Replacing Existing Petro-Chemicals With Bio-Based Alternatives

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Philippa Davies/Doris de Guzman – Tecnon OrbiChem
TECNON ORBICHEM CORE STRENGTHS
Intermediates, Fibres & Specialty Resins

- Soda Ash
- Caustic Soda
- Chlorine
- Derivatives
  - Acetic Acid
    - Paraxylene
      - DMT
        - Caprolactam
          - Polyamide 6
            - Polyamide Fibre
          - Polyamide 66
            - Polyamide Resin
  - Vinyl Acetate Monomer
- Peroxy PO Chlorohydrin PO
- Isocyanates
- EDC
- VCM
- PVC
- Epichlorohydrin
- Epoxy Resins
- Bisphenol A
- Acetone
- Phenol
- Acrylic Acid
  - Methyl Acrylate
  - Ethyl Acrylate
  - 2-Ethylhexyl Acrylate
  - Butyl Acrylate
- 2-EH
- 2-PH
- DOP
- Phthalic Anhydride
- Orthoxylene
- 1,4-Butanediol
- Maleic Anhydride
- Styrene
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POTENTIAL FOR BIO-BASED CHEMICALS

• Companies under increasing pressure to demonstrate their environmental action improvements, by reducing their carbon footprint and raising the sustainability of their operations
  o Government regulation
  o Limited fossil fuel source
  o Consumer demand
  o Waste reduction

• Big brands want to employ bio-based materials or waste recycling (e.g. biomass; agricultural crops, preferably non-food; CO₂; biogas) for their sustainability goals

• The choice of bio-based monomers and polymers is limited at present, but is widening rapidly.

Source: Tecnon OrbiChem
• **As direct replacements for petrochemicals**
  o ‘Drop-in Chemicals’
    Example: 1,3-Propanediol
    Dodecandioic acid

• **As alternatives, with similarities to established chemicals**
  o ‘Semi Drop-in Chemicals’
    Examples: Pentamethylene diamine
    Furan dicarboxylic acid

• **Bio-Products under development, uncertain potential**
  o ‘Novel building blocks’
    Examples: Levulinic acid
    Itaconic acid

Source: Tecnon OrbiChem
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ASIA PETROCHEMICALS, NAPHTHA, CRUDE OIL & SUGAR PRICES 2014-2016

Source: Tecnon OrbiChem
BIO 2017

PROGRESS IN HOPED-FOR ‘DROP-IN CHEMICALS’

- Adipic Acid
  - Technically feasible, economics poor
- Acrylic Acid
  - Getting closer to success
- Ethylene and Propylene
  - Bio-PE a lonely success
- MEG and MPG
  - Struggling, new approaches needed
- Butadiene and Isoprene
  - Work in progress
- Epichlorohydrin
  - Plants built, economics now poor
- n-Butanol and Isobutanol
  - Getting much attention
- 1,4 Butanediol
  - Almost there
- Dodecandioic acid
  - Bio-Product triumphs!!!
- 1,3-Propanediol
  - Bio-product has ousted petro-product, but production from glycerol has stalled
- Paraxylene
  - Several R&D approaches

Source: Tecnon OrbiChem
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PROGRESS IN ‘SEMI DROP-IN CHEMICALS’

- Succinic Acid In commercial production
- 5-Hydroxymethyl furfural In small scale production
- Furan dicarboxylic acid (FDCA) Approaching commercialisation
- Methyl ester of FDCA (FDME) Plant under construction
- 1,5 Pentanediol In commercial production
- 1,3 Propanediol In commercial production

Source: Tecnon OrbiChem
BIO 2017

PROGRESS IN ‘NOVEL BUILDING BLOCKS’

- Levulinic acid: Plants operating in Italy and China. Many R&D projects
- Itaconic acid: Production mostly in China
- Glucaric acid: Approaching
- Malonic acid: In development
- Polyhydroxyalkanoate: 30+ companies active worldwide
- Polylactic acid: 15+ producers worldwide
- Aspartic acid: Produced by a fermentation route, but mostly from fumaric acid
- Farnesene: 12 ktpa plant in Brazil

Source: Tecnon OrbiChem
**BIO 2017**

‘WITH LOW CRUDE OIL AND PETROCHEMICAL PRICES, NOVEL BIO-BASED MOLECULES ARE GAINING ATTENTION IF THEY CAN OFFER BETTER PROPERTIES/PERFORMANCE’

<table>
<thead>
<tr>
<th>Factor</th>
<th>Drop-in</th>
<th>Unique molecule</th>
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<tbody>
<tr>
<td>Market acceptance</td>
<td>↑↑</td>
<td>↓↓</td>
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<td>Speed of introduction</td>
<td>↑↑</td>
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<td>Fit with existing infrastructure</td>
<td>↑↑ ←</td>
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<td>Oil/Feedstock price sensitivity</td>
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<td>Sustainability</td>
<td>↑ ← → ↓</td>
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<tr>
<td>Unique market space</td>
<td>↓↓↓↓</td>
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<tr>
<td>Scalability</td>
<td>↑↑↑</td>
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<tr>
<td>Legislation (e.g. REACH)</td>
<td>↑↑↑</td>
<td>↑↑↑↓↓↓</td>
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Source: Ed de Jong, Avantium February 2014 presentation
THE VALUE CHAIN FROM FRUCTOSE TO FDCA

- Avantium – XYX technology = whole chain, as left
- Sugar dehydration to MMF or HMF: ADM (USA), Ava Biochem (Switzerland), Micromidas which is now called Origin Materials (USA), xF Technologies (USA), and ADM/DuPont partnership (USA).
- Previously also BASF.
- Oxidation of HMF or MMF to FDCA: ADM, Corbion (the Netherlands), Novozymes (Denmark), Eastman (USA) and ADM/DuPont partnership
- Polymerisation of FDCA to PEF: Avantium (NL), Canon (Japan), Uhde (Germany)
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BIO-SUCCINIC ACID

Slow but steady progress

• Total bio-SA capacity at 60 ktpa but production is low
• Petro and Bio-SA prices equivalent
• Difficult to compete against petro-based diacids such as adipic and PTA
• Slow market in Poly(butylene succinate) – PBS
• Potential use of cellulosic sugar feedstock by 2020

Four companies dominate the bio-succinic acid business

• BioAmber, operating a 30 ktpa plant in Canada in a jv with Mitsui, on stream in Q1 2015. Planning a jv with ChielJedang to convert a plant in China to 36 ktpa SA
• Myriant, owned by PTT Global Chemical, started production in a 14 ktpa plant in Louisiana, USA in 2013, but now idle. Promoting SA-based plasticisers.
• Reverdia, a jv of DSM and Roquette, operating a 10 ktpa plant in Italy since 2013. Developing microcellular bio-based PU foam with Xinhuarun Technology. Promoting bio-PBS with Sharpak (UK), Wageningen (NL) and Hangzhou Xinfu (China)
• Succinity GmbH, a jv of BASF and Corbian Purac, operating a 10 ktpa plant in Spain since 2014.

Source: Tecnon OrbiChem
SEMI DROP-IN TARGETS OF SUCCINIC ACID

Diacids that can be replaced by Succinic acid:

• **Adipic acid**, as used in:
  - Polyester polyols for polyurethanes
  - Lubricants (in long chain esters)
  - Saturated polyester resins

• **Phthalic anhydride** or **isophthalic acid**, as used in
  - Unsaturated polyester resins (UPR)
  - Alkyd resins
  - Plasticisers

• **Maleic anhydride**, as used to make:
  - Butanediol

• **Isophthalic acid**, as used to make:
  - PET polymer

Source: Tecnon OrbiChem
Tough economics for 1,4-Butanediol

- Genomatica has developed a non-SA route, used by DuPont Tate & Lyle and Novamont, licensed to BASF
- Novamont started Bio-BDO 30 ktpa in Italy in 2016
- BASF continues customer trials via toll production
- BioAmber continues plans for succinic acid based 70 ktpa BDO project
- No BDO plans as of yet by other Bio-SA producers

Source: Tecnon OrbiChem
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BIO-BASED PRODUCTION OF 1,4-BUTANEDIOL

Source: Tecnon OrbiChem
BIO 2017
APPLICATION FOCUS: POLYURETHANES/POLYOLS

Source: Wageningen UR, Tecnon OrbiChem
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APPLICATION FOCUS: POLYURETHANES/POLYOLS

- Maturing vegetable oil-based polyester polyols market.
- Increasing R&D in novel bio-based diacids/diols
  - Succinic acid; 1,3 PDO; ODDA (C18), FDCA
- CO₂-based polyols commercialisation
  - Covestro starts 5 ktpa facility
  - Saudi Aramco acquires Novomer’s Converge® PPC polyol assets/IP in 2016
- Limited in bio-isocyanates R&D
  - Bio-based PDI based on 1,5 pentanediamine
  - Cathay Industrial Biotech, CJ Cheiljedang (1,5 PDA)
  - Covestro, Mitsubishi Chemical (PDI)
  - 1,5 PDA to make pyridine, piperidine (used in adhesives)

Source: Tecnon OrbiChem
POLYESTER POLYOLS CAN BE MADE FROM SUCCINIC ACID IN PLACE OF ADIPIC ACID

Source: Tecnon OrbiChem
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APPLICATION FOCUS: POLYAMIDES

naphtha → butadiene → benzene → cyclohexane → adipic acid → hexamethylenediamine → cyclooctadiene → dodecanedioic acid

PA6,6 → PA12 → laurolactam

PA6,12

1,5 Pentanedioc acid → PA6,10 → Sebacic Acid (D10)

PA5,6

PA5,10 (100% bio)

Source: Tecnon OrbiChem
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APPLICATION FOCUS: POLYAMIDES

- Stalled R&D on bio-based drop-ins such as butadiene, adipic acid, caprolactam, HMDA
  - DSM R&D on levulinic to adipic acid route
- Bio-based dodecanedioic acid economics believed to be better than petro-DDDA. Invista exited in 2016
  - Verdezyne building a diacid plant in Malaysia
  - Cathay Industrial to expand LDCA capacity in China
- Sebacic acid market is matured and centered in China
- Potential 100% bio-based PA using 1,5 PDA
- Evonik producing bio-based PA12 using amino lauric acid in a pilot plant in Slovakia
- Arkema remains the lone producer of castor-based 11-aminoundecanoic acid (for PA11)

Source: Tecnon OrbiChem
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BIO-BASED ‘DROP-IN CHEMICALS’ STATUS

• ACRYLIC ACID
  o Mostly stalled R&D
  o Novomer plans for demo on CO/EO-based C4s by 2019

• BUTANOLS
  o Green Biologics started n-butanol/acetone production in 2016 focusing on specialty applications
  o Gevo continue to struggle with isobutanol production
  o Butamax recently acquires an ethanol plant to convert to bio-isobutanol production

• ISOPRENE
  o Mostly stalled R&D and commercialisation plans
  o Amyris/Kuraray continue R&D for liquid farnesene rubber as alternative

• EPICHLOROHYDRIN
  o Glycerol-based ECH in China struggles to compete
  o ABT maintains competitive edge through partnerships, R&D

Source: Tecnon OrbiChem
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BIO-BASED NOVEL BUILDING BLOCKS STATUS

- **FARNESENE**
  - High-growth in consumer applications: F&F, cosmetics/PC
  - Application in lubricants/base oils, rubber materials, adhesives, fuel
  - Current production in Brazil, expanding production in China

- **LEVULINIC ACID**
  - GFBiochemicals in Italy, several producers in China
  - Many potential applications still at R&D (F&F, polymer, resins, and coatings, etc).
  - DSM on levulinic to adipic acid route

- **ITACONIC ACID**
  - Most production in China, Itaconix/Revolymer produces polymerised itaconic acid for specialty applications
  - AkzoNobel/Itaconix collaboration on polymers
  - Leaf Technologies R&D on cellulosic-based itaconic acid
  - MethaForm Project: Methacrylic acid from itaconic acid

Source: Tecnon OrbiChem
GLUCARIC ACID
- ADM plans for future production using Rennovia’s glucose-to-glucaric technology and catalysts from Johnson Matthey
- Rivertop Renewables producing glucarates-derived products in Danville, Virginia via tolling
- Kalion, Warner Babcock Institute of Green Chemistry R&D collaboration on technologies derived from glucaric acid.

1,3 PROPYANEDIOL
- DuPont Tate & Lyle using corn glucose feedstock
- Glycerol feedstock: Glory Biomaterial, Shenghong Group
- METEX, Technip licensing glycerol-based PDO process
- Growing applications in fibres, cosmetics/PC, detergents, Heat Transfer Fluids, PU, UPR, paints/coatings, deicing fluid

MALONIC ACID
- Lygos in pilot production of yeast-based malonic acid
- Sirrus claims beneficial properties using malonic acid in adhesive formulations (as opposed to acetic acid use)
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LOW OIL DRIVING NEW BIO-REALITIES

• Companies are refocusing on high profits, low volume specialty areas
  o Food and Nutrition, Flavours/Fragrances, Cosmetics/PC
  o Pharmaceutical, fine chemicals
  o Higher R&D-based chemicals: lubricants, surfactants, engineering resins, coatings, solvents, high-tech materials (e.g. biomedical)
  o Animal feed
• Novel molecules gaining more interests vs drop-ins
  o Challenge is building the market
• Bio-based drop-ins will continue as niche markets
• Novel polymers and applications will have to undergo lengthy testing before they will be accepted

Source: Tecnon OrbiChem
BIO 2017
THE BIO-REALITIES

• Success in bio-based monomers:
  o Monomers with competitive or even better performance than traditional materials
  o Monomers that offer novel properties
  o Regulation-based demand

• Price premiums acceptable as long as offered properties are improved. The low crude oil price made it very difficult for drop-ins to get premiums.

• Companies introducing bio-based chemicals required:
  o That their operations do not reduce the food supply
  o That a direct replacement ('drop in') costs the same as its synthetic equivalent – or maybe 10-20% more if it allows the end user to boast of his environmental friendliness

Source: Tecnon OrbiChem
...your source of expert chemical industry knowledge