Conversion of Hydrolyzed Douglas fir Biomass into Isobutanol and Biojet

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Gevo, Inc. and NARA
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Located outside Denver, Colorado with Minnesota production facility
Founded in 2005 and now composed of ~100 people
Experienced & successful management team
  – Management team has commercialized lactic acid, polylactide polymers & lysine
  – Management team has developed and commercialized engineered yeast
Public company listed on Nasdaq as ‘GEVO’
A primary building block chemical that can be converted into approximately 40% of all petrochemicals and 100% of all hydrocarbon fuels

We make it from renewable feedstocks – not petroleum

We believe we can make it for less than petroleum-based isobutanol
How do we produce isobutanol?

Feedstock

Bio-Cracker

GIFT® Separator

Direct “drop-in”

Green Processing

Target Markets

Sugars → Isobutanol

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How We Produce Isobutanol (GIFT®)

- Our patented Gevo Integrated Fermentation Technology® (GIFT®) continually separates isobutanol during fermentation
- Gevo owns the patent covering ethanol plants retrofitted to produce isobutanol

Standard Fermentation Process

START: Feedstock

- Fresh & Recycled Water
- Steam
- Enzymes
- CO₂
- Enzymes
- Isobutanol Recovery
- Beer
- Distillation System
- Water
- Syrup
- Wet Grain
- Thin Stillage

Isobutanol

Animal Feed

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### Seven Strategic End Markets; Strong Customers

<table>
<thead>
<tr>
<th>Specialty Chemicals</th>
<th>Gasoline Blendstock</th>
<th>C4 Market</th>
<th>Bio-PX/PET</th>
<th>Bio-Jet</th>
<th>Hydrocarbon Fuels</th>
<th>Co-Product Revenues</th>
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<tr>
<td>Sasol</td>
<td>Mansfield</td>
<td>LANXESS</td>
<td>Coca-Cola</td>
<td>United</td>
<td>PURINA</td>
<td>LAND &amp; LAKES</td>
</tr>
<tr>
<td>reaching new frontiers</td>
<td>agreement in place</td>
<td>agreement in place</td>
<td>district agreement to create fully renewable PET for plant-based packaging</td>
<td>muscles interested in energy security / alternative jet fuel supply</td>
<td>the premier brand owner, partnership to maximize value of co-products</td>
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<td>Accounts for majority of initial capacity</td>
<td>VP Racing Fuels to evaluate a wide array of fuel applications</td>
<td>Negotiating terms for Canadian supply agreement</td>
<td>USAF initial volume delivered with testing underway</td>
<td>exploring how to enhance the value of isobutanol Distillers Grains (iDGs™ or animal feed)</td>
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<td>Customer sampling of Gevo’s isobutanol has begun</td>
<td>LOI with Total to evaluate isobutanol as a second-gen biofuel blendstock</td>
<td>Torray off-take agreement to create renewable Paraxylene for fibers and films</td>
<td>USAF test flight end of June</td>
<td>United Airlines LOI in place</td>
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</tbody>
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**“Lower Cost, Drop-In”** ~$7bln TAM

**“Cleaner Performance”** ~$100bln TAM

**“Structurally Short Supply”** ~$6bln TAM

**“Green Supply Chain”** ~$100bln TAM

**“High Performance”** ~$200bln TAM

**“Fully Renewable”** >$1trl TAM

**“Food First”** ~$7bln TAM

Source: Company materials, IEA, EIA and Nexant
Verify Woody Biomass Feedstocks & Pretreatment in Biojet Process

- Screen fermentable biomass sugars to determine optimal feedstock and pretreatment technology for isobutanol production
- Adapt yeast to fermentable biomass sugars
- Produce isobutanol from biomass sugars

ASTM Testing & End Users: Commercial and Military

Biojet

Isobutanol
NARA has established several standardized Douglas fir residual feedstocks. Multiple pretreatment partners provide diverse hydrolyzate streams for fermentation testing at Gevo.

**Table 1.** Sugar and inhibitor concentrations in FS-01 and FS-03 feedstocks from different pretreatments. Compositional analysis was determined using high performance liquid chromatography (HPLC) at Gevo. (n.d. = not detected)
Gevo evaluates each hydrolyzate/feedstock combination for biocatalyst growth and production of iBuOH

High-throughput growth, shake flask fermentations, then bioreactors

Shake flask fermentations showing the percent relative growth (Left) and relative isobutanol titer (Right) of the wet oxidation adapted parent LB4 in different percentages of FS-03 WO hydrolyzate. The clarified FS-03 wet oxidation pretreated hydrolyzate was supplemented with a nutrient package, salts, and a buffering agent. Different percentages of hydrolyzate media contained equal amounts of corresponding sugars and supplements. At 100% (v/v, not shown), wet oxidation pretreated hydrolyzate was equal to approximately 20-30% equivalent solids. Fermentation was carried out at 33°C for 96 hours in shake flasks. Isobutanol levels were determined by GC analysis.
Relative cell densities (Left) and average specific isobutanol productivity (Right) of hydrolyzate adapted LB4 and LB20 derived biocatalysts using 40% (v/v) FS-03 SPORL pretreated hydrolyzate medium in shake flask fermentations. All hydrolyzates were clarified to remove solids and were supplemented with a nutrient package, salts, and a buffering agent. The 40% (v/v) mixtures have sugars and acetate equivalent to 100% of the hydrolyzate. 100% hydrolyzate is equal to approximately 30-36% equivalent solids. Fermentation was carried out at 33°C. Cell density was measured using a spectrophotometer. Error bars represent the standard deviation. Abbreviations: SPORL, sulfite pretreatment to overcome recalcitrance of lignocellulose.
Abbreviations: CMB (Combined Mild Bisulfite), UMW (Unconcentrated Milled Wood), WO (Wet Oxidation), SPORL (Sulfite Pretreatment to Overcome Recalcitrance of Lignocellulose), MB (Mild Bisulfite)

Isobutanol producing biocatalyst LB4 was grown in fermentors with 20% (v/v) of each hydrolyzate type, and then harvested and pitched into GIFT® fermentation systems with 60% (v/v) of each hydrolyzate.
Average specific isobutanol productivity is the amount of isobutanol produced per cell density over time (g isobutanol / g DCW·h).

Abbreviations: CMB (Combined Mild Bisulfite), UMW (Unconcentrated Milled Wood), WO (Wet Oxidation), SPORL (Sulfite Pretreatment to Overcome Recalcitrance of Lignocellulose), MB (Mild Bisulfite).

Hydrolyzate adapted isobutanol producing biocatalyst LB4 was grown in fermentors with 20% (v/v) of each hydrolyzate type, and then harvested and pitched into GIFT® fermentation systems with 60% (v/v) of each hydrolyzate.
Percent of Theoretical Isobutanol Yield at 1L GIFT® Scale

Percent of Theoretical Isobutanol Yield of GEVO LB4 in 60% (v/v) FS-10 Hydrolyzate Media

- Percent of Theoretical Yield is calculated by dividing the experimental isobutanol yield by the maximum theoretical isobutanol yield.
- Abbreviations: CMB (Combined Mild Bisulfite), UMW (Unconcentrated Milled Wood), WO (Wet Oxidation), SPORL (Sulfite Pretreatment to Overcome Recalcitrance of Lignocellulose), MB (Mild Bisulfite).
- Hydrolyzate adapted isobutanol producing biocatalyst LB4 was grown in fermentors with 20% (v/v) of each hydrolyzate type, and then harvested and pitched into GIFT® fermentation systems with 60% (v/v) of each hydrolyzate.
Gevo’s Alcohol to Jet Process

Synthetic Alcohol-to-Jet (ATJ)

- Fermentation

Alcohols → Olefins → Kerosene Jet Blendstock

isobutanol → isobutylene concentrate → isoctene + jet precursor → isoctane (MON ~95) + Gevo Jet

i-BuOH

Dehydration

Isobutylene Concentrate

2-phase separator

Water

Oligomerization

Iso-octene + Jet Precursor

Hydrogenation

Distillation

Isoctane Co-Product 5-10%

Gevo Bio-Jet
Hydrocarbon demonstration facility

- Jet production started up Dec 2011
- Delivered ~30,000 gallons of isobutanol-derived jet fuel to the Air Force, Army and Navy
- PX Demo startup Oct 2013
- Nameplate capacity 8,000 gal/month isobutanol feedstock.
- Isooctane and other renewable hydrocarbons produced as byproduct of jet process have been sampled and sold to customers.

Major Products

- Jet Fuel Blendstock
- Para-xylene (for PET)
Gevo ATJ Fuel Makes History in USAF Flight

“It flew like a usual A-10 without any issues.”

Maj. Olivia Elliott
A-10 pilot

“You won’t be able to determine the difference and you won’t care, because all perform as JP-8.”

Jeff Braun
Chief for the Air Force Alternative Fuel Certification Division
US Army flew a Sikorsky UH-60 Black Hawk helicopter on a 50/50 blend of Gevo ATJ.

“This test is the final milestone test leading to certification of the Black Hawk for use with ATJ fuel blends. ATJ is a renewable, drop in alternative fuel for JP8 that addresses the Army Energy Security Strategy and Plans mandate that the Army certify 100% of its air platforms on alternative/renewable fuels by 2016.”

The Significant Activity Report from the U.S. Army