



Bioprocessing Separations Consortium Steering Committee

March 11, 2021

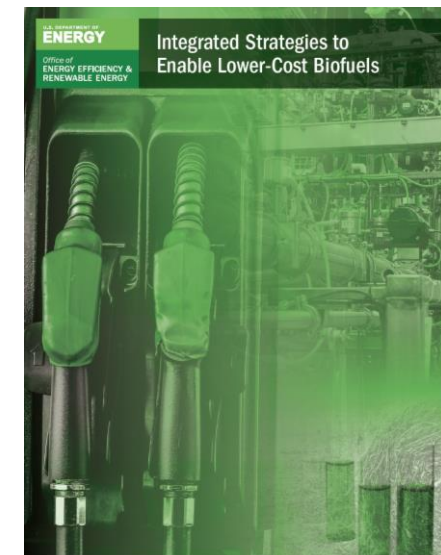
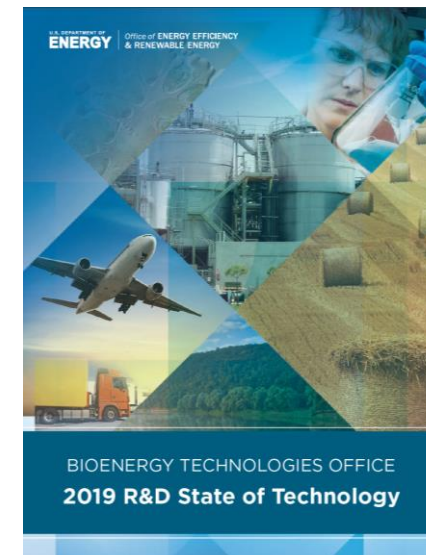
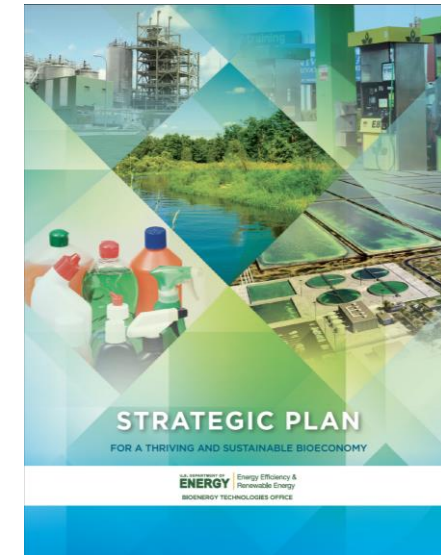
Technology Area Session: Performance-Advantaged Bioproducts,
Bioprocessing Separations, and Plastics

Jennifer B. Dunn, Gregg Beckham, Taraka Dale
Argonne, NREL, LANL

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview

- 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. Biddy 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.

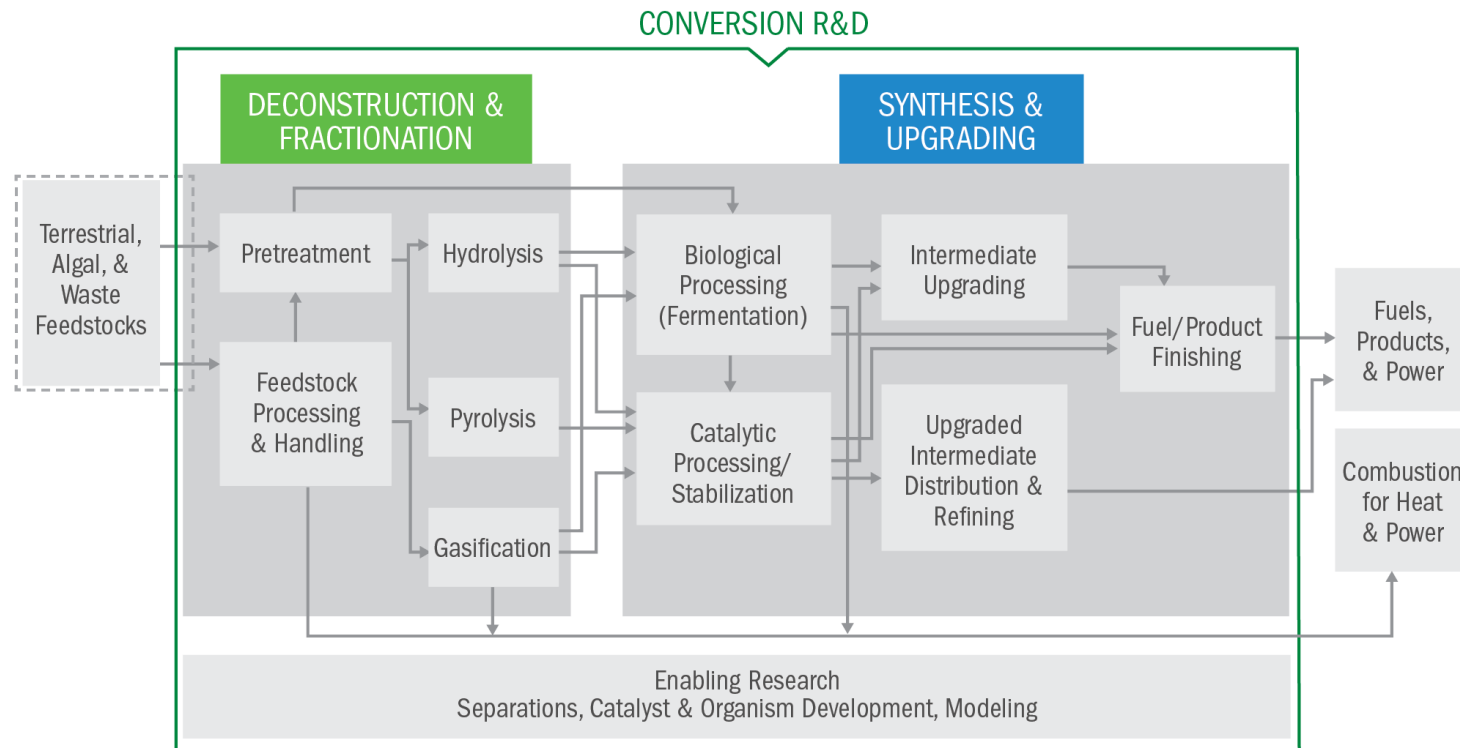
4. EERE. 2019. Bioenergy Technologies Office 2019 R&D State of Technology.

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

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

Bioprocessing Separations Consortium Rationale

- The consortium formed in FY17 to address stakeholder feedback that separations challenges impede the cost-competitive production of biofuels and bioproducts.
- Furthermore, BETO analyses identified separations challenges that, if resolved, could reduce minimum fuel selling price of biofuels by up to 50%-70%.
- All biomass conversion pathways require cost-effective, molecularly-efficient separations.



Bioprocessing Separations Consortium Overview

Importance: Separations often impede cost-effective and sustainable bioprocess development.

Current status: Case-by-case, customized approaches that often treat separations as an afterthought following design of a conversion step leads to energy and water intensive separations processes that are expensive. Bioprocessing separations are often not well-suited to existing separations processes and materials.

Risks: Technologies under development could be more costly than existing approaches, new materials may prove unstable or perform poorly in bioprocessing environments.

Goal: Develop cost-effective, high-performing separations technologies through coordinated separations research that targets industry-relevant bioprocessing separations challenges.

Consortium approach coordinates and brings to bear breadth and depth of national laboratory expertise, capabilities, and resources on this foundational challenge.

1 - Management

Bioenergy Technologies Office

Steering Committee

Advisory Board

Analysis

**R&D-guiding
TEA and LCA**
(E. Tan and C. Freeman)

**Update Assessment
of BETO Separation
Challenges/
Opportunities**
(E. Tan and C. Freeman)

**Computational
Separations**
(V. Glezakou)

BETO Collaborative Projects

**Lignin-Rich Stream
Fractionation
and Purification**
(E. Karp)

**Redox-based
Electrochemical
Separations**
(E. Barry)

**2,3-Butanediol
Separations**
(A. Church)

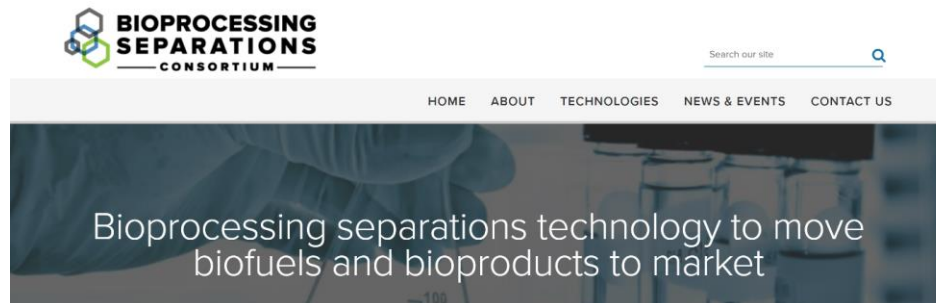
New Capability Development

**Counter
Current
Chromatography**
(E. Karp)

**Volatile
Product
Recovery**
(P. Laible)

Risks and Mitigation

Risk	Mitigation
Tasks not coordinated, duplicative, or not leveraging advances elsewhere in consortium	Monthly full-consortium calls, Regular task-level calls. Example: Analysis Team meets weekly
Tasks not on progress towards milestones, task interdependencies cause unforeseen slow-downs	SmartSheets tool used to monitor interdependencies and progress towards milestones
Technical targets don't account for economic viability, sustainability	Cross-cutting analysis team engages with each R&D team to inform technical targets and economic viability, sustainability using consistent baselines and methods
Tasks use different input streams leading to results that can't be compared	Exemplary streams used across tasks
Team lacks access to project management documents	Box folder used to store common files
Limited interactions with outside stakeholders constrains innovation	External facing website, external events, and interaction with Advisory Board keep Consortium up-to-date on separations challenges



<http://bioesep.org/>

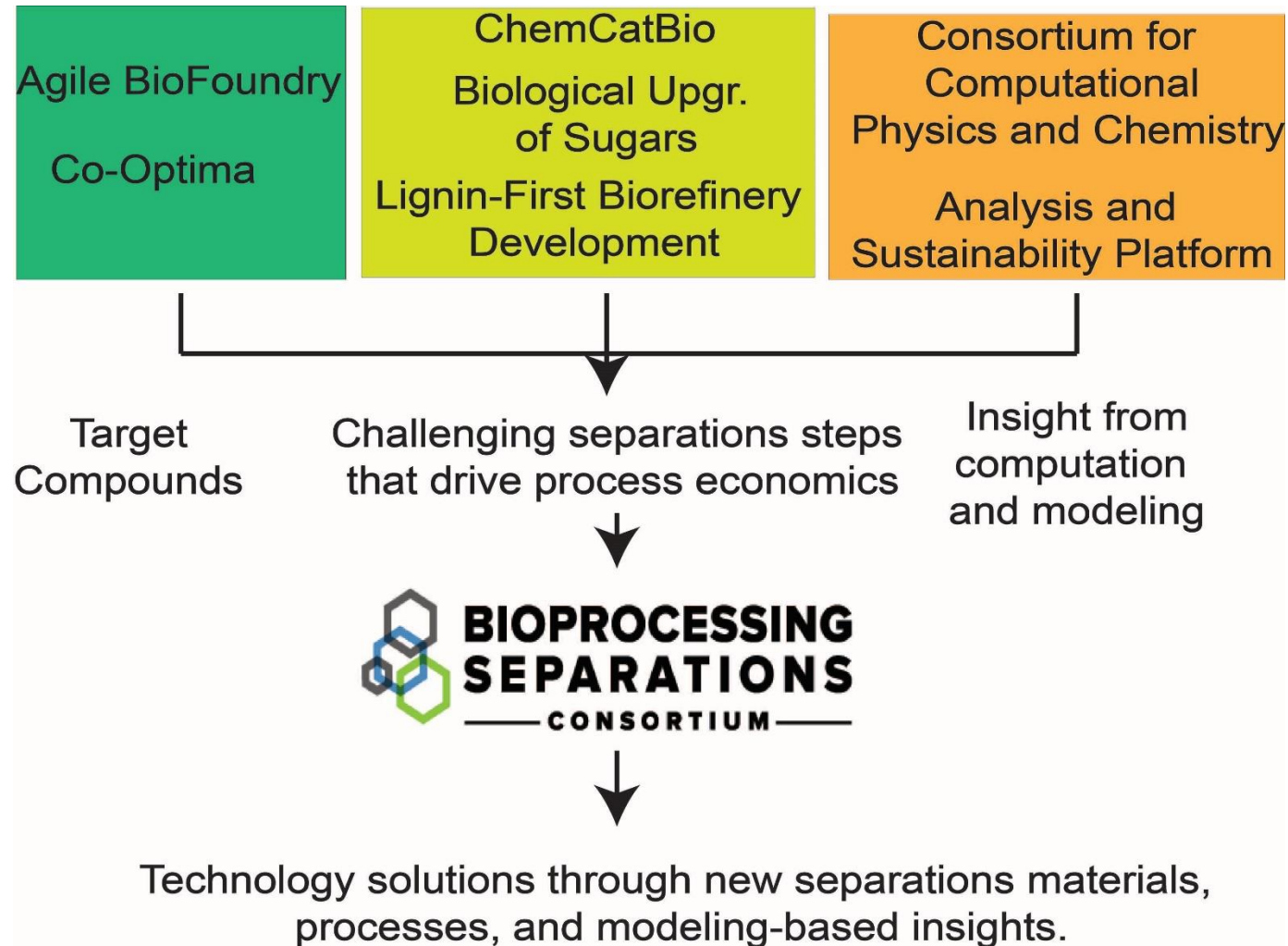
Industrial Advisory Board

- Industrial Advisory Board Interactions
 - Consortium holds biannual face-to-face meetings with IAB
 - IAB receives quarterly reports, publications as pre-reading, and presentations regarding technical progress and future plans
 - Feedback is delivered to consortium steering committee and team leads after a closed-door session.

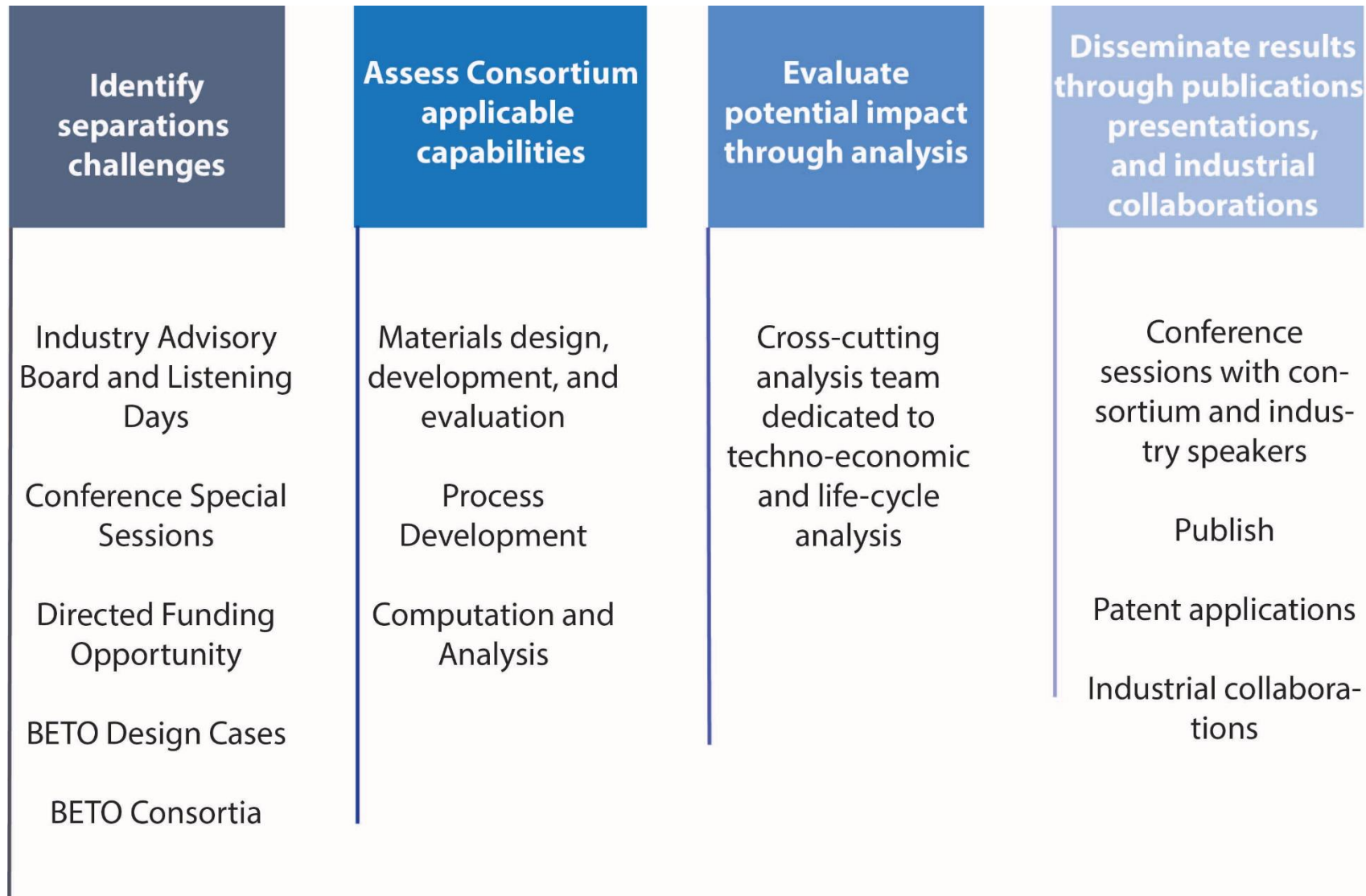


- Industrial Advisory Board Charter
 - Help the consortium maintain an industry-relevant focus and knowledge of recent technology advances and challenges.
 - Provide advice, review results and progress in comparison with work plans, provide feedback regarding prioritization of research projects (experimental and analytical), and inform development of the consortium's strategy for out years.

Interactions with BETO Consortia and Projects



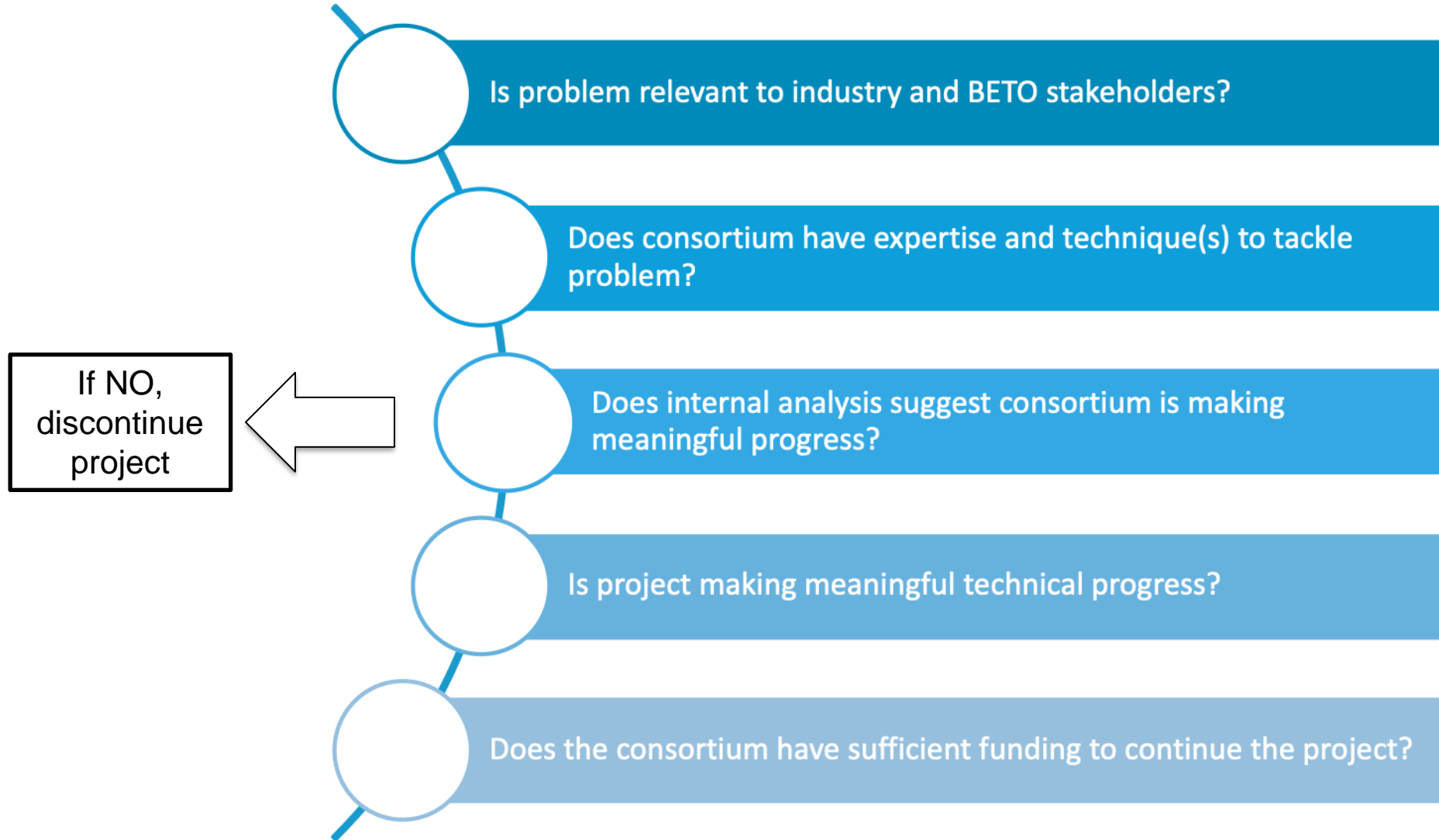
2 - Approach: Portfolio Selection



Portfolio Selection

- FY21 Challenge Stream Task will expand efforts to identify key separation cases from BETO design cases
- From upcoming listening day and interactions with BETO researchers, we will generate a list of challenge streams
- Generic separations solutions for each stream will be evaluated considering first principles thermodynamics and high-level techno-economic analysis
- **Goal: Identify possible paths for inclusion in portfolio that will reduce the minimum fuel/chemical selling price by 20% relative to BETO state of technology models or other known baseline estimates.**

Go/No-Go Decisions



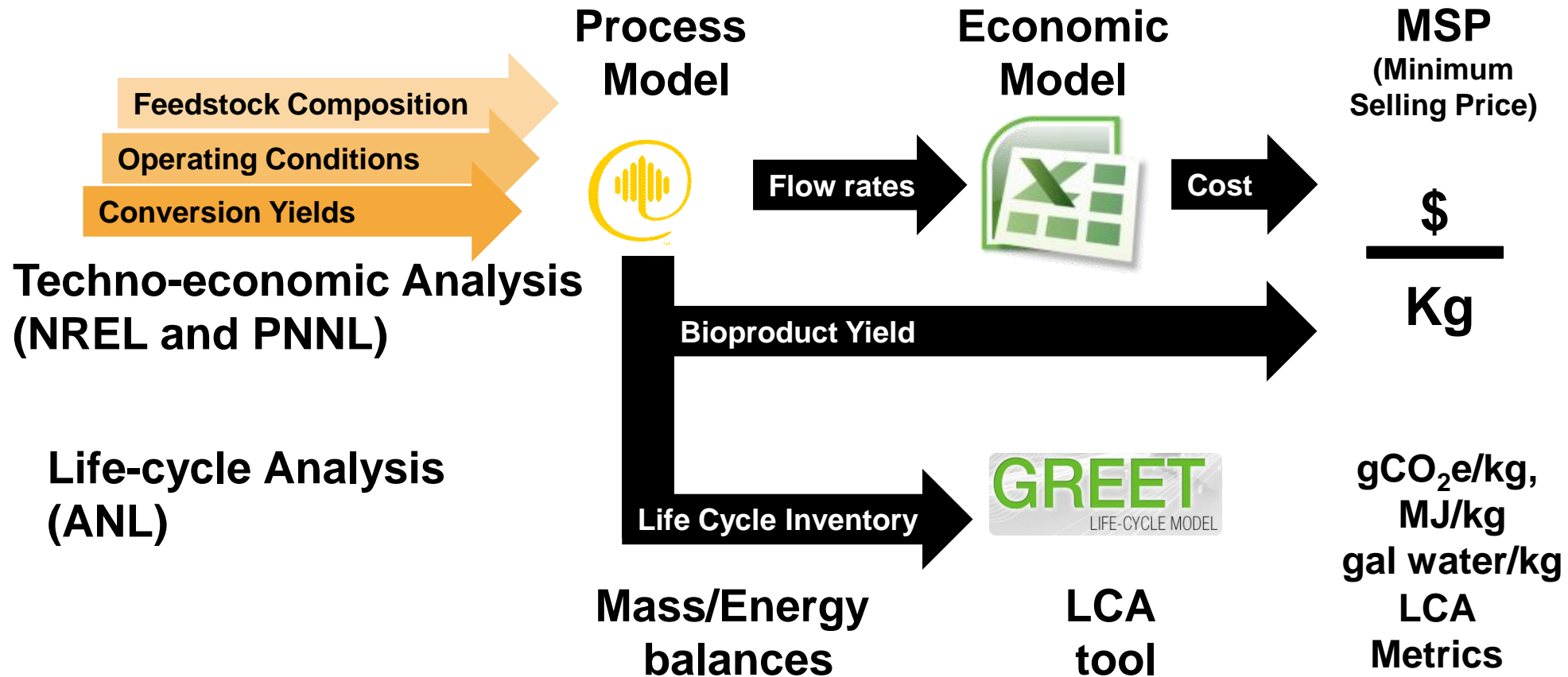
Challenges

- Bioprocessing separations challenges are diverse and wide-ranging
 - We have developed and are expanding a method to screen and prioritize multiple possible projects
- Baselines are not always available; process models and accompanying economic and sustainability analyses must be built
 - We increased investment in analysis to enable clear baselines and detailed modeling and analysis
- Staying up-to-date with separations challenges
 - The Consortium's Industrial Advisory Board and participation in and leading of conference sessions keeps Consortium members up-to-date with separations challenges
 - Interaction with other BETO projects informs knowledge of challenges

Integrated Analysis Technical Approach

Assess technical, economic, & environmental feasibility of bioproduct/biofuel conversion processes:

- Detailed process analysis with rigorous mass and energy balances
- Identified data needs and further R&D need to improve overall cost and efficiency
- Assess environmental impacts (greenhouse gas emissions, fossil fuel and water consumption)
- Approach is consistent with other DOE BETO sponsored analyses



Analysis Plans Guide Consistent, Transparent Analysis Across Consortium

Key Elements in Each Plan:

- Technology/project description
- Baseline comparison technology
- Initial process(es) for techno-economic (TEA) and life cycle analysis (LCA) evaluations
- Data needs for TEA/LCA
- Methodology/approach for TEA/LCA
- Task schedule
- Technical comments (including those from IAB) that need to be tracked and ultimately addressed

Important Points:

- Plans are iterative and require ongoing communication with experimentalists
- Each analysis is independent of experimental work to provide objective evaluations

Analysis is integrated into all task presentations and, when applicable, so is computation/theory

3 – Impact: Disseminating Results from FY17-FY19



Technical Advances,
Process Economics Influence,
and State of the Science



Report
featured
on
BETO's
blog

Technology	Challenges Addressed					Capabilities Applied			
	BC	TC	Lignin Fractionation	Process Intensification	Dilute C Recovery	Inhibitor Removal	Materials	Processes	Analysis & Computation
HED-ISPR	X			X				X	X
EDI-ISPR	X			X			X	X	X
EDI	X	X			X	X	X	X	X
Ultrasonic	X		X					X	X
Pervaporation	X			X	X			X	
Distillation (membrane)	X				X			X	
Polymeric membranes	X		X		X			X	
Ceramic membranes	X		X					X	
Simulated moving bed	X				X			X	
Catalytic gas hot filtration		X		X		X	X	X	X
Adsorbents	X	X			X	X	X	X	X

Consortium-wide:

9 journal articles

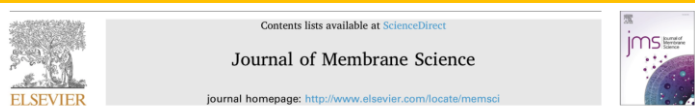
1 technical report

3 patents filed or pending since 2019

Publications in the Consortium

In addition to the technical report, publications and patents include

- 9 journal publications + 3 patent applications or patents filed
- Separation technologies: adsorption, extraction-distillation, membranes, catalytic hot gas filtration, capacitive deionization, electrodeionization, and counter current chromatography
- Separation applications: Product separation and recovery, impurity/foulant removal, new material development
- Cross-cutting computational modeling
- Additional journal articles and patents in progress



Atomic scale understanding of organic anion separations using ion-exchange resins

Difan Zhang^a, Pradeep Gurunathan^a, Lauren Valentino^b, Yupo Lin^b, Roger Rousseau^a, Vanda Glezakou^{a*}

Experimental and computational collaboration, cross-institutional



Capacitive deionization using carbon derived from an array of zeolitic-imidazolite frameworks

Hao Wang^{a,d}, Louis Edaño^b, Lauren Valentino^b, Yupo J. Lin^{b,*}, Varada Menon Palakkal^b, Dong-Li Hu^c, Biao-Hua Chen^d, Di-Jia Liu^{b,*}



Catalytic Hot-Gas Filtration with a Supported Heteropolyacid Catalyst for Preconditioning Biomass Pyrolysis Vapors

Braden Peterson,^{a,*} Chaiwat Engtrakul,^{a,*} A. Nolan Wilson,[†] Stefano Dell'Orco,^{§,||} Kellene A. Orton,[†] Steve Deutch,[†] Matthew M. Yung,[†] Anne K. Starace,[†] Yves Parent,[†] David Chiamonti,^{§,||} and Kimberly A. Magrini[†]

Green Chemistry

PAPER

Check for updates

Cite this: *Green Chem.*, 2019, 21, 5306

In situ product recovery of bio-based ethyl esters via hybrid extraction-distillation[†]

Patrick O. Saboe, Hanna R. Monroe, William E. Michener, Lorenz P. Manker,[‡] Stefan J. Haugen, Gregg T. Beckham[‡] and Eric M. Karp^{‡,*}



Short communication

Selective adsorption removal of carbonyl molecular foulants from real fast pyrolysis bio-oils^{*}

Aimee L. Church^{a,†}, Michael Z. Hu^{b,*}, Suh-Jane Lee^b, Huamin Wang^{b,*}, Jian Liu^b



Novel porous ceramic tube-supported polymer layer membranes for acetic acid/water separation by pervaporation dewatering

Mi Lu, Michael Z. Hu^{*}

MSDE

PAPER

Check for updates

Cite this: DOI: 10.1039/c9me00179d

Promoting water-splitting in Janus bipolar ion-exchange resin wafers for electrodeionization[†]

Matthew L. Jordan,^{‡,*} Lauren Valentino,^{‡,§} Nargiza Nazrynbekova,^{‡,§} Varada Menon Palakkal,^{‡,§} Subarna Kole,^{‡,§} Deeptra Bhattacharya,^{‡,§} Yupo J. Lin^{‡,§} and Christopher G. Arges^{‡,*}

npj | Clean Water

www.nature.com/npjcleanwater

ARTICLE OPEN

Advancing electrodeionization with conductive ionomer binders that immobilize ion-exchange resin particles into porous wafer substrates

Varada Menon Palakkal^{‡,§}, Lauren Valentino^{‡,§}, Qi Lei[‡], Subarna Kole[‡], Yupo J. Lin^{‡,§} and Christopher G. Arges^{‡,§}

Conference Symposium



Bioprocessing Separations: Advancing a Research Agenda

18 abstract submissions from industry, academia, and internationally

To be followed by a Listening Day to gather detailed feedback from industrial stakeholders in summer 2021.

Directed Funding Opportunity

- **Goal:** Accelerate the development of separations technologies for the commercialization of biomass-derived fuels and chemicals through engaging with industry to overcome their most pressing bioprocessing separations challenges and leveraging Separations Consortium capabilities and expertise
- **Approach:** Conference calls with interested applicants to review industry needs, consortium capabilities and to identify partners
- **Result:** \$2.4 million in federal funds requested (>2x over subscription). Five \$200k federal fund projects awarded
- **Outcome:** Opportunity for industry to test BETO funded separations technologies/validate that these technologies have promise

DFO projects covered diverse feedstocks and products

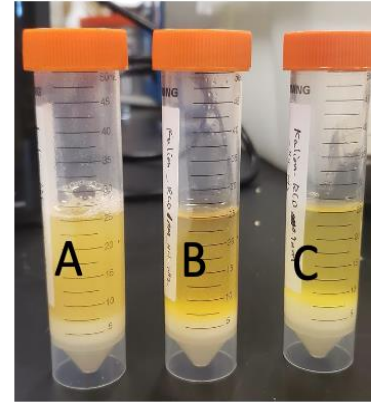
Company	Waste/gas feedstock	Cellulosic sugar feedstock	Product	Lab(s)
Visolis		X	Mevalonic acid	ANL, LBNL
Kalion		X	Glucaric acid	ORNL, LBNL, ANL, NREL
Mango Materials	Biogas		Polyhydroxyalkanoates from methanotrophs	LBNL
DMC Biotechnologies		X	Farnesene, liquid hydrocarbons	ANL, LBNL
HelioBioSys	Atmospheric CO ₂		Expandable Polystyrene from cyanobacterial consortium	LBNL, SNL, LANL

DFO projects derisked separations step for partners

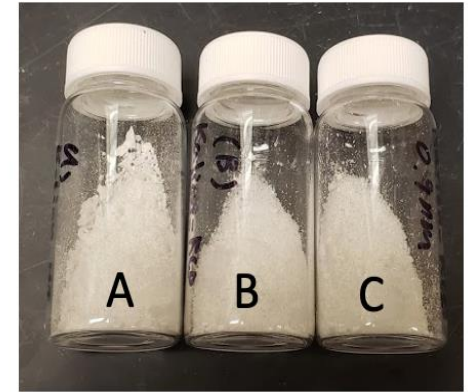
De-risked separations step for Kalion. Trialed crystallization, pervaporation, electrodeionization, and adsorption to separate glucaric acid from fermentation broth.

Scaled up Mango Materials' chemical treatment process from mL to 100 L scale by assessing filter press and tangential flow filtration. Kilograms of product were produced for testing.

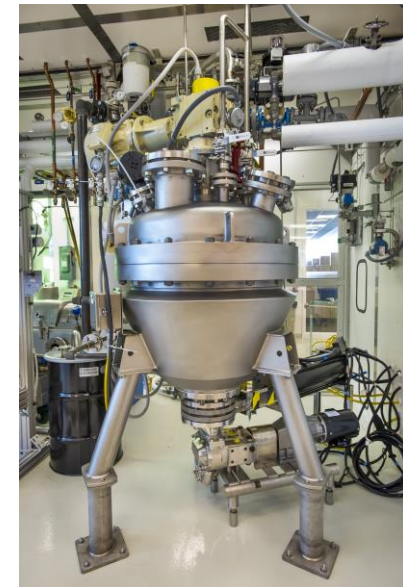
Broth samples



K-glucarate crystals



210 L Andritz reactor



4 - Steering Committee Objectives and Achievements

Objectives

- **Consortium guidance:** Lead discussions on technical direction, external engagement
- **Progress and impact monitoring:** Evaluate milestone status, risks affecting projects in the portfolio
- **Coordinate external communications:** Interactions with Industrial Advisory Board, establish and maintain website
- **Manage consortium business:** Reporting, monthly conference calls

Achievements

- Coordinate interaction with Industrial Advisory Board and coordinate board communications and meetings
- Planning industrial listening day and symposium at ACS Green Chemistry & Engineering Conference
- Maintain website to communicate consortium capabilities, progress
- Coordinated Directed Funding Opportunity
- Managed consortium reporting and monthly communications
- Led writing and release of three-year overview report

Quad Chart Overview

Timeline

- Project start date: October 2019
- Project end date: September 2022

	FY20-22	Active Project
DOE Funding	(10/01/2019 – 9/30/2022)	\$10,425,000 <i>ANL: \$3,200,000</i> <i>LANL: \$486,000</i> <i>LBNL: \$1,130,000</i> <i>NREL: \$2,929,000</i> <i>ORNL: \$810,000</i> <i>PNNL: \$1,820,000</i>

Project Partners

- ANL
- LANL
- LBNL
- NREL
- ORNL
- PNNL

Barriers addressed

Ot-B: Cost of production
Ct-O: Selective separations of organic species
Ct-D: Advanced bioprocess development

Project Goal

The goal of the Consortium is to develop cost-effective, high-performing separations technologies, through coordinated research at the national laboratories that targets challenges relevant to industry and BETO's priority pathways.

End of Project Milestone

Technical goals will be covered in each subtask presentation.

The overall end of project milestone is to demonstrate the Consortium's value to BETO and the biofuel and bioproduct communities through documentation of technical advances, influence on process economics, and potential industrial applications of Consortium technologies.

Funding Mechanism

Merit-reviewed AOP-based Consortium

Quad Chart Overview - Analysis

Timeline

- Project start date: October 2019
- Project end date: September 2022

	FY20-22	Active Project
DOE Funding	(10/01/2019 – 9/30/2022)	\$3,125,000 <i>ANL: \$565,000</i> <i>LANL: \$300,000</i> <i>NREL: \$890,000</i> <i>PNNL: \$1,370,000</i>

Project Partners

- ANL
- LANL
- NREL
- PNNL

Barriers addressed

Ot-B: Cost of production
Ct-O: Selective separations of organic species
Ct-D: Advanced bioprocess development

Project Goal

The goal of this task is to inform research direction and go/no-go decisions by identifying the separations challenges that most influence the cost and sustainability of producing fuels in BETO priority pathways. The cross-cutting computational task applies modeling to assist in the down selection and optimization of material properties.

End of Project Milestone

Complete TEA and LCA for all projects in Consortium and document results.

Complete the revised separations challenge stream analysis, identifying top streams based on the economic potential of effective product separation. Submit as a final report or journal manuscript.

Funding Mechanism

Merit-reviewed AOP-based Consortium

Summary

Management	Coordinate research portfolio among Bioprocessing Separations Consortium technical teams through monthly meetings, file sharing, and project management tool.
Approach	<ul style="list-style-type: none">• Select consortium projects based on understanding of BETO and industry needs• Use economic and sustainability analysis as guiding tools in project evaluation and selection• Interact with internal and external stakeholders to achieve impactful project portfolio, disseminate results
Impact	Provide leadership to consortium to support task leads in their accomplishments of objectives, oversee directed funding opportunity. Disseminate results through publications, conferences, and outreach to industrial stakeholders. Combined impact of the Consortium includes new materials and processes to lower bioprocessing costs towards BETO targets and, more generally, for industrial stakeholders, as borne out by analysis.
Progress	<ul style="list-style-type: none">• Industry interaction- Met with industrial advisory board biannually, released capstone report to disseminate progress from first three years, and conducted directed funding opportunity. Listening day planned for summer 2021• Communications - Website highlights and provides detail concerning consortium capabilities. ACS Green Chemistry and Engineering Symposium will be held in June• Consortium organization – Coordinate intra-consortium planning, communications and reporting

Questions



Additional Slides

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