Plant Based Composite Materials for Automotive
They Exist and Are Ready for Prime Time

Mark Remmert
Chief Executive Officer
Green Dot Bioplastics
Bioplastic by Type

Global production capacities of bioplastics 2018 (by material type)

- PBAT: 7.2%
- PBS: 4.6%
- PLA: 10.3%
- PHA: 1.4%
- Starch blends: 18.2%
- Other (biodegradable): 1.5%
- Other (bio-based/non-biodegradable): 0.9%
- PE: 9.5%
- PET: 25.6%
- PA: 11.6%
- PP*: 0.0%
- PEF*: 0.0%
- PTT: 9.2%

Total: 2.11 million tonnes

*Bio-based PP and PEF are currently in development and predicted to be available at commercial scale in 2023.

Source: European Bioplastics, nova-Institute (2018)
Global production capacities of bioplastics in 2022 (by market segment)

- **Packaging (flexible & rigid)**: 58%
- **Consumer goods**: 10%
- **Automotive & transport**: 7%
- **Building & construction**: 6%
- **Textiles**: 5%
- **Agriculture & horticulture**: 4%
- **Electrics & electronics**: 8%
- **Others**: 2%

Total: 2.44 million tonnes in %

Source: European Bioplastics, nova Institute 2018
What is a bioplastic?

1. Biobased: comes from a renewable resource; plants
2. Compostable/biodegradable: can break down into organic matter that nourishes the planet, not destroying it.

Biocomposites are bioplastics + natural fiber reinforcements (NFRP)
# Types of reinforced composites

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Inorganic</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>• E-glass</td>
<td>• Flax</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>• Carbon</td>
<td>• Sisal</td>
</tr>
<tr>
<td>Epoxy resins</td>
<td></td>
<td>• Jute</td>
</tr>
<tr>
<td>Nylon</td>
<td></td>
<td>• Hemp</td>
</tr>
<tr>
<td>Plant-based</td>
<td></td>
<td>• Coir</td>
</tr>
<tr>
<td>Polylactic Acid – 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green PE – 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodegradable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch-based hybrids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodegradable polyesters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbe derived – PHA</td>
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<tr>
<td>PLA</td>
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</tbody>
</table>
Use of Natural Fiber Reinforced Plastic Composites (NFRPs) Increasing in Automotive

Value Propositions for NFRPs

1. **Sustainable** – increased use of renewable resources and/or biodegradable at end of life

2. **Light-weighting** – lower specific gravity compared to glass or carbon reinforced plastics
Advantages to Natural Fiber Composites

- **Low Density** - May lead to weight reductions of 10-30%
- **Low GHG Emissions** - in two ways: plants convert CO₂ to O₂ & less energy in production
- **Safer** - reduced wear of tooling, healthier working conditions, and no skin irritation, no off gassing, reduced fogging behavior
- **Sustainable** - from renewable sources
- **Quieter** - Good thermal and acoustic insulating properties
Criteria for Selection of NFRPs

Physical
• density, texture, sound absorption, fiber characteristics – length/ diameter ratio, thermo conductivity

Mechanical
• elastic modulus, shear modulus, tensile strength, elongation at break

Technical
• processing time/cost, energy input cost, processability

Environmental
• eco-friendly, government support, biodegradability, social positive view
Manufacturing of NFRPs is Specific

- Glass and carbon have known health and safety issues
- Natural fibers have known moisture and handling concerns
- Processing of NFRPs is both an art and a science
  - Degradation of fiber through processing must be avoided
    - Processing temperatures
    - Fiber breakage
  - Dispersion and bonding must overcome hydrophilic fiber properties
    - Adhesion incompatibility
    - Hydrolysis can occur if H₂O is absorbed
Sustainability

- Renewable content
- Energy consumption
- Life Cycle Analysis
Natural Fiber Are Inherently Sustainable

Natural Fibers

Mineral
- Asbestos
  - Fibrous brucites
  - Wollastonite

Plant/Vegetable
- Bast
  - Flax
  - Hemp
  - Jute
  - Kenaf
  - Ramie
- Leaf
  - Abaca
  - Banana
  - Henequen
- Seed
  - Coir
  - Cotton
  - Milkweed
- Wood
  - Hardwood
- Grass stem
  - Cereal straw
  - Reed canary grass
- Wood
  - Softwood
- Wood
  - Elephant grass
- Grass stem
  - Switch grass

Animal
- Wool
  - Angora wool
  - Sheep wool
- Silk
  - Tussah silk
  - Mulberry silk
- Hair
  - Alpaca hair
  - Goat hair
  - Horse hair

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The biobased content of a product is the carbon molecular weight % from renewable resources used in the formula.
Energy Consumed in Fiber Production

plant fibers are inherently lower energy

Cumulative Energy Demand and GHG Emissions by Reinforcement

- Glass fiber
- Flax fiber
- Hemp fiber
- Jute fiber

CED (MJ/kg) vs. GHG (kg CO2e/kg)

GHG Emissions & Energy Consumed In Polymer Production

*biopolymers are typically lower energy*

![Graph showing GHG emissions and cumulative energy demand by polymer](image)

Data on EU production from Plastics Europe. Data on US production from American Chemistry Council.
## Life Cycle Analysis for NFRPs in Production

<table>
<thead>
<tr>
<th>Product</th>
<th>Composite material</th>
<th>Replaced traditional material</th>
<th>Change in weight</th>
<th>Change in cumulative energy demand</th>
<th>Change in greenhouse gas emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car side door</td>
<td>Hemp/EP</td>
<td>ABS</td>
<td>-27%</td>
<td>-45%</td>
<td>-15%</td>
</tr>
<tr>
<td>Under-floor pan</td>
<td>Flax/PP</td>
<td>GF/PP</td>
<td>0</td>
<td>-14%</td>
<td>NA</td>
</tr>
<tr>
<td>Rotor blade</td>
<td>Flax/EP</td>
<td>CF/EP</td>
<td>0</td>
<td>-50%</td>
<td>-45%</td>
</tr>
<tr>
<td>Car interior</td>
<td>Bagasse/PP</td>
<td>Talc/PP</td>
<td>-20%</td>
<td>-22%</td>
<td>-21%</td>
</tr>
</tbody>
</table>

Lightweighting

Natural fibers vs E-glass

• Can increase fuel economy
Lightweighting Examples
Natural Fibers Are Inherently Lighter Weight

Specific Gravity

- E-glass
- Carbon
- Flax
- Sisal
- Jute
- Hemp
- Coir
Lighter Fibers = More Fibers By Weight

- Glass fiber 2.6 SG
- Jute fiber 1.4 SG

Advantage of Lighter Fibers: Less is More
Property Comparison of 20% Glass Filled PP vs. 20% Sisal Filled PP

Data collected from tests performed in Green Dot Laboratory
Comparative Cost

typical cost of fiber reinforced PP composite

- Jute
- SG Equivalent
- Glass
- 100% PP

40% Fiber Content

(¢/lb)
Product Examples
Biocomposite Product Examples

Green Dot Bioplastic NFRP biocomposites

Terratek® CC200500
Corn Cob Composite using Braskem Green PE

Product Description
Terratek® CC200500 is a proprietary blend of corn cob and biobased polyethylene for injection molding applications. CC200500 contains 15% corn cob fiber and with Braskem Green PE this formulation is fully biobased.

<table>
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<tr>
<th>Property</th>
<th>Test Method</th>
<th>Value</th>
</tr>
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<tr>
<td>Specific Gravity</td>
<td>ASTM D792</td>
<td>1.04 g/cm³</td>
</tr>
<tr>
<td>Shrinkage</td>
<td></td>
<td>0.013 mm/mm</td>
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<tr>
<td>Melt Index(190C 2.16kg)</td>
<td>ASTM D1238</td>
<td>6.7 g/10 min</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ASTM D638</td>
<td>21 MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>ASTM D638</td>
<td>1.7 MPa</td>
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<tr>
<td>Flex Strength</td>
<td>ASTM D790</td>
<td>40 MPa</td>
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<tr>
<td>Flex Modulus</td>
<td>ASTM D790</td>
<td>1540 MPa</td>
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<tr>
<td>Elongation</td>
<td></td>
<td>5.23 %</td>
</tr>
<tr>
<td>Notched Izod</td>
<td>ASTM D256</td>
<td>28.4 J/m</td>
</tr>
</tbody>
</table>

100% plant base
John Deere EcoRigs® made with corncob fiber & I’m Green® PE
## Biocomposite Product Examples

### Green Dot Bioplastic NFRP biocomposites

**Terratek® SC200500**

**Product Description**

**Terratek® SC200500** is a proprietary blend of biofillers and polypropylene for injection molding applications.

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<td>17.5 g/10 min</td>
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<tr>
<td>Tensile Strength</td>
<td>ASTM D638</td>
<td>22.256 MPa</td>
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<tr>
<td>Tensile Modulus</td>
<td>ASTM D638</td>
<td>1940 MPa</td>
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<tr>
<td>Flex Strength</td>
<td>ASTM D790</td>
<td>47.629 MPa</td>
</tr>
<tr>
<td>Flex Modulus</td>
<td>ASTM D790</td>
<td>1760 MPa</td>
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<tr>
<td>Elongation</td>
<td></td>
<td>4.07 %</td>
</tr>
<tr>
<td>Notched Izod</td>
<td>ASTM D256</td>
<td>19.6 J/m</td>
</tr>
</tbody>
</table>

lightweight natural (animal based) fiber with agricultural waste filler in PP for strength and toughness
Plant based composites can be either monolithic structures or laminates. Both can consist of plant based and/or biodegradable components.
Plant Based Synthetic Leather

• Cleaner manufacturing process. No solvents. No air or water discharge.

• High renewable content

• Can be 100% biodegradable
science based • style driven • socially conscious

GreenDotBioplastics.com