DUPONT BIOMATERIALS

2-12-2019
Christian Lenges – DuPont Industrial BioSciences
One of the strongest, deepest chemistry toolkits with robust technology and asset integration, scale and competitive capabilities

World-class innovation process and application development capabilities

Broad offering and robust pipeline across germplasm, biotech traits and crop protection
DuPont Industrial Biosciences At-a-Glance

2017: $2.1B Sales --- 2800 Employees --- 19 Plants

Revenue Breakdown by Business & Product Group

By Region

<table>
<thead>
<tr>
<th>Region</th>
<th>% 2017 Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Americas</td>
<td>49%</td>
</tr>
<tr>
<td>Europe, Middle East and Africa</td>
<td>25%</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>26%</td>
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</tbody>
</table>
MARKETS are hungry for innovative new materials

Moving towards the Circular & Bio Economy means getting to accessible scale & price points

DuPont believes the winning formula for Biomaterials is:

Renewable Feedstocks at Scale
+ New Conversion Technologies
= New, Better Products

FDME/PTF and Enzymatic Polysaccharides are DuPont’s next wave
The world’s population in 2050

- Forecast in millions
  - North America: 352 (2013), 448 (2050)
  - Latin America and the Caribbean: 606 (2013), 779 (2050)
  - Europe: 740 (2013), 726 (2050)
  - Africa: 1,101 (2013), 2,435 (2050)
  - Asia: 4,305 (2013), 5,284 (2050)
  - Oceania: 38 (2013), 58 (2050)

Countries with the biggest populations

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Population</th>
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<tbody>
<tr>
<td>2013</td>
<td>China</td>
<td>1,361</td>
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<tr>
<td></td>
<td>India</td>
<td>1,277</td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>316</td>
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<td></td>
<td>Indonesia</td>
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<td>Brazil</td>
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<tr>
<td></td>
<td>Pakistan</td>
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<tr>
<td></td>
<td>Bangladesh</td>
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<td></td>
<td>Russia</td>
<td>144</td>
</tr>
<tr>
<td></td>
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<td>2050</td>
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<td></td>
<td>DR Congo</td>
<td>182</td>
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<tr>
<td></td>
<td>Ethiopia</td>
<td>178</td>
</tr>
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</table>

Source: NIDS France
MATERIAL INNOVATION & CIRCULAR ECONOMY

**renewable materials**: critical role to achieve a circular economy at the lowest carbon footprint

- Responsible sourcing & secure supply to build supply chain resilience
- Integrated into overall material recycle & reuse strategies

Renewable Materials role in…
- Reduce Waste / Design for Reuse
- Light-Weighting / Downgauging
- Recycling
- Design for End of Life: Composting/Biodegradation
- At Accessible Price & Relevant Scale
DuPont Biomaterials takes cues from nature to create eco-efficient renewable biomaterials that enhance the performance of everyday products.
DuPont Industrial Biosciences is working to reform the way we produce and consume

**ADVANCING THE FUTURE OF INDUSTRY TO SERVE SOCIETY AND SAFEGUARD THE ENVIRONMENT**

**Renewable Agricultural Resources**

**Industrial Scale Conversion**

**Sustainable, High-Performance Products**

- **Bio/chemical transformation**
- **Bio/chemical transformation**
- **BIOACTIVES**
- **BIOMATERIALS**
- **BIOFUELS**
We consider a range of important, inter-connected factors when developing new biomaterials technology.
The type of crop used and where that crop is grown matters in terms of efficiency and impact on the environment.
Today’s farmers produce enough to feed the entire global population yet 800 million people still remain undernourished.

**KEY DRIVERS OF FOOD INSECURITY**

**Weather**
- Climate change, extreme drought & Flooding affect harvests

**Water Scarcity**
- By 2025, 1.8 billion people will be living in countries with severely limited access to water

**Food Waste**
- 1/3 of the food produced every year gets lost or wasted

**Infrastructure**
- Lack of investment and poor infrastructure development hurt agricultural productivity

**Policy**
- Import/export tariffs, price controls and land rights

Sources: World Food and Agriculture Organization (FAO) of the United Nations, World Food Programme, World Hunger Education Service, WWF bioplastics feedstock alliance.
Today’s farmers produce enough to feed the entire global population yet 800 million people still remain undernourished.

KEY DRIVERS OF FOOD INSECURITY

- Reduce Food Loss & Waste: agricultural practices, supply chain improvement & consumer education
- Shifts to Healthier Diets: reduction in farming with heavy environmental impact
- Boost Crop Yields, Farmer Productivity and Land Output
- Shift Agriculture to Degraded Lands & Increase Aquaculture's Productivity

Sources: World Food and Agriculture Organization (FAO) of the United Nations
World Food Programme
World Hunger Education Service
WWF bioplastics feedstock alliance
LESS THAN 1/3 OF GLOBAL ARABLE LAND IS USED TO GROW FOOD

**Pasture**
- 3.3 billion ha = 67%*

**Arable land**
- 1.4 billion ha = 29%*

**Food & Feed**
- 1.24 billion ha = 25%*

**Material use**
- 106 million ha = 2%*

**Biofuels**
- 53 million ha = 1%*

**Bioplastics**
- 2017: 0.82 million ha ≈ 0.016%*
- 2022: 1.03 million ha ≈ 0.021%*

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Land use for bioplastics in 2017 and 2022

Sources: European Bioplastics, Institute for Bioplastics and Biocomposites, IFBB, 2015
For Centuries, We’ve Used Land to Grow Non-Food Crops for Everyday Products

- **Paper** (from Wood Pulp): 80 mm ha
- **Cotton**: 31 mm ha
- **US Corn for Ethanol**: 13.7 mm ha
- **Rubber**: 12 mm ha
- **European Biodiesel**: 5.4 mm ha
- **Brazil Sugar Cane for Ethanol**: 4.6 mm ha
- **Tobacco**: 4.1 mm ha
- **Advanced Biomaterials** (PLA, PHA, PEF, PCF, PTF, Bio-PDO™, and Starch blends): 0.75 mm ha

RENEWABLE FEEDSTOCKS

Carbohydrate crops are the most resource efficient, renewable feedstocks

Biomaterial Production:
access to fungible sugars for efficient production

- **Hard to Access & Increased Complexity:** cellulose feedstocks require complex innovation to access the required sugars building blocks

- **Lack of Consistency:** 2nd generation feedstocks do not offer a consistent supply of sugars adding in variability to the manufacturing process

- **LCA:** 2nd generation feedstocks do not guarantee a lower environmental impact through the extra processing required to access the sugars

- **Cost:** not competitive at this time - government incentives required to off set added cost & innovation required

### Crop Carbohydrate Efficiency

- **Sugarbeet (DE)**
  - Beet Juice
  - Beet Pulp
- **Sugarcane (BR)**
  - Sugarcane Juice
  - Sugarcane Bagasse
- **Cotton Plant (CN)**
  - Cotton Lint
  - Cottonseed
- **Maize Plant (US)**
  - Maize Grain
  - Maize Stover
- **Wheat Plant (US)**
  - Wheat Grain
  - Wheat Straw
- **Beech (DE)**
- **Eucalyptus (AP)**

Source: DuPont LCA group

Source: DuPont LCA group
PERFORMANCE, PURITY, AND SUSTAINABILITY

Biotechnology enables a combination of benefits from natural and petro-based polymer.

- **Petro-based polymers & monomers**
- **Engineered BioMaterials from DuPont**
- **Polymers & Monomers Extracted from Plants**

<table>
<thead>
<tr>
<th></th>
<th>CUSTOMIZED STRUCTURE &amp; PERFORMANCE</th>
<th>HIGH PURITY</th>
<th>RENEWABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petro-based polymers &amp; monomers</td>
<td>✔️</td>
<td>✔️</td>
<td>✗</td>
</tr>
<tr>
<td>Engineered BioMaterials from DuPont</td>
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DUPONT BIOMATERIALS’ FOUR BUSINESSES DELIVER PERFORMANCE, ACCESSIBILITY AND SUSTAINABILITY

- **Industrial & Personal Care**: 1,3, propanediol
- **Apparel & Carpet**: PTT (triexta) polymer
- **Packaging**: Furan polymers (PEF & PTF)
- **Packaging, Paper, Fibers, Composites, etc.**: Engineered Polysaccharides
ADM AND DUPONT COLLABORATE TO BRING A NEW MOLECULE TO THE MARKET

With their combined expertise in agriculture and food science, the two companies developed an innovative new process for turning fructose into biomaterial – specifically, the molecule furan dicarboxylic methyl ester (FDME) – a building-block that can be converted into a number of high-value, bio-based chemicals or materials.

THIS SCIENTIFIC BREAKTHROUGH OPENS THE DOOR TO NEW POLYMER GROUPS AND HAS CREATED A MORE EFFICIENT, ECONOMICALLY VIABLE PROCESS.
THE ADM-DUPONT INTEGRATED PROCESS ADVANTAGE

Highlights:

- Elimination of intermediate, on-path product purification steps
- Oxidation converts all on-path products to target molecule
- Energy produced in the oxidation step is integrated into the process
Polytrimethylene Furandicarboxylate (PTF)  
A novel polyester made from FDME and Bio-PDO™ (1,3-propanediol)

Superior gas barrier properties

Recyclable polymer

100% renewable polymer

Provides lightweighting and smarter packaging

More packaging with recycled materials

Enables use of more sustainable materials
ADM-DUPONT FDME MARKET DEVELOPMENT PLANT IN DECATUR, IL

- Fully integrated process
- Refining commercial estimates
- 60 T/yr
- Process optimization & Sample supply
Enzymatic Polymerization
A GOOD IDEA
Inspired by Nature

Polysaccharides extracted from plants are widely used to provide unique end-use applications but are limited by processes and raw material source. Nature often produces mixtures.

Cellulose
\(\beta(1,4)\) linkage

Starch
\(\alpha(1,4)\) linkage

alpha (1,3) linkage
Engineered Polysaccharide
ENGINEERED POLYSACCHARIDES DIRECTLY FROM SUCROSE

Using enzymatic polymerization to create a variety of polymer structures with unique product features and application benefits

- Linkage control: Selective polymerization of sucrose to polysaccharide
- Structural control: Crystallinity, solubility – DPW & PDI Control
- Process control to define polymer microstructure

PolySaccharide Applications

- Coatings
- Fibers & Fiber Additives
- Composites
- Packaging
BIOPROCESS CONTROL: FROM MOLECULAR DESIGN TO POLYMER ARCHITECTURE & PARTICLE MORPHOLOGY
Platform Technology to Engineer New Raw Materials

SUCROSE

ENZYMATIC POLYMERIZATION

MOLECULAR DESIGN

POLYMER ARCHITECTURE

MATERIAL MORPHOLOGY

Linkage Control
Selective Functionalization

Linear vs Branched Structures
BIOCATALYST – GLUCOSYLTRANSFERASE (GTF)

Highly conserved structure despite significant sequence diversity

- Glycoside-Hydrolase family 70 (GH70)
- Monomer with typical MW of 160 kDa
- Extracellular enzymes, mainly produced by:
  - Streptococcus species
  - Leuconostoc species
  - Lactobacillus species
NUVOLVE™ ENGINEERED POLYSACCHARIDES
PATH TO COMMERCIAL REALITY

Key Status Highlights

- Advancing process, product & application development
- Targeting first commercial scale supply
- Ongoing pilot plant operations to supply first sales
- Development materials available

Engineered PolySaccharide BioProcess
Nuvolve™ - Engineered Polysaccharides: Inherently biodegradable

Evolving Certification & Test Requirements: Disintegration & Biodegradation

Material Applications:
End of Life Options

- Controlled (Waste Management)
  - Solid Waste
  - Waste-water
  - Land-fill
  - Industrial Composting
  - Home Composting
  - Aerobic & Anaerobic
- Uncontrolled (Litter)
  - Soil
  - Marine

ASTM D5511: simulates & accelerates biodegradation process in landfill
ASTM D6691: aerobic biodegradation in marine environments
ISO 17556: Plastics: determines ultimate aerobic biodegradability

Nuvolve™ enables biodegradable product options across a wide range of environmental conditions

Industrial & home compostable, anaerobic digestion, as well as soil & marine degradable scenarios

This supports a broad range for disposal options as end of life infrastructures are developed within a circular economy framework
• Corrugated Board: $245B in 2018 (CAGR 4%)
• Paper & Paper Board recovery (recycle) rate > 70% (from ~35% in 1990)
• 120 Mton (NA & EU)
• Internet fulfillment, point of sale & wood/metal replacement
• Fiber quality drops with each recycle (downcycle!)
• Light-weighting, lower water consumption, increase of filler content
NUVOLVE™ ENGINEERED POLYSACCHARIDES
PROCESS OPTIONS TO SHAPE MICROFIBERS

- Efficient access to engineered microstructures
- Options to impart surface charge: cationic or anionic
- Formulation additive to achieve paper strength improvement

Design of Fiber charge & length (aspect ratio)
Direct chain entanglement / Charged fiber interaction
Increase retention of fines

micron-scale fibrils
Nuvolvë™ Engineered PolySaccharides: Microfibers - Results

Improvement in Dry tensile, Burst & Internal Bond strength [Scott Bond]

Increase inorganic filler & maintain strength

Increased Recycle Content - Maintain Performance

- Optimize Strength with viable other properties:
  - Low densification at same strength gain
  - Gains also in initial wet & re-wetted strength
  - Options to improve drainage of system
  - Sheet permeability decreased (denser paper)
NUVOLVE™ ENGINEERED POLYSACCHARIDES THROUGH ENZYMATIC POLYMERIZATION

INNOVATIVE SCIENCE  
HIGH PERFORMANCE  
New Class of Renewable Material with Unique Properties  
Key Processing Benefits

SCALABLE SUPPLY  
ACCESSIBLE & AFFORDABLE  
Advancing to Commercial Reality  
Multi ton quantities available for Development

RENEWABLE SOURCING  
RESPONSIBLE BIOMATERIALS  
Rapidly Renewable, Regional Feedstock  
LCA, Land Use, & Reduced Material Use

Accelerating Industrial Glycomics
THANK YOU FOR YOUR ATTENTION

Learn more about DuPont Biomaterials

biosciences.dupont.com/biomaterials

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