Working towards a Circular Economy through the Innovation of Bioproducts at the University of Guelph

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Canada’s ag-food university
Partnership with OMAFRA for several decades

- Ranked #1 in Canada for agri-food and veterinary science
- Founding colleges date back to more than 150 years.
- Learning and research in engineering, agricultural and veterinary sciences, physical and life sciences, business, arts, and social sciences.
• Focus on development of new sustainable materials based on Circular Bio-economy (closed loop system)
• Links plant science/crop research with material science & engineering
The concept of bioeconomy is referred to as a revolution in getting industrial products of commercial value from renewable resources.

For addressing:

- Depletion of natural resources
- Environmental concern
- Climate Change

Organisation for Economic Co-operation and Development (OECD) Estimate: Bio-economy will contribute 2.7% of Global GDP by 2030

Sustainable Development: Triple Bottom Line

Defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987/ Brundtland Commission)

Socio-economic: Economic Impacts, use of agricultural feedstock

Socio-environmental: Low greenhouse gas emission

Enviro-economic: Reduced manufacturing cost

Sustainable Development Exists: When all three overlap

Legacy of World War II
Shortage of natural materials: led to a search for synthetic alternatives—and an exponential surge in plastic production

Plastic use has risen since 1950
448 million tons
Produced in 2015

Lifetime of Plastic

<table>
<thead>
<tr>
<th>Product</th>
<th>Lifetime (years)</th>
<th>Quantity (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building &amp; construction</td>
<td>35</td>
<td>72</td>
</tr>
<tr>
<td>Industrial machinery</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Electrical</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Textiles</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>Consumer products</td>
<td>3</td>
<td>46</td>
</tr>
<tr>
<td>Packaging</td>
<td>Less than six month</td>
<td>161</td>
</tr>
</tbody>
</table>

Packaging: The largest market for plastics today is packaging—more than 50% of total plastics

Eighty-six percent of plastic packaging produced globally is never collected for recycling.

Sources: World Economic Forum; Ellen MacArthur Foundation
Plastic Pollution

- World population- to reach 8.6 billion in 2030, 9.8 billion in 2050 and surpass 11.2 billion in 2100.

- Plastic pollution including littered single used utensils, bottles, bags and food packaging that end up in world’s rivers and oceans.

- According to the UN, during every minute, a dump truck of plastic waste is pouring to the sea: By 2050, there will be more plastic in the ocean than fish.

Sources: World Economic Forum; Ellen MacArthur Foundation

KEY POINTS

- **Circular Economy? “Waste-free” World – Linear model vs. Closed-loop System**
- **Research & Innovation to supplement “Circular Economy” – Focus on Biobased Materials**
  - (I) Compostable Packaging & Consumer Products
  - (II) Durable Auto-parts
- **SUSTAINABLE MATERIALS? From Bio-sourced, recycled materials, waste resources & their Various Combinations**
- **Concluding thoughts**
The Circular Economy vs. Linear? – “A New Relationship with our goods and materials”

Key principles of a ‘waste-free’ world: reuse, repair, remanufacture and upgrading.

In a circular economy, waste materials and energy are redefined as inputs by breaking down and repurposing goods or supplying them as services.  

*Walter R. Stahel, Nature 531, 443–446 (24 March 2016)*

Bioproducts Discovery & Development Centre, University of Guelph, Canada
Complete Sustainability!
Bio-economy combines Circular economy

Sustainability Goals Associated with Bioeconomy
Need Advancement in Feedstock (Supply chain), Technology (Innovation), Market (New products)

THE EUROPEAN BIOECONOMY IN 2030

Sustainable Packaging Trends

Green Packaging: Degradable, reusable or recyclable

$ 274 Billion market by 2020!
Bio-based

- Poly (Lactic Acid), PLA
- Polyhydroxyalkanoates, PHAs
- Cellulose Acetate

- Bio-PE/PP
- Bio-Nylons
- Bio-PTT

Biodegradable

- Poly (Butylene Succinate), PBS
- Poly (ε-Caprolactone), PCL
- Poly(butylene adipate co-terephthalate), PBAT

- Polyethylene
- Polypropylene
- Polystyrene
- Poly (Vinyl Chloride)

Petro-based

- Polyethylene
- Polypropylene
- Polystyrene
- Poly (Vinyl Chloride)

Bioplastics Types

- 'Durable'
  ~120% growth
  ~560% growth

Ref: www.designnews.com
**Biodegradable plastic market size by application: 2015 vs 2020**

<table>
<thead>
<tr>
<th>Application</th>
<th>2015</th>
<th>2020</th>
<th>CAGR%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging</td>
<td>1,227</td>
<td>1,928</td>
<td>9.5%</td>
</tr>
<tr>
<td>Fibers</td>
<td>279</td>
<td>580</td>
<td>15.8%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>198</td>
<td>259</td>
<td>5.5%</td>
</tr>
<tr>
<td>Injection Molding</td>
<td>109</td>
<td>241</td>
<td>17.3%</td>
</tr>
<tr>
<td>Others</td>
<td>223</td>
<td>383</td>
<td>11.5%</td>
</tr>
</tbody>
</table>

**Packaging:** Single-use compostable packaging materials including carry bags, food packaging, boxes, laminating films, etc.

**Fibers:** clothing, automotive interiors, and carpets, among other products...

**Ag:** Mulch film for protecting crops, maintaining soil temperature, soil moisture retention, and weed management.

Ref: https://www.marketsandmarkets.com/Market-Reports/biodegradable-plastics-93.html?gclid=CjwKCAjwns_bBRBCEiwA7AVGHpgGniCvGh9OV-kym-iuJ3bSiOKLBNLp0bdCvBquKJzM3c9mKyGtRBoCyQwQAvDwE
The global biodegradable plastics market was estimated to be ~$2 billion in 2015 and is expected to reach ~$3.4 billion by 2020 at a CAGR of 10.8% between 2015 and 2020.

Ref: https://www.marketsandmarkets.com/Market-Reports/biodegradable-plastics-93.html?gclid=CjwKCAjwns_bBRBCEiwA7AVGHpgGniCvGh9OV-kymiuJ3bSiOKBNLp0bdCv8quKJzM3c9mKyGtRB0CyQwQAvDwE
**Biopolymers: Need New & Emerging Applications**

- **Automotive**
- **Electronics:** TV, Computer, Housing, Cellphone
- **Packaging**
- **Consumer Goods, Furniture**
- **Blending**
- **Nanocomposites**
- **Agricultural tools**

**Biopolymers:**

Cost/Performance limitations
(New & Emerging Value-added applications)

Billion Dollars Wastes as Resource ?: Plastic Wastes + Food/Agro-food Wastes from landfills to Industrial Products

Plastic pollution like food packaging: End up in world’s rivers and oceans

Well-known Food Wastes & Agro-food Wastes
Utilization of Food Industry Waste: A Biofiller in Green Composites: Apple Pomace and Grape Pomace

- Valorization of food industry waste
- Improve material properties like cost, toughness, stiffness
- Tailor properties to specific applications
- Environmentally friendly products


Composites from Sustainable & Renewable Resources: Challenges & Innovations

Mohanty et al. Science 2018;362:536-542

Cover Page: November 2018

Polymer Matrix

Petrobased non-biodegradable
- Epoxy
- PP
- UPE
- PVC

Biobased biodegradable
- Bio-PBS
- PHAs
- PLA

Petrobased biodegradable
- Bio-PE
- Bio-PA
- PFA

Biobased non-biodegradable

Fillers & reinforcements

Traditional natural fibers
- Wood pulp
- Kenaf, flax, jute, sisal, ramie, cotton, bamboo, henequen, wood (soft and hard)

Agro and forestry residues
- Wheat
- Corn
- Miscanthus
- Straws (wheat, rice, soy, and canola), woody biomass (willow), grasses (Miscanthus), stover (corn)

Industrial co-products
- Lignin, DDGS, biocarbon, pomace, bagasse, coir, hull and husks

Recycled fibers/fillers
- Carpet
- Cardboard
- Carbon

Grape pomace
- Bagasse
- Lignin
Perennial Grass Reinforced Recycled Plastic (PP) based Biocomposites in Market

Product Status | Biobins (Home Hardware) and Eco-Resin flower pots (Lowes and Kroger)

“Circular Economy: Value-addition of recycled plastic: Reduce virgin plastic use

Coloured Storage Bio-bins @ Home hardware

Flowerpot @ LOWES & KROGER

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High-Filled (~75 wt.%) PLA based Bio-tiles

IDEA OF INVENTION: PLA + Maleic anhydride Grafted Polymer + Functionalized Oil + Additives + ~75% CaCO₃

PLA-BASED BIO-TILES

Novel PLA-high filled Green Composites

A. K. Mohanty et al; US Patent #7,354656 B2; CA 2427012; DE 60- 60307536 D1; EP 1361039 B1

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Compostable Coffee Pod Invented @ U of Guelph *

Single-serve coffee: Continues to Grow!
$1Bn - 2014 Cdn sales & $4Bn - 2014 US sales

Eco-Impact: Single-serve Coffee Pods
Sale:
14 billion in 2016
Wrap around the earth 14 times


Mohanty et al; WO 2016/138593 A1

Biobased Biocomposites Engineered @ U of Guelph

Bioproducts Discovery & Development Centre, University of Guelph, Canada
An Example of Circular Economy based Biocomposites – Now in Market Place

US, Canada, South America, Mexico & beyond

PP/PET-based non-compostable

Bioplastic-based biocomposites & compostable

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Value-added Uses: Food & Food Production Wastes: In New Compostable Products

Spent coffee grounds

Waste tomato skin

New Compostable coffee pods

High HDT

Post-Industrial PLA cloth

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New Biocarbon (BioC)-based Materials: BDDC Invented >30 Types of BioC

Control: Mechanical Properties, Modulus, Electrical Conductivity etc.

Carbon Structures

Biocarbon

Auto-parts, Consumer Products, Packaging, Super Capacitor.

Miscanthus based Carbon Dots Optical Devices

- What are carbon dots?
- Carbon dots are nano particles ranging from 2-10 nm in size and are well known for their electrical properties, optical properties and biocompatibility.

Bio-graphite from *Miscanthus* FeCo Biocarbon Composite

**Research Goal:**
- Develop method for producing biobased graphite from *Miscanthus*

1. *Miscanthus* was treated with Fe(NO₃)₃ and Co(NO₃)₂ prior to pyrolysis to catalyzed graphitization

2. Thermal oxidation of resulting biocarbon composite

3. Graphite purification and recovery by acid treatment

Toughened PP-Biocarbon Composites

**Challenge:** High Notched Izod IS ~150-400 J/m & Flex modulus ~1.4 – 2 GPa

**Effective biocarbon modification:** Impact Strength (IS) >400 J/m

Mohanty, Misra, Bahazin, Rodriguez, US 15/674,015; CN 2,975,803
Bahazin, Misra, and Mohanty *ACS Omega* 2017
Bahazin, Misra, and Mohanty, *Composites Part B* – Engineering 2017

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Application Areas
Products in the Marketplace or under development

- Compostable coffee pod, Purpod100
- Bio-bin
- Flowerpot
- Console box
- Spare tire cover
- Air duct controller
- Compostable Mulch Film
- Coca Cola bottle packaging tray
- Fender cover

USDA Certification for Bio-carbon:
- 99% new carbon – world’s first substitute for carbon black – lighter and price-performance-process competitive

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“Circular Economy in packaging and other good and services”: an inevitable transformation and a trillion $ business; disruptive technology; closed loop system, achievable & profitable

- “Nothing is waste – Waste is a Resource for a new Industry”

- Value-added biobased materials from wastes – Food/Agro-food wastes & Plastic Wastes Integration to Products

- Certified compostable products & packaging: reduce landfill

Circular Economy: Sustainable global growth and development: Zero Waste, Reduced GHG, a better planet.
Collaboration is the only way to proceed

- The key driver: Leaders from Academia, Industries, Govt. (Policy and Legislation), NGOs & International partners

Thank you all!

American Society of Materials (ASM)