Cellulosic n-butanol
Co-production of n-butanol and derivatives at biomass plants and pulp mills

Rick Wilson, PhD
Chief Executive Officer
- **Approach:** Fermentation to n-butanol integrated with biomass facilities
- Addressing large existing high-value chemical and derivatives markets
- Significant cost advantage vs. petroleum with low-cost waste biomass
- Capital light enabled by bioreactor technology & co-location
- Co-location with biomass power, pellet plants, sugar mills, pulp mills
- 470,000 GPY demonstration unit under construction
Approach: Fermentation with Biomass Processing

**Biomass Power Partner**
- **Power Generation**
- **Electricity**
  - **C₅ Sugars**

**Specialty Pulp Mill Partner**
- **Energy**

**Biodiesel Partner**
- **Glycerol (C₃)**

**Phase I**
- **Lignin**
- **C₆ Sugars**
- **Steam & Electric**

**Bolt On**
- **Biodiesel**
- **Biodiesel Partner**
- **Glycerol (C₃)**

**Biomass**
- **Bagasse**

**Extraction & Hydrolysis**
- **C₅ Sugars**
- **Phase II C₆ Sugars**

**Conditioning**
- **Low Energy**
- **Low OPEX**
- **Continuous**
- **High Rate & Yield**
- **Low Capital**

**Bioreactors**
- **Clean Sugars**
- **Broth**

**Distillation**
- **Butanol**
- **Acetone (minor)**
- **Lignin to Deployment Partner**

**Future**
- **Low Capital**
# High Value Chemical & Derivative Markets

## Market Potential: Chemicals ($33B) & Fuels ($2T)

<table>
<thead>
<tr>
<th>Products</th>
<th>N-Butanol</th>
<th>OXO Derivatives</th>
<th>Butene Derivatives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Participants</strong></td>
<td>Acetates</td>
<td>2-Ethyl Hexanol</td>
<td>LLDPE</td>
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<tr>
<td></td>
<td>Acrylates</td>
<td>N-Butyraldehyde</td>
<td>Valeraldehyde</td>
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<tr>
<td></td>
<td>Glycol Ethers</td>
<td>Butyric Acid</td>
<td>Polybutene</td>
</tr>
<tr>
<td><strong>Market Size &amp; Avg. Sales Price</strong></td>
<td>$7B $2300/mt</td>
<td>$9B $2600/mt</td>
<td>$5B $1500/mt</td>
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<tr>
<td><strong>Chemical End Uses</strong></td>
<td>Paints</td>
<td>Plasticizers</td>
<td>Plastics</td>
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<tr>
<td></td>
<td>Solvents</td>
<td>Paint Dryers</td>
<td>Liquid Polymers</td>
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<tr>
<td></td>
<td>Acrylics</td>
<td>Stabilizers</td>
<td>Ag Intermediate</td>
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<tr>
<td></td>
<td>Amines</td>
<td>Preservatives</td>
<td>Lube Additives</td>
</tr>
<tr>
<td><strong>Fuels Markets</strong></td>
<td>Jet Fuel $250B</td>
<td>Gasoline $980B</td>
<td>Synthetic Rubber</td>
</tr>
<tr>
<td></td>
<td>Diesel $1,040B</td>
<td>?</td>
<td>Polypropylene</td>
</tr>
</tbody>
</table>

- **Paints**: Paints
- **Solvents**: Solvents
- **Acrylics**: Acrylics
- **Amines**: Amines
- **Plastics**: Plastics
- **Paint Dryers**: Paint Dryers
- **Stabilizers**: Stabilizers
- **Liquid Polymers**: Liquid Polymers
- **Ag Intermediate**: Ag Intermediate
- **Preservatives**: Preservatives
- **Lube Additives**: Lube Additives
- **Synthetic Rubber**: Synthetic Rubber
- **Polypropylene**: Polypropylene
- **ABS**: ABS
- **Cumene**: Cumene
Feedstock Comparison

Disruptive Cost Advantage with Waste Cellulosic Feedstocks

~ Eighty Percent (80%) cost advantage
Cost Advantage with Biomass Feedstocks

The chart illustrates the cost of production for various feedstocks, including Crude Oil (Biomass Equivalent), Corn, Sugarcane, Wood, Bagasse, and Glycerol. The cost is shown in dollars per tonne, with bars divided into two sections: blue for Feedstock and dark blue for Other Fixed and Variable costs.

- Crude Oil (Biomass Equivalent) shows a high cost, mainly due to Feedstock.
- Corn and Sugarcane have moderate costs, with a significant portion attributed to Feedstock.
- Wood, Bagasse, and Glycerol have lower costs, with Wood showing a higher Feedstock portion.

The chart highlights the advantage of using biomass feedstocks in terms of cost efficiency compared to conventional sources like Crude Oil.
Sugars Extraction

Biomass

Hemicellulose Extraction

Phase I

1. Autohydrolysis
2. Dilute Acid Hydrolysis

To Fermentation

Cellulose Conversion

Phase II

1. Enzymatic Hydrolysis
2. Dilute Acid Hydrolysis

To Fermentation

Residual Solids to Biomass Boiler
Low Production Cost with Cellulosic Feedstock

- Utilizes all five and six carbon sugars found in biomass
- Directed evolution strain technology for complete sugar utilization
- Extensive strain library for hardwood, softwood, and bagasse
- Focus on using five carbon hemicellulose
Capital Efficient Using Cobalt Bioreactor Technology

- Immobilized bio-films concentrate fermentation
- Continuous process minimizes operating expense
- Robust to fermentation inhibitors
- No GMO containment costs
Piloted Technology: Extraction & Conditioning

**Biomass Extraction**
20 dmt/ day

**Conditioning**
2 dmt/ day
Piloted Cobalt Technology

60 ml
Batch

10 L
0.26 gal
1.3 #/day feed
Continuous

1 L
133 #/day feed
Continuous

Pilot – 30 gal
267 #/day feed

Improved Pilot
154 gallons
10 Runs x 1 month

>24000 Tests
320 Tests
180 Runs
14 Runs X 1 month
10 Runs x 1 month

180 Runs
Key Technology

- **Hemicellulose extraction**
  - Method for Extracting Soluble Sugar Molecules from Biomass Material

- **Hydrolysate conditioning**
  - Removal of Inhibitors to Microbial Fermentation from Cellulosic Hydrolysates

- **Bacterial strain improvement**
  - Selection of Microbial Mutants to Increase Solvent and Inhibitor Tolerance

- **Bioreactor design and operation**
  - Methods for Producing Butanol from Immobilized Product Tolerant Microorganisms

- **System design**
  - Low energy distillation and energy integration
Commercialization Timeline

- **Lab:** 60 ml batch Q4 2008
- **Bench Milestone:** 24X 1-month runs Q4 2008
- **Pilot:** Q2 2009
- **Demo Plant Biomass Boiler:** 470,000 GPY Q1 2012 ANNOUNCED SOON
- **Commercial:** 10-50 MGPy MOU's in 2012

Timeline:
- 2006
- 2009
- 2011
- 2012
- 2013
Deployment Options: Colocation

- Co-location could be with a pulp mill, biomass power, or pellet operation
- Power boiler is 25% of project capital cost
- Waste water treating
- Wood handling
- Fiber basket
- Permits
Deployment Options: Pulp Mill Integration (VPP)

- Hemicellulose pre-extraction in front of a Kraft Pulp mill
- Recovers C5 sugars from recovery boiler
- Fermentation of C5 sugars to ethanol or butanol
- Works best with hardwood, limiting opportunity
- Acetic acid recovery from hardwood extracts adds capital
- Hemicellulose extraction impacts pulp quality
- Limited quantities of recoverable sugars impairs facility size – diseconomies of scale
Deployment Options

Re-purpose pulp mills (or co-locate)

Sugar cane bagasse power - 1.77 billion GPY
(Brazil, India, China across 232 sites)

Wood biomass power and pellets - 1.14 billion GPY
(US and Europe across 126 sites)

Specialty pulp mills - 274 million GPY
(Global across 26 mills - Low CAPEX option)

Cane trash “straw” with C6 sugar technology - 4.60 billion GPY

Palm waste with C6 sugar technology - 4.11 billion GPY
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