



Separations and Performance Advantaged Bioproducts

April 6, 2023

Coralie Backlund

Technology Manager

Agenda Overview

- Schedule for the Technology Area Review
- Reviewer Welcome
- Separations Overview
- Performance Advantaged Bioproducts Overview
- BETO Efforts

Session 2: Performance Advantaged Bioproducts

Thursday April 6 – Separations Consortium

Friday April 7 – FY21 Scale up | PABP Consortium | FY19 BEEPs | FY20 Multi-topic

Schedule for April 6, 2023

DAY 4 Thursday, April 6, 2023						
8:00 AM	10:00 AM	120		Registration, Breakfast	All	
10:00 AM	10:30 AM	30		Technology Area Daily Intro	BETO	Coralie Backlund
10:30 AM	11:10 AM	40	SEP1.0	Overview, Project Management and Integration, & DEI		Lauren Valentino
11:10 AM	11:30 AM	20	SEP3.1	R&D-Guiding TEA and LCA		Jian Liu / Thathiana Benavides
11:30 AM	11:50 AM	20	SEP2.1	Adsorption Based ISPR for ABF products		Gregg Beckham
11:50 AM	1:00 PM	70		Lunch	All	
1:00 PM	1:20 PM	20	SEP2.7	Volatile Products Recovery		Phil Laible
1:20 PM	1:40 PM	20	SEP2.4	Diol Separations		Ramesh Bhawe
1:40 PM	2:00 PM	20	SEP2.6	Enabling SAF production by Adsorptive Denitrogenation (ADN)		Miki Santosa
2:00 PM	2:20 PM	20	SEP3.2	Computational Studies Supporting Experimental Designs		Difan Zhang
2:20 PM	2:50 PM	30		Break	All	
2:50 PM	3:10 PM	20	SEP2.2	Co-optimization of Scalable Membrane Separation Processes and Materials		Meltem Urgun-Demirtas
3:10 PM	3:30 PM	20	SEP2.5	Electrochemical Separation Technologies to Extract Intermediate Organic Compounds		Yupo Lin
3:30 PM	3:50 PM	20	SEP2.3	Continuous Counter Current Chromatography		Gregg Beckham
3:50 PM	4:10 PM	20		Q&A		
4:10 PM	4:50 PM	40		Closed Door Comment Review Session	Reviewers	

Schedule for April 7, 2023

DAY 5 Friday, April 7, 2023						
8:00 AM	8:30 AM	30		Registration, Breakfast	All	
8:30 AM	8:45 AM	15		Technology Area Daily Intro	BETO	Coralie Backlund
8:45 AM	9:15 AM	30	2.3.4.210	High Solids In Situ Product Recovery; The Next Generation of Arrested Anaerobic Digestion Technology	Quasar Energy Group, LLC	Xumeng Ge
9:15 AM	9:45 AM	30	2.3.4.212	Continuous Biobutanol Fermentation Integrated with Membrane Solvent Extraction	Archer Daniels Midland, Co. (ADM)	Jesse McVay
9:45 AM	10:15 AM	30	2.4.2.200	Enabling Lignin Valorization with Liquid Liquid Chromatography	Lignolix, Inc	Eric Gottlieb
10:15 AM	10:30 AM	15		Break	All	
10:30 AM	11:00 AM	30	2.5.1.200	Physical Property Data and Models in Support of Bioprocessing Separation Technologies for Organic Acids Separation	RAPID Manufacturing Institute	Ignasi Palou-Rivera
11:00 AM	11:30 AM	30	2.5.1.500	Inverse biopolymer design through machine learning and molecular simulation	NREL	Brandon Knott
11:30 AM	12:00 PM	30	2.3.4.501	Synthesis and Analysis of Performance-Advantaged Bioproducts	NREL	Gregg Beckham
12:00 PM	1:00 PM	60		Lunch	All	
1:00 PM	1:30 PM	30	2.5.1.600	Identifying Performance Advantaged Biobased Chemicals Utilizing Bioprivileged Molecules	Iowa State University	Brent Shanks
1:30 PM	2:00 PM	30	2.2.3.400	Upcycling of CFRP Waste: Viable Eco-friendly Chemical Recycling and Manufacturing of Novel Repairable and Recyclable Composites	Washington State University	Jinwen Zhang
2:00 PM	2:30 PM	30	2.3.2.224	Bioconversion of Heterogeneous Polyester Wastes to High-Value Chemical Products	UMass Lowell	Margaret Sobkowicz-Klein
2:30 PM	3:00 PM	30	2.3.2.219	Design and development of bio-advantaged vitrimers as closed-loop bioproducts	University of California, Berkeley	Jay Keasling
3:00 PM	4:00 PM	60		Closed Door Comment Review Session		

Reviewer Introductions

Name	Affiliation
Michael Mang	Danimer
Vera Schroeder	Safar VC
Alper Kiziltas	Amazon
Debbie Mielewski	Dione Solutions

Separations & PABP Strategy | BETO Specific Goals

- Support scale-up of **sustainable aviation fuels and other biofuels** with >70% reduction in GHG emissions relative to petroleum.
- Enable commercial production of **10+ renewable chemicals and materials** with >70% GHG reduction relative to relevant petroleum-derived counterparts
- Enable **1+ cost-effective and recyclable bio-based plastic** that mitigates $\geq 50\%$ GHG emissions relative to virgin resin or plastic intermediates.

Separations Strategy | Motivation

- Chemical separations account for up to **15% of total energy consumption** in the United States.¹
- Separations account for up to **50-70% of processing costs** for biofuels and bioproducts.^{2,3}
- Efficient separation and purification are key integration challenges for all technology pathways.⁴
- There is a need to raise technical maturity of biobased processes, including separations. Improving separations will positively affect the entire bioeconomy.⁵
- Additional research is needed to bridge the gap between small-scale and large-scale technologies.⁵
- Synergy of separations with conversion processes has the potential to reduce costs while maintaining high recovery rates and yields.⁶



1. Sholl and Lively. "Seven chemical separations to change the world," *Nature*, **2016** 532: 425-437.

2. EERE. 2016. Strategic Plan for a Thriving and Sustainable Bioeconomy.

3. Bidy et al. "The Techno-Economic Basis for Coproduct Manufacturing To Enable Hydrocarbon Fuel Production from Lignocellulosic Biomass." *ACS Sustainable Chem. Eng.* **2016** 4: 3196-3211.

4. EERE. 2019. Bioenergy Technologies Office 2019 R&D State of Technology.

5. EERE. 2018. Moving Beyond Drop-In Replacements: Performance-Advantaged Biobased Chemicals

6. EERE. 2020. Integrated Strategies to Enable Lower-Cost Biofuels.

PABP& Separations Strategy | Funding Approach

	FOA	AOP
Selection Method	Competitive	Lab Call
Open to the Public	✓	✗
National Lab Participant	Only as Subrecipient	✓
Go/No-Go Decision Points	✓	✓
Verifications	✓	✗
Award Modifications Method	Contracting Officer (CO)	AOP Tool Change Control

FOA = Funding Opportunity Announcement

AOP = Annual Operating Plan

2020

SepCon AOP

- Address industrially relevant separations challenges in bioenergy
- Research approach(es) grounded in technoeconomic analysis
- High impact or broadly applicable separations techniques

2021

Scale-Up FOA

- Separations to Improve Arrested Anaerobic Digestion Process Development
- Separations to Enable Biomass Conversion

Separations Strategy | Separations Consortium

SepCon
AOP

- Address industrially relevant separations challenges in bioenergy
- Research approaches grounded in technoeconomic analysis
- High impact or broadly applicable separations techniques

Launched Separations Consortium in FY17, ~\$3.5M/year

➤Renewed in 2020

- Established an Industry Advisory Board with regular interactions
- Launched a lab-directed funding opportunity
- Developed an easy-to-use [website](#) to encourage partnerships

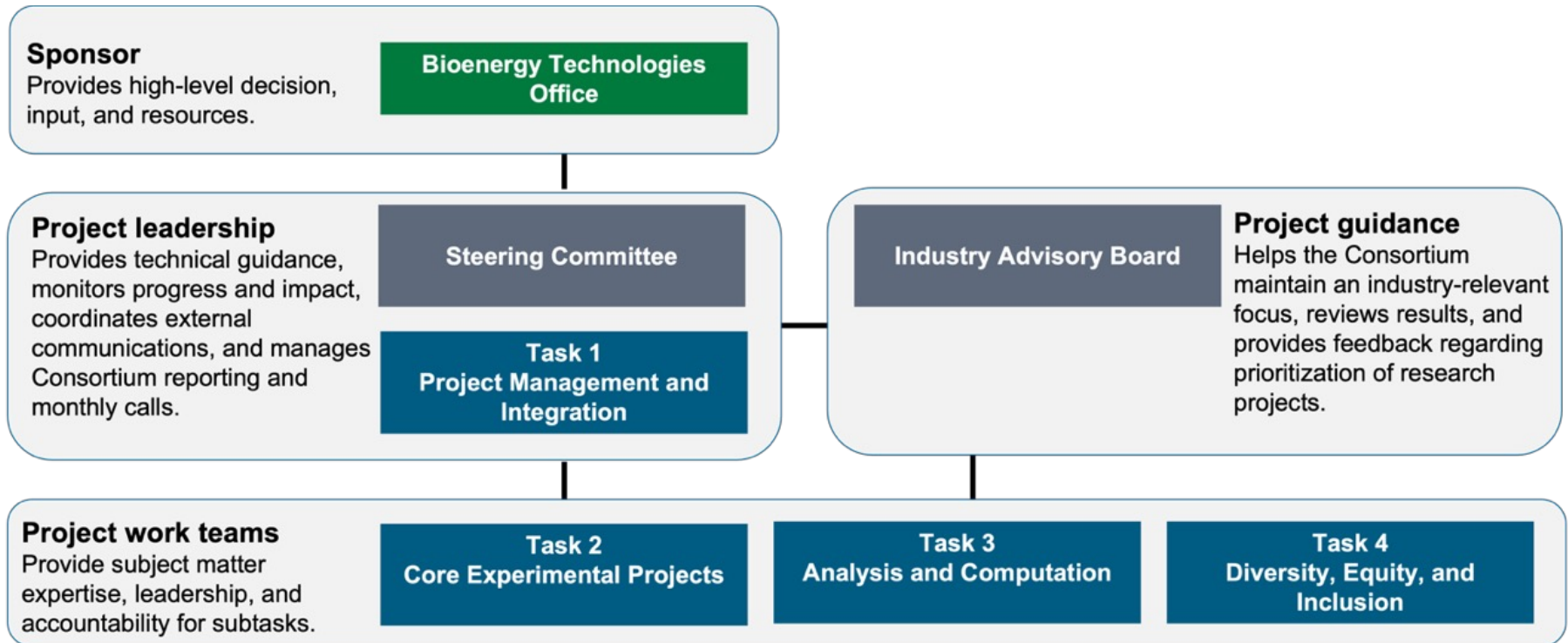
Goals:

- Address industrially relevant separations challenges in bioenergy
- Research approaches grounded in technoeconomic analysis
- High impact or broadly applicable separations techniques
- Avoid developing separations processes that are not well suited for biofuel applications
- Capitalize on shared expertise, resources, and passion

Challenges:

How do we determine what the most promising separations opportunities are?

Separations Strategy | Separations Consortium



Separations Strategy | 2021 Scale Up AOP

Scale-Up FOA

- Separations to Improve Arrested Anaerobic Digestion Process Development
- Separations to Enable Biomass Conversion

Topic 3a: Separations to Improve Arrested Anaerobic Digestion Process Development

- Develop efficient and cost-effective separations approaches to isolate and potentially upgrade organic acids and products of interest from digesters

Topic 3b: Separations to Enable Biomass Conversion

- Improve availability of data that will support separations development, as well as to develop supporting technologies to improve bioprocessing separations
- Collaborate with the Separations Consortium to address critical bioprocess separations challenges

PABP Strategy | Definitions

Drop-in Replacement: a bioderived compound that is chemically identical to its petroleum counterpart

Functional Replacement: a bio-derived compound that has a different chemical structure than a petroleum counter part, but performs the same function/has the same performance attributes

Performance Advantaged Bioproduct: a bio-derived compound that does not resemble an existing petroleum-derived compound in structure, function, or performance attributes. The bio-based compound offers novel functionality or improved performance attributes

PABP Strategy | Motivation



Product Design Benefits

- Biomass contains functionality not present in other feedstocks
- Opportunity to design and bring new products to market



Economic Benefits

- Increase value of domestic feedstock; revitalize rural economies
- Provide additional source of revenue for existing bioprocessing facilities

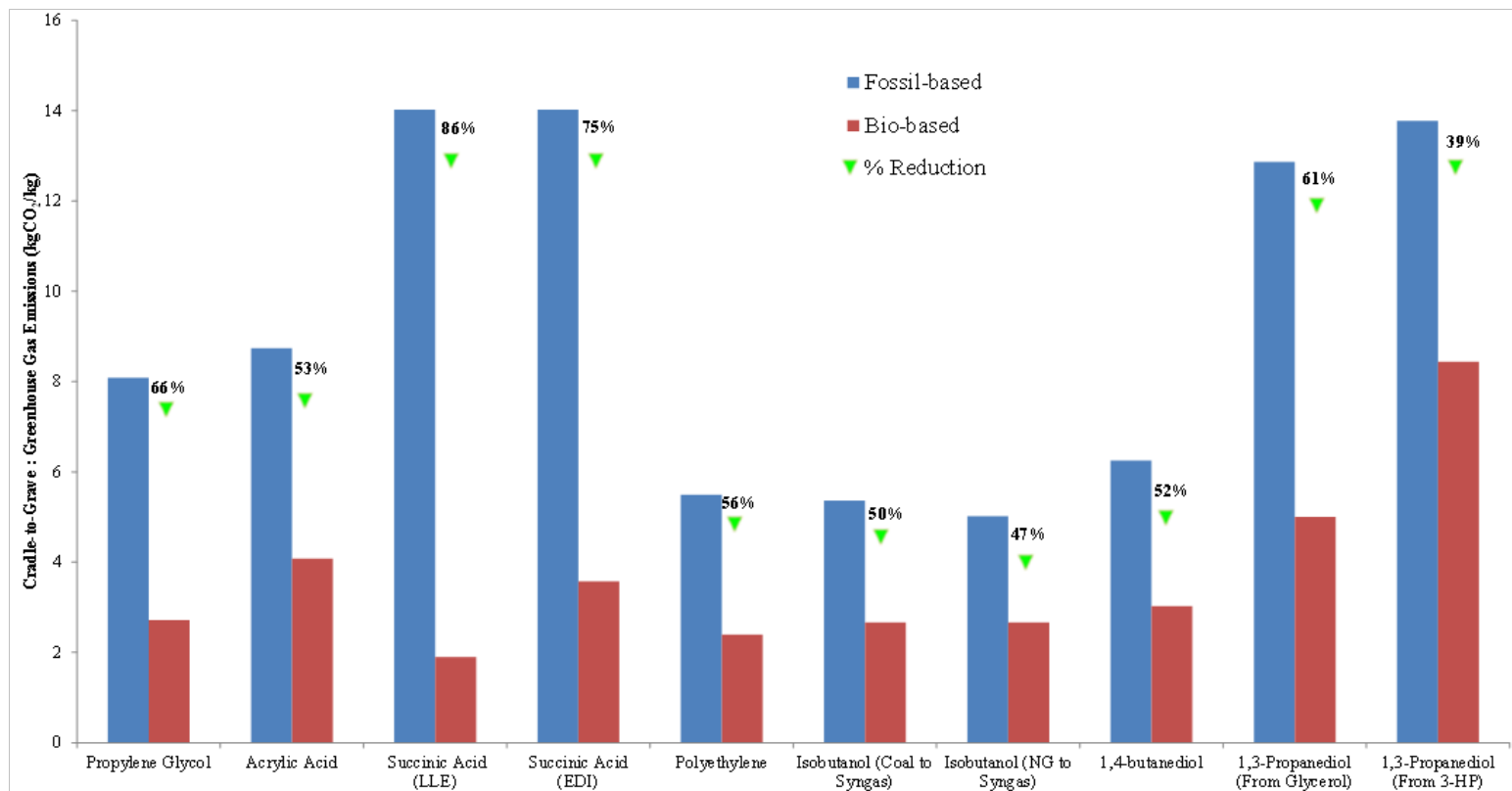


Environmental Benefits

- Potential for lower toxicity
- Reduced life cycle impact
- Reduced energy requirements



Bioproducts uniformly show emission reductions compared to their fossil-derived counterparts



Life-Cycle Fossil Energy Consumption and Greenhouse Gas Emissions of Bioderived Chemicals and Their Conventional Counterparts – Felix Adom, Jennifer Dunn, Jeongwoo Han, and Norm Sather.

PABP Strategy | Conversion Specific Goals

Identifying strategic opportunities for direct renewable chemical replacement

- Identify products with near term deployment/impact
- Decision matrices for cost, performance, and life cycle impacts of the targeted renewable chemical
- Understand process advantages, market size, and supply chains that favor renewable chemicals

Exploring novel compounds that can be derived from renewable carbon

- Investigate benefits of biomass conversion that cannot be matched by fossil carbon
- Determine end-product performance needs and identify biomass products that offer improved performance
- Developing unique biochemical and catalytic conversion strategies to such end products.

Separations & PABP Strategy | Portfolio Development

2018

BEEPs FOA

- Performance Advantaged Bioproduct Identification
- Performance Advantaged Bioproduct Production

2019

Multi Topic

- Impact of Storage and Handling on Biomass Characteristics
- Designing Novel Methods for Deconstruction and Upcycling of Plastics

2020

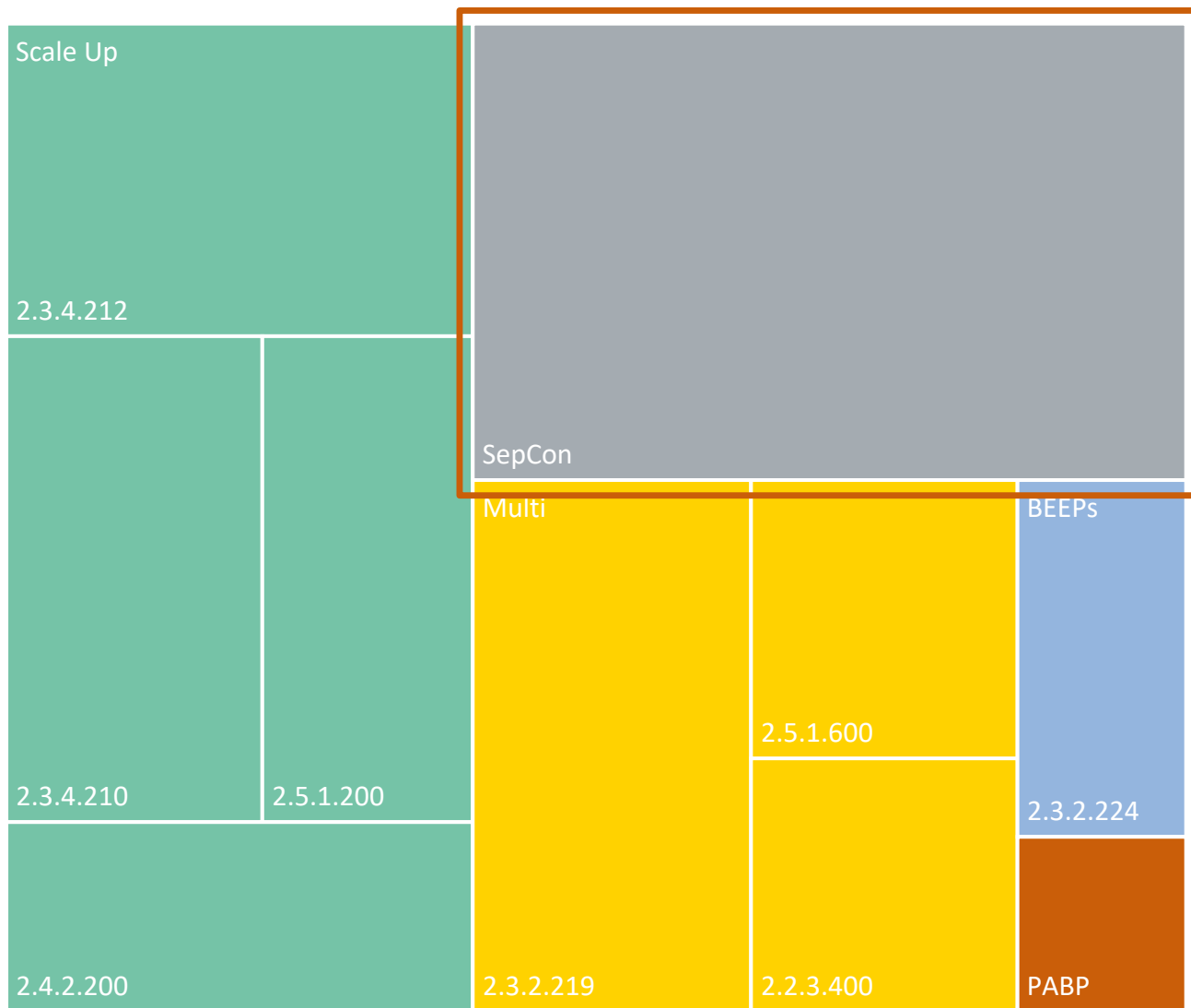
PABP AOP

- Identifying strategic opportunities for direct renewable chemical replacement
- Exploring novel compounds that can be derived from renewable carbon

Separations & PABP Strategy | Reviewer Feedback

- Consider other separations technologies, including reactive distillation, centrifugal enhanced heat transfer and extraction, and flash recovery from volatile pressurized extraction media
- Introduce the concept of prototyping. Aim to identify products and technologies that can be put into the hands of “customers,” where appropriate, to test at early and regular time points.
- Ensure the best use of industry/commercial/subject matter experts and robust industry advisory boards (IABs) from the onset of projects and throughout.
- The availability of feedstocks from plastic waste recycle/recovery is particularly uncertain, so it is worth considering how the technology area can influence this. Coordination and collaboration across government funding agencies (e.g., National Science Foundation/DOE Office of Energy Efficiency and Renewable Energy) and R&D development arms of agencies (e.g., U.S. Department of Transportation, U.S. Environmental Protection Agency) would be an efficient use of taxpayer dollars

Separations & PABP Strategy | Current Portfolio



Schedule for April 6, 2023

DAY 4 Thursday, April 6, 2023						
8:00 AM	10:00 AM	120		Registration, Breakfast	All	
10:00 AM	10:30 AM	30		Technology Area Daily Intro	BETO	Coralie Backlund
10:30 AM	11:10 AM	40	SEP1.0	Overview, Project Management and Integration, & DEI		Lauren Valentino
11:10 AM	11:30 AM	20	SEP3.1	R&D-Guiding TEA and LCA		Jian Liu / Thathiana Benavides
11:30 AM	11:50 AM	20	SEP2.1	Adsorption Based ISPR for ABF products		Gregg Beckham
11:50 AM	1:00 PM	70		Lunch	All	
1:00 PM	1:20 PM	20	SEP2.7	Volatile Products Recovery		Phil Laible
1:20 PM	1:40 PM	20	SEP2.4	Diol Separations		Ramesh Bhawe
1:40 PM	2:00 PM	20	SEP2.6	Enabling SAF production by Adsorptive Denitrogenation (ADN)		Miki Santosa
2:00 PM	2:20 PM	20	SEP3.2	Computational Studies Supporting Experimental Designs		Difan Zhang
2:20 PM	2:50 PM	30		Break	All	
2:50 PM	3:10 PM	20	SEP2.2	Co-optimization of Scalable Membrane Separation Processes and Materials		Meltem Urgun-Demirtas
3:10 PM	3:30 PM	20	SEP2.5	Electrochemical Separation Technologies to Extract Intermediate Organic Compounds		Yupo Lin
3:30 PM	3:50 PM	20	SEP2.3	Continuous Counter Current Chromatography		Gregg Beckham
3:50 PM	4:10 PM	20		Q&A		
4:10 PM	4:50 PM	40		Closed Door Comment Review Session	Reviewers	

Ground Rules

Presenters: We will give you a 5 minute warning. When your time is up, we will verbally let you know. Please wrap up quickly.

Reviewers: Please ask questions during the Q&A period. Be considerate to allow all reviewers the opportunity to ask a question.

General public: We will field questions as time allows after the reviewers have asked questions.



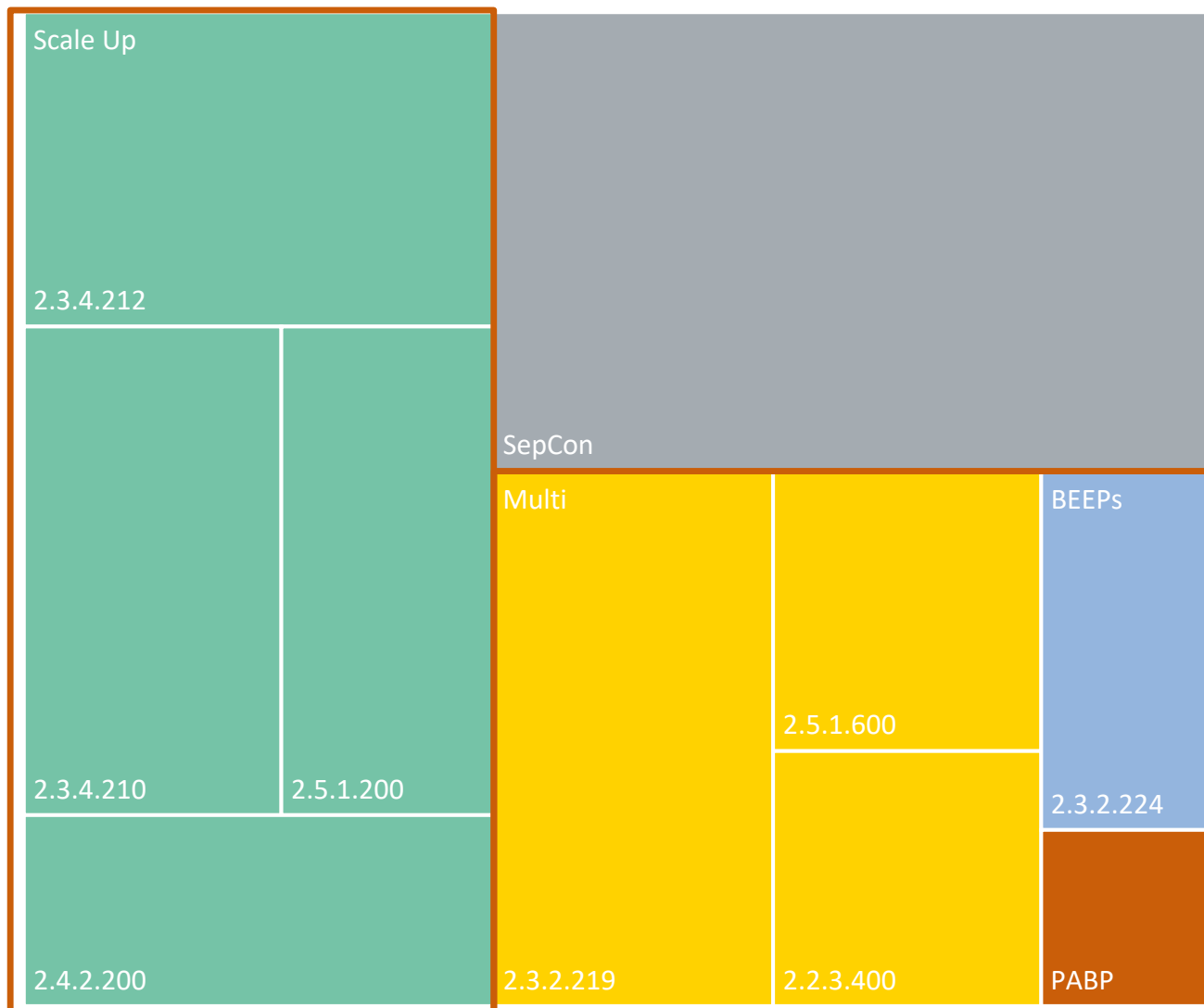
Separations and Performance Advantaged Bioproducts

April 7, 2023

Coralie Backlund

Technology Manager

Separations & PABP Strategy | Current Portfolio



Separations Strategy | 2021 Scale Up AOP

Scale-Up FOA

- Separations to Improve Arrested Anaerobic Digestion Process Development
- Separations to Enable Biomass Conversion

Topic 3a: Separations to Improve Arrested Anaerobic Digestion Process Development

- Develop efficient and cost-effective separations approaches to isolate and potentially upgrade organic acids and products of interest from digesters

Topic 3b: Separations to Enable Biomass Conversion

- Improve availability of data that will support separations development, as well as to develop supporting technologies to improve bioprocessing separations
- Collaborate with the Separations Consortium to address critical bioprocess separations challenges

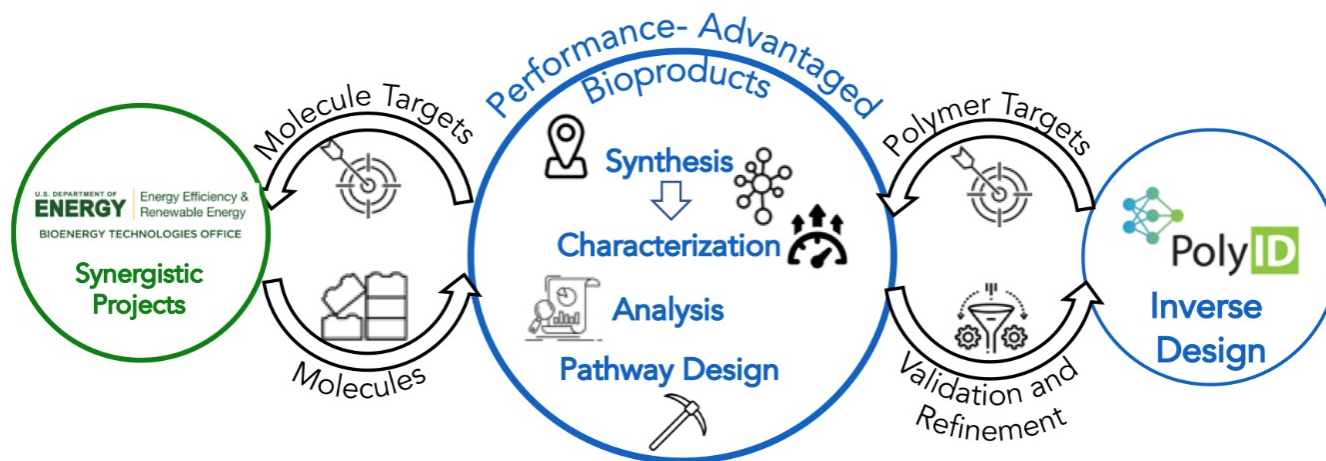
PABP Strategy | 2020 PABP AOP

PABP AOP

- Identifying strategic opportunities for direct renewable chemical replacement
- Exploring novel compounds that can be derived from renewable carbon

Funded in 2018 with an initial focus on *polymers* → expanded to include *small molecule* PABPs

➤ Renewed in 2020 as a consortium between machine learning and synthesis



Separations Strategy | 2018 BEEPs FOA

BEEPs
FOA

- Performance Advantaged Bioproduct Identification
- Performance Advantaged Bioproduct Production

Topic Area 3a: Performance Advantaged Bioproduct Identification

- Elucidating structure-function relationships for novel biobased compounds by using computational methods and/or high-throughput screening
- Identifying and publishing performance attributes unique to biobased compounds along with example compounds that display those attributes

PABP Strategy | 2019 Multi-Topic FOA

Multi Topic

- Impact of Storage and Handling on Biomass Characteristics
- Designing Novel Methods for Deconstruction and Upcycling of Plastics

Topic Area 2b: Impact of Storage and Handling on Biomass Characteristics

- Novel storage and handling approaches for management of physical and chemical characteristics of the biomass and resulting feedstock
- New technologies and/or analytical tools to relate properties of plant tissue components to performance in storage and handling, and intrinsic inorganic element content
- Strategy design for field research-scale approaches for evaluating the effect of biomass transport on segregation of biomass by tissue type and/or compaction of biomass
-

Topic Area 8b: Designing Novel Methods for Deconstructing and Upcycling Existing Plastics

- Biological, low-temperature (<300 C) chemical, or hybrid systems capable of:
 - Breaking plastics down into low molecular weight streams which are either consumable by an organism, or are easily separable
 - Breaking down plastics into intermediates for upgrading into high value products
 - Breaking down multiple plastic streams simultaneously or sequentially
 - Tolerating contaminants generally found in mixed plastic waste streams

Schedule for April 7, 2023

DAY 5 Friday, April 7, 2023						
8:00 AM	8:30 AM	30		Registration, Breakfast	All	
8:30 AM	8:45 AM	15		Technology Area Daily Intro	BETO	Coralie Backlund
8:45 AM	9:15 AM	30	2.3.4.210	High Solids In Situ Product Recovery; The Next Generation of Arrested Anaerobic Digestion Technology	Quasar Energy Group, LLC	Xumeng Ge
9:15 AM	9:45 AM	30	2.3.4.212	Continuous Biobutanol Fermentation Integrated with Membrane Solvent Extraction	Archer Daniels Midland, Co. (ADM)	Jesse McVay
9:45 AM	10:15 AM	30	2.4.2.200	Enabling Lignin Valorization with Liquid Liquid Chromatography	Lignolix, Inc	Eric Gottlieb
10:15 AM	10:30 AM	15		Break	All	
10:30 AM	11:00 AM	30	2.5.1.200	Physical Property Data and Models in Support of Bioprocessing Separation Technologies for Organic Acids Separation	RAPID Manufacturing Institute	Ignasi Palou-Rivera
11:00 AM	11:30 AM	30	2.5.1.500	Inverse biopolymer design through machine learning and molecular simulation	NREL	Brandon Knott
11:30 AM	12:00 PM	30	2.3.4.501	Synthesis and Analysis of Performance-Advantaged Bioproducts	NREL	Gregg Beckham
12:00 PM	1:00 PM	60		Lunch	All	
1:00 PM	1:30 PM	30	2.5.1.600	Identifying Performance Advantaged Biobased Chemicals Utilizing Bioprivileged Molecules	Iowa State University	Brent Shanks
1:30 PM	2:00 PM	30	2.2.3.400	Upcycling of CFRP Waste: Viable Eco-friendly Chemical Recycling and Manufacturing of Novel Repairable and Recyclable Composites	Washington State University	Jinwen Zhang
2:00 PM	2:30 PM	30	2.3.2.224	Bioconversion of Heterogeneous Polyester Wastes to High-Value Chemical Products	UMass Lowell	Margaret Sobkowicz-Klein
2:30 PM	3:00 PM	30	2.3.2.219	Design and development of bio-advantaged vitrimers as closed-loop bioproducts	University of California, Berkeley	Jay Keasling
3:00 PM	4:00 PM	60		Closed Door Comment Review Session		

PABP & Separations | Ground Rules

Ground Rules

Presenters: We will give you a 5 minute warning. When your time is up, we will verbally let you know. Please wrap up quickly.

Reviewers: Please ask questions during the Q&A period. Be considerate to allow all reviewers the opportunity to ask a question.

General public: We will field questions as time allows after the reviewers have asked questions.