BETO 2021 Peer Review

Solid Lignin Recovery
WBS#: 3.4.2.601

March 24, 2021
Systems Development and Integration

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NREL

Project Overview

Need to use the entire biomass (carbohydrates and lignin) for effective carbon utilization and economic viability of biofuel and bioproduct processes.

Project goal: Find a solution for recovering **DMR-derived solid lignin** where no well-researched option **currently exist.**

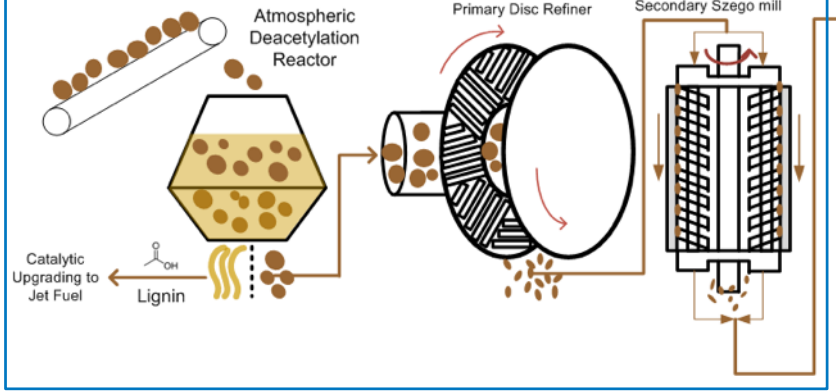
- **What:** Find effective solution for recovering solid lignin
- **How:** Flocculation but limited information available
- **Why:** Improve process performance and economics, establish baseline
- **Risk:** Good performance may not be possible, difficult separation

Project History: Two-year (~$600,000) BETO seed project starting in FY20

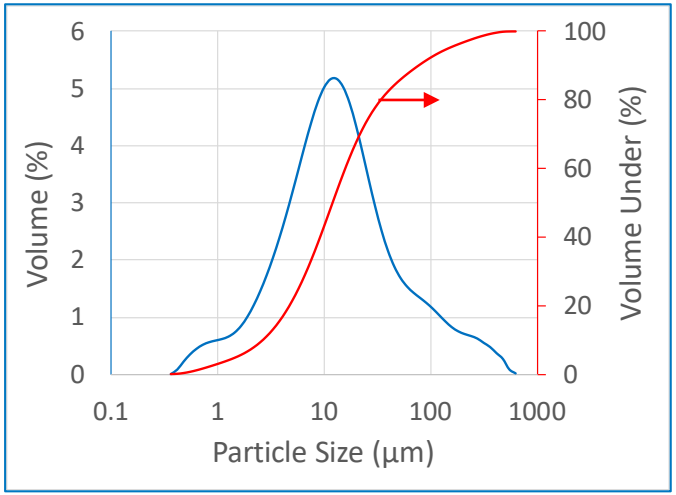
- Initial work non-flocculated, commercial processes
- Mid-project (end of Dec. 2020) decision point to determine future focus

DMR and Enzymatic Hydrolysis Process

Deacetylation and Mechanical Refining (DMR) Process



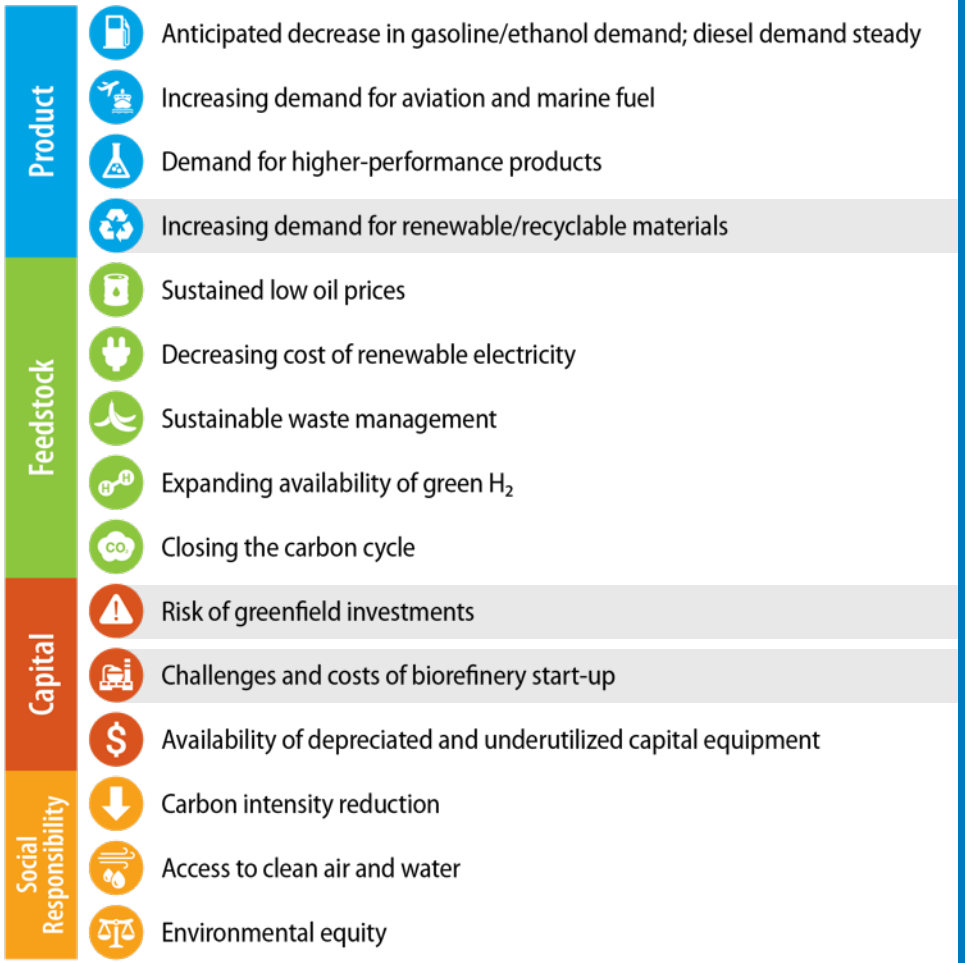
Enzymatic Hydrolysis



Water → Solid-Liquid Separation → Washed Lignin (Lignin Valorization)

Solid-Liquid Separation → Sugars (Biological Conversion)

Market Trends



NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- Provide a better researched and validated option for recovering DMR-derived lignin

Key Differentiators

- Base approach on commercially available equipment and processes
- Provide baseline results for comparison to new technologies or other approaches

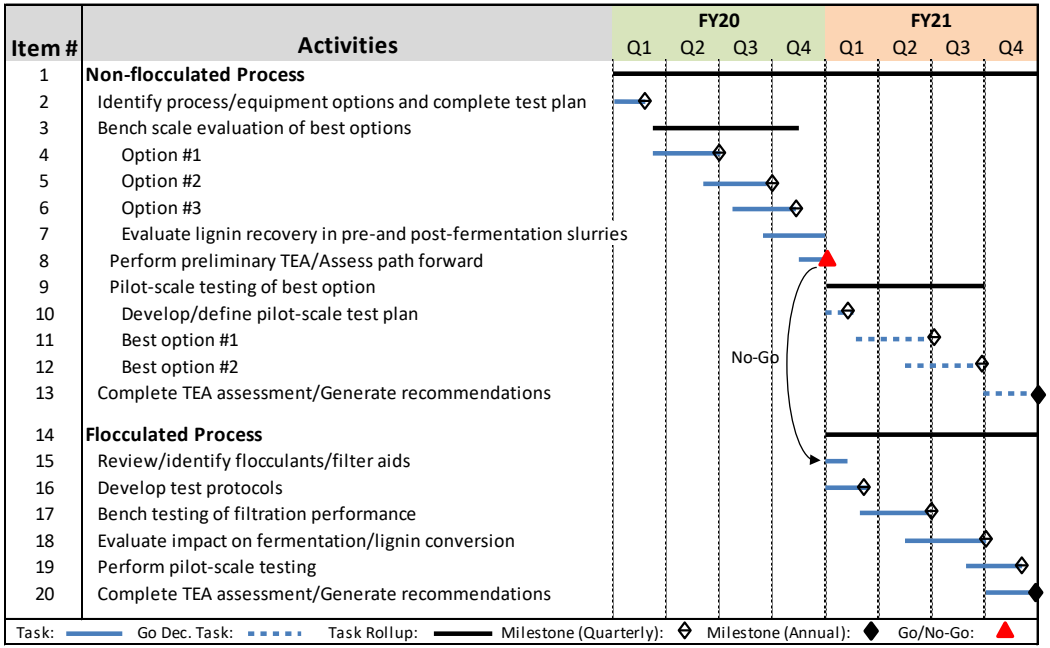
1. Management

- No collaborators, but interactions with BioProcessing Separations Consortium (BPSC)
- Risks
  - Changes in technical scope
  - Project delays

Project Team

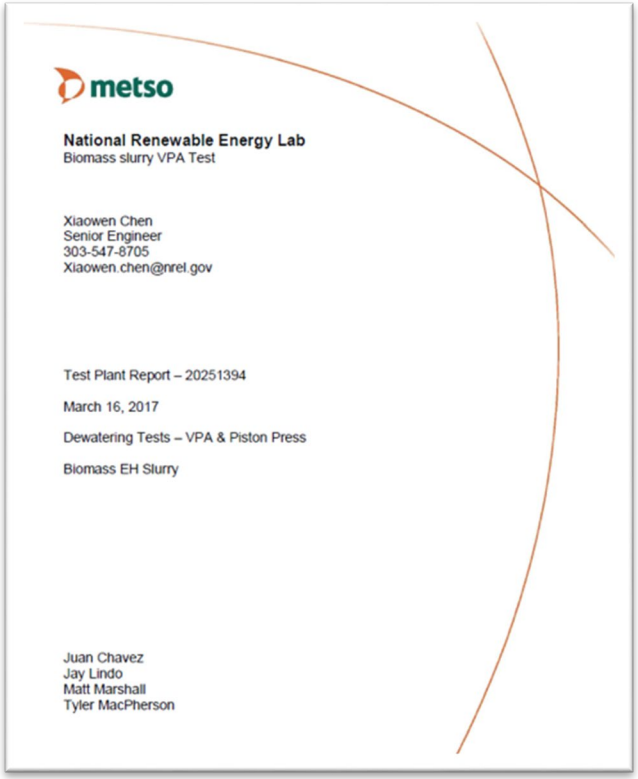
- PI/Management: Schell
  - Separations Science: Sievers, Saboe (BPSC), Gunther
  - Plant Operations: Jennings, Sievers, Gunther, Operating Staff
  - TEA: Davis, McNamara

Initial Project Plan (Merit Review Proposal)



2. Approach

Technology History/Background – Vendor Testing


metso

National Renewable Energy Lab
Biomass slurry VPA Test

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Test Plant Report – 20251394

March 16, 2017

Dewatering Tests – VPA & Piston Press

Biomass EH Slurry

Juan Chavez
Jay Lindo
Matt Marshall
Tyler MacPherson

Major Findings (Report Quotes):

- "During the VPA (pressure filtration) test a very thin filter cake formed on both sides of the chamber. **At this time, filtrate was unable to escape through the filter cloth.** This was under low filter pressures, 3-4 bar. **Filtrate was very brown and cloudy."**

- "During the Piston Press Test, a very thin filter cake formed against the filter cloth. **At this point, filtrate ceased to penetrate through the filter cake.** The remainder of the feed slurry was stuck in the chamber. This occurred both under high pressures, 100 bar, and low pressure, 10 bar. **Filtrate was very brown and cloudy."**

2. Approach

Year One Goal: Establish performance and cost of non-flocculated options for recovering DMR-derived lignin (new state-of-the-art).

Challenges:

- Could a non-flocculated process be found; investigate before dismissing
- Flocculants have potential (at a cost), but impacts on downstream process performance has not been tested

2. Approach

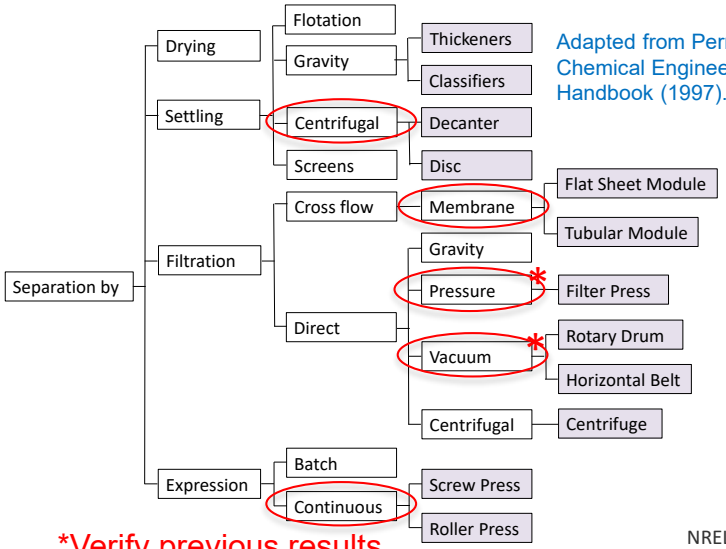
Year One Goal: Establish performance and cost of non-flocculated options for recovering DMR-derived lignin (new state-of-the-art).

Approach: Evaluate non-flocculated separations using bench-scale experimental data and techno-economic analysis (TEA). Is minimum fuel selling price (MFSP) < baseline value (TBD)?

- **No-Go:** Evaluate flocculation process option
- **Go:** Continue more rigorous investigation on non-flocculated process options

Challenges:

- Could a non-flocculated process be found; investigate before dismissing
- Flocculants have potential (at a cost), but impacts on downstream process performance has not been tested



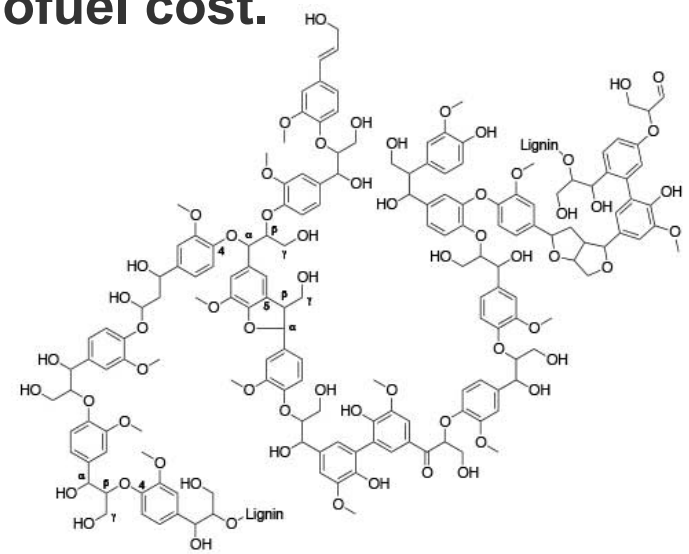
*Verify previous results

3. Impact

Lignin valorization is needed to lower biofuel cost.

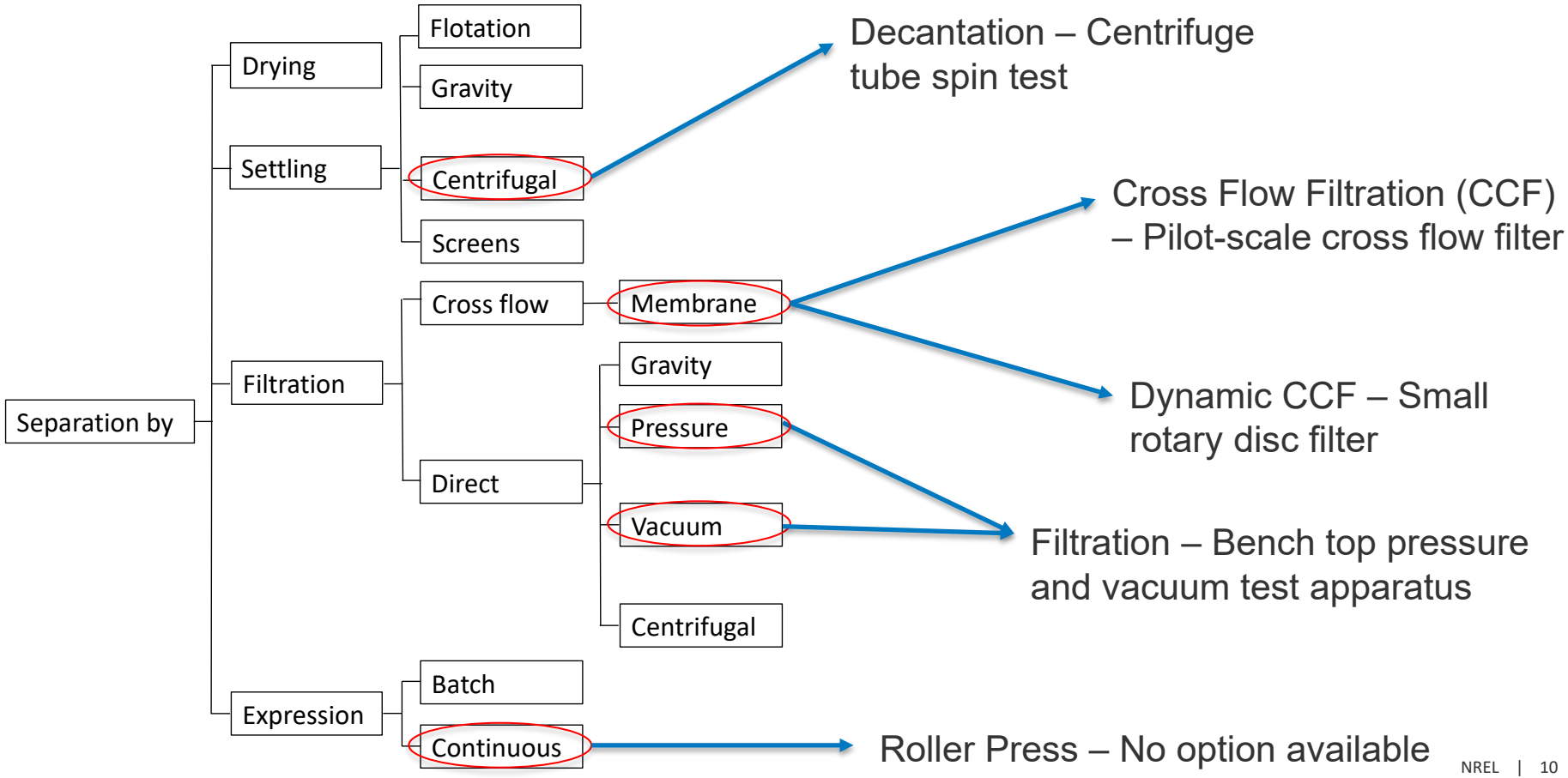
Better understanding of performance and drivers for a DMR-derived lignin separation process.

- More efficient integrated solid separation and sugar recovery
- New separation ideas or suggestions to equipment manufacturers
- Guidance to bioeconomy/biofuels industry
- Better TEA models for this unit operation

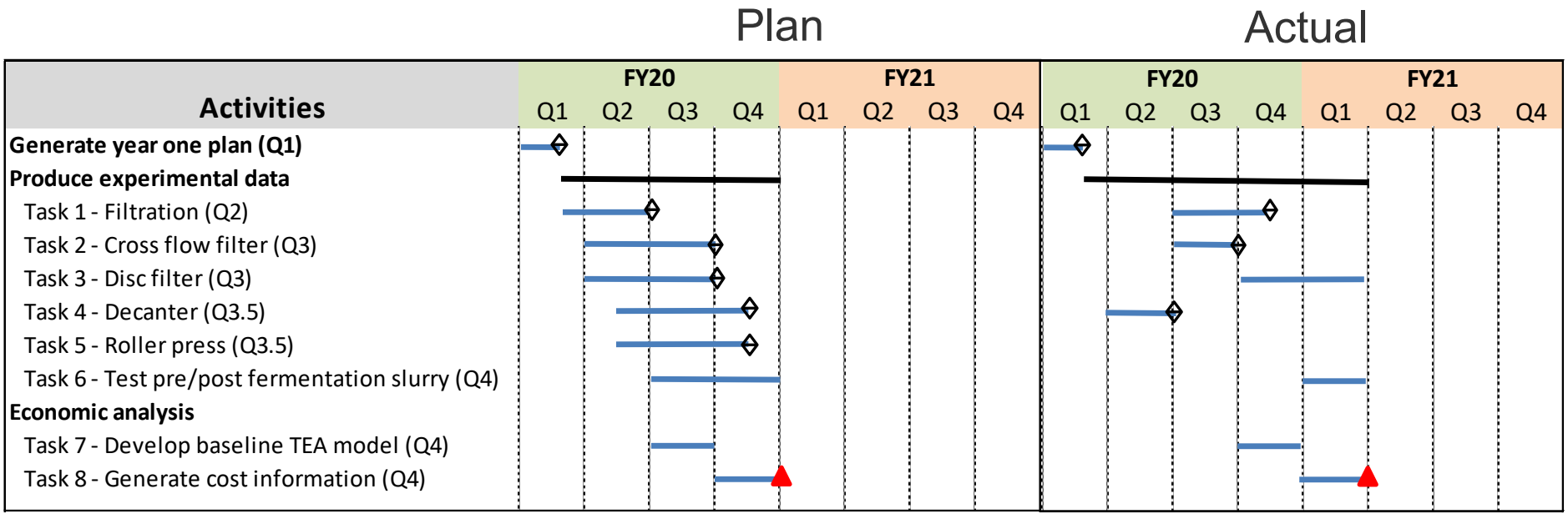


Development of publication from first year work is in progress.

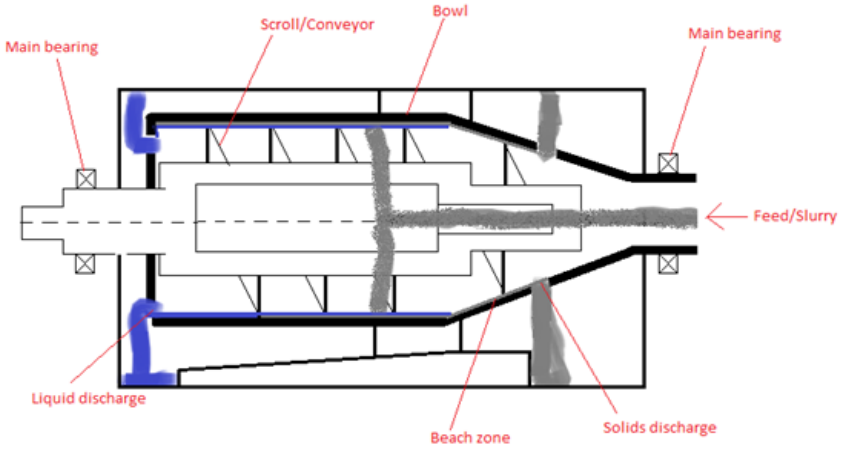
4. Progress and Outcomes



Project Plan



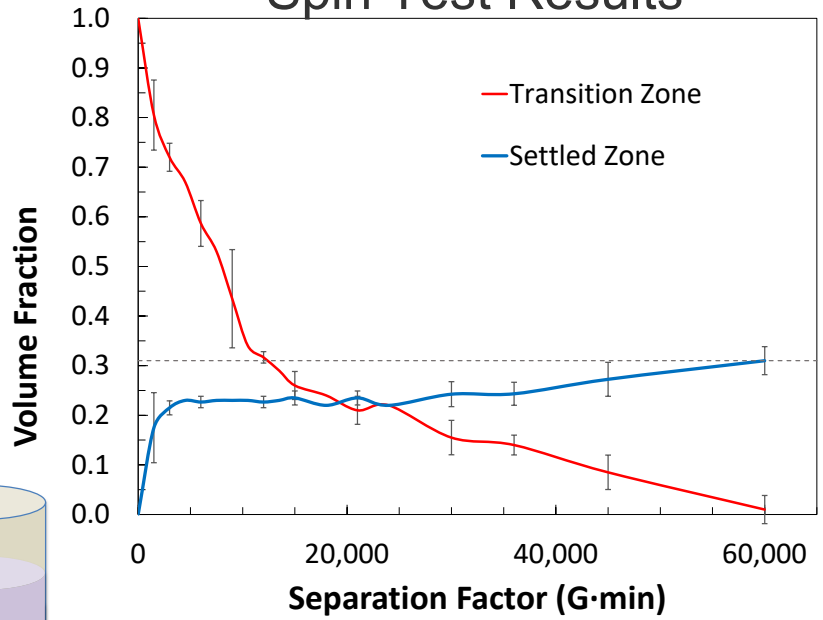
Decantation



Decanter Schematic

Industrial Decanter

Spin Test Results



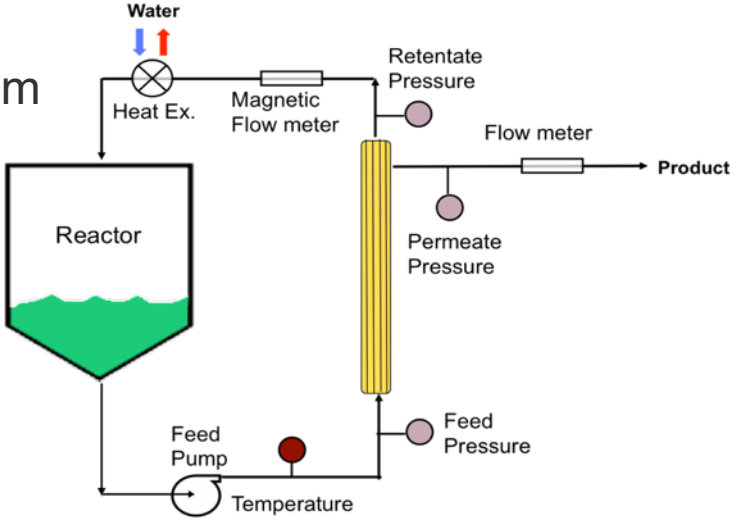
Supernate

Transition Zone

Settled Solids

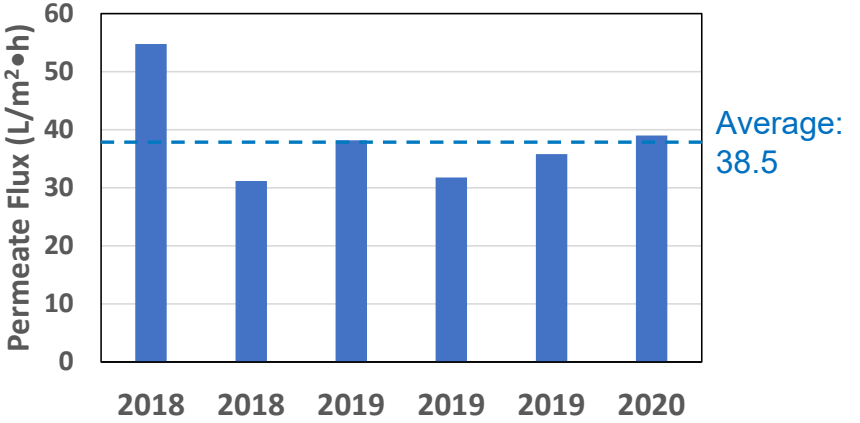
Cross Flow Filtration (CFF)

CCF System Schematic



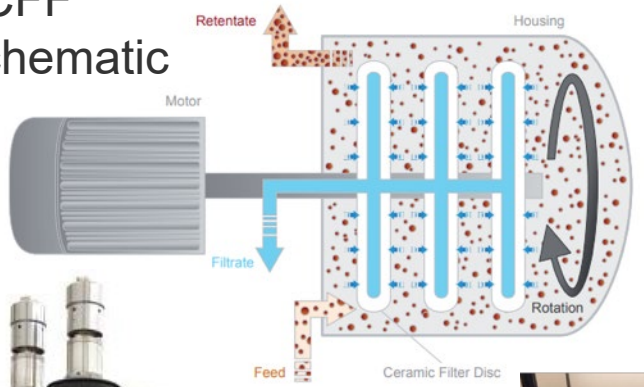
Pilot CFF Unit (located in the NREL IBRF pilot plant)

Average permeate flux over several hours of operation (0.07 µm filter) for runs performed on different days.

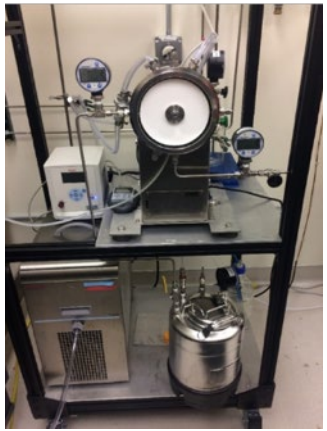


Dynamic Cross Flow Filtration (DCFF)

DCFF Schematic

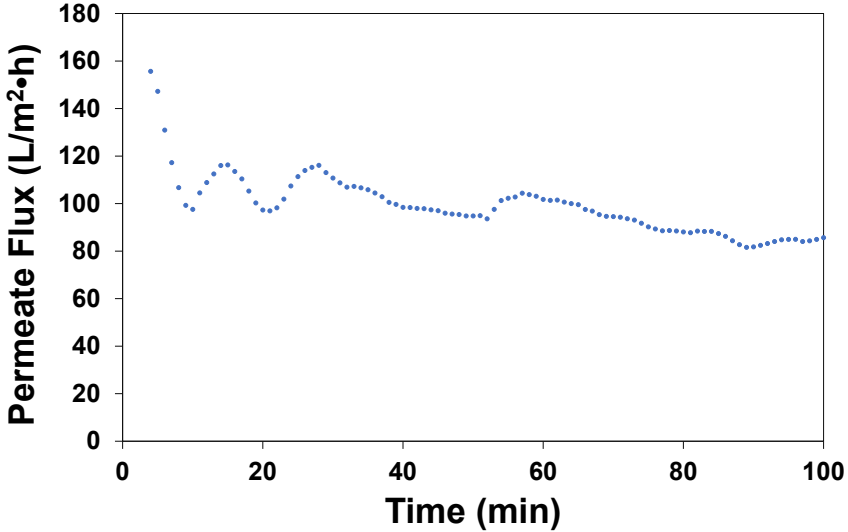


Industrial Unit (multiple disc)

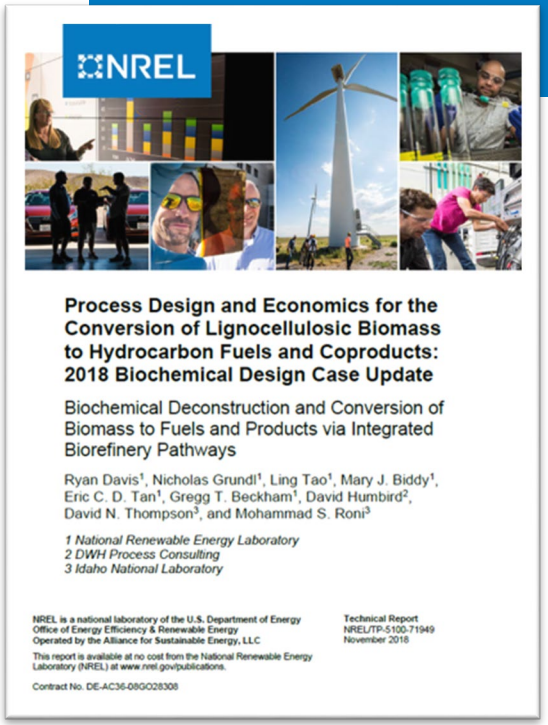


Bench-Scale Unit (single disc)

Permeate flux over several hours of operation (0.2 µm filter).



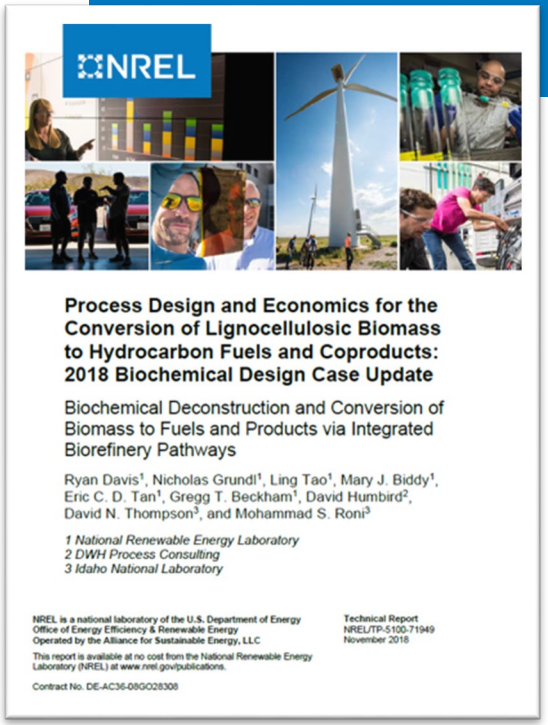
TEA Modeling

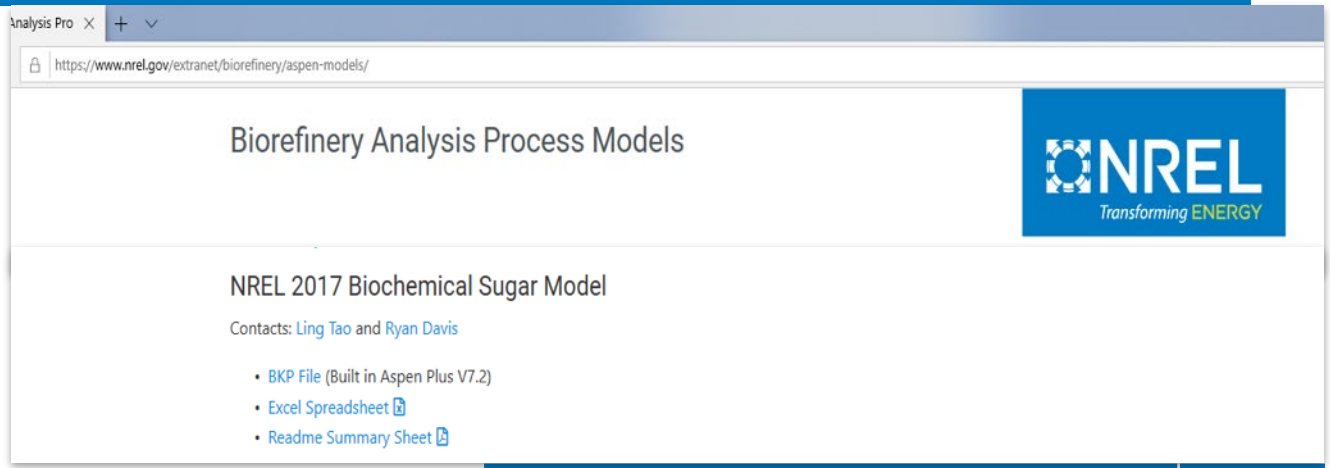


TEA assumptions:

- n^{th} plant economics
- Projected yields
- Lignin recovered and valorized by base-catalyzed depolymerization and fermentation to muconic acid
- Sugar model: Flocculant has no impact on downstream processing

TEA Modeling





Incorporated sugar model separation process into the 2018 TEA model.

Expt. Separation Process Parameters	Value
Sugar retention (%)	95
Wash ratio (L/kg IS)	17.5
Flocculant loading (g/kg IS)	20
Equipment capacity (kg IS/m^2-h)	12
IS recovery (%)	99.5
Recovered IS cake total solids content (%)	27

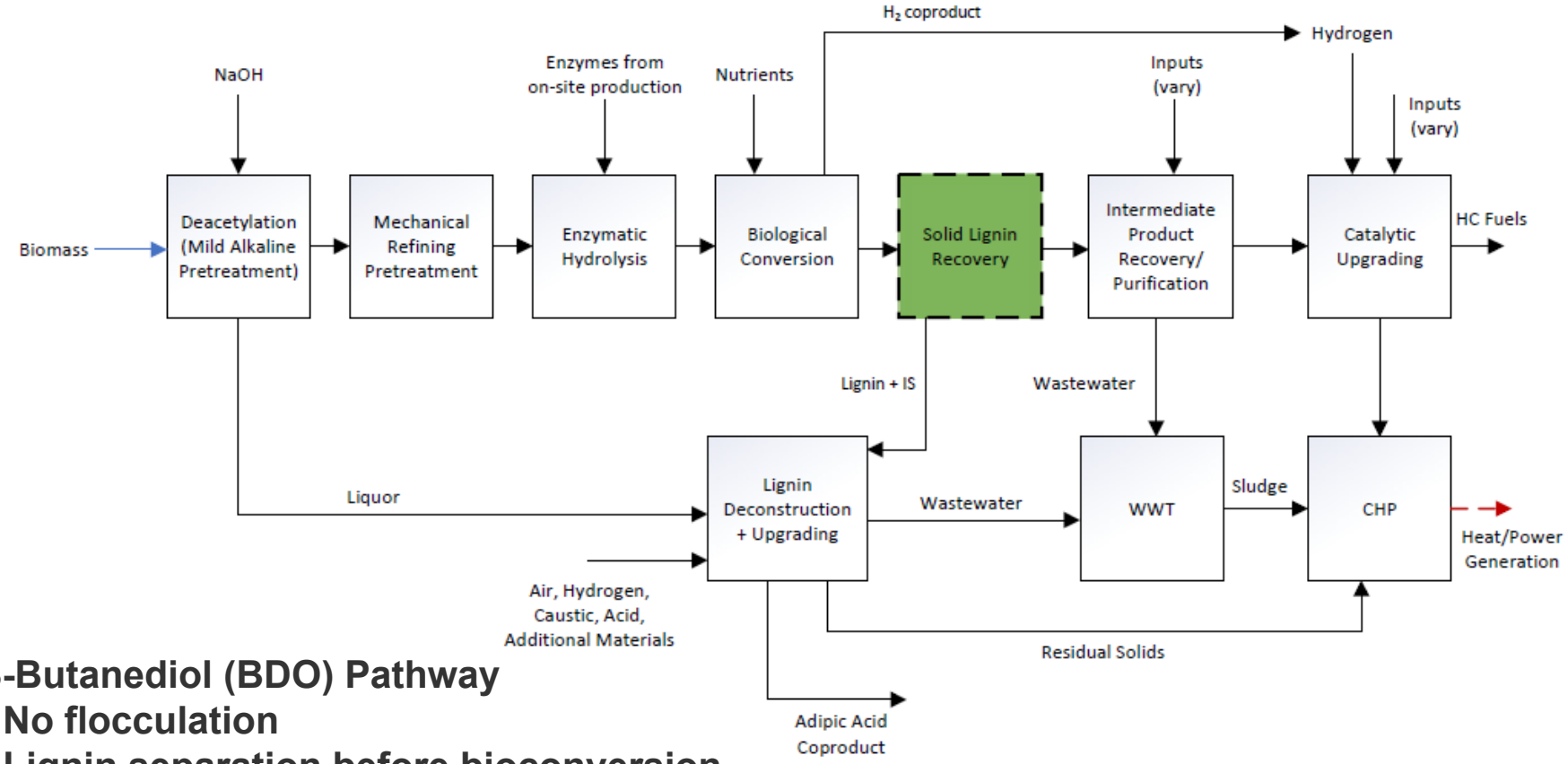
IS: Insoluble Solids

TEA assumptions:

- nth plant economics
- Projected yields
- Lignin recovered and valorized by base-catalyzed depolymerization and fermentation to muconic acid
- Sugar model: Flocculant has no impact on downstream processing

TEA Modeling

2018 TEA Model

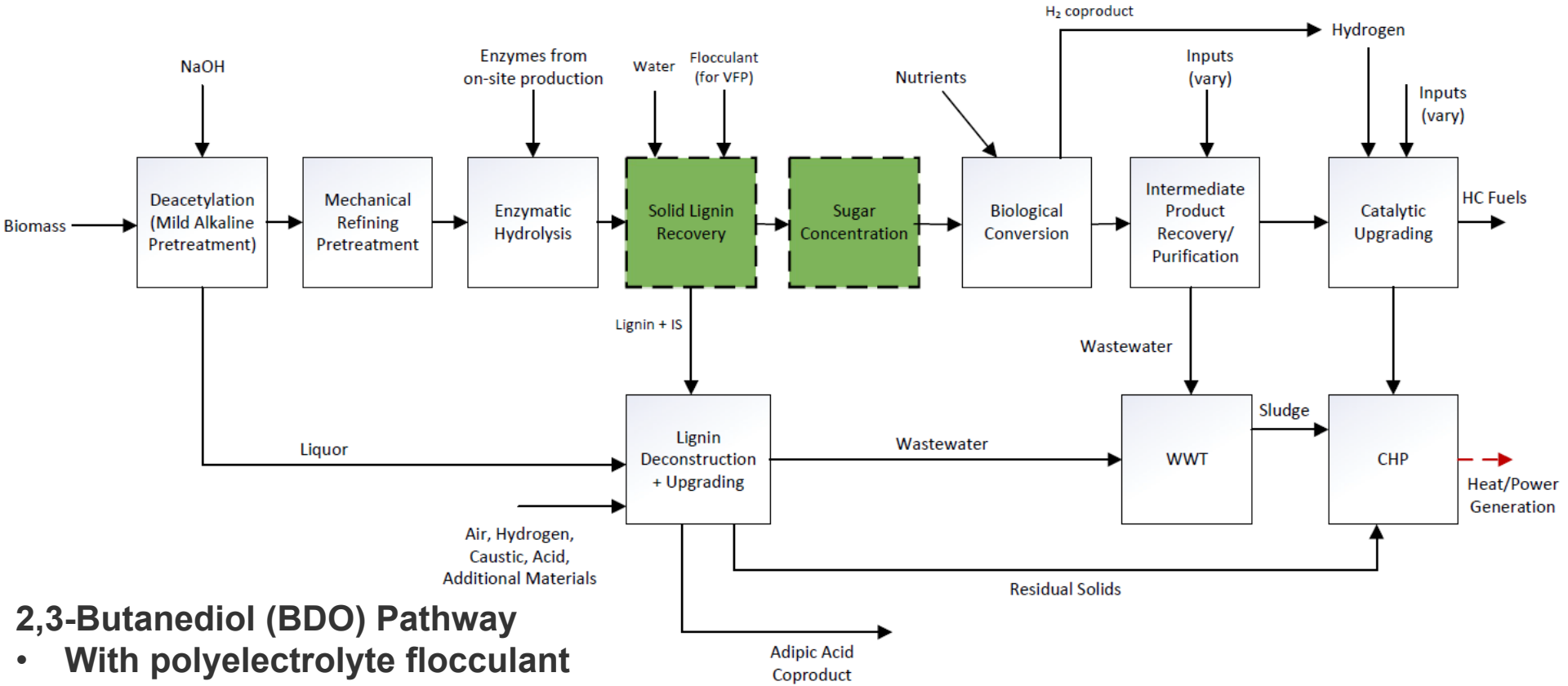


2,3-Butanediol (BDO) Pathway

- **No flocculation**
- **Lignin separation before bioconversion**

TEA Modeling

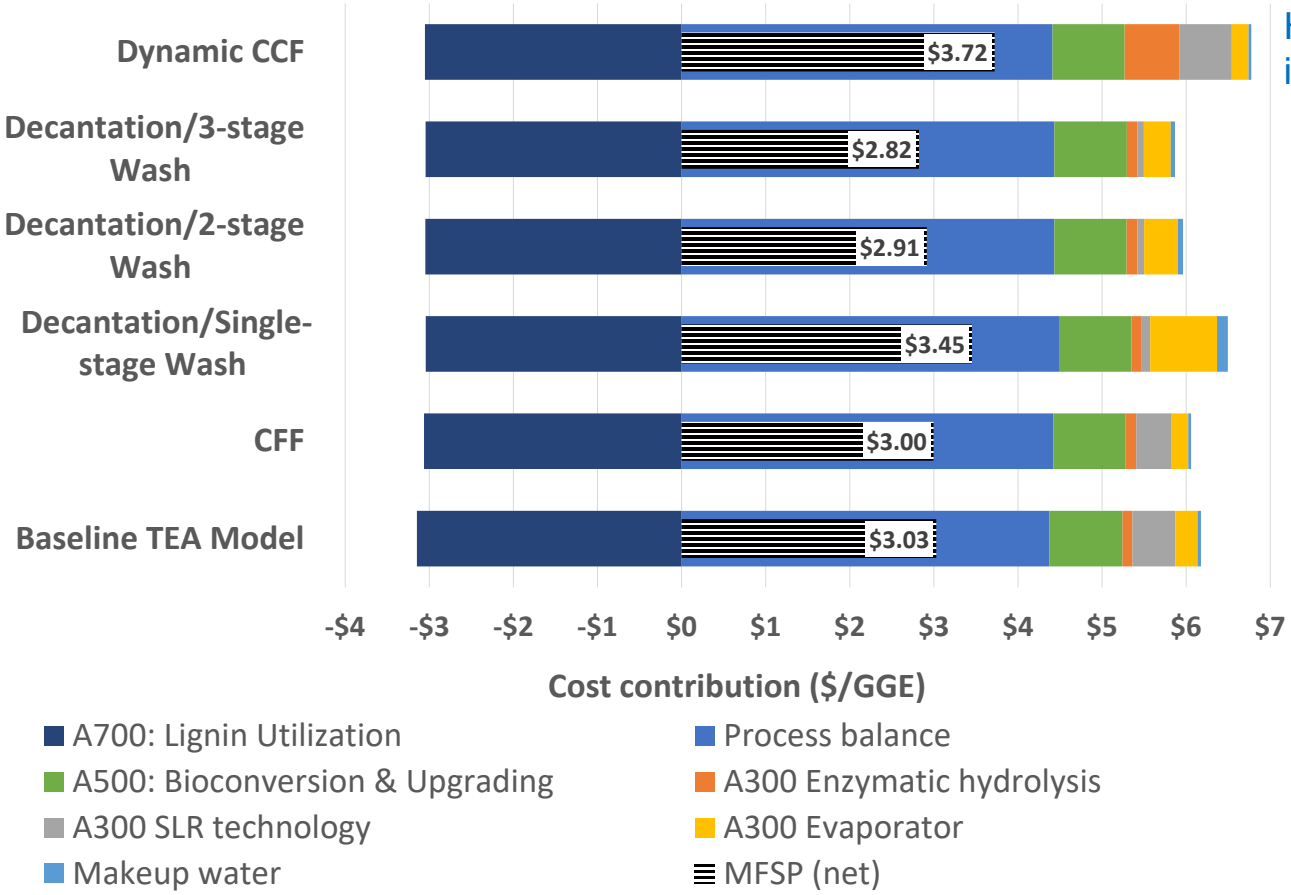
Modified Model Incorporating Flocculation - Baseline



2,3-Butanediol (BDO) Pathway

- **With polyelectrolyte flocculant**
- **Lignin separation before bioconversion**

TEA Results From Experimental Data



Higher degree of uncertainty in Dynamic CCF TEA results.

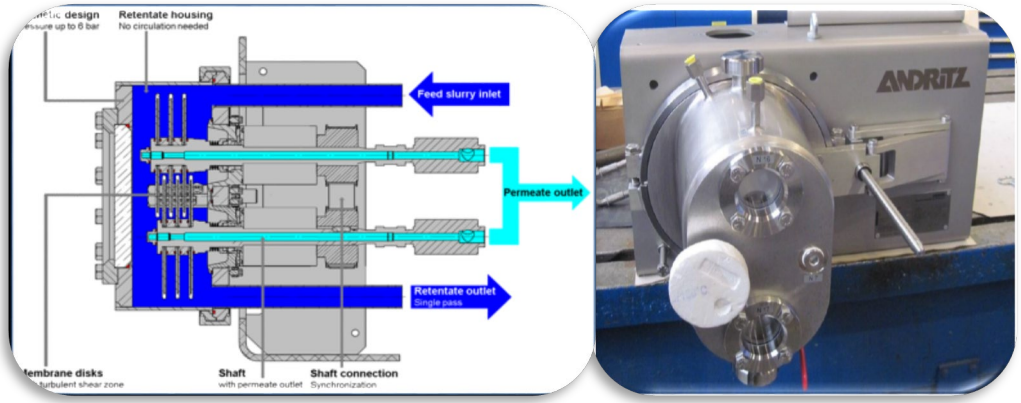
TEA generated a Go decision (< baseline to pursue pilot scale testing of non-flocculated process options.

Next Steps

- Generate pilot scale data (replicated data sets where possible)
- Validate washing models
- Update/improve TEA for non-flocculated processes

Pilot Plant Decanter

Pilot Plant CFF Unit



Larger Scale Dynamic CFF Unit

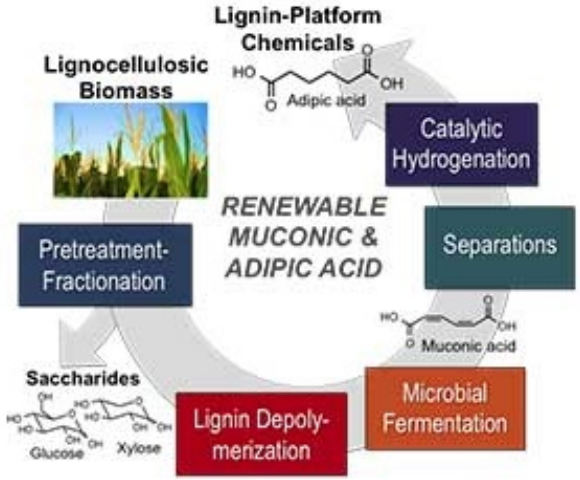
Summary

Management:

- Well developed project plan
- Strong NREL team

Approach:

- Year one focused effort on non-flocculated separations
- Year two effort determined by TEA



Impact:

- Lignin recovery performance data supporting the efficacy of the DMR process
- Guidance to industry and separations equipment manufacturers

Accomplishments:

- Found lower cost non-flocculated separation options
- More realistic/reliable data and models for this separation

Acknowledgments

Team Members

- Ryan Davis
- Matt Fowler
- Casey Gunther
- Wes Hjelm
- Ed Jennings
- Luke Klin
- Bob Lyons
- Ian McNamara
- Patrick Saboe
- Dave Sievers

Funding

- US Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office
- Josh Messner – BETO Technology Manager
- Jim Spaeth – SDI Program Manager

Quad Chart Overview

Timeline

- Project start date: Oct. 1, 2019
- Project end date: March 30, 2022

	FY20	Active Project
DOE Funding	$250,000	$600,000

Project Partners*

- Partner 1
- Partner 2

Barriers addressed

CT-C: Process Development for Conversion of Lignin

ADO-D: Technology Uncertainty of Integration and Scaling

Project Goal

Valorizing lignin residue remaining after enzymatic hydrolysis of pretreated biomass is necessary to achieve BETO's $2.50/GGE biofuel cost target for a biochemical pathway. But no clear options exist for recovery of washed/dewatered lignin residue for valorization—particularly for a DMR-process-derived lignin. The goal of this work is to develop an effective washing and recovery strategy for DMR-derived solid lignin that is more cost effective than current state-of-the-art.

End of Project Milestone

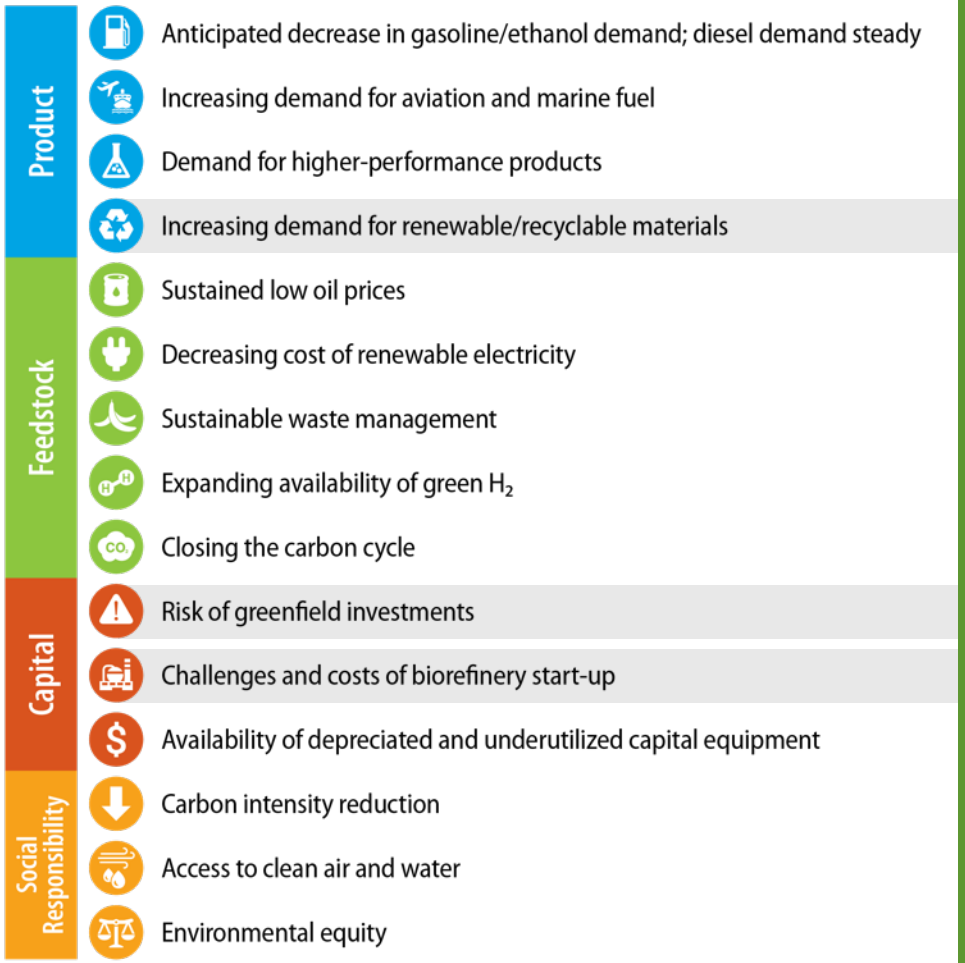
Generate pilot scale data for TEA still meeting year one economic results while retiring previously assumed performance assumptions.

Funding Mechanism

FY19 BETO Seed Project Lab Call

**Only fill out if applicable.*

Summary



NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- Provide a better researched and validated option for recovering DMR-derived lignin

Key Accomplishments

- Found several promising commercial options for DMR-derived solid lignin
- Lower cost compared to previously assumed separation process (i.e., flocculation)

Additional Slides

Responses to Previous Reviewers' Comments

From Merit Review Proposal (this is the project's first peer review)

- The milestones could be improved and should align with the targets described in the proposal. It would be useful to understand the project's methodology in prioritizing the processing options in the first year of the project.
    - Response: The various options will be selected base on the lowest cost equipment providing the best anticipated separation performance (sugar recovery > 95% and wash ratio < 20 L/g IS).

- The reviewer would have liked to see some test plans on the effect of flocculants on lignin conversion using biochemical conversions in addition to the catalytic tests. It seems that the proposal basically thinks the non-flocculated lignin separation will not work. If this is the case it might be better to either go ahead and test the flocculated lignin earlier in the project or bump the go no go earlier in the project in order to make better use of task 2 time and money.
    - Response: We believe, but don't know, that the non-flocculated option will likely not meet cost targets, nevertheless, the data has not been generated to prove this conclusion. It seems worth the risk and for a relatively small investment to better assess this option before dismissing it because it would eliminate the potential downstream problems that flocculants might cause.

Publications, Patents, Presentations, Awards, and Commercialization

- Publications to be developed