Biosuccinium®
Enabling biobased Polyurethanes

June 27th 2017

Lawrence Theunissen
Global Director Application Development
Global Megatrends Drive the Need for Sustainability

Consumer demand increasing for environmentally responsible products

- Sustainability / Renewability
  - Long-term maintenance of planet’s well being
  - Drives the growth of new jobs in a new economy

- Decreasing Oil Dependency
  - Scarcity
  - Price volatility
  - Energy security

- Environmental Concern
  - Consumer demand for safety and sustainability
  - Governmental regulation on climate change
Reverdia - Powered by DSM + Roquette

Leveraging the distinct and unique competencies of two leading companies

**Roquette**
- Experts on the potential of biomass
  - Top global starch and derivatives producer
  - Biorefinery experts
  - ~€3.3 billion turnover
  - Member of UN Global Compact

**DSM**
- Experts on using microorganisms to convert sugars from biomass into chemicals/materials
  - Biotechnology leader
  - Annual net sales of ~€10 billion
  - Top ranking Dow Jones Sustainability Index
- Produces and sells Biosuccinium® bio-based succinic acid since Dec 2012
- Develops performance-enhanced bio-materials with value chain partners
- Has leading low pH yeast fermentation technology
- Offers best-in-class environmental footprint

Headquartered in Geleen, The Netherlands

Production plant (10kt) in Cassano Spinola, Italy

Biotech R&D, Delft Materials R&D, Geleen The Netherlands
Producing Biosuccinium®, Bio-based Succinic Acid

A versatile green chemical building block that provides a sustainable advantage

- 4-carbon, dicarboxylic acid
- 100% bio-based alternative to traditional chemicals
- Production started in December 2012
- High quality based on leading best-in-class technology
- Global supply and approved in multiple applications
Biosuccinium® as a versatile building block

<table>
<thead>
<tr>
<th>Polyurethanes</th>
<th>Resins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running Shoes</td>
<td>Coatings Resins</td>
</tr>
<tr>
<td>Automotive Textiles</td>
<td>Composite Resins</td>
</tr>
<tr>
<td>Wheels</td>
<td></td>
</tr>
<tr>
<td>Wood &amp; Furniture coatings</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Polybutylene Succinate (PBS)</th>
<th>1,4 BDO/THF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Utensils</td>
<td>Elastic Fibers</td>
</tr>
<tr>
<td>Disposable Cups</td>
<td>Engineering Plastics</td>
</tr>
<tr>
<td>Food Packaging</td>
<td></td>
</tr>
<tr>
<td>Agricultural Films</td>
<td></td>
</tr>
<tr>
<td>Non-wovens Fibers</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pyrrolidones</th>
<th>Miscellaneous</th>
<th>Plasticizers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvents</td>
<td>Pharmaceuticals</td>
<td>Food Flavor</td>
</tr>
<tr>
<td>Cables</td>
<td>Metal Plating</td>
<td>Lubricants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymer Modification</td>
</tr>
</tbody>
</table>
Biosuccinium® in the Value Chain

Creating demand and demonstrating feasibility

- One single company cannot make the change
- Collaboration all along the value chain is required
- Development cost as well as value created should be well-distributed
  - Push (left to right): demonstrate feasibility and technical differentiation
  - Pull (right to left): create demand by showing improved sustainability
Joint Ambition of Reverdia with Customers

1. Replacing oil based products
2. Adding new functionality
   - Stronger Lighter Thinner
3. Circularity and circular design
## Succinic acid – the molecule

Molecular structure very similar to adipic acid

<table>
<thead>
<tr>
<th></th>
<th>Succinic acid</th>
<th>Adipic acid</th>
<th>Phthalic anhydride</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecular formula</strong></td>
<td>C₄H₆O₄</td>
<td>C₆H₁₀O₄</td>
<td>C₆H₄(CO)₂O</td>
</tr>
<tr>
<td><strong>Molecular structure</strong></td>
<td><img src="image1" alt="Succinic acid" /></td>
<td><img src="image2" alt="Adipic acid" /></td>
<td><img src="image3" alt="Phthalic anhydride" /></td>
</tr>
<tr>
<td><strong>Molecular mass [g/mol]</strong></td>
<td>118,1</td>
<td>146,1</td>
<td>148,1</td>
</tr>
<tr>
<td><strong>Biobased content [%]</strong></td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Carbon footprint [kg CO₂-eq/kg]</strong></td>
<td>0,9</td>
<td>1,9</td>
<td>9,0</td>
</tr>
</tbody>
</table>
Example: Biosuccinium® based Running Shoe

Biosuccinium® enabled carbon footprint reduction of ~1 kg CO₂ per shoe

~400 million running shoes sold annually

~ total carbon footprint of 80,000 world citizens
Microcellular PU Foam Outsole

Equal performance, significant biobased content and reduced carbon footprint

Indicative examples of biobased content and carbon footprint reduction of the final microcellular PU

Exact results depend on specific situations.
Joint Ambition of Reverdia with Customers

1. Replacing oil based products

2. Adding new functionality
   - Stronger
   - Lighter
   - Thinner

3. Circularity and circular design
Polyurethanes based on succinate-polyols show improved chemical resistance
   – Strongly reduced swell index

Longer life-time for parts exposed to (aggressive) solvents
   – Printer rollers
   – Squeegees
   – …
Differentiated performance characteristics

Broadened formulation potential

- Reverdia evaluated many experimental formulations with differentiated properties

- Examples
  - Polyster polyol composition
  - Biosuccinium
  - Biosuccinium + Adipic acid
  - Biosuccinium + Sebacic acid
  - Mixed diols

- Improved property
  - Chemical resistance
  - Resilience/compression set
  - Hydrolysis resistance
  - Abrasion resistance
Adhesion in 2K Molding

- Study performed by SKZ, Germany
  - 10 (partly) biobased elastomers
  - 14 (partly) biobased thermoplastics

- Results
  - Adhesion ranges from poor (< 10N) to excellent (>60N)
  - Biobased TPU (Desmopan) excellent adhesion to all (polar) biobased substrates
  - Biobased TPU with biobased PBS; adhesion of ~450N
Polyurethane Adhesives

Succinic acid increases tendency to crystallize

- **PU reactive hotmelt adhesives**
  - Modular system of amorphous, liquid and crystalline polyols
    - Some are based on succinic acid
- **Advantages**
  - Flat lamination: longer open time with shorter set time
  - Edge banding: lower application temperature

- **PU hotmelt adhesives**
  - TPU based on highly crystalline succinate polyols
    - Crystallinity depends on diol (BDOSA)
- **Advantages**
  - Higher melting point and heat resistance
  - Faster processing times
  - Better abrasion resistance and resilience
Joint Ambition of Reverdia with Customers

1. Replacing oil based products
2. Adding new functionality
3. Circularity and circular design

STONGER
LIGHTER
THINNER
Circularity and circular design

Some examples and thoughts

- **PET recycling**
  - Biosuccinium as monomer in rPET based polyester polyols
  - Polyols commercially available, for a range of PU applications (adhesives, coatings, ..)

- **PU recycling**
  - Biosuccinium as potential monomer in PU flex foam recycling?

- **(Bio)degradable PU**
  - Reversible adhesives
  - Waste management solution
Summary

- **Biosuccinium®**
  - bio-based content / reduced carbon footprint for your products
  - improved performance for your products

- **Reverdia**
  - Industry leading fermentation technology
  - Co-develops with customers via in-house application development
Thank you

Lawrence Theunissen
lawrence.theunissen@reverdia.com