Biobased 1,3-Propanediol
A New Platform Chemical
For The 21st Century

Carl F. Muska and Carina Alles
BioPerspectives 2005
BREW Symposium
May 11, 2005
Overview

• What is 1,3-Propanediol (Bio-PDO™)

• Bio-PDO™ as a New Platform Chemical

• Bio-PDO™ as a Product of DuPont Transformation

• Life Cycle Assessment as a Tool for
  - Process Development
  - Market Development

• LCA Results
  - Bio-PDO™ Monomer
  - Sorona® Polymer
  - Final Product - Carpet

• Summary
Joint Venture Announced - May 26, 2004

DuPont pairs with British firm

Sweetener company will aid in the production of polymers and fibers

Creating Clothing from Corn

Compiled by staff

DuPont And Tate & Lyle Form Bio-Products Joint Venture; New Company Will Replace Petrochemicals With Renewable Resources

May 26, 2004: 7:16 a.m. EST

Wednesday/Thursday, May 26-27, 2004

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DuPont comes to Loudon

Joint venture with Tate & Lyle to create new bioProducts company in Blair Bend

Tate & Lyle hopes corn on the peg will become fashionable

David Teather in New York
Thursday May 27, 2004

The Guardian

DuPont, Tate & Lyle Form Bio-Products Joint Venture

By Amy Yee in New York
Published: May 26, 2004 20:28 / Last Updated: May 26, 2004 20:28

Tate & Lyle, DuPont form ‘bio’ venture

DuPont and Tate & Lyle Bio Products President John D. Halarctic talks community leaders about the new company named for Loudon during a breakfast meeting at the Log Cabin Restaurant. Picture: By Linda Brevern.
Loudon Site
The Product

**Bio-PDO™ (1,3- Propanediol; 3G; Propylene glycol)**

- Clear
- Colorless
- Odorless
- Low Toxicity
- Biodegradable
Sorona® Polymer

- Softness
- Stretch & Recovery
- Vibrant Colors
- Printability

Apparel

Fiber

Carpet

Autos
Bio-PDO™ Market Opportunities

Market Uncertainty

Technical Uncertainty

low

medium

high

Athletic Shoes

Molded Composites

Packaging Film

Non-wovens

Green Sorona

Performance Coatings

Staple

Textiles/Yarn

Bi-Components

Carpets

Performance Coatings

Packaging Film

Non-wovens
DuPont - Transforming for our Third Century

1802 1830 1850 1900 1925 1945 1990 2000 2050 2100

Birth  Growth  Maturity  Growth  Birth

Explosives  Chemicals, Energy

Strong history of innovation, reinvention

Chemistry, Materials, Systems, Biology...
Our Mission

Sustainable Growth: Increasing shareholder and societal value while reducing our environmental footprint.
2010 Goal

25% of revenue is from non-depletable resources.
How Did We Get Here?

Biotechnology

Bio-PDO™...

...from corn
Transition to Renewable Feedstock

Fossil-Based Feedstock

\[ \text{CH}_2=\text{CHCH}_3 \]

Propylene

\[ \text{HOCH}_2\text{CH}_2\text{CH}_2\text{OH} \]

3G

Catalyst

Renewable Feedstock

\[ C_6\text{H}_{12}\text{O}_6 \]

Glucose

Bio-Process

\[ \text{HOCH}_2\text{CH}_2\text{CH}_2\text{OH} \]

3G

Biocatalyst

Advantages:

- Use of Renewable Feedstock
- Smaller environmental footprint
- Lower manufacturing cost
- Lower capital
A Brief History of the Program

- 1994: 3G Genes Isolated
- 1995: Genencor-DuPont Collaboration Started
- 1997: Process Development Team Formed
- 1998: Gen I Biocatalyst Milestone
- 1999: Tate&Lyle-DuPont Process Piloting Started
- 2000: Tate&Lyle-DuPont Process in Pilot
- 2001: Commercial-Performance Biocatalyst in Pilot
- 2002: Commercial Plant Start-Up
Process to Bio-PDO™

Ferment glucose to PDO using patented microorganism

Refine to Fiber Grade

Corn → Dextrose → Bio-PDO™ (1,3-Propanediol)
The 3G Bioprocess

Fermentation
- Water
- Glucose
- Nutrients
- Biocatalyst

Separations
- Cells
- Impurities
- Water

Refining
- FIBER GRADE 3G

Putting it all together
- Sorona® Polymer & Fiber
An important question was asked.

*How green are green plastics?*

*It is now technologically possible to make plastics using green plants rather than fossil fuels. But are these new plastics the environmental saviors researchers have hoped for?*

Scientific American. August 2000

Tillman U. Gerngross and Steven C. Slater
Energy as a Key Indicator

• energy production causes large environmental footprint
  – depletion of fossil fuels
  – greenhouse gases
  – water consumption
  – toxic emissions (eg, heavy metals)

• There are energy-related concerns with bio processes:
  – difficult separations
  – not as optimized as incumbent technologies
How Do We Answer the Question?

Life Cycle Analysis (LCA)
Life Cycle Assessment Framework

Goal & Scope Definition

Inventory Analysis

Impact Assessment

ISO 14041

ISO 14042

ISO 14043

Interpretation

Conclusions, recommendations, and reporting

Direct Applications:

Product development & Improvement

Strategic Planning

Public Policy Making

Marketing

Other
How We Use LCA

ICBR Program

Stakeholder Engagement

Market Development

Process Development

Bench-marking

1999 2000 2001 2002 2003 2004 2005 2006

Tate&Lyle-DuPont Joint Development Agreement Process Piloting Started

Joint Venture established

Commercial Plant begins operation

TATE & LYLE

DuPont Tate & Lyle BioProducts
Life Cycle Assessment of PDO

Present

Petroleum → Refining → CHEMICALS (eg: PDO) → Polymers

Future

Renewable Crops → Bioprocessing → FUELS, Pharmaceuticals, solvents, crop protection CHEMICALS . . .

Plastics
Fibers
Coatings
LCA System Boundaries

Previous work: “cradle-to-gate”

On-going: “gate-to-grave”
Bio-PDO™ LCA System

**INPUTS**

- Raw Materials
- Energy

**OUTPUTS**

- Co-Products
- Emissions to air, water & land

1. **Corn farming**
2. **Corn wet milling**
3. **PDO fermentation**
4. **PDO purification**
5. **PDO**
Fossil-Based PDO LCA System

**INPUTS**
- Raw Materials
- Energy

**OUTPUTS**
- Co-Products
- Emissions to air, water & land

**Fossil Feedstock**
- Extraction & refining

**Secondary Processes**
- Hydrogen production
- Propylene production

**Chem. PDO production**

**PDO**
PDO Comparison: LCA Total Primary Energy

1,3 Propanediol from Bio-Route  1,3 Propanediol from Chemical Route

[Bar chart showing comparison between 1,3 Propanediol from Bio-Route and 1,3 Propanediol from Chemical Route.]
PDO Comparative LCA

Cumulative Energy Consumption

- Generation 1
- Generation 2
- Generation 3

Fossil-Based PDO vs. Bio-PDO™
Sorona® LCA System

**INPUTS**
- Raw Materials
- Energy

**OUTPUTS**
- Co-Products
- Emissions to air, water & land

- **PDO production**
- **TPA or DMT production**
- **3GT polymerization**
- **Sorona®**
Comparative Polymer LCA - Energy

Cumulative non-renewable energy consumption per kg of polymer

- Nylon 6
- Sorona®
Comparative Polymer LCA - CO₂

Greenhouse gases as CO₂ equivalents per kg of polymer

Nylon 6

Sorona®
Why Carpet?

For United States Carpet Industry

- 1.9 billion square yards produced in 1999
  - supplies 45% of world’s carpet
  - 53% is residential
  - 47% is industrial

- 3.5 billion pounds of fibers consumed/year
  - 57% nylon
  - 36% olefin
  - 7% polyester
  - 0.4% wool

Carpet LCA System

INPUTS

- Raw Materials
- Energy

OUTPUTS

- Co-Products
- Emissions to air, water & land

Polymer → Carpet Manufacture → Installation → Residential Use → End-of-Life
Carpet Comparative LCA

Cumulated Energy Demand in MJ per square yard of carpet

- Nylon6
- Sorona®

Carpet Fiber
Other Carpet Materials
Carpet Manufacture
Carpet Cleaning
Total
Comparative Carpet LCA - CO₂

Greenhouse gases as CO₂ equivalents per square yard of carpet

- Nylon 6
- Sorona®

Carpet Fiber
Other Carpet Materials
Carpet Manufacture
Carpet Cleaning
Total
Sustainability in Business

Sustainability: Three Legs

• In Markets: Greater Functionality
• In Business: Lower Cost & Investment
• In the World: Smaller Environmental Footprint
It's an exciting time to be at DuPont
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