Fermentative Isobutanol Production from Woody Biomass and Conversion to IPK

Andrew C. Hawkins, Ph.D.
Glenn Johnston
Joseph Ley

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Company Overview

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

Luverne Isobutanol/Ethanol Plant
Why iBuOH? Low-Cost Renewables!

Feedstock

Proprietary Technology
Proven at commercial scale

Yeast Biocatalyst

GI FT® Separator

Commercial Markets
Price and performance attributes driving demand

Direct “drop-in"

Derivatives

Sugars
Isobutanol

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. Secure ASTM Certification of Alcohol-to-Jet process
**Yeast biocatalyst**

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<th>Sugars</th>
<th>iBuOH</th>
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**Commentary**

- Synthetic microbiology to modify existing commercial ethanol (EtOH) yeast to produce isobutanol (iBuOH)

- **Engineered 19 fundamental pathways to create multiple classes of iBuOH producing yeast**

- Library of >19,000 iBuOH producing strains in several classes of yeast (FRED, THOR, CB-1)

- Operate in million liter fermenters

- Meets commercial iBuOH production requirements

- Biocatalysts are engineered for “structural cross breeding” to speed pathway development

- Capable of using multiple carbohydrate feedstock (starch, sucrose, cellulosic)

- **Took 8+ years and 50+ people to re-program yeast!!!**
Adaptation of Biocatalysts to NARA Hydrolyzates

Direct selection (agar plates)

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

Serial transfer

Biomass concentrations
• NARA leverages Gevo fermentation technology developed and proven
• GIFT® is a patented, continual iBuOH removal and recovery system for fermentation
Benefit of GIFT® with Isobutanol

- 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.

Producing iBuOH From Woody-Biomass Sugars

NARA
Northwest Advanced Renewables Alliance

START
1kl PK 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
- **Enzymatic Saccharification**: use commercial enzymes from Novozymes
- **Isobutanol Production**: via fermentation using Gevo patented organisms and fermentation process
- **Jet Fuel Conversion**: via Gevo process
Developed Hydrolysis & iBuOH Fermentation Process from Woody Biomass in Lab, then Scale

Fermentation

Hydrolysis

GIFT®

Vacuum controller
GIFT® Preheater controller
GIFT® reboiler controller
2LDasGip Fermenter
GIFT® flash column
GIFT® condensate trap/liquid-liquid separation
GIFT® recirculation pump
GIFT® Preheater controller
GIFT® reboiler controller

GI FT®
Recovery of iBuOH

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Locations Contributing to 1,000 gallons IPK

- Cosmo, Cosmopolis, WA
- Muckleshoot, Auburn, WA
- Salish Kootenai, Lone Pine, MT
- Zeachem, Boardman, OR
- Lane Forest Prod, Junction City, OR
- WY, Creswell, OR
- Gevo, Englewood, CO
- Yeast Vendor, Milwaukee, WI
- ICM, St. Joseph, MO
- SHR, Silsbee, TX
Producing Renewable Biojet from iBuOH and Why Biojet Fuel?
Gevo ATJ technology benefits:

- **Replaces petroleum C with renewable C!**
- **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** - 5 yrs of testing working across the supply chain.
IBA to Hydrocarbons: Simple, Economic Process

Technology overview

- Proprietary processing based on standard unit operations leads to high yields, with minimum of coproducts.
- Gevo has been producing jet fuel and isooctane since 2011 and PX since 2013 at Silsbee, TX demo plant (~10,000 gal/mo input basis).
- Simple product mix of isooctane and jet.
- Isooctene has been converted to paraxylene (PX) and hydrogen.
- Processes work well. Ready for commercial engineering and deployment.

Process Flow

[Diagram showing the process flow from isobutanol to isooctane and jet, including dehydration, oligomerization, hydrogenation, and distillation steps.]
ASTM Specification Done! Process Protects YOU!

**Tier 1**
- Specification Properties

**Tier 2**
- Fit-For-Purpose Properties
- Phase 1 ASTM Research Report

**Tier 3**
- Component/Rig Testing

**Tier 4**
- Engine/APU Testing
- Phase 2 ASTM Research Report

- OEM Review & Tier 3 & 4 Requirements

- FAA Review

- ASTM Specification
- ASTM Balloting Process
- ASTM Review & Ballot
  - Accept
  - Re-Eval As Required
  - Reject
  - ASTM Specification Done!
Gevo ATJ is technologically ready
Pathway has been vetted through the ASTM process
Gevo biojet believed to be the most scalable with lowest CapEx and OpEx
Remaining challenge: **FUND AND BUILD A FACTORY**

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<tbody>
<tr>
<td>Freezing Point (ASTM D2386)</td>
<td>-40°C max Jet A -47°C max Jet A-1</td>
<td>-50°C</td>
<td>-80°C</td>
</tr>
<tr>
<td>Flash Point (ASTM D3828)</td>
<td>38°C min</td>
<td>48°C</td>
<td>48°C</td>
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<tr>
<td>Energy Density (Net Heat of Combustion) (ASTM D3338)</td>
<td>42.8 MJ/kg min</td>
<td>43.1 MJ/kg</td>
<td>43.2 MJ/kg</td>
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<tr>
<td>Thermal Oxidation Stability (JFTOT) (ASTM D3241)</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
</tr>
<tr>
<td>Total Sulfur Content (ASTM D2622)</td>
<td>0.3% max</td>
<td>0.05%</td>
<td>&lt;0.01%</td>
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Thank you!
GHG’s from Airlines Coming Into the “Gunsights”

According to NYT, 2% of global GHGs are due to airline industry

Jets Will No Longer Get a Free Ride on Carbon Emissions

U.N. Agency Proposes Limits on Airlines’ Carbon Emissions

By JAD MOUAWAD and CORAL DAVENPORT  FEB. 8, 2016

After more than six years of negotiations, the global aviation industry agreed on Monday to the first binding limits on carbon dioxide emissions, tackling the fastest-growing source of greenhouse gas pollution.

The deal is the latest in a series of international efforts to address climate change. Until now, airplanes had not been included in any international climate change deals, like the recent Paris Agreement, or the Montreal Protocol, expected to be completed later this year.

The proposed new rules, announced in Montreal by the International Civil Aviation Organization, the United Nations’ aviation agency, would apply for all new airplanes delivered after 2028.

Airlines account for about 2 percent of global emissions — about the same as Germany. But many analysts think the emissions could triple by the middle of the century given the expected growth in air travel over the next decades.

It took little time, though, for the announcement to set off a debate over how effective the proposed rules would be.

Some environmental groups, pointing to the airline industry’s close involvement in crafting the deal, said the proposed rules were too weak and failed to include aircraft currently in use.

But advocates of the deal, including the Obama administration, praised it,
New IATA Passenger Forecast Reveals Fast-Growing Markets of the Future

Geneva – the International Air Transport Association (IATA) released its first 20-year passenger growth forecast, projecting that passenger numbers are expected to reach 7.3 billion by 2034. That represents a 4.1% average annual growth in demand for air connectivity that will result in more than a doubling of the 3.3 billion passengers expected to travel this year.
Environmental Goals of ICAO

- Carbon-neutral growth of aviation by 2020, compared to 2005 levels.

Global Market-Based Measure (GMBM)

- Offsetting through purchase of emissions units that certify emission reductions in other locations or sectors.
- Scope: International flights & CO2 only.
  - Lower Emissions from alternative fuels
  - Methodology of alternative jet fuels in GMBM - CAEP mtg Feb 2016

Technological improvements can’t close this gap, therefore, alternative fuels will be required.
Jet Fuel from IBA Included in Commercial Specification

Gevo ATJ is one of three alternative jet fuel products included in spec, and believed to be the most scalable with lowest CapEx and OpEx.