PEF, the next generation polyester, produced from the biobased building blocks FDCA and MEG

Ed de Jong

avantium
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Avantium - business units

**Renewable Chemistry portfolio**
- Zambezi: sugar from non-food biomass
- Mekong: 1-step conversion to bio-MEG
- Early stage research: various biomass
- Electrochemistry: various e-chem routes

**YXY technology: bio-based plastics**
- 100% biobased, recyclable PEF with superior properties
- Major market potential in packaging materials and fibers

**Supported by an established business based on proven technology**

**Catalysis R&D business**
- Leading service and systems provider for blue chip clients in chemical and energy industry

Oct 2016, joint venture with BASF: Synvina
A lignocellulosic Biorefinery

Biomass → Hemi-cellulose → Cellulose → Sugar → Furanics

Fuels

Chemicals

Materials

Lignin

one possible route: via furanics

R=COOH, CH₂O, CH₂OH

Confidential
Strategic Options to Deploy Renewable Chemistries Projects

- Lab-scale
- Pilot plant
- Reference plant
- Industrial scale

- Scale
- Business model / earnings
- Strategic choices

- Strategic choices

- Stand-alone
- Partnering
- Sell technology

Coherent portfolio, each targeting blockbuster markets

- ZAMBEZI
- Glucose
- FDCA
- YXY Technology
- MEKONG
- MEG
- PEF
- Bottle
ZAMBEZI
Lignocellulose pretreatment
Biorefinery
Glucose

Glucose is a central building block for many bio-based chemicals and polymers.
Sugar from 1G & 2G Biomass

First generation (1G) – Sugar cane, corn, sugar beet, wheat

- Well established technology
- Delivers high quality sucrose & dextrose

Second generation (2G) - Wood, agricultural waste, waste paper, energy crops

- Technologies still in development
- A challenge to deliver high quality dextrose

Now
- Corn
- Sugar cane
- Sugar beet

Future
- Wood
- Corn stover
- Waste paper
Zambezi Process
Process outline

Improved Bergius-Rheinau process
Two stage, concentrated HCl hydrolysis
Acid / sugar separation by proprietary evaporation technology
High purity glucose product
Opportunity and Impact of Zambezi

- Demand for sugars will increase
  - Arable land will come under increasing pressure
    - Demand for 1G products (grain, starch, sugars) will increase
    - More 1G milling will need to come on-line (primarily for food and feed)
  - Demand for 2G glucose to support bio-fuels will increase
  - Volume of plastics, especially bio-based, will increase
    - Demand for high purity 2G glucose will increase

- 2G Advantages:
  - free-up more 1G sources for food
  - reduce pressure on arable land
  - reduce volatility due to reduced seasonal effects

- We believe Zambezi, more than any other 2G technology, addresses the feedstock demands for the growing bio-based chemicals industry
Expected to enter commercial stage after 2020

Clear roadmap from lab to commercialization
Production Routes for MEG

Prime Raw Material

- **Fossil based**
  - Crude Oil/Naphtha/Gas/Fuel Oil
  - Natural Gas
  - Shale Gas
  - Coal

- **Biomass based**
  - Sugar Cane
  - Maize/Corn
  - 1G and 2G C6 carbohydrates

- **Biomimetic**
  - Carbon dioxide

Intermediates

- Ethylene
- Methanol
- Ethanol
- Sorbitol
- Oxalic acid

Product

- EO
- Mix of Glycols
- White MEG
- Black MEG
- Green MEG

- Direct hydrogenolysis – Efficient conversion
- Multi-step: Low atom efficiency
- Difficult separation
MEKONG: Superior Carbon Efficiency
Superior economics

Current Commercial Production of Bio-based MEG

Fermentation

Fermentation, dehydration, Oxidation, hydration

4 steps
Max theoretical yield = 67%

Avantium MEKONG Process

Hydrogenolysis

Catalysis
1 step
Max theoretical yield = 100%
Polymerization trial with distilled-only EG
Mn/Mw similar to Petro- and Bio-MEG
Color very similar

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<tr>
<th></th>
<th>Monomers</th>
<th>Ex-Reactor PEF</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Mn</td>
</tr>
<tr>
<td>1</td>
<td>Bio-MEG</td>
<td>16100</td>
</tr>
<tr>
<td>2</td>
<td>Petro-MEG</td>
<td>16100</td>
</tr>
<tr>
<td>3</td>
<td>Mekong-MEG</td>
<td>16100</td>
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VOLTA

Electrochemical CO$_2$ Reduction
Replacing existing processes is not easy:
- $\text{H}_2 / \text{O}_2$ for reduction / oxidation is often more economical
- Margins on bulk processes are low: everything needs to be optimized

Combination of skills required to design new electrochemical process:
- Organic chemistry, Electrochemistry, Catalysis, Electrochemical engineering, Process design, Process Economics

Opportunities: regimes that are not accessible to conventional catalysis or chemistries:
- Target specific molecules / new feedstocks
- Where number of process steps can be reduced
- Where the amount of waste can be diminished
Building the PEF Value Chain
1. Manufacturing Strategy of FDCA and PEF

2. Commercial Opportunities for PEF films
SYNVINA: Joint Venture of two strong parents

- Building first commercial scale production plant
- Reference plant of up to 50,000 tons FDCA capacity
- PEFerence BBI Flagship project
- Commercial launch of FDCA and PEF
- Joint market development with key customers to go to market
- Building licensing package for Synvina’s technology and enabling industrial scale roll-out

BASF’s Verbund site in Antwerp, Belgium
Applications of PEF

Applications of FDCA
- Polyesters (incl. PEF)
- Polyamides
- Polyurethanes
- Other polymers
- Chemical building blocks

YXY technology
- Fructose
- FDCA
- PEF

Chemical building blocks
Polyesters (incl. PEF)
Polyamides
Polyurethanes
Other polymers

Applications of PEF
- Bottle
- Film
- Fiber
Synvina Pilot Plant

- Synvina Pilot Plant Objectives
  - Process development
  - Engineering baseline for reference plant
  - Production of FDCA and PEF for evaluation of market applications with customer

- The pilot plant is in operation from 2011, and runs continuously 24hrs per day, 365 days per year

- New pilot plant building opened in 2016
### Commercial Scale Up

<table>
<thead>
<tr>
<th>Lab-scale</th>
<th>Pilot Plant scale</th>
<th>Commercial scale</th>
<th>Industrial scale</th>
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<tbody>
<tr>
<td>Amsterdam</td>
<td>Geleen</td>
<td>Antwerp</td>
<td>Licensee Site (tbd)</td>
</tr>
<tr>
<td>Kg’s</td>
<td>Tons</td>
<td>Up to 50kt</td>
<td>Industrial Scale</td>
</tr>
<tr>
<td>Innovative research</td>
<td>Technology development</td>
<td>Commercial launch of FDCA &amp; PEF</td>
<td>Roll-out of FDCA &amp; PEF at larger scale</td>
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- **Synvina Licensing**
Agenda

1. Introduction to FDCA and PEF

2. Examples of Commercial Opportunities for PEF packaging
PEF performance benefits

- Biobased: 100% biobased
- Gas barrier performance: Oxygen 10x, CO2 10x, Water 3~4x
- Strength: 60% higher modulus
- Superior heat resistance: 12°C higher glass transition
- Recyclability: 100% recyclable
Recycling

- Optimize end-of-life solutions for PEF polymer

- PEF to PEF recycling is similar to PET recycling
  - Mechanical recycling
  - Chemical recycling

- Transition period: PEF in the rPET stream
  - **Sorting**: PEF can be separated from PET by IR sorting
  - **Effect of PEF in rPET stream**:  
    - Impact on rPET processes and end products assessed with recycling industry organizations
    - PEF significantly less impact on rPET than Nylon or PLA
Performance benefits of small PEF bottles for carbonated beverages

- Weight
- Transport
- CO₂ barrier
- Shape freedom
- Production complexity

Glass

PET

Aluminium / Steel / Tin

Multi-layer
Small size PEF bottles for carbonated beverages
Customer demand for smaller servings

In collaboration with ALPLA

Compared to same bottle in PET:
- 2x Top Load
- Up to 6x CO₂ shelf life
- Improved creep resistance

Opportunities:
- Longer supply chains enable new sales channels
- Optimized production cycles
- Shape freedom enables Brand differentiation (vs. cans)

8 oz (237 mL)
Thank you for your attention.

Questions??

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