Low-Lignin Feedstock
Improving Yields of Biofuels and Chemicals

David Goetz
Phuong Nguyen
Peter Thompson
Darren Woulfe
Situation
- The biofuels industry is a rapidly-growing, multi-billion dollar market
- Margins are currently very low
- Securing long-term profitability requires:
  - Maximizing yields
  - Minimizing costs

Value Proposition
Our innovation can significantly increase yields by reducing the amount of undesirable lignin for cellulosic processes
Technology Overview

Market Assessment

Feedstock Industry Dynamics

Recommendations
What is Cellulosic Biofuel

- Target of 36bn gallons of biofuels by 2022
- Minimum **12bn gallons** of cellulosic biofuels

**Cellulosic**
- Non-food feedstock material
- Break down plant cellulose into sugars
  - e.g. corn stover
  - switchgrass
  - miscanthus

**Advanced Fuels and Biodiesel**
- Alternative pathways involving plant oils
  - High potential but unproven at scale
  - e.g. algae

**Conventional**
- Crops with high sugar and starch contents
  - Technically easiest to produce and lowest cost
  - e.g. Corn in US, Sugar Cane in Brazil

Source: Ceres
Technology Introduction

**TuLP**

Tunable Location of Important bio-Products
TuLIP 1.0 – Low Lignin

Our Innovation

- A genetic modification that tunes the location and amount of lignin produced
- Potential applications for tuning the location and amount of other bioproducts including hemicellulose, and cellulose

Yield Improvement

- Wildtype
- TuLIP 1.0

<table>
<thead>
<tr>
<th>Time</th>
<th>Sugar Yield (%)</th>
<th>Wildtype</th>
<th>TuLIP 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>24hr</td>
<td>45</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>48hr</td>
<td>30</td>
<td>60</td>
<td>80</td>
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</table>
Value Proposition of our Technology

Value of Reduced Lignin for Cellulosic Crops

- Higher yields of more valuable plant materials
- Easier to deconstruct plants and extract cellulose
- Fewer enzyme-inhibiting byproducts after deconstruction

Value Specific to this Innovation

- Maintains Plant Strength
- Potentially Feedstock Agnostic
- Product Agnostic
Quantifying the value of our technology

- Our innovation can **improve yields by 42%** over base-case cellulosic ethanol
- This could lead to a **cost reduction of $1/gallon** for cellulosic ethanol

![Price Chart]

- **$1 / gallon**
- **Potential cost reduction**
- **x12bn gallons**
- **2022 US Cellulosic Target**
- **$12 billion**
- **Rough Potential Annual Value**

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**1. Greater revenue per ton of feedstock**
- More biofuel per ton of biomass and per acre

**2. Reduces feedstock transportation costs**
- More cellulose per truckload of feedstock

**3. Reduces refining costs in the biorefinery**
- Deconstruction easier, lowering input costs

*JBEI: Technoeconomic Model*
Our technology is still not in a commercial crop but inventors are patenting IP discovery.

Crop Innovation Development Process

Current Status

Source: Ceres
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Identifying End Markets

Assessment Criteria

- Biomass Products
- Addressable Market Size
- Lignin Adjustment Enhances Value?
- Sufficient Added Value Potential
- Market Penetration Feasible

Biomass Products:
- Lumber
- Adhesives
- Paints
- Glucose
- Lubricants

Lignin Adjustment Enhances Value?
- Biodiesel
- Animal Feedstock
- Butanol
- Fertilizer
- Mulch

Sufficient Added Value Potential
- Paper
- Combustible Biomass
- Glycerin

Market Penetration Feasible
- Ethanol
- Lactic Acid
End Product Markets

There are a number of end products which could potentially benefit from low-lignin

**Biofuels**
- Growth industry with government support
- Reduced lignin will improve yields and costs

**Animal Feed**
- Feed with a lower lignin yield will provide more energy per kg for animals

**Biomass-Derived Synthetic Chemicals**
- High-growth industry
- Reduced lignin will improve yields and costs

**Price for Protein**

**Paper**
- Paper industry uses cellulose to make paper
- Higher cellulose yields may be attractive

**Value Insufficient**
Biofuels Market

Market demand for biofuels is essentially unbounded in the near future – Khosla

![Biofuel Market Size Graph](image)

- **US Market Size**
- **World Market Size**

<table>
<thead>
<tr>
<th>Year</th>
<th>US Market Size</th>
<th>World Market Size</th>
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<tbody>
<tr>
<td>2011</td>
<td>$30bn</td>
<td>$30bn</td>
</tr>
<tr>
<td>2015</td>
<td>$60bn</td>
<td>$60bn</td>
</tr>
<tr>
<td>2022</td>
<td>$90bn</td>
<td>$90bn</td>
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</tbody>
</table>

**Market Drivers:**
- Rising gasoline prices
- Government support – RFS programs
- Costs will decrease with innovation in:
  - Enzymes
  - Agronomy
  - Process Technologies

**Risks:**
- Cellulosic margins and cost are not competitive with first-generation ethanol
- Competing technologies
  - Other Biofuels
  - EV Deployment
- Changes to regulations – Removal of RFS

**2022**
- US - $90bn biofuels market
- 12bn of 36bn gallons of biofuel from cellulosic
- Projected $30bn cellulosic biofuel market
There are a range of chemical markets which could use biomass feedstocks, of which plastics is the most attractive.

<table>
<thead>
<tr>
<th>Product</th>
<th>Market size</th>
<th>Feedstock source applicability</th>
<th>Substitution for petroleum</th>
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<tr>
<td>Plastics</td>
<td><img src="#" alt="Green" /></td>
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<td>Adhesive</td>
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<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Yellow" /></td>
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<tr>
<td>Pigments</td>
<td><img src="#" alt="Yellow" /></td>
<td><img src="#" alt="Red" /></td>
<td><img src="#" alt="Yellow" /></td>
</tr>
<tr>
<td>Wall Paints</td>
<td><img src="#" alt="Red" /></td>
<td><img src="#" alt="Red" /></td>
<td><img src="#" alt="Yellow" /></td>
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*Market size based on USDA Industrial Bioproducts, Today and Tomorrow. 2004.*
There are tens of billion-dollar markets in chemicals - Khosla

US Plastics Consumption by Market Segment, 2009

- Packaging: 23391
- Building & Construction: 11139
- Consumer & Institutional: 14862
- Exports: 14738
- Transportation: 941
- Furniture: 2008
- Electronics: 1495
- All Other: 1004

World Platform Biorenewable Chemical Market, 2006–2010 (in million $)

- 2006: $10.0 M
- 2007: $271.0 M
- 2008: $338.0 M
- 2009: $480.0 M
- 2010 (E): $652.0 M

$650 million market

Source: American Chemistry Council’s Plastics Industry Producers’ Statistics Group
Case Study: NatureWorks Ingeo

Selling bio-derived chemicals is already a growing market with specialist players

NatureWorks is a leader in the development of bio-based plastics and fibers

- Started as JV between Dow Chemical and Cargill
- Product: Ingeo is a biopolymer, Polylactic Acid
- Ingeo is used in a range of plastics, replacing petrochemical feedstocks

<table>
<thead>
<tr>
<th>2009 Ingeo Information</th>
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</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
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<tr>
<td><strong>Price</strong></td>
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<tr>
<td><strong>Revenue</strong></td>
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Recommendations
Feedstock Value Chain

Our Innovation’s Market

Trait Optimization

Seed Production

Farming

Biorefining

End Product Market

Biofuels

Biomass-derived Synthetic Chemicals (BDSC’s)

Fertilizer, Pesticides

Enzymes
### Feedstock Market Dynamics

<table>
<thead>
<tr>
<th>Agricultural Firms / Labs</th>
<th>Farmers</th>
<th>Biorefineries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trait Engineering → Seed Development</td>
<td>Planting &amp; Farming → Harvest &amp; Transport</td>
<td>Processing → Synthesis</td>
</tr>
</tbody>
</table>

**Agricultural Firms / Labs**
- Mendel Biotechnology
- ADM
- Monsanto
- Ceres
- Monsanto

**Farmers**
- US Cooperatives
- Big Sugar - Brazil

**Biorefineries**
- US Cooperatives
- Amyris
- POET
- Amyris
- Solazyme

**Characteristics**
- **Highly consolidated**
- “Big Ag” dominates traditional markets
- Focused Bioenergy players entering market
- Disaggregated, few large players
- Risk averse to innovation
- Close relationships with seed makers
- Emerging industry
- Pure cellulosic and mixed feedstock players
- Feedstock is critical to success, driving upstream integration
The Cellulosic Feedstock Industry

Corn Stover
- Large existing market
- Grown on prime arable land
- Low energy return – parity with output

Bioenergy Crops
- Small industry
- Grown on cheap marginal land
- High energy return – low input/high output

Source: Billion ton Vision, DOE & USDA 2005
Market Structure Issues

Farmers are paid by dry mass...

but our product improves yield quality, not mass

Weight and moisture measured

Standard = 42% more sugar

TuLIP =

The feedstock market must develop pricing premiums for quality:

- Biorefineries sign long-term contracts with farmers for specified crops
- Sufficient dedicated bioenergy crop activity to establish market standards
- There are precedents in differentiating crop types
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## Commercialization Strategies

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<tr>
<th>Strategy</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
</table>
| **License Trait**    | • Less financial risk  
• Faster to market  
• No additional investment or new skills required | • Lower share of any returns  
• Loss of control  
• Innovation can be culled if not aligned with licensee’s product |
| **Go-it-Alone: Develop Seed and Sell** | • Capture all potential profits  
• Control market approach  
• Potential to leverage TuLIP | • Financially risky  
• Capital intensive  
• Longer time to market  
• Requires other skills/experience |
| **Joint Venture**    | • Gain experience and skills from partners  
• Retains some control  
• Access to upside value  
• Potential to leverage TuLIP | • Share potential value  
• Less control than alone  
• Financial risk of investment |
## Recommendations – Corn vs. Bioenergy Crop

We recommend a different go-to-market strategy for corn vs. bioenergy crops

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Bioenergy Crop</th>
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</thead>
<tbody>
<tr>
<td><strong>Action</strong></td>
<td>License</td>
<td>Consider JV</td>
</tr>
<tr>
<td><strong>Market</strong></td>
<td>Mature industry dominated by large, powerful agricultural firms</td>
<td>Maturing industry with few entrenched players and little market power</td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Heavily modified strains Contain dozens of proprietary innovations to improve a range of characteristics</td>
<td>Plants are still only moderate variations on wild-type with limited IP on characteristics</td>
</tr>
<tr>
<td><strong>Conclusion</strong></td>
<td>A single trait innovation in a wild-type plant cannot compete with existing crops</td>
<td>Immaturity creates opportunity to pro-actively bring an innovation to market</td>
</tr>
<tr>
<td><strong>Recommendation</strong></td>
<td>License the trait for corn Supports the production of cellulosic ethanol with corn ethanol production</td>
<td>Combine trait innovations to develop a market-competitive bioenergy crop Seek partner with skills in field trials and commercial production</td>
</tr>
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Recommendations – Importance of Milestones

Financial value of the innovation grows significantly with each technical milestone achieved due to the reduction of risk

![Graph showing financial value growth over time with milestones: Theoretical Concept, Lab Test Plants, and Testing in Commercial Crop.]

**Recommendation**

- Seek non-dilutive funding to allow demonstration of the innovation in a commercially-used crop
- Potential Sources: SBIR, USDA, DOE, University Funding
Roadmap to Commercialization

1-2 years
- **Proof of Concept**
  - In real plants
  - Regulatory hurdles

1-2 years
- **Greenhouse Study**
  - Seek funding e.g. SBIR phase I/Discovery Grants
  - Early marketing

5-7 years
- **Field Study**
  - License for corn use
  - Assess Scalability
  - Determine Productivity
  - Seek funding e.g. SBIR II

Commercialization
- Partnership
- Licensing
- Start-up
Appendix
Intellectual Property and Protection

• **Patentability and Freedom to Operate for the TuLIP platform assessed**
  • No prior art found, innovation is novel and non-obvious
  • Inventors have freedom to operate

• **A provisional patent application has been filed**
  • An updated international PCT application will be filed within 1 year
  • Patent protection will be pursued in the US and other select countries

• **Additional patent applications will be filed on tunable production of bio-products and the TuLIP platform**
Selling Trait vs. Platform

The potential of our lignin innovation to form part of a wider crop enhancement platform technology is an important go-to-market consideration.

Partnership Case Study:

- Mendel has developed and retained IP to form a complementary portfolio.
- Mendel has partnered with Monsanto and Bayer CropScience to leverage their experience in trials and commercialization.
- In exchange, these companies gain use of Mendel’s IP and learning curve.
- Partnerships allow Mendel to retain more control and value than licensing, but take on greater risk.
BDSC Market – Distinction Between Platform and Final Chemicals

Difference between the Platform and Final Chemicals

Platform Chemical World Markets (million)
- Glycerin, $1,128.90
- Lactic Acid, $652.00
- Others, $65.10

Intermediate Chemical World Markets (million)
- Polylactic acid, $266.80
- Polyhydroxy-alknoates, $150.30
- Polyhydroxy-alknoates, $266.80
- Biorenewable 1,3-Propanediol, $75.20
- Biobutanol & Others, $82.60

We’re targeting platform chemical producers
Interviewed Companies

• Arbogen
• Amyris
• Ceres
• Catchlight
• Terviva
• Weyerhauser
• Poet
• Mendel
• HCL Cleantech
• Dow
• Elan Management
• United Sugars
• Farmer – Bob
• Fertilizer Company
# The Team

**Principal Researchers – JBEI**

<table>
<thead>
<tr>
<th>Henrik Scherrer</th>
<th>Dominique Loque</th>
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**C2M Team**

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<tr>
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