are areas that the user facilities will help you. I think some great examples we've had in the past, is where the technology offices have put forward some key targets. For example if an office came to us saying "I wish we knew more about these kinds of plants, or these kinds of microbes, our user facilities have responded by helping get that genome sequencing information so that everyone can then take a look at it and then come up with their own ideas to innovate and then make some new bioproducts.

Lester: The USDA basically has four centers, that were established eighty years ago and one of the major things we're proud to have is at our center in Peoria, Illinois—the world's largest collection of microorganisms. We have the opportunity to exploit this collection on a regular basis and in doing so many industry individuals, university individuals, and our partners in DOE, for example, will come and partner with us to solve a number of problems. For example, we've developed a fungal source that removes the inhibitory chemicals in our biorefining and recycling of water. This is important and so to clean it up and keep it usable helps in keeping the costs down. We've discovered new yeast strains along with an orifical steering procedure that reduces the number of enzymes needed during scarification and fermentation. We've determined key proteins in yeast strains, which serve as a selection criteria to detoxify inhibitory chemicals in the pretreatment of lignocellulosic biomass. We've also discovered microbes that make xylitol in a cost-effective process; plant sugars (particularly xylose, which is a waste biomass by and large), and we've also discovered an alcohol tolerant bacteria for the use in the fermentation of biofuels, which helps lower the cost of ethanol and butanol production. In our facilities be it in Peoria, Philadelphia, San Francisco, or New Orleans, we're there to work with any and all partners to advance breakthroughs in the technological area.

Reed: Those three presentations couldn't be a more appropriate for leading in what BETO does looking into the bioproducts space. We heard about innovations, discoveries, and tools that could enable industry to look at what bioproducts are possible. The importance of the bioproducts in the bioeconomy equation is that these are often higher value products that bring in higher value earlier in the process

than a biofuel would. Though biofuels can be produced at high volume, they must be very low cost to compete in the market. So as we look at the bioeconomy equation we can learn a lot early on partnering with industry to help develop the bioproduct equation which becomes a win-win. Industry wins because they have products that can be commercialized and they can begin to make a profit and we win because we are able to demonstrate incredible high-risk technologies, particularly associated with scaling up some of the processes that underlie in the production of biofuels. It is very important for us to be able to consider the entire barrel of oil and that we need both the fuels and the products. We can continue to learn a lot and reduce risk on the engineering scale earlier when it is related to bioproducts. One example of this I would like to share is within our algae program. We all know that algae is an incredible organism that can do a lot of things and the bioenergy program is trying to harness that activity to be able to produce biofuels at very low cost. Through our algal program we've partnered with a number of industry partners who have interest in using algae for a variety of reasons, for instance the company, Algix. Algix has launched a line of foams coming from algal oils that are being used for footwear, today, and are being sold. The story that is being told about this footwear to the consumer is about the environmental benefits, such as cleaner water and the sequestered carbon dioxide that is basically the result of every shoe that is purchased and the material within them. Algix recently doubled their output in their Mississippi factory and they're producing 20 million pairs of shoes this year. This demonstrates that kind of information that is getting out into the private sector and into the public about the benefits of these renewable resources and how they might be used industrially and then ultimately in the energy space.

Scaling Transformative Technologies

Scaling transformative technologies: What funding opportunities are there at Biomass R&D Board Agencies to financially assist with scale demonstration of transformative technologies?

Lester: We are able to utilize those small business innovation research grants and we also have grant funding opportunities within the agricultural research service specifically for dealing with scaling transformative technologies. For example we've worked with the Corn Growers Association and we've made food grade emulsifiers that can be used in salad dressings and ice cream. We've also worked with startup companies developing plant-based oils that can be used at the 2% level as opposed to the current 40% level for helping the performance of high sulfur diesel fuels. Dr. Hutchins yesterday mentioned estolides, which we developed as a plant-based motor oil that improves mileage, performance, and keeps engines clean. That work was done with a startup company that came and worked with us with little to no cost at their point, they just had an idea on moving forward. We've also worked with some universities in making reversible antimicrobials, which is a very simple process as opposed to most microbials from fossil fuels which exist in the environment (which allows for antimicrobial resistance). The reversible antimicrobials breakdown into their starting molecules and they are basically innocuous. We're also working with DOE and universities on plastics derived from biomass that will dissolve in the oceans. We have many opportunities both funded and non-funded from an intellectual property standpoint or just from a person wanting to work with us, all of those collaborative research and development opportunities are available.

Reed: I'd like to continue my previous answer on bioproducts to address this one if I could for a moment. Scale up Is incredibly important especially since we're trying to develop an industry that for the most part does not exist yet. Biofuels exist when it comes to starch-based ethanol or biodiesel, but

when we talk about the more complex equation associated with using lignocellulosic and algae for the production of fuels and chemicals there are much more complicated technical equations that emerge. These equations require demonstration not only at the bench scale with the great research you've heard about going on across all the agencies, but also as we move toward a commercial facility. These technologies need to be scaled up appropriately to make sure we don't run into any issues on integration or as the scale increases what might happen at an engineering level. When those types of things occur they can drive our research platforms to try to overcome the issues that add risk and therefore financial risk to finally developing a commercial facility. Our program at BETO has a scale up program in which we put out in ideal circumstances on annual (appropriations willing) additional opportunities for technologies to work their way up to scale. In FY20, building off of Daniel Simmons' earlier comments when he mentioned our awarding $97 million worth of research projects, a major portion of that funding went into a topic called "scale up of bench applications" (SCUBA). With the SCUBA funding opportunity what we were looking for were process steps or integrating process steps that had shown promise at the bench but needed to go up to the next scale, so therefore greater than bench scale but perhaps not as great a pilot scale. We awarded eight projects, a total of $29.5 million of government funding, representing an exciting step forward for a lot of technologies that have been in development with our partners and national labs up until now. Our next phase would be to go to pilot scale and pilot for us typically means an integration of process steps at a much higher scale (10% or 10 fold higher scale). This can be very useful to the company who's looking at the final product whether it be an intermediate, or a fuel, looking to do some product or consumer testing so that they can assure that they are meeting standards that are appropriate for the industry. Pilot scale helps them do that while verifying across the board what the cost of the final product might be as well as identify any hiccups that we need to take back to the bench for research and development. Our last and most difficult phase of scale up is demonstration. This is incredibly expensive, as biorefineries are in the order of $100–$200 million and even more when building out what we need when creating a biorefining industry. This demonstration scale is an expensive test facility that is working towards finalizing the engineering design for commercial financing. The government plays a role here because of the cost associated with this and so we can help buy down the risk. Within our scale up strategy we will go as high as the demonstration facility if the project has met all the metrics throughout the scale up that prove that they're ready to move into that space. Hopefully, that gives you a picture of what it is like to take an innovation from its earliest conception all the way through to a final commercial product.

CO_2 Utilization and Sequestration

CO_2 Utilization and Sequestration, Bio-based Electricity Storage: What are current and future programs on using biomass and biochemical components to store electrical energy, CO_2 utilization, and bio-based CO_2 sequestration?

Simmons: When it comes to CO_2 sequestration it can't only be sequestered it must also be utilized in some way, and so in this year FY20 we announced $7.5 million in funding for scalable CO_2 electro-catalysis. Given that this is a newish technology area we recognize that we are a long way from making electro-catalysis a cost-effective reality but we announced three project selections on July 31, 2020, looking at how to use these technologies because of CO_2's potential as a high-volume feedstock. Obviously, we also need to sequester it but once it is sequestered it is so much better that we can put into a fuel rather than just putting it into the ground. We're definitely excited about the opportunities, though we know we definitely have a ways to go to do it in a cost-effective way.

Weatherwax: When we think of CO_2 sequestration we naturally think of plants because that is one of the things that they're born to do and a lot of what we've done is try to understand it. For example examining what are the balances required in order for plants to actually take up CO_2 and grow out their root systems and have healthy *<inaudible>* and the relationship between plants and the microbes that are associated with that. That is a big part of what we want to know because we're interested in actually sequestering it for a long time down there in the soil and then possibly having it serve as a feedstock for lots of other microbes that are going to be doing things with it. Some of that can be genetically engineered but a lot of it depends on the balance of nutrients and all the nutrients that are cycling through the ecosystem.

Dickinson: Similar to my last answer, NSF, is organized around disciplines and we fund many different fundamental research projects in the space in the core programs. While we don't have a program identified specifically for CO_2 sequestration you'll find funded projects across the bio-directed engineering and other directorates as well. So it is really critical to try and identify what the fundamental research questions are in those projects and align them with the program description. You can go to NSF.gov and see all the program descriptions for the core programs. Let me just mention in my division, the chemical bioengineering, environmental and transport systems, has 16 programs funding research in this general area. There is one program that is explicit in mentioning bioconversion to fuels and chemicals and the title of that program is the "process systems reaction engineering and molecular thermodynamics." There is also the "cellular molecular bioengineering program" which is more interested in how to engineer cells to survive manufacturing. We also have an environmental sustainability program so these may be means of assisting in re-engineering the circular economies for the larger scale questions. We have less chemical systems programs, so it is more focused on the less chemical energy storage. While I can't identify one currently in this space that doesn't rule out one appearing in the near future.