DEVELOPMENTS AND TRENDS IN BIOPLASTICS TECHNOLOGY AND MARKETS FOR FLEXIBLE, POUCH AND BARRIER PACKAGING

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OUTLINE

• Basic definitions, classifications and drivers for bioplastics

• Feedstocks and concept of platform chemicals

• Commercial and developmental biobased polymers; “drop-in” versus new polymers and key producers

• Commercial and developmental biodegradable plastics

• Some current markets and applications, bioplastics growth projections and market trends

• “Green issues”, consumer and environmental concerns
DEFINITION & CLASSIFICATIONS OF BIOPLASTICS

- **PLASTICS WHICH ARE BIOBASED, BIODEGRADABLE OR BOTH:**

  **BIOBASED OR RENEWABLE PLASTICS:**
  - USDA Definition: Organic plastics composed wholly or significantly of recently fixed (new) carbon from biological sources such as renewable plant, forestry, animal, algal or marine materials (based on C¹⁴ content measurement as defined by ASTM D6866)
  - Renewable within 1-2 years (vs. millions of years for fossil-based) via biological carbon cycle
  - Focus is ONLY on origin of carbon constituents
  - Can be fully or partially biobased and biodegradable or non-biodegradable

  **BIODEGRADABLE AND COMPOSTABLE PLASTICS:**
  - Focus only on “end-of-life” processes, independent of carbon sources
  - Biodegradability determined by polymer structure & environmental conditions, not carbon source
  - May be bio-based (renewable) or fossil-based (non-renewable)

**THESE TWO CLASSIFICATIONS ARE NOT MUTUALLY EXCLUSIVE**

**BIOBASED DOES NOT NECESSARILY MEAN BIODEGRADABLE AND BIODEGRADABLE DOES NOT NECESSARILY MEAN BIOBASED**
INDUSTRY DRIVERS FOR BIOPLASTICS

- Growing regulatory, NGO and consumer concerns over carbon footprint, climate change, environmental and ocean pollution, health, “single use” plastics; Paris, Glasgow, UN and other international agreements; Circular Economy

- Government, consumer and NGO demands worldwide to reduce dependence on fossil feedstocks and convert to biobased and sustainable materials which are recyclable and/or biodegradable, carbon neutral and have low environmental and health impacts

- Increasing legislation and regulations globally restricting uses and disposal of petrochemical plastics (particularly “single-use”) and promoting bioplastics

- Development of enhanced production routes from renewable feedstocks and wastes due to rapid advances in thermal, catalytic, gasification, pyrolytic, supercritical fluid, microbiological and other processes to make biobased “drop-in” conventional materials and improved-function new materials

- Renewables are increasingly regarded as a fundamental pillar of a coming bioeconomy where biological sources produce energy, chemicals and materials with lower carbon footprint than petro-based products
EUROPEAN COMMISSION NEW BIOECONOMY STRATEGY

- Accelerate institution of sustainable European bioeconomy
- Develop renewable resources and scale-up and deploy new sustainable biorefineries across the EU
- Legislation for market development and green public procurement
- Seed investment platform (€100M) and research funding
- Standards, labeling and certifications
- Leads into EU Circular Economy package European Green New Deal
USDA CERTIFIED BIOBASED PRODUCT PROGRAM

- www.biopreferred.gov/BioPreferred/

- SETS MINIMUM THRESHOLD OF 25% NEW CARBON FOR PRODUCTS TO BE CONSIDERED BIOBASED

- FIRST “CERTIFIED BIOBASED PRODUCT” LABELS AWARDED MARCH 2011

- NOW OVER 3,000 CERTIFIED PRODUCTS IN 109 CATEGORIES
FEDERAL BIOMASS BIOECONOMY INITIATIVE

- Co-Chaired by USDA and USDOE
- Starting 2020, aim to accelerate innovative strategies to harness US biomass resources for affordable biofuels, bioproducts & biopower
  - Advanced algae systems
  - Feedstock genetic improvement, production, management, logistics
  - Biomass conversion and carbon utilization
  - Transportation, distribution, infrastructure and end-use
  - Bioeconomy analysis and sustainability
EUROPEAN BIOBASED CERTIFICATIONS

- **TUV Austria “OK BIOBASED” (Formerly VINCOTTE)**
  Certification marks for biobased content levels of: 20-40%  40-60%  60-80%  >80%

- **DIN CERTCO**
  Requires minimum organic material proportion of 50% and minimum biobased proportion of 20%
  Certification marks for biobased content levels of: 20-50%  50-85%  >85%
FEEDSTOCKS FOR BIOBASED POLYMERS

MAJOR RENEWABLE FEEDSTOCK CATEGORIES:

- AGRICULTURAL FOOD CROPS, BY-PRODUCTS & WASTES (USABLE FOR HUMAN OR ANIMAL CONSUMPTION) – Mono- & poly-saccharides, fats, oils, proteins
  Food versus fuels, materials and chemicals controversy

- NON-FOOD CROPS – Lignocellulosics, cellulosics, algae
  Land use controversy

- NON-FOOD WASTES – Agricultural, municipal, industrial

- CHEMICAL FEEDSTOCKS – Biomethane, CO₂, CO

Microbiological or thermal/catalytic conversion to plant sugars, syngas (CO + H₂), hydrocarbons and downstream chemicals

Industry aim is sustainable feedstock diversification: “transforming whatever are the right, abundant, local resources” (NatureWorks)
CONCEPT OF PLATFORM CHEMICALS

To make a renewably sourced material, only the FIRST chemical or monomer in the synthesis chain needs to be made from a renewably sourced feedstock. All later synthetic steps can be performed using standard chemical processes already developed for petrochemicals.

BIO-ETHYLENE CHEMICAL PLATFORM

Source: NNFCC
ADVANTAGES OF DROP-IN RENEWABLE CONVENTIONAL POLYMERS

Current developments are often aimed at renewably-sourced conventional polymers rather than new polymers, since there is lower financial and business risk:

- Downstream conversion technology is understood and integrated manufacturing infrastructure available
- Downstream products are identical to petrochemical products and fit existing compounding, conversion, applications and end-of-life infrastructure
- Market, supply chain and business infrastructure already developed (often more difficult than the science and technology)
- Drop-in products are chemically identical to fossil-based products and compete only on cost, quality, “green” credentials and sustainability
BIOBASED NON-BIODEGRADABLE PLASTICS

SOME COMMERCIAL & DEVELOPMENTAL BIOBASED NON-BIODEGRADABLE PLASTICS FOR FLEXIBLE PACKAGING

Commercial:
- **POLYOLEFINS**: PE from bioethanol or bio-naphtha
  - EVA, PVC (partially biobased)
  - PP from waste oils and fats
- **POLYESTERS**: PET (PlantBottle®) – 30% biobased by wt.
- **POLYAMIDES**: PA 5,10; 11 (totally biobased)
  - PA 4,10; 5,6; 6,10; 6,12; 10,10; 10,12 (partial bio);

Developmental:
- **POLYESTERS**: PET (totally biobased)
  - PEF – polyethylene furanoate
  - PTF – polytrimethylene furanoate
SOME PRESENT AND POTENTIAL MANUFACTURERS OF BIOBASED NON-BIODEGRADABLE POLYMERS

- Braskem, Solvay, Inovyn (Ineos), Neste/LyondellBasell/Borealis, Sabic, Mitsui, Dow/UPM, Total/Lanzatech/IFP/Exxens/L’Oreal PE, EVA, PVC, PP

- Covation, Teijin, SK Chemicals, Toray, Indorama/Coca-Cola Aromatic Polyesters

- Avantium, Covation/ADM, Origin Materials, AVA, Novamont Furanoate Polyesters

- BASF, DSM, Arkema, DuPont, Toray, Evonik, Cathay Polyamides

- Many large chemical and petrochemical companies are involved together with many small companies and start-ups. Key factor in routes from lab to commercialization is partnering of groups of companies where each contributes different parts of the technology and market knowledge.
GREEN POLYETHYLENE

- Braskem production in Brazil started 2010 using ethylene from sugarcane ethanol, 200Ktpa; expanding to 260Ktpa by 4Q 2022
- HDPE, LDPE and LLDPE grades available, identical to fossil-based PE made by same polymerization process
- Biobased “Green PE” recyclable in same way as fossil-based PE
- Higher production cost than PE from shale ethylene; 40% mass loss when ethanol is converted to ethylene
- Advantageous carbon-negative footprint and global warming potential over fossil-based polyethylene (-3.09 kg CO2 eq vs + 1.86) which provides green marketing credentials
- Now used by over 150 companies worldwide
- Packaging users include Coca-Cola (Odwalla), P&G, Danone, J&J, Tetra Pak, Avery Dennison, Seventh Generation, Ecover, Bramhults, Rosport, Plastic Omnium, Trudi, Printpack, Peel Plastics, Lego, Mondi, Café Favorito, DUO UK, Grupo Boticário, Natura, Nissin, Shiseido, Unilever and Nestlé.
“GREEN” POLYETHYLENE

Source: Braskem
ONLY NATURAL PET DRY DOG FOOD

Source: Braskem
TETRA PAK “TETRA REX” CARTONS

USE OF GREEN HDPE AND LDPE

Source: Braskem
PARTIALLY-BIOBASED PET

Coca-Cola PlantBottle®

- Made with commercially available biobased ethylene glycol component up to 30% by weight (20% renewable carbon by ASTM D6866 Method)
- Active development to produce biobased terephthalic acid to make 100% biobased PET a commercial reality
- Goal to make fully recyclable PET for bottles, films and other applications from 100% renewable feedstocks and plant-based waste
COCA-COLA PLANTBOTTLE®

Source: European Bioplastics
PARTIALLY-BIOBASED PET LAMINATING FILM

Source: Mondi
BIIOBASED ROUTES TO TEREPTHALIC ACID

p-Xylene

Terephthalic acid (TPA)

Via p-Xylene

- Anellotech/Suntory/Toyota Tsusho/JM: Catalytic Fast Pyrolysis (BioT-Cat) conversion of biomass to aromatics (Benzene, Toluene, Xylene; BTX). 40 Ktpa plant under construction in TX
- Virent (Marathon)/Renmatix/BP/JM: Chemical catalytic BioForming® Platform from biomass or plant sugars to p-xylene. 10K gallon/yr pilot plant; 100% bio-PET bottles demonstrated with Coca-Cola
- Origin Materials: (Ligno)cellulosics conversion with HCl to 5-chloromethylfurfural, then catalytically to p-xylene. Pilot plant in Sarnia, ON operational end of 2022, commercial plant planned for 2025 Geismar, LA converting 1Mtpa dry wood waste
- BioBTX bv (Netherlands): Catalytic pyrolysis from glycerol, fatty acids, lignocellulosic biomass or plastic waste followed by catalytic vapor conversion. Pilot plant started up September 2018

Competitiveness with fossil-based TPA depends on oil and naphtha prices
POLYETHYLENE FURANOATE (PEF)

- Furan-2,5-dicarboxylic acid or methyl esters as alternative monomer to terephthalic acid (TPA)

\[
\text{FDCA: } \quad \begin{array}{c}
\text{O} \\
\text{HO} \\
\text{O} \\
\text{OH} \\
\text{CO} \\
\text{O}
\end{array} \quad \text{TPA: } \quad \begin{array}{c}
\text{HO} \\
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\text{C} \\
\text{O}
\end{array}
\]

- Synthesis routes from C6 plant sugars (fructose, glucose) or (ligno)cellulosics

- Avantium, Origin & Novamont (thermocatalytic); AVA Biochem; Covation/ADM. Avantium building 5Ktpa demo plant in Netherlands onstream mid-2023.

- More favorable economics from plant sugars than TPA. No added hydrogen needed. Requires less than half the mass of sugars to produce a kg of FDCA compared to purified TPA

- Generates PEF as alternative to PET with improved properties. PEF is totally biobased if FDCA copolymerized with biobased ethylene glycol.
POLYETHYLENE FURANOATE PROPERTIES

- Property improvements over PET:

  THERMAL, PHYSICAL AND PROCESSABILITY PROPERTIES
  • Higher Tg; Heat distortion temperature increased by 12°C to 87°C
  • Lower Tm (213-235°C): easier processability at lower temperature
  • 60% higher modulus and tensile strength
  • Permits greater lightweighting and better thermal stability without heat setting – hot fillable at 85-90°C

BARRIER PROPERTIES

  Oxygen barrier: 6-10 times higher than PET
  Carbon dioxide barrier: 6-10 times higher than PET
  Water vapor barrier: 2-3 times higher than PET

Barrier properties further improved by metallization, AlOx/SiOx vapor coating or orientation

- 100% biobased if made with biobased ethylene glycol as comonomer

- Separable from PET by NIR scanning. Interim approval by European PET Bottle Platform for recycling up to 2% level in PET without adverse effect on PET performance (haze, color, processing and other properties). Under test by APR in US.
PEF Barrier Paper Bottle

Source: Avantium
BIODEGRADABILITY AND COMPOSTABILITY

BIODEGRADABILITY
- Biodegradable - undergoes enzymatic fragmentation and degradation by microorganisms to form water, CO2 (aerobic) and methane (anaerobic)
- Very imprecise term – no defined criteria, environments, products or time limits. Biodegradability under one set of conditions (e.g. aerobic industrial or home compost) does not necessarily imply biodegradability under other conditions (e.g. anaerobic, soil, aquatic, marine)
- Biodegradability is NOT a license to litter

COMPOSTABILITY
- Composting is an aerobic process
- Products meet specific requirements of industrial compostability (e.g. ASTM D6400, EN13432 or JIS K6950 ) or home compostability standards (e.g. TUV Austria OK Home Compost)
- Certification covers a product, not just a material, and includes determining the maximum thickness of material which can be degraded within one composting cycle
- Compostable plastics require infrastructure for collection, identification, sorting and composting and distinction is necessary between home compostable and industrially compostable materials
MAJOR COMPOSTABLE CERTIFICATION PROGRAMS

TUV-Austria “OK Compost INDUSTRIAL” and “OK Compost HOME”

EN 13432

DIN CERTCO
Industrially and Home Compostable

Japan Green Pla
JIS K 6950
Industrially Compostable

Biodegradable
Products Institute (US)
ASTM D-6400
Industrially Compostable
BIODEGRADABLE & COMPOSTABLE PLASTICS

Major current commercial types are:

- Polylactic acid (PLA) – biosourced lactic acid monomer from starches, sugars or biomethane, then ring-opening chemical polymerization. Industrially-compostable only

- Polyhydroxyalkanoates (PHAs; PHB, PHBV, PHBH, PHBO etc)
  - direct fermentation of starch, plant-based fatty acids, oils, CO₂, bioCH₄
  Extensively biodegradable – industrial & home compostable, anaerobic, marine, aquatic, soil

PLA & PHAs are biodegradable and biobased new polymers, not drop-ins

- Aliphatic and aliphatic/aromatic copolyesters (PBS, PBSA, PBAT, PCL) – mostly petro-based but PBS now partially biobased. Generally used by blending in PLA-, PHA- and starch-blend formulations
- Starch blends and derivatized starch blends
- Cellulose and some derivatives and blends
- Polyvinyl alcohol and polyglycolic acid

Under development or market testing:

- Protein-based materials, e.g., keratin-, zein-, casein-, whey and soy-based (e.g., whey-based barrier layers; Lactips/BASF casein-based water-soluble polymers)
- Polysaccharides (e.g., Chitosan) and bacterial-, algal- and fungal-based materials
SOME CURRENT LEADERS IN BIODEGRADABLE PLASTICS

Primary Polymer Producers

- **PLA** NatureWorks-PTT (US), Total-Corbion (Thai), Hisun, COFCO, BBCA/Futerro (China)
- **PHAs**
  - From plant oils: Danimer Scientific (US), Kaneka (Japan),
  - From used cooking oil: Nafigate-Hydal-Panara, RWDC
  - From starches: Shenzen Ecomann, Tianan (PHBV), CJ Bio (Korea),
  - From sugars: Biomer
  - From organic waste: Full Cycle Bioplastics
  - From biomethane: Newlight, Mango Materials
  - From CO$_2$: Newlight
  - From CO: Novomer

- **Aliphatic/Aromatic Polyesters (PBAT)** BASF, Jinhui Zhaolong, Xinfu, Tunet, Kingfa
- **Aliphatic Polyesters (PBS, PBSA etc)** Kingfa, Xinfu, PTT-Mitsubishi, Novamont
- **Polycaprolactone (PCL)** Ingevity, Daicel, BASF
- **Polyglycolic acid (PGA)** Kureha, Solvay
- **Polyvinyl alcohol (PVOH)** Kuraray, Nippon Gohsei, Sekisui
MAJOR COMPOSTABLE PLASTIC USES

COMPOSTABLE APPLICATIONS
Where compostability is a significant benefit (e.g., food contamination), collection & segregation is easy (e.g., large venues or restaurants), or there are tax incentives or legal constraints

- Single use packaging, food service and food waste bags and films
- Mulch films and other horticultural uses and loose-fill packaging
- 3D printing filaments

IMPORTANT NOTE:
Compostable plastics require dedicated infrastructure for collection, identification, sorting, and composting. Distinction is necessary between home compostable and industrially compostable materials.

DURABLE APPLICATIONS
- Neither require nor benefit from degradability or compostability
- Durable biobased products for electronic, household, consumer and automotive applications
- Often used in blends with non-biobased non-biodegradable polymers, e.g., PMMA/PLA, PC/PLA
- End of life recovery is by mechanical recycling, chemical recycling, or energy conversion
### PLA APPLICATIONS

<table>
<thead>
<tr>
<th>Rigids</th>
<th>Food Serviceware</th>
<th>Films</th>
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<td><img src="image1.png" alt="Rigids Category" /></td>
<td><img src="image2.png" alt="Food Serviceware Category" /></td>
<td><img src="image3.png" alt="Films Category" /></td>
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<th>Durables</th>
<th>Lactides</th>
<th>Bus. Dev.</th>
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<td><img src="image5.png" alt="Durables" /></td>
<td><img src="image6.png" alt="Lactides" /></td>
<td><img src="image7.png" alt="Bus. Dev." /></td>
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*Ingenious materials from plants not oil*
BASF “ECOVIO” BAGS

Source: European Bioplastics
NOVAMONT STARCH BLEND APPLICATIONS
Futamura NatureFlex cellulosic film laminated to a Novamont Mater-Bi starch blend film. NatureFlex is made from Forestry Stewardship Council (FSC)-certified birch and eucalyptus wood pulp, and Mater-Bi is made from non-GMO corn starch. Printed with certified commercially compostable non-toxic ink.

Source: Alter Eco
### SOME TYPICAL PRICE RANGES FOR BIOPLASTICS

<table>
<thead>
<tr>
<th>BIOPLASTIC TYPE</th>
<th>PRICE US$/POUND</th>
</tr>
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<tbody>
<tr>
<td>PLA</td>
<td>1.50 -- 3.00</td>
</tr>
<tr>
<td>PBAT</td>
<td>2.30 -- 3.80</td>
</tr>
<tr>
<td>PBS (Partially biobased)</td>
<td>2.40 -- 2.60</td>
</tr>
<tr>
<td>PLA Blends</td>
<td>2.20 -- 2.50</td>
</tr>
<tr>
<td>STARCH Blends</td>
<td>1.80 -- 2.50</td>
</tr>
<tr>
<td>PHA Blends</td>
<td>2.50 -- 3.00</td>
</tr>
<tr>
<td>Note: the above bioplastics all have about 30% higher density than polyolefins</td>
<td></td>
</tr>
<tr>
<td>BIOBASED PE</td>
<td>1.20 -- 1.45</td>
</tr>
</tbody>
</table>

### COMPARATIVE FOSSIL-BASED PRICING*

*Prices as of 2022-07-02. Unusually high due to supply chain and production problems worldwide. Expected to be temporary with eventual reversion to more normal levels 30-50% lower.*

HDPE: 0.87 – 0.93; LDPE: 0.90 -- 1.03; LLDPE: 0.82 – 1.09;
Projected overall growth rates 2021-2026: 33%pa Biobased and 48%pa Biodegradable; 42%pa All Bioplastics

Nova Institut/European Bioplastics
Projected overall growth rates 2021-2026: 33%pa Biobased and 48%pa Biodegradable
42%pa All Bioplastics
FACTORS RESTRAINING BIOPLASTICS GROWTH

- High price and often higher density versus virgin petrochemical polymers. Higher and stable oil and natural gas prices and/or carbon pricing needed to make some bioplastics price competitive.

- Low “Green Premium” value: consumers say they want sustainable products, but only 80% would pay 5% extra, and only 50% would pay 15% extra, if they meet performance requirements.

- Biodegradable/compostable plastics require different processing conditions from conventional petrochemical plastics and exhibit different property combinations and functionality.

- Major challenge in advancing from “proof of concept” to industrial-scale production. High financial risk (> $1 billion) setting up new industry competing against depreciated petrochemical assets.

- Concerns over use of foodstuff feedstocks, competition for land & water availability and whether bioplastics really do have lower carbon footprints than petro-based plastics given agricultural, land, water and fuel inputs needed to grow feedstocks. Major development work on routes from non-food biomass to avoid competition with food.

- Improved recycling technologies and infrastructure for fossil-based plastics, making them more sustainable and reducing bioplastics demand (e.g., PET).

- Bioplastics are now growing faster than the overall plastics market but are likely to maintain <2% market share over the next 5 years.
FUTURE GROWTH OF BIOPLASTICS

This will depend on:

- Future trends in oil, natural gas and virgin petrochemical polymer prices and potential institution of carbon pricing
- Continuing transition from fossil-based to bio-based feedstocks and improvements in pricing, carbon footprint and performance
- Development of economic routes from non-food feedstocks to biobased monomers and polymers identical to fossil-based versions as drop-ins for existing processes and manufacturing and recycling infrastructure
- Development of improved-property biobased/biodegradable polymers from non-food feedstocks
- Continuing increases in legislation worldwide enforcing use of renewable biobased and/or biodegradable plastic materials and restricting use of fossil-based polymers
- Whether the Green Premium remains low or increases
- How well bioplastics address future environmental, societal, political, legislative and economic issues, not just technological factors
THANK YOU FOR YOUR INTEREST

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