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Transforming ENERGY

Production of Low-Cost and Highly Fermentable Sugar from Corn Stover via Chemical-Recovery-Free Deacetylation and Mechanical Refining (CRF-DMR) Process

4/7/2023

Biochemical Conversion and Lignin Valorization Technology

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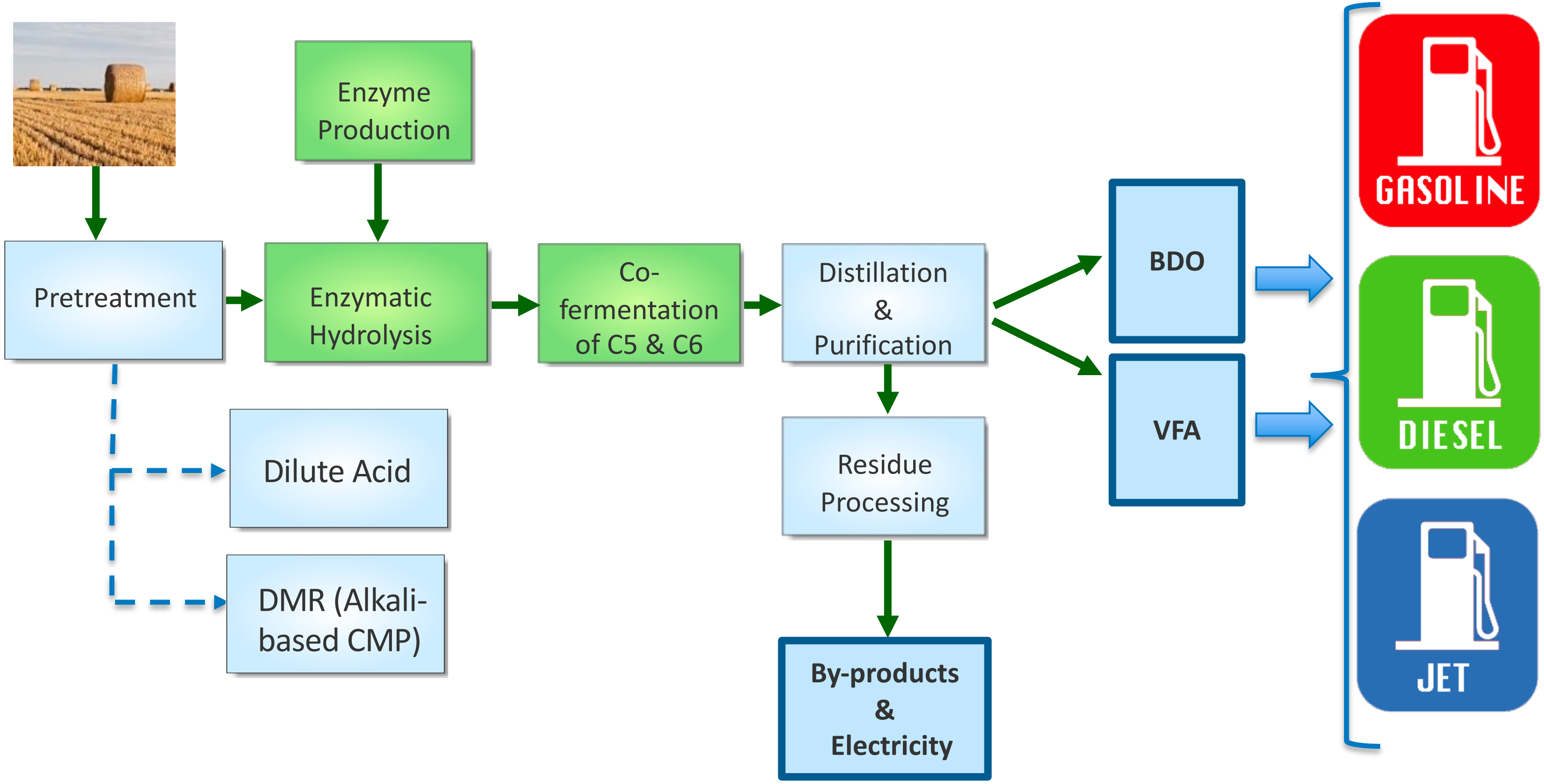
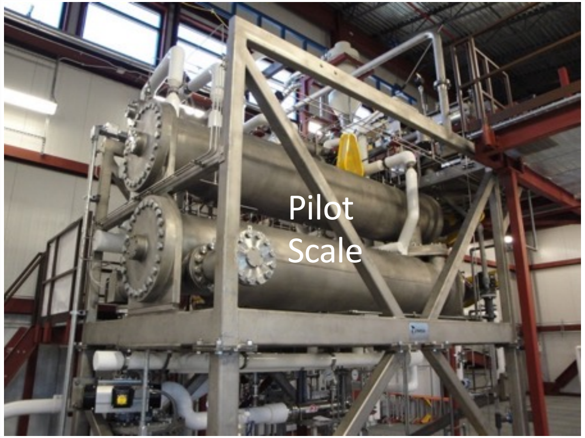
National Renewable Energy Laboratory

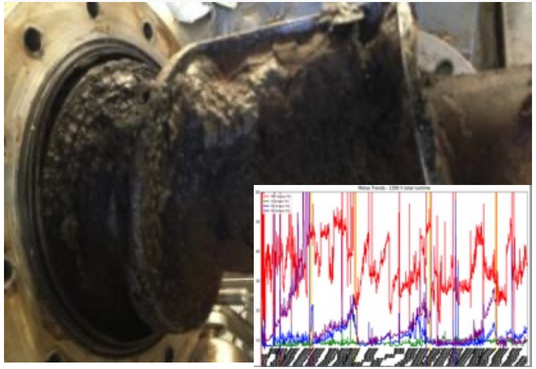
Project Background



Why NOT Dilute Acid?

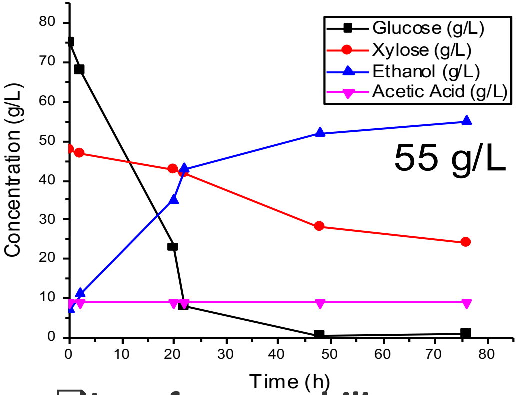


❑Unable to feed or steam blow back



❑Accumulating chars

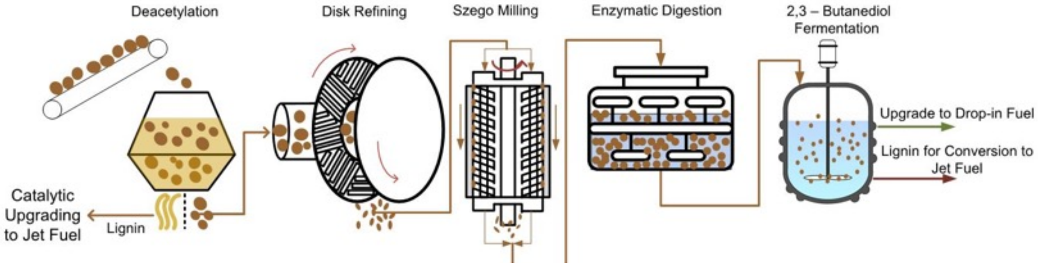
❑Wearing out feeding screws

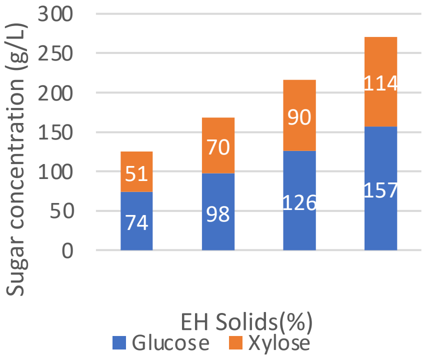


❑Low fermentability

Why DMR?

The Deacetylation and Mechanical Refining process

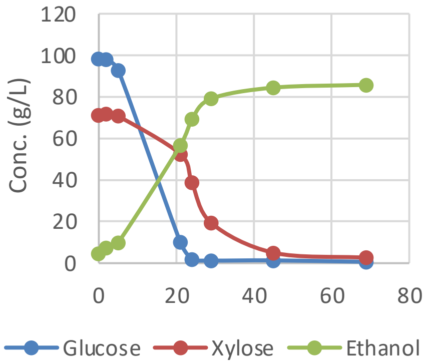




Advantages & Importance

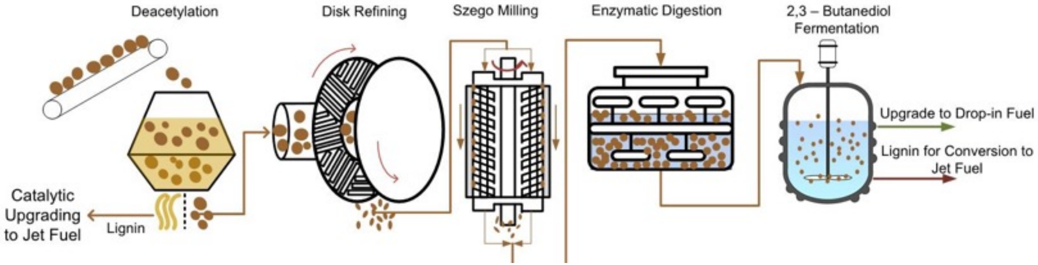
- Low Temp
- Atmospheric Pressure
- No toxic chemicals
- Uses industrial equipment
- High sugar yield/titer
- Low enzyme loadings
- Highly fermentable
- Reactive Lignin
- Does not contain sulfur

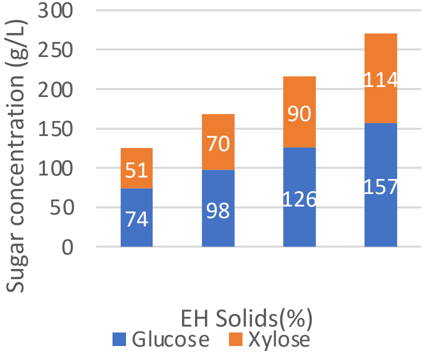
- ↘ Capital cost
- ↗ Operation reliability
- ↘Maintenance cost
- Scalable and Industry relevant
- ↗ Revenue
- ↘Operational cost
- ↗ Revenue and value-added products
- ↗ Catalyst life

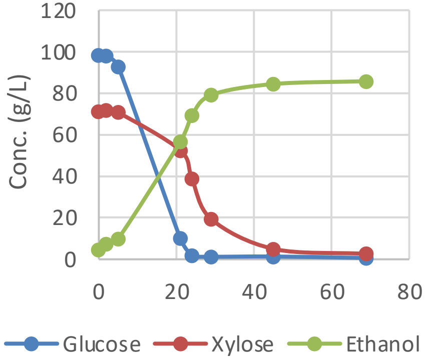


Why DMR?

The Deacetylation and Mechanical Refining process





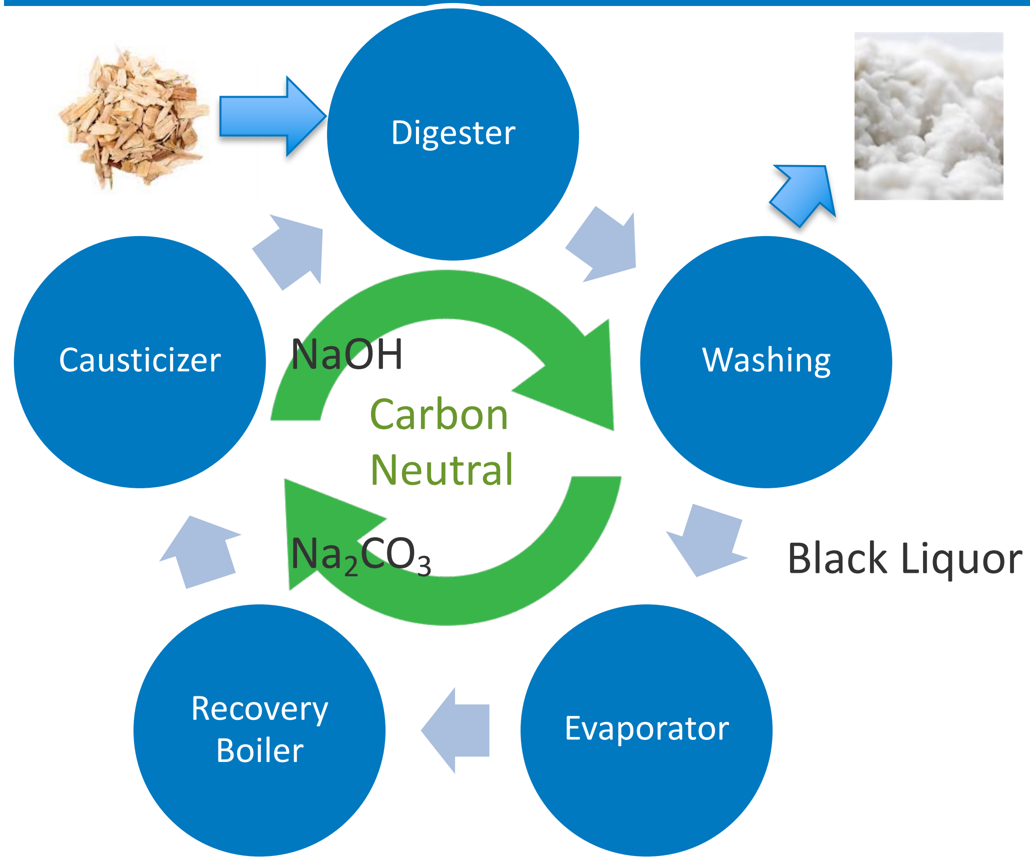


Challenges and Risks

NaOH Recovery!

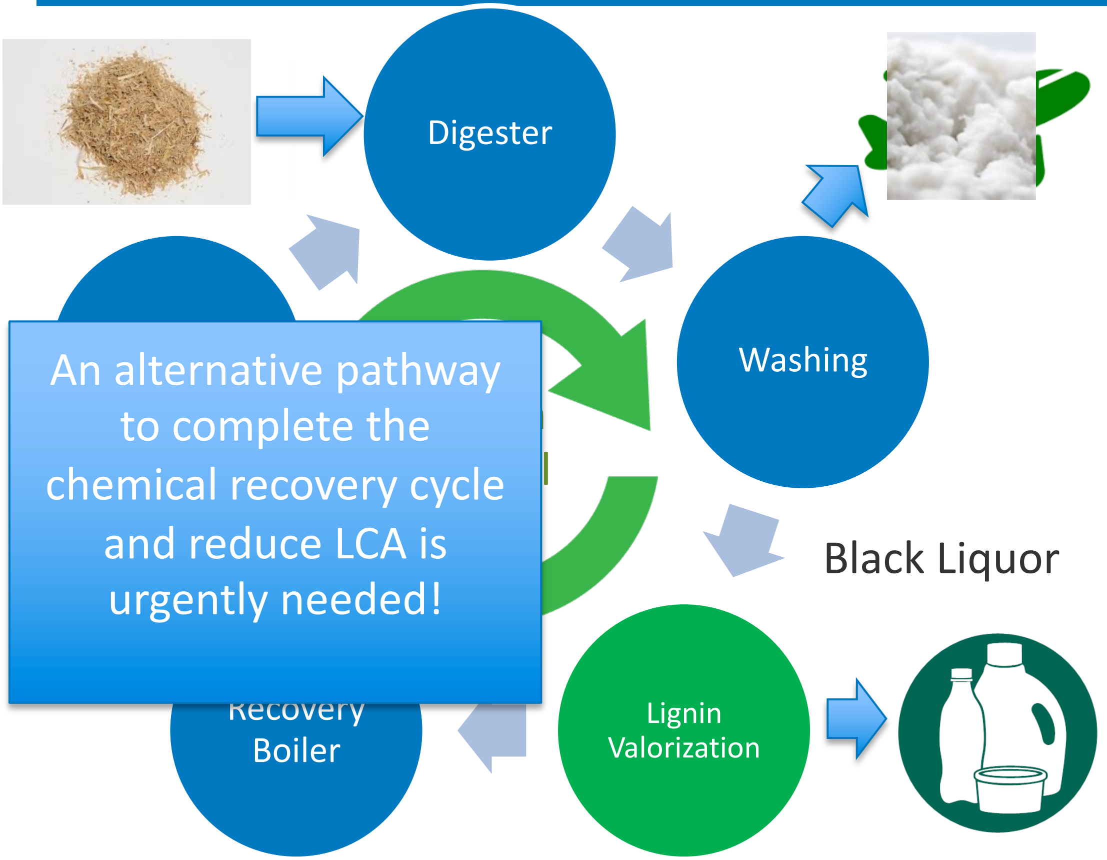
- High cost and GHG emission producing fresh NaOH
- High volume of wastewater
- Disposal of sodium salts
- Electricity usage (refining)

NaOH Recovery in a Kraft Pulp Mill



- DMR shares similarities with the Kraft pulping/ soda pulping process (much less alkali loading and lower temperature)
- NaOH are consumed by neutralizing acids produced from pulping process.
- Lignin from Kraft pulping is combusted in the recovery boiler to provide energy to recover NaOH and energy.
- Kraft pulping is generally considered as a Carbon Neutral process.

NaOH Recovery Challenges in Biorefinery



Jet fuel = $1200/tonne

Pulp = $750 /tonne.

During the conversion of carbohydrate to jet fuel, about 60% of the sugar weight is lost in the fermentation and hydrodeoxygenation process. So the revenue:

1 tonne cellulose to 1 tonne pulp =$750

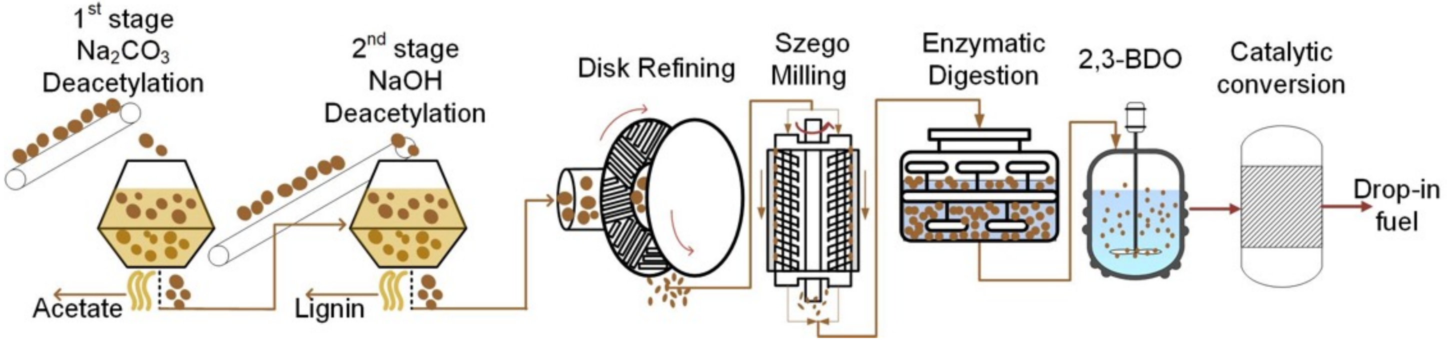
1 tonne cellulose to 0.4 tonne jet fuel < $500

- To reduce the production cost of SAF from lignocellulosic biomass, lignin needs to be converted into high value-added products.
- However, losing the heating value from lignin results in NaOH recovery and LCA issues.

Background: 2-stage Na_2CO_3 and NaOH Deacetylation (LTAD)

Modified DMR Process to Reduce GHG Emissions While Improving Sugar Yields

2-stage Na_2CO_3 and NaOH deacetylation replacing traditional 1-stage NaOH deacetylation



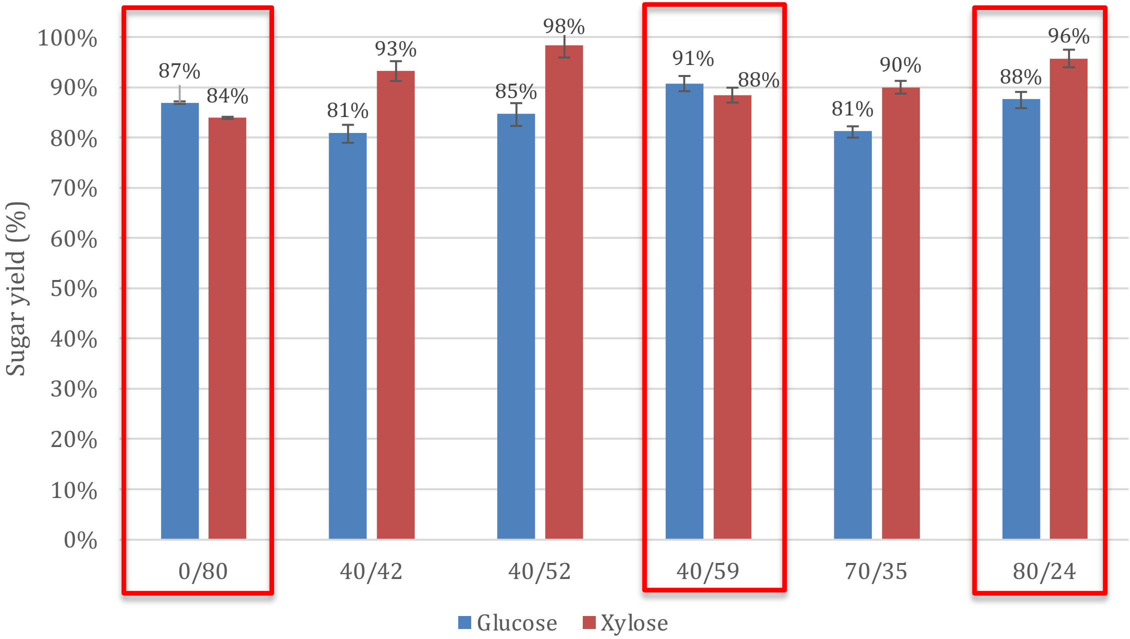
	GHG* (CO_2e/kg of chemical)	Cost ($/lb of chemical)
NaOH (100%)	2.1	0.24
Na_2CO_3 (100%)	0.7	0.08

*The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)

Hypothesis:

- 1st stage deacetylation uses Na_2CO_3 to neutralize acids in corn stover (acetic, formic, lactic acids and etc.)
- 2nd stage partial delignification with a reduced amount of NaOH to reduce usage of NaOH related GHG emissions.

2-Stage Deacetylated and Mechanical Refining

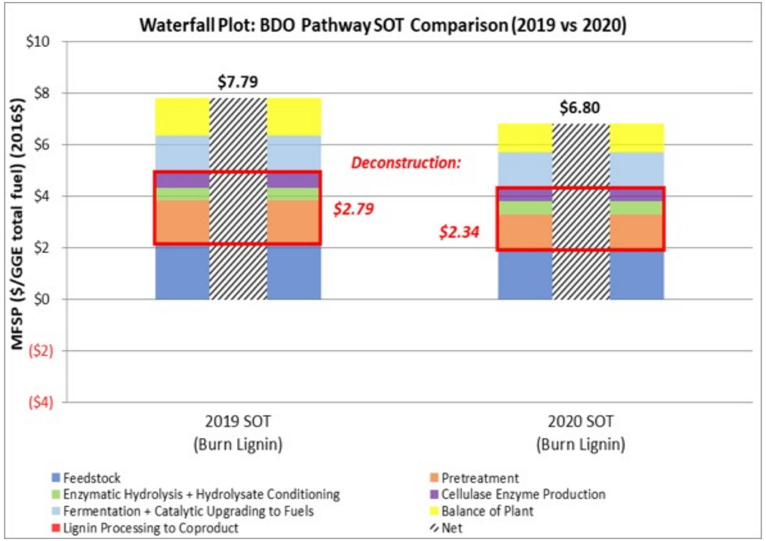


xx/xx : Na_2CO_3 (kg/tonne) / NaOH (kg/tonne) (all loadings based on original biomass weight)
Enzyme loading: 8 mg CTec3/g of cellulose and 2 mg HTec3/g of cellulose

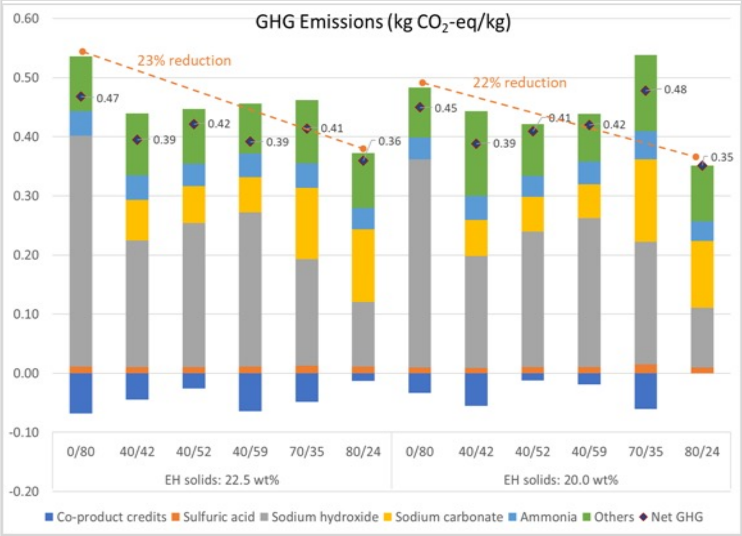
- Achieved target glucose yields (>90%) at 20% solids with an enzyme loading at 10 mg protein/g of cellulose.

Impact of 2-stage Deacetylation on TEA and LCA

Minimum Fuel Selling Price



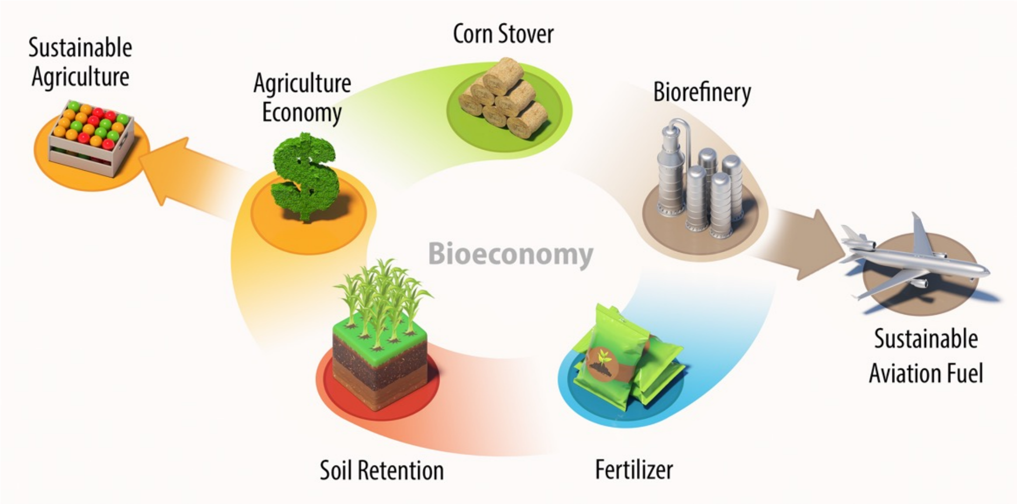
LCA Analysis

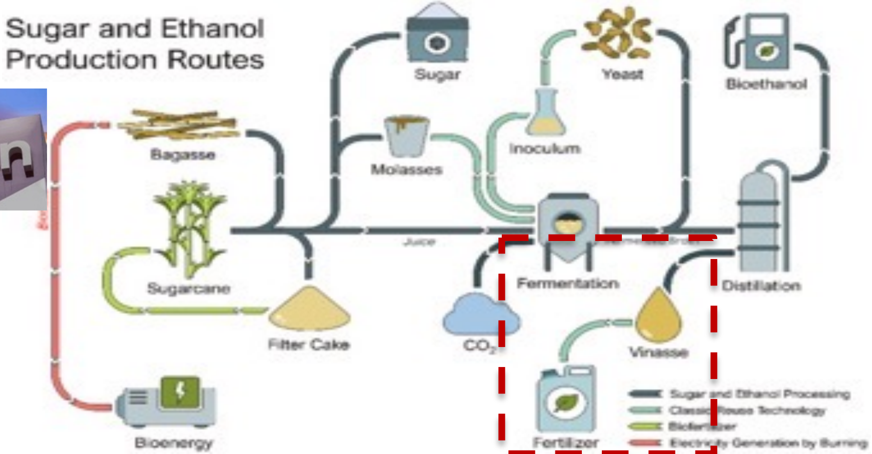


- The 2-stage deacetylation contributes nearly $1/gge reduction on the Minimum Fuel Selling Price (MFSP) in the FY20 SOT.
- The 2-stage deacetylation also reduces GHG emissions of sugar production by up to 23%.

Sustainable Aviation Fuels From Renewable Ethanol (SAFFire) Project

This Project: Closing the Loop





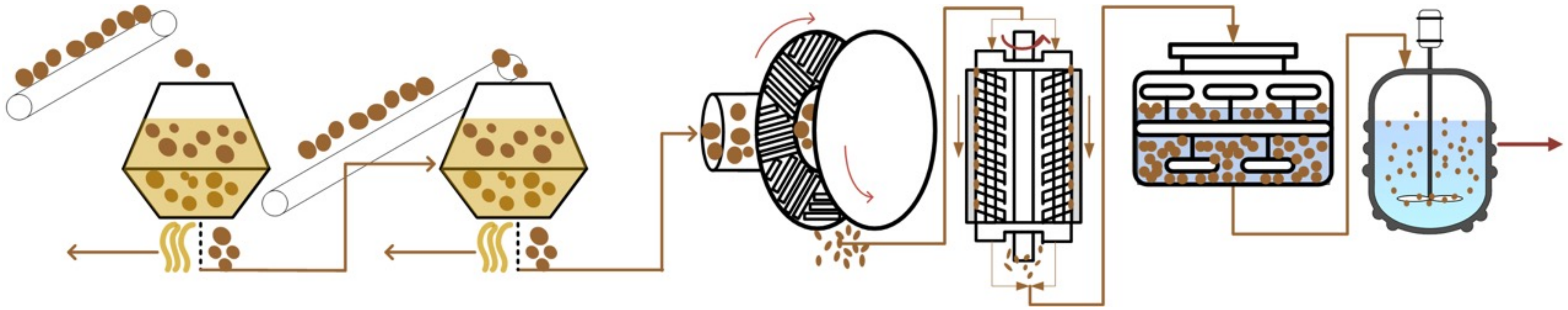
Creating a sustainable system where agricultural waste or by-products are converted into value-added products such as fuels and chemicals through biorefining processes, and these products including process wastes are then used in the agricultural sector, closing the loop of material and energy flow.

Project Goal

The goal of the proposed project is to develop a chemical-recovery-free Deacetylation and Mechanical Refining (CRF-DMR) pretreatment technology:

- Produce sugars at a Minimum Sugar Selling Price (MSSP) ≤ $0.20/lb.
- Achieve >90% biological upgradability related to pure sugar mock solution using industrial microbial organisms.
- Valorize pretreatment waste liquor as fertilizers to reduce GHG emissions as well as DMR sugar cost by avoiding the chemical recovery step.

1. Approach



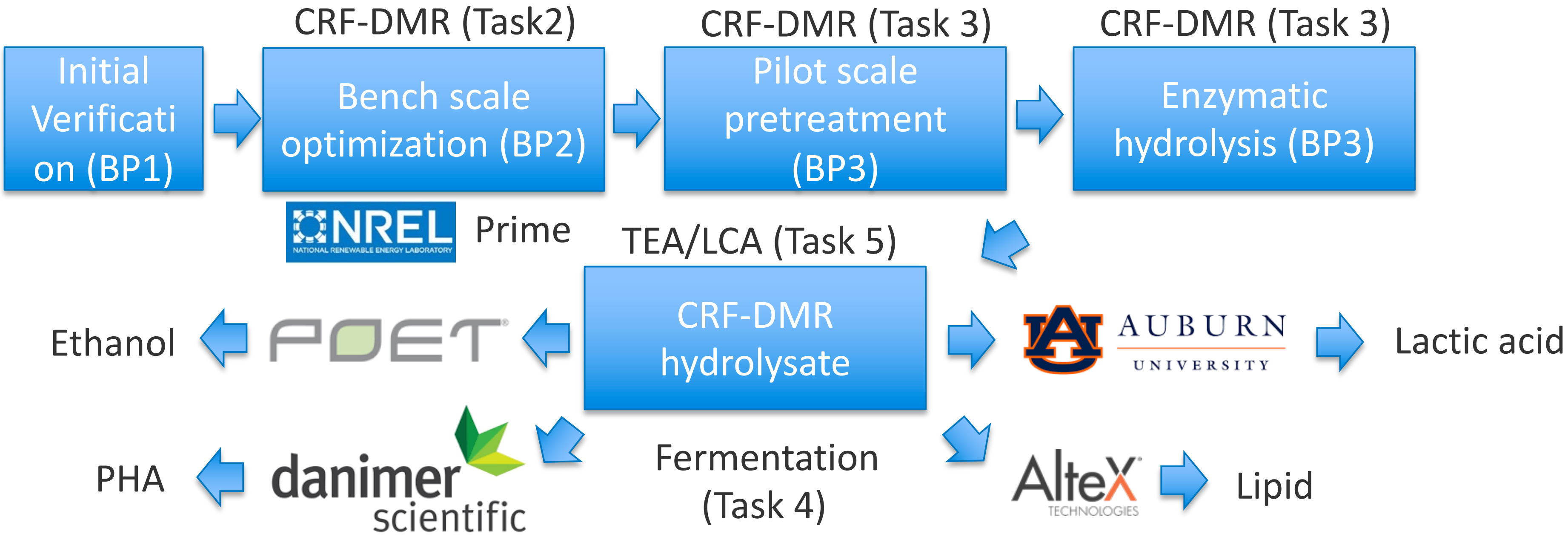
Advancing the current SOT of DMR pretreatment

- Use ammonia and potassium-based salt and alkali to soak and pretreat the biomass to remove acetate and reduce biomass recalcitrance by partial lignin removal
- Apply mechanical refining to further improve biomass digestibility
- The waste chemical from pretreatment will be utilized as fertilizer. The extracted lignin (30-50% of the total) will be returned to soil to enhance soil retention.

Potential Innovations

- Develop a novel chemical-recovery-free DMR process to reduce GHG emissions as well as CAPEX for chemical recovery system

1. Approach (cont.)



Critical Interim milestones (G/NG Q7):

- Show MSSP at $0.23/lb using CRF-DMR; Reduce CI by 10%
- Achieve over 75% of sugar convertibility for CRF-DMR sugars related to pure glucose and xylose with at least 3 partners

1. Approach (cont.)

A greenhouse bioassay test will be conducted to evaluate fertilizer replacement value of nitrogen (N), potassium (K), and sulfur (S). (Task 6)

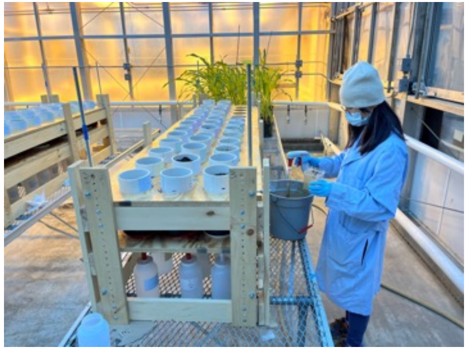
Sandy soil low on N, K, S compared with plant needs

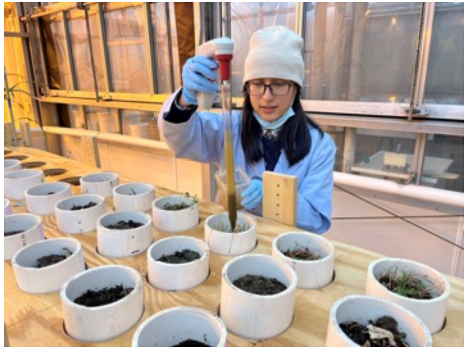
Treatments:
I. CRF-DMR waste liquor
II. Fertilizer N (bioassay 1), K (bioassay 2), S (bioassay 3)

Bioassay: Corn grown to 6-8-leaf stage, harvested, measured for total dry matter, concentrations of N, K, S

Estimate total uptake for N, K, S

Statistical comparison for total N, K, S uptake between green liquor and fertilizer treatments





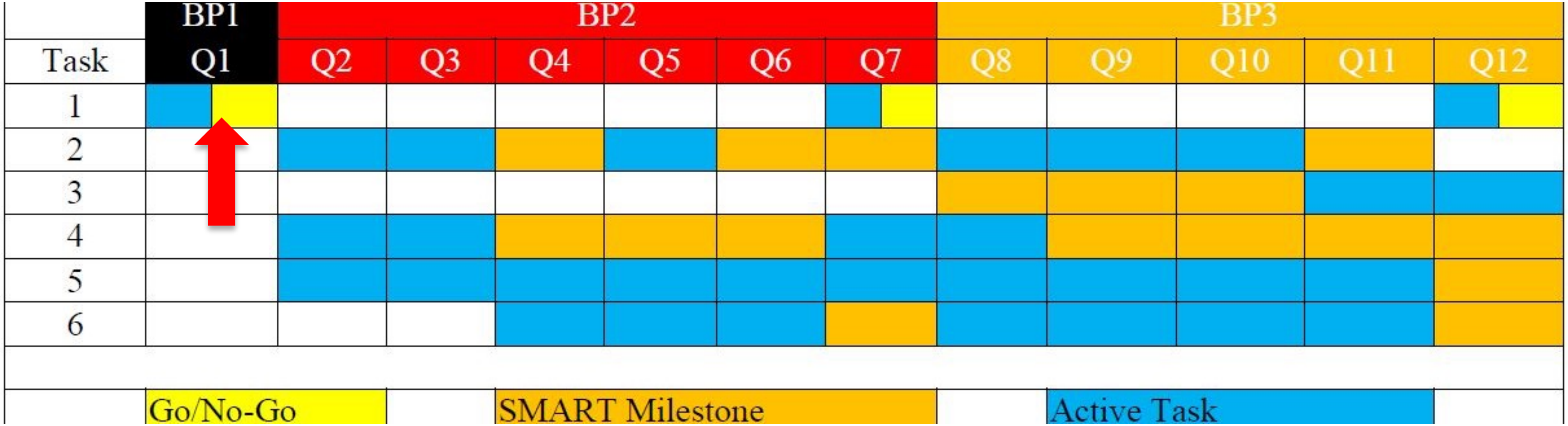
Critical Interim milestones (G/NG Q7):

- Increase N, S, and K nutrients availability and uptake by plants by 5% comparing with control plants

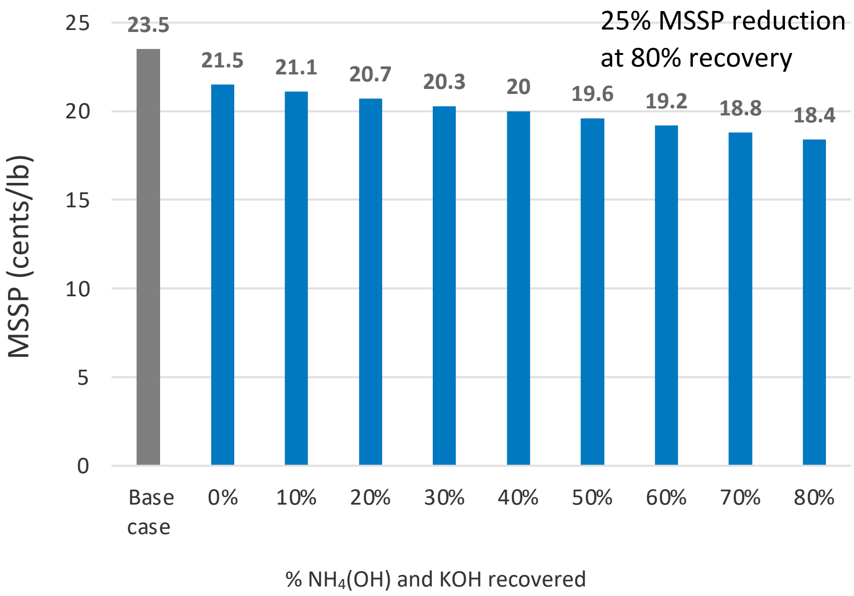
2. Progress and Outcomes

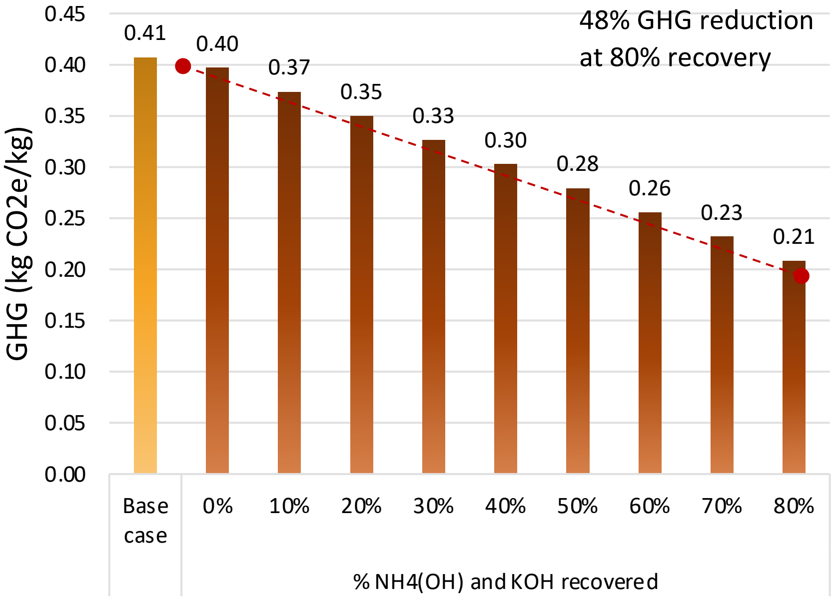
DMR Hydrolysate	Concentration (g/L)	Yield (%)
Glucose	131.6	92%
Xylose	50.6	81%
Arabinose	4.1	61%
Acetate/furfural/HMF	0	0%

- Currently at Initial verification
- Met the verification metrics by showing:
  - >80% glucose and xylose yields
  - >90% of PHA yield relate to pure sugar yield
- Fermentability of DMR hydrolysate will be verified using 2 more strains at industry partners



Preliminary TEA and LCA

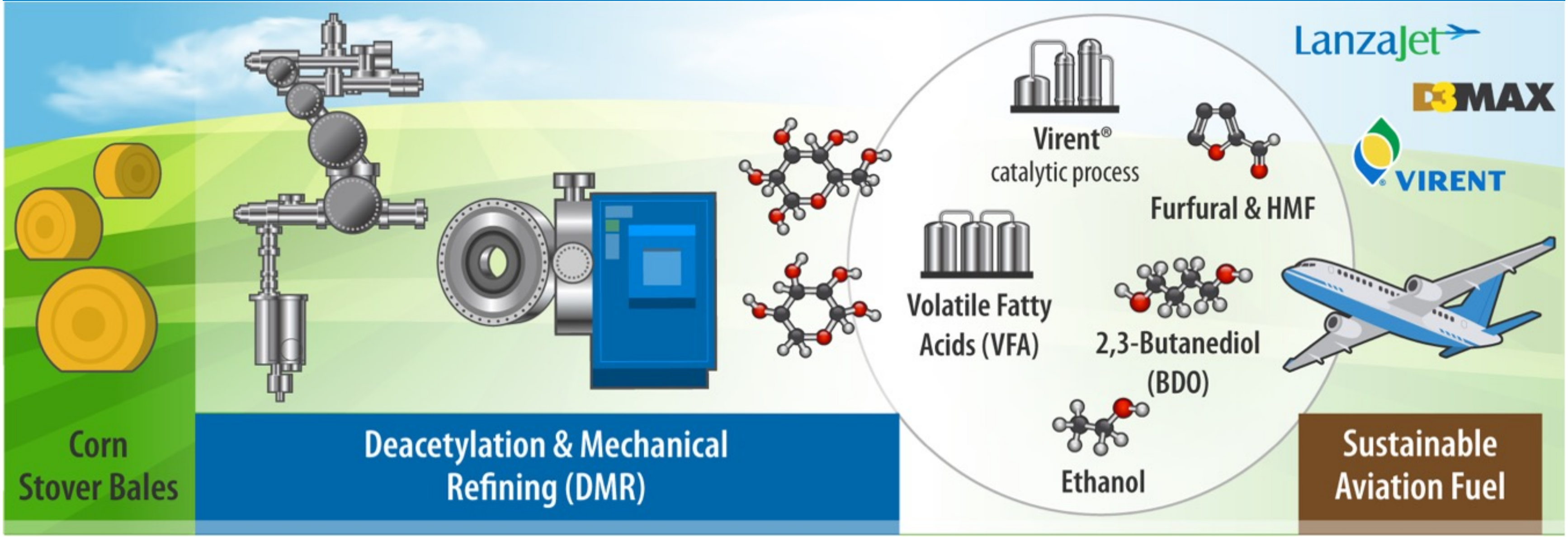




With 80% recovery of pretreatment waste chemicals as fertilizer

- 25% lower MSSP
- 48% lower GHG

3. Impact: DMR Process as a Clean Sugar Platform



- More robust and reliable compared to dilute acid pretreatment
- Produces highly fermentable cellulosic sugars at 0.20-0.25 cents/lb
- Reduces GHG emissions and increases revenue for corn EtOH plants
- DMR sugar is the platform chemical for SAF production via 2,3 BDO/ Ethanol, VFA, etc.
- By unlocking the SAF production from 150 million tons of corn stover/year, DMR process could produces > 10 billion gallons of SAF from corn stover sugars.
- The project will address the alkali recovery issues for DMR process

3. Impact

- Decarbonize the **transportation sector** by reducing the energy consumptions during the production of sustainable aviation fuel from terrestrial biomass. (Reduce GHG in biomass sugar production)
- Decarbonize the **industrial sector** by collaborating with industries for producing low carbon biofuels and biochemicals.
- Compared to a lower technology readiness level (TRL) recovery technology, using fertilizer as an end product offers a significant advantage because it has an existing market and would not require extensive process development.
- Develop **integrated biorefinery with sustainable agriculture** to close the loop of carbon sequestration while improving soil nutrients and retention by combining the processes of bioenergy production and waste stream valorization in agriculture industry.

Summary

- This project is aiming to connect the gap **between Agriculture and Biorefinery Industries**, closing the loop of material and energy flow.
- Our approach is to use ammonia and potassium-based salt and alkali in pretreatment, and valorize the waste chemicals and extracted lignin for fertilizer use and soil retention.
- We will pave the way to integrate lignocellulosic sugar production with commercial fermentation and downstream upgrading process by our industry partners
- Our project is targeted to go through initial verification in April 2023.

Quad Chart Overview

Timeline
- 4/1/2023
- 3/31/2026

	FY22 Costed	Total Award
DOE Funding	$0	$2.8MM
Project Cost Share*	*$0*	$700k

TRL at Project Start: 3
TRL at Project End: 4

Project Goal
The goal of the proposed project is to develop a chemical-recovery-free Deacetylation and Mechanical Refining (CRF-DMR) pretreatment technology to produce highly fermentable cellulosic sugars at a Minimum Sugar Selling Price (MSSP) ≤ $0.20/lb.

End of Project Milestone
- Reduce MSSP to $0.20/lb
- Achieve over 85% of sugar convertibility
- Introduce agronomic and economic value to the byproduct liquor

Funding Mechanism
FOA

Project Partners*
- University of Washington at St. Louis • USDA
- POET • Washington State University
- Danimer Scientific • Auburn University • Altex

Only fill out if applicable.

Thank you!

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