Novel Membrane Technology Applications and “Green” Product Development for Industrial Pollution Prevention

Bioconversion of High-Starch Food Wastes into High-Value Products

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1995 Energy Systems Division Review
DISCLAIMER

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Project Overview

- Sponsor: U.S. Department of Energy
  Industrial Waste Program,
  Office of Industrial Technologies

- Goal: Develop rational, integrated lactic-acid-related
  processes and products that can potentially save energy
  and reduce waste by utilization of waste carbohydrates

- Starting Date: April 1988

- DOE Funding: $4.495 million to date, at
  $400,000-800,000 per year
Project R&D Strategy

Argonne's BioLac Approach is "Green" and Versatile

Current Industrial Approach

Carbohydrates → Fermentation → Separation → Lactic Acid → PLA

Salt By-Product (1:1)

ANL Approach

Carbohydrates → Fermentation → 2-stage ED → Lactic Acid → Lactate Ester

No Salt By-Product

Polymerization

Modified PLA

Hydrogenolysis

Propylene glycol

Catalytic dehydration

Acrylic acid

Specialty products

“Green” solvents

Plant growth regulators
# Market Potential

<table>
<thead>
<tr>
<th>Product</th>
<th>Uses</th>
<th>U.S. Market* Volume (10^6 lb/yr)</th>
<th>Selling* Price ($/lb)</th>
<th>Total Value (10^6 lb/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degradable plastics</td>
<td>Packaging, films</td>
<td>0.3-2.0**</td>
<td>0.4-0.6**</td>
<td>120-1200</td>
</tr>
</tbody>
</table>

**Oxychemicals:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Uses</th>
<th>Volume (10^6 lb/yr)</th>
<th>Price ($/lb)</th>
<th>Total Value (10^6 lb/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene glycol</td>
<td>Polymers, food, de-icers, humectants</td>
<td>0.8</td>
<td>0.55</td>
<td>440</td>
</tr>
<tr>
<td>Acrylates</td>
<td>Polymers, plastics, films, coatings</td>
<td>1.1</td>
<td>0.65</td>
<td>710</td>
</tr>
<tr>
<td>Propylene oxide</td>
<td>Polymers, plastics</td>
<td>3.2</td>
<td>0.55</td>
<td>1760</td>
</tr>
</tbody>
</table>

**"Green" Chemicals/Solvents:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Uses</th>
<th>Volume (10^6 lb/yr)</th>
<th>Price ($/lb)</th>
<th>Total Value (10^6 lb/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esters</td>
<td>Plasticizers, food processing, packaging</td>
<td>0.1-0.2***</td>
<td>0.5</td>
<td>50-100</td>
</tr>
<tr>
<td>Ester derivatives</td>
<td>Same as above</td>
<td>0.05-0.1***</td>
<td>0.5</td>
<td>25-50</td>
</tr>
</tbody>
</table>

**Plant Growth Regulators:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Uses</th>
<th>Volume (10^6 lb/yr)</th>
<th>Price ($/lb)</th>
<th>Total Value (10^6 lb/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-1-Lactates</td>
<td>Mulch film for vegetables and fruit crops</td>
<td>0.05-0.1***</td>
<td>1.0</td>
<td>50-100</td>
</tr>
</tbody>
</table>

**Total**                  |                               | 5.6-7.5             | 3155-4360     |                          |

* Market volumes and prices are for 1991 (Chemical Marketing Reporter) unless otherwise stated

** Estimates from Battelle, SRI, Gargill (1993) Announcement

*** Argonne's estimates
### Lactic Acid Manufacturing Costs

**Capacity**
- 100 MM lb lactic acid
  (>99% pure, 85% d.s.)/yr

**Year**
- 1990

**Location**
- U.S. Midwest

**Process**
- ED membrane-based

**Capital (-15% +30%)**
- Direct Fixed, $10^6
  - 35.3
- Total Invest., $10^6
  - 40.9

**Cost per lb lactic acid, c**

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td>7.4</td>
</tr>
<tr>
<td>Chemicals, Supplies</td>
<td>3.4</td>
</tr>
<tr>
<td>Variable Utilities</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Total Variable Cost</strong></td>
<td>16.3</td>
</tr>
<tr>
<td>Labor and Maintenance</td>
<td>2.4</td>
</tr>
<tr>
<td>Plant Overhead</td>
<td>1.0</td>
</tr>
<tr>
<td>Insurance and Taxes</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Total Fixed Direct Cost</strong></td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Total Cash Cost</strong></td>
<td>20.3</td>
</tr>
<tr>
<td>Depreciation (12.5%)</td>
<td>5.1</td>
</tr>
<tr>
<td><strong>Manufacturing Cost</strong></td>
<td>25.4</td>
</tr>
<tr>
<td>(Cash + Depreciation)</td>
<td></td>
</tr>
</tbody>
</table>
## Manufacturing Costs of Lactic Acid Derivatives

<table>
<thead>
<tr>
<th>Product</th>
<th>Process</th>
<th>Target Manufacturing Cost, ¢/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactic acid</td>
<td>ED membrane</td>
<td>25.4</td>
</tr>
<tr>
<td>Lactate ester</td>
<td>Membrane-based</td>
<td>29.3</td>
</tr>
<tr>
<td>Propylene glycol</td>
<td>John Brown</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td>(Davy Mckee)</td>
<td></td>
</tr>
<tr>
<td>Lactic co-polymer</td>
<td>Coupling</td>
<td>74.6</td>
</tr>
</tbody>
</table>

Based on the expected selling price, 25% to 50% gross margin will be feasible.
Technical Accomplishments

- Developed an integrated enzymatic hydrolysis/fermentation process for the efficient conversion of carbohydrate to lactate

- Developed an electrodialysis-based primary purification process and demonstrated feasibility to a major agriprocessor

- Demonstrated key technical advantages of a novel secondary purification technology in proof-of-concept experiments

- Developed novel, modified poly-lactic acid and specialty lactic acid derivatives and initiated demonstration of their applications with industrial collaborators
Technology Transfer and Industrial Collaborations

- CRADA and cost-share agreements:
  - AURI/Mankato State University
  - TVA
  - NTEC EDsep, Inc. (pending)

- Licenses:
  - Advanced Polymer Design (new spin-off from CogniTek)
  - Kyowa Hakko

- Work-for-Others Projects:
  - State of Illinois
  - Major agriprocessor
  - Advanced Polymer Design (pending)

- Other Collaborations:
  - Plastigon/University of Florida
  - Iowa State University
  - University of Massachusetts at Lowell
  - Membrane technology companies
Future Directions

- Develop, demonstrate, and commercialize electrodialysis process applications for industrial pollution prevention

- Obtain proprietary position for the secondary purification technology and initiate pilot demonstration

- Develop novel applications for lactic acid derivatives as degradable polymers, surfactants, plasticizers, and “green” solvents
Technical Capabilities of the Project Team Have Led to New Funded Projects

- Electrodialysis applications in industrial pollution prevention
  - Recovery and reuse of salt in a major domestic manufacturing industry (funded by DOE)
  - Produced water treatment in the gas industry (funded by Gas Research Institute)

- Bioprocessing
  - Microorganism development, product separation, and polymer development in the DOE-funded Alternative Feedstocks Program, Succinic Acid Project
  - Product separation and process integration in a joint, multi-year proposal with industrial companies (pending)