DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Integrated Biorefinery for Chemicals and Fuels Production from Waste Biomass

3/9/2021
Organic Waste Session

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Presentation Outline

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Waste-to-Products Vision

Conversion of Waste Biomass to High-Value Chemicals & Fuels

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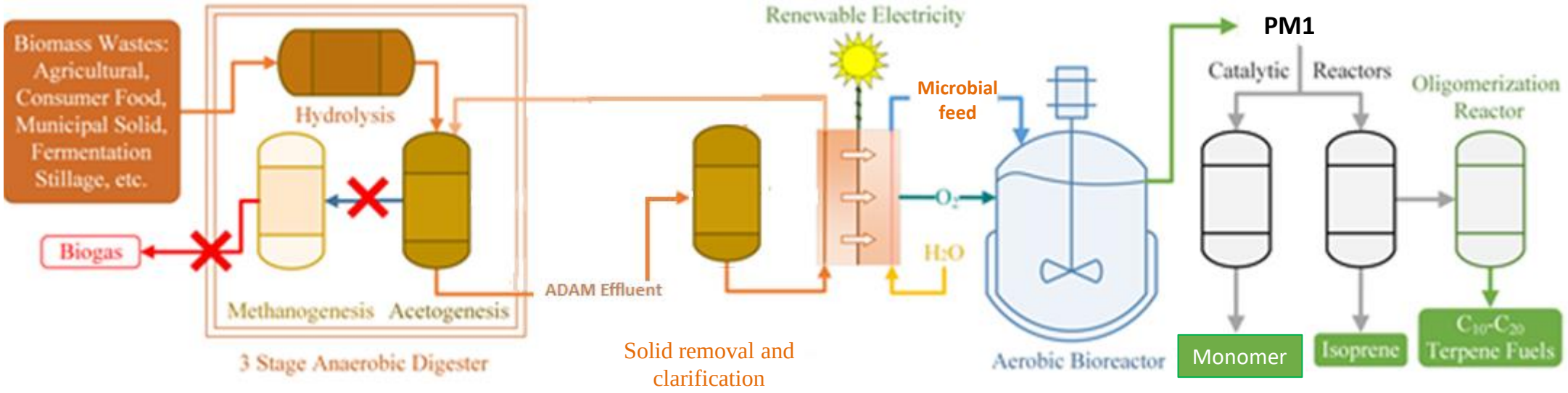
Hybrid Processes: Modular & Scalable Renewable Chemicals Production



Fermentation

- Efficient biological pathway
- Production at high titer and yield
- Platform Molecule I is a poly-functional, non-toxic, stable liquid at room temperature
- It is extracellular, simplifying recovery

Catalytic Conversion

- Cheap and efficient catalysis
- Products produced at high selectivity (>90%) and ~100% conversion, simplifying recovery
- Decouples production of flammable products that may be incompatible with aerobic fermentation

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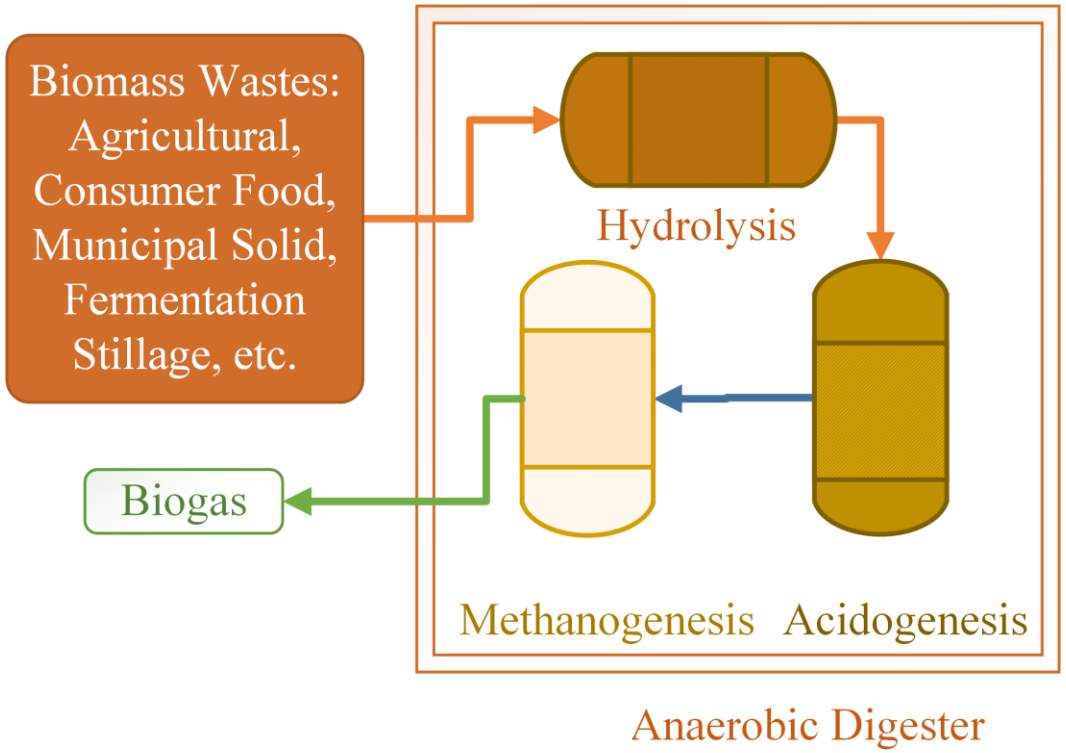
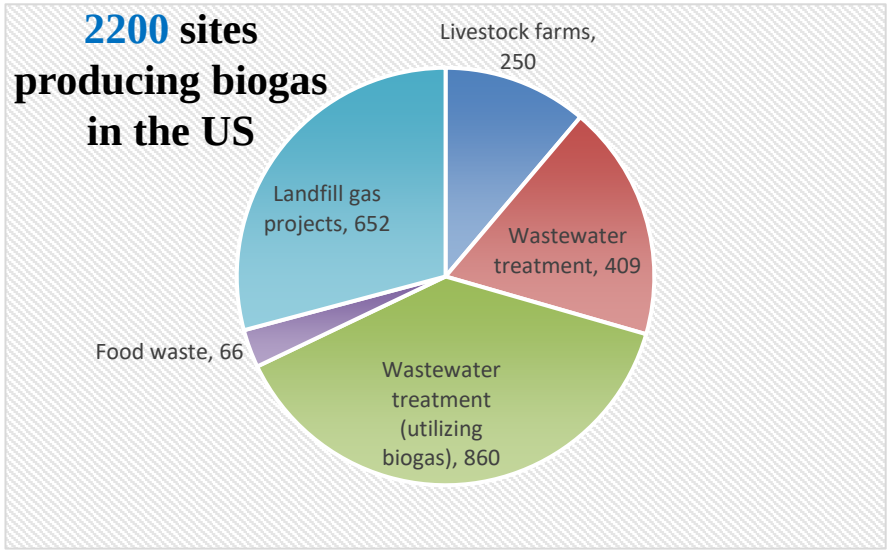
Current State of Technology

Biogas Production via Anaerobic Digestion of Waste Biomass





- Potential to be expanded from 2200 to ~15000 sites.
- Only 66 digesters running on food waste at present, can be expanded to ~2000 sites
- AD using current technology is only viable for large scale operations.
- Usage of biogas for electricity production requires even larger scale, in most cases it is vented or flared.

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Value Proposition

High-Value Chemicals & Fuels Instead of Low-Value Biogas

Process	2nd Gen Cellulosic	Petrochemical route	Visolis (projected)	AD-Biogas
Product	Ethanol	Fuels and Chemicals	Fuels and Chemicals[1,2,3]	Methane
Production cost ($/kg)	2-5	0.5-3	1-2	0.5-1
Product Value ($/kg)	1	0.5-3	1-3	0.1
Capital Intensity ($/kg)	6-10	1.5-3	2-3	1-2
Minimum size ($M/plant)	250-500	1,000	15-25	5-7
Feedstock source	Biomass	Petroleum	Biomass	Biomass
Feedstock flexibility	Medium	Low	High	High

1-Tracy, N.I., et al., Fuel, 2009. **88**(11): p. 2238-2240
2-Lee, W. S., et al., Chemical Engineering Journal, 2014. **235**, 83–99.
3-https://www.biofuelsdigest.com/bdigest/2014/04/21/biofuels-in-aviation-to-fly-or-not-to-fly/

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Technical Approach

High-Value Chemicals & Fuels Instead of Low-Value Biogas

The proposed project consists of the following unit operations:

- Anaerobic Digestion with Arrested Methanogenesis (ADAM) to optimize for low cost hydrolysis and breakdown of complex wet organics like food waste, manure and fermentation stillage to intermediate ADAM effluent that can be used as a feedstock for microbial conversion.
- Process optimization for clarifying ADAM effluent by solids removal.
- Optimization of selective extraction and concentration from clarified ADAM effluent to produce the microbial feed for use in bioproduction.
- Engineering of a microbial production strain for efficient upgrading of ADAM effluent to platform molecule 1 (PM1)
- Downstream diversification of PM1 into high-value monomers and high energy density fuels using chemical catalysis.

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Technical Approach- Risks and mitigation

Risk- The ADAM process will be affected by variability in waste feedstock streams
Mitigation- Working with various batches of ADAM effluent from real food waste feedstock early in the project. We have evaluated multiple samples for suitability as microbial feed and continue to monitor the impact of variability in food waste input on composition of ADAM effluent.

Risk- Multiple Unit operations from diverse scientific fields involved in the process
Mitigation- The project is a collaboration involving subject matter experts on all issues

Risk- Failure of even one unit operation will lead to failure of whole process
Mitigation- Working with multiple approaches in parallel in order to have multiple paths to success

Risk- Difficult to integrate processes, that are being optimized in different locations, at the project site
Mitigation- Have identified this as a major risk and have started organizing and planning the integration effort months in advance.

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Project Team

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Food Waste to Feedstock for Microbial Bioproduction

Microbial feed production from food waste AD at UC Davis' READ facility

- Renewable Energy Anaerobic Digester (READ) Facility at UC Davis
- Processing capacity 50 ton per day
- Receives food waste from UC Davis campus and local businesses
- Operates on a continuous basis producing renewable biogas for use on campus

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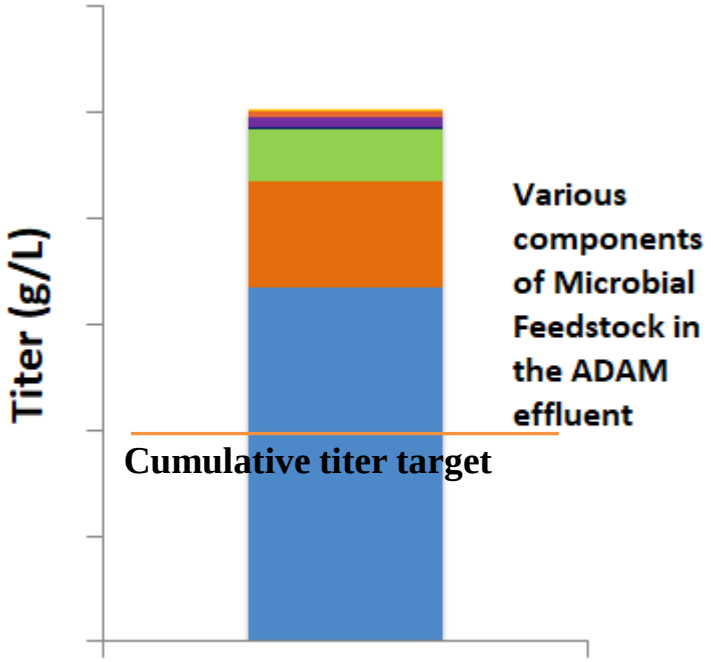
Anaerobic Digestion Development

Microbial feed production from food waste at UC Davis' READ facility



The titer of microbial feed components generated in ADAM effluent has exceeded the set target by 40%

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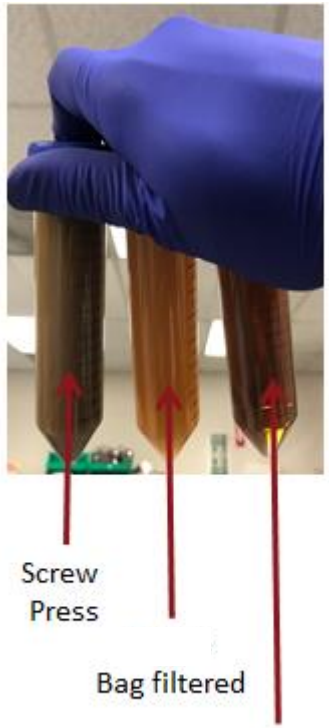
ADAM Effluent Processing

Obtaining clarified and concentrated microbial feed from ADAM Effluent

ADAM effluent solid removal and clarification

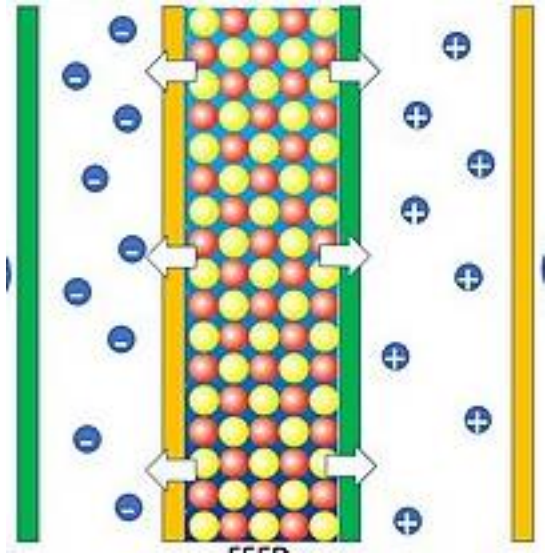
Step 1-
Solid removal-
Bag filtration

Step 2-
Clarification-
Tangential flow
ultrafiltration

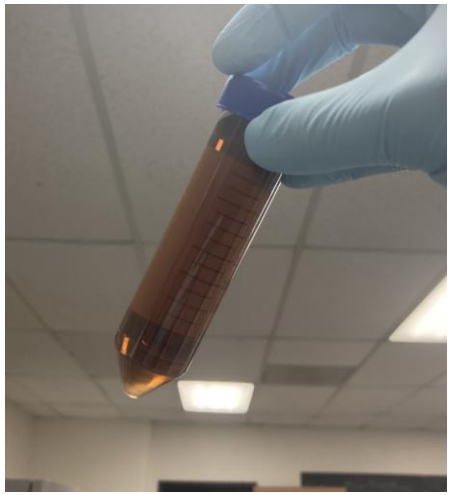


After TFF

Selective extraction and concentration of microbial feed from clarified ADAM effluent



Final concentrated microbial feed



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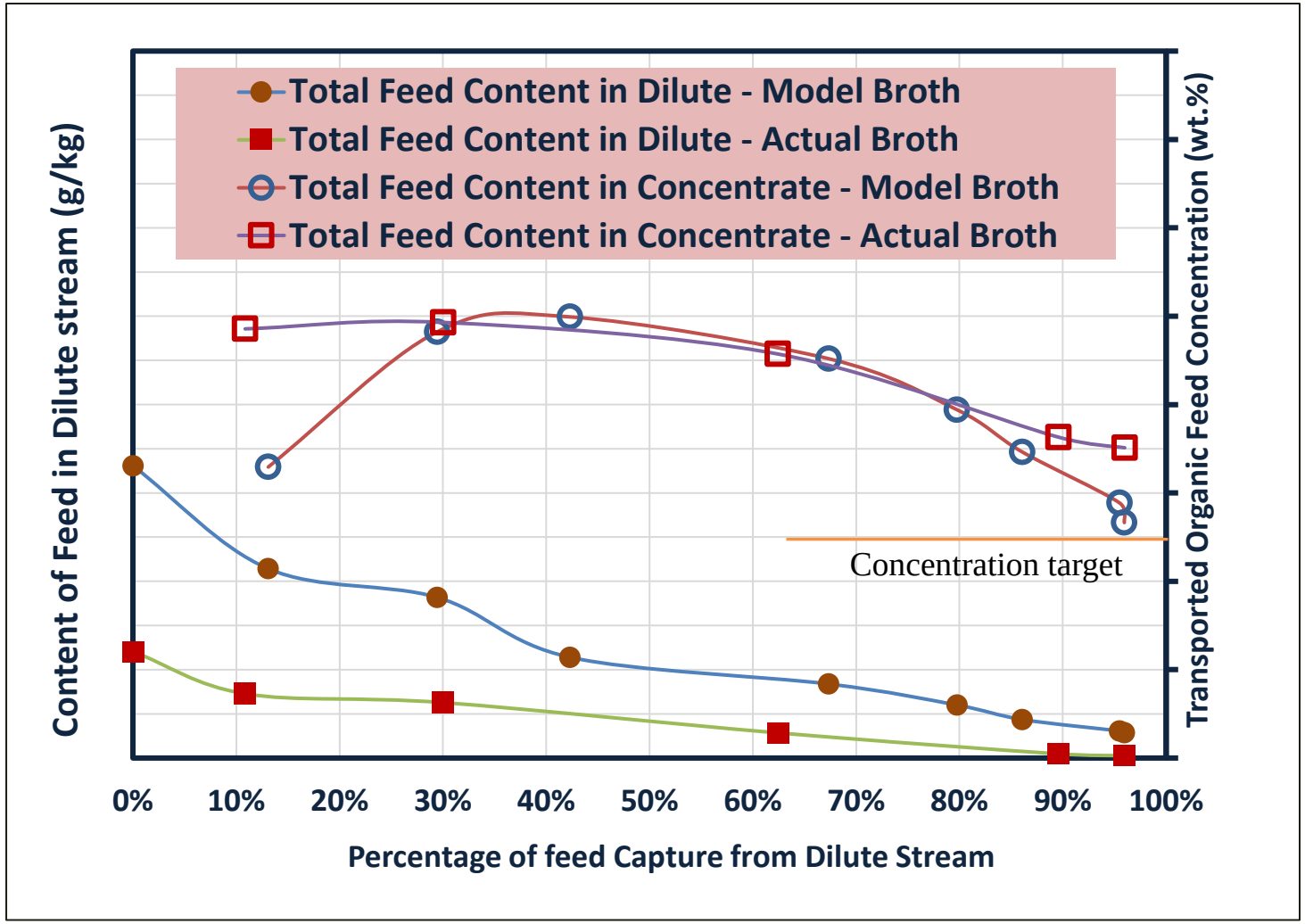
Development of the Selective Concentration Process

Concentrating microbial feed using mock and real samples



- The dilute stream is obtained after the clarification of the ADAM effluent.
- The microbial feed components in the dilute ADAM effluent are then transferred to the concentrate stream which is obtained at 5-10X higher concentration

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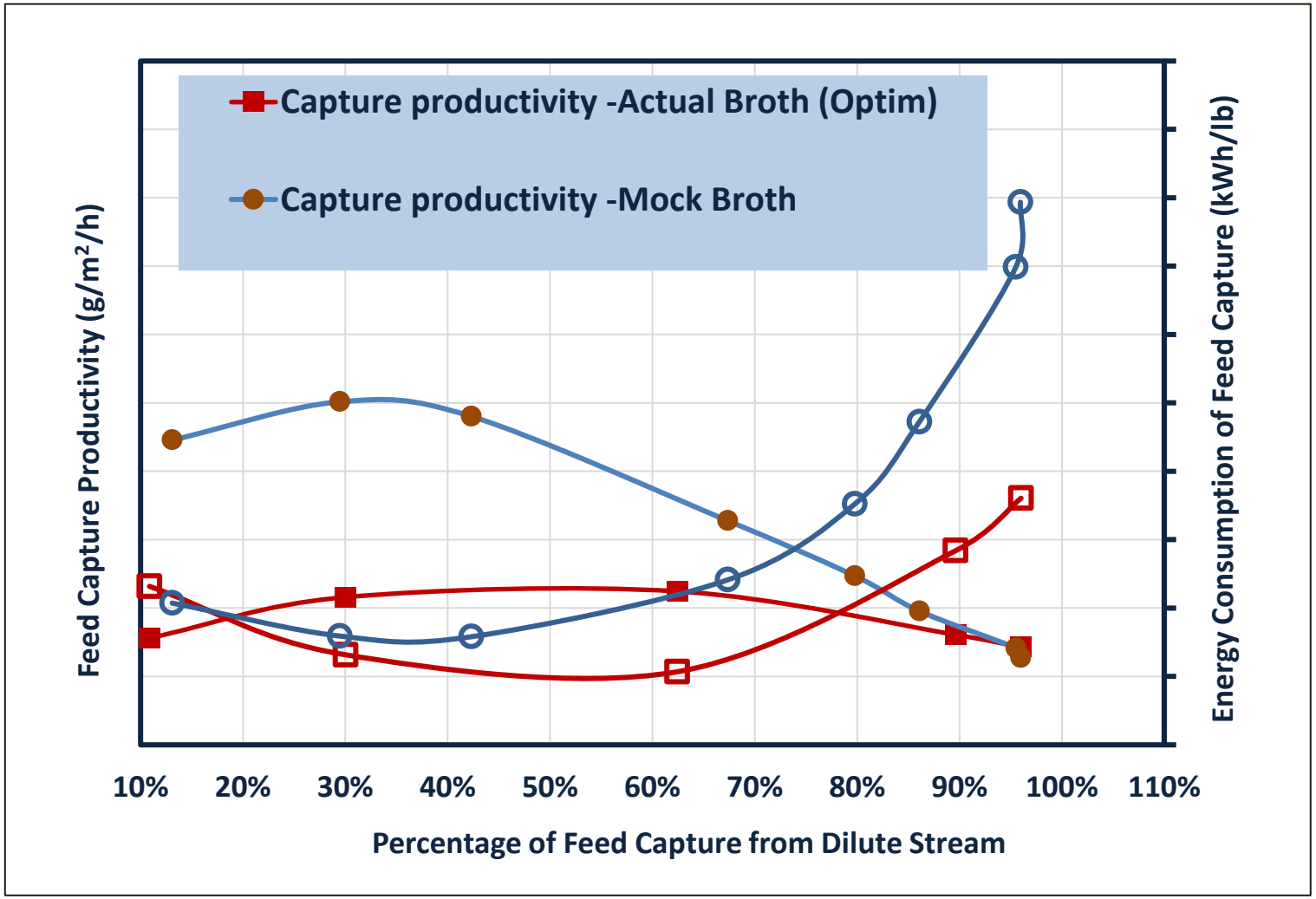
Development of the Selective Concentration Process

Energy consumption for the capture and concentration of Microbial Feed



- This data shows the productivity of capture of the microbial feed components from the clarified ADAM effluent dilute stream.
- The data is for running the operation in a batch mode
- When running in continuous mode at pilot/full scale- the process will operate at a feed capture %age range of 30-50% to optimize for productivity and energy consumption

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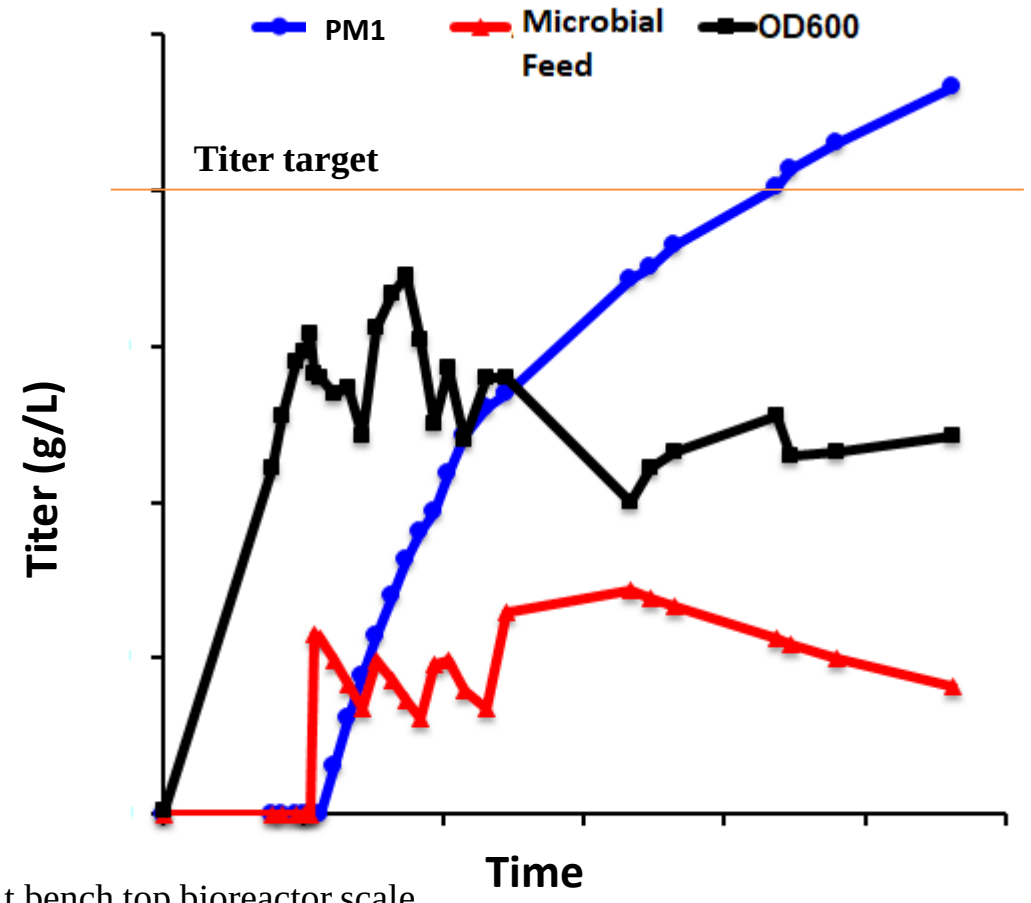
PM-1 Bioproduction from model ADAM effluent



At bench top bioreactor scale
OD (optical density) = cell density

- Successfully demonstrated co-consumption of various compounds found in model ADAM effluent
- Achieved target titer for PM1 production from model ADAM effluent with high yields

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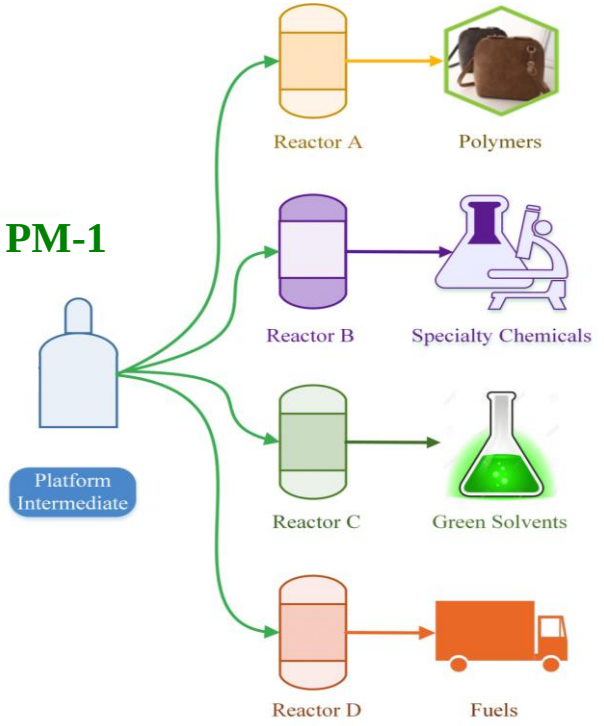
PM-1→ End Products

Catalytic Conversion of PM-1 to Various High-Value Chemicals and Fuels

Hydrogenation reactor

Oligomerization reactor



Eg. Isoprene based polymers

Eg. Polyurethanes

Replacing chlorinated petrochemicals

Eg. High energy density terpenes

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Potential Impact

The process to convert organic waste to high-value chemicals and high energy density fuels using modified anaerobic digestion approach will provide the following benefits:

- Will open a new market in the bioeconomy for waste biomass.

- Allow small communities/municipalities to upgrade their organic wastes
  - Small modular ADAM facilities will cost only $2-5 M to construct
  - Potential for up to 70% reduction in waste disposal costs for small communities/municipalities
  - The small scale ADAM facilities will transport concentrated microbial feed to a larger scale PM1 production and catalytic upgrade facility.
  - Supports production of higher value products compared to low value biomethane

- Can have the same impact on organic waste management as solar panels and wind turbines have had on power generation by allowing for modular and small-scale implementation.

- Wide variety of potential end products with a range of market size and price allows the adoption of technology to be economically viable for small, medium and large-scale application.

- Can replace petrochemical sources for polymers, such as polyurethanes, and high energy density fuels.

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Progress and Outcomes- Summary

• Production of microbial feed components via the ADAM process at titers **40% higher than target**.

• Developed process for filtering and clarifying the ADAM effluent at lab and small pilot scale

• Developed technique for **selective concentration (5-10X)** of microbial feed components from the ADAM effluent at high productivity

• Developed a strain capable of tolerating high concentration of microbial feed components in the ADAM effluent

• PM-1 production from model microbial feed at titers **exceeding target by 45%.**

• PM-1 production from actual microbial feed from ADAM effluent, optimization underway for achieving Go/No-Go milestone

•We have ongoing collaborations with industrial partners that are testing PM1 derived intermediate chemicals for production of specialty polymers

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Quad Chart Overview

Timeline

- July 1, 2019
- June 30, 2022

	FY20	Active Project
DOE Funding	(10/01/2019 – 9/30/2020)	$450,000 (provisional)

Project Partners

- Argonne National Lab
- University of California, Davis

Barriers addressed

1. Develop cost-effective biological synthesis technologies.

Project Goal

Visolis proposes a novel biorefinery to rewire anaerobic digestion (AD) to produce a range of higher value chemicals and energy-dense fuels using microbial fermentation and chemical catalysis. Result will be small, in-expensive systems for upgrading wet organic waste to higher value products instead of low-value biogas

End of Project Milestone

Run the process at pilot scale to hit targets of high titers for i. separation of microbial feed from ADAM ii. production of PM-1 from the microbial feed and iii. production of high value chemicals and fuels from PM-1

Funding Mechanism

BioEnergy Engineering for Products Synthesis (BEEPS) 2018

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