Bio-based Materials for Durable Automotive Applications

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Roadmap

• Sustainability at Ford
• Bio-based materials developments
• Automotive material requirements
• How materials stack up
• Future perspective
Ford’s Commitment

“It was always clear to me our industry had to be green...Our competitors used to love to laugh about the Ford green story. Those same people now are all falling all over themselves to see who can be greenest, which I find amusing.”

-Bill Ford, Jr.
Executive Chairman
Ford Motor Company
What is Sustainability?

- **Environmental**
  - CO₂
  - Energy Security

- **Economic**
  - Profitability
  - Cash Flow

- **Social**
  - Human Rights
  - Working Conditions

Sustainable products and manufacturing

Viable business

Feedstocks and processes
Ford’s Sustainable Materials Strategy

• Vision
  – Ford Motor Company will ensure that our products are engineered to enable sustainable materials leadership without compromise to Product Quality, Durability, Performance or Economics.

• Key Positions
  – Recycled and renewable materials must be selected whenever technically and economically feasible. We will encourage the best green technologies to meet the increasing demand for these materials.

  – When we use recycled and renewable materials, there will be no compromise to Product Quality, Durability & Performance or Economics.

  – We will enhance technologies, tools and enablers to help validate, select and track the use of these materials in our products.

  – The use of recycled and renewable content is increased year by year, model by model where possible.
History of Biomaterials at Ford

• 1937 Ford was producing 300,000 gallons of soy oil a year for use in car enamels (Soybean Digest 1947).
• 1939 the Ford Motor Company was harvesting about 100,000 bushels of its own soybeans.
• The "Soybean Car" was unveiled by Henry Ford on August 13, 1941.
• ‘Fordite’ material used in steering wheels contained wheat straw.
Biomaterials at Ford Today

• renewable oils in partial substitution of petroleum for foams
  – soy oil based urethanes and foam
  – castor oil based foam
• renewable fibers and fillers in plastic composites
  – reinforcements: wheat straw, hemp, cellulose, coconut coir
  – fillers: soy hulls, soy flour, coconut shell powder
  – impact modifiers: TKS, guayule
• renewably sourced thermoplastic resins
  – bio-polymers: PLA, Sorona (PTT), etc.
  – bio-based chemicals: PE, PP, PET, etc.
Automotive Requirements

• harsh operating environments
  – temperatures from -30 °C to 85 °C; 90%+ RH for interiors
  – temperatures from -30 °C to 150+ °C underhood
  – dent/ding mar resistance for exteriors

• long product lifetime

• large volumes

• fast cycle times

• mass customization
Soy-based Polyurethane Foam

**Status:** Ford is leader in technology and first OEM to launch in production; migration to other non-automotive applications

- all vehicle platforms in North America with soy foam seats
- 75% of vehicle platforms in N.A. with soy foam headrests
- Ford Escape: soy foam headliner
- Soy foam + 25% recycled tires for gaskets in 14 vehicle platforms
- diverts >5 million lb petroleum annually
- reduces CO$_2$ emissions by >20 million lb annually
R&A initiates research project on soy foam

Model U concept vehicle

Completed TDI trials & testing with Lear & Bayer

Materials Engineering approval TDI

Component approval; Processing Evaluation completed

2002 2003 2004 2005 2006 2007

R&A initiates research project on soy foam

United Soybean Board awards R&A 3yr. $230k grant

Completed TDI trials & testing with Lear & Renesol

Press release on Mustang soy foam seats
Soy-based Polyurethane Foam

• passes all material and performance specifications
• cost neutral / reduction over petroleum based foam
• improved carbon footprint
• durable
• Next steps for research and development:
  ‒ increase bio-content in foams
  ‒ development of foams with alternative renewable oils
  ‒ recycled polyols from glycolysis of PU foams
Natural Fiber Reinforced Composites

**Objective:** Replace fiberglass and mineral reinforcements in plastics with natural fiber for injection molding materials

### Wheat straw/PP versus conventional composites

<table>
<thead>
<tr>
<th>Material Replaced</th>
<th>Cost Reduction</th>
<th>Density Reduction</th>
<th>CO₂ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc/PP</td>
<td>0 - 5%</td>
<td>5-10%</td>
<td>0.58 kg CO₂/kg</td>
</tr>
<tr>
<td>GF/mica/PP</td>
<td>5 - 10%</td>
<td>10-15%</td>
<td>0.61 kg CO₂/kg</td>
</tr>
<tr>
<td>ABS</td>
<td>10 - 15%</td>
<td>15-20%</td>
<td>1.3 kg CO₂/kg</td>
</tr>
</tbody>
</table>

**Benefits:** Sustainable material  
*Environment* – by-product; CO₂ reduction; reduced petroleum  
*Social* – local agri-economy  
*Business* – weight reduction; cost equivalent or reduction; reduced processing energies
Wheat Straw Bio-Filled Polypropylene
Industry and World-First Usage in Quarter Trim Bins on 2010 Ford Flex

reduces petroleum usage by some 20,000 pounds per year and reduces CO\textsubscript{2} emissions by 30,000 pounds per year
NF Reinforced Composites: Wheat Straw PP

- **3Q07**: Ford joins BioCar Initiative
- **2Q08**: ongoing material property testing, material formulation
- **1Q09**: part selection interior
- **6/09**: Part “B” trial
- **9/09**: Part “A” trial 2
- **Fall 2009**: Ford Flex component level testing
- **11/09**: IMPLEMENTED

- **4Q07**: UWaterloo, OMTEC, A.Schulman approach Ford R&A
- **3Q08**: meets 293-B & 941-A material specs
- **5/09**: Part “A” trial 1
- **7/09**: Part “C” trial
- **9/09**: Trial Ford Flex Bin/Cover
- **10/09**: meets necessary interior component level requirements

Ontario BioCar Initiative → compressed timeline
Natural Fiber Reinforced Composites

- improved carbon footprint
- reduced processing energy and cycle time
- durable

Next steps for research and development of natural fiber reinforced composites:
  - migration of wheat straw PP to other vehicles and applications
  - higher performance fibers: cellulose, NCC
  - natural fiber reinforcement in bio-based resins
Bio-Based Resins

renewable feedstock for thermoplastic resins:

– bio-based polymers
  • Polylactide (PLA) – corn, sweet potatoes, sugarcane
  • PTT (Sorona) – corn
  • PHA (Mirel) – corn
  • nylons (PA610, PA1010, PA410, PA11) – castor oil

– bio-based chemical precursors
  • polyolefins (PE, PP) – sugarcane
  • nylons (PA6, PA6,6) – castor oil, corn, biomass
  • polyesters (PET, PBT) – corn, biomass
Bio-Based Resins: PLA

• **Advantages:**
  – renewable resource / fossil fuel reduction
  – reduced CO$_2$ emissions
  – end-of-life options: compostable, recyclable

• **Challenges:**
  – processing and mechanical properties
  – density
  – hydrolytic stability
  – long-term durability in automotive environments

• **Potential applications for automotive:**
  – packaging and protective wrap – manufacturing facilities
  – textiles: floor mats, carpet, upholstery
  – interior applications: trim, labels
PLA Hydrolytic Stability

• PLA susceptible to hydrolysis:

\[
\begin{array}{c}
\text{RCH}_3 \underbrace{\text{O}}_{n} \text{R'} \quad \text{H}_2\text{O} \quad \text{RCH}_3 \underbrace{\text{O}}_{n} \text{H} + \text{HOR'}
\end{array}
\]

• Ford has history of durability research for polymeric materials:
  – accelerated testing to correlate elevated temperature and humidity conditioning to in-vehicle, in-field
  – cumulative damage models
  – one week exposure at 50 °C/90% RH is roughly equivalent to 2 months exposure in southern Florida for an interior application
PLA Durability: Molecular Weight

- weight average molecular weight (Mw) – measured by GPC
- MW degradation over conditioning time at 50 °C/ 90% RH
- crystalline material – 2 degradation regimes
- degradation rates converge at long times

![Graph showing degradation rates of NeatPLA_Amorphous and Neat PLA_Crystalline](image)
PLA Durability: Mechanical Properties

- decrease in strength at longer conditioning times
- after 8 weeks samples lose integrity and can no longer be tested
- current PLA materials not the best bio-resin option for auto interiors
- continued work
  - blends
  - new formulations

Quasi-static three-point bend testing
ASTM D-790 method
Strain rate of 1 mm/min with a 50 mm span at RT
PLA Blends

- evaluate various blends of PLA-PC
- further accelerated testing conditions: 70 °C/ 90%RH
- 1 week conditioning is roughly equivalent to 1 year exposure in southern Florida for an interior application
- evaluate performance as a function of time

<table>
<thead>
<tr>
<th>Sample</th>
<th>Resin</th>
<th>PLA Content</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA-100</td>
<td>Neat PLA</td>
<td>100%</td>
<td>NatureWorks</td>
</tr>
<tr>
<td>PLA-45</td>
<td>PC/PLA</td>
<td>45%</td>
<td>1</td>
</tr>
<tr>
<td>PLA-30</td>
<td>PC/PLA</td>
<td>30%</td>
<td>2</td>
</tr>
<tr>
<td>PLA-25</td>
<td>PC/PLA</td>
<td>25%</td>
<td>3</td>
</tr>
<tr>
<td>PCABS</td>
<td>PC/ABS</td>
<td>0%</td>
<td>Sabic</td>
</tr>
</tbody>
</table>
PLA Blends Durability

• slight improvement to initial performance
• 3x durability than neat PLA; still only one year in S. FL
• side / competing reactions
• blends with other resins may be more effective

not yet durable enough for automotive applications!
Bio-based Polyamides

• Polyamides derived from castor bean oil
  – PA10,10
  – PA 6,10
  – PA 4,10
  – PA11

• Benefits
  – castor beans are not food source
  – high mechanical strength and HDT
  – excellent chemical and stress cracking resistance
  – low moisture absorption compared to PA6
  – durable
Automotive Applications for Bio-based Polyamides

- Finding the right balance between performance and cost
- Example: PA 6,10 potential candidate for
  - radiator end tanks
  - air brake lines – supply issues with PA12
  - fuel connectors – more resistant to chlorides & hydrolysis
  - multi-layer fuel tubes
Bio-based Nylon 11 Usage

- Nylon 11 – 100% derived from castor bean oil
- used in fuel tubes (in-tank)
- 95% of Ford vehicles use this product
- reduces petroleum usage by close to 1 million lbs/yr
- reduces CO₂ emissions by 1.1 million lbs/yr (compared to PA12)
- potential to migrate to other high performance underhood applications
Bio-based Chemical Precursors

• **Advantages:**
  – use of renewable feedstocks
  – same chemical compounds
  – ease of substitution
  – durable

• **Challenges:**
  – infrastructure and scale up
  – purification
  – cost
Challenges for Biomaterials

• material challenges
  – processing: modifications or completely new methods
  – material properties
    • part design and geometry
    • different failure modes
    • durability
  – crop to crop variations

• supply chain challenges
  – infrastructure for agricultural feedstocks and pre-cursors
  – volumes – supply and demand
  – cost – economies of scale
Future Perspective

• people vote with their wallets – consumers will drive the migration of bio-based materials
• need to seek solutions that meet automotive durability
• continue to take small steps and implement when ready
• development of new material technologies can be accelerated by collaboration with all partners in supply chain
"Someday you and I will see the day when auto bodies will be grown down on the farm."

– Henry Ford
Driving Green Solutions For All FMC Vehicles