Fermentative Isobutanol Production from Woody Biomass and Conversion to Biojet

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Company Overview

Commercial scale renewable resource technology platform targeting the $1 trillion chemical and fuel product markets

Luverne, MN: Commercial Isobutanol/Ethanol/Animal Feed Plant

- R&D and HQ in Colorado
- Small company, ~75 people at 2 sites
- Public on the NASDAQ market
Why iBuOH? Low-Cost Renewables!

**Feedstock**
- Sugars
- Isobutanol

**Proprietary Technology**
- Proven at commercial scale
- Yeast Biocatalyst
- GIFT® Separator

**Commercial Markets**
- Price and performance attributes driving demand
- Direct "drop-in"
- Derivatives
  - Solvents
  - Marine / Off-road blendstock (i16)
  - Premium flex fuel (i60)
  - Specialty blendstock (i12.5)
  - PX / PET
  - Jet fuel
  - Isooctane
  - Diesel fuel
  - Chemical intermediates

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Gevo’s Role in NARA
1. Leverage Gevo-made isobutanol fermenting yeast biocatalysts
2. Screen pretreated hydrolyzates to determine optimal feedstock and pretreatment combination for isobutanol fermentation
3. Adapt yeast to hydrolyzate as needed
4. Develop fermentation and GIFT® process for hydrolyzate to isobutanol
5. Produce fuel-spec isobutanol from biomass sugars
6. Convert fuel-spec isobutanol into IPK for biojet blending
7. **BONUS**: Secure ASTM Certification of Alcohol-to-Jet process
Gevo made a natural EtOH producing yeast into a homofermentative, iBuOH producing yeast

<table>
<thead>
<tr>
<th>Yeast biocatalyst</th>
<th>Commentary</th>
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<tbody>
<tr>
<td>Sugars</td>
<td>• Synthetic biology &amp; genetic engineering used to modify existing commercial ethanol (EtOH) yeast to produce isobutanol (iBuOH)</td>
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<td>• Engineered 19 fundamental pathways to create multiple classes of iBuOH producing yeast</td>
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<td></td>
<td>• Library of &gt;18,000 iBuOH producing strains in several classes of yeast (FRED, THOR, CB-1)</td>
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<tr>
<td>iBuOH</td>
<td>• Operate in 1,000,000 liter fermenters</td>
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<td>• Meets commercial iBuOH production requirements</td>
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<td>• Biocatalysts are engineered for “structural cross breeding” to speed pathway development</td>
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<td>• Capable of using multiple carbohydrate feedstock (starch, sucrose, cellulosic=NARA)</td>
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<td>• Took 8+ years and 50+ people to re-program our yeast!!!</td>
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Adaptation of Biocatalysts to NARA Hydrolyzates

Direct selection (agar plates)

Culture → Dilute and Plate → Pick and screen in liquid media

Serial transfer

Biomass Hydrolyzate Concentration

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Adaptation of Biocatalysts to Hydrolyzate

- Early isobutanol yeast strains would not grow in SPORL hydrolyzate past a 60%/40% blend with sugar water.
- The power of adaptation led to yeast strains that could grow in and ferment sugars from hydrolyzate.
• >60% hydrolyzate meant NO YEAST GROWTH!
• Shake flasks allow comparison of multiple strains, growth and iBuOH production with small volumes (50 mL) hydrolyzate/replicate
• Used for screening strains for fermentation performance before 2L fermenter scale
• GIFT® is a proprietary, continual iBuOH removal and recovery system for fermentation

• GIFT® is essential for production of high amounts of iBuOH by fermentation
• Gevo has compared commercial fermentation at Luverne with and without GIFT
• The highest n-butanol concentration reported in literature (as of 2009) was 21 g/l in 50 hours.
• Without GIFT: Gevo achieved 16 g/l isobutanol in 35 hours using a yeast that is not our most isobutanol tolerant and under suboptimal fermentation conditions
• With GIFT: Gevo achieved ~90 g/L effective isobutanol titer in ~65h


Commercial Isobutanol Batch, no GIFT® vs Commercial Isobutanol Batch with GIFT®
THOR18241 – not our most tolerant yeast or optimum fermentation conditions
FREDb15182 – not our fastest yeast

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Producing iBuOH From Woody-Biomass Sugars
Developed Hydrolysis & iBuOH Fermentation Process from Woody Biomass in Lab

Hydrolysis

Fermentation

GIFT® Recovery of iBuOH

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1kIPK Task Objective: Produce 1,000 gallons of jet fuel using the feedstock and process identified and researched by the USDA funded NARA project at a relevant scale.

Use key aspects from the NARA project in the production:

- **Feedstock**: softwood forest residues, primarily Douglas-fir and Western hemlock
- **Pretreatment**: mild bisulfite variant of the SPORL process as developed by USDA/FPL and Catchlight Energy; Cosmo Specialty Fibers pretreatment
- **Enzymatic Saccharification**: use commercial enzymes from Novozymes
- **Isobutanol Production**: via fermentation using Gevo patented organisms and fermentation process
- **Jet Fuel Conversion**: via Gevo process
IBA to Hydrocarbons: Simple, Economic Process

Technology overview

- Proprietary processing based on standard unit operations leads to high yields, with minimum of co-products.
- Gevo has been producing jet fuel and isooctane since 2011 at Silsbee, TX demo plant (~10,000 gal/mo input basis).
- Simple product mix of isooctane and jet.
- Processes work well. Ready for commercial engineering and deployment.

Process Flow

Isobutanol → Dehydration → 2-phase separator → Water

Isobutylene

C8-C16 olefins → Dehydration → Oligomerization

Isooctane → Hydrogenation → Distillation

Jet

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Gevo ATJ technology benefits:

- **Converts sugars to Jet Fuel** - Sugars are cheaper and more plentiful than oils.
- **Demonstrated technology** – Operational production asset for 4 years producing >100,000 gal of ATJ.
- **Efficient processing** – High yielding chemical conversion steps.
- **ASTM certification** – 8 yrs of testing working across the supply chain.
- **Replaces petroleum C with renewable C!**
Thank you!