DOE Bioenergy Technologies Office 2023 Project Peer Review

Sugar is the New Crude®

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Biochemical Conversion & Lignin Valorization

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Project Overview- History

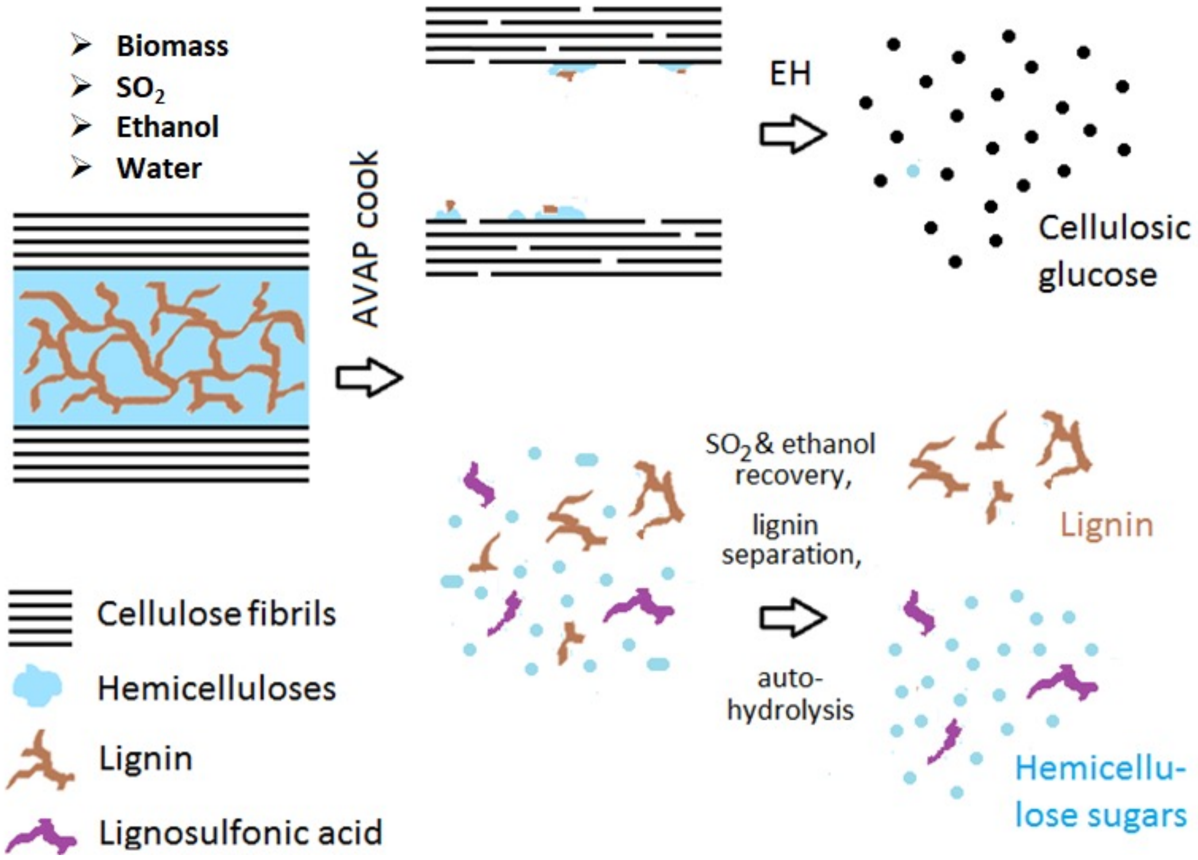
AVAPCO has produced cellulosic sugars from biomass with our patented AVAP® process at the Thomaston Biorefinery since 2010, 1000's of run hours.

- Up to 2.5 BDt/d biomass fractionation capacity (depending on feedstock)
- 0.5 – 1.6 BDt/d cellulosic sugars capacity
- ½ BDt/d BioPlus nanocellulose capacity
- DCS automation with fully integrated PI data historian
- Designed for 24/7 operation
- State-of-the-art process control/analytical and R&D laboratory
- Fully integrated bio-butanol pilot plant
- Integrated cellulosic jet fuel pilot plant

Project Overview- AVAP Process Advantages

- **Fractionation & Saccharification**
  - Biomass feedstock agnostic
  - Recovery of pretreatment chemicals
  - Separate pure streams of hemicellulose, cellulose, and lignin allow co-product utilization
  - Low sugar and ethanol production costs

- **Saccharification**
  - Low enzyme consumption resulting from cellulose purity (low lignin content)



Total sugar yield from cellulose + hemicellulose is 87–97% of theoretical depending on feedstock

Project Overview- AVAP Process Advantages

AVAP sugars from various forms of biomass have been confirmed by third-party partners to be highly fermentable to biochemicals, with C6 sugars performing similar to starch-based dextrose.

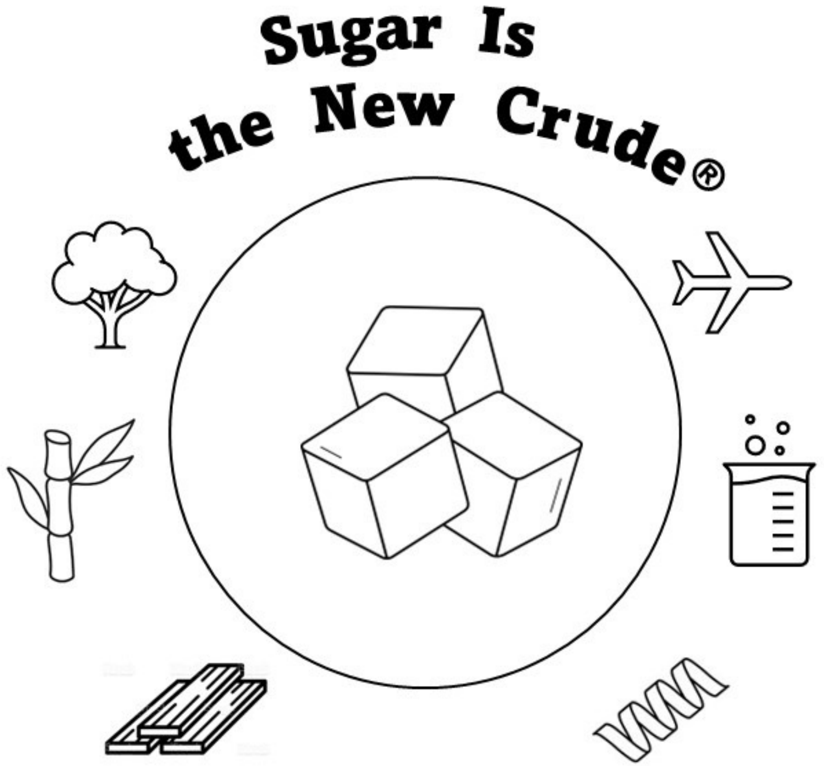
Feedstocks Utilized	
Hardwoods	**Softwood**
Aspen	Spruce
Beech	Larch
Birch	Red Pine
Black Ash	Jack Pine
Eucalyptus	Loblolly Pine
Agricultural Residues	Balsam Fir
Corn Stover	Douglas Fir
Oil Palm Empty Fruit Bunch	Mixed softwoods
Sugarcane & Energy Cane Straw and Bagasse	
Tobacco Stalks	
Wheat straw	

Biochemicals Made
1,4 BDO
n-butanol
Ethanol
Ethylene
Sustainable Aviation Fuel
Succinic Acid

Inhibitors Studied
Residual fractionation chemicals
Furfurals and hydroxy methyl furfurals from sugar degradation
Phenolic compounds from lignin degradation
Acetic acid from hemicelluloses
Formic acid from furan degradation
Metal salts from biomass
Lignosulfonates from SO_2

Project Overview- Goals

- Reduce AVAP's minimum sugar sales price (MSSP) to <$0.20/lb
  - Exceptionally low-cost residual feedstocks
  - Process Intensification
- Produce 400 kg of raw C5+C6 sugars from each feedstock
- Clean sugars to two different levels of purity and deliver raw and cleaned sugars to third-party conversion partners
- Quantify the conversion performance of each sugar grade compared to dextrose and xylose
  - Cellulosic ethanol (an alcohol to jet SAF intermediate)
  - Lactic acid
  - Proprietary biochemical
  - Second-generation feed protein
- Update the Techno-Economic and Life Cycle Analysis baselines for each sugar grade from each feedstock



Project Overview- Partners

Feedstock Suppliers

Energy Cane Straw	Forest Residues	Construction & Demolition Wood Debris
USDA	Georgia Forestry Commission	Lucky Stone

Conversion & Academic Partners

Proprietary Biochemical	2G Feed Protein	Lactic Acid	Data science analysis and visualization
BASF – We create chemistry	ARBIOM	Corbion – Keep creating	Clark Atlanta University

Project Overview- Relevance to BETO Goals

AVAPCO's **"Whole Barrel"** Biorefinery approach demonstrates how ***low-volume, high-value coproducts*** along with ***high-volume commodity liquid fuels*** enables profitable biorefineries.

There is growing demand for **sustainable, low carbon footprint chemicals** that are not derived from food.

The market size of sugar-derived biochemicals is estimated to reach **113 million tons by 2050**.

We know that all kinds of people want to buy products with a significantly reduced or even net-zero carbon footprint. That's why so many of our products are created to help other companies and their customers reach their climate targets.

Products for climate protection

BASF
We create chemistry

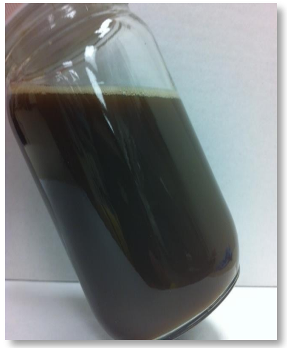
"The Program is focused on developing and demonstrating technologies that are capable of producing low-carbon drop-in biofuels at $2.50 per gallon gasoline equivalent (GGE) by 2030, as well as associated renewable chemical co-products to achieve this target"

"*Enabling a diverse product slate from a biorefinery* can substantially reduce risks associated with early biofuel plants and biorefineries."

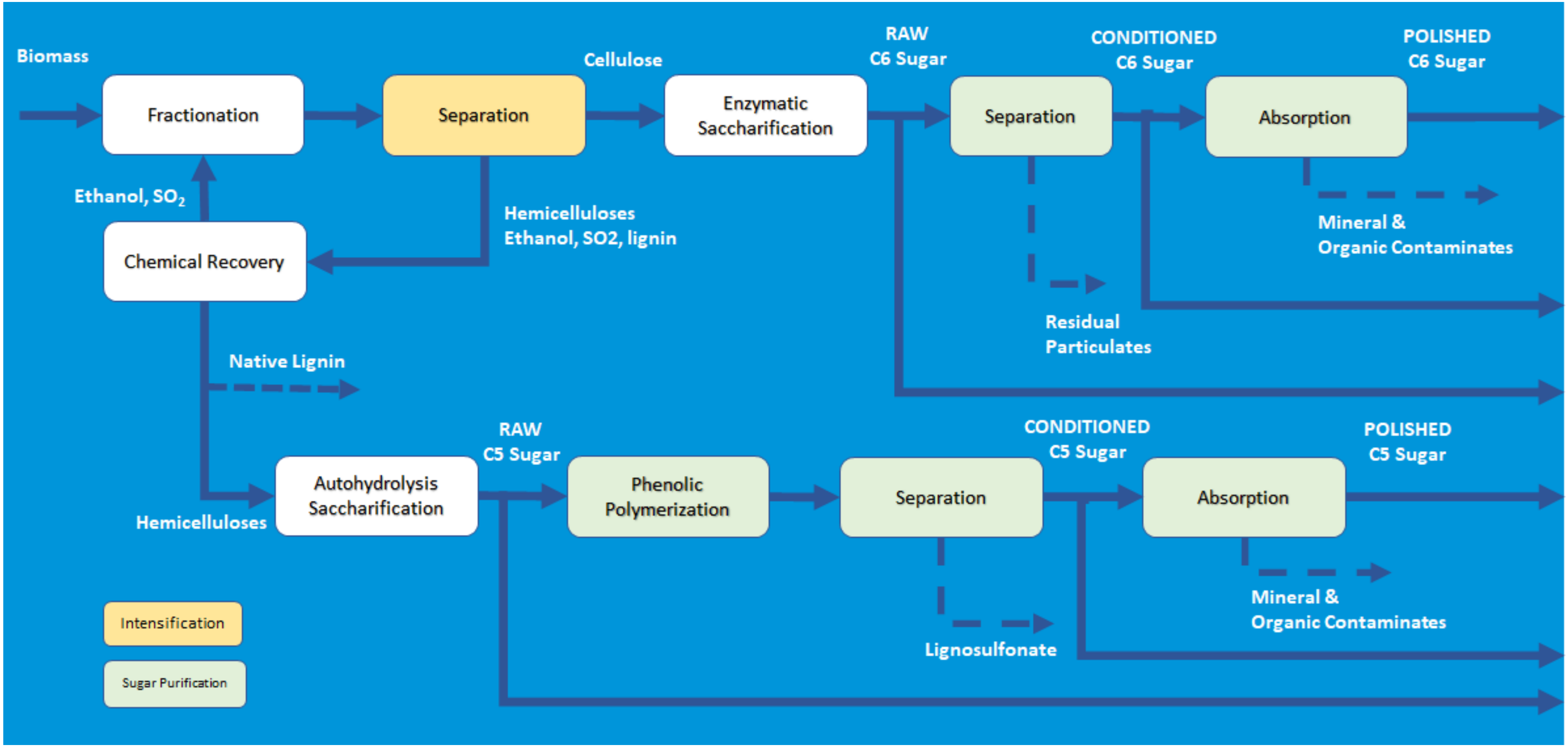
"Bioproduct production can also significantly de-risk upstream infrastructure and processes needed for biofuels by providing an increased economic incentive for construction of pioneer biorefineries"
- BETO

Project Overview- Relevance to Scientific and Commercialization Goals

- Prove at the integrated pilot scale that the AVAP process can convert a variety of non-ideal, low-cost feedstocks to high quality sugars to enable price sensitive biobased fuels, chemicals, and protein markets.
- Define the relationship between feedstock inhibitor profile, sugar purification cost OPEX and CAPEX, and sugar conversion performance for a variety of waste feedstocks and conversion processes.
- Decrease MSSP and carbon footprint of cellulosic sugars to enable lower cost biofuels and biochemicals through effective use of abundant domestic biomass residues.



1. Approach- Process



1. Approach- Major Tasks

Project Execution Phase has just begun

- **Feedstock Procurement**
  - Regional partners are secured
- **Equipment Procured, Installed, & Commissioned**
  - 5 months allocated for procurement and installation
- **Sugar Production**
  - Laboratory-scale optimization of AVAP fractionation conditions for each feedstock followed by integrated pilot runs to produce several hundred kgs of sugar from each feedstock
- **Sugar Conditioning**
  - Analysis of inhibitor profile of both C5 and C6 sugars from each feedstock
  - Production of “conditioned” and “polished” sugars from each feedstock utilizing proprietary methods based on membranes, activated carbon, ion exchange, and lacasse catalyzed polymerization of lignin-derived species
- **Sugar Conversion**
  - Partners will quantify convertibility of the various sugars compared to pure dextrose and xylose
- **LCA & TEA Updates**
  - Based on the pilot trial and conversion data, the baseline LCA and minimum sugar sales price will be updated for each sugar grade

1. Approach- Challenges, Risks, and Decision Points

- **Top challenges facing the approach**
  - Inflation related price escalation of equipment
  - Potential for extended equipment delivery time due to Covid-related back-ups
- **Project Risks Related to Non-Ideal Feedstocks**
  - Low Feedstock Sugar Yield (medium)- Fractionation optimization
  - Low Sugars Conversion Yield (medium)- Extensive characterization of raw sugars
- **Go/No-Go Decision Points**
  - Intermediate Verification: 7/30/2024
    - All sugar grades produced that meet yield and quality targets
  - Final Verification: 4/30/2025
    - Conversion data received from partners identifying potential market value of each sugar grade and MSSP targets achieved

1. Approach- Success Metrics

Parameter	Target	Units
Digestion		
Sugars Recovered	96	% of sugars in biomass
Sugar Hydrolysis		
Enzymatic Hydrolysis (C6)	≥85	% glucan to glucose
Autohydrolysis (C5)	95	% hemis to monomer form
Sugar Conditioning		
Suspended Solids Removed (C6/C5)	≥95 / ≥70	% wt.
Low Molecular Weight Phenolics Removed (C5)	≥30	% wt.
Sugar Polishing		
Conductivity (C5 & C6)	per partner spec	mS/cm
Overall Process		
Sugars Yield	85-90	%, kg total monosaccharides produced/ kg total biomass saccharides
Minimum Sugar Sales Price	<0.20	$/lb

1. Approach- Diversity, Equity & Inclusion

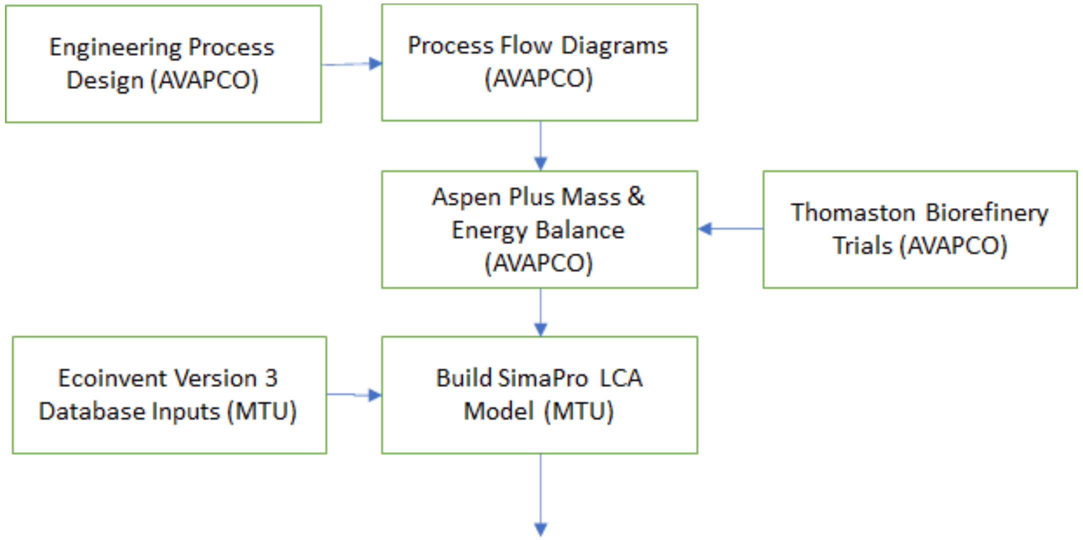
- Project builds on 8+ year close collaboration with HBCU Clark Atlanta University (CAU)
- Students will perform data science analysis and visualization to correlate
  - Feedstock properties
  - AVAP process conditions
  - Purification requirements
  - Sugar quality and performance
- Jointly Develop a biorefining and conversion special topics course for CAU
- AVAPCO will recruit for project internships and staff positions at CAU and Southern Crescent Technical College in Thomaston
  - Thomaston is classified as a rural, disadvantaged population with 23% living in poverty

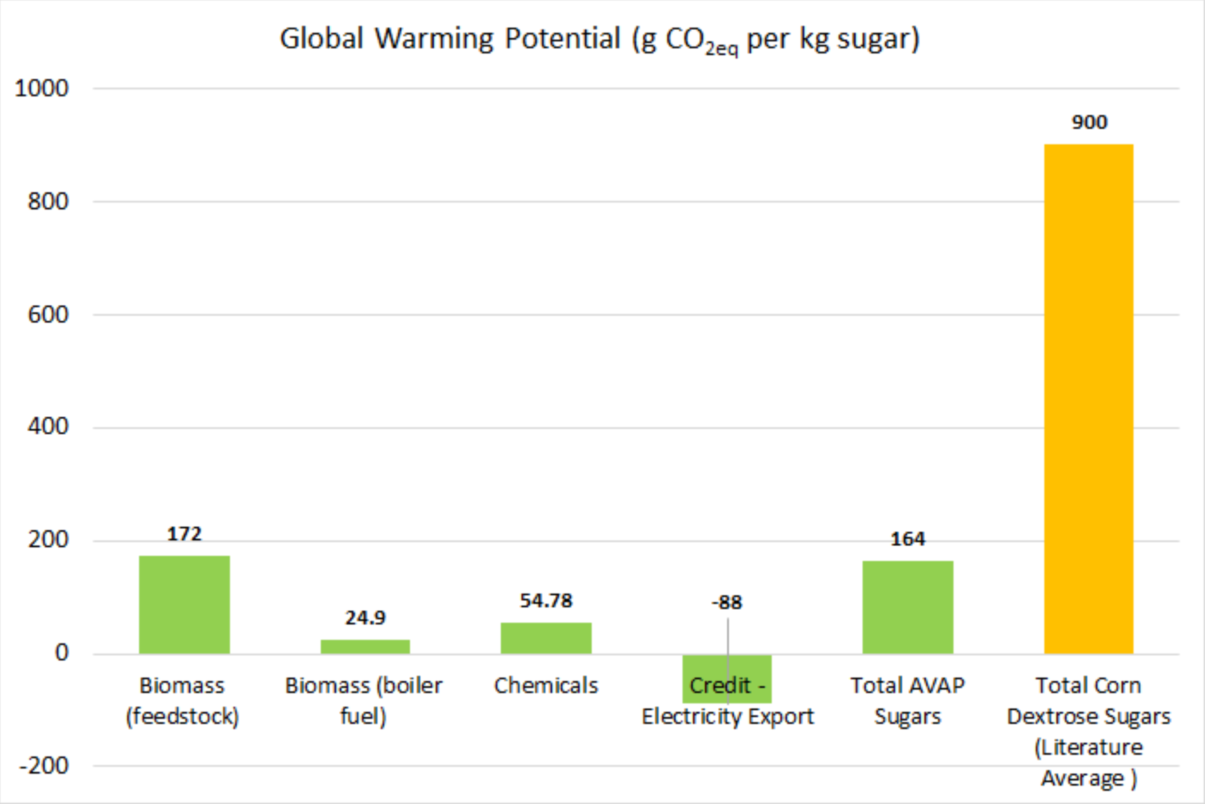
CAU
CLARK ATLANTA UNIVERSITY

SOUTHERN CRESCENT TECHNICAL COLLEGE

2. Progress & Outcomes- Life Cycle Analysis Baseline

The GHG emissions (g CO_{2eq} / kg sugar) associated with a 70 tpd AVAP C5+C6 sugars plant using HW chips as feedstock with an onsite biomass boiler are ~82% less than corn dextrose sugars





2. Progress & Outcomes- Techno-Economic Analysis Baseline

At commercial scale (~900 BDT/day stand-alone sugars plant), the MSSP of AVAP sugars is below $0.20/lb for the three feedstocks based on supplier delivered feedstock price.

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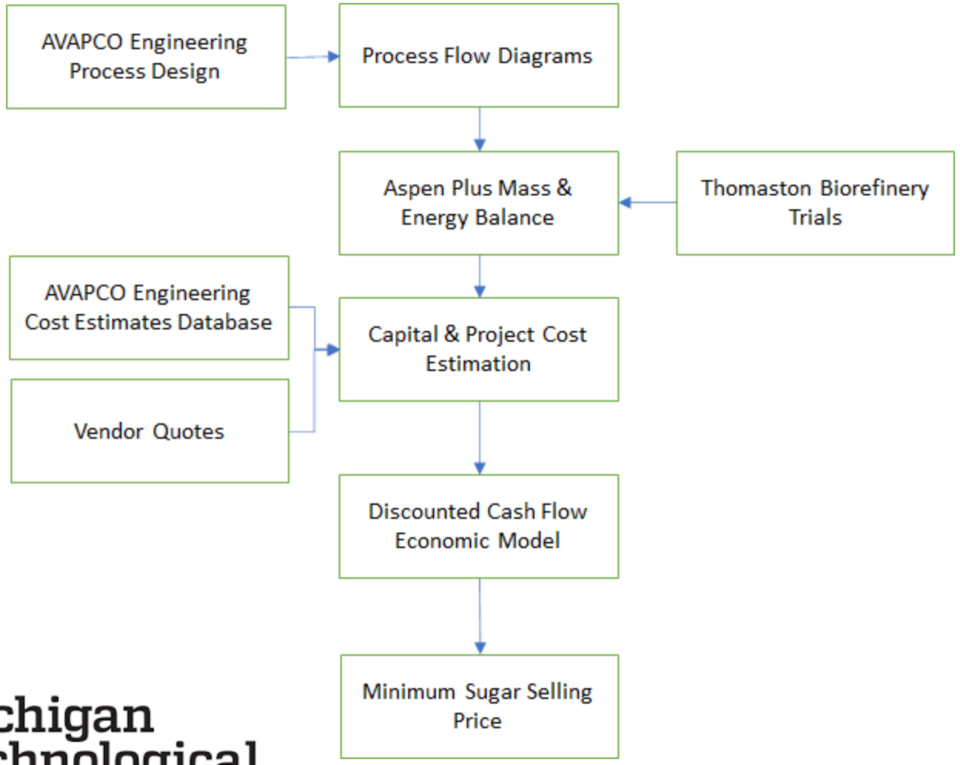
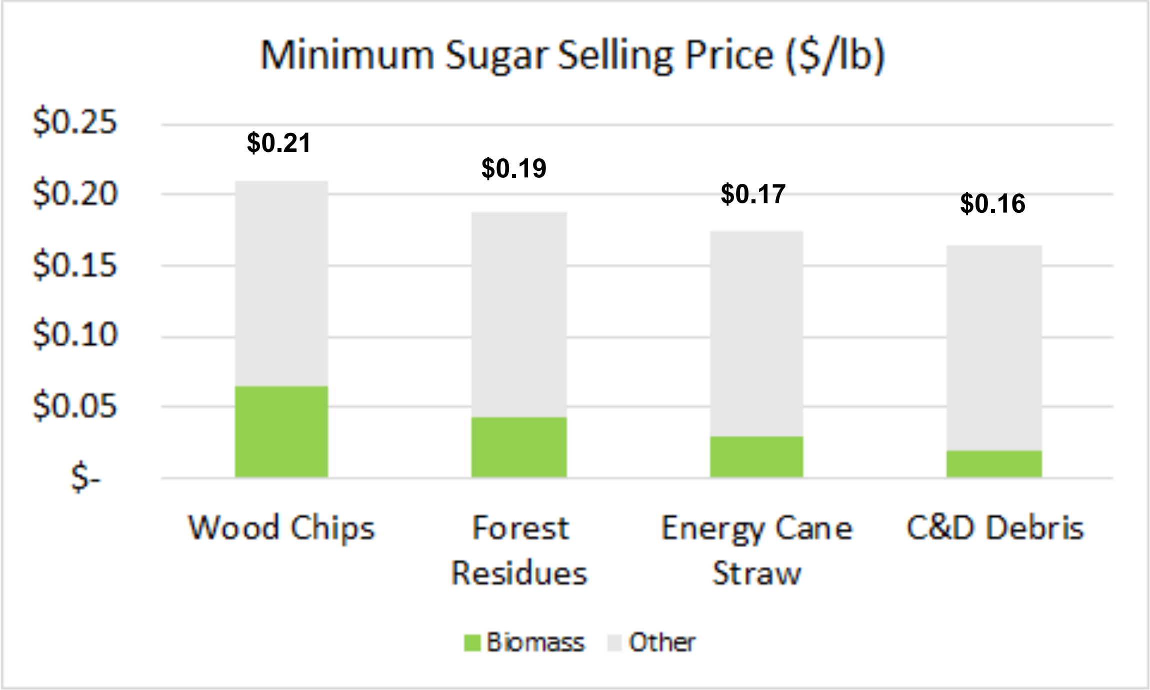
Process intensification lowers the prices further by $0.02/lb.

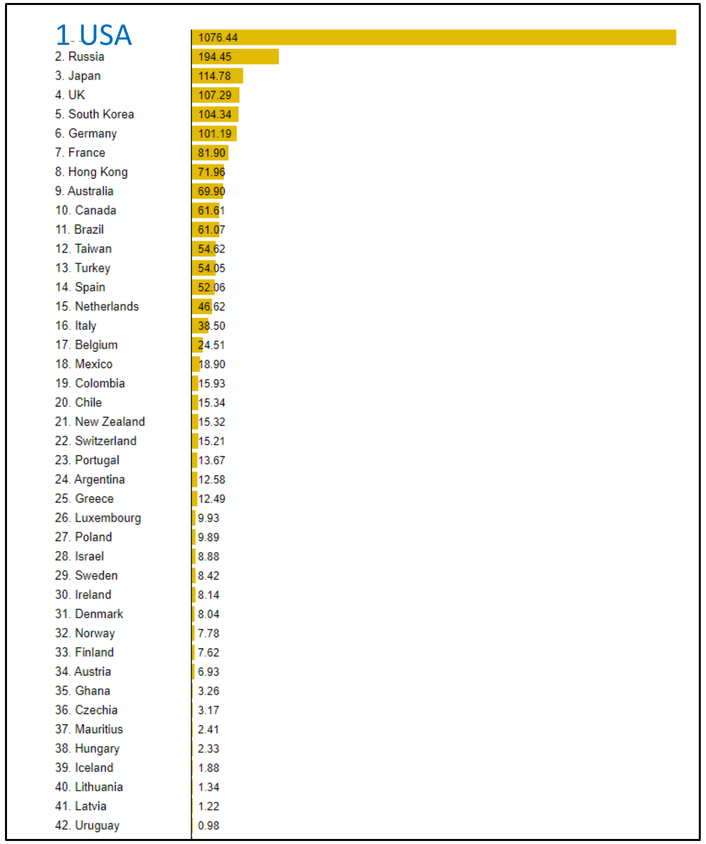


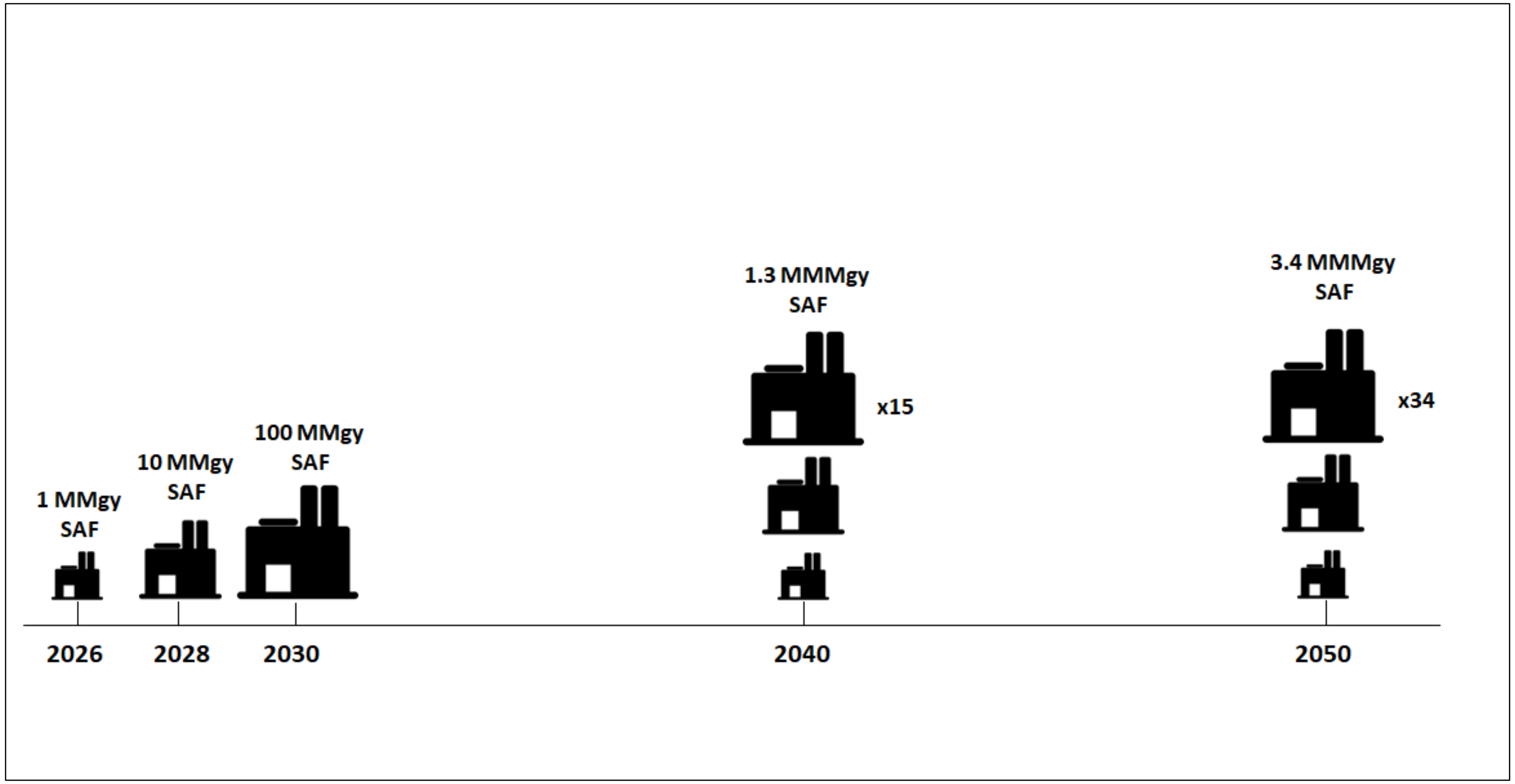


Michigan Technological University 1885

3. Impact- #1 Enable Lower Cost Production & Replication of SAF

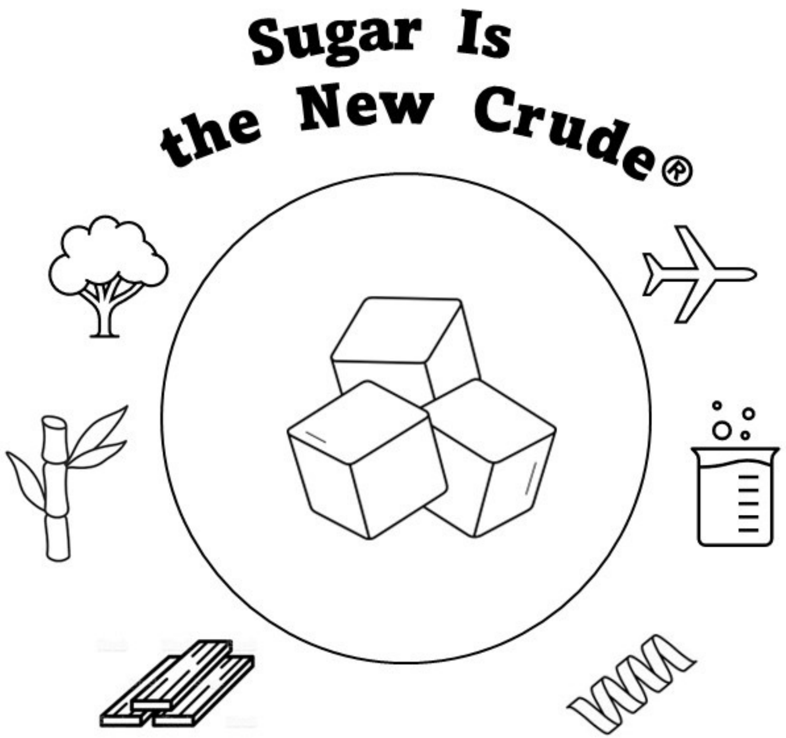
- The United States accounts for ~43% of global jet fuel consumption
- According to the Air Transport Action Group, global SAF demand could reach 160 billion gallons per year by 2050
- With a conservative 5% market penetration in the U.S., 34 AVAP-enabled SAF could be built domestically by 2050





3. Impact- #2 Expand Utilization of U.S.'s Billion-Ton Biomass Resources

- **Approximately 340,000 tons dry biomass per day would be consumed by 34 AVAP-enabled SAF plants**
  - Roughly equivalent to the daily consumption of the U.S. Pulp & Paper Industry
  - DOE estimates 85 million dry tons of construction waste, forest residues and energy cane will be available at $40-60/ton compared to $85/ton for woodchips



Summary

- Next Steps- equipment and feedstock procurement, installation, commissioning and start-up
- Energy cane straw, forest residues, and wood-based construction debris will be converted to sugars having three-different levels of purity
- Conversion partners will convert each grade of sugar to lactic acid, feed protein, a proprietary biochemical
- AVAPCO will convert each grade to ethanol for SAF production
- LCAs and TEAs will be produced for each sugar to determine their carbon footprint and MSSP

Quad Chart Overview

Timeline
- *10/01/2021*
- *5/31/2024*

	FY22 Costed	Total Award
DOE Funding	*$41,161.85*	*$2,800,000*
Project Cost Share	*$10,290.46*	*$700,000*

TRL at Project Start: 5
TRL at Project End: 7

Project Goal
Determine the lowest purity and cost of AVAP® sugars from three different residual feedstocks that gives a convertibility ≥90% of the pure dextrose/xylose standard for each of the four conversion products studied and a minimum sugar sales price of ≤$0.20/lb sugar.

End of Project Milestone
At least one grade of sugar from each feedstock with a manufacturing cost price of ≤$0.20/lb sugar has achieves a convertibility ≥90% of the pure dextrose/xylose standard.

Funding Mechanism
FY21 BETO Scale-up and Conversion
DE-FOA-0002396
Topic Area 2: Affordable, Clean Cellulosic Sugars

Project Partners
- BASF
- Corbion
- Arbiom
- Clark Atlanta University

Thank You

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AVAPCO

Additional Slides

Highlights from Initial Verification Go/No-Go Review

- The verification team was satisfied with background data that the team presented to justify the technical basis for the current project.
- The verification team reviewed the technical target metrics and concluded that they are reasonable.
- The verification team concluded that the AVAP process is industrially relevant and future commercial scale operation is feasible.
- The Thomaston Biorefinery has demonstrated the efficacy of the AVAP process for other feedstocks on several previous products for over a decade, demonstrating expertise in and the capability of operating the process and the facility.
- The Thomaston Biorefinery has demonstrated key operational parameters necessary for successful processing of biomass.
- The equipment and facilities seem correctly sized to the scale of the proposed operations.
- The AVAPCO facility has been operating for over a decade and conforms with the proper safety measurements and procedures.

Commercialization Status

Results from the project are eagerly awaited by AVAPCO's licensees and development partners in the Sustainable Aviation Fuels and biochemicals spaces.