U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Bioprocessing Separations Consortium

Directed Funding Opportunity Industry CRADAs

Bioenergy Technologies Office Peer Review

March 4, 2019

Denver, Colorado

Presented by Todd Pray, Lawrence Berkeley National Laboratory

CRADA National Lab PIs:

- Jim Coons, Los Alamos
- Ryan Davis, Sandia
- Michael Hu, Oak Ridge
- Eric Karp, NREL
- Phil Laible, Argonne
- YuPo Lin, Argonne
- Ning Sun, Berkeley
- Eric Sundstrom, Berkeley

Quad Chart Overview

Timeline

- Project start: 10/1/2018
- Project end: 9/30/2019
- Percent complete: 5%

	Total Costs Pre FY17**	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded				$1 million
Project Cost Share*				$0.44 million

•**Lab funding distribution: ANL 35%, LANL 6.5%, LBNL 40%, NREL 6%, ORNL 6%, SNL 6.5%**

•**Cost-share partners:** DMC Biotech, HelioBioSys, Kalion, Mango Materials, Visolis

Barriers addressed

Ot-B: Cost of Production. Advanced and robust separations and molecular efficiency are required to reduce the up to 50% share of separations costs in bioprocesses.

Objective

Develop cost-effective, high-performing separations technologies through coordinated separations research that targets challenges relevant to industry and BETO.

End of CRADA Project Goal

Accelerate the development of each company's separations technologies for the commercialization of biomass-derived fuels, chemicals and materials.

Visolis (Lin, ANL)
DMC (Laible, ANL)
Mango Materials (Sun, LBNL)
HelioBioSys (Sundstrom, LBNL)
Kalion (Hu, ORNL)

Section 1: Project Overview

Separations Consortium Project Overview

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

Outcome: Biofuels and bioproducts industries will have new, high-performing, low-cost separations technologies available to them.

Relevance to Industry: BETO industrial stakeholders have long raised separations challenges as a major barrier to cost competitive biofuels and bioproducts. BETO analyses indicate that separations steps can constitute up to 50% of processing costs.

Directed Funding Opportunity for Industry CRADAs

- **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:*** The consortium oversaw a directed funding opportunity for industrial partners to develop new approaches and technologies for bioprocess separations
- ***Details:*** **$1M** to be made available to the National Labs to collaborate with industrial partners. Projects limited to 2 years and $200k federal funds per project (≥30% cost-share).

Companies selected and collaborating Labs

DMC

Visolis
CARBON NEGATIVE MATERIALS

Kalion, Inc.

Mango Materials

HelioBioSys, Inc.

Argonne NATIONAL LABORATORY

BERKELEY LAB

Argonne NATIONAL LABORATORY

BERKELEY LAB

Oak Ridge National Laboratory

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Argonne NATIONAL LABORATORY

BERKELEY LAB

BERKELEY LAB

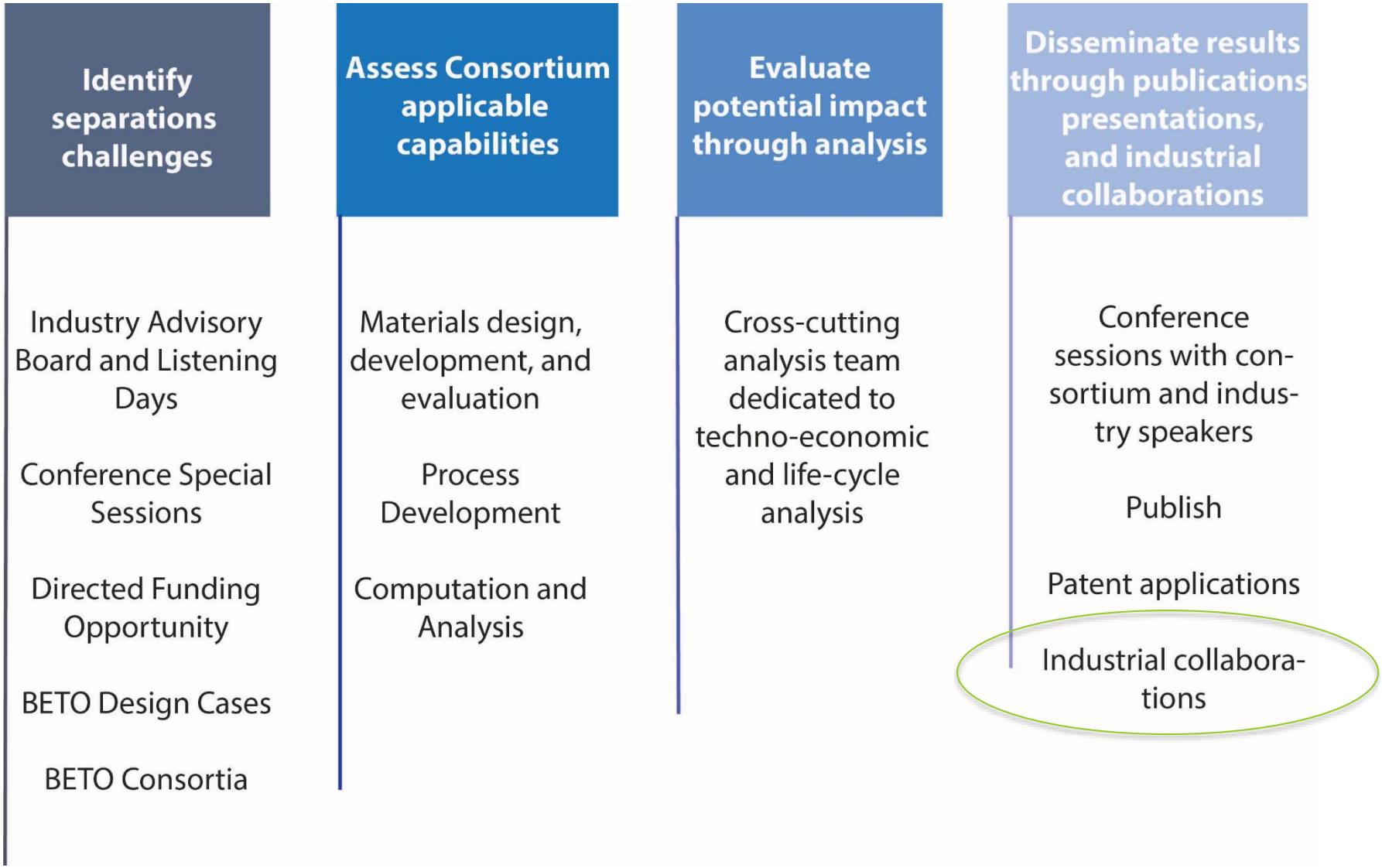
Sandia National Laboratories

Los Alamos NATIONAL LABORATORY

12 proposals submitted and reviewed by panel of subject matter experts

Section 2: Management Approach

1 - How does the Consortium choose projects?



Solicitation and Selection Process

- Speed Dating teleconference between each company and all Labs
- Each proposal was reviewed by 5 external subject matter experts from industry, consulting, or academia who signed conflict of interest statements
  - Proposals were scored based on the following criteria:
    - Challenges Addressed and Research Approach (30%)
    - Impact of Proposed Research on the Biofuels and Bioproducts Industry (25%)
    - Benefit to Bioprocessing Community (10%)
    - Key Personnel, Resources, and SepCon Capabilities (20%)
    - Requested Budget, Milestones, and Appropriateness of Gov't Funding (15%)
- Separations Consortium Steering Committee to make selections:
  - Topic area diversity
  - Capability diversity
  - Relationship to existing AOP work
  - National lab diversity
  - Collaborative projects across NLs
  - Industry partner diversity

Five CRADA projects span range of feedstocks and projects relevant to BETO and industry

Company	Feedstock	Separations	Product
Visolis	Cellulosic Sugar	RW-EDI, wiped film distillation	Hydroxyacid (PM1)
Kalion	Cellulosic Sugar	pervaporation, RW-EDI, nano-adsorbents	Glucaric acid
Mango Materials	Biogas	Tangential Flow Filtration	PHAs from methanotrophs
DMC Biotechnologies	Cellulosic Sugar	Nano-adsorbents	Farnesene, liquid hydrocarbons
HelioBioSys	Atmospheric CO_2	Ultrasonic Separations	Extracellular polysaccharides from cyanobacterial consortium

Management approach moving forward

- Steering committee to monitor progress toward milestones of each DFO project and report to BETO on a regular basis
- DFO project PIs will present key results to broader team for input and feedback
- DFO workshop and additional industry listening day(s) to be planned in the future around SepCon team meetings to raise awareness of project outcomes and chart out next steps

Section 3: Technical Progress and Accomplishments (selected project summary)

Visolis: Two-step process to pure hydroxyacid product

Goal:

- Develop a novel process with limited steps for the separation of a biologically-derived PM1 to a purity level that avoids poisoning of downstream catalyst

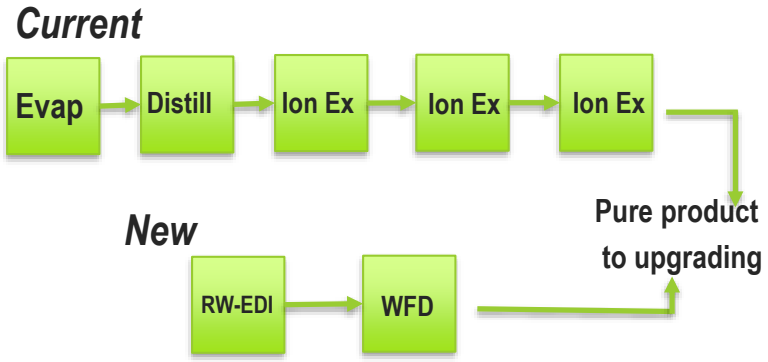
Approach:

- Use resin wafer electrodeionization (RW-EDI) to separate and concentrate the hydroxyacid product from fermentation broth, followed by wiped film distillation (WFD)
- WFD feed will be relatively pure, free of salts and fermentation residues, necessitating only one pass to remove water and a second pass to distill the hydroxyacid.

Capability Leveraged:

- RW-EDI at ANL
- WFD at LBNL / ABPDU

VISOLIS
CARBON NEGATIVE MATERIALS



Kalion: Water removal strategy development

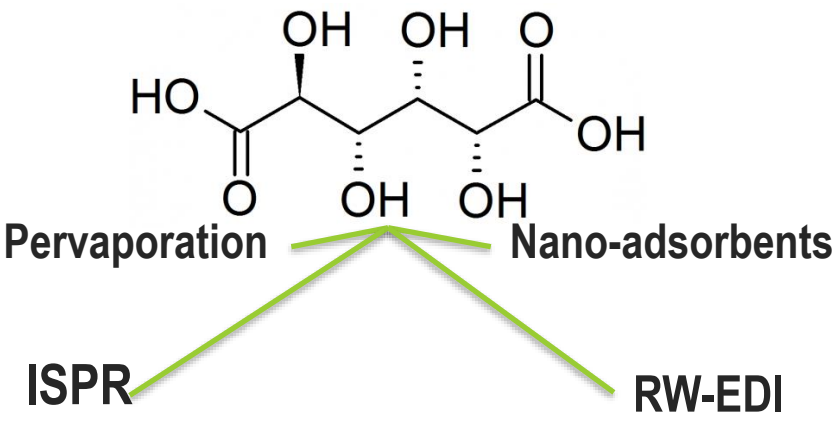
Goal:

- Develop novel, low-cost means of water removal in Kalion's glucarate/glucaric acid purification process

Approach:

- Survey four novel technologies to find the most applicable for Kalion's process : pervaporation, RW-EDI, in-situ product recovery through solvent extraction, functionalized nano-adsorbents
- Demonstrate proof-of-concept using authentic fermentation broth

KALION, INC.



Capability Leveraged:

- HiPAS (ORNL)
- RW-EDI (ANL)
- ISPR (NREL)
- Nano-adsorbents (ANL)

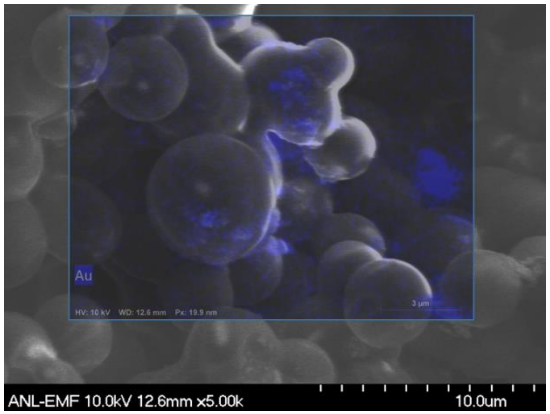
DMC Biotechnologies: At-scale demonstration of in-situ product recovery with nano-adsorbents

Goal:

- Demonstrate the use of novel materials to continuously adsorb liquid hydrocarbons from culture as they are produced by microbial fermentation

Approach:

- Screen potential adsorbents under bioreactor conditions at laboratory scale
- Scale up the continuous adsorption recovery process to 300-liter scale, directly compare adsorptive recovery to traditional separation approaches
- Develop an integrated TEA



Example functionalized nanoadsorbent

Capability Leveraged:

- Nanoadsorbents at ANL
- ABPDU pilot processing at LBNL

Mango Materials: Advancing Downstream Processing of Biopolymers from Methane

Goal:

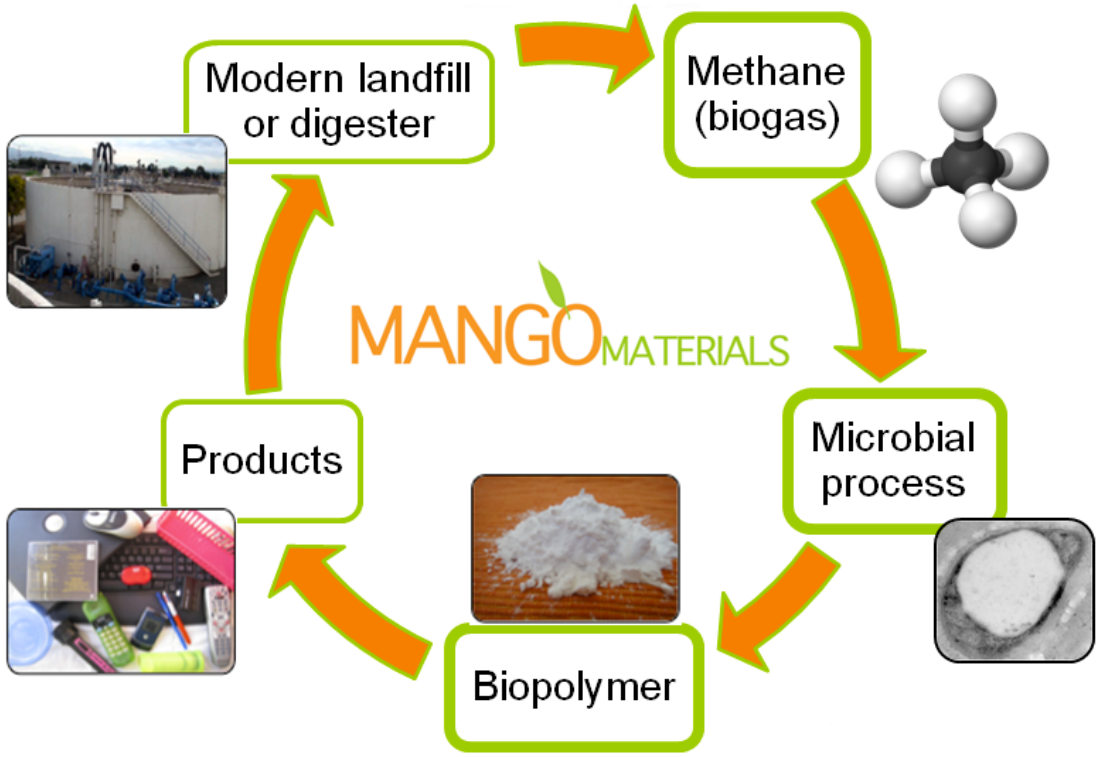
- Verify a platform technology and process configuration to convert methane gas into a biodegradable biopolymer using microbial fermentation.

Approach:

- Utilize the unique testing capabilities and facilities of the Separations Consortium to optimize separations operations using tangential flow filtration (TFF) and decanter centrifugation for PHA recovery from methanotrophs.

Capability Leveraged:

- Filtration and centrifugation at LBNL



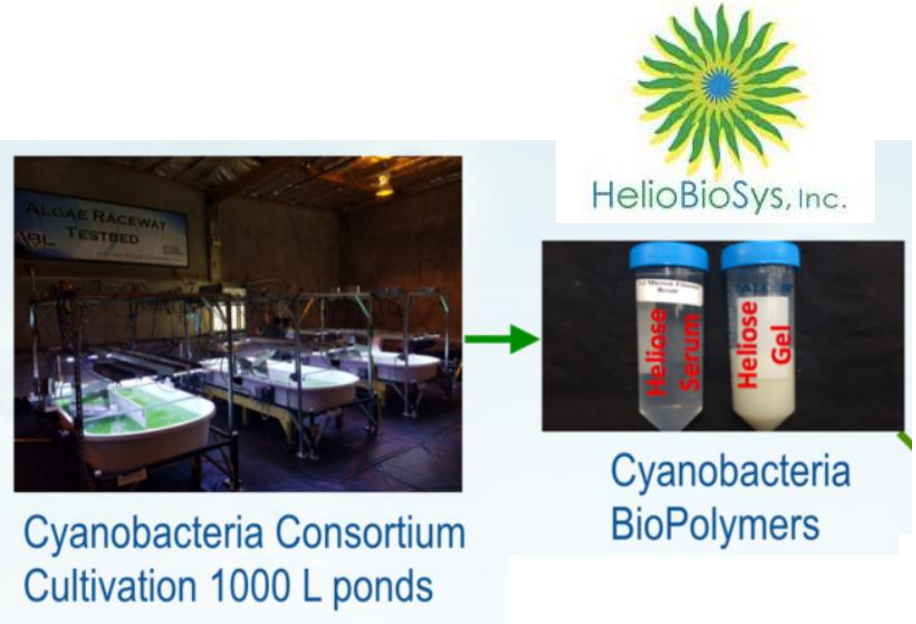
HelioBioSys: Biomass separation, biopolymer concentration and salt removal from a marine cyanobacterial culture

Goal:

- Design of an integrated system with the lowest possible capital and operational costs for cultivation and downstream processing of cyanobacterial EPS.

Approach:

- Test ultrasonic separation and membrane-based filtration for biomass removal, EPS concentration, and desalting and apply the data as inputs for techno-economic analysis (TEA) based on comparisons of the DSP technologies.



Capability Leveraged:

- Cyanobacterial cultivation (SNL)
- Ultrasonic separations (LANL)
- Membrane-based filtration; tangential flow filtration (LBNL)

Section 4: Relevance

4 – Overall Separations Consortium Relevance

- The goal of this project is to develop cost-effective, high-performing separations technologies through coordinated separations research that **targets challenges relevant to industry** and BETO.
- The project develops new materials and processes to lower bioprocessing costs towards BETO targets and, more generally, **for industrial stakeholders**, as borne out by analysis. It therefore directly addresses BETO's mission to develop and transform renewable biomass resources into commercially viable biofuels.
- **Industrial stakeholders** and the Industrial Advisory Board continue to reiterate the challenging nature of bioprocessing separations and the need for this consortium.
- Success of the consortium will elevate and enable strategic incorporation of cost-effective, efficient separations in bioprocessing at the initial stages of process design.

Five CRADA projects span range of feedstocks and projects relevant to BETO and industry

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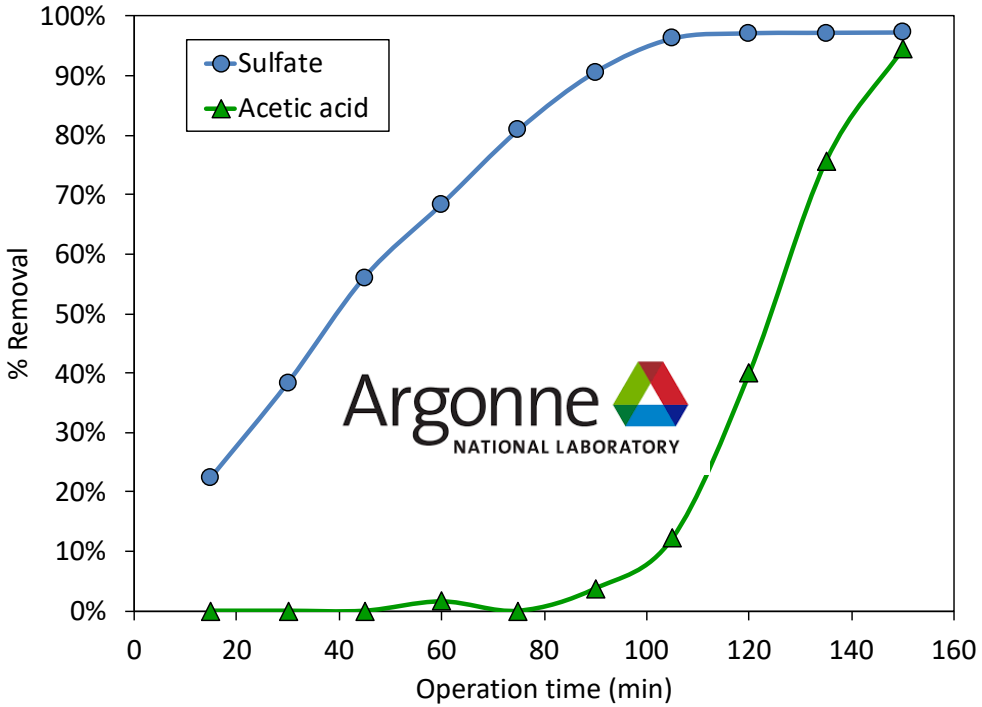
Section 5: Future work

5 – Future Work

- Potential for additional rounds of DFO CRADA solicitation(s) following FY20 merit review
- Extension or expansion of current DFO projects to leverage additional Lab capabilities to address new challenges and larger scales?
- Deliver on technical targets and milestones with our industry partners (see following slides)

Process optimization and integration from RW-EDI to wiped-film evaporation for hydroxyacid recovery / purification

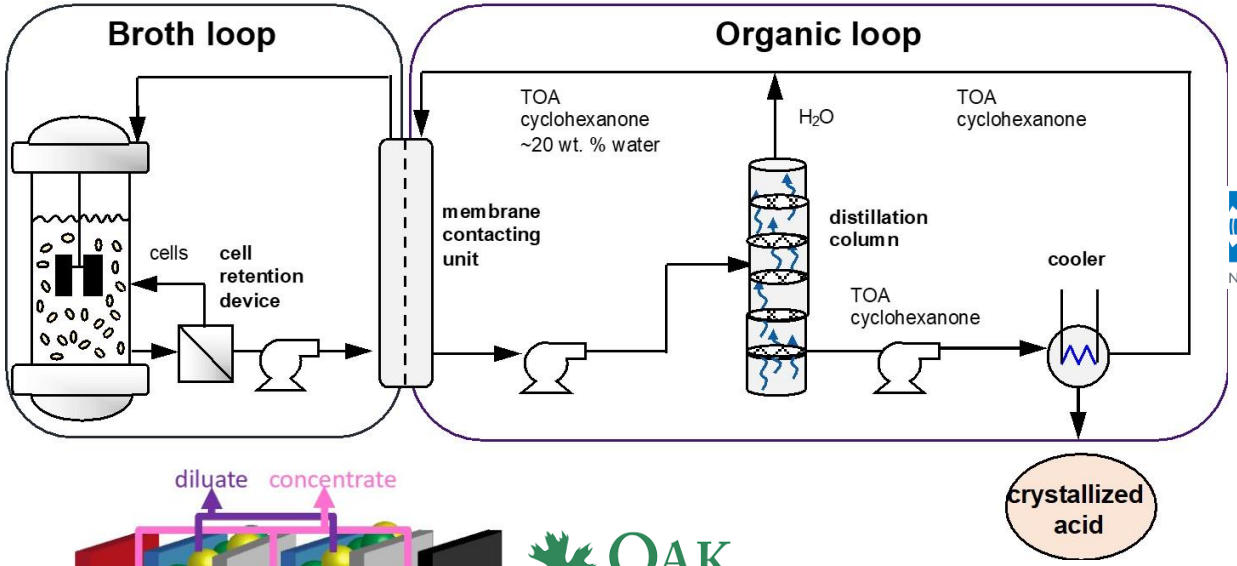


Demonstration of sulfate – acetic acid separation using RW-EDI at ANL

Purification of carboxylic acids from mixed broth at ABPDU using wiped-film evaporation

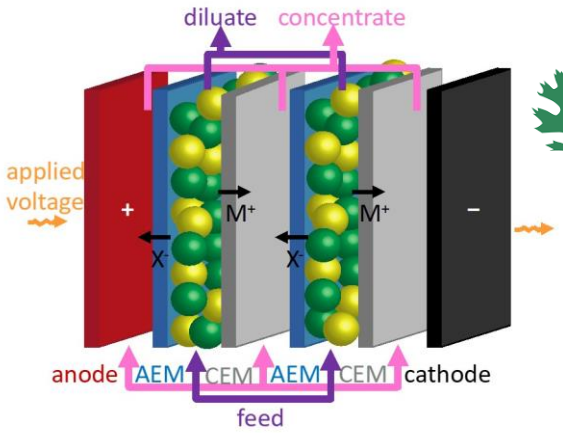
Overall objective: Determine the efficiency and viability of extracting product from the fermentation broth while minimizing the ionic contaminants in the captured aqueous stream

Coupling extractive fermentation with HiPas, RW-EDI, adsorbents



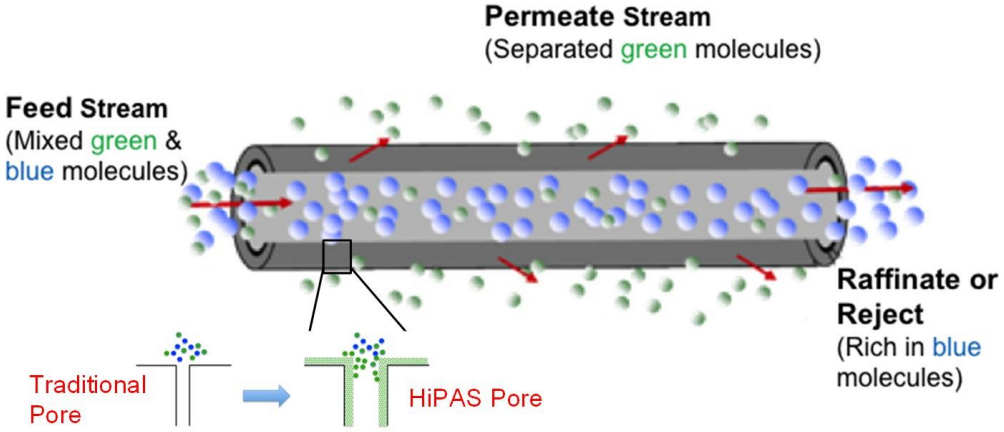
KALION, INC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



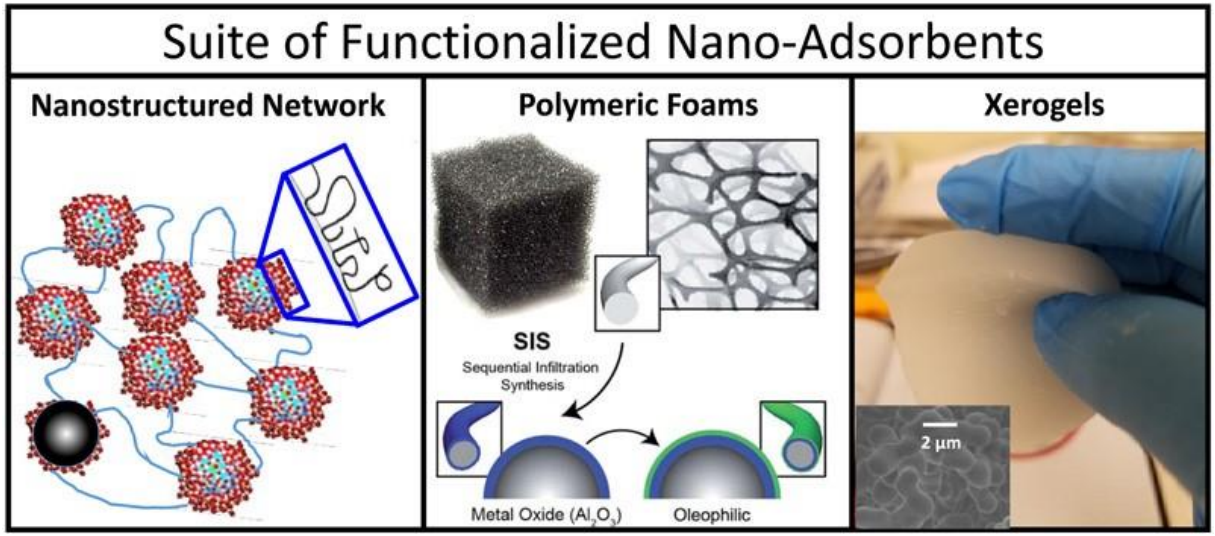
OAK RIDGE National Laboratory

Argonne NATIONAL LABORATORY



Goal: This project aims to develop novel, low-cost means of water removal in Kalion's glucarate/glucaric acid purification process.

Scaling and deploying ANL Adsorbents at LBNL



Argonne NATIONAL LABORATORY

BERKELEY LAB

Goal: Maximize production of high-value terpenoids from microbial fermentations through an adsorptive product recovery process

Optimizing and scaling filtration and centrifugation for PHA recovery

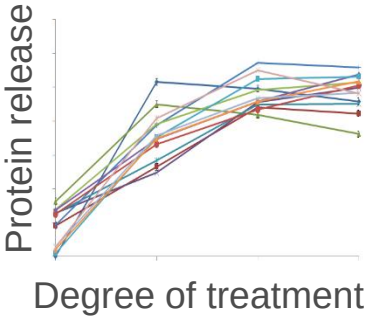
BERKELEY LAB

MANGO MATERIALS

De-watering → **Mechanical separation** → **PHA-rich product** → **Biopolymer product**

Increased rate of de-watering by 5x → from 8 to 1.5 hours for a 500L batch

Protein released demonstrated cell lysis



>95% purity

Met internal quality control standards for pure product

Goal: To dewater lysed cells and recover the biopolymer, polyhydroxyalkanoate (PHA), using industrial relevant equipment to help MM reach commercial scale production

Verification and scaling of cultivation, recovery and dewatering

1000L raceway ponds for cyanobacteria cultivation

Sandia National Laboratories

Disc stack centrifugation

BERKELEY LAB

Continuous flow ultrasonic separation

Los Alamos NATIONAL LABORATORY

Goal: To develop a cost-effective and efficient protocol for separation and purification of extracellular polysaccharides from marine cyanobacterial culture broth

HelioBioSys, Inc.

Summary

Summary

Overview – The DFO projects' key objectives are to accelerate the development of separations technologies for the commercialization of biomass-derived fuels and chemicals through engaging with industry.

Management approach – The SepCon steering committee and BETO solicited several proposals in an open call, and used external merit reviewers and a robust internal process to select awardees.

Progress – 5 industry partners were selected, and CRADA contracting is well underway. A subset of the projects are commencing as of Peer Review.

Relevance – Biomass and waste gas feedstocks will be converted into biomaterials and bio-based chemicals that are relevant to both BETO and the companies involved.

Future work – Detailed workplans and milestone schedules have been incorporated into all the projects' CRADAs. Check out the posters!