U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel

Workshop Summary Report | June 2023

Disclaimer

Foreword

The mission of the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) is to accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, and to ensure the clean energy economy benefits all Americans, creating good-paying jobs for the American people — especially workers and communities impacted by the energy transition and those historically underserved by the energy system and overburdened by pollution.

The EERE Bioenergy Technologies Office (BETO) supports research, development, and demonstration to enable the sustainable use of domestic biomass and waste resources for the production of biofuels and bioproducts. Program focuses include technologies and processes that transform renewable carbon sources into conversion-ready feedstocks.

This report summarizes the input received from attendees of a public workshop sponsored by BETO on June 6–7, 2023. A record of the workshop agenda and presentations is available online at: www.energy.gov/eere/bioenergy/events/workshop-deploying-purpose-grown-energy-crops-sustainable-aviation-fuel

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Table 1. Breakout Session Organization

Breakout Session	Moderator	Co Moderator/Scribe
Algae	Dan Fishman	Jamie Meadows
Herbaceous Energy Crops	Mark Elless	Andrew Zimmerman
Short-Rotation Woody Energy Crops	Elizabeth Burrows	Atilio de Frias
Overwintering/Secondary Energy Crops	Alexander Jansen	Philip Lee

We gratefully acknowledge the introductory speakers who framed the workshop topics for attendees: Michael Berube (DOE — Deputy Assistant Secretary for Sustainable Transportation and Fuels), Dr. Kevin Kephart (U.S. Department of Agriculture [USDA] — Deputy Director of the Institute of Bioenergy, Climate, and Environment), and Dr. Vance Owens (USDA — National Program Leader, Division of Plant Systems-Production). We appreciate the panel participants and invited speakers who provided their expertise and insight to help inform and shape the breakout group discussions. We also want to express our gratitude for the 20 attendees who gave five-minute lightning talks to provide additional insight into various feedstocks and logistics related to purpose-grown energy crops.

The authors sincerely thank all workshop participants for their contributions, which provided input for this publication and helped inform our future renewable carbon resource strategies. The full list of workshop participants is provided in Appendix B: Workshop Participants.

This report was funded and prepared by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Bioenergy Technologies Office.

List of Acronyms

AFRI	Agriculture and Food Research Initiative
AzCATI	Arizona Center for Algae Technology and Innovation
BCS	Business Consulting and Services LLC
BETO	Bioenergy Technologies Office
BFL	Bioenergy Feedstock Library
CO_2	Carbon Dioxide
DISCOVR	Development of Integrated Screening, Cultivar Optimization, and Verification Research
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EERE	Office of Energy Efficiency and Renewable Energy
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fueling Aviation's Sustainable Transportation
FOA	Funding Opportunity Announcement
GHG	Greenhouse Gas
HUD	U.S. Department of Housing and Urban Development
IRA	Inflation Reduction Act
LCA	Life Cycle Analysis
NIFA	National Institute of Food and Agriculture
R&D	Research and Development
RCR	Renewable Carbon Resources
RD&D	Research, Development, and Demonstration
RDD&D	Research, Development, Demonstration, and Deployment
RFP	Regional Feedstock Partnership
RFS	Renewable Fuel Standard
SAF	Sustainable Aviation Fuel
TEA	Techno-Economic Analysis
USDA	U.S. Department of Agriculture

Executive Summary

From June 6–7, 2023, the U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) hosted the workshop "Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel" in Kansas City, Missouri. The purpose of the workshop was to examine topics related to large-scale cultivation of purpose-grown energy crops—including algae—that can contribute feedstocks for the production of biofuels and bioproducts. This workshop was a means to gather a variety of stakeholders with the intent to identify elements for a potential future research strategy designed to overcome challenges and delve into the barriers related to the large-scale cultivation of purpose-grown crops. This document provides an overview and summary of the workshop's presentations, breakout session discussions, and outcomes.

The two-day workshop drew 117 participants representing a wide range of stakeholders and experts from academia, DOE National Labs, industry, governmental organizations, and others. The workshop began with plenary presentations from BETO officials on the goals of the event and an overview of the BETO mission and interest in purpose-grown energy crops. The plenary sessions included further details on the mission and goals of BETO, the mission and goals of the U.S. Department of Agriculture (USDA), and presentations from invited speakers regarding biomass supply, specific feedstocks, and resource considerations. The main technical content of the workshop was presented via panel presentations and followed by group discussions on prepared topics.

Breakout sessions were divided into the following feedstock categories: algae, herbaceous energy crops, short-rotation woody energy crops, and overwintering/secondary energy crops. The breakout sessions resulted in discussions around the following prepared topics: (1) identifying knowledge gaps, (2) ideas and strategies for addressing knowledge gaps, and (3) innovative solutions for successful deployment of purpose-grown crops. In the first session, each feedstock group identified a set of five priority knowledge gaps and continued to address those knowledge gaps in the second and third sessions.

There was a surprising amount of overlap in the top five knowledge gaps between the different feedstock categories. Three of the four groups recommended investment in large-scale demonstrations. Additional knowledge gaps that ranked highly among several groups included (1) the need for information on preprocessing/fractionation and downstream processing/logistics and (2) consistent carbon accounting.

A networking session was planned because, in addition to requiring research, successful widespread deployment of purpose-grown energy crops will require technical transfer and stakeholder engagement. This report outlines the workshop participants' ideas for stakeholder networks by region and by feedstock category.

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Introduction

The Biden-Harris Administration has established ambitious goals to address the global climate crisis and is committed to developing and implementing robust and actionable transportation decarbonization strategies. Goals include the creation of carbon pollution-free electricity by 2035 and to "deliver an equitable, clean energy future, and put the United States on a path to achieve net-zero emissions, economy-wide, by no later than 2050"[1] to the benefit of all Americans. The U.S. Department of Energy (DOE) is committed to pushing the frontiers of science and engineering, catalyzing clean energy jobs through research, development, demonstration, and deployment (RDD&D), and ensuring environmental justice and inclusion of underserved communities.

In response to the Biden Administration's Executive Order 14008, DOE, U.S. Department of Transportation (DOT), U.S. Department of Housing and Urban Development (HUD), and the Environmental Protection Agency (EPA) released the U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation.[2] This landmark document outlines the strategies and actions to remove all emissions from the transportation sector by 2050 and offers a whole-of-government approach to addressing the climate crisis. Individual agencies followed suit with specific strategies of their own. DOE, DOT, U.S. Department of Agriculture (USDA), and other federal agencies released the Sustainable Aviation Fuel (SAF) Grand Challenge, a government-wide approach to reduce the cost, enhance the sustainability, and expand the production of domestic SAF to meet 100% of aviation fuel demand by 2050. More recently, DOE announced the Energy Earthshots™ Initiative to accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade.

The SAF Grand Challenge and the associated SAF Grand Challenge Roadmap lays out six action areas spanning all activities with the potential to impact supply and end use expansion, cost reduction, and sustainability enhancement of SAF. Four of the six action areas—Feedstock Innovation, Building Supply Chains, Policy and Valuation Analysis, and Communicating Progress and Building Support—are of particular interest to the Office of Energy Efficiency and Renewable Energy (EERE) Bioenergy Technologies Office (BETO) under DOE. All four of these action areas will require substantial research and development (R&D) in feedstock production and sustainability to ensure that feedstocks of sufficient quality and quantity are available to inform policy decisions and support SAF demands.

In May 2023, DOE launched the Clean Fuels & Products Shot™, the seventh Energy Earthshot. This Energy Earthshot focuses on decarbonizing the fuel and chemical industry using alternative sources of carbon to advance cost-effective technologies with a minimum of 85% lower Greenhouse Gas (GHG) emissions by 2035. Mobilization of renewable carbon resources, at

[1] Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," January 27, 2021.

[2] U.S. Department of Energy. 2023. U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation. Technical Report DOE/EE-2674. Available at: www.energy.gov/eere/us-national-blueprint-transportation-decarbonization-joint-strategy-transform-transportation.

scale, will provide feedstocks that are needed for decarbonizing the transportation and chemical industries.

As described in the 2016 Billion-Ton Report from DOE, the United States has the potential to produce more than 1 billion tons of sustainable biomass per year that can be used as feedstocks for renewable transportation fuels and chemicals. The report estimated that over 400 million tons of herbaceous and woody energy crops alone can be sustainably collected each year, with the potential to supply over a third of the biomass needed to fuel hard-to-decarbonize modes of transportation such as aviation, maritime, rail, and off-road vehicles (e.g., heavy duty and mobile equipment). In subsequent analyses, similar supply potentials were described for microalgae crops.[3] BETO-funded RDD&D has continuously focused on reducing the cost and energy inputs for biomass feedstock production and supply.

BETO Mission

The mission and goals of BETO are in line with the SAF Grand Challenge and are outlined in the 2023 Multi-Year Program Plan as follows:

- Decarbonize the transportation sector through research, development, and demonstration (RD&D) to produce cost-effective, sustainable aviation and other strategic fuels;
- Decarbonize the industrial sector through RD&D to produce cost-effective and sustainable chemicals, materials, and processes utilizing biomass and waste resources; and
- Develop cost-effective, sustainable biomass and waste utilization technologies and innovative approaches contributing to the decarbonization of the agricultural sector, generating carbon-negative power, developing carbon drawdown strategies, or other beneficial uses.

BETO-Renewable Carbon Resources

The Renewable Carbon Resources (RCR) subprogram is housed within the BETO office. RCR develops science and engineering-based strategies and technologies to cost-effectively transform renewable carbon resources into high-quality, environmentally sustainable, conversion-ready feedstocks for biofuels and bioproducts. These strategies and technologies are designed to improve the efficiency, sustainability, and reliability of feedstock production, harvesting or collection, storage, preprocessing, and transportation, and identify the key feedstock quality and operational variables for conversion performance.

[3] Davis, R.; Coleman, A.; Wigmosta, M; Markham, J.; Kinchin, C.; Zhu, Y.; Jones, S.; Han, J.; Canter, C.; Li, Q. 2018. 2017 Algae Harmonization Study: Evaluating the Potential for Future Algal Biofuel Costs, Sustainability, and Resource Assessment from Harmonized Modelling. Technical Report ANL-18/12; NREL/TP-5100-70715; PNNL-27547 (August 2018), 91.

The Regional Feedstock Partnership

From 2008 to 2014, BETO funded a large-scale effort to address information gaps associated with enabling a sustainable, reliable, billion-ton U.S. bioenergy industry. Named the Regional Feedstock Partnership (RFP), this collaborative effort improved our scientific understanding of the potential commercial use of multiple feedstocks for bioenergy, including energycane, sweet and biomass sorghum varieties, switchgrass, miscanthus, mixed perennial grasses, shrub willow, and poplar. This project provided multi-year yield and sustainability data to help support the development of the bioeconomy at regional and national scales. The numerous accomplishments from this work are summarized in the Regional Feedstock Partnership Summary Report. In this workshop, BETO wanted to move beyond the RFP and learn what is needed to deploy purpose-grown energy crops for biofuels production. BETO expected to hear about technical needs, market and policy needs, data needs, and even land use needs.

Workshop Structure and Objectives

From June 6–7, 2023, BETO hosted the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel workshop in Kansas City, Missouri (see Appendix A: Workshop Agenda). The purpose of the workshop was to examine topics related to large-scale cultivation of purpose-grown energy crops, including algae, that can contribute feedstocks to aid in reaching the SAF Grand Challenge goals. This workshop was a means to connect a variety of stakeholders with the intent to identify elements of a research strategy designed to overcome challenges and to delve into the barriers related to large-scale cultivation of purpose-grown crops. The workshop sought to achieve the following objectives:

- Determine challenges and barriers to deploying purpose-grown energy crops and implementing climate-smart agricultural practices;
- Develop potential strategies to overcome knowledge gaps;
- Identify innovative solutions in the collection of reliable, long-term growth data and specific sustainability metrics of success; and
- Establish and understand how to expand stakeholder networks in energy crops deployment.

The two-day workshop drew 117 participants representing a wide range of stakeholders and experts from a variety of affiliations (see Appendix B: Workshop Participants). The full list of workshop participants can be found in Appendix B: Workshop Participants. After initial introductions and background information was provided by the workshop organizers, the technical program began with three presentations by special guests from DOE and USDA. A panel discussion followed (Session 1) in which four panelists gave individual presentations on the potential of purpose-grown energy crops in the bioeconomy followed by a question-and-answer discussion from the audience. In the following agenda item (Session 2), invited speakers presented resource considerations for growing purpose-grown energy crops. Several breakout sessions were planned for workshop participants to interact with each other to identify knowledge gaps, develop ideas and strategies for addressing knowledge gaps, and develop innovative solutions for successful purpose-grown crop deployment. In addition, two separate

3x5 sessions were included in the agenda, in which selected presenters were given up to five minutes and three slides to share their perspectives on successes and challenges of deploying purpose-grown energy crops, recent promising innovations, and visions for future work in this field. The 3x5 sessions were tremendously popular, with more participants submitting presentations than time available. The workshop concluded with a series of networking exercises (Session 3) in which participants discussed and presented ideas or concerns around specific regions or feedstock categories.

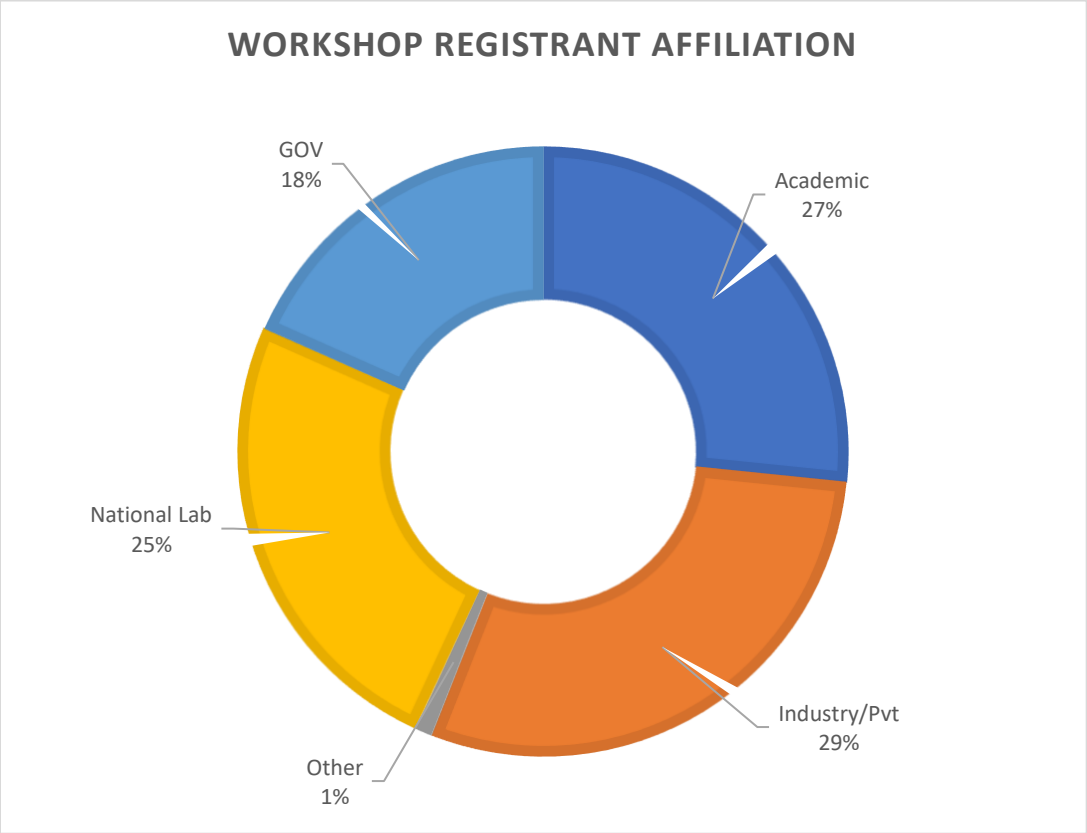

Figure 1. Workshop attendance by affiliation

Presentations by Special Guests

The workshop began with presentations intended to frame the desired workshop outcomes. These included welcome statements from BETO, presenters from DOE and USDA, and an overview of previously BETO-funded work on regional feedstocks, including purpose-grown energy crops.

Workshop Opening Remarks

Michael Berube, Deputy Assistant Secretary for Sustainable Transportation and Fuels, Bioenergy Technologies Office, Office of Energy Efficiency and Renewable Energy, Department of Energy was unable to attend the workshop, but he recorded a video to demonstrate his support of the workshop and to share information on the overall transportation and decarbonization blueprint

from DOE, including the important role of sustainable aviation fuel. He recognized, by extension, the critical role different feedstocks, including purpose-grown energy crops, will have in achieving our success.

Mr. Berube continued by stating that in January 2023, Secretary Granholm, along with the Secretary of DOT, the Secretary of HUD, the United States EPA Administrator, and the President's Climate Advisor all joined together to issue the first United States National Blueprint for Transportation Decarbonization. This document lays out a plan for how the United States can achieve net-zero GHG emissions across all forms of transportation by 2050. It outlines the steps that need to be taken to address every part of the transportation sector, including aviation, which is one of the fastest-growing areas in BETO. Aviation is now projected to account for 10–12% of our future total transportation emissions and will also be a large portion of global carbon dioxide (CO_2) emissions. There is broad consensus that sustainable aviation fuels will be critical to decarbonizing aviation transportation. The SAF Grand Challenge set an aggressive goal of having 3 billion gallons of sustainable aviation fuel produced and used in the United States by 2030, which puts the United States on the path to reach 35 billion gallons of sustainable aviation fuel by 2050. To meet this future goal, additional feedstocks will be needed, and these feedstocks must be produced within a reasonable cost-effective range. This is where energy crops can have a critical role. Mr. Berube emphasized the need to start the development of the technology and processes now so that feedstocks will be ready for commercial production in time to meet the 2050 goals.

The Billion-Ton Report issued in 2016 is currently being updated. In the 2016 report, the United States had an estimated 400 million dry tons of energy crops that could be available by 2040. Mr. Berube called the participants of the workshop to action: to take the Billion-Ton Report as a challenge and to work individually, collectively, and creatively to produce new energy crops, including algae. He called on participants to bring together the best of our National Labs, our universities, our industry partners, and other federal agencies. At the heart of the Sustainable Aviation Fuel Grand Challenge, which was started over one year ago, is to bring together the best and brightest from federal agencies and others beyond the federal government to help solve the big challenges ahead of us.

Opportunities for Feedstock R&D through National Institute of Food and Agriculture (NIFA) Programs

Dr. Kevin Kephart, Deputy Director of the Institute of Bioenergy, Climate and Environment, USDA National Institute of Food and Agriculture shared information on USDA's flagship extramural research program, the Agriculture and Food Research Initiative (AFRI) program, which funds research, extension, and education projects.[4] Selected projects support national science

[4] Kephart, Kevin, PhD. "Opportunities for Feedstock R&D through NIFA Programs." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-02-energy-crops-saf-opening-june-2023-kephart%20.pdf.

priorities, critical and emerging issues, administration priorities, and interagency collaborations. Dr. Kephart shared the priorities of the USDA administration, which include climate-smart agriculture and forestry practices, measurable carbon sequestration, SAFs, and others. He also shared the current USDA five-year strategic plan. AFRI's foundational and applied science program funded $273 million across six programs in 2023. The AFRI Sustainable Agriculture Systems program funded $80 million in research. This program has four topic areas, including one that addresses strengthening the bioeconomy, which may relate well to purpose-grown energy crop deployment. The funding process often starts with a workshop to gather facts and identify research needs. This is followed by a Request for Applications where, through a competitive process, applications are submitted and selected for funding. USDA is one of the collaborating agencies with DOE and other agencies in the SAF Grand Challenge. USDA has funded several SAF-related projects across the United States that focus on biomass feedstocks, including purpose-grown energy crops.

The Regional Feedstock Partnership

Dr. Vance Owens, National Program Leader, Division of Plant Systems — Production, Institute of Food Production and Sustainability, USDA National Institute of Food and Agriculture provided a summary of the Regional Feedstock Partnership (RFP), which was formed in 2007 in cooperation with BETO and the USDA NIFA Sun Grant Program.[5] The RFP addressed information gaps associated with enabling the vision of a sustainable, reliable, billion-ton U.S. bioenergy industry by 2030. Through a competitive funding process, regional projects were selected and field trials were initiated. Projects were led by participants from land grant universities, USDA — Agricultural Research Service, DOE National Labs, and industry. Field trials included a variety of herbaceous energy crops, grasses, residues, and short-rotation woody energy crops. Field trial locations were across much of the United States. These trials drew from the 2005 Billion-Ton Study and contributed to the 2016 Billion-Ton Report. Research findings included data on topics such as cold tolerance limits for energycane, crop responses to severe drought, and stand persistence for perennials. These data, combined with yield and other data, were analyzed to produce national yield potential maps. One of the takeaways from the RFP was that five years of field data isn't enough to capture the impact of drought, floods, frost, and other climate impacts on crop yields. RFP research results were documented in many publications, including the Regional Feedstock Partnership Summary Report: Enabling the Billion-Ton Vision.

Session 1: Panel Discussion — The Promise of Purpose-Grown Energy Crops

This panel session, held on the first day of the workshop, helped to jumpstart the conversation from a variety of perspectives. Invited speakers were asked to speak about their perspective on the promise of purpose-grown crops in the future bioeconomy. The presentations, summarized

[5] Owens, Vance, PhD. "The Regional Feedstock Partnership." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-03-energy-crops-saf-opening-june-2023-owens%20.pdf.

below, included an analysis of the future potential biomass supply, industry insight into using purpose-grown energy crops, and presentations on the potential of perennial crops and algae.

2023 Billion-Ton Report, in Preparation

Dr. Matthew Langholtz, Natural Resource Economist, Oak Ridge National Laboratory presented a history of the previous Billion-Ton reports that summarized the potential of biomass supply for the production of biofuels and bioproducts.[6] The first report was published in 2005 and primarily addressed the goal of displacing 30% of the country's petroleum consumption with biomass-based alternatives. In 2011, the supply analysis was updated to include more information about costs, including county-level supplies by cost. In 2016, the report was updated to include more feedstocks, more analytical models, and new visualization tools. Data from the RFP was also incorporated into the 2016 analysis. The newest update, the 2023 Billion-Ton Report, will add more feedstocks, such as oilseed crops, macroalgae, and biomass resulting from fuels treatments used by USDA Forest Service to reduce wildfire risk. Questions remain as to where purpose-grown energy crops meet their yield plateaus, how to incorporate poorer soil lands into the analysis, evaluating mixed grass yields, and even the potential impact of agroforestry-related alley cropping.

Purpose-Grown Energy Crops: Regenerative Benefits

Dr. Sam Jackson, Vice President of Feedstock and Supply Chain, Genera, Inc. shared Genera's full portfolio for using agricultural fibers across a range of products.[7] At its facility in Vonore, Tennessee, Genera uses diverse biomass feedstocks with an emphasis on purpose-grown agricultural fibers. Genera chose purpose-grown energy crops for the following reasons: (1) their high production efficiency; (2) their adaptability to tolerate drought, pest, disease, and other factors; (3) their consistent homogeneous feedstock quality; and (4) their sustainability. Sustainability is achieved through reduced fertilizer use, reduced land use impacts, reduced freshwater use, and other benefits. Dr. Jackson also shared some of the challenges associated with purpose-grown energy crops, including the following: (1) higher establishment costs and length of time it takes to reach full yield potential; (2) a five-to-ten-year commitment required before landowners/farmers can achieve the best economics; (3) aging landowners (average age is 65); and (4) the lack of risk management tools for landowners/farmers.

The Promise of Purpose-Grown Energy Crops

Dr. Emily Heaton, Professor, Department of Crop Sciences, University of Illinois at Urbana-Champaign is the Feedstock Production Theme Leader for the Center of Advanced Bioenergy

6 Langholtz, Matthew, PhD. "2023 Billion-Ton Report, In Preparation." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-01-energy-crops-saf-panel-june-2023-langholtz.pdf.

7 Jackson, Sam, PhD. "Purpose-Grown Energy Crops: Regenerative Benefits." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-03-energy-crops-saf-panel-june-2023-jackson%20.pdf.

and Bioproducts Innovation.[8] Her research investigates the growth and productivity of perennial C4 (warm season) grasses to guide their management for biomass, ecosystem services, and profit. Dr. Heaton presented information from two long-term projects produced in collaboration with large transdisciplinary teams; contributors ranged from lawyers tasked with addressing regulations to engineers with input on the operational side. The teams investigated a wide range of impacts associated with planting perennial grass in patches of corn-soybean fields that are not profitable to farm. Determining the size and shape of the patches was an important consideration to ensure that the cash crops weren't negatively impacted. Incorporating perennial grasses, such as miscanthus, can provide environmental benefits including reduced water and nutrient runoff, reduced soil loss, and new habitats for beneficial insects and birds. Dr. Heaton stated that these benefits are possible without any reduction in per acre yields of the traditional crops.

Unique Promises and Challenges of Algae

Dr. Kimberly Ogden, Professor of Chemical and Environmental Engineering and Department Chair, University of Arizona addressed the important role of algae in meeting the target of 35 billion gallons of SAF by 2050.[9] Meeting the goal would be difficult without algae's contribution due to land use required by terrestrial crops and the ability for algae to be cultivated on lands where other crops may not be viable. The Regional Algal Feedstock Testbed project at the University of Arizona was funded by BETO with the intent to conduct long-term algal cultivation trials replicated across different regional, seasonal, environmental, and operational conditions. Results included identifying best-of-class strains and a series of robust and unique cost, growth, and process models. The Arizona Center for Algae Technology and Innovation (AzCATI) examines the production of algae for biofuels, performs research on strategies and molecules for crop protection, and examines cultures for use in wastewater treatment. While research has been performed on these topics, additional research is still needed in process controls and wastewater treatments, and to understand carbon capture through the entire cultivation process. Dr. Ogden concluded that algae cultivation attached to flue gas output and tracing carbon throughout systems are other important areas for continued research.

Panel Discussion — Question and Answer

The panel presentations gave workshop participants a broad overview of the potential of purpose-grown energy crops from various perspectives. A question-and-answer session followed the presentations. Panel members responded to the discussion topics listed below:

[8] Heaton, Emily, PhD. "The Promise of Purpose-Grown Energy Crops." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-00-energy-crops-saf-panel-june-2023-heaton%20.pdf.

[9] Ogden, Kimberly, PhD. "Unique Promises and Challenges of Algae." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-02-energy-crops-saf-panel-june-2023-ogden%20.pdf.

How do you define marginal lands?
Marginal lands can be deemed marginal due to environmental, economic, or even social constraints. In croplands, there can be different categories of marginality. In the Billion-Ton analysis, marginal lands were not identified. Instead, models drove where biomass crops could be feasibly produced. In croplands, there can be different categories of marginality.

Land use change — things to consider?
Carbon intensity scores should be considered when proposing land use change.

Why is Genera so successful where others have failed?
Adaptability is necessary. The Genera process is feedstock agnostic, and the company recognized that a combination of feedstocks would be needed to be successful. Genera knew that it also needed to have biomass delivered at a reasonable rate that would be realistic for farmers and feedstock suppliers.

How do you make markets?
Getting into existing markets is challenging, and new ones even more so. More open communication from industry is needed. From the academic side, a lot of work is currently shelved. For successful markets, we need more partnerships to integrate academic knowledge into the marketplace. The RFP was a good initiative, but a challenging one. Markets are critical to success, and policies will only get you so far. Industry knows how policy changes; industry knows which policies are variable or short term. Economics need to make long-term sense.

Is more government support needed for more aggressive goals?
Consumers drive government policies. Change occurs when consumers question the current norm, such as the use of unsustainable plastic products, and demand more sustainable biodegradable options. Consumer demand is key. One example is that BMW is setting new standards for sustainable premium quality by focusing their R&D efforts on incorporating environmentally compatible raw materials in their 2030 cars. The market is starting to drive more of those types of consumer demands.

How do you address food prices versus commodity prices?
Food prices are high; commodity prices are low. In order to be adopted, purpose-grown energy crops must be feasible. There isn't a relevant insurance industry for purpose-grown energy crop growers like there is for food growers. The financial sector isn't currently involved in purpose-grown energy crops.

How do you start conversations with farmers?
You have to find innovative farmers in the community and work with them. For example, innovative farmers were the early adopters of no-till. With one on board, others will join. Genera had experience with one big family growing switchgrass on 70

acres, then others then joined for a total of 300 acres. However, to be early adopters, farmers need the guarantee of a return.

Which agricultural crops are you replacing?
Every farmer does things differently for different reasons. For some farmers, 75% of the land they use is for pasture or hay. The problem is that, too often, the farms are not managed well. For hay or energy crop production, landowners can buy land from cattle businesses that go out of business. Farmers must retain the ability to make their own business decisions.

What purpose-grown energy crops are promising?
The crops that give growers an opportunity for sustainability gains, both on the economic side and on the environmental side.

Session 2: Resource Considerations

In the Resource Considerations Session, invited speakers were asked to share the results of their experiences with purpose-grown energy crops. Invitations requested that speakers frame their presentations around successes, challenges, knowledge gaps, and future needs for deploying purpose-grown energy crops. The presentations, summarized below, offer insights from different perspectives and for a variety of feedstock categories.

How to Get Airplanes High on Grass!

Bill Belden, Senior Agricultural Specialist, Stark Technologies, LLC shared some of the past work by the Antares Group Inc., which is now a Stark Technologies LLC company and continues to operate in several facets of the renewable technologies space.[10] Mr. Belden shared how policy, sound science, data, risk mitigation, and long-term financial commitments are imperative to optimize purpose-grown cropping systems. A diversified cropping system approach is needed to produce a new, or increased, biomass supply. Use of cover crops in traditional agricultural commodity management, planting perennial energy grasses on marginal lands, and growing perennial energy grasses as streamside buffers are just a few ways to increase the biomass supply potential. For sustainable biomass production, farmers and landowners need to be engaged, understand product quality, and have a dependable end user. They also require terms and conditions from a biorefinery that will reward the risk of growing while rewarding the environmental benefits garnered by growing an energy crop.

[10] Belden, Bill. "How to Get Airplanes High on Grass!" Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-00-energy-crops-saf-resource-june-2023-belden.pdf.

AzCATI — Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel

Dr. John McGowen, Director of Operations and Program Management, Arizona Center for Algae Technology and Innovation (AzCATI), Fulton Schools of Engineering, Arizona State University stated that AzCATI has an extensive network of collaborators offering a wide range of expertise, research capacity, and high-quality services.[11] Core research areas include DNA-based strain-typing, carbon dioxide air capture and membrane delivery, long-term cultivation studies and crop protection, and a host of other capacities. With initial funding by DOE, the Algae Testbed Public-Private Partnership was developed to provide increased stakeholder access to algae facilities, expertise, and high-quality services. Further collaboration includes the Development of Integrated Screening, Cultivar Optimization, and Verification Research (DISCOVR), a consortium of four DOE National Laboratories. Under DISCOVR, there has been a 60% improvement in average annual productivity during the period from 2018–2022. There is a concern that productivity gains have lessened over the last three years, leading to concerns about how to overcome the plateau. Costs were also reviewed and indicate an overall downward trend in the cost of producing algal biomass for the period from 2015–2022. Overall, sustainable algae farming could produce ~30 tons of biomass per acre per year, which equates to 6 tons of oil per acre per year or ~5 tons of jet fuel and 60 tons of carbon dioxide captured per acre per year. It is also important to note that algal biomass composition is not static; rather, it is highly responsive to cultivation manipulation and species, which can tailor biomass quality for end-product use. Current challenges are that long-term cultivation at larger scales is limited, and while multi-year and multi-cultivar research is being performed, it is not at a large scale and is commonly limited to a single location.

Feedstock Quality Variability

Rachel Emerson, Senior Research Scientist, Bioenergy Feedstock Technologies, Idaho National Lab discussed the work of the Idaho National Laboratory, which manages the Bioenergy Feedstock Library (BFL).[12] The BFL houses biomass feedstock samples that are catalogued with their associated metadata and uses it to perform analyses on feedstock variability. It currently houses over 4500 samples, including samples from the RFP. A workshop was held in 2019 to fill in metadata and analytical gaps from the RFP, share results from the analysis of RFP biomass properties, discuss preparation of peer-reviewed publications, and review the potential to develop biomass quality maps. The workshop report is available at Regional Feedstock Partnership 2019 Workshop Report. In January 2022, the Regional Feedstock Partnership Biomass Quality Assessment Final Report was published. This report contains a summary of

[11] McGowen, John, PhD. "AzCATI — Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-01-energy-crops-saf-resource-june-2023-mcgowen.pdf.

[12] Emerson, Rachel. "Feedstock Quality Variability." Presentation given at the Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop, Kansas City, MO, June 6–7, 2023. Available at: www.energy.gov/sites/default/files/2023-06/beto-02-energy-crops-saf-resource-june-2023-emerson.pdf.

chemical quality results from samples collected as part of the RFP field trials. The report assesses the impact of experimental agronomic designs on biomass properties followed by analyses of the impact of environmental and production variables on biomass properties. Data gaps, such as the impact of soil and other environmental factors, were identified as potentially significant to the chemical quality of biomass. Ms. Emerson concluded that these analyses help to define the current knowledge gaps associated with the deployment of purpose-grown energy crops.

Breakout Sessions

During the workshop, breakout sessions were used to gather information about purpose-grown energy crops. There were four breakout groups assigned by the following feedstock categories:

- Algae,
- Herbaceous energy crops,
- Short-rotation woody energy crops, and
- Overwintering/secondary oilseed energy crops.

Workshop participants self-selected their breakout group assignments, but were free to change groups if another was more suitable for their interests. During three separate breakout sessions, the feedstock groups discussed the following prepared topics:

- Identifying knowledge gaps, including technical needs, market and policy needs, data needs, and land use needs;
- Ideas and strategies for addressing knowledge gaps; and
- Innovative solutions for successful deployment.

The results of the breakout sessions are summarized by feedstock category below.

Algae Breakout Session

Identifying Knowledge Gaps

Technical Needs: Here the group identified production data—long-term and at-scale—as being key focal points. The group reached consensus that for production data to be reliable and impactful, growing trials must be at least one year in length and at least one acre in size. Increasing scale brings new challenges. With each increment there are new challenges or aspects of farming to consider and conclusions to be drawn. The algae community needs to consider harvesting, pests, weather, integrative pest management, long-term data productivity and product quality, key parameters (e.g., energy use, CO_2, nutrients), and system data (e.g., biological kinetics). All these data need to be collected and combined into one publicly accessible repository. Other technical needs that algae researchers and farmers need to consider are operational designs, mass transfer, gas transfer, control strategies, conversion, and product considerations. The end product, whatever it may be, needs to be in the right form and make economic sense. The economic system encompasses matching location, pH, strain (i.e., whether genetically engineered or not), water source, nitrogen and phosphorus reuse efficiency for cultivation and conversion, and making these variables cost effective.

Market and Policy Needs: The discussion around market and policy requires identifying capital expenditure reduction opportunities, determining closed carbon balance, building the potential to work with wastewater treatment plants, and identifying the products that are in demand. There is plenty of demand for products if algae can be fractionated into the desired components for the end user supply chain.

Data Needs: Data needs overlapped significantly with the discussion of technical needs. Additional identified needs included standard operating procedures, regional analysis of water sources, and siting for ponds and refineries.

Land Use Needs: Land use concerns were primarily centered around water usage.

The top five knowledge gaps for deploying algae as a purpose-grown energy crop for SAF were determined to be:

1. Large-scale cultivation demonstrations of at least one acre;
2. Long-term data and product quality in relation to consistency;
3. Product fractionation and downstream processing;
4. Engineering models for systems integrated with process control; and
5. Carbon intensity closed accounting.

Ideas and Strategies for Addressing Knowledge Gaps & Innovative Solutions for Successful Deployment

Once the algae breakout group determined what they thought were the top five knowledge gaps, it was then discussed how they could be addressed and what strategies should be considered. The results of this discussion are summarized below.

1. Large-scale Cultivation Demonstrations of at least One Acre

As indicated above by the extent to which detail and ideas are associated with scale, the most significant knowledge gap was identified as large-scale cultivation demonstrations. As scale increases, kinetics change and must be taken into account (e.g., edge effects become negligible at larger scales). As noted above, the type of data and access to the data is important for performing cultivation at larger scale. Different groups are performing lab- to large-scale experiments, and it would benefit researchers to consider pond optimization since it is a common practice to refrain from modeling small ponds. Regarding ponds and cultivation, the following need to be considered: pond design, ratios and depths, resource efficiency, seed, dissolved oxygen needs, and variable being tested (e.g., dissolved oxygen, pH, photophysiology, microbiome, total organic carbon, particulate). It is important to identify the most critical questions to answer when it comes to scaling and advancing the algae industry.

2. Long-term Data and Product Quality in Relation to Consistency

Regarding long-term data and product quality, the algae breakout session group proposed the strategy to run cultivation trials under the same approach for at least one year—not adjusting with each cultivation trial or season, but maintaining the same strain and control plan. The deployment of this strategy would require continuous yield monitoring, multiple rounds of

consistent production, implementation of high data standards, and management and delivery of data to the public. The algae community needs to standardize metrics to move concepts forward, ensure consistency amongst different groups, and analyze the collected data. Tech transfer and other forms of communication are needed to inform the entire algae supply chain, from farmers to regulators, with information on how algal cultivation and farming can be a valuable and viable source of SAF and bioproducts.

A suggested possible solution to address the large-scale cultivation gap is to compose a Funding Opportunity Announcement (FOA) that is not innovation based, but instead focused on data collection, data standards, and the creation of a database for the public dissemination of data sets and project impacts. The recommended FOA would call for a focus on multiple partners joining with the National Laboratories to develop a defined model algal system before scaling up, including analyses such as Life Cycle Analysis (LCA).

3. Product Fractionation and Downstream Processing

The strategy for addressing the knowledge gap of product fractionation and downstream processing is to use LCA to inform the separation of each component of biomass for the best use. Not only does a product need to be accepted, but it needs to be performed in the multi-kilogram scale, ensuring that supply can be continuous and consistent. If the product is food or feed, it will need to be processed in a food-safe manner and the regulations and quality standards will need to be met. Algal production would be needed for a reliable, year-round supply chain.

4. Engineering Models for Systems Integrated with Process Control

Regarding the fourth knowledge gap identified—engineering models for systems integrated with process control—it was discussed that many of the methods for addressing this gap are noted in the large-scale demonstrations topic, but this group also noted the additional necessity for the biological model to feed into the engineering model. Many participants believed that large-scale cultivation will contribute toward filling this gap.

5. Carbon Intensity Closed Accounting

Lastly, participants identified carbon intensity closed accounting as a knowledge gap resulting in barriers to deployment for algae cultivated as a purpose-grown energy crop. To close this gap, the group suggested noting inputs and outputs, accounting for nitrogen, phosphorus, and other nutrients in addition to carbon, and the need for carbon intensity closed accounting to be a community practice. Deploying the strategy would enable comparison between algae cultivation baselines and other crops to aid in understanding differences in carbon intensity.

Herbaceous Energy Crops Breakout Session

Identifying Knowledge Gaps

Technical Needs: Improved, geo-referenced datasets are needed to determine how genotypes will perform. There is a need for more modeling and datasets, which can be achieved through breeding and by matching cultivars and species to environmental conditions. Long-term field

studies in agronomically relevant regions are needed to better understand how crop cycles will behave between years 0–20, as well as the potential impacts of pests and disease and strategies to manage them. As new cultivars and techniques are developed, the trade-offs will need to be quantified for accelerating growth. All stakeholders will need to understand which aspects of the crop are valued from a sustainability and carbon intensity standpoint. Improved techniques will be needed for handling and processing the crops in an industrial setting.

Market and Policy Needs: The discussion identified many risks associated with long-term crop production. Specifically, growers need assurances of crop yields, available markets, and investments to decrease their risk. Identifying commercial market requirements and market players is a critical component of this risk reduction. Altogether, there will be increased probability of crop adoption when the risks to farmers are reduced and more incentives for them exist. Support at all levels of government will be needed to drive market access and to standardize protocols. One knowledge gap that is critical to fill is to improve the understanding of value chains for energy crops. In addition to allowing growers to maximize profits, it would also provide a framework for financing at scales.

Data Needs: Another key gap discussed was that protocols need to be standardized to improve consistency of carbon emissions quantification and data quality so that growers, as well as governments, can better understand how practices compare in terms of carbon emissions. Better estimates of carbon intensity and economics for herbaceous energy crops are needed, and soil carbon quantification protocols need to be accepted by commercial entities. Creating a definition of "success" for how landowners can valorize crops is critical. Growers need performance targets (e.g., production, sustainability, cost) that will help ensure market growth and a greater likelihood of profit for the grower. Having specific metrics that define success and developing feedstock-specific, farmer-friendly protocols is critical for implementation.

Land Use Needs: Needs identified in the land use category centered around mitigation of risk for landowners and growers. Additional financial and analytical tools are needed to allow these groups to assess the viability of adopting a new crop. Landowners and growers need assurances that planting a certain crop over a certain number of acres will likely result in a profit. New growers need additional resources to better understand land management practices.

The top five knowledge gaps for deploying herbaceous energy crops as a purpose-grown energy crop for SAF were determined to be:

1. Risk associated with long-term crop production;
2. What are the commercial market requirements and who are the market players?
3. How do we measure and achieve success?
4. Standardized protocols for data collection and carbon intensity calculation; and
5. Understanding value chains for energy crops.

Ideas and Strategies for Addressing Knowledge Gaps & Innovative Solutions for Successful Deployment

Once the herbaceous energy crops breakout group determined what they thought were the top five knowledge gaps, it was then discussed how they could be addressed and what strategies should be considered. The results of this discussion are summarized below.

1. Risk Associated with Long-term Crop Production

The risk associated with long-term crop production was one of the key knowledge gaps identified for deploying purpose-grown herbaceous energy crops. To address this gap, participants stated the importance of evaluating technology and feedstocks at commercially relevant scales with multi-locational testing. To do this, partnerships with insurance providers and bankers will be important. Furthermore, gathering better data that relates regional variability to ecosystem services, carbon intensity, and feedstock quantity and quality will mitigate the risk of adopting these crops. Expanding and utilizing regional research stations (through universities with government support) that have long-term commitments to regionally adapted feedstock types—such as the existing BFL—will expand access to user facilities for feedstocks and lead to an improved index of feedstocks. Altogether, identifying specific traits and protocols that are optimal for conditions will help with farmer adoption and deployment. Furthermore, adoption may increase with improved modeling to compare bioenergy crops and existing crops alongside Techno-Economic Analysis (TEA) and LCA. There is a need for clear and concise marketing and public relations materials to share information with key stakeholders, including farmers. In this way, DOE could have a balanced portfolio of projects, which includes not only conversion and feedstock production research, but also research on economics and social science perspectives, all of which are critical for technology adoption and deployment. Another critical piece of de-risking farmer adoption of herbaceous energy crops is to identify alternative markets and to create insurance products, more of which is discussed below.

2. What are the Commercial Market Requirements and Who are the Market Players?

Identifying commercial market requirements and key market players was another knowledge gap identified and discussed in detail. The results of long-term studies at commercially relevant scales—both crop production and processing—can help fill this knowledge gap. For instance, it is critical to disseminate knowledge concerning the minimum field size required to be commercially relevant and profitable; furthermore, individual crop models need to be developed. The studies must be representative of demonstration scale (10–20% of commercial scale minimum) and yields must be sufficient for continuous (not batch) assessment. Furthermore, development of feedstock supply needs to be aligned with conversion technology evolution and plant demand. This will require public/private partnerships and clear information on effective feedstock conversion technologies. Critical material attributes for different feedstocks and technologies will need to be identified, with Failure Mode and Effects Analysis by technology. Real time quality analysis (rapid/non-invasive) is also essential. Another important consideration is the process of developing industry contractual terms with farmer engagement harmonized with state laws and upfront capital. Legal regulations will need to be identified, meetings with agricultural lawyers and lenders will need to take place, existing

statutes will need to be reviewed and assessed, and an adaptive framework for contracting will need to be proposed.

3. How do we Measure and Achieve Success?

Also discussed were strategies and solutions for mitigating the knowledge gap regarding how to achieve success with feedstock and farmer-friendly protocols. The amount of feedstock needed to produce sufficient volumes of SAF needs to be well quantified and communicated so that biomass can be produced at relevant commercial scales. Optimal site location based on infrastructure should also be identified. In terms of markets, farmers need more information farmers to understand alternative markets, including access to existing consulting firms and proprietary reports on energy crop assessments. In terms of insurance products, iterative face-to-face meetings with insurance decision makers to inform risk management, driven by USDA Risk Management Agency, will be critical. Financial difficulties were discussed, with emphasis on insurance and lending. Farmers relate that they currently assume too much of the burden when growing herbaceous energy crops. Assurances and support from financial institutions and insurance companies for product development specific to energy crops would help alleviate these concerns. Government engagement with farmers in policy spaces can also contribute to success. Another strategy discussed was the distribution of "success stories," because broader knowledge of "successes" would enable more adaptive project management and a greater ability to minimize risk.

4. Standardized Protocols for Data Collection and Carbon Intensity Calculation

Regarding data collection and carbon intensity calculation, discussion centered around ensuring data quality alongside a standardized and consistent method for carbon accounting. To ensure quality, data should be geo-referenced at different spatial and temporal scales, include details on the climate-smart agricultural practices needed to achieve the results, and define strategies employed to mitigate risks associated with weed and pest management. Long-term field trials at pre-commercial scales will be necessary to generate ground truth data that can then be used for large-scale models. These studies need to be performed over multiple growing seasons and in all regions applicable to each feedstock to generate data that can help certify crops for market adoption and be utilized by extension agents, lenders, insurance agencies, and policy makers. In order to determine optimal locations for infrastructure (e.g., depots and biorefineries), it will be necessary to forecast long-term production for consistent feedstock supply and composition by region and site.

5. Understanding Value Chains for Energy Crops

Understanding the value chain for energy crops at a regional scale will be critical for successful scale-up and deployment. Each type of feedstock and their associated regions will have unique logistical opportunities and challenges that will need to be overcome for energy crops to be produced at the scales needed for future SAF goals. One such challenge will be generating awareness for the potential impact that herbaceous energy crops can have on SAF markets. Educating growers and eventual SAF end users on the similarities between herbaceous energy crops with the current solutions used by the aviation industry to meet airline sustainability goals will be key to gain support. The framework for outreach materials should be provided by

BETO to ensure a clear, standardized message. Additionally, BETO should leverage the funded demonstration-scale projects in other programs to utilize feedstock from a demonstration-scale-size field trial to fully evaluate the quantity and quality of feedstock streams needed. Future FOAs could require demonstration applications to partner with growers and farmers to supply their feedstock and encourage industry partnerships and interactions. Ultimately, the fuels produced from these types of crops will need to be drop-in ready. The burden of these efforts should be placed on BETO and its partners, rather than on current growers.

Short-Rotation Woody Energy Crops Breakout Session

Identifying Knowledge Gaps

Technical Needs: Various needs must be addressed to enable widespread deployment of purpose-grown energy crops. On the technical front, there is a demand for improved feedstock preparation and classification processes before conversion. Additionally, there is a need to design solutions that work efficiently across different scales and with better prediction models. Ensuring the interoperability of equipment is crucial. Another important aspect involves combining short-rotation woody crops with long-rotation crops and herbaceous crops through intercropping.

Market and Policy Needs: It is essential to expand Renewable Fuel Standard (RFS) credits and establish closer collaboration with farmers to enhance their engagement in the bioenergy market.

Data Needs: There are gaps in comprehensive data on yields and genetics, as well as trials on existing crops with favorable genetic traits. These data should be public, easily discoverable, usable, and interoperable.

Land Use Needs: Addressing land use needs includes evaluating ecosystems and ecosystem services to create incentives for producers, incentivizing farmers to work with short-rotation woody crops, conducting large pre-commercial trials, understanding the behavioral aspects of farmers in their engagement with the bioenergy market, and comprehending the physicochemical changes in wood from woody crops grown in damaged lands. Additionally, focusing on below-ground coverage is crucial.

Other Needs: Addressing other needs involves establishing off-take agreements among various stakeholders, bringing operational biorefineries to the commercial level, and engaging stakeholders across the entire value chain, including communities.

The top knowledge gaps for deploying short-rotation woody crops as a purpose-grown energy crop for SAF were determined to be:

1. Large-scale and long-term temporal/spatial studies and system-level based research (15–20 years);
2. Preprocessing and logistics; correlating data needs from feedstocks to conversion specifications;

3. Updated yield and quality information for new cultivars and varieties;
4. Better understanding of soil and below ground characteristics;
5. Attention to the human dimension, farmers/producer engagement, and social science; and
6. Robust carbon intensity and water use values.

Ideas and Strategies for Addressing Knowledge Gaps & Innovative Solutions for Successful Deployment

Once the short-rotation woody energy crops breakout group determined what they thought were the top knowledge gaps, it was then discussed how they could be addressed and what strategies should be considered. The results of this discussion are summarized below.

1. *Large-Scale and Long-Term Temporal/Spatial Studies and System-Level Based Research (15–20 years)*

Researchers should aim to conduct research across a spectrum of scales, with only the most promising systems tested at large-scale. This allows for a thorough evaluation of various systems and their impacts. To ensure a well-informed and streamlined R&D process, effective connections between data from small trials should feed into larger ones for scale-up. This approach optimizes the transfer of knowledge and insights, while fostering efficient innovation. Importantly, only the most promising systems will transition to large-scale testing, considering both crop yield and soil health. These data, combined with concrete data on yields per acre and end-product performance, could be used to develop a robust economic model. This model would serve as a persuasive tool for stakeholders throughout the supply chain, making a strong business case for the adoption of bioenergy technologies. Additionally, valuable lessons can be gleaned from past experiences, such as those with Loblolly Pine. The coordinated large-scale studies conducted on Loblolly Pine have provided invaluable insights into optimizing its growth and utilization. Now, the intention is to leverage this experience and apply it to other woody crops like poplar, willow, eucalyptus, and sweet gum.

2. *Preprocessing and Logistics; Correlating Data Needs from Feedstocks to Conversion Specifications*

To tackle this challenge, researchers should consider the perspective of bioenergy refiners. They are delving into the dynamics of how various feedstocks interact with catalysts during the conversion process. It's understood that different feedstocks can have distinct impacts on the performance and longevity of catalysts used in bioenergy conversion. With this perspective, end users should establish the quality attributes needed from feedstocks. Similarly, the development of robust biomass field-to-product value chains is pivotal. This involves not only creating certified sustainable feedstocks but also effectively leveraging co-products. The mobilization of related industries—such as equipment manufacturers and investors—in tandem with bioenergy research will foster a synergistic ecosystem for faster adoption of short-rotation woody energy crops towards biofuels at the commercial scale.

3. Updated Yield and Quality Information for New Cultivars and Varieties

There are two key strategies that researchers should employ to address the need for updated yield and quality information for new cultivars and varieties. The first is to identify the specific industry bottlenecks to inform the genetic targets. This approach will ensure that the genetic targets set for new cultivars and varieties align with the practical requirements of bioenergy production. Achieving a comprehensive understanding of how the quality of new cultivars and varieties changes in storage over time provides the industry with critical insights into crop management and preservation. The second strategy is to study intercropping regimes, particularly with herbaceous species. These intercropping strategies involve growing different crops side-by-side. In this context, researchers should investigate how the combination of woody bioenergy crops with herbaceous species can maximize land use and potentially enhance yields.

4. Better Understanding of Soil and Below-ground Characteristics

To better understand soil and below-ground characteristics, one key approach is to conduct full lifecycle studies on woody material at depth to understand decomposition rates, carbon sequestration rates of below ground versus above, and carbon percentage returned to the soil system. Woody roots decompose more slowly and thus potentially store carbon longer in the soil, especially with harvesting techniques that leave the root structure intact. Another approach is to develop reliable field devices that farmers can use to collect data without going to a lab, including spatial and temporal data. These tools would allow farmers to gather essential data without the need for cumbersome lab equipment or specialized training.

5. Attention to the Human Dimension, Farmers/Producer Engagement, and Social Science

Researchers should address human dimension aspects by determining the best entry markets. Valuable examples are found in states like New York and Virginia, where farmer engagement has been integral to the end-to-end sustainable use of feedstocks for power generation. By taking lessons learned from these regions, the aim is to de-risk the entire supply chain. In addition to engaging farmers and producers directly, focusing on the human dimension requires understanding the role of market intermediaries, such as aggregators, who bridge the gap between feedstock producers and end users. Another key aspect is identifying the types of feedstocks that provide the most significant ecosystem services. Recognizing the ecological benefits of certain feedstock choices—which could include carbon sequestration, enhanced soil health, or support for biodiversity—is pivotal. The extent to which these ecological benefits are delivered can significantly influence the adoption of woody crops and, in turn, determine the ultimate scale-up of bioenergy production.

6. Robust Carbon Intensity and Water Use Values

To address carbon intensity and water use, the breakout session group determined that a key strategy for researchers to investigate is to conduct comprehensive studies on the carbon and water intensity of short-rotation woody crops. Such studies would provide a thorough understanding of the environmental impacts associated with the production and utilization of short-rotation woody energy crops. By examining the carbon footprint and water usage throughout the lifecycle of these feedstocks, researchers could pinpoint areas for improvement

towards deploying short-rotation woody crops. A strong knowledge base of carbon intensity and water use data for short-rotation woody energy crops is imperative to inform stakeholders regarding carbon credits. Another strategy is to identify the key parties responsible for establishing and maintaining carbon credit systems. It's essential to ensure that these stakeholders have access to the necessary data to make informed decisions about carbon credits. The availability of reliable and certified low-cost sensors and instrumentation for carbon measurement, along with the ability to obtain carbon balance certification from field data, ensures the accuracy of carbon-related assessments in the bioenergy sector.

Overwintering/Secondary Energy Crops Breakout Session

Identifying Knowledge Gaps

Technical Needs: The technical knowledge gaps identified in the overwintering/secondary energy crops breakout session included logistical needs for the farmer: planting and harvesting timelines, equipment required, and data collection methods for researchers. Participants also highlighted that they would want to understand what effects might occur on primary crops. The time from planting to harvest is important for a secondary crop to fit between the growing seasons of other crops in the same field. This will differ across regions and will be dependent upon the crop planted before and after the secondary crop. If the next crop needs to be planted prior to the maturation of the current crop, it is important for research plans to understand this from a biological and operational standpoint, for instance with attention to the impact on yield and soil from an early harvest. Maturation timing of any new crop would need to be homogeneous to maximize yield and farm operations. The group expressed concerns that the secondary crop could affect the productivity of the primary crops in the same field, either in the next rotation or over longer time periods. These impacts could result from production of molecules from the plant, effects on soil or nutrient quality/availability, effects on the microbiome, or crop protection. The group suggested that remote data collection and visualization (including in real time) may be necessary, especially in the research setting. Depending on the location and type of primary crops in the area, secondary crops may have different equipment (e.g., planting and harvesting) requirements to those used in the current location. This could have financial impacts and/or be a barrier to entry.

Market and Policy Needs: The discussion of market and policy needs centered around ways to simplify the adoption of new practices and incentivize farmers to adopt new practices. It was repeatedly stated that adoptions would have to increase rapidly to meet the 2050 goals of SAF production. Market discovery and pricing information are needed to demonstrate the economic benefit to the farmer. To improve economics, tax credits for SAF production need to be linked to farm production and the farmer needs to be aware of how to access these credits. Rules and policy can be restrictive and create a barrier to entry. These barriers must be reduced or removed to incentivize change in practice. One regulatory barrier that was repeatedly discussed was that currently the term “cover crop” has problematic regulatory connotations. For example, as defined by the USDA, a cover crop cannot be harvested. In some states, cover crop species are listed as noxious weeds and cannot be farmed, while farming is allowable in other states. Thus, the terminology is important; new terminology should be considered carefully and

agreed upon by all stakeholders. Additionally, insurance would need to be available for a crop to become viable. New business models should bring together and inform all parties including insurance firms, investors, and farmers to enable decisions and action.

Data Needs: For data needs, the economic and agronomic benefit to the farmer must be demonstrated. Field trials should cover a wide range of regions and funding could be used to help smaller entities improve field trials (e.g., duration, size, region, replication) to speed time to market. Information distribution is key and generating both vertical and virtual supply chains could facilitate information flow between interested parties. There is a strong need to standardize methods for soil carbon measurements and carbon intensity calculations. This must include where the boundaries are placed, including effects of displaced activities resulting from new crops, and understanding the tradeoffs between a traditional cover crop (that is not harvested) and one that is used for fuel production.

Land Use Needs: In the land use needs discussion, participants wanted to understand where it makes sense to grow these crops. One example of a land use barrier was that of leased land where there would be less incentive for a farmer to introduce new practices that may not pay off economically or agronomically until the longer term. Again, the very rapid adoption that is needed to meet fuel production goals was stated as a potential issue since large amounts of land would need to be quickly changed in use and the associated infrastructure for processing would need to be rapidly developed in parallel. This relates not only to the selection of a crop and demonstrating its benefit, but also all the infrastructure that would be required for this crop, including processing facilities (ginning, crushing etc.) and supply chains. If existing infrastructure could be used (e.g., if it is off season for its target crop), this would reduce barriers to entry while providing economic incentive for others in the value chain outside of the farmer.

The top five knowledge gaps for deploying overwintering/secondary energy crops as a purpose-grown energy crop for SAF were determined to be:

1. Economic solutions to adoption including markets and business models;
2. Mobilizing resources and regulatory solutions to adoption;
3. What should be grown where considering both genetics and the environment;
4. Carbon and other soil-related calculations, modelling, and measurement; and
5. Facilitating information flow between parties in the supply chain including education and social engagement.

Ideas and Strategies for Addressing Knowledge Gaps & Innovative Solutions for Successful Deployment

Once the overwintering/secondary energy crops breakout group determined what they thought were the top five knowledge gaps, it was then discussed how they could be addressed and what strategies should be considered. The results of this discussion are summarized below.

1. Economic Solutions to Adoption Including Markets and Business Models

Since a massive investment in infrastructure will be required (e.g., for processing facilities), ways to generate or incentivize this funding need to be investigated. Participants brought up the issue that infrastructure and equipment is not always allowed or easy to obtain on cooperative agreements or grants. Loan guarantees or other funding avenues need to be open to allow the investment required for the rapid scale-up. With only seven years to meet the 2030 goals of the SAF Grand Challenge, scale-up of promising technologies needs to happen very fast. Longer-term planning for rapid scale-up needs to happen in parallel to R&D, with funding made available to support it. Data is needed in multiple areas to minimize the risk to the farm and farmer. Crop enterprise budgets developed from this data can then be used by producers, lenders, and others to estimate costs and returns. The impact of growing a secondary crop on other crops grown in the same location needs to be understood. Along the same lines, potential ecosystem benefits from the primary crops also need to be understood, such that the whole system effects on global warming potential are considered. For any new crop, crop protection tools and approaches must be developed and pest issues need to be identified during R&D and scale-up. The USDA Risk Management Agency should be involved to allow for future crop insurance programs. The IR-4 Project, established by the USDA, is one method that can reduce risks associated with crop protection. Data gathered on new crops need to cover as broad a region as possible to better understand the yield and risk profile under different conditions. Farmers must be partners in the value chain. Farmer-owned co-ops, the grouping of farmers together, or profit-sharing with farmers were brought up as examples to foster partnership with farmers.

The group also discussed existing programs that could be leveraged to advance the deployment of secondary crops. The Regional Clean Hydrogen Hubs Program (H2Hubs) is a DOE program funded through the Inflation Reduction Act of 2022 (IRA) that will create networks of producers, consumers, and local infrastructure. There are likely lessons learned from this program that could be applied to energy crop regional feedstock partnerships funding. Additionally, multiple government agencies are pursuing R&D and scale-up towards SAF goals. BETO should be aligned with these agencies. The specific example of Fueling Aviation's Sustainable Transition (FAST) SAF grants was provided during the breakout session. FAST-SAF grants are administered by the Federal Aviation Administration (FAA) and will provide $244.5M for projects relating to production, transportation, blending, or SAF storage.

2. Mobilizing Resources and Regulatory Solutions to Adoption

Feedstock certification programs can be used or developed to provide reassurance to farmers and other participants in the supply chain. Developing the correct terminology is important to align stakeholders and regulatory bodies. Currently, carbon intensity is calculated at the level of the crop, not the farm or farm practice. Using farm-level carbon intensity models could incentivize farmers to use different practices at farm scale. Crop protection chemicals are labeled for specific uses. Any new crop would require label changes before chemicals could be used on them. IR-4 exemptions are discussed above. Options for fast-tracking approvals or involving crop protection manufacturers and regulators early to maximize the speed to regulatory approval should be explored.

To quickly mobilize large-scale adoption of new practices, all levels of the supply chain (including end users and producers) must be engaged and incentivized. One possible approach to this could be off-take agreements to support long-term, large-scale trials. There is a need for interagency alignment between various agencies; likely partners include USDA, EPA, DOE — Office of Science, Biological and Environmental Research Program, and Advanced Research Projects Agency — Energy. Interagency alignment is crucial to the long-term success of purpose-grown energy crops. Alignment could be facilitated by exploring ways to co-fund projects or other ways to collaborate. If co-funding is not possible, other methods could be used to help align portfolios. Input from the Treasury will also be needed regarding tax credits, particularly those relating to the IRA. Interactions between agencies should not be confined to one level but need to occur from the lower levels all the way to the Secretary of Energy. Also needed are pathways for data and information to pass from labs to the farm. It was unclear to participants whether data from DOE is used to inform the various farm system models. Outside of the federal system, state-level partnerships should also be explored.

Information can be hard to find. To improve accessibility, experience from the BFL at Idaho National Lab or the Bioenergy Knowledge Discovery Framework at Oak Ridge National Lab could be applied. For example, applying links and redirects to websites will assist users in finding the correct location, information, or data.

3. What Should be Grown Where, Considering both Genetics and Environment?

To answer the question of what should be grown where, field trials length should span at least 6–7 years. Trial locations should include the broadest geographies possible to cover multiple different soil types, environments, and weather patterns. Biomass removal rates should be documented along with impacts on soil health. The quality of any downstream intermediates and oils produced from the biomass is another key data point. Intermediate crop timing was brought up as a risk multiple times, since any new crop must be planted and harvested within a period of time that does not affect operations or yield of primary crops. Gaps in primary crop rotations should be analyzed to explore varieties that would allow ground cover year-round in different locations.

Research on new varieties of plants should be funded. Small plot standardized trials, defined by equipment size, should be completed in multiple locations for extended time periods. To facilitate compliance and better data collection, a kit could be supplied to the farmer that includes data collection information. For certain crops, it may be possible for separate parts of the biomass to enter multiple markets such oil and feed markets. All outputs would need to be included in an LCA, which, along with a TEA, could be positively impacted by such practices. Any removal of crop residue needs to be sustainable and must account for the impacts versus the effect of remaining in the field. To maximize cooperation and inclusion, business-sensitive information must be protected. Any trials with new crops need to consider crop protection. Data should be collected on pest pressure, disease, impact on rotation with other crops, and any interactions between crops grown consecutively in the same location. Risk assessments should consider effects on both yield and quality of each crop.

4. Carbon and Other Soil Related Calculations, Modelling, and Measurement

Additional funding is necessary for real-time measurements of soil carbon. Carbon data in trial locations needs to include year-round data, including when crops are not present in the field and data for the whole farm with multiple crops, rather than just the respective trial field. The whole farm should be included in the LCA and different farming practices for the same crop should be analyzed for LCA effects. Field and farm data should extend for multiple rotations. To increase collection and dissemination of soil carbon data, carbon monitoring could be added to existing field trials to take advantage of experiments already in progress and funded. The scale of field trials needs to reach multi-county (150,000–200,000 acres) and then to greater than a million acres. Removing residual biomass could have negative effects on soil health. The effects of both the above- and below-ground biomass need to be considered. For example, varieties with increased root biomass could be trialed for effects on soil carbon.

In addition to the effects on an LCA as stated above, the effect of different farming practices on yield and soil health metrics should be considered for different varieties. Testing should be done to determine unexpected secondary effects; for instance, inhibitory compounds that build up over time could affect future crops (e.g., the inhibition of nitrification caused by glucosinolates). Data collection methods would need to take unexpected effects into consideration. Even when such effects may not result in a non-viable crop, any effects need to be balanced against the gained benefit in an LCA/TEA.

5. Facilitating Information Flow between Parties in the Supply Chain Including Education and Social Engagement

As was addressed in the discussion regarding the second knowledge gap of aligning government agencies, information-sharing between parties in the supply chain must improve as well. Extension services, such as the USDA Natural Resources Conservation Service, could be leveraged to utilize existing relationships and channels of communication. The USDA is often the connection point between DOE researchers and farmers. Multiple examples were given that could maximize inclusion of stakeholders in the research process, including:

- Grower groups,
- Annual meetings to facilitate information-sharing between all parties,
- Farmer appreciation days,
- Farmer co-ops,
- Farmer participation from project inception,
- Analogous learnings from bioethanol pathway from research to plants in the ground, and
- Contract and cost share flexibility.

Session 3: Expanding the Network for Energy Crop Deployment

In Session 3, participants were asked to participate in an exercise intended to provide input regarding expanding the network for deployment of purpose-grown energy crops. In the first

half of the exercise, participants were asked to gather in small interactive discussion groups regarding pre-identified regions of the United States. In the second half, participants were asked to gather for discussions around specific feedstock categories. A foam board and sticky notes were used in each discussion group to capture brainstorming ideas and concerns around the region or feedstock category. The brainstorming ideas are listed below.

Ideas for Stakeholder Networks by Region

Stakeholder Network Ideas for the Northern Great Plains Region

- Purpose-grown energy crops
  - Switchgrass
  - Miscanthus
  - Sorghum
  - Winter oil crops
- Farmers unions
- USDA — Natural Resource Conservation Service
- Sustainable Agriculture Research and Education
- Regional sustainable aviation fuel processing facilities
- Small farmers
- Industrial Hemp, more acreage
- Cooperatives, farming
- Increase product portfolios of corn ethanol plants
- Minority farmers
- National Association of Wheat Growers
- National Corn Growers Association
- USDA-Farm Service Agency
- Need to recruit more farmers
- Field level management on key GHGs
- Sustainable farming practices and their impact on carbon intensity
- State and federal commodity check-off organizations
  - Wheat
  - Corn
  - Soybean
  - Sorghum
- Economic development barriers
- Connect sustainable aviation fuel regulators with farmers
  - Carbon Offsetting and Reduction Scheme for International Aviation
  - IRA
  - LCFS
  - RFS
- Commodity growers
- Water quality interests

Stakeholder Network Ideas for the Southern Great Plains Region

- Engage State Farm Bureaus
- Engage USDA Research Centers
- Agricultural check-off organizations, for example:
  - Wheat
  - Sorghum
  - Rice
  - Cotton
- Oilseed processors / fuel producers
- Find retiring farmer networks who want to pass on the farm
- Engage land grant universities
- Corn ethanol producers
- Local agriculture producers
- Airlines

Stakeholder Network Ideas for the Northeast Region

- Extension offices
- Farm Bureau
- Grower associations, maybe via extension
- Other grant awardees (e.g., climate smart commodities grant)
- Policy makers (e.g., local, state, federal)
- Industry
  - Near-term off-take
  - Longer term products/fuels
- Underserved groups and communities
- USDA — Natural Resources Conservation Service
- Transition of workforce from declining industries
- USDA–Farm Service Agency
- USDA/DOE co-hosting events
- Forest Industry
- Field Days — invite key speakers
- Regional Economic Development
- K-12 education organizations
- Empire State Forest Products Association or similar in other states
- Conservation groups (e.g., Ducks Unlimited, Pheasants Forever, National Wild Turkey Federation)
- People who understand social change
- Transportation and logistics
- Financial and insurance industry

Stakeholder Network Ideas for the Pacific Northwest Region

- Get sawdust qualified for carbon credits to engage sawmills in the Pacific Northwest
- Engage with other industries to create diverse feedstock blends for fuels (e.g., forestry residues and food processing wastes)
- Engage with local Native American tribes to build a bioenergy workforce
- Engaging absentee landlords
- Empower farmers
- Social education
- Involve all of the community
  - Start with school's programs

Stakeholder Network Ideas for the Hawaii Region

- Utilize USDA team in Hilo, HI
- Ability to migrate feedstock crop from existing locations to new locations (as to things on invasives species list)
- Talk to growers at farmers markets
- Better define invasive species

Stakeholder Network Ideas for the Southeast Region

- Short-rotation woody energy crops approved under the conservation reserve program
- Offer certified crop advisor and other credits
- Conservation Districts and food
- Scouts
- Work with the pulp and paper industry to use waste biomass that goes to bark boilers or left in the forest
- Farm Bureau providing food
- Crop consultants
- Extension podcasts and fact sheets

- State Level Department of Agriculture
- Feedstock users
  - Animal bedding
  - Pellet mills
- John Deere and other manufacturers
- Youth Programs
  - Future Farmers of America
  - 4-H
  - High school agriculture programs
- USDA — Natural Resource Conservation Service
- Farm talk radio shows
- Citrus growers (new land available after citrus greening)
- Florida phosphate mines – Florida Industrial and Phosphate Research Institute
- Financial Investors
- Carbon credit companies
- Biofuel cruise (demonstration cruise using sustainable fuels)
- Farmer focus groups with social scientists
- Insurance companies
- YouTube (cool energy crop influencer)
- Airlines
- Bioenergy field days

Stakeholder Network Ideas for the Rocky Mountain Region

- U.S. Forestry logging
- Forest products
- Fire prevention
- Beetle kill
- American Forest Foundation
- Logistics
- Check-off $
- Extension specialists
- Agrivoltaics and utilities to reduce evaporation and sustainability and select wavelength photovoltaic cells.
- Mountain Grain Growers Association
- Water agencies
- Wastewater treatment algae production
- Include water rights
- Arid region low irrigation plants (gumwood)
- Water efficiency associations
- Water reuse conservation / lavish lifestyle
- Testbed for low water crops, high light (guayule)

Stakeholder Network Ideas for the Southwest and California Region

- Incentivize water treatment plant participation
- Extension through land grand institutions
- Build on state/federal small business programs
- 1:1 network with the “radical”/”push the envelope” farmers
- Engage landowners of marginal land
- See I-West as an example for engagement
- Work with economic development funding groups
- Greater web presence of algae
- Expand on USDA connections and collaborations
- Outreach and public education
- Regional algae commercialization facility
- Prioritize seawater desalination in California
- Greater conference presence of algae

- Interface with leaders of municipalities
- Find the hotshot farmer that others want to emulate
- Interact with tribal communities

Ideas for Stakeholder Networks by Feedstock Category

Brainstorming Ideas for Algae Stakeholder Networks

- Municipalities — wastewater treatment
- Include the whole list from how you engage the southwestern and California stakeholders from the regional network discussion
- Locate regional producers willing to lease their facilities for R&D opportunities
- Interagency working group
- Engage the stakeholders who may potentially grow the algae — farmers
- Instagram (outreach)
- Engage Commercial Aviation Alternative Fuels Initiative
- CO_2 credit
  - Capture and sequestration
  - @ $100/ton can be economical
- Growing algae in between fields to catch runoff
- Co-locate with CO_2 producers (e.g., breweries, and downstream processors)
- Lobbying (e.g., Algae Biomass Organization)
- More interactions with farmers, extension, 1:1s
- Algas as farm additive (make own fertilizer)
- Identify incentives
- Reasons to change to algae for farmers (financial incentives)
- Integrate algae with current farm system to reduce barriers to entry
- Drive and specification acceptance of quality oils

Brainstorming Ideas for Herbaceous Energy Crop Stakeholder Networks

- Target crops that have additional economic value, like guayule (rubber)
- Subsidize farmers
- Natural resource organizations
- Biomass conversion (downstream users) to understand quality
- Animal producers (open-minded)
- Anaerobic digestion firing/utilize 2G residues

Brainstorming Ideas for Short-Rotation Woody Energy Crops Stakeholder Networks

- Equipment access in the U.S.
- K-12 outreach about woody bioenergy renewable resources
- New crop opportunities for citrus growers
- Have discussions with detractors early to find common ground
- Engagement from industry stakeholders
- Forestry extension (e.g., Florida Forestry Extension)

- Involve conservation groups, where possible
- Nurseries to produce the cuttings
- Network of growers and short-rotation woody crops field days
- Landowner-to-landowner communications
    - Learn from each other, not from scientists
- Peer support network — biomass anonymous
- Involve hunting groups and hunting lease landowners
- Include short rotation woody energy crops in the conservation reserve program
    - Need approval and policies
    - Policies differ by state

Brainstorming Ideas for Overwintering/Secondary Energy Crops Stakeholder Networks

- Farm Bureau
- Seed crushers
- Think in rotation context; they are not standalone plants
- Extension publications
- Impacts on primary cash crop yield — research is needed
- LCA Experts
- Regional species and variety trials (yield and quality)
- Nutrient movement versus utilization
- Sustainable farming practice for lowering the carbon intensity of winter crops
- Off-season cover
- Meal consumers (livestock)
- Anaerobic digestion to firing/ downstream conversion of 2G residues
    - Define quality needs
- Food for farmers
- Crop rotation and weed control benefits
- Farmers
- Commodity boards
- Oil consumers (Refiners)

Many networking ideas were common across regions and feedstocks. Outreach and extension were among those most frequently cited by workshop participants. Several groups mentioned communications with extension offices, other organizations, USDA agencies, community leaders, farmers/landowners, and even K–12 grades. The need to incentivize growers and provide financial support was also frequently mentioned. From the participants' responses, it is apparent that there is a great need to expand the networks in support of deploying purpose-grown energy crops.

Participant 3x5 Presentations

In addition to the keynote and invited speaker presentations, the workshop provided an opportunity for stakeholders to discuss successes and challenges of deploying purpose-grown energy crops, recent promising innovations, and visions for future work in this field, among other topics. Presenters were given up to three slides and five minutes (3x5) (not including a title slide) to share their perspectives on deploying purpose-grown energy crops. Over 30 participants submitted slides for consideration in the two 3x5 sessions. In total, 20 presenters

were selected with backgrounds ranging from industry, academia, and National Laboratories. Selected themes allowed for the representation of a wide range of feedstocks of interest, as well as a diverse set of topics such as LCA of existing cropping systems, current on-going research at different universities and research institutes, and future potential purpose-grown energy crops.

Table 2 below includes a list of all submitted 3x5 presentations. Due to time constraints and overwhelming interest from attendees, not all submitted presentations could be accommodated during the time allotted for the 3x5 sessions. The following table lists all submitted presentations along with links to the online presentations. The presentations, along with speaker biographies, are available on the Deploying Purpose-Grown Energy Crops Workshop website.

Table 2. List of Submitted 3x5 (three slides and five minutes) Presentations.[13]

Name	Affiliation	Presentation Title
Selected Presentations		
Ana P. Alonso	University of North Texas	Advancing Pennycress as Alternative Renewable Energy
Bill Belden	Stark Tech	Successes and Challenges Developing a Commercial Biomass Supply
Barney Bernstein	Global Clean Energy Company	Purpose-Grown Energy Crop: Camelina Sativa - Renewable Fuel Feedstock with Cover Crop Benefits
Lokendra Chauhan	Qen Labs Inc.	Software Tools for Sustainable Aviation Fuel
Dr. Matthew Darr, Keith Webster	Digital Ag Innovation Lab	Successes and Challenges in Commercial Biomass Supply Chains
David Hazlebeck	Global Algae Innovations	Algae feedstock for SAF
Anjli Kumar	Tek Holding Sustainable Solutions	Climate-Smart Agriculture: Farm-to-Tank SAF Growing Oilseeds for Biofuel in Rural America
D.K. Lee	University of Illinois at Urbana-Champaign	Purpose-Grown Bioenergy Crops, Switchgrass & Miscanthus Biomass Yield, Carbon Storage, and Nutrient Dynamics
Xinyu Liu, Hao Cai, Michael Wang	Argonne National Laboratory	Winter Cover Crops for Sustainable Aviation Fuel: Life Cycle Analysis and Key Issues
Jay McCarren	Viridos	Harnessing the power of photosynthesis to mitigate climate change
John McKay	New West Genetics	Hybrid Crops of Industrial Hemp for a scalable, sustainable and net-negative feedstock

[13] Selected presentations are those that were selected for presentation during the workshop. Submitted presentations were submitted but not selected for presentation during the workshop due to time constraints.

B. Greg Mitchell, Ike Levine, Ali Fares	Prairie View A&M Algae Center of Excellence, Algae Foundation	Algae research, education and workforce development at Prairie View A&M University in collaboration with the Algae Foundation
Kimberly Ogden	Arizona State University	A New Industry for Southern Arizona
Wendy Owens	Hexas	Nature-based, carbon negative fiber substitute for wood & fossil fuel- based raw materials
Bin Peng, Kaiyu Guan, DoKyoung Lee	University of Illinois at Urbana-Champaign	Measuring and Quantifying Carbon and Water Footprints of Purpose-Grown Energy Crops for Sustainable Aviation Fuel
Virginia Sykes	University of Tennessee	Will Winter Oilseeds Work in the Mid-South?
Timothy Volk	State University of New York, College of Environmental Science and Forestry	Willow Biomass Crops: Past Lessons, Future Potential
Erin Webb	Center for Bioenergy Innovation	Opportunities to Scale up Promising Feedstock Genotypes
Lloyd Wilson, et al.	Texas A&M AgriLife Research — Beaumont/Eagle Lake	Sustainable Herbaceous Energy Crop Production in the Southeast United States
Colleen Zumpf, et al.	Argonne National Laboratory	Production of Dedicated Energy Crops: From Conceptualization to Application
Submitted Presentations		
Zia Abdullah	National Renewable Energy Laboratory	Who will Invest First, The Feedstock Grower or the Converter?
Michael Burkart	Algenesis Materials, Inc.	Algae can be a Complete Solution to Replace Petroleum Fuels and Plastics
Nicholas Carpita, Maureen C. McCann	National Renewable Energy Laboratory	Genetic Targets for Overcoming Biomass Recalcitrance
Sean Carr, Paul Blum, Nicole Buan	University of Nebraska, Lincoln	Using Extremophile Enzymes to Improve Agricultural Waste Valorization
Brutus Clay	Sunflower Fuels	Purpose-grown Energy Crops at Sunflower Fuels
Doug Collins	Washington State University, Pacific Northwest National Laboratory	Maximizing the value of cover crops in the Pacific Northwest
Chuck Coronella	University of Nevada	SAF from Native Crops on Arid Lands: The Case for Grindelia
Ryan Davis	Sandia National Laboratories	Purpose-grown Energy Crops at Sandia National Laboratories
Justin Eisenach	Lincoln University Missouri	Scaling Up the Industrial Hemp Supply Chain as Carbon Negative Feedstock for Fuel and Fiber

Zackary Johnson	Duke University	Marine Algae Industrialization Consortium (MAGIC)
Matt Luetje	Cover Cress	Discover the Benefits of a New Winter Oilseed Crop
Craig Simmons	Independent Consultant	Industrial Hemp for use as an oilseed crop to produce Sustainable Aviation Fuel
Ty Stukenholtz	FarmMax	Biomass Harvesting Equipment
Paul Wever	Chip Energy	Biomass Conversion Facility Depot Advanced Feedstock Supply Systems

Summary

While it is common to think of algae, herbaceous energy crops, short-rotation woody energy crops, and overwintering/secondary energy crops as unique or standalone types of crops due to their individual characteristics, there was a surprising amount of overlap in the top five knowledge gaps identified by each of the breakout groups. These are summarized in Table 3.

Table 3. Top Five Knowledge Gaps Identified by Breakout Sessions

Knowledge Gap	Breakout Session			
	Algae	Herbaceous Energy Crops	Overwintering/ Secondary Energy Crops	Short-Rotation Woody Energy Crops
Large-scale demonstrations	X		X	X
Preprocessing and Logistics	X	X		X
Consistent carbon accounting	X	X	X	
Long-term yield and quality data	X			X
Market requirements		X	X	
Social and stakeholder engagement			X	X
Engineering models with process control	X			
Long term risk for farmers		X		
How to measure success		X		
Regulatory barriers			X	
Soil characteristics				X

Three of the four breakout groups identified long-term, large-scale demonstrations as a top knowledge gap preventing deployment of their purpose-grown energy crops. Many of these feedstocks are still at the test plot or mini-pond scale and will require larger trials to generate the data needed to demonstrate feasibility at commercial scales. Breakout groups identified the need for these trials to be long-term (at least five years in duration) and at multiple acre/larger than mini-pond scale to better capture the system's performance in differing conditions such as temperature or rainfall. Crops should also be grown in different regions, where applicable, to better understand how regional factors such as soil type or weather patterns impact yield and quality. Many of the groups understood that RDD&D studies of this type and scale would be expensive, preventing many groups from tackling these challenges alone. In addition to cost, the risks associated with developing crops at low technology readiness levels will require external support to complete. The groups considered that both BETO and the USDA were well positioned to provide financial support to universities, National Labs, and industry stakeholders who are interested in mobilizing purpose-grown energy crops.

In parallel with yield and quality data generated from long-term, large-scale demonstrations, RDD&D will also be needed to determine market requirements, processing, and logistical requirements to bring purpose-grown energy crops to commercial scales. Conversion studies for optimal conditions and catalyst impacts need to be better understood, as do the pre-processing requirements to get the feedstocks to a conversion-ready state. Variables including moisture content and dewatering, size reduction, and storage impacts will all need to be researched to facilitate the conversion of energy crops to sustainable fuels and products that are economically viable at scale. The location and size of future biorefineries will be based on the feedstock types and quantities available in the surrounding area that can be delivered at costs competitive with conventional fuels.

Another common theme across the breakout groups was the need for consistent carbon accounting. Currently, there are many methods for calculating carbon intensity for a crop system that can make it difficult to compare performance. Carbon intensity scores will likely play a large role in any future credit systems needed to incentive farmers to adopt purpose-grown energy crops. A standardized method for carbon accounting will not only be needed to be eligible for credits, but also to certify these crops for commercial scales.

The only way to ensure that advancements made in the purpose-grown energy crop mobilization RDD&D can be effective is to develop a better stakeholder engagement and information-sharing network. As much of the burden will be placed on growers and farmers, those that attended the workshop expressed a desire to be included in projects and conversations from the outset. This group is often brought in after projects have already been developed. When engaged at a project's conception, growers and farmers can lend a unique perspective on "real-world" experiences that may otherwise be overlooked. Field days or annual meetings hosted by existing projects or extension services were recommended to facilitate better information-sharing across all stakeholders. Developing better ways to disseminate information and results on the successes of other groups will be valuable for increasing the deployment of purpose-grown energy crops.

Appendix A: Workshop Agenda

Agenda: Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel Workshop
U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO)
June 6–7, 2023. Kansas City, Missouri. All times CDT.

AGENDA		
Day 1: June 6, 2023		
Opening Session: Introductions/Opening Remarks		
Time (CDT)	**Agenda Item**	**Speaker**
8:00–9:00 am	Registration/Check-in	
9:00–9:30 am	Welcome and Opening	Dana Mitchell, Alexander Jansen
9:30–10:30 am	Overview of Workshop Purpose and Progress	Mr. Michael Berube — BETO Dr. Kevin Kephart — USDA NIFA Dr. Vance Owens — USDA NIFA
Break — 10:30 – 10:45 am		
Session 1 — Promise of Purpose-Grown Energy Crops (10:45 am–12:15pm) Moderator: Dana Mitchell Co-moderator: Alexander Jansen		
Time (CDT)	**Agenda Item**	**Speaker**
10:45 am–12:15 pm	Panel Presentations and Discussion	Dr. Matthew Langholtz — Oak Ridge National Lab Dr. Sam Jackson — Genera Inc. Dr. Emily Heaton — U. of Illinois Urbana-Champaign Dr. Kimberly Ogden — U. of Arizona
Lunch — 12:15–1:15 pm (provided)		
Session 2 — Resource Considerations (1:15–2:10 pm) Moderator: Alexander Jansen Co-moderator: Dana Mitchell		
Time (CDT)	**Agenda Item**	**Speaker**
1:15–2:10 pm	Presentations with Q&A	Mr. Bill Belden — Stark Tech Dr. John McGowen — Arizona Center for Algae Technology and Innovation Ms. Rachel Emerson — Idaho National Lab
Break — 2:10–2:25 pm		
Breakout Session 1 — Identifying Knowledge Gaps (2:25–3:35 pm)		
Time (CDT)	**Agenda Item**	**Discussion Facilitator**
2:25–3:15 pm	Breakouts: Identifying Knowledge Gaps	Group Activity
3:15–3:35 pm	Breakout Highlights	Various

AGENDA		
3x5 Presentations (3:35–4:45 pm) Moderator: Dana Mitchell Co-moderator: Alexander Jansen		
Time (CDT)	**Agenda Item**	**Speaker**
3:35–4:45 pm	3x5 Presentations	Various
Check-In and Close Day 1 (4:45–5:00 pm)		
4:45–5:00 pm	Check-In and Close Day 1	Dana Mitchell, Alexander Jansen
ADJOURN DAY 1 (5:00pm)		
Day 2: June 7, 2023		
Opening Remarks/Housekeeping		
Time (CDT)	**Agenda Item**	**Speaker**
8:30–9:00 am	Registration/Check-in	
9:00–9:15 am	Opening Remarks Day 2	Dana Mitchell & Alexander Jansen
Breakout Session 2 — Ideas and Strategies for Addressing Knowledge Gaps (9:15–10:25 am)		
Time (CDT)	**Agenda Item**	**Discussion Facilitator**
9:15–10:25 am	Breakouts: Ideas and Strategies for Addressing Knowledge Gaps	Group Activity
Break — 10:25–10:40 am		
Breakout Session 3 — Innovative Solutions for Successful Deployment (10:40 am–12:00 pm)		
Time (CDT)	**Agenda Item**	**Discussion Facilitator**
10:40 am–12:00 pm	Breakouts: Innovative Solutions for Successful Deployment	Group Activity
Lunch (12:00–1:00 pm) (provided)		
3x5 Presentations (1:00–2:10 pm) Moderator: Alexander Jansen Co-moderator: Dana Mitchell		
Time (CDT)	**Agenda Item**	**Speaker**
1:00–2:10 pm	3x5 Presentations	Various
Break — 2:10–2:25 pm		
Session 3 — Expanding the Network for Energy Crop Deployment (2:25–3:30pm)		
Time (CDT)	**Agenda Item**	**Discussion Facilitator**
2:25–3:30 pm	Discussion: Expanding the Network for Energy Crop Deployment	Melissa Ladd
Check-In and Close Day 2 (3:30–4:00 pm)		
3:30–4:00 pm	Review and Closing Activity	Alexander Jansen & Dana Mitchell
ADJOURN DAY 2 (4:00 pm)		

Appendix B: Workshop Participants

The following is a list of participants who, during registration, elected to share their contact information in these proceedings.

Last Name	First Name	Company	Job Title
Abdullah	Zia	National Renewable Energy Laboratory	Laboratory Program Manager
Alonso	Ana Paula	University of North Texas	Professor
Amerigian	Zoe	Gevo	Sustainable Agriculture & Carbon Analyst
Asmus	Chad	BASF Corporation	Sustainable Ag Product Strategist
Baldwin	Brian	Mississippi State University	Professor
Bard	Sharon	Terra Economics, LLC	Principal
Belden	William	Antares Group Inc., a Stark Technologies-owned company	Sr. Agricultural Specialist
Bernstein	Barney	Sustainable Oils, Inc.	VP North America
Brown	Louis	Los Alamos National Laboratory	Technical Project Manager 3
Burkart	Michael	University of California, San Diego	Professor
Burrows	Elizabeth	Department of Energy, Bioenergy Technologies Office	Technology Manager
Carpita	Nicholas	National Renewable Energy Laboratory	Visiting professional
Carr	Sean	University of Nebraska, Lincoln	Post-doctoral researcher
Carrieri	Damian	Sandia National Laboratories	R&D Manager, Bioresource and Environmental Security
Chauhan	Lokendra Pratap Singh	Qen Labs Inc.	Founder
Clay	Brutus	Sunflower Fuels, LLC	CEO
Collins	Doug	Washington State University	Extension Specialist and Soil Scientist
Corcoran	Alina	New Mexico Consortium/New Mexico State University	Senior Research Scientist
Coronella	Chuck	University of Nevada, Reno	Professor
Croxton	Steve	Drax Power	Head of BECCS for Alternative Fuels

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McKay	John	New West Genetics	Chief Scientific Officer
McManus	James	USDA — Agriculture Research Service	Research Chemist
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Last Name	First Name	Company	Job Title
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Rials	Tim	University of Tennessee	
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Salcedo	Braxton	MicroBio Engineering	Engineer
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Stukenholtz	Ty	FarmMax	Partner
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