# DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

# ABBA: Advance Biofuels and Bioproducts with AVAP

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Systems Development and Integration

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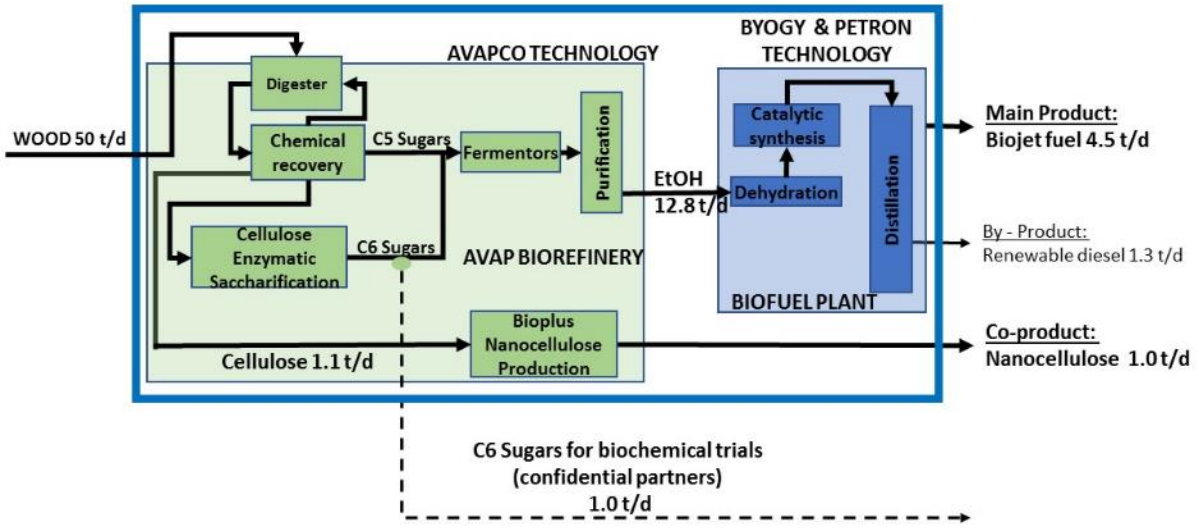
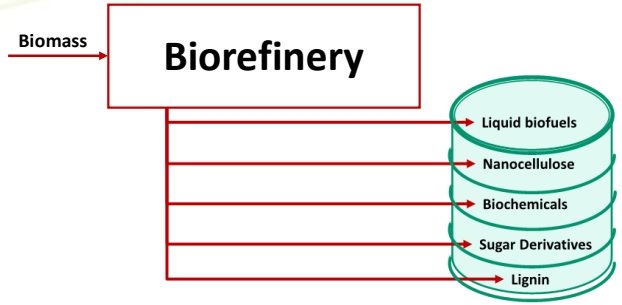
This presentation does not contain any proprietary, confidential, or otherwise restricted information

# Project Overview

- **What are we trying to do?**
  - Perform technical validation of integrated process, process optimization, and basic engineering for an AVAP® 50 tpd woody biomass demonstration plant for co-production of full replacement bio jet fuel and nanocellulose
  - Demonstrate how ***low-volume, high-value nanocellulose*** co-produced with ***high-volume commodity liquid jet fuel*** enables a profitable biorefinery at reasonable scale.
  - Meet BETO goal of ***a mature modeled sale price of $3/gallon*** gasoline equivalent of Advanced Biofuel in 2007 dollars.
- **What are the risks?**
  - Policy uncertainty related to premium value for low carbon fuels
  - Financing demonstration plant construction and operation




## The "Whole Barrel" Approach

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# Project Overview

## How is it done today and what are the limits? Why is it important?

### AVAPCO LLC.

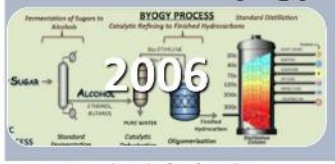
Biorefinery R&D

Engineering & Construction

Demo Operations

Nanocellulose Installation

### Byogy Renewables



Drop-in Biofuels R&D

Pilot Operations

Air Force Testing

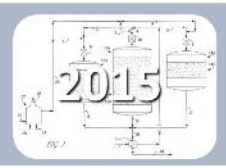
ATJ-SKP w/ Ethanol

## ABBA

**Advanced Biofuels and Bioproducts with AVAP®**

**Full synthetic replacement, second generation jet fuel**

### Petron Scientech Inc.



Technology Improvements

Ethanol to Ethylene Commercial Production

### Genomatica

World's First BIO-BDO Plant

## Integrated validation of ABBA process steps performed at GranBio's Thomaston Biorefinery in Georgia





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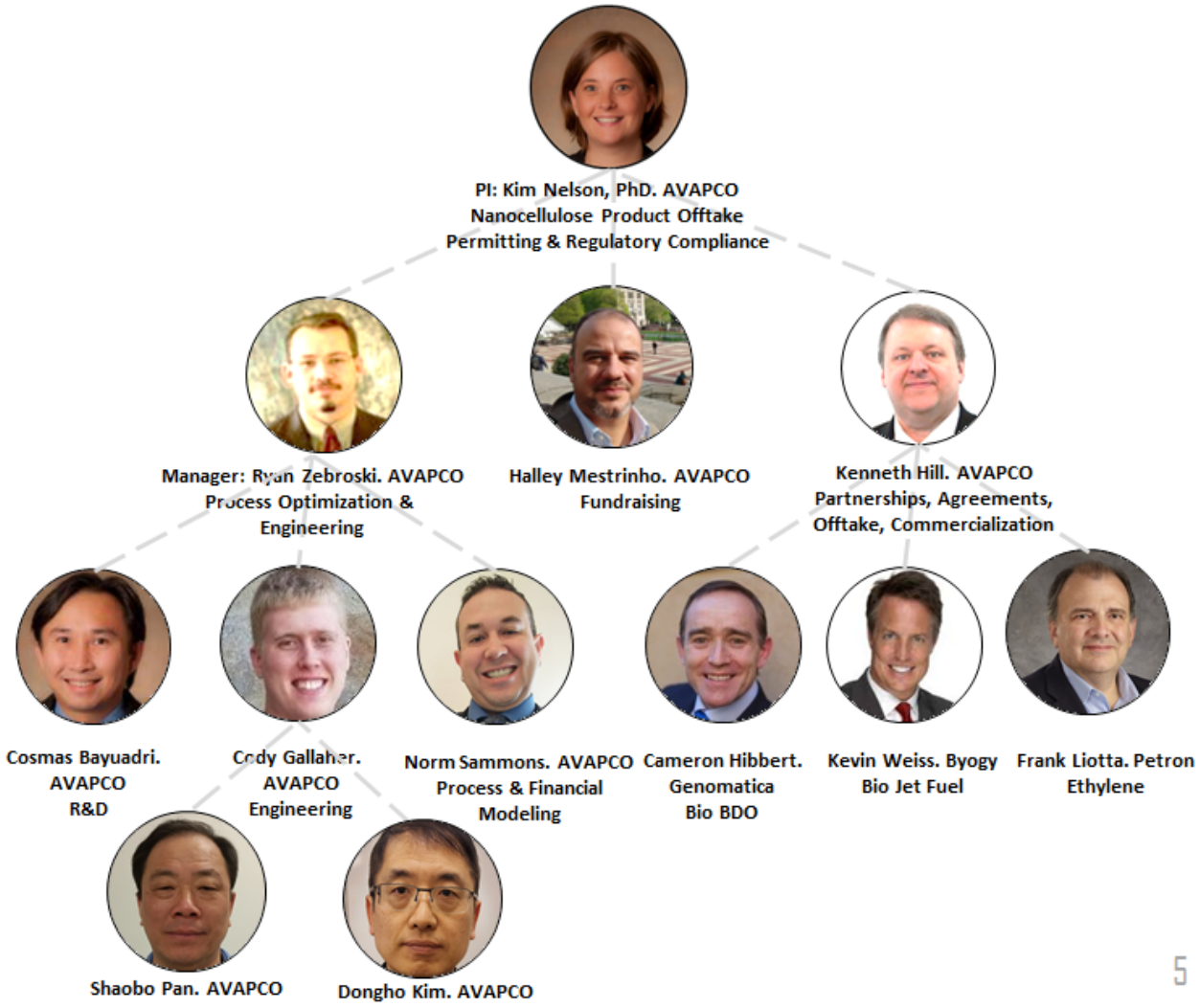
# 1 – Management

AVAPCO has a formal Project Management utilized for multiple multi-million dollar biorefinery R&D, engineering, construction and commercialization projects. The plan addresses

- Effective communications and integration among team members and partners
- Early identification and planning of all work required to complete the project,
- Early identification, evaluation and management of risks and changes
- Effective use of resources
- Tracking of budget and schedule and mitigation of slippage



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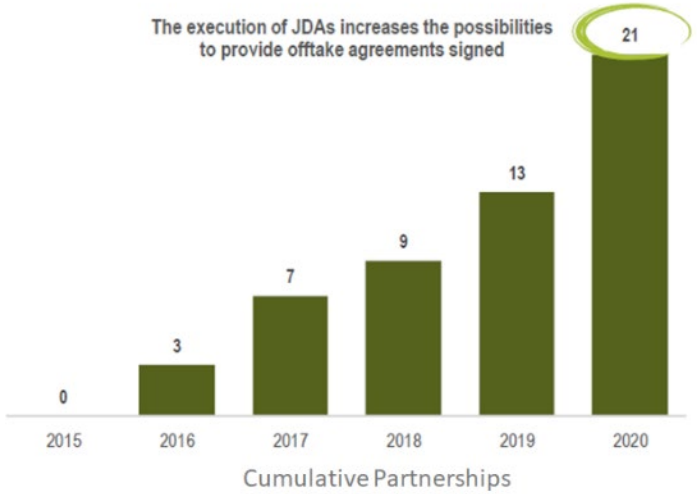
# 1 – Management

AVAPCO uses a Risk Management Plan (RMP) to identify potential project risks, estimate the impact of the risks, and create a response plan to mitigate the risks. The RMP is updated on a regular basis. Excerpt below:

| Risk | Risk Rating | Current Mitigation Strategy |
|---|---|---|
| **Conversion Technology Risks** | | |
| **AVAPCO Ethanol Production** | | |
| AVAP Ethanol does not meet the specification for ethylene conversion | Low | AVAP ethanol meeting the Petron ethanol specification was produced during the BP1 validation period. |
| **Ethylene Production** | | |
| Ethylene does not meet the specification for jet fuel conversion | Low | During validation, the initial ethylene produced contained contaminants that were above the specification; however, Petron made adjustments to the purification system and resolved the issues. |
| **Jet Fuel Production** | | |
| Short catalysis life | Medium | Byogy has 1000's of hours of pilot scale production experience from which catalysis life and oligomerization yield data is available. Byogy has built a new integrated pilot with Partner Petron to gather additional data. |
| Poor oligomerization yield to jet fuel | | |
| **Nanocellulose Production** | | |
| Poor dispersablity of dry product in end-use application | Low | The drying pilot trial for an aqueous and non-aqueous/rubber application gave excellent dispersion in the end-use products. |
| **Operations Risks** | | |
| Equipment underperformance | Low | The selected equipment vendors have supplied equipment in similar service. All equipment is installed industrially at large scale for other processes. |
| **Regulatory Risks** | | |
| Extended NEPA Process | Low | PI obtained timely NEPA review decisions for construction of the Alpena Biorefinery. |
| RFS2 Registration of Jet Fuel | Low | PI registered the cellulosic ethanol produced and sold at the Alpena Biorefinery under the RFS2 program.. |

# 2 – Approach

- Process Optimization
  - Close collaboration with technology providers, equipment suppliers, and nanocellulose product development partners
- Basic Engineering
  - Update detailed data package obtained from integrated validation trials and process optimization
  - Produce integrated Aspen Plus mass and energy process simulation model based on data package for engineering design, equipment sizing, and bid packages.
  - Optimize FEL2 project financial model including CAPEX, OPEX, and financing structure
  - Utilize extensive experience with permitting and regulatory compliance (TSCA, NEPA, RFS2) from the Alpena and Thomaston Biorefineries
- Off-take Contracts
  - Cimmaron Products partnership for jet fuel offtake from the ABBA demo plant. The Sales Director traded all of the cellulosic ethanol from the Alpena Biorefinery under the RFS2 program.
  - Leverage multi-year nanocellulose product development partnerships with global companies across a wide variety of markets for offtake

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# 2 – Approach

- Top challenges facing the approach
  - Low oil prices create offtake challenge for bio jet fuel
  - Policy uncertainty related to premium value for low carbon fuels
  - Financing demonstration plant construction and operation
- Critical Go/No-Go Decision Points & Success Metrics
  - Process optimization
    - ✓ Fermentation yield (improved to 89% vs 85% from validation)
    - ✓ Dry nanocellulose dispersibility in end-use (fully dispersed in aqueous and rubber applications)
    - Catalysis life (economically viable: purchase, disposable, regeneration)
    - Oligomerization yield (ethylene to hydrocarbon products ≥ 97%)
  - Offtake contracts for nanocellulose product and jet fuel obtained / Project Financing
  - Investment grade financial returns that facilitate project financing

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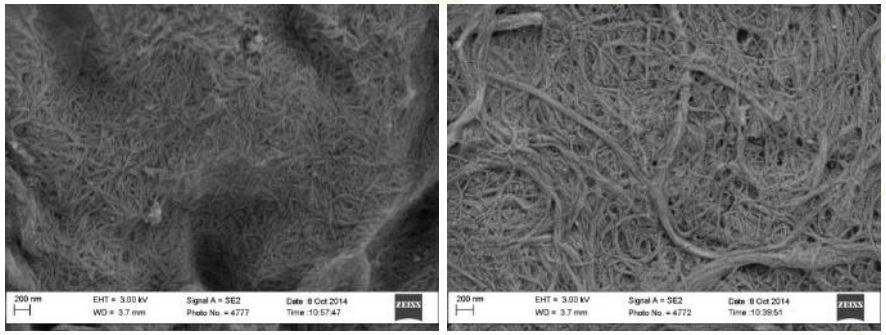
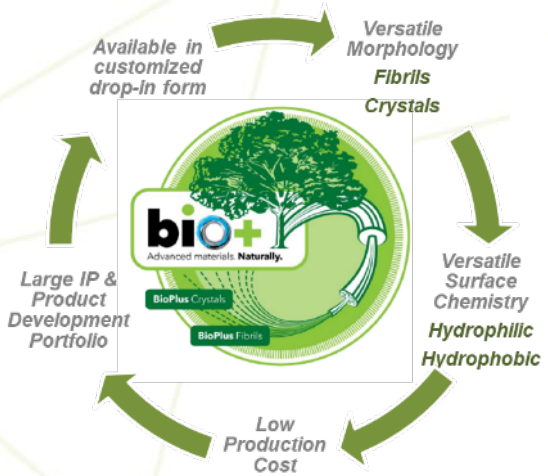
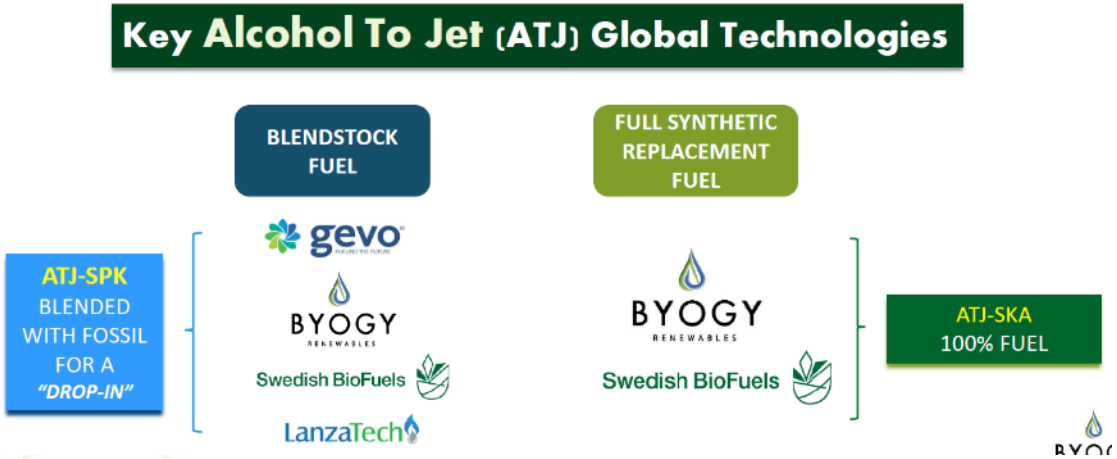
# 3 – Impact

- Benefits of 2G biojet:
  - ~95% reduction of greenhouse gas (GHG) emissions compared to conventional jet fuel
  - Abundant, price stable feedstock that does not compete with food (21 - 116 million dry tons woody biomass in US)
- Synergistic co-production of nanocellulose enables commercial plant profitability.
- BioPlus nanocellulose is produced as specifically engineered masterbatch forms that offer unique performance over traditional materials. Pricing depends on its unique performance value proposition and is not linked to oil prices.








***Adopting full replacement fuels will save cost and minimize safety concerns by eliminating the downstream issues of:***

- **Blending Logistics**
- **Storage, Handling, Distribution**
- **Transportation Infrastructure Accounting**

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# 3 – Impact

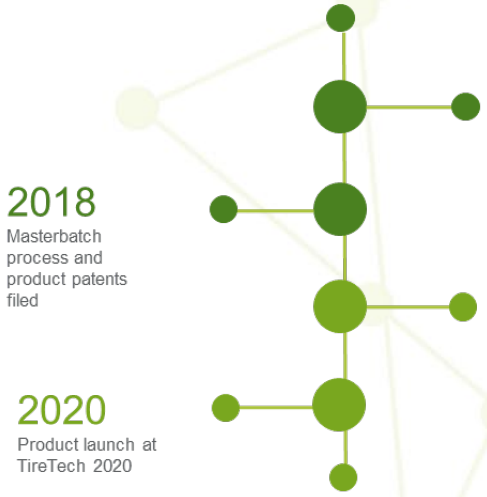
**Entire nanocellulose capacity for the ABBA demo-plant can supply tire and rubber goods industry. AVAPCO and Birla Carbon have entered commercial negotiations for production.**

## Sustainable materials goals in the tire industry:

Bridgestone–"towards 100% sustainable materials" 2050
Michelin–"manufacturing tires with 80% sustainable materials" 2048
Pirelli–"double share of renewable raw materials" by 2025 vs 2017

## Drivers for reduced tire rolling resistance:

CO2 and fuel use reductions
European Union bans on high rolling resistance tires



**2017**
JDA Executed

**2018**
Masterbatch process and product patents filed

**2019**
Lab process scale up

Customer roadshows in Asia and Europe

**2020**
Product launch at TireTech 2020

Customer product qualifications

Pilot process scale-up

GranBio & Birla Carbon agreement to enter commercial negotiations for first commercial plant


## Market Estimate:

6,500 tpy nanocellulose in masterbatch form

**"One of the 20 innovations most likely to enhance the environmental profile of the elastomer/rubber industry" - European Rubber Journal (June 2020)**

# 4 – Progress and Outcomes

- **SOPO TASK: Obtain optimized engineering scale-up data for CNC & CNF drying system**

GranBio has developed break-through drop-in masterbatch forms of nanocellulose specifically engineered to achieve unique performance characteristics in a wide range of products, using proprietary production process and chemical formulations. Overcome well-known nanocellulose drying “Grand Challenge” Conventional drying methods cause nanocellulose to bond together irreversibly into macroscopic aggregates that deteriorate physical properties.

**Patent pending production process and chemical formulations**

**Nanocellulose gel**

Water-based form is incompatible with most applications

**Proprietary Additives for Each Application**

**Nanocellulose Concentrate**

**Nanocellulose Masterbatch**

Engineered for compatibility with various applications

**Lightweight sealants**

**High barrier food packaging**

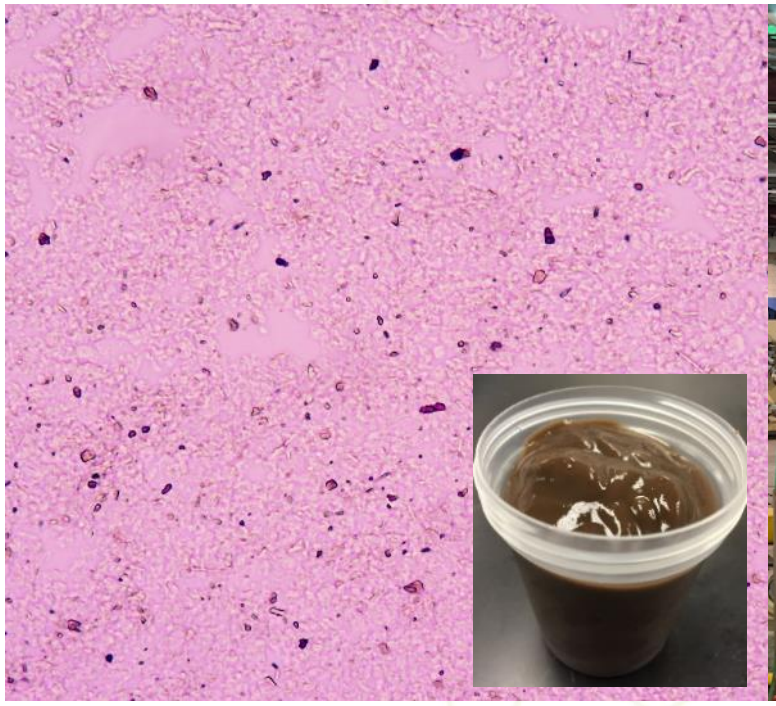
**Natural cosmetics**

**Low rolling resistance tires**

**Vehicle light-weighting**

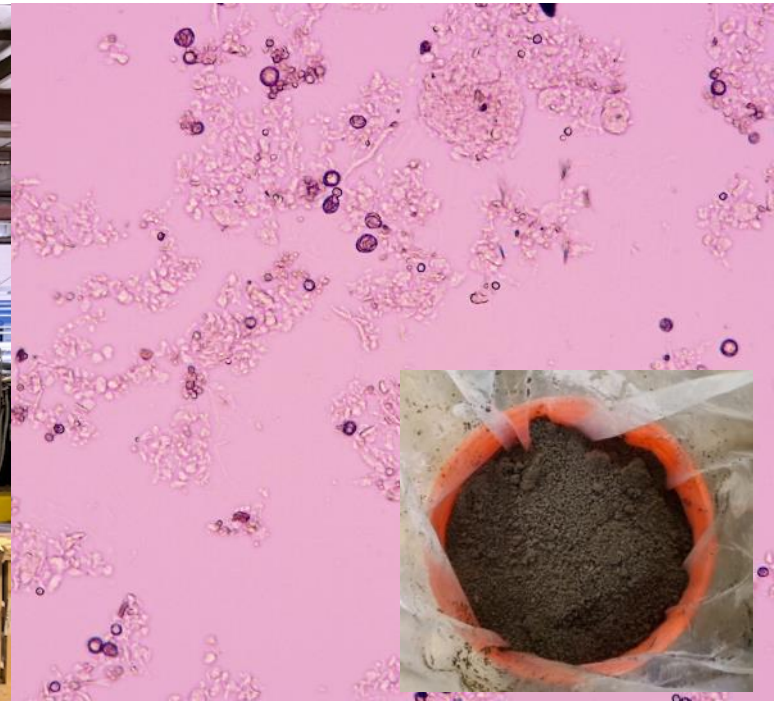
# 4 – Progress and Outcomes

- Produced BioPlus Lignin-Coated Cellulose Nanocrystals Concentrate for personal care applications with ultraviolet absorption / SPF protection and antibacterial properties.
- Fully redispersable in water with industry standard mixing equipment



LCNC Gel

Cosmetics Additive + Continuous Drying Under Shear



LCNC Concentrate + Redispersion in Water

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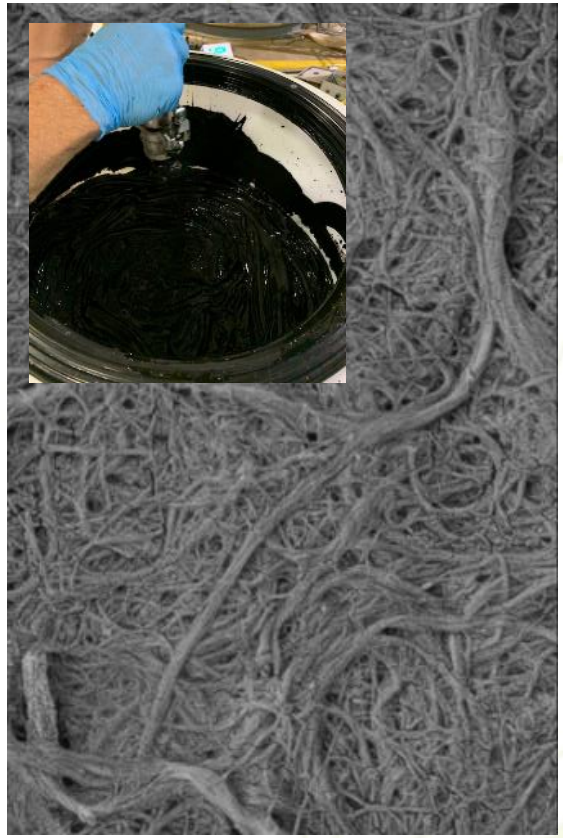
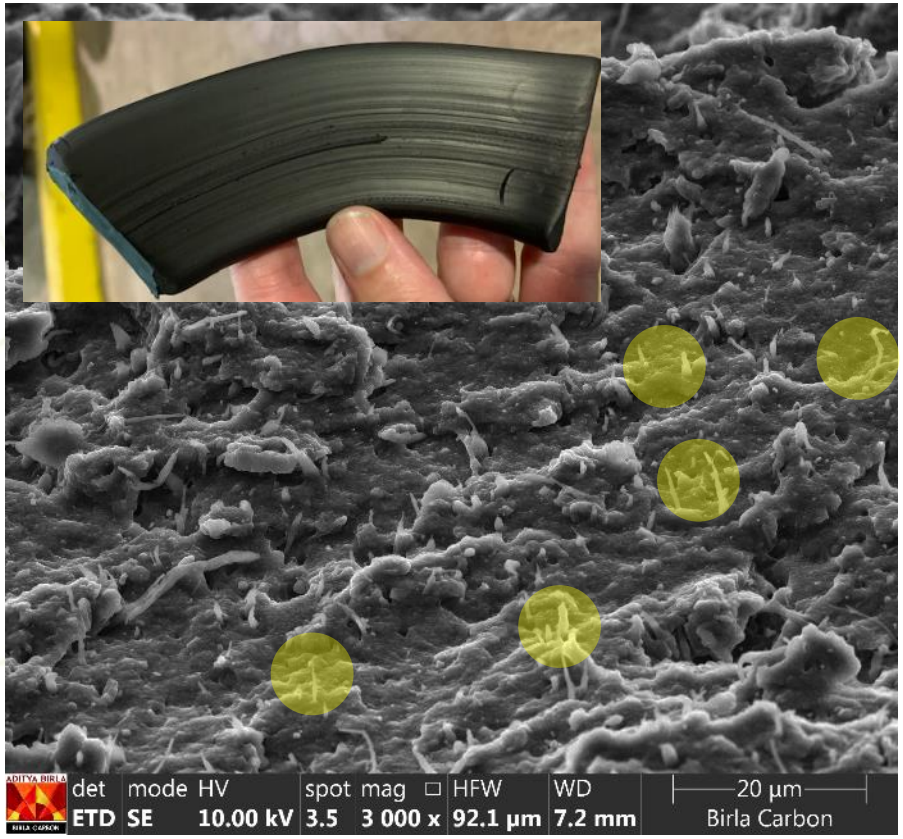
# 4 – Progress and Outcomes

- Produced BioPlus Lignin-Coated Cellulose Nanofibrils Masterbatch for tires and rubber goods applications.
- Fully redispersable in standard tire formulations



LCNF + Additives

Proprietary dewatering and drying process




LCNF Masterbatch + Redispersion in tire formulation

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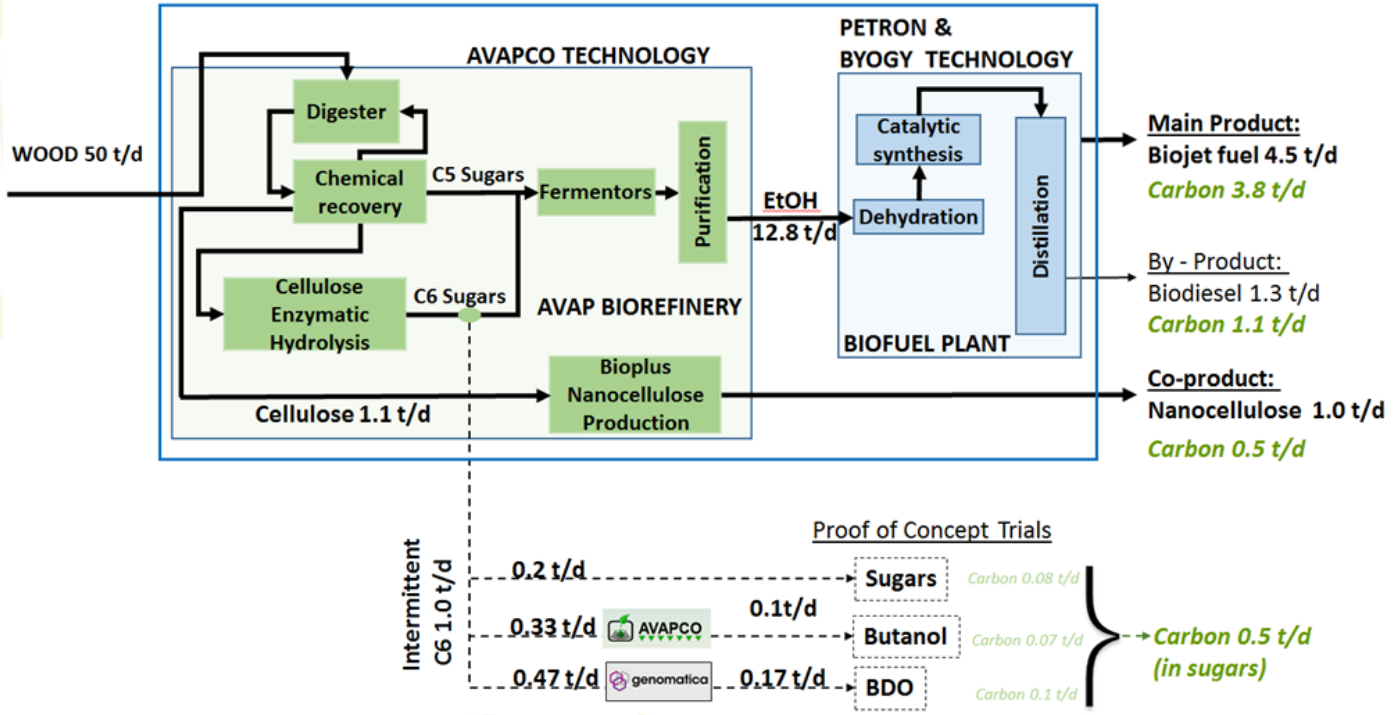
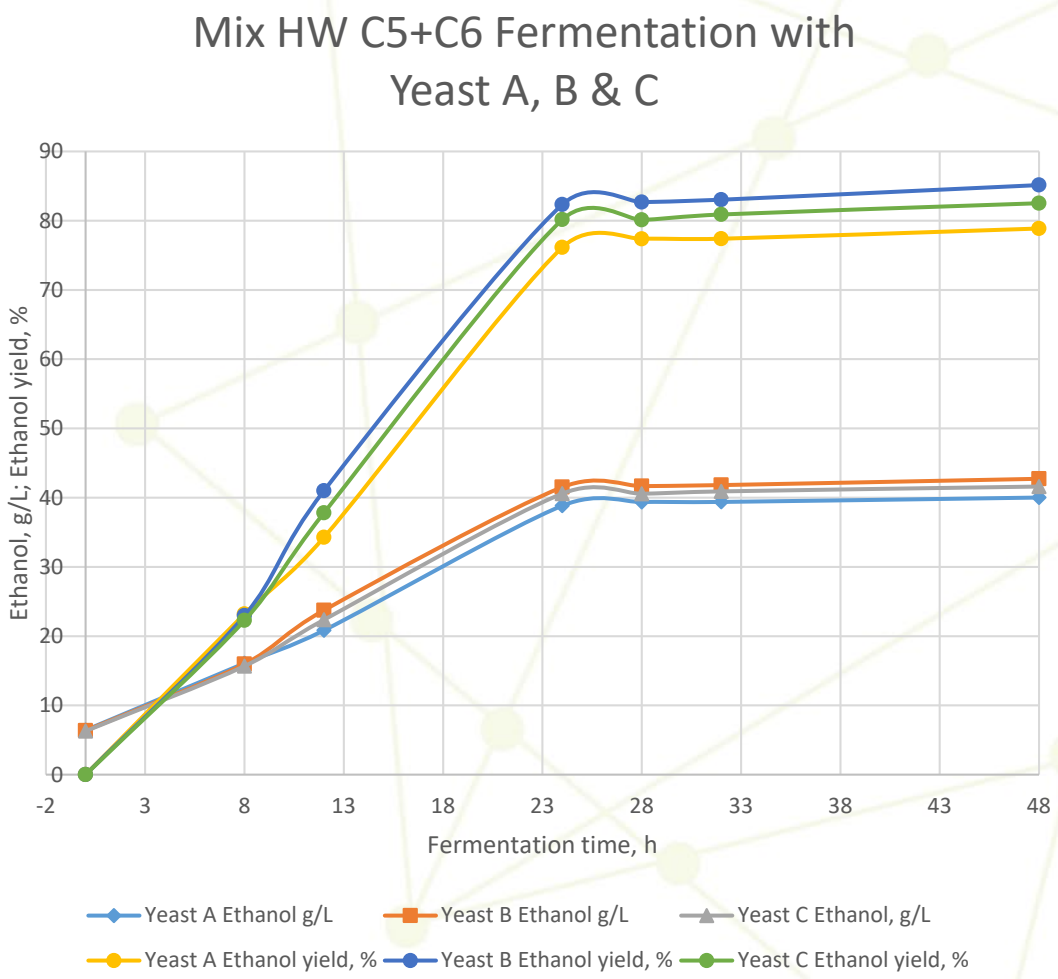
# 4 – Progress and Outcomes

- The amount of 50 tpd feedstock directed to the nanocellulose performance advantaged bio-coproduct was increased to improve the demo plant's IRR and attractiveness to investors.
- The biofuel primary products (jet fuel and biodiesel) still account for 51% of the biogenic carbon leaving the facility as salable product, as required by the program.
- Intention to further increase nanocellulose production to 6,500 after DOE demonstration period for expanded commercial sales



# 4 – Progress and Outcomes

**SOPO Task: Evaluation of best commercially available organisms for conversion of 2G sugars to ethanol.**




| Yeast | Ethanol Yield (% theoretical) |
|---|---|
| A | 81.9 |
| B | 89.9 |
| C | 88.4 |

- Of the 13 yeasts screened, the top performing yeasts A, B & C were run in a series of fed batch fermentations to obtain the optimized results shown above.
- Yeasts B and C were comparably less stressed and more tolerant to the mixed hardwood C5+C6 sugar stream.
- Yeast A produced more glycerol and consumed less arabinose.
- The ammonia consumption in the yeast B fermentations was less than half that of the other yeasts.
- The fermentation yield was increased from a demonstrated 85% to 89%, while decreasing the pitch rate from 0.5 gDCW/L to 0.3 gDCW/L

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# 4 – Progress and Outcomes

**SOPO Task: Optimize the ethylene quality specification for the feed to the oligomerization system.**

| Contaminant | Original Purified Ethanol Specification | Revised Purified Ethanol Specification | Purified Run 133 (SW) Ethanol |
|---|---|---|---|
| | (mg/L) | (mg/L) | (mg/L) |
| Acetaldehyde | 30 | 30 | 0 (ND) |
| Acetal | 50 | 50 | 0 (ND) |
| Ethyl Acetate | 80 | 80 | 0 (ND) |
| Methanol | 50 | 50 | 0 (ND) |
| Isopropanol | 20 | 20 | 11.9 |
| n-Propanol | 20 | NA | 58.3 |
| Butanol | 10 | 10 | 0 (ND) |
| Higher Alcohols | 100 | 100 | 84.4 |

Contaminant concentrations based on 95% (v/v) ethanol.

- Ethylene produced in the EtOH -> ETE unit is to be used as feed to the HC oligomerization unit where propylene and heavier HC's are acceptable; therefore, n-propanol does not have to be removed from the raw ethanol feed.
- The n-propanol will dehydrate to propylene in the ETE Reactor and will remain in the ethylene product.
- This purity specification change significantly reduced the ethanol purification cost for the project.

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# Summary

- Next Steps:
  - Complete FEL3 Engineering, permitting, offtake agreements, supply agreements and financing
- Demo plant co-product reallocation to improve IRR and attractiveness to investors
- Entire nanocellulose capacity for the ABBA demo-plant can supply the tire and rubber goods industry. AVAPCO and Birla Carbon have entered commercial negotiations for production.
- Fuel trading partner has long-term successful history with AVAPCO team for 2G fuel sales under RFS2 program.

# Quad Chart Overview

## Timeline

- January 15, 2017
- March 30, 2022

| | FY20 Costed | Total Award |
|---|---|---|
| **DOE Funding** | $1,328,147 | $4.7 million |
| **Project Cost Share** | $1,332,358 | $4.7 million |

## Project Partners*

- Petron Scientech
- Byogy Renewables
- Genomatica
- Georgia Tech & UT

## Project Goal

Perform technical validation, process optimization, and basic engineering for an AVAP™ 50 tpd woody biomass demonstration plant for co-production of full replacement bio jet fuel, and nanocellulose to demonstrate how low-volume, high-value nanocellulose co-produced with high-volume commodity liquid jet fuel enables a profitable biorefinery at reasonable scale.

## End of Project Milestone

GO / NO-GO Decision to proceed with project implementation and plant construction.

## Funding Mechanism

DE-FOA-0001232, Project Development for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower, 2016.

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# Additional Slides

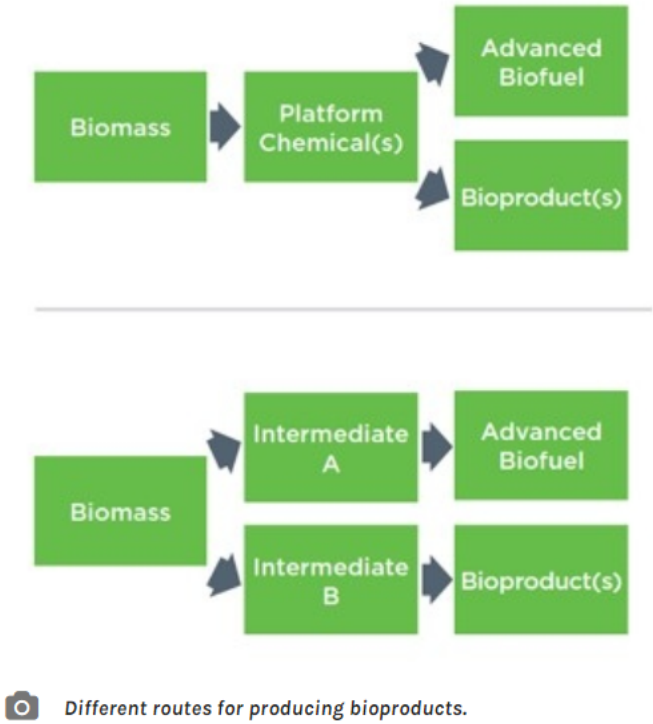
# Responses to Previous Reviewers' Comments

- **"Biofuel is primary target but alternative products limit relevance to BETO goals."**
  - Co-products support BETO goals by de-risking and incentivizing biofuels production

"***Enabling a diverse product slate from a biorefinery***, especially by valorizing materials that are currently waste products, **can substantially reduce risks associated with early biofuel plants and biorefineries. Bioproduct production** can also **significantly de-risk the upstream infrastructure and processes needed for biofuels** by providing **an increased economic incentive for the construction of pioneer biorefineries**." - BETO

There are many types of strategies that BETO can invest in to encourage bioproduct production. These strategies include investing in:

- Products that enable and support existing biorefineries (e.g., biogas conversion, acid pretreated lignin)
- Products that enable the operation of future biorefineries based on current research projections (e.g., alkaline lignin)
- Products that are manufactured in stand-alone facilities intended to help de-risk biorefineries through lessons learned (e.g., products that enable the construction of supply systems/depots).

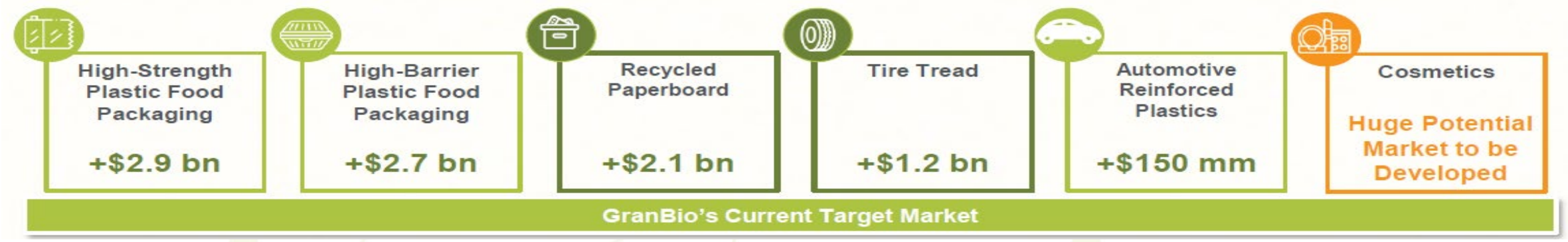



*Different routes for producing bioproducts.*

https://www.energy.gov/eere/bioenergy/bioproduct-production

# Responses to Previous Reviewers' Comments

- **What is the final market for nanocellulose? I do not see how this process can match the large scale of the fuel market with the much smaller scale of the nanocellulose market- especially today.**
- In the near-term (5-10 years) AVAPCO's BioPlus nanocellulose market size estimate is 53,000 tpy for products currently under development with partners.



# Responses to Previous Reviewers' Comments

- **"The project claims to produce "drop-in" biofuels but it appears that is produces an intermediate; at a minimum, hydrogenation is required for fuel production."**
  - Since hydrogenation and distillation are known technologies not related to the uniqueness of Byogy's 100% replacement jet full, which is determined by it's hydrocarbon distribution, validation was based on the intermediate prior to hydrogenation and distillation to confirm that it was equivalent to previous Byogy development trials. Certainly, the intermediate would be distilled and hydrogenated for the demonstration plant and commercial sales.

# Publications, Patents, and Presentations

- **Publications**
  - M, Li et al. “Recent Advancements of Plant-Based Natural Fiber-Reinforced Composites and Their Applications,” Vol 200, 108254.
- **Patents**
  - International Patent Application WO 2020/160565 A1, Systems and Methods for Dewatering and Drying Nanocellulose, 22 March 2020.
  - International Patent Application WO 2020/142793 A1, Nanocellulose-Dispersion Concentrates and Masterbatches, Methods of Making and Using the Same, and Nanocellulose-Containing Composites, 28 February 2020.
- **Presentations**
  - K. Nelson, BioPlus Nanocellulose: A High-Value AVAP® Biorefinery Coproduct, ABLCGlobal2018, San Francisco, November 2018.
  - K. Nelson, BioPlus Nanocellulose: A High-Value AVAP® Biorefinery Coproduct, BDC Fall Forum, Montreal, September 2019.
  - K. Nelson, Overview and Update of GranBio Nanocellulose Technology and Markets, BDC 2020 Webinar Series, Webinar, September 2020.

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# Awards and Commercialization

- **Awards**
  - NDC™ nanocellulose rubber masterbatch named “one of the 20 innovations most likely to enhance the environmental profile of the elastomer/rubber industry” -European Rubber Journal (June 2020)
  - Rubber Chemistry & Technology Journal “Editors Choice” Award for “Reinforcement of Rubber by Carbon Black and Lignin-Coated Nanocellulose Fibrils”, L.B. Tunnicliffe, K. Nelson et all, Rubber Chem. Technol. 2020, 93, 633-651.
  - GranBio, parent company of AVAPCO, named 2020 NEXT 50 Companies to Disrupt the World by Biofuels Digest for “performance nanocellulose from any biomass”.
- **Commercialization**
  - AVAPCO and Birla Carbon have entered into commercial negotiations for nanocellulose masterbatch production and sale.