From Trees to Tires
Development and Scale-Up of the Nanocellulose Dispersion Composite™

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[1]GranBio [2]Birla Carbon

TAPPI Nano Conference 2023

Introductions

Birla Carbon

- Leading supplier of carbon black to rubber industry
- 16 manufacturing sites worldwide
- HQ and central R&D in Atlanta, GA.

GranBio

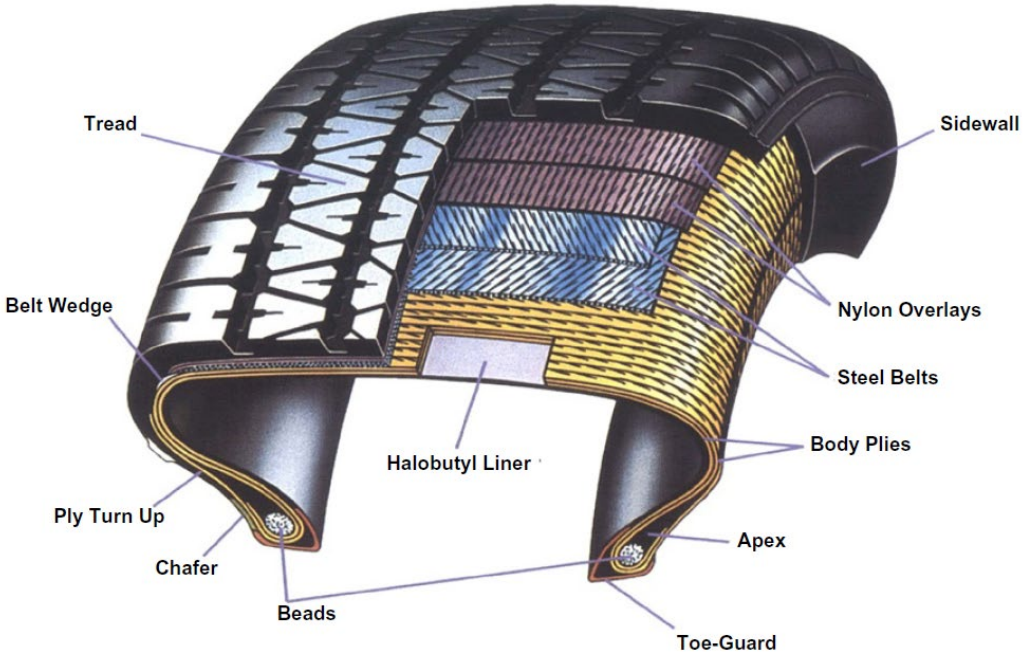
- Bio-mass derived fuels, chemicals, sugars and materials technologies
- Expertise in nanocellulose manufacture & end-use
- Manufacturing facilities in Thomaston, GA & Alagoas, Brazil

Tire Technology

Highly engineered, safety critical, key component of modern life:

- ~90% rubber compound by weight
- ~25% reinforcing particles by weight

- Durable (safe)
- Long tread life
- Energy efficient
- Cost effective



Passenger car tire construction

Image from: The Science and Technology of Rubber 4th Edition, Elsevier, 2013

Sustainability in the Tire Industry

Tire industry transition to “sustainable” raw materials:

- **Bridgestone**[1] – “towards 100% sustainable materials” 2050
- **Michelin**[2] – “objective of 100% sustainable materials by 2050”
- **Pirelli**[3] – “using…less than 40% fossil-derived materials…by 2025”
- **Continental**[4] – “target by 2050 at the latest: tires made entirely from sustainable materials”
- **Goodyear**[5] – “create a tire made 100% from sustainable materials by 2030”

(1) https://www.bridgestone.com/responsibilities/environment/resources/
(2) https://www.michelin.com/en/innovation/vision-concept/sustainable/(3) https://corporate.pirelli.com/corporate/en-ww/sustainability/sustainability-plan
(4) https://www.continental.com/en/press/press-releases/20230214-sustainable-solutions/
(5) https://corporate.goodyear.com/us/en/responsibility/sustainable-sourcing/sustainable-materials.html#:~:text=In%202020%2C%20Goodyear%20set%20a,70%25%20sustainable%2Dmaterial%20tire.

Nanocellulose as a Material for Tires

Growing interest in use of NC for rubber and tire applications:

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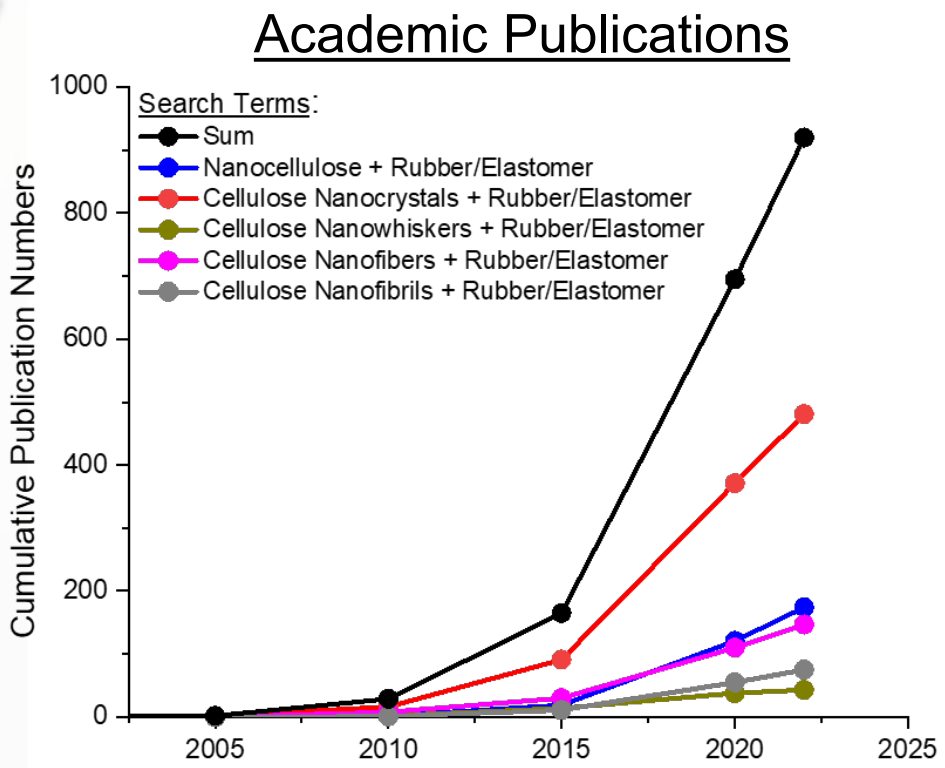


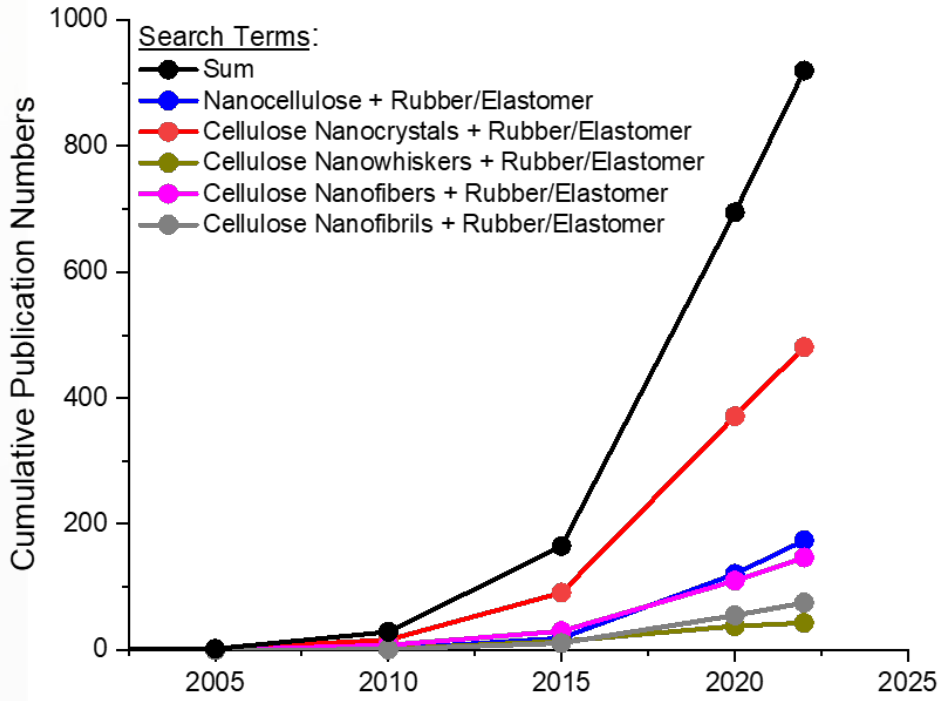
Source: Web of Science searches conducted July 2022

For more details: "*Role of Nanocellulose Composites in the Tyre Industry*", Tunnicliffe, Nelson and Herd in "*Elastomeric Nanocellulose Composites*" October 1st 2023, ISBN: 9780443186080 , Elsevier Ltd.

Nanocellulose as a Material for Tires

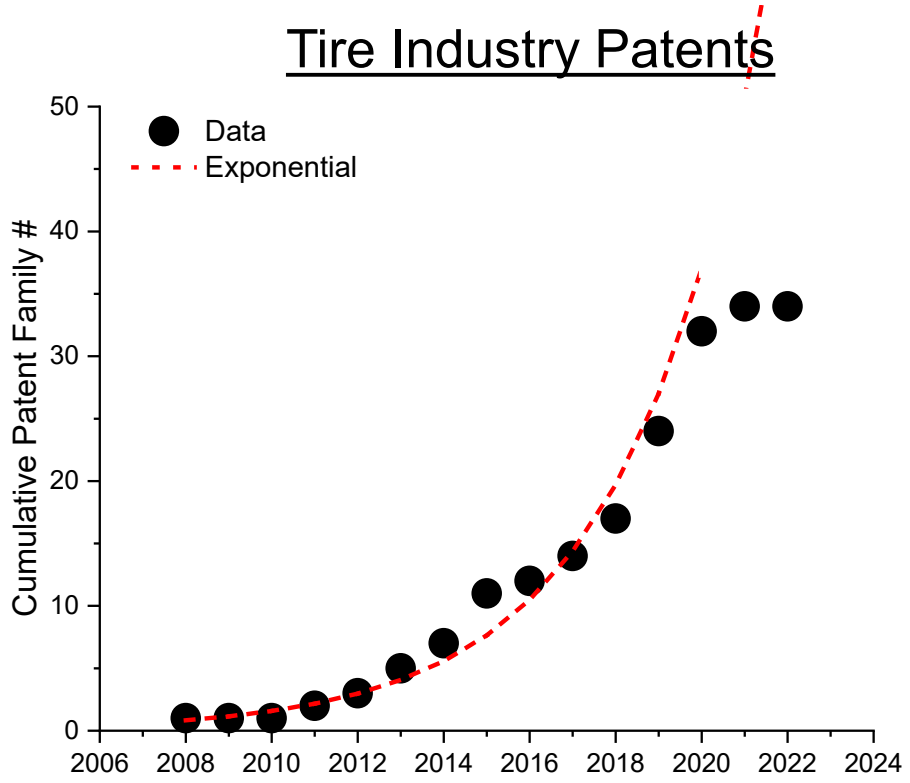
Growing interest in use of NC for rubber and tire applications:

Academic Publications



Source: Web of Science searches conducted July 2022

Tire Industry Patents



Patent Landscape Survey conducted June/July 2022

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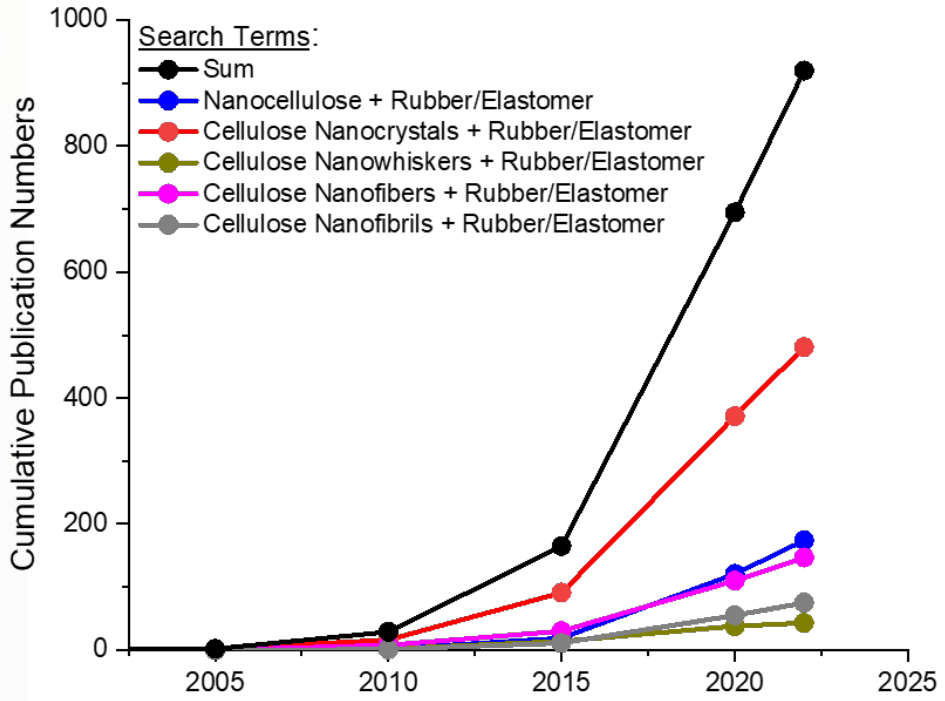

Source: Web of Science searches conducted July 2022

Sumitomo Rubber Industries

Enasave Next III Tire – Commercial (Japan)

ENASAVE NEXT III

"…world's first tires to incorporate "Cellulose Nanofiber" biomass material…simultaneously improving overall tire performance while also reducing the environmental impact of these tires."

https://www.srigroup.co.jp/english/newsrelease/2020/sri/2020_064.html

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Nanocellulose as a Material for Tires

The pro's and con's of NC from the perspective of the tire industry:

- ✓ Bio-derived (sequestered carbon content)
- ✓ Nanoscopic dimensions
- ✓ Plentiful feedstock

- ✘ Physical form (low solids aqueous gel)
- ✘ Polar surface
- ✘ Irreversible agglomeration

For more details: "*Role of Nanocellulose Composites in the Tyre Industry*", Tunnicliffe, Nelson and Herd in "*Elastomeric Nanocellulose Composites*" October 1st 2023, ISBN: 9780443186080 , Elsevier Ltd.

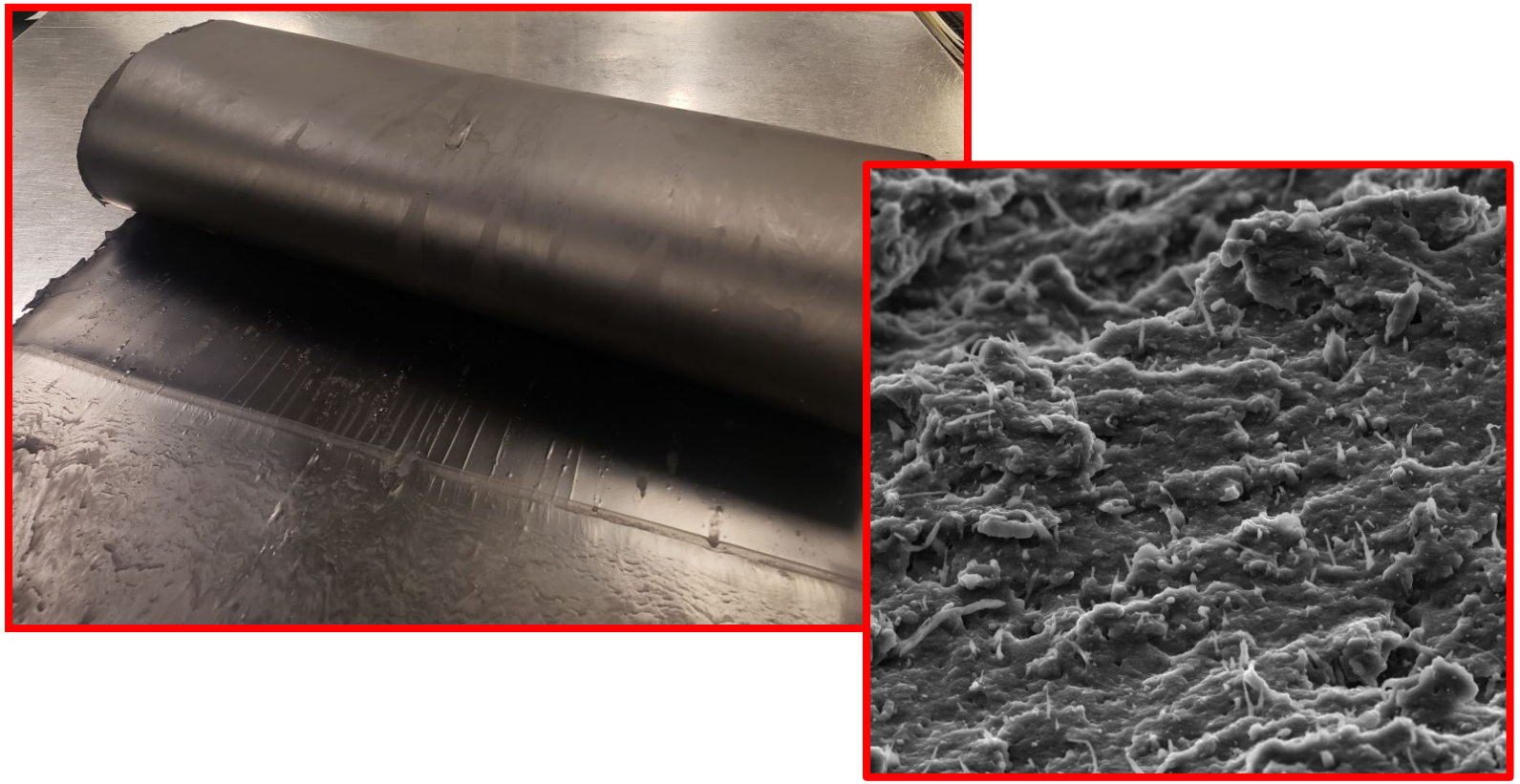
Nanocellulose Dispersion Composite

Overcomes traditional challenges of NC in tire industry:

- ✘ Physical form (low solids aqueous gel)
  - → Solid rubber “drop-in” masterbatch
- ✘ Polar surface
  - → BioPlus® Lignin-Coated Nanocellulose disperses uniformly in rubber
- ✘ Irreversible agglomeration
  - → Nanocellulose is pre-dispersed within masterbatch matrix as individual particles

Nanocellulose Dispersion Composite

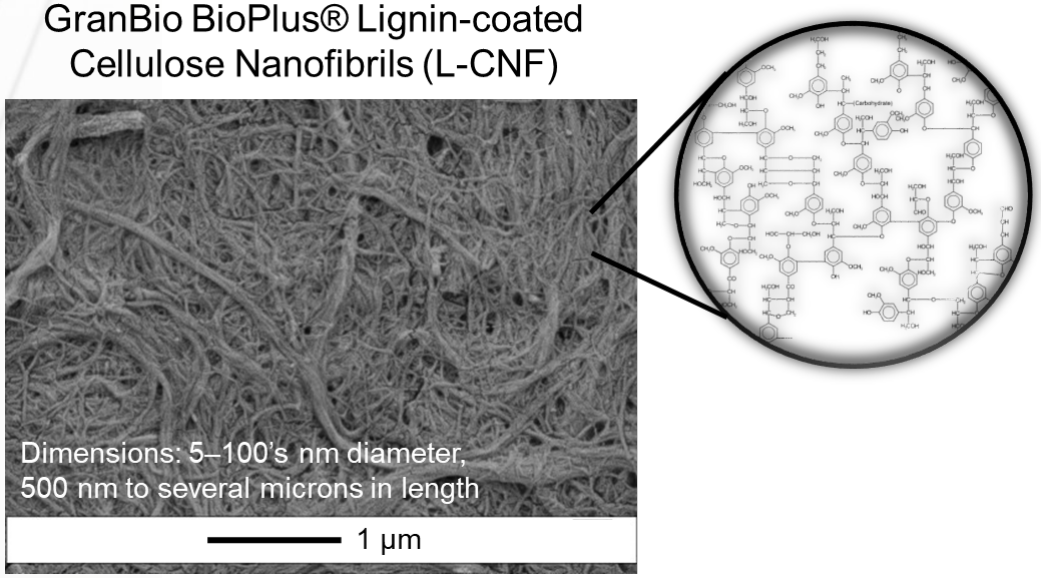
- Highly concentrated pre-dispersion of discrete NC fibrils in rubber
- No powder handling required, no gel handling
- Easily weighed
- Easily processed
- Easily mixed

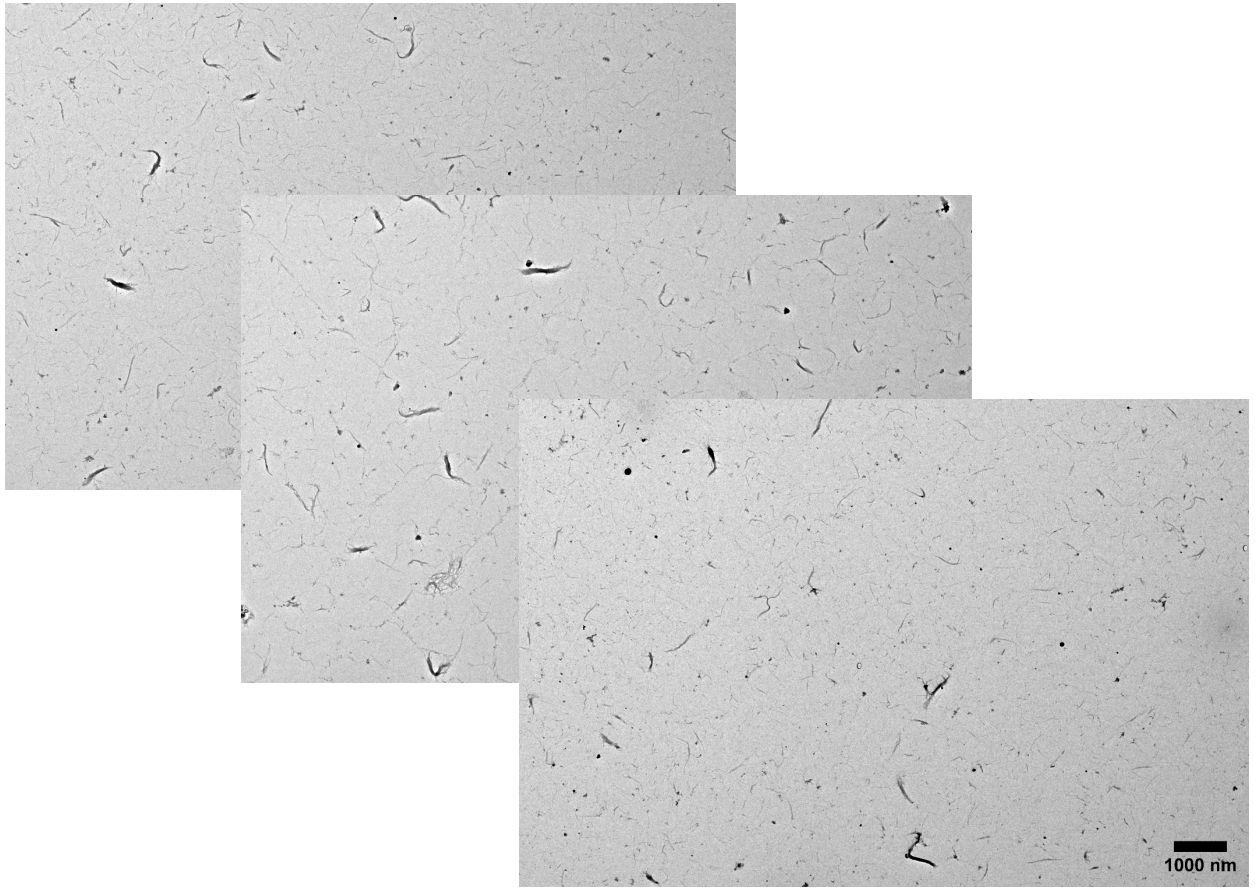


Nanocellulose Dispersion Composite

- Utilizing GranBio BioPlus® Lignin Coated Nanocellulose Fibers
- Fibers imaged using newly developed TEM dispersion technique

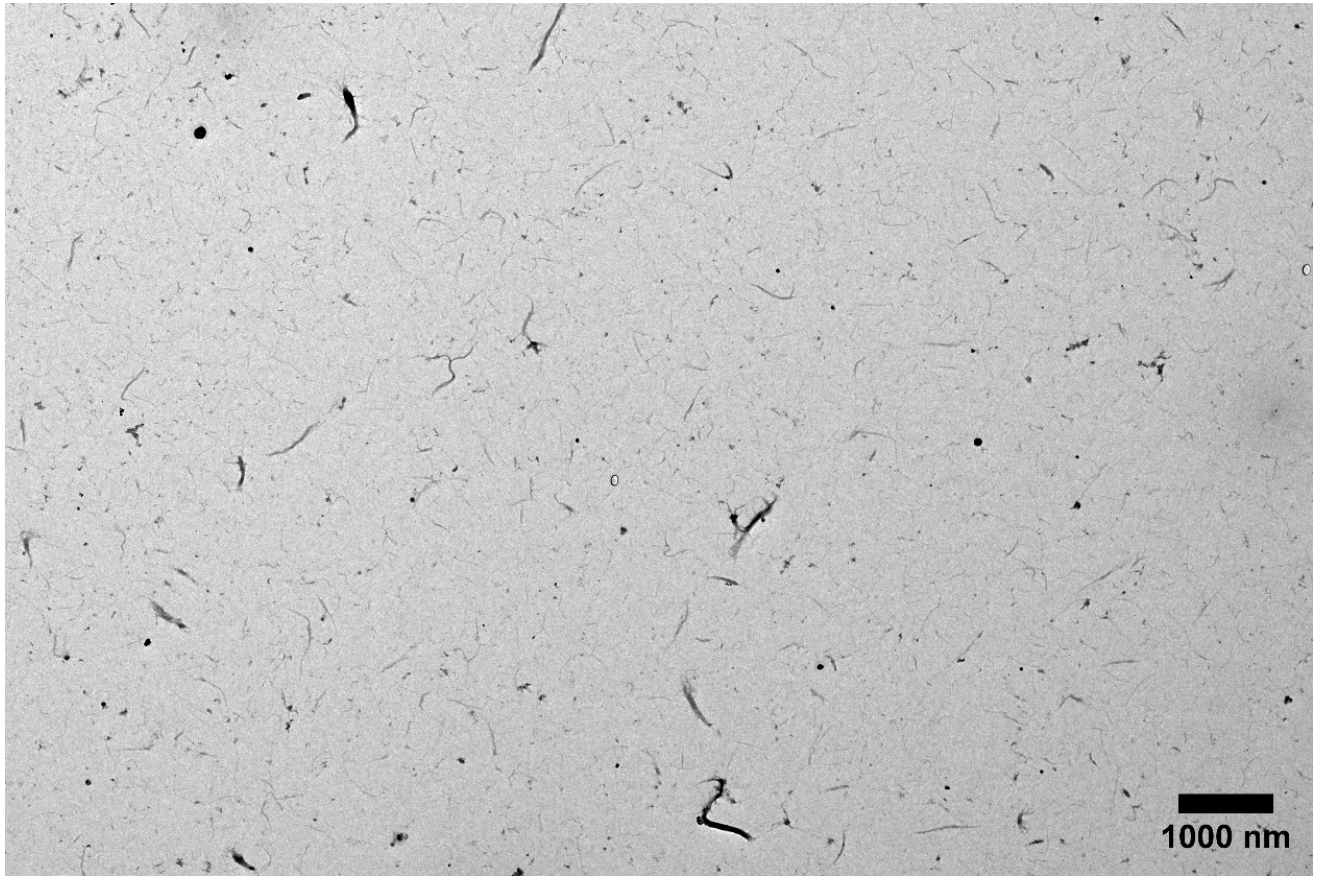
GranBio BioPlus® Lignin-coated Cellulose Nanofibrils (L-CNF)





TEM Dispersion Technique

- Proprietary method
- Separates fibrils into individual particles for characterization (length and width) using particle size analysis software
- Allows direct correlation between tunable BioPlus LCNF particle size and tire compound properties



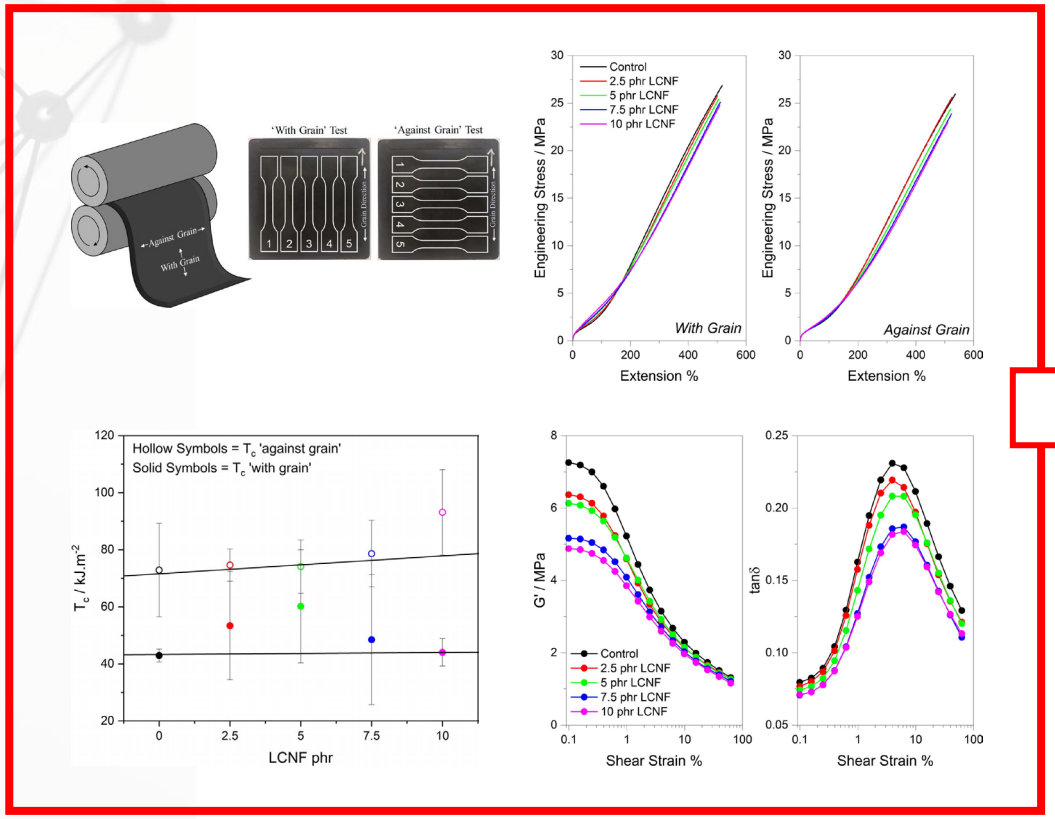
Step Change in NC Dispersion Quality

Scanning Electron Microscopy Images of Compound Surfaces Prepared Through Razor Cutting

	Standard Truck Tread	+ dried nanocellulose	+ nanocellulose using NDC
Backscattered ↓	300 µm	300 µm	300 µm
Secondary ↓			

Example Performance in Rubber

Performance in truck tire formulation with 20% NC in place of carbon black:



Property	Change with 20% NC
Dispersion Quality	Maintained
Fuel Economy	+20%
Stiffness	Maintained
Strength	Maintained
Abrasion Resistance	Maintained
Tear Resistance	Maintained / Slightly improved
Light weighting	~1%

For more details: Tunnicliffe et al., *Reinforcement of Rubber by Carbon Black and lignin-Coated Nanocellulose Fibrils*, Rubber Chem. Technol., (2020), 93(4): 633-651

NDC Development Trajectory

2015
- BioPlus Nanocellulose Pilot Line Start-Up

2016
- Nanocellulose Sampling to Birla Carbon

2017
- JDA Signed between GranBio & Birla Carbon
- $7.3M grant for SAF & Nanocellulose Masterbatch Pilot from DOE

2018
- NDC Laboratry Development

2019

2020
- NDC Product Launch at Tire Tech for Customer Evaluation
- Batch Pilot Trials

2021
- Continuous Pilot Trials
- P3Nano Scale-Up Grant

2022
- USDA Wood Innovations TEA Grant

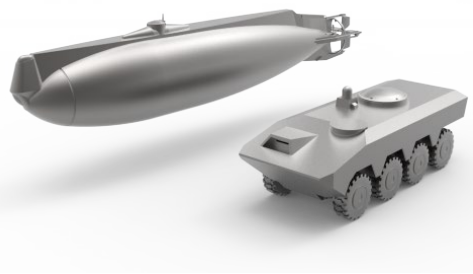
2023
- $80 million grant for SAF & NDC Demo Plant
- 2 NDC patents granted and 26 pending globally

NDC Customer Pre-Qualifications

Market	No. of Companies Sampled	Location of Companies
Tires	9	Europe, Asia
Rubber Goods	2	Europe, USA
Sustainable Footwear	1	USA








P3Nano Funding for

From Trees to Tires: Nanocellulose Dispersion Composite™ (NDC) Scale-Up for On-Road Tire Trials

Goals: Demonstrate continuous scaled-up production (~1-ton) of NDC rubber masterbatch for full-scale on-road tire trials.

Collect engineering data for commercialization Techno-Economic Analysis

Grant Amount: $500,000

USDA Funding for TEA

Nanocellulose Dispersion Composite™ (NDC) Techno-Economic Analysis for the Tire Industry

Goal: Fully validate commercial profitability of production and global sale of NDC.

Techno-economic analysis to include FEL II- Design Engineering Package and detailed examination of the production and market conditions.

Grant Amount: $229,836

DOE Funding for NDC 1st Commercial

DOE Grant
$80 million cost share

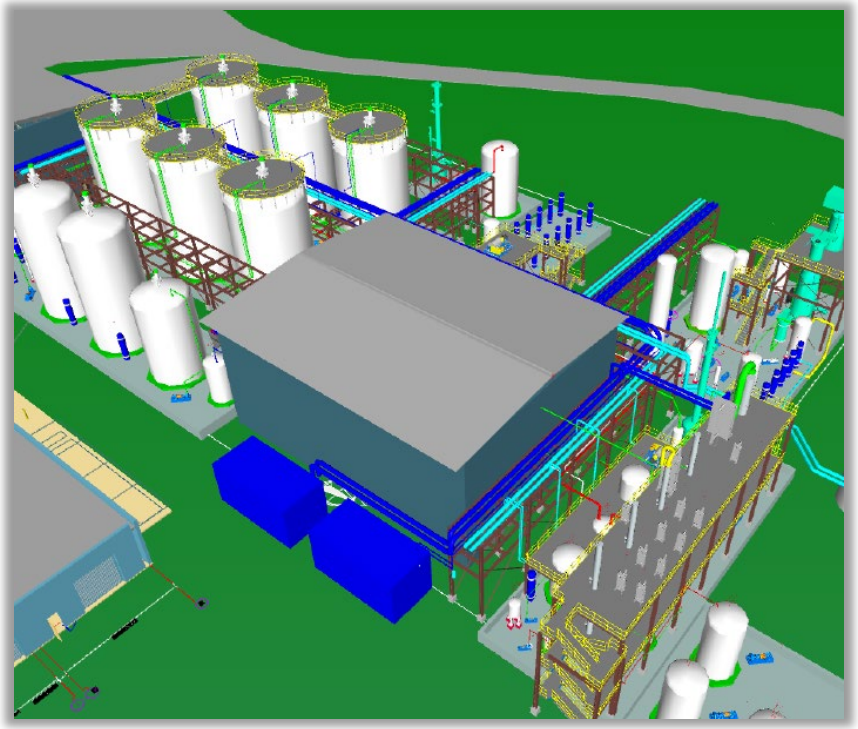
NDC Production
750 tons per year SAF

SAF Production
1 million gallons per year SAF

Feedstock
Sawmill residue chips

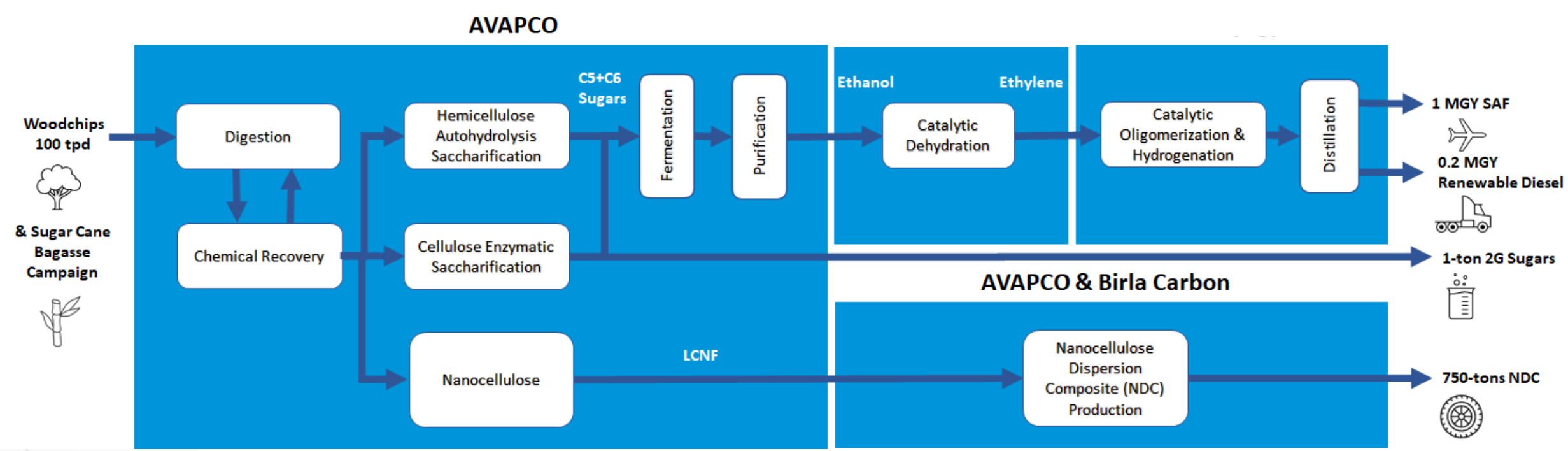
Start-Up
Q3 2026

Growth
Builds on previous DOE award for project's technical validation and design phase



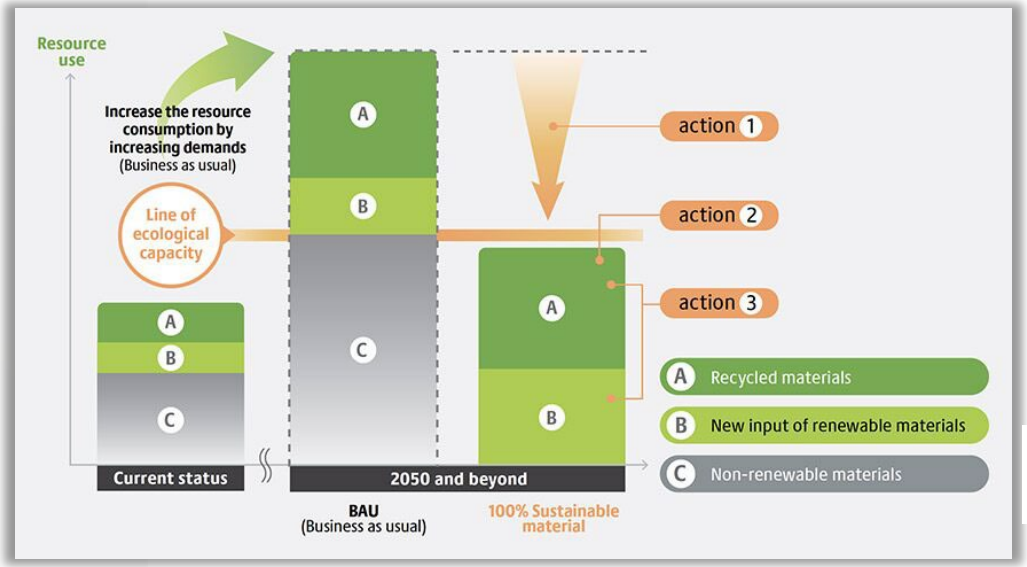
Enabling Net Zero Project Goals

- Demonstrate how *low-volume, high-value nanocellulose NDC* co-produced with *high-volume commodity liquid fuels* enables a profitable biorefinery at reasonable scale.
- Produce cost-effective Sustainable Aviation Fuel with a GHG reduction of ~93% compared to conventional jet fuel.
- Collect techno-economic data for expansion to larger scales.



The “Whole Barrel” Biorefinery

- The NET ZERO project 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 fuels, chemicals and materials** that are not derived from food.
- Market sizes for demo plant products:
  - SAF = about 160 billion gallons per year
  - Sugar-derived biochemicals = 113 million tons by 2050
  - Green tires = 870 million tires by 2030



“Smarter, more sustainable use of resources is important not only for addressing environmental issues, but also for society and the Bridgestone Group’s businesses.”

BRIDGESTONE
Solutions for your journey

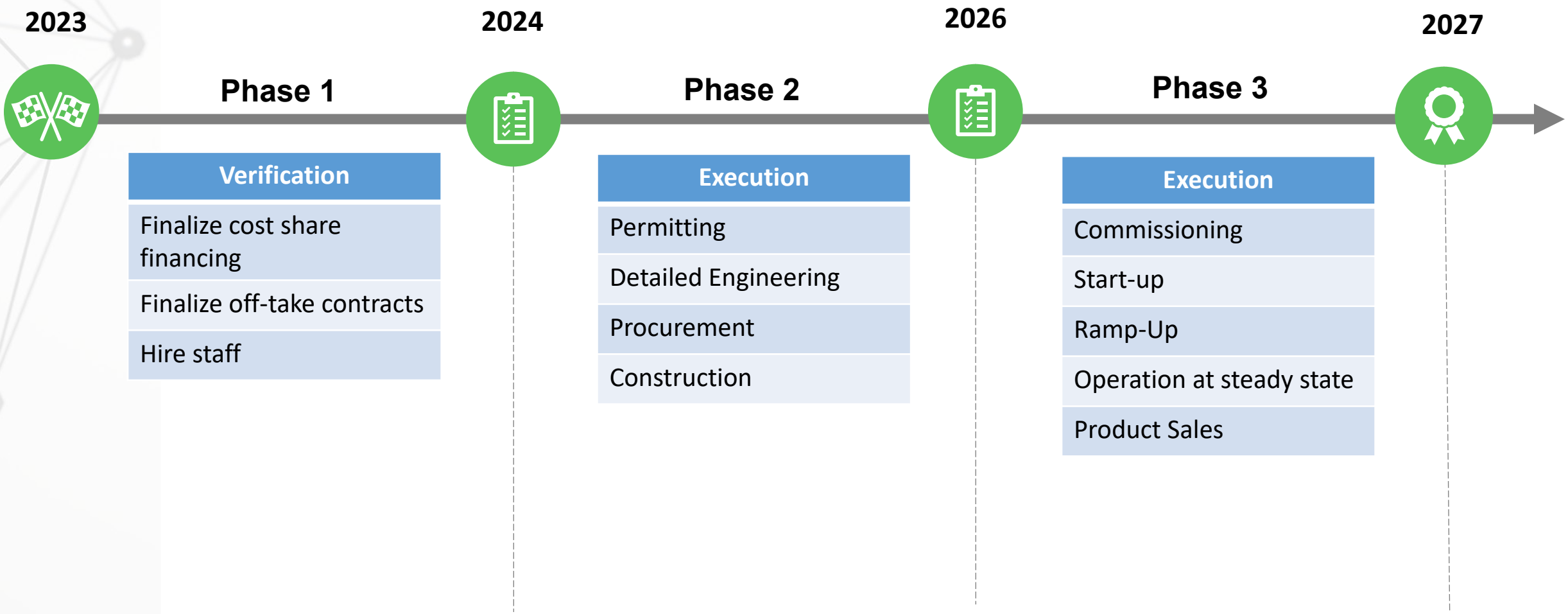
We know that all kinds of people want to buy products with a significantly reduced or even net-zero carbon footprint. That’s why so many of our products are created to help other companies and their customers reach their climate targets.

Products for climate protection

BASF
We create chemistry

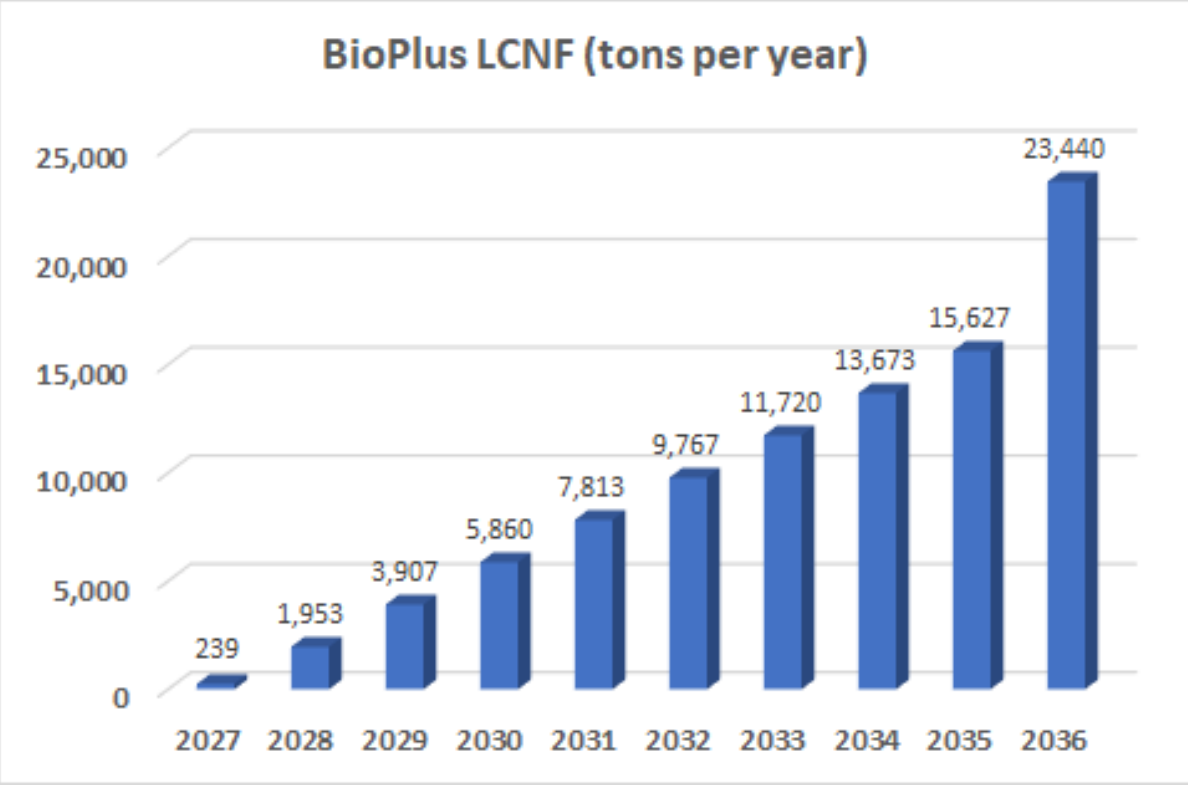
Project Schedule

NDC product sales will begin in 2027.



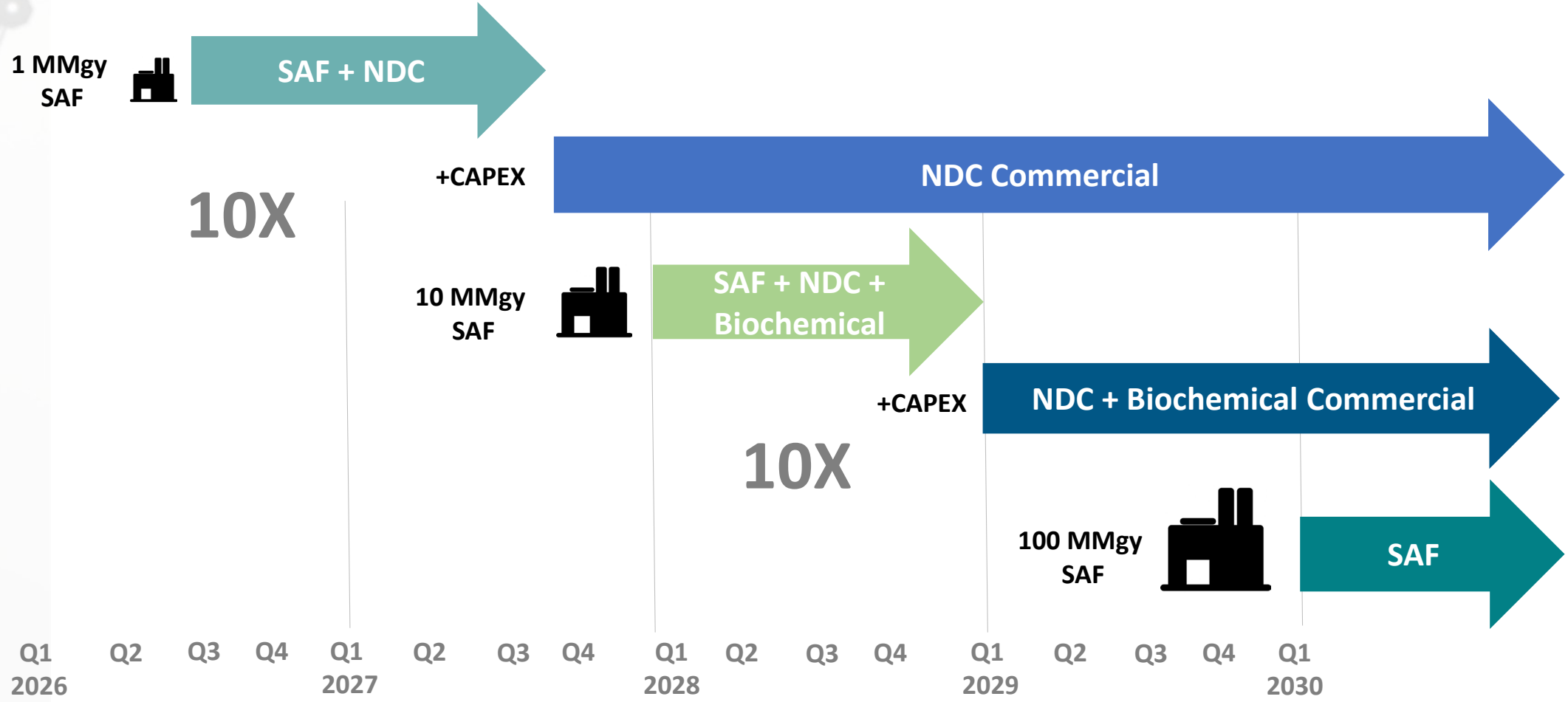
Estimated Tire Market Adoption

- Conservative estimate based on incremental adoption into various tire rubber compounds for OEM light truck and passenger car tires
- Based on Birla Carbon market experience and historical precedents
- Aggressive sustainability goals of tire companies and governments could significantly increase rate of adoption.



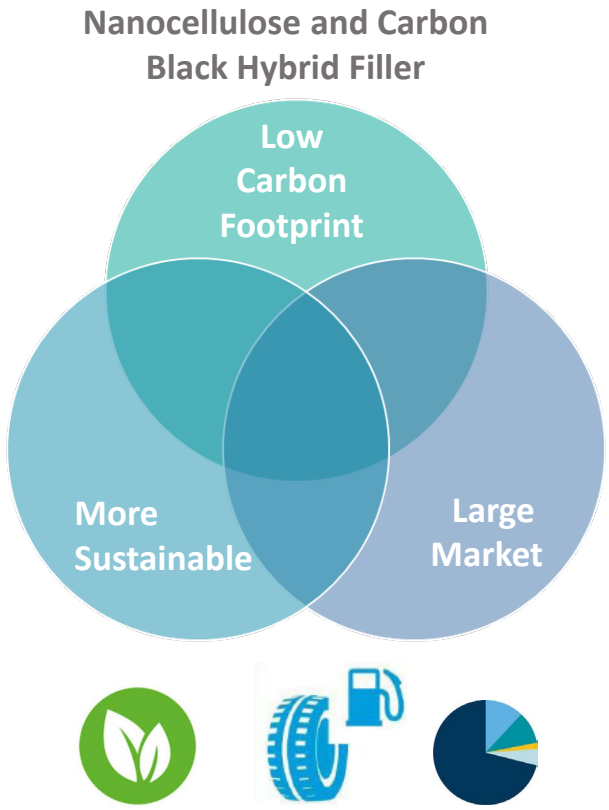
Production Scale-Up

The NET ZERO demo plant and first commercial can be converted to NDC and other high value co-products plants after collecting the necessary techno-economic data for the next scale SAF plant, thereby extending the useful life of each asset and reducing scale-up financing challenges.



Summary

- A nanocellulose and carbon black hybrid filler packages offers synergistic advantages to the tire industry
  - Carbon black is the dominate filler for tires with global production of ~13 million tons per year
    - Unique ability to significantly enhance the properties of any elastomer rubber system
    - Exceptional processability.
  - Nanocellulose combined with carbon black offers
    - Lower tire rolling resistance and fuel use
    - Lower GHG emissions from cradle to grave
    - Increased sustainable, biobased content



Thank You!

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