World Bio Plastics Market Outlook: Status and Issues

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Principal
Nexant, Inc.

Co-organized by:
Nexant is a leading global advisory in Polymers

- Expertise in energy, fossil, and renewables fuels, chemicals, and polymers; offices & operations in Americas, Europe, the Middle East, Africa, South Asia, Southeast Asia, and North Asia; 150 consultants advising for 50 years

- Products (multiclient reports) and Services (bespoke consulting)

<table>
<thead>
<tr>
<th>Natural Gas Markets &amp; Prices</th>
<th>Petrochemical Markets and Profitability</th>
<th>Process Technology and Costs</th>
<th>Specialized Sectors and Topical Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Detailed gas model/simulator which supports our consulting assignments and multiclient reports</td>
<td>- Analysis and forecasts of the profitability, competitive position and supply/demand trends of global petroleum and petrochemical industry</td>
<td>- Source of process evaluations of existing, new/emerging and embryonic technologies of interest to the energy and chemicals industries</td>
<td>- Review of fundamental business drivers, dynamics, markets, pricing and competitiveness</td>
</tr>
<tr>
<td></td>
<td>- Cost-of-production information on over 200 chemicals and polymers</td>
<td></td>
<td>- In-depth evaluations and reliable data on the technology, cost competitiveness and business developments of biorenewable chemicals and fuels</td>
</tr>
<tr>
<td></td>
<td>- Up-to-date supply/demand and pricing over 50 major chemicals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Why bio-based polymers?

Primary environmental benefits:
• Reduce CO$_2$, other GHGs emissions to mitigate climate change
• Reduce other pollutant emissions in feed supply, production
• If biodegradable, reduce risks of litter in water and on land

Primary economic and strategic benefits:
• Biomass globally abundant (agricultural/forest wastes, MSW, sewage)
• Bio-feedstock supplies are sustainable
• Biomass prices less volatile – oil could be $60-70/bbl in 2017
• Bio-based building blocks independent of petro byproducts
• Address market and policy drivers around the world

‘Biobased’ does not equal ‘biodegradable’
High level economics – feeds for all polymers

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>$ / MT&lt;sub&gt;Product&lt;/sub&gt;</th>
<th>$ / MT&lt;sub&gt;Carbon&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil @ $40/bbl</td>
<td>305</td>
<td>363</td>
</tr>
<tr>
<td>Crude Oil @ $70/bbl</td>
<td>534</td>
<td>635</td>
</tr>
<tr>
<td>Crude Oil @ $100/bbl</td>
<td>762</td>
<td>908</td>
</tr>
<tr>
<td>Natural Gas @ $5/MMBTU</td>
<td>277</td>
<td>369</td>
</tr>
<tr>
<td>Natural Gas @ $7/MMBTU</td>
<td>387</td>
<td>517</td>
</tr>
<tr>
<td>Natural Gas @ $10/MMBTU</td>
<td>554</td>
<td>738</td>
</tr>
<tr>
<td>Sugar Low</td>
<td>132</td>
<td>331</td>
</tr>
<tr>
<td>Sugar Medium</td>
<td>254</td>
<td>634</td>
</tr>
<tr>
<td>Sugar High</td>
<td>353</td>
<td>882</td>
</tr>
<tr>
<td>Palm Oil Low</td>
<td>455</td>
<td>599</td>
</tr>
<tr>
<td>Palm Oil Medium</td>
<td>665</td>
<td>875</td>
</tr>
<tr>
<td>Palm Oil High</td>
<td>965</td>
<td>1270</td>
</tr>
<tr>
<td>CELLULOSIC BIOMASS</td>
<td>75</td>
<td>188</td>
</tr>
</tbody>
</table>

Biobased feeds look competitive with crude oil at first glance, but in sugar fermentation (carbon lost as CO₂), $/MT<sub>Carbon</sub> doubles (not for palm oil). The lower cost biofeeds can be competitive with petro feeds, but fall short with low oil/natural gas prices. Efficient use of cellulosic biomass would be a game changer.
High level economics - feeds for biopolymers

<table>
<thead>
<tr>
<th>Product</th>
<th>$ / MT Product</th>
<th>$ / MT Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEA Polyethylene (Low Oil/Gas)</td>
<td>1150</td>
<td>1342</td>
</tr>
<tr>
<td>SEA Polyethylene (Medium Oil/Gas)</td>
<td>1400</td>
<td>1633</td>
</tr>
<tr>
<td>SEA Polyethylene (High Oil/Gas)</td>
<td>1650</td>
<td>1925</td>
</tr>
<tr>
<td>SEA Polypropylene (Low Oil/Gas)</td>
<td>1000</td>
<td>1167</td>
</tr>
<tr>
<td>SEA Polypropylene (Medium Oil/Gas)</td>
<td>1300</td>
<td>1517</td>
</tr>
<tr>
<td>SEA Polypropylene (High Oil/Gas)</td>
<td>1500</td>
<td>1750</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>$ / MT</th>
<th>$ / MT Carbon Processed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Low</td>
<td>132</td>
<td>661</td>
</tr>
<tr>
<td>Sugar Medium</td>
<td>254</td>
<td>1268</td>
</tr>
<tr>
<td>Sugar High</td>
<td>353</td>
<td>1764</td>
</tr>
<tr>
<td>Palm Oil Low</td>
<td>455</td>
<td>599</td>
</tr>
<tr>
<td>Palm Oil Medium</td>
<td>665</td>
<td>875</td>
</tr>
<tr>
<td>Palm Oil High</td>
<td>965</td>
<td>1270</td>
</tr>
<tr>
<td>CELLULOSIC BIOMASS</td>
<td>75</td>
<td>375</td>
</tr>
</tbody>
</table>

In low and medium oil/gas price scenarios for products, both sugar and natural oils can be competitive as feeds for polymers--Biomass remains a game changer if it can be efficiently utilized.
Major issues, trends affect biopolymers

- Inter-material competition - conventional vs. biopolymers and among biopolymers
- Green drop-ins versus new, different biopolymers
- Market and regulatory demand drivers
- Marine, other ecological risks of plastics litter
- Biodegradability – ocean micro-plastics?
- Green premiums?
- High interest among many brand owners
- GMOs and LCAs
- Recyclability

“Biopolymers” also include fibers, elastomers, and coatings
Low oil prices have disabled bio-based economy

- Many smaller companies have been acquired, with limited further development:
  - OPX Bio by Cargill
  - TetraVitae by Eastman
  - Virent being acquired by Tesoro
- Many companies forced to change business models (e.g., Amryis, TerraVia (fka Solazyme), etc.):
  - Focus has shifted to:
    - Cosmetics
    - Animal / Human feed ingredients
    - Pharmaceuticals
    - Nutraceuticals
- Many others forced to bankruptcy and to liquidate assets (e.g., KiOR, Cobalt, etc.)

Adaptability has been the key to survive these downturns—government regulations, concerns for sustainability, and consumer demand for biobased products will keep the industry alive but not growing as fast until oil prices return to levels that make bio-based materials more competitive.
Global / Asian transition to bioplastics needed

1- Top 20 Fast Moving Consumer Goods company headquarters
2- Top 20 plastics and resins manufacturers headquarters
3- Production of thermoplastics (excluding thermosets and PURs)
4- Sources of plastics “leaked” into the ocean
The bioplastics sector is complex and challenging

- Conventional (drop-in) biopolymers versus new / emerging:
  - 100% bio-based
  - Partly bio-based
- Petro-based versus partly or 100% bio-based:
  - Compostable
  - Biodegradable
  - Neither biodegradable or compostable
- End-markets are rigid / flexible packaging, textiles, durables
- Packaging dominates markets, with ~2/3 share, 1/10 textiles,
- Non-biodegradable bioplastics exceed biodegradable, indicates sustainability is priority
- Asia dominates with 60% market share; North America, South America, and Europe have roughly equivalent shares of the rest
- Bioplastics production, now about 2 million tpy, could triple by 2020, but much depending on crude oil prices and a possible global carbon reduction regime
Diverse biopolymers are in the market

- Conventional, 100% bio-based – viscose rayon, cellulose acetate
- Drop-in – conventional, bio-based monomers substitutable:
  - PE – polyethylene
  - PET – Polyethylene terephthalate
  - PTT – Poly trimethylene terephthalate
  - PBT – Polybutylene
  - PBS - Polybutylene succinate
- Unconventional, 100% bio-based
  - PLA – polylactide polyester
  - PHA/PHB – polyhydroxyalkanoate / polyhydroxybutyrate - natural polyesters
Acrylates, PHA, PAs, PEF also commercializing

- Acrylic acid-based polymers
  - PAA fibers and resins
  - SAPs
- High MW di-acids (with HMDA) for specialty polyamides (PAs)
- Green benzene to poly-caprolactam (PA6)
- Green adipic acid and HMDA (hexamethylene diamine) to green PA66 (or Nylon 6,6)
- PP blends with starch or soy meal
- PEF – Polyethylene Furanoate
## Key players at various stages of commercialization

### Leading Bio-Monomer / Biopolymer Developers

<table>
<thead>
<tr>
<th>Developer</th>
<th>Product development</th>
<th>Biopolymer</th>
<th>Development Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genomatica</td>
<td>1,4-BDO</td>
<td>PBS, PBT</td>
<td>Commercial, 70 ktpy</td>
</tr>
<tr>
<td></td>
<td>Butadiene</td>
<td>PBD, ABS, others</td>
<td>pilot</td>
</tr>
<tr>
<td></td>
<td>Capolactam</td>
<td>PA6</td>
<td>bench scale</td>
</tr>
<tr>
<td>Succinity (BASF- Corbion Purac)</td>
<td>Succinic acid</td>
<td>PBS</td>
<td>Commercial, at least 10 ktpy</td>
</tr>
<tr>
<td>Myriant</td>
<td>Succinic acid</td>
<td>PBS, 1,4-BDO</td>
<td>Commercial, 13.6 ktpy</td>
</tr>
<tr>
<td>BioAmber</td>
<td>Succinic acid</td>
<td>PBS, 1,4-BDO</td>
<td>Commercial</td>
</tr>
<tr>
<td>Global Bioenergies</td>
<td>Butadiene</td>
<td>PBD, ABS, others</td>
<td>pre-pilot</td>
</tr>
<tr>
<td>Cargill</td>
<td>Lactic acid</td>
<td>PLA</td>
<td>Commercial</td>
</tr>
<tr>
<td>(with Novozymes)</td>
<td>Acrylic acid</td>
<td>PAA, SAP</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>Dow (OPXBio)</td>
<td>Acrylic acid</td>
<td>PAA, SAP</td>
<td>bench scale</td>
</tr>
<tr>
<td>Reverdia</td>
<td>Succinic acid</td>
<td>PBS</td>
<td>pilot</td>
</tr>
<tr>
<td>Anellotech</td>
<td>p-xylene</td>
<td>PET</td>
<td>building pilot - Suntory and Toyota</td>
</tr>
<tr>
<td></td>
<td>benzene</td>
<td>PA66, PS</td>
<td>building pilot - Suntory and Toyota</td>
</tr>
<tr>
<td>Avantium</td>
<td>FDCA</td>
<td>PEF</td>
<td>commercializing with BASF</td>
</tr>
<tr>
<td>Micromidas</td>
<td>p-xylene</td>
<td>PET</td>
<td>Small demo</td>
</tr>
<tr>
<td>Cathay Industrial Biotech, Ltd</td>
<td>Long chain diacids</td>
<td>High MW polyamides</td>
<td>Small commercial</td>
</tr>
<tr>
<td>DuPont</td>
<td>1,3-PDO</td>
<td>PTT</td>
<td>Commercial</td>
</tr>
<tr>
<td>LanzaTech</td>
<td>2,3-BDO to butadiene</td>
<td>PBD, ABS, others</td>
<td>Basic process demo - 360 tpy</td>
</tr>
<tr>
<td>Metabolix (now CJ CheilJedang)</td>
<td>2,3-BDO to butadiene</td>
<td>PBD, ABS, others</td>
<td>Commercial</td>
</tr>
<tr>
<td>NewLight Technologies (CO₂-based)</td>
<td>Lactic acid</td>
<td>PLA</td>
<td>Commercial</td>
</tr>
<tr>
<td>Meridian</td>
<td>PHA</td>
<td>Commercial for medical</td>
<td></td>
</tr>
<tr>
<td>Mango Materials (methanotrophic)</td>
<td>PHA</td>
<td>pilot</td>
<td></td>
</tr>
<tr>
<td>NatureWorks</td>
<td>PHA</td>
<td>Commercial</td>
<td></td>
</tr>
<tr>
<td>Braskem</td>
<td>Ethylene</td>
<td>PE</td>
<td>Commercial</td>
</tr>
<tr>
<td>NatureWorks</td>
<td>Ethylene</td>
<td>PE</td>
<td>Commercial</td>
</tr>
<tr>
<td>Coca-Cola / India Glycols</td>
<td>MEG</td>
<td>PET</td>
<td>Commercial</td>
</tr>
</tbody>
</table>
A variety of polyesters can be made all bio-based

<table>
<thead>
<tr>
<th>Polymer Name</th>
<th>Alcohol</th>
<th>Available</th>
<th>Soon</th>
<th>Longer Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET - Poly(ethylene terephthalate)</td>
<td>MEG</td>
<td></td>
<td></td>
<td>PTA/DMT</td>
</tr>
<tr>
<td>PTT - Poly(trimethylene terephthalate)</td>
<td>PDO</td>
<td></td>
<td></td>
<td>PTA/DMT</td>
</tr>
<tr>
<td>PBT - Poly(butylene terephthalate)</td>
<td>BDO</td>
<td></td>
<td></td>
<td>PTA/DMT</td>
</tr>
<tr>
<td>PBS - Poly(butylene succinate)</td>
<td>BDO</td>
<td></td>
<td>Succinic Acid</td>
<td></td>
</tr>
<tr>
<td>PBSA - Poly(butylene succinate adipate)</td>
<td>BDO</td>
<td>Succinic Acid</td>
<td>Adipic Acid</td>
<td></td>
</tr>
<tr>
<td>PBST - Poly(butylene succinate terephthalate)</td>
<td>BDO</td>
<td>Succinic Acid</td>
<td></td>
<td>PTA/DMT</td>
</tr>
<tr>
<td>PBAT - Poly(butylene adipate terephthalate)</td>
<td>BDO</td>
<td></td>
<td>Adipic Acid</td>
<td>PTA/DMT</td>
</tr>
<tr>
<td>PEF - Poly(Ethylene Furanoate)</td>
<td>MEG</td>
<td></td>
<td></td>
<td>FDCA</td>
</tr>
</tbody>
</table>

Essentially, any conventional polymer has the potential to be 100% bio-based
Bio-based monomers/intermediates emerging

- Olefins
  - Ethylene via ethanol
  - Propylene via ethanol or propanol
  - Isobutylene via direct fermentation, isobutanol, or ethanol
  - Butylene via n-butanol
  - Butadiene via direct fermentation, 1,4-BDO, or 2,3-BDO (LanzaTech)
- BTX – Anellotech (Suntory, Toyota Tsusho), Virent
- *para*-xylene focus – Micromidas, Gevo
- Sorbitol (polycarbonate) – Mitsubishi Chemical
- Acrylic acid
- Adipic acid
- HMDA

*COPs of petro PA66 (adipic and HMDA) or petro PBS (succinic and BDO), with many-step value chains, are less sensitive to oil price than PE*
Bio-acrylic acid has diverse potential routes

- Via dextrose fermentation 3-hydroxypropionic acid:
  - Novozymes/Cargill
- Via acrolein from glycerol:
  - Nippon Shokubai
  - Arkema
- Via polypropiolactone from bio-ethylene oxide:
  - Novomer
- Via fumaric acid:
  - Genomatica
- Via bio-based lactic acid:
  - SGA Polymers
  - Myriant

Source: Nexant’s Biorenewable Insights report “Bio-based Acrylic Acid”
Other specialty polymers are commercializing

- AcC (cellulose acetate, triacetate / CTA) – commercial since 1954, biodegradable or non-biodegradable depending on acetylation – fiber, tow, film, membrane, $5 billion market, 50% in Asia, rapid growth

- Spider silk: *Bolt Threads, AMSilk, Araknitek, KAIST, Kraig Labs

- Guayule rubber – Yulex, Patagonia, tire companies

- Thermosets
  - Polyurethanes (PURs) – polyols reacted with isocyanate, biobased polyol can be produced from vegetable oils
  - Unsaturated polyester resins - condensation polymerization of polyols, organic acids, and fatty acids or triglyceride oils with or without styrene – most monomers can be bio-based
  - Urea-formaldehyde
  - Glycix – glycerol-citric acid, 100% biodegradable

*In order of development status

<table>
<thead>
<tr>
<th>Material</th>
<th>Toughness</th>
<th>Tensile Strength</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dragline spider silk</td>
<td>120,000-160,000</td>
<td>1,100-2,900</td>
<td>1.18-1.36</td>
</tr>
<tr>
<td>Kevlar</td>
<td>30,000-50,000</td>
<td>2,600-4,100</td>
<td>1.44</td>
</tr>
<tr>
<td>Steel</td>
<td>2,000-6,000</td>
<td>300-2,000</td>
<td>7.84</td>
</tr>
</tbody>
</table>

September 15-16, 2016  InnoBioPlast2016, BITEC, Bangkok, Thailand
Bio-monomers / biopolymers made variously

- Fermentation
  - Conventional or cellulosic (2nd Generation) sugars
  - Waste CO, CO₂, or syngas from biomass gasification
  - Methane
  - Lipids
- Pyrolysis
- Catalytic chemical conversion
  - Sugars
  - Cellulose
  - Lipids
  - Alcohols, other primary fermentation or pyrolysis products
  - Syngas from biomass gasification
- Extraction from plants

Some routes are a combination of these
Biodegradability issues are many and complex

- Drop-in green vs. new and different green
- Recycling goals can be at odds with biodegradable bioplastics
- Many drop-in sustainable plastics (e.g., green PE) are not biodegradable, and that can be OK, even preferable
- "Oxo-biodegradable" plastics and others with degradation additives are worse than conventional (ocean micro-plastics debris) - fragmentation is not the same as biodegradation
- For truly biodegradable bioplastics whether biobased or fossil-based, biodegradability is an inherent property
- Truly biodegradable polymers degrade totally into water, biomass, and CO₂ (completely return to the carbon cycle)
- However, biodegradation depends on conditions such as location, temperature, humidity, and material or application
- A UN report in May, 2015 suggests that a biodegradable label may encourage people to pollute
Biobased, biodegradable, or compostable?

Biodegradable

- PBS
- PBSA
- PCL
- PBAT (Ecoflex)
- PGA (Kureha)
- PVOH

PHA

- Cellulose
- Starch
- PLA (Ingeo NatureWorks)

Bio-PE (Braskem)
- PA610, PA1010, PA1012
- (VESTAMID® Terra)
- PTT (Sorona DuPont)

Non-Biodegradable

- Conventional Polymers:
  - PE, PP, PS ...

Petro-based

PHAs are both biobased and biodegradable

Bio-based
In soil tray tests, average disintegration time showed strong improvement for PHA blends with PBS, PLA, PBAT, which perform even better than starch blends.
If PHA is so good, why not more successful?

- Price, the “oxo-biodegradable” plastics hangover, and opposition to GMOs challenge PHAs use in film mulch.
- GMOs are a key socio-scientific issue seen in the advent of drop-in and new types of biopolymers, as with Sorona.
- Incredibly, opposition to / fear of GMOs is strong in organic farming - would rather use fossil-based PE film mulch than biodegradable bioplastic that employs GMOs to make, despite no GMO in the product or released in manufacture.
- A key question is whether new CRISPR gene editing vs. transgenic engineering will allow bio-polymers to “sail around” the GMO controversy in the US (vs. in the EU).
“Green polyethylene” could be carbon-negative

Sugarcane* uses sun’s energy to metabolize CO₂

In the distillery, sugar juice is fermented and distilled

Dehydration transforms ethanol to ethylene

Ethylene is polymerized to polyethylene

Green polyethylene is fabricated into products

Green polyethylene is 100% recyclable mechanically and by incineration; even landfilling comprises CARBON CAPTURE!

Sugarcane is shown, but applies to any bioethanol — fermentation or thermochemical
Drop-in bioplastics are key in sector growth

- Nexant believes the fastest route to sector growth is in replacing petro-monomers with bio-monomers, because:
  - Existing polymer production infrastructure can be employed
  - Greater market certainty for developers, investors, lenders
  - Vast investments globally in conversion equipment and application infrastructure that does not need replacement or modification
  - End users’ (packagers, etc.) experience and familiarity with existing plastics

- This addresses the sustainability driver (GHG, and other pollutant reduction), but does not address ocean litter, which requires PHA, cellulosics, and starch polymers

- As shown by history, development of non-drop-ins (PLA, PHA) has been slow and problematic

- All bioplastics are held back by low oil price and no global carbon regime
Conventional projections of growth are optimistic

For a conventional view, a Nova-Institute 2015 report projected 36% CAAGR based on large capacity additions for PHA, PLA, and PET, which Nexant finds unsubstantiated.
Capacity announcements need analyzing

- Nexant’s analysis does not support a 36% growth rate
- Conventional growth projections generally take at face value monomer and/or polymer new capacity PR
- In contrast, Nexant adjusts (discounts) announcements based on project and/or company-internal objective risk factors
- Besides, macro-economic factors such as low oil price, financial sector loss of confidence in biorenewables, and lack of carbon price drivers have conspired to thwart development
- Also, no bioplastic besides PHA, currently solves the ocean litter problem

<table>
<thead>
<tr>
<th></th>
<th>Announced CAAGR 2016-2020</th>
<th>Adjusted CAAGR 2016-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactic Acid Capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>1.3%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Asia</td>
<td>2.0%</td>
<td>1.1%</td>
</tr>
<tr>
<td>China</td>
<td>2.6%</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Announced CAAGR 2016-2020</th>
<th>Adjusted CAAGR 2016-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioethylene Glycol and Oxide Capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>15.66%</td>
<td>8.67%</td>
</tr>
<tr>
<td>China</td>
<td>40.90%</td>
<td>25.37%</td>
</tr>
</tbody>
</table>
“The cure for low oil prices is low oil prices”

Source: Nexant

Nova-Institute’s 2015 report (with 2014 data) projecting 36% CAAGR was at a time of high oil price; low oil price put the brakes on
Bioplastics are a slowly emerging solution

- Government / NGO policies and markets, responding to consumer imperatives and economics, are drivers
- Diverse bioplastics are being developed, drop-in, compostable and non-biodegradable, but few are truly biodegradable
- Biobased drop-ins may not be compostable/biodegradable but would be recyclable – otherwise, biopolymers might compete with recycling goals; a non-biodegradable biopolymer in a landfill is a form of carbon sequestration
- Biopolymers developments are thwarted by low crude oil price, but low-cost/negative cost biomass or wastes as feedstocks could make biopolymers more competitive
- GMO push-back is another challenge for some biopolymers
- The industry should focus on partnering and sponsoring drop-in bioplastics developers and projects
Questions?
Thank You!

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