Creating Value

Building a value chain for emerging bio-based polymers

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Asia Petrochemical Industry Conference 2018

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Do we still care about bio-based?

AGENDA

1. Do we still care about bio-based?
2. Mapping strategic alignment between key players
3. Defining your role in the bio-based value chain
Bio-based innovation interest has waned in recent years.

**Bio-based innovation interest**

Y-axis: Non-linear (log-based) scale summary of trends in patents, academic papers, funding, and more.

(100 = Maximum score)
While petrochemical companies spend billions to expand

2040 Oil Demand Projections by Applications

- Marine: 24%
- Power generation: -46%
- Steam and process heat: 12%
- Aviation: 60%
- Buildings: -21%
- Petrochemicals: 46%
- Other: 5%
- Heavy-duty vehicles: 20%
- Light-duty vehicles: -5%

Change in demand from 2017 to 2040

Saudi Aramco, SABIC plan to build $20 bln oil-to-chemicals complex

DHAHRAN, Saudi Arabia (Reuters) - State oil giant Saudi Aramco [IPO-ARMO.SE] and petrochemical producer Saudi Basic Industries Corp (SABIC) signed a preliminary deal to expand a $15 billion facility in the Saudi city of Ras Tanura

RIL completes $16-b expansion, doubles ethylene capacity to 4mt

PTI | Jan 2, 2018, 18:07 IST
But brands and retailers are driving interest

Leading brands, retailers, and packaging companies work towards 100% reusable, recyclable or compostable packaging by 2025 or earlier.
The bio-based polymer network
Partnership maps help visualize how players strategically align themselves.

- **Node color:** Type of partnership with respect to the overall value chain.
- **Node size:** Size of the organization
- **Edge thickness:** Strength of partnership such as joint ventures and consortia.

**Drop-In Polymers**
Drop-in biopolymers are chemically equivalent to incumbent petroleum-based polymers.

**Near-Drop-In Polymers**
Biopolymers that are chemically similar to incumbent polymers with similar processing and downstream applications.

**Substitute Polymers**
Biopolymers that are not chemically similar to incumbent polymers and are often of interest for their end-of-life attributes.

<table>
<thead>
<tr>
<th>Value Chain Position</th>
<th>Employees</th>
<th>Partnership Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock Provider</td>
<td>10</td>
<td>1.0</td>
</tr>
<tr>
<td>Processing Partner</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Product Producer</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Scaling Partner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Developer</td>
<td>100000</td>
<td></td>
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</table>
**Polyethylene furanoate (PEF):** Near-drop-in biopolymer with better gas barrier properties, glass transition temperature, and tensile strength compared to PET

- **Composition:** Monomers include monoethylene glycol (MEG) and furan-2,5-dicarboxylic acid (FDCA)
- **Feedstock:** MEG produced from bio-based ethanol and FDCA produced catalytically from sugars
- **Target applications:** Downstream markets to replace PET and other packaging materials

<table>
<thead>
<tr>
<th>Developer</th>
<th>Technology</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synvina</td>
<td>&quot;YXY&quot; technology uses a two-step catalytic oxidation process to convert glucose and fructose to FDCA</td>
<td>Pilot: Operates a 15 tpa pilot plant; plans to build commercial plant with 25,000 tpa to 50,000 tpa FDCA, yet the construction date has been pushed back</td>
</tr>
<tr>
<td>Corbion</td>
<td>Fermentation platform to produce FDCA from sugar-derived 5-hydroxymethylfurfural (5-HMF); highly selective microbes lead to high-purity FDCA</td>
<td>Pilot: Corbion Purac scaled its FDCA process to pilot level in 2016, aiming to supply enough material to its partners for researching and testing; specific capacity not disclosed</td>
</tr>
<tr>
<td>Avabiochem</td>
<td>Hydrothermal processing to produce 5-HMF from biomass; 5-HMF is then oxidized catalytically to obtain FDCA</td>
<td>Pilot: Plans to build commercial plant for 5-HMF/FDCA with a first phase of 30,000 tpa FDCA expected for 2019 and set to increase to 120,000 tpa</td>
</tr>
<tr>
<td>Eastman</td>
<td>Oxidation of 5-HMF in the presence of oxygen, a saturated organic acid solvent, and a catalyst to produce FDCA</td>
<td>License: Origin Materials licensed Eastman’s FDCA technology and purchased an oxidation pilot plant from Eastman in 2017</td>
</tr>
</tbody>
</table>
Near-drop-in bio-based PET replacements targeting packaging applications

<table>
<thead>
<tr>
<th>Partnership map highlights and major moves</th>
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<tbody>
<tr>
<td>Following the successful release of a partially plant-based bottle in 2009, the Coca-Cola Company announced partnerships with Virent, Gevo, and Avantium aimed at a 100% plant-based bottle in 2011.</td>
</tr>
<tr>
<td>Yet, more recently, Virent and Gevo have shifted focus away from bioPET toward fuel production. Virent was acquired by Tesoro/Andeavor in 2017.</td>
</tr>
<tr>
<td>Synvina – a frontrunner in the PEF space with several partnerships along the value chain due to its parents Avantium and BASF – announced that it is delaying construction of its commercial facility.</td>
</tr>
<tr>
<td>Also on the pursuit of 100% bioPET bottles, Origin Materials formed partnerships with Danone and Nestlé in May 2017. Later in the year, however, Origin licensed FDCA technology from Eastman Chemical.</td>
</tr>
<tr>
<td>In addition to bioPET and PEF, in 2016, DuPont and ADM announced a breakthrough platform for PTF precursor FDME and opened a demonstration facility in April 2018.</td>
</tr>
</tbody>
</table>
After PlantBottle success, brands pursue drop-in and near-drop-in solutions for 100% bio-based beverage bottles

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Bio-PET</th>
<th>PEF</th>
<th>PTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Chemically equivalent to petroleum-based PET</td>
<td>• Improved barrier properties could allow for product shelf lives to be extended</td>
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<td></td>
</tr>
<tr>
<td>• The same processing equipment can be used, reducing upfront costs, and products can be recycled using existing infrastructure</td>
<td>• Improved mechanical properties could translate to less material per bottle, reducing costs</td>
<td>• Improved mechanical properties could translate to less material per bottle, reducing costs</td>
<td></td>
</tr>
<tr>
<td>• Improved thermal properties</td>
<td>• Improved thermal properties</td>
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<table>
<thead>
<tr>
<th>Challenges</th>
<th>Bio-PET</th>
<th>PEF</th>
<th>PTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More expensive than PET yet with the same performance</td>
<td>• Must develop new bottles to take advantage of the improved barrier and mechanical properties</td>
<td>• Must develop new bottles to take advantage of the improved barrier and mechanical properties</td>
<td></td>
</tr>
<tr>
<td>• Must develop more price-competitive routes for bio-based PTA</td>
<td>• Must build up a new raw material supply chain</td>
<td>• Must build up a new raw material supply chain</td>
<td></td>
</tr>
<tr>
<td>• Must build up a new raw material supply chain</td>
<td>• Lower melting point than PET</td>
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Source: Coca-Cola
Bio-based nylon intermediates: Drop-in polymer and near-drop-in to petroleum-based nylon intermediates

- **Composition:** Varies depending on nylon type; monomers being targeted include adipic acid (AA), sebacic acid (SA), dodecanedioic acid (DDDA), hexamethylenediamine (HMD), 1,5-pentanediamine (DN5), and caprolactam (CPL)

- **Feedstock:** Varies depending on monomer type and production route

- **Target applications:** Downstream markets to replace petroleum-based nylon for fibers, textiles, packaging, medical, and automotive

<table>
<thead>
<tr>
<th>Monomers</th>
<th>Description</th>
<th>Key Developers</th>
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<tbody>
<tr>
<td>AA</td>
<td>Derived via fermentation and used for the production of nylon 6,6 with HMD; also used for nylon 4,6 with other diamines</td>
<td>Verdezyne, Rennovia, Genomatica</td>
</tr>
<tr>
<td>SA</td>
<td>Derived from castor oil and used for the production of nylon 6,10 with HMD; also used for nylon 4,10, nylon 5,10, and nylon 10,10 with other diamines</td>
<td>Arkema, BASF, DuPont, DSM, Evonik</td>
</tr>
<tr>
<td>DDDA</td>
<td>Derived via fermentation and used for the production of nylon 6,12 with HMD; also used for nylon 12,12 with other diamines</td>
<td>Verdezyne, Cathay Biotechnology</td>
</tr>
<tr>
<td>HMD</td>
<td>Derived via fermentation and used primarily for the production of nylon 6,6 via condensation with adipic acid</td>
<td>Rennovia, Genomatica</td>
</tr>
<tr>
<td>DN5</td>
<td>Derived via fermentation and used for the production of near-drop-in nylon 5,6</td>
<td>Cathay Biotechnology</td>
</tr>
<tr>
<td>CPL</td>
<td>Derived via fermentation and used primarily for nylon 6</td>
<td>Genomatica</td>
</tr>
</tbody>
</table>
Major players in the chemical space have long been active in developing bio-nylon intermediates

**Partnership map highlights and major moves**

**1** Large players like Arkema, BASF, DuPont, Evonik, and DSM have long been active in the bio-based polyamide space, producing materials from castor oil derivatives.

**2** In 2012, Arkema further bolstered its polyamide position by acquiring both Suzhou HiPro Polymers and Hebei Casda Biomaterials.

**3** Cathay Biotechnologies works to expand capacity for bio-based polyamide and 1,5-pentanediamine (DN5) targeting polyamide 5,6.

**4** In 2018, Rennovia ceased operations, a few years after shifting its strategy to target glucaric acid (GA) and 1,6-hexanediol (HDO).

**5** Also in 2018, Verdezyme closed its doors after the exit of key investor Sime Darby, months before the completion of its dodecanedioic acid (DDDA) commercial plant with partner Malaysian Biotechnology Corporation at Bio-XCell Malaysia.

**6** Genomatica hedges its exposure to scale up risk by licensing its technology to Aquafil.
Genomatica licenses its technology, hedging exposure to scale-up risks

- **Strategy:** Genomatica’s primary business model is to develop and license process technologies. Its nylon intermediate portfolio includes HMD, caprolactam (CPL), and AA. In January 2018, it licensed its CPL technology to Aquafil, a producer of nylon 6 fiber. In May 2018, Aquafil and Genomatica announced a multi-company collaboration funded by EU’s Horizon 2020 to accelerate the commercialization of bio-nylon.

- **Key Issue:** While a licensing model reduces addressable market size, Genomatica is hedging its exposure to scaling risk. Although the company must still demonstrate production at a commercial scale, this will largely be the responsibility of its licensees. Furthermore, focused on developing bio-based routes for drop-in molecules, the company need not be concerned about building a downstream market for its licensees.

- **Moving Forward:** Monitor Aquafil and Genomatica’s collaboration and Project EFFECTIVE’s progress in bringing bio-nylon to market.
Polyhydroxyalkanoate (PHA):
Substitute aliphatic linear polyester known for being biodegradable and compostable

- **Monomers:** Aliphatic linear polyesters produced via bacterial fermentation for different structures (includes polyhydroxybutyrate [PHB] and polyhydroxybutyrate-valerate [PHBV])
- **Feedstock:** Varies and can include gases (CO$_2$ and CH$_4$), bio-oils, sugars, and organic waste
- **Target applications:** Downstream markets yet to be developed, although often targeting single-use and products with short lifespans

<table>
<thead>
<tr>
<th>Developer</th>
<th>bio-on</th>
<th>danimer scientific</th>
<th>MANGO MATERIALS</th>
<th>CJ CHEILJEDANG</th>
<th>NEWLIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>PHB and PHBV from agricultural/industrial waste using wild-type bacteria</td>
<td>PHA from canola oil via aerobic fermentation; combines PHA and PLA to develop new materials</td>
<td>PHB from CH$_4$ using mixed bacteria</td>
<td>Amorphous PHA via genetically modified microbes; lacks differentiation</td>
<td>PHA from CO$_2$ and CH$_4$</td>
</tr>
<tr>
<td>Scale</td>
<td>Pilot: 10 tpa pilot plant; aims to open 1,000 tpa commercial plant by H2 2018; has 14 licensees with combined capacity over 100,000 tpa</td>
<td>Pilot: Meridian Holdings Group looked to scale PHA capacity to 136 tpa in 2017 (no news of completion)</td>
<td>Pilot: Previously scaled to 500 L fermenter producing less than 1 tpa; pre-engineering for its 70,000 L commercial system</td>
<td>Pilot: Metabolix operated a 270 tpa pilot facility; CJ set to construct and operate 10,000 tpa commercial PHA facility by 2018</td>
<td>License: agreement with Paques Holdings to produce up to 1.3 million tpa in 2016; 20-year contract with Vinmar includes plans to build 23,000 tpa facility</td>
</tr>
</tbody>
</table>
Substitute polymers like PLA and PHA are mainly for single-use plastics, though other uses are emerging.

**Partnership map highlights and major moves**

1. Efforts by Total Corbion and NatureWorks have focused on improving PLA grades to extend the range of applications for their materials. In addition, PHA developers are partnering downstream to develop markets for these biopolymers.

2. Lacking offtake agreements, Metabolix restructured in 2016, selling its PHA assets to CJ CheilJedang.

3. Bio-on leads the space in terms of number of downstream partnerships and efforts to develop a downstream market for its polymers.

4. Danimer Scientific also has several downstream partners, including PepsiCo, Solo/Dart, and Graphic Packaging. Unlike Bio-on, however, it plans to primarily build, own, and operate its own facilities.

5. Newlight also plans to build up its capacity, working with Vinmar International to bring its 23,000 tpa facility online in the near future.

6. Mango Materials struggled to find off-takers and began pursuing its own applications development.
Developing new market opportunities for substitute biopolymers like PLA and PHA

- **Polylactic acid (PLA):**
  - Stereochemical pure monomers result in homopolymers that crystalize fast and provide improved heat stability.
  - Purac exploring new applications for its PLA in more durable products
  - NatureWorks is looking for applications such as paper coatings, fibers, and packaging.

- **Polyhydroxyalkanoate (PHA):**
  - Poor reputation for its high cost, poor thermal stability, and brittleness
  - However, combining PHA with other polymers result in altered properties that are value added
  - Crowded PHA space alludes to partnerships being critical for developing markets for these materials
Know your role in the value chain
All strategies point towards collaboration

1. Material producers must work with product developers to determine if sustainability and improved performance bring enough of a value proposition to offset higher costs.

2. Compounders should work with polymer producers to improve processing performance to increase the range of downstream applications for the new materials.

3. Product developers must rank desired performance attributes to ensure product specifications are met, and not compromise functionality and economics for sustainability.
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Questions?

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