PEF Polyester:
From an idea to a product

Ed de Jong, VP Development
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Key topics of this Presentation

PEF Polyester: From an idea to a product

- What are the challenges in setting up the supply chain for a novel polyester?
- Which novel applications can be addressed by PEF?
- What added value does PEF bring to potential customers?
- Is PEF a competitor to PET, or an opportunity for market growth?
Agenda

1. Introduction to PEF: Opportunities for a novel biobased polyester

2. Creating up the PEF Value Chain

3. PEF properties

4. PEF Application business cases
Avantium, an innovative renewable chemicals technology company

- Founded in 2000 in Amsterdam
- 61 patent families
- Geleen pilot plant 24/7 operational
- 140 employees
- 18 nationalities

Intended JV with BASF, the global #1 chemical company,

- YXY Technology
- Catalysis
- Renewable Chemistries

€20m Last financing round April 2016
The YXY technology

YXY: Avantium technology to convert plant-based sugars to FDCA and PEF

FDCA (Furan-dicarboxylic acid): the green versatile chemical building block

PEF (Polyethylene Furandicarboxylate): the next generation polyester
PEF the next generation polymer with blockbuster potential

**PEF**

**Superior Performance**
- Gas barrier
  - Oxygen 10x
  - CO2 10x
  - Water 2x
- Heat resistance
  - 12°C higher glass transition
- Rigidity
  - 60% higher modulus

**Favourable characteristics**
- 100% bio-based
- 100% recyclable
- -70% carbon footprint
- Same recycling processes

**vs. PET**
PEF end-markets

Packaging
- CSD
- Water
- Personal care
- Food
- Spirits/wine
- Home care
- Beer
- Dairy
- Still & sports drinks
- Foil pouches

Fibers
- Carpets
- Sport apparel
- Clothing
- Performance
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YXY unique end-to-end process proven at pilot scale

Sugar DeHydration → Oxidation → Purification → Polymerization → Processing (ISBM) → PEF

New assets → New or Retrofit assets → New or Retrofit assets → Existing assets → Existing assets

Sugar syrup → RMF → crude FDCA → purified FDCA → PEF resin → PEF

- H₂O → +O₂ → +MEG

(Carbohydrate – Fructose) → (5-methoxyMethylFurfural) → (FuranDiCarboxylicAcid) → (FuranDiCarboxylicAcid) → (Polyethylene-Furanoate)
Avantium operates a pilot plant at the Chemelot Campus in Geleen, the Netherlands

- Constructed in 2011, start-up in 2012
- Full-time operation: runs 24 hours per day, 7 days per week
- Objectives:
  - Process development
  - Production of FDCA and PEF for testing purposes and application development
Strong strategic partnerships with key customers creating PEF bottle market pull

- PEF bottles for carbonated beverages and still drinks
- PEF bottles for water: still, sparkling, flavoured
- JDA field: PEF bottles for alcoholic beverages, solid & liquid food, home & personal care
BASF and Avantium intend to establish Joint Venture

15 Mar 2016  Press release

• Production and marketing of furandicarboxylic acid (FDCA) based on renewable resources, the main new building block for polyethylenefuranoate (PEF)

• Further development and licensing of Avantium’s production processes for FDCA and PEF at industrial scale

• Intention to build a reference plant for FDCA with an annual capacity of up to 50,000 tons at BASF’s Verbund site in Antwerp, Belgium
Broad engagement with end-customers in various applications

<table>
<thead>
<tr>
<th>PEF</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoforming</td>
<td>Joint development Agreement with OMV//Polytype and various end-users</td>
</tr>
<tr>
<td>Film</td>
<td>Joint development with leading thin film converter and end-users</td>
</tr>
<tr>
<td></td>
<td>Evaluation with a world leading high-end film specialist</td>
</tr>
<tr>
<td>Fiber</td>
<td>Evaluation with leading carpet manufacturer</td>
</tr>
<tr>
<td></td>
<td>Evaluation with apparel manufacturer and brand-owners</td>
</tr>
<tr>
<td></td>
<td>Evaluation of technical fiber applications</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>FDCA based Co-polyesters</td>
<td>Evaluation with leading toys manufacturer</td>
</tr>
<tr>
<td></td>
<td>Development with a leading biochemicals player</td>
</tr>
<tr>
<td></td>
<td>Initiating evaluation with a leading chemicals player</td>
</tr>
</tbody>
</table>
Next stop: commercialization

<table>
<thead>
<tr>
<th>Lab-scale</th>
<th>Pilot Plant scale</th>
<th>Commercial scale</th>
<th>Industrial scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>Geleen</td>
<td>Antwerp</td>
<td>TBD</td>
</tr>
<tr>
<td>Scale: kg’s</td>
<td>Scale: tons</td>
<td>Up to 50kt</td>
<td>100’s of kt</td>
</tr>
<tr>
<td>Goal: Innovative research</td>
<td>Goal: proof of technology</td>
<td>Goal: commercial launch of FDCA &amp; PEF</td>
<td>Goal: further roll-out of FDCA &amp; PEF at larger scale</td>
</tr>
<tr>
<td>Avantium → JV</td>
<td>Avantium → JV</td>
<td>Joint Venture</td>
<td>Licensing and or own &amp; operate by partner</td>
</tr>
</tbody>
</table>
Agenda

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3. PEF properties
4. PEF Application business cases
PEF – An in-depth look

- A small change in chemical structure – intrinsically different properties

Straight aromatic bond – more flexible chain

Shorter, angled aromatic – more rigid chain

<table>
<thead>
<tr>
<th>Property</th>
<th>PET</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.36 g/cm³</td>
<td>1.43 g/cm³</td>
</tr>
<tr>
<td>O₂ permeability</td>
<td>0.114 barrer</td>
<td>0.0107 barrer</td>
</tr>
<tr>
<td>CO₂ permeability</td>
<td>0.46 barrer</td>
<td>0.026 barrer</td>
</tr>
<tr>
<td>T&lt;sub&gt;g&lt;/sub&gt;</td>
<td>~76°C</td>
<td>~88°C</td>
</tr>
<tr>
<td>T&lt;sub&gt;m&lt;/sub&gt;</td>
<td>250-270°C</td>
<td>210-230°C</td>
</tr>
<tr>
<td>E-modulus</td>
<td>2.1-2.2 GPa</td>
<td>3.1-3.3 GPa</td>
</tr>
<tr>
<td>Yield strength</td>
<td>50-60 MPa</td>
<td>90-100 MPa</td>
</tr>
<tr>
<td>Quiescent Crystallization time</td>
<td>2-3 min</td>
<td>20-30 min</td>
</tr>
</tbody>
</table>

Oriented PEF: Barrier properties

### Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>BOPEF$^1$</th>
<th>BOPET$^1$</th>
<th>BOPET$^2$</th>
<th>BOPP$^2$</th>
<th>BOPLA$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTR, cc-mm/m²-day-atm</td>
<td>0.15-0.51</td>
<td>2.4-3.3</td>
<td>2.0-6.0</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>CO₂ TR, cc-mm/m²-day-atm</td>
<td>1.4-2.6</td>
<td>24-28</td>
<td>21-22</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>WVTR, g-mil/100in²-day</td>
<td>0.6</td>
<td>1.3</td>
<td>1.0-2.0</td>
<td>0.25-0.4</td>
<td>24</td>
</tr>
</tbody>
</table>

1 Data obtained using Mocon OXTRAN & Mocon PERMATRAN at CWRU, 77°F 0% RH for O2 & CO2, 100°F, 90%RH for Water
3 Natureworks Technical data sheet 4043D
Oriented PEF: Mechanical Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>BOPEF¹</th>
<th>BOPET¹</th>
<th>BOPET²</th>
<th>BOPP²</th>
<th>BOPLA³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile modulus, GPa</td>
<td>4.5-8.0</td>
<td>3.9-5.3</td>
<td>3.3-3.5</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Max tensile Strength, MPa</td>
<td>120-300</td>
<td>170-250</td>
<td>140-180</td>
<td>184</td>
<td>123</td>
</tr>
<tr>
<td>Elongation at break, %</td>
<td>40-80</td>
<td>60-120</td>
<td>90-110</td>
<td>80</td>
<td>130</td>
</tr>
</tbody>
</table>

1 Data obtained using instron 5565 tensile tester at Avantium, 50%/min extension rate
3 Natureworks Technical data sheet 4043D
Safety

- Food Contact Safety studies being finalized:
  - All data indicates the polymer and monomer are safe
  - EFSA scientific opinion published October 2014
    - Positive opinion for FDCA 5mg/kg for all food
    - European regulation expected 2015
  - FDA registration to be prepared ~2017

- Safety studies FDCA monomer to support REACH registration:
  - Monomer is demonstrated to be safe
  - REACH registration completed 2013
Recycling

- Optimize end-of-life solutions for PEF polymer

- End goal: PEF to PEF recycling:
  - Mechanical recycling: demonstrated using same steps as PET
  - Chemical recycling: demonstrated PEF depolymerization to monomers
  - Timing depends on volume and value

- PEF and the rPET stream
  - Conducting sorting trials at waste separation & recycling sites
    - Different IR profile than PET or any other known plastic
    - Food grade approved recycling companies have sorting capability
  - Effect of PEF in rPET processes and end products being assessed
    - Incidental contamination
    - Higher PEF contents
First PEF T-shirts of 100% recycled PEF bottles

100% Biobased

Made from 100% Recycled PEF

Conventional polyester spinning technology

Conventional polyester dyeing technology
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Market direction towards smaller servings

How small can you go?

1.5L  1.0L  0.5L  <0.33L
Market direction towards smaller servings

How small can you go?

<table>
<thead>
<tr>
<th>Solution</th>
<th>Glass</th>
<th>Can</th>
<th>PET</th>
<th>Multilayer</th>
<th>Coating</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>Mid-Low</td>
<td>Mid-Low</td>
<td>Low</td>
</tr>
<tr>
<td>CO₂ BIF</td>
<td>∞</td>
<td>∞</td>
<td>1x</td>
<td>~3x</td>
<td>~3x</td>
<td>~5x</td>
</tr>
<tr>
<td>Transport</td>
<td>Poor</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Production Complexity</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Mid</td>
<td>Low</td>
</tr>
<tr>
<td>Recycling</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Shape freedom</td>
<td>Mid</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Small Size PEF Bottles

**Smaller is Better!**

Small size carbonated drink bottles with PEF

Compared to same bottle in PET:
- 2x Top Load
- 4-6x CO₂ shelf life
- Improved creep resistance

Opportunities:
- Brand differentiation (vs. cans)
- New sales channels & supply chains
- Event drinks
Market direction to clean labels, health conscious drinks and event bottles - *Keeping the oxygen out*

- Sauces
- Dressings
- Edible Oil
- Vitamin
- Flavored waters
- Juice
- RTD tea/coffee
- Beer
- Alcohol Pops
## Market direction to clean labels, health conscious drinks and event bottles - *Keeping the oxygen out*

<table>
<thead>
<tr>
<th>Solution</th>
<th>Glass</th>
<th>PET</th>
<th>Multilayer</th>
<th>Coating</th>
<th>Active O$_2$</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>High</td>
<td>Mid</td>
<td>Mid-Low</td>
<td>Mid-Low</td>
<td>Mid</td>
<td>Low</td>
</tr>
<tr>
<td>O$_2$ BIF</td>
<td>$\infty$</td>
<td>1x</td>
<td>10x</td>
<td>10x</td>
<td>10x</td>
<td>10x</td>
</tr>
<tr>
<td>Hot filling and Pasteurization</td>
<td>Excellent</td>
<td>Fair</td>
<td>Fair/poor</td>
<td>Fair</td>
<td>Fair/poor</td>
<td>Good</td>
</tr>
<tr>
<td>CO$_2$ pressure resistance</td>
<td>Excellent</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Production Complexity</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Mid</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Recycling</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
</tbody>
</table>
New packaging format PEF bottles

Strong shape flexibility for O$_2$ sensitive products with PEF

Compared to same bottle in PET:
- 10x O$_2$ shelf life
- 4-6x CO$_2$ shelf life
- Heat resistance

Opportunities:
- Clean Labels (preservative free)
- (Biobased) Packaging differentiation
- Event drinks
The PEF packaging opportunity

- PEF is a 100% biobased polyester with unique performance advantages over PET; allowing novel packages:
  - Switching from glass to plastic, e.g. for events and/or long transport
  - Replacement of barrier technologies by transparent monolayer PEF
  - Clean labels with a hot fillable O$_2$ barrier bottle
- Avantium’s proprietary YXY technology for FDCA and PEF is compatible with existing PTA and PET assets.
- PEF demonstrated at pilot scale in wide range of applications:
  - Wide variety of bottles
  - Trays, cups and capsules
  - Films for sealing/wrapping and pouches
  - Fibers for apparel and technical performance
- Avantium and BASF are in planning stage for first commercial FDCA facility
Thank you for your attention!

Contact details:
E-mail: ed.dejong@avantium.com
Telephone: +31 6 34347096