DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

March 12, 2021

Data, Modeling, and Analysis

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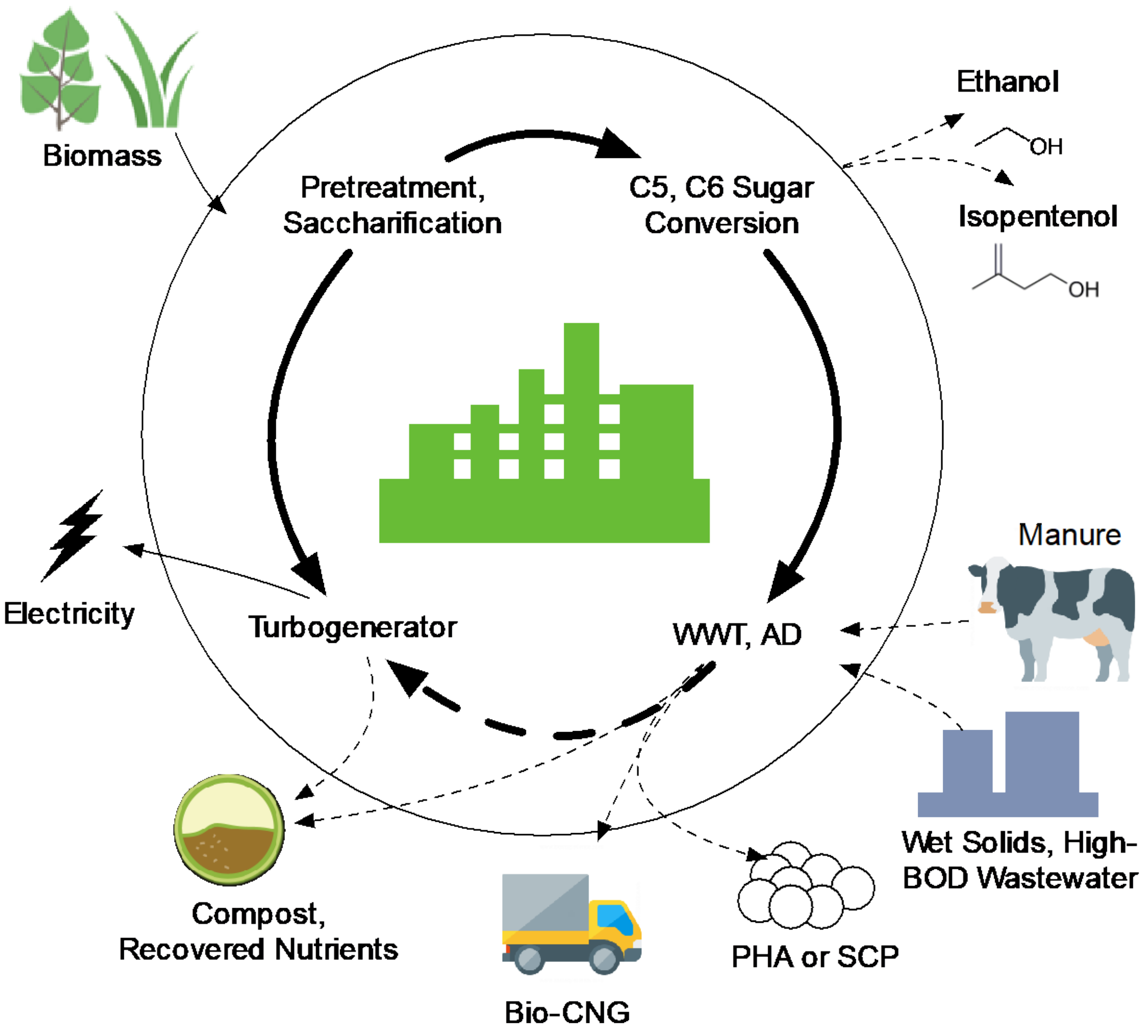
Project Overview

Motivation: Biorefineries can improve economics and societal benefit by offering multiple services to rural communities.

Objective: Conceptualize, design and assess the economic and environmental performance of multi-input, multi-output biorefineries

Goals:

– Design a set of cost-competitive biorefineries capable of taking in lignocellulosic biomass and organic waste, producing multiple value-added products
– Build and demonstrate integrated siting, TEA, and LCA models to simulate these designs and explore tradeoffs



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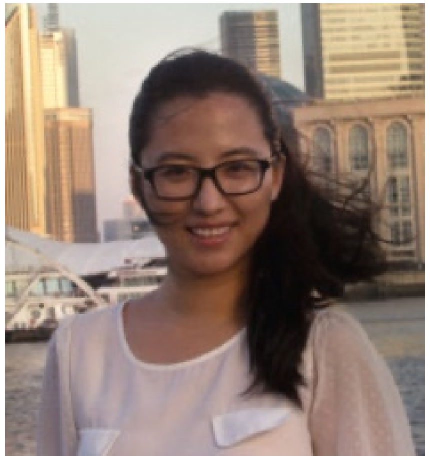
1 – Management

Corinne Scown (PI)
TEA/LCA Expert



Yan Wang (Postdoc)
TEA/LCA

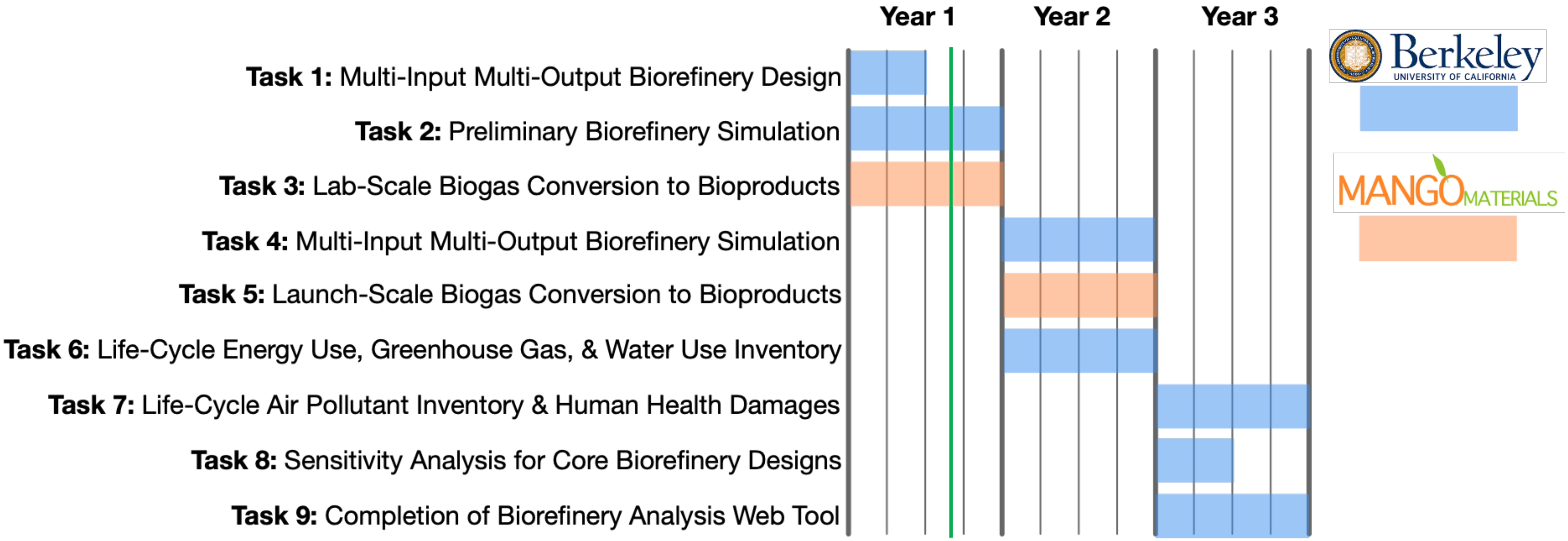
Allison Pieja (Co-PI)
CTO, Mango Materials

Molly Morse (Co-PI)
CEO, Mango Materials

Additional partners:

- EBMUD (data, advisory board)
- JBEI (modeling resources)
- California Ethanol + Power (data, advisory board)

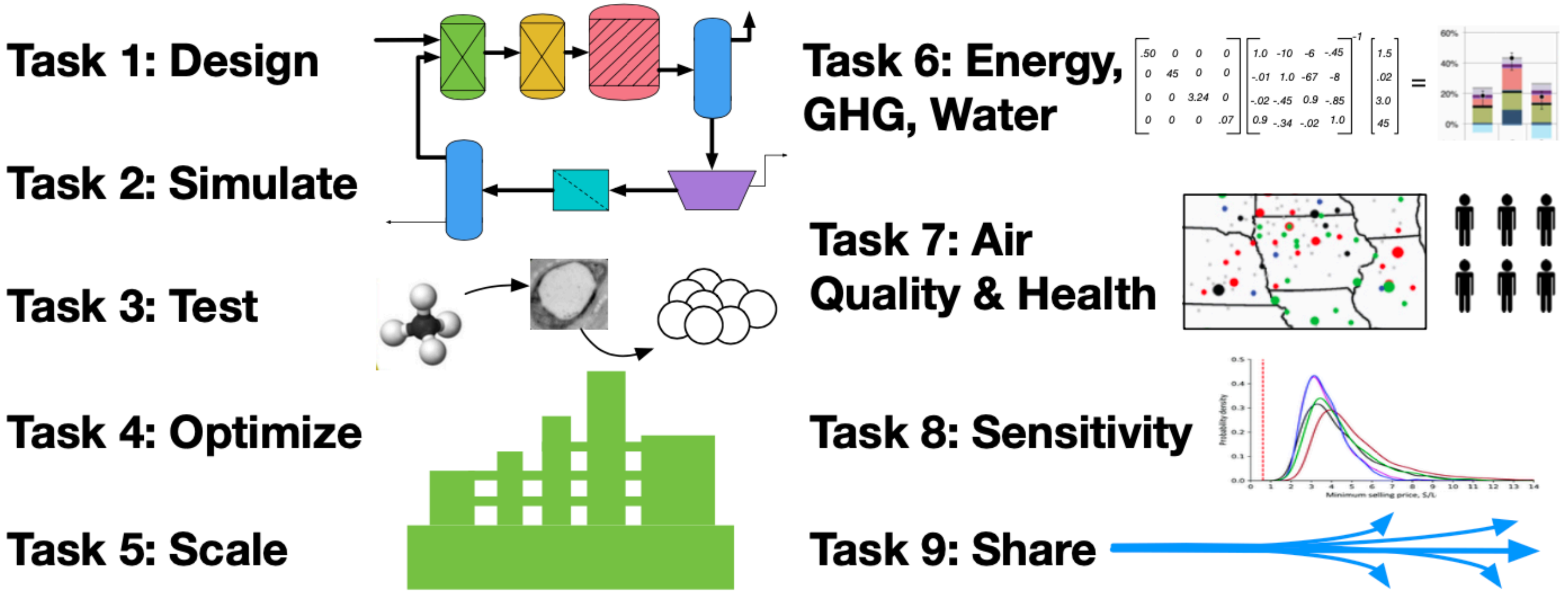
1 – Management



Risk	Mitigation
Extrapolating small-scale results to commercial-scale operation	Input from industry advisers, ABPDU
Uncertainty in product selling prices	Sensitivity analysis
Challenges deploying to web-tool	Early dev. & testing of proof of concept

2 – Approach

1. Biorefinery scenarios designed & simulated in SuperPro Designer to generate mass/energy balances & estimate costs
2. Biogas yield & composition simulated using promising feedstock types & real-world AD data from EBMUD
3. PHA & SCP yields @ bench scale tested
4. Biorefinery designs optimized based on early modeled & empirical results
5. Gas fermentation scaled up at launch facility, data collected at larger scale
6. Life-cycle assessment developed for optimized biorefinery designs for energy, GHG, water
7. Sensitivity analysis to explore technical & market risks
8. Air pollutant & health damages estimated using integrated assessment model
9. Web-based modeling tools deployed for use in broader research & industry community



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2 – Approach

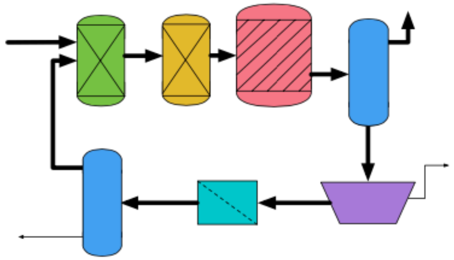
Challenges
- Determining tipping fees/costs & local availability for organic waste inputs
- Quantifying air quality impacts of our scenarios & business-as-usual baseline
- Maintaining schedule under COVID restrictions

BP 1 Go/No-Go: Complete biorefinery designs for 4 configurations including ethanol, isopentenol, bio-CNG, & PHA

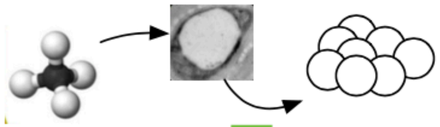
BP 2 Go/No-Go: Report bioproduct yields on key nutrients at launch scale in biogas & estimate minimum yield required for profitability

Task 1: Design

Task 2: Simulate



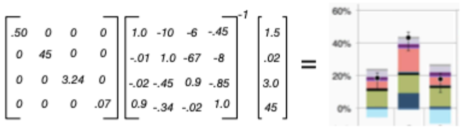
Task 3: Test



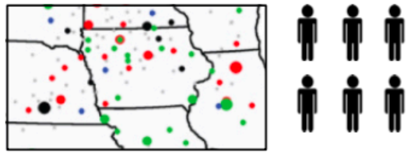
Task 4: Optimize

Task 5: Scale

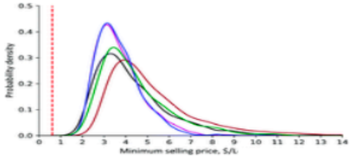
Task 6: Energy, GHG, Water



Task 7: Air Quality & Health



Task 8: Sensitivity



Task 9: Share

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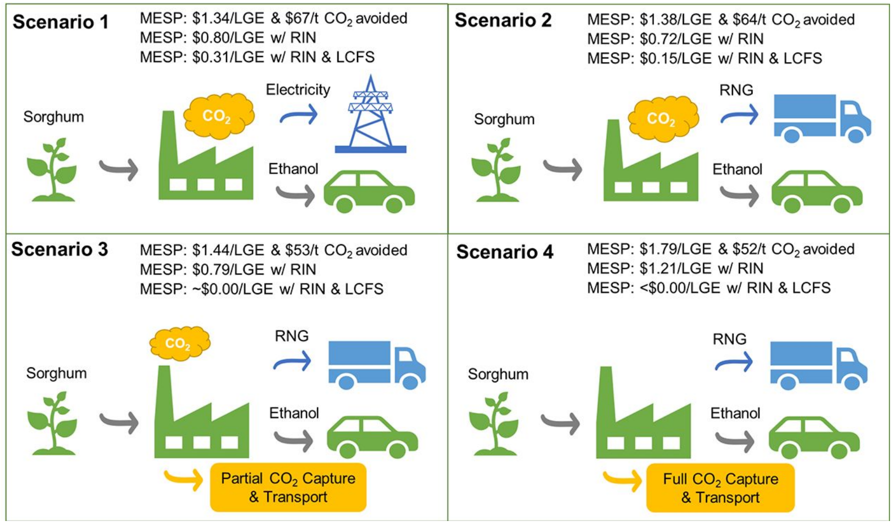
3 – Impact

- Relevance: We know there is an economic advantage to shifting from biogas combustion to cleanup for bio-CNG
- Co-digesting organic waste and upgrading biogas offers potential for
  - Local water quality benefits
  - Diversion from landfills
  - Concentrated CO2 capture & sequestration opportunities
- CE+P is doing this for a planned ethanol facility, we are closely following their progress and getting feedback
- Web-based tools offers ability to explore economics & environmental impacts for non-experts



Co-producing RNG makes economic sense (Yang et al. 2020)

Manure lagoons emit significant methane (Source: UC Davis)

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3 – Impact

- By designing, simulating, and optimizing multi-input multi-output biorefineries for rural communities, **this project will chart a detailed technical vision for advanced biorefineries that not only produce liquid fuels, but also treat organic waste, produce high-value biodegradable polymers, reduce GHG and local air pollutant emissions, and produce valuable soil amendments**.
- Producing advanced biofuels from lignocellulosic material at cost-parity with petroleum is still the single greatest challenge to be overcome in scaling up the broader bioeconomy. This project addresses the cost challenge by:
  - identifying and quantifying additional revenue streams for biorefineries in the form of organic waste tipping fees
  - upgrading raw biogas to higher-value materials and uses (PHA, SCP, or bio-CNG) relative to the base case assumption of on-site combustion
  - simulating production of versatile products that can serve as platform chemicals or fuels depending on market prices
  - deploying a set of web-based TEA and LCA tools for companies and potential investors to explore the cost implications of variations on proposed designs.
- Project will result in design, simulation, and optimization of multi-input multi-output biorefineries that can reduce greenhouse gas (GHG) emissions by at least **70%**, reduce fossil energy consumption by **50%**, and reduce air pollutant emissions (normalized based on monetized local human health damages) by at least **20%** relative to conventional alternatives.

4 – Progress and Outcomes

Budget Period 1 Milestones

Quarter	Milestone	Description
1	1.1.1	Identify ≥3 key feedstock contaminants, report concentrations in >10 feedstock types.
2	3.1.1	Report bench-scale PHA yields on key nutrients (nitrogen).
3	3.2.1	Report bench-scale SCP yields on key nutrients (nitrogen).

Complete

On schedule

Budget Period 2 Milestones

Quarter	Milestone	Description
5	4.1.1	Develop MSP, mass/energy balances for ≥3 AD feedstock blends.
6	5.2.1	Report launch-scale bioproduct yields on key nutrients (nitrogen).
7	6.1.1	Estimate fossil energy demand for ≥5 designs.

Budget Period 3 Milestones

Quarter	Milestone	Description
9	7.1.1	Life-cycle air pollutant inventory for ≥5 designs.
10	8.2.1	Uncertainty analysis for cost, GHG, and air pollutants.
11	9.1.1	Demonstrate web tool for at least 2 biorefinery designs.

Metrics

Optimized biorefinery designs will produce a suite of fuels and products that, compared to an identical portfolio of conventional alternatives, will:

- Reduce GHG emissions by > 70%
- Reduce fossil energy use by > 50%
- Reduce air pollutant emissions (on monetized local human health damage basis) by > 20%

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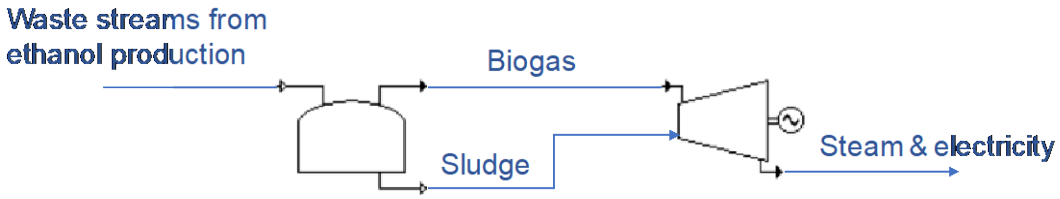
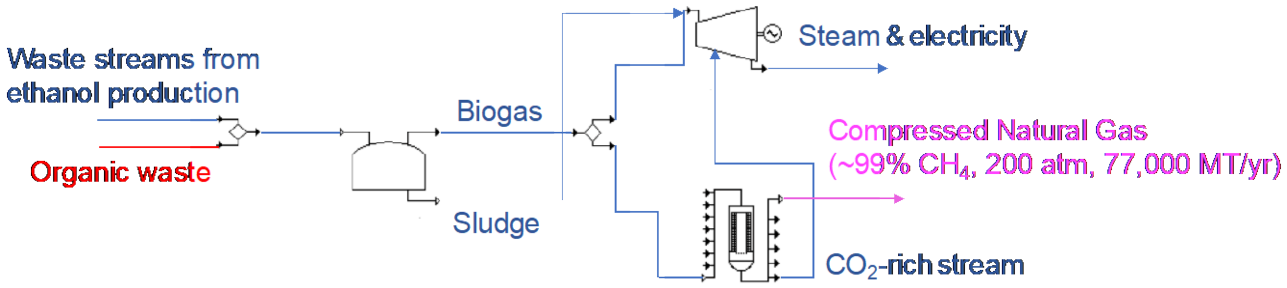
4 – Progress and Outcomes

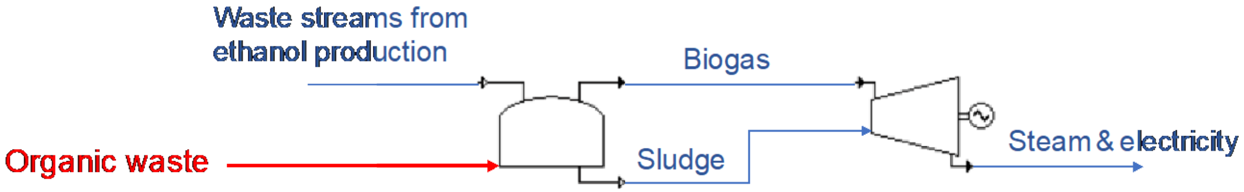
Base case biorefinery scenarios completed
Biogas generation & utilization scenarios developed



(a) Biogas onsite combustion (base case)



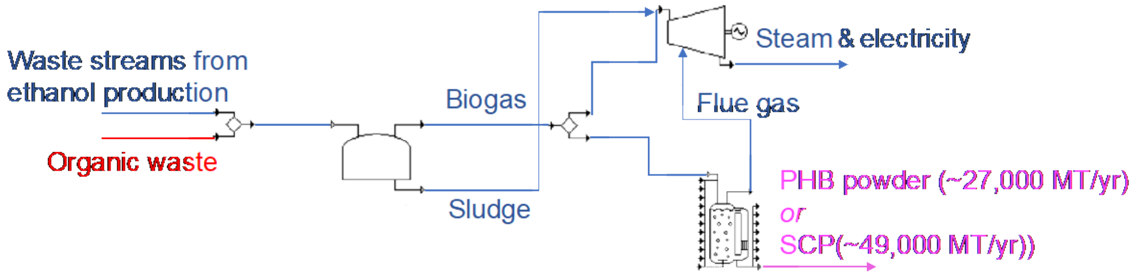
(c) AD codigestion & biogas upgrading



- *Hog manure (4500 MT wet/day)*
- *Cattle manure (1100 MT wet/day)*
- *Food waste (600 MT wet/day)*

- *AD organic loading rate: 3-5 kg VS/day/m3*
- *Residence time: 25 day*

(b) AD codigestion & onsite combustion



(d) AD codigestion & PHB/SCP production

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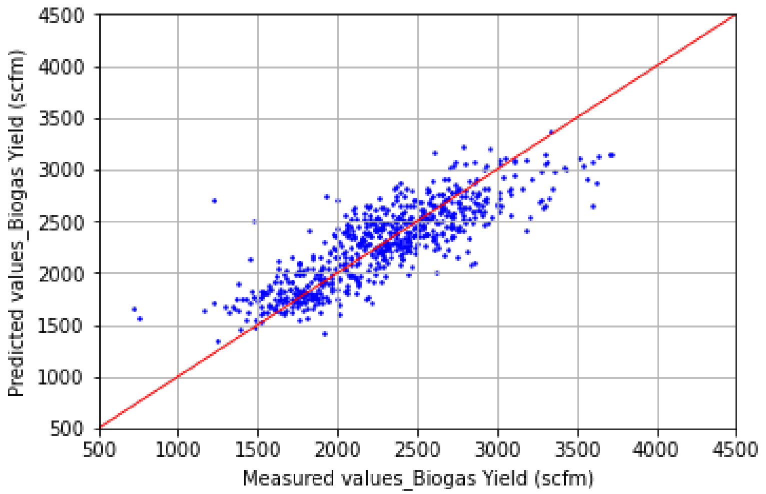
4 – Progress and Outcomes

Sample Results:
ML model trained on historical EBMUD data from high-strength waste co-digestion program

TPOT Identified Pipeline Regressor:
Extra Trees Regressor

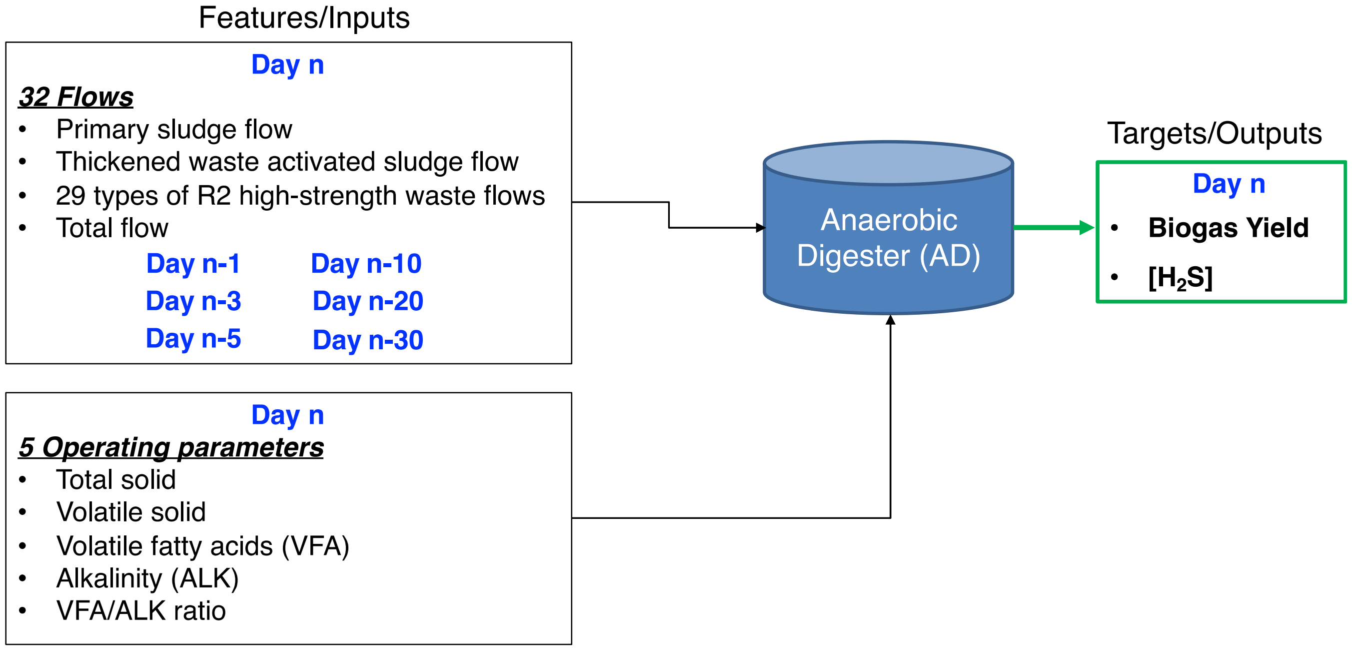
Predicted-versus-Measured for test dataset



Dataset STDV:
491.60 scfm

Model performance:
RMSE: 282.03 scfm
R^2: 0.67

Training features shape: (2001, 224)
Training target shape: (2001, 1)
Testing features shape: (668, 224)
Testing target shape: (668, 1)



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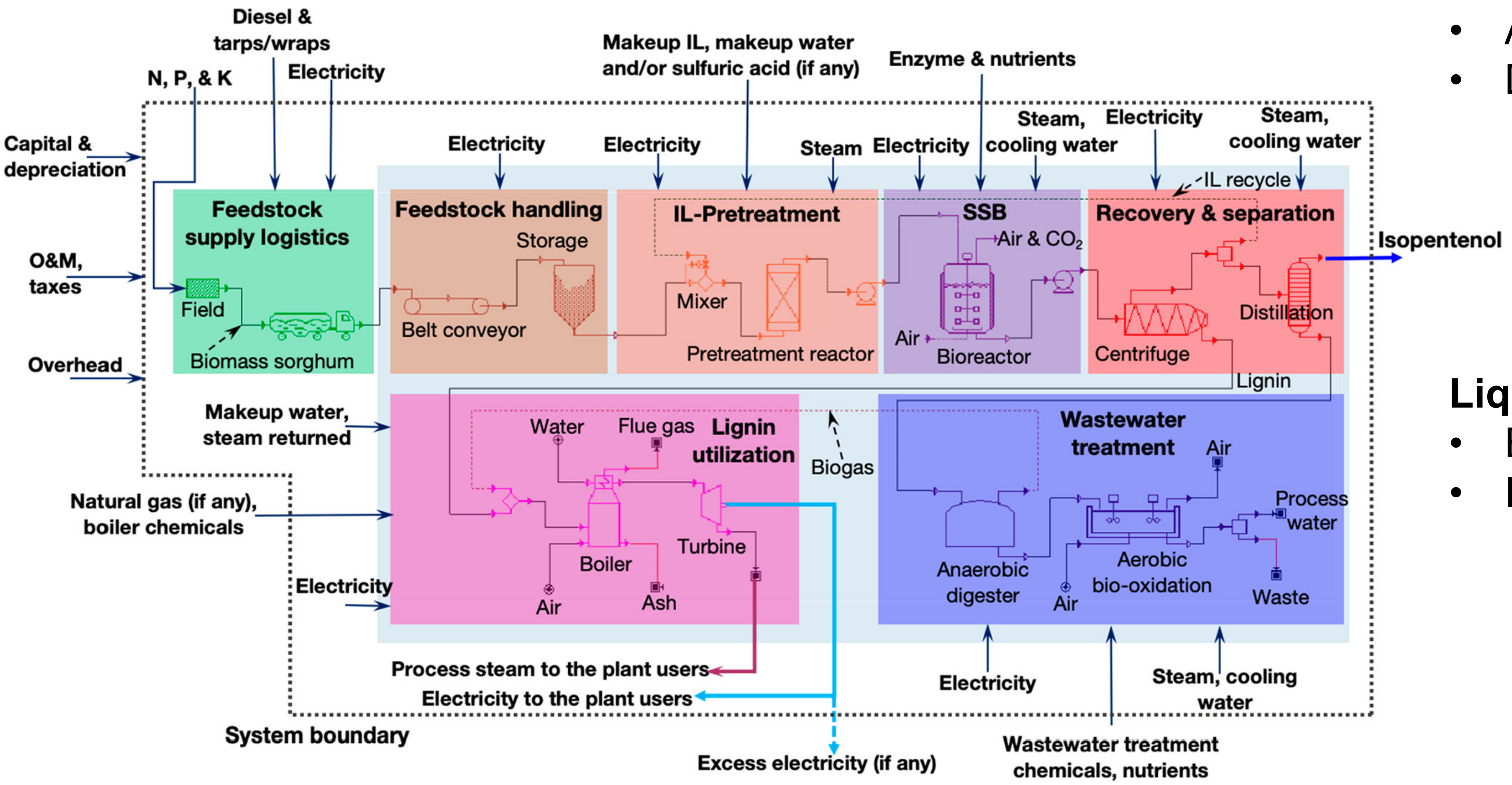
4 – Progress and Outcomes

Sample biorefinery configuration w/out co-digestion:
IL-based pretreatment, bioconversion of sugars to isopentenol

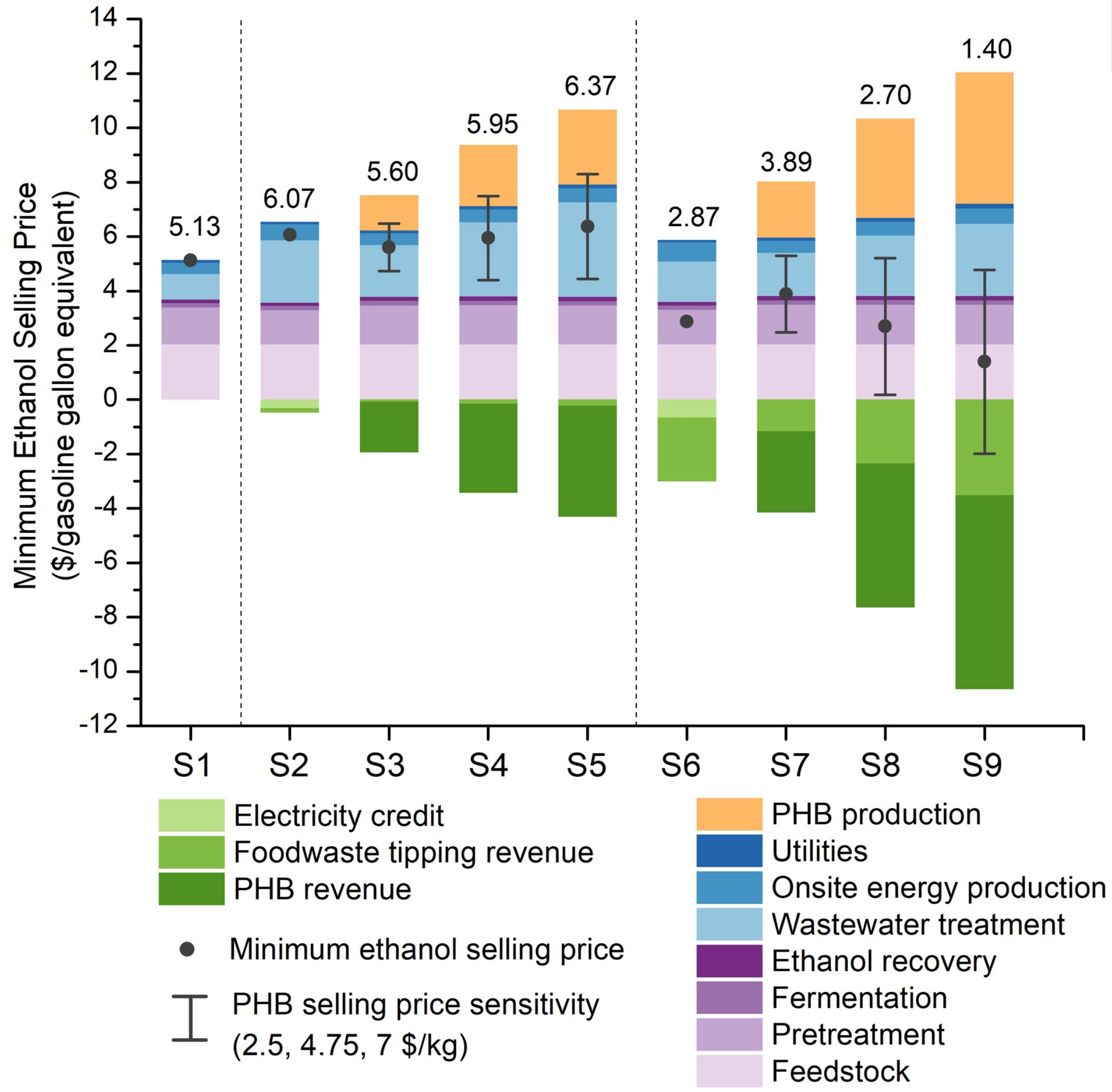


Pretreatment methods:
- Ionic Liquid
- Dilute Acid
- AFEX
- DMR

Liquid Fuels:
- Ethanol (anaerobic)
- Isopentenol (aerobic)

4 – Progress and Outcomes

*In 2020 dollars



Sample Results:
Corn stover, DMR pretreatment, ethanol product

S1: Onsite combustion

Hog and **C**attle manure and **F**oodwaste (wet MT/day)
S2: Codigestion (4600H+1100C+400F)
S3: Codigestion & PHB (2300H+ 550C+200F)
S4: Codigestion & PHB (4600H+1100C+400F)
S5: Codigestion & PHB (6900H+ 1650C+600F)

Foodwaste with tipping fee (wet MT/day)
S6: Codigestion (6100F)
S7: Codigestion & PHB (3050F)
S8: Codigestion & PHB (6100F)
S9: Codigestion & PHB (9150F)

Key takeaways:

- Waste with tipping fees will always make a big difference in economics
- If PHB price is on higher end of range, it makes codigestion and PHB production economically favorable

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Summary

- **Goal:** Conceptualize, design, and asses the economic and environmental performance of multi-input, multi-output biorefineries that can convert locally-produced lignocellulosic biomass, manure, and other wet organic waste into liquid fuels, platform chemicals, and high-value products.
- **Approach:** Use an LCA and TEA framework to design and evaluate multi- input, multi-output biorefineries. Integrate empirical data on the production of polyhydroxyalkanoate (PHA) and single cell protein (SCP) from raw biogas, in addition to empirical data on pretreatment and bioconversion from previous work.
- **Progress:** Data generated on PHA and SCP yields on key nutrients, preliminary biorefinery designs completed, initial cost and GHG data generated.
- **Potential Impact:** Improved environmental quality and jobs in rural communities, > 70% GHG reduction, > 50% fossil energy reduction, and > 20% air pollution health damage reduction relative to base case.
- **Future Work:** Continue refining designs, generate and integrate PHA and SCP yield data based on scaled-up operations, produce cost, GHG, water, air pollutant results, deploy web-based tool.

Quad Chart Overview

Timeline
- Start date: July 1, 2020
- End date: June 30, 2023

	FY20 Costed	Total Award
DOE Funding	(7/01/2020 – 6/30/2023)	$1M
Project Cost Share		$250K

Project Partners
- Mango Materials

Project Goal
Conceptualize, design, and asses the economic and environmental performance of multi-input, multi-output biorefineries that can convert locally-produced lignocellulosic biomass, manure, and other wet organic waste into liquid fuels, platform chemicals, and high-value products.

End of Project Milestone
Provide a set of optimized biorefinery designs that take in biomass and wet organic waste to produce a suite of fuels and products, valuable results on the economic and environmental impacts of these multi-input multi-output biorefineries, as well as a set of important modeling tools for researchers and stakeholders interested in evaluating their own technologies in in the context of their communities.

Funding Mechanism
BETO FY19 Multi-Topic FOA, AOI 10: Reducing Water, Energy, and Emissions in Bioenergy
DE-FOA-0002029

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*Only fill out if applicable.

Additional Slides

Publications, Patents, Presentations, Awards, and Commercialization

- Corinne Scown (Keynote Talk) “Environmental Impacts of Organic Waste Management and Conversion to Energy” AIChE Food-Water-Energy Nexus Conference, February 12, 2021

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