IH²® Technology: Journey to Commercialization

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Agenda Points

• Shell Commitment
• What is IH²® Technology?
• Product Quality
• Life Cycle Analysis
• Demo Progress
• Certification & Approvals Process
Shell New Energies

Future of Transport
A range of factors are changing the transport sector...

- Increasing demand for energy and transport
- Climate change and air pollution
- New technologies available
- New transport policies

New Energies
Exploring new opportunities

- Winning company in the energy transition
- Established credentials: exploring options

New Fuels


- GTL
  Pioneering Gas to Liquid (GTL) technology

- Biofuels
  Conventional & advanced biofuels

- Hydrogen
  Active in hydrogen electric

- Electricity
  Exploring a role in the charging of EVs

New fuels
- Cleaner transportation
- Biofuels + hydrogen

Integrated energy solutions
- NL & USA wind
- Solar for enhanced oil recovery in Oman

Connected customer
- Connected mobility
- Connected energy
What is IH²® Technology?

Feedstock agnostic
Flexible process, integrate with refinery, pulp mill, etc
Continuous catalytic thermochemical process
Produces hydrocarbon transportation fuels
Gasoline, Jet and Diesel
IH²® technology takes only minutes to achieve what Nature requires millions of years to

But it does her one better by providing refined fuel
At 100,000 Feet…

Biomass/Waste → H₂

Exports
Biogenic CO₂
High Pressure Steam
BioChar
Hydrocarbon Fuel
NH₃ Fertilizer Concentrate
S Fertilizer

Solid Fuel Sales, Heat, Power

Gasoline
Jet
Diesel

BioChar
Product Quality

High quality hydrocarbon transportation fuels
Gasoline, Jet and Diesel
Meet ASTM Road Transport Specs
Meet Jet A/A-1 Specs
‘Drop In’ Replacement Fuels

US - Gasoline
• Meets ASTM D4814-16d
• 86/87 Octane w/ E15
• S < 10-ppm
• Fully renewable (CA)RBOB

EU – Petrol
• EN 228: Petrol – Jan 2009
• RON 87 vs 95
• S ~10-ppm
• Blend Stock

World-wide Civil Jet Fuel Grade
• Meets Jet A/A-1 Specs
• S < 2-ppm
• Freezing Point BDL
• No napthenanes
• Low aromatics – CPK
• Ability to allow aromatics

US - Diesel
• Meets ASTM D975-15c
• Cetane Number 44
• S < 10-ppm

EU Diesel
• EN 590:2009+A1:2010
• Cetane Number 48
• S <15-ppm
• Blend Stock
A Picture is Worth…
Life Cycle Analysis

In all cases GHG reduction >60%
Can be as high as 86.4% processing MSW
Demo Progress

- Invention by GTI in 2009
- Joint development proceeding with CRI since 2010
- ~7000 hours pilot testing since 2012
- Scaled up particle sizes from multi micron to multi mm
- Scaled up process from mL/d to 20L/d
- 5 tonne MAF feedstock/day scale (2000L/d)
- On target for commissioning end Q1 2017
- Demonstrates critical process elements
- All equipment commercially proven

10/31/2016
IH²-5000 Demo location Shell Bangalore
IH²-5000 current high level timeline

- **FEED**
  - Detailed Eng.
  - Site prep & construction

- **Vendor packages**
  - Main process unit (ZETON)
  - HMU (Hydro-Chem)
  - H₂ Compressor
  - Vent stack
  - Feed handling

**Timeline**
- **BOP**
  - 2016
    - January
      - FEED
    - February
      - Detailed Eng.
    - March
      - Site prep & construction

- **Vendor packages**
  - 2017
    - January
      - Commissioning
IH²-5000 Zeton Skid (10/19/2016)
Fuels Certification & Registration

2014-2016  500 gallons of TLP produced at GTI on IH2-50 pilot

1H17  EPA engine screening tests Light & Heavy Duty @ SwRI; Initial jet fuel screening
3Q17+  IH2-5000 demo TLP production
4Q17  Light & Heavy Duty EPA Testing @ SwRI
1H18  Submit SwRI engine test results to EPA
2H18  Large volume jet blend for aircraft testing
2H18+ EPA registration response; Continued jet program

Jet approval under ASTM D7566 (50/50 blend)
Petrol approval under ASTM D4814-16d (E10 blend)
Diesel approval under ASTM D975-15c (neat)

EPA Pathway M (gasoline) and L (jet and diesel)
RINs D3 (gasoline) and D7 (jet and diesel) US market sales
Thank You

Learn more at
http://www.cricatalyst.com/catalysts/renewables.html


Smaller scale gas- and biomass-to-liquids
A commercially available route for airlines to fulfil renewable fuels commitments

VELOCYS
Velocys
The company at the forefront of smaller scale gas-to-liquids (GTL) and biomass-to-liquids (BTL)

- **Leader** in smaller scale GTL and BTL
  - 15 years and >$300 million invested in product development
  - Exhaustive and proven patent protection

- First class **partners** offering a complete solution

- Commercial roll-out underway

- One of the largest dedicated development teams in the industry
  - Commercial center in Houston, Texas; technical centers near Columbus, Ohio and Oxford, UK
  - Permanent pilot plant in Ohio, USA

Construction complete at ENVIA Energy’s GTL plant
The GTL / BTL process using Fischer-Tropsch
For the production of high value products

Reforming

Fischer-Tropsch (FT)

Hydro-processing

Natural gas or landfill gas

Gasification

Syngas (carbon monoxide + hydrogen)

“Syncrude”

Premium fuels & chemicals (diesel, jet fuel, waxes, etc.)

Products are renewable if using landfill gas or biomass as feedstock

Smaller scale GTL/BTL. The FT section of a plant
Construction complete at ENVIA
World’s first commercial renewable FT facility
ENVIA Energy Oklahoma City project - status

Renewable fuel credentials

• Construction complete

• Pre-commissioning substantially complete

• Commissioning underway
  — Ensure each process system in sequence is working robustly, safely & within specification to best assure successful, safe, uneventful start-up

• Renewable feedstock (landfill gas) co-fed with pipeline natural gas

• Portion of fuels produced will generate Renewable Identification Number (RIN) credits
ENVIA Energy Oklahoma City project
Increased involvement for Velocys

• February 2016, Velocys gained
  — Greater equity stake in the project
  — Greater influence in commissioning, start-up
    & operations of the plant

• Highly-skilled Velocys managers, engineers &
  operators on site under secondment agreement
  with ENVIA
  — Considerable experience in GTL plant start-
    up, commissioning and performance
    optimisation
  — From operating commercial large-scale
    GTL plants (and VPP)
  — Serving under ENVIA Plant Manager until
    permanent operations team phased in as
    planned
Red Rock Biofuels
US DoD sponsored BTL

- **16 MMGPY** biomass-to-liquids (BTL) plant
- Located in Oregon, USA
- Will use forestry waste as feedstock
- Licensed plant agreement signed with Velocys
- FEED study complete
- **Southwest Airlines & FedEx** to each offtake 3 million gal/yr of jet fuel from the plant
- Supported by US Department of Defense and US Department of Energy
  - $4.1m phase 1 grant for engineering
  - **$70m construction grant**
- Targeting **final investment decision** in 2016
## Velocys FT jet fuel versus specification

Supporting delivery of drop in jet fuel – ASTM D7566 for neat synthesized paraffinic kerosene (SPK) component

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Units</th>
<th>Velocys FT SPK</th>
<th>Specification</th>
<th>Meets spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity at 15ºC</td>
<td>kg/l</td>
<td>0.76</td>
<td>0.73-0.77</td>
<td>✓</td>
</tr>
<tr>
<td>Flash point</td>
<td>ºC, min</td>
<td>&gt;38</td>
<td>38</td>
<td>✓</td>
</tr>
<tr>
<td>Freeze point</td>
<td>ºC, max</td>
<td>-47</td>
<td>-40 (Jet A)</td>
<td>✓</td>
</tr>
<tr>
<td>Sulphur</td>
<td>% mass, max</td>
<td>&lt;5</td>
<td>15</td>
<td>✓</td>
</tr>
<tr>
<td>Carbon &amp; hydrogen</td>
<td>% mass, min</td>
<td>&gt;99.5</td>
<td>99.5</td>
<td>✓</td>
</tr>
<tr>
<td>Composition</td>
<td>% max, aromatics</td>
<td>0.5</td>
<td>0.5</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>% max, cycloparaffins</td>
<td>&lt;15</td>
<td>15</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>% paraffins</td>
<td>90%</td>
<td>Report</td>
<td>✓</td>
</tr>
<tr>
<td>Metals</td>
<td>ppm</td>
<td>Nil</td>
<td>0.1 ppm each</td>
<td>✓</td>
</tr>
</tbody>
</table>
Fuel specifications met by FT jet fuel

- Meets Jet A and Jet A-1 for synthesized paraffinic kerosene (SPK)
  — Must be blended with conventional jet fuel at a maximum of 50%

- “Drop in” replacement for petroleum derived fuels, lubricants and other products

- FT route to jet fuel from municipal solid waste reduces lifecycle greenhouse gas emissions by ~70%

- Align with airline industries need and desire to tackle CO₂ emissions and sustainability

- United Airways, Cathay Pacific, Southwest Airlines, FedEx all content with the at-wing solution that FT jet fuel can deliver
Renewable Fischer-Tropsch jet fuel projects

- Velocys and partners are developing renewable FT projects
- **Plentiful, low cost biomass** feedstocks available
  - Landfill gas
  - Woody biomass and agricultural residues
  - Municipal and industrial waste
- FT fuel products **meet all required specifications**
- **Velocys** provides **enabling technology, operational expertise** and other key resources to enable industry growth
Thank you

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Think Smaller
Commercialization of Aviation Biofuels

October 26, 2016
Commercial Renewable Aviation Biofuels…Now a Reality

United Airlines is first commercial airline in U.S. to use renewable jet fuel on regular scheduled flights

Fuel provided by AltAir Fuels in first dedicated commercial production of HEFA SPK renewable jet fuel

Honeywell UOP Technology Produces First Commercial Volumes of Aviation Biofuel
Drop-in Renewable Fuels from Honeywell UOP

Plant-derived Oils
Animal Fats & Grease
Used Cooking Oil
Algal Oil

Ecofining™ Process or UOP Renewable Jet Fuel Process

Honeywell Green Diesel™
Honeywell Green Jet Fuel™
(HEFA SPK)

2015 Advanced Bioreconomy Awards
Process of the Year: Honeywell’s UOP Green Fuels Technology
Platts Global Energy Awards
ACS Chemistry for Life®
Heroes of Chemistry Award

Honeywell Green Jet Fuel™
2016 Heroes of Chemistry Award

Proven Technologies for Feedstock Flexible Drop-in Fuels
Progress Producing Renewable Fuels

**Worldwide Capacity for HEFA type Renewable Diesel/Jet**

- HEFA SPK is being commercially produced using Honeywell UOP technology and is in use in regular commercial flights
- Commercial offtake agreements
- Substantial capacity has been installed for HEFA type fuels
  - 3.7% of global biofuels demand
  - 0.2% of global diesel & jet fuel demand
  - Predominantly diesel
  - Additional capacity under design or construction
- Five aviation biofuels currently approved by ASTM International
- Additional aviation biofuels are being tested under ASTM
  - Includes testing by Honeywell of expanded HEFA

Growing supply but more capacity is needed
Expanding Feedstocks for Renewable Diesel/Jet Fuel Production

UOP participation in Feedstock Programs:
- **USDA**
  - Redesigned Oilseed Feedstocks for HEFA SPK

  - Collaborations on developing and testing of new feedstock pathways
    - Algal oils
    - Cellulosic

  - Biofuel Producers, Project Developers, & Feedstock Suppliers:
    - Support for oilseed crop commercialization
    - Approval of new feedstocks

Focus on expanded utilization of sustainable & economic feedstocks
Summary

• There are four types of biofuels produced today in large commercial volumes but only one that is currently approved for aviation fuel
  - Ethanol (not suitable for aviation)
  - FAME Biodiesel (not suitable for aviation)
  - HEFA Renewable Diesel (potentially suitable for aviation)
  - HEFA SPK Renewable Jet (approved for aviation)

• Honeywell UOP technology for producing HEFA SPK has been commercialized and costs of production have been reduced as expected
  - Ground transportation fuels currently offer greater incentives for producers and this must be overcome to expand the supply of renewable aviation fuels (ICAO CORSIA)

• New types of feedstocks will emerge as the demand for HEFA continues to increase
  - Must be economically competitive and sustainable
The Carbon Imperative

**Energy** can be Carbon free
- Wind
- Solar
- Hydro

**Liquid Fuels & Chemicals** must contain

**Efficiency** Recycle C

*Be Carbon Smart!*
From Waste to Wing

Flight will provide fuel performance data to help accelerate ASTM certification of ATJ production pathway.

Dehydration → Oligomerization → Hydrogenation → Fractionation

ATJ-SPK Diesel

Ethanol

Lanzanol
Recycling Gases: Environmental, Economic, Social Benefit

Water Recycle

No Land Biodiversity

Life Cycle GHG Emission

<table>
<thead>
<tr>
<th></th>
<th>Conventional Jet Fuel</th>
<th>LanzaTech ATJ-SPK</th>
</tr>
</thead>
<tbody>
<tr>
<td>gCO₂e/MJ</td>
<td>90</td>
<td>40</td>
</tr>
</tbody>
</table>

Life Cycle Analyses (LCA) for ethanol and jet fuel performed in cooperation with:
Michigan Tech University, Roundtable on Sustainable Biomaterials (RSB), E4Tech, Ecofys and Tsinghua University

50-70% GHG Reduction over Petroleum Jet Fuel

- Provides new revenue stream from waste materials
- Provides energy security from sustainable, regional resources
- Provides affordable options to meet growing demand
- Provides economic development that creates “green jobs”
LanzaTech ATJ Production Status

- 4000 gallons Jet
- 600 gallons Diesel
- Properties of neat fuel and 50% blends meet specifications
Jet Fuel Production Status

- Demonstrated feedstock flexibility
  - 1,500 gal from Lanzanol
  - 2,500 gal from Grain Ethanol

- Technical feasibility established at demo scale

- Lanzanol produced in an RSB-certified facility
  - Shougang-LanzaTech 100,000 gal/yr demonstration plant in China

- Phase 1 Research Report submitted September 2016

Increased Run Time and Production Rate
Improved Product Yield
Reduced Operating Cost

Lower Cost Commercial Product
**ASTM D4054 Qualification for New Aviation Fuels- Fit for Purpose Testing**

**Current Status Sept 2016**

**Tier 1**
- Specification Properties

**Tier 2**
- Fit-For-Purpose Properties

**Tier 3**
- Component/Rig Testing
- ASTM Specification

**Tier 4**
- Engine/APU Testing
- ASTM Balloting Process

**Phase 1 ASTM Research Report**
- OEM Review & Tier 3 & 4 Requirements

**Phase 2 ASTM Research Report**
- OEM Review & Approval
- FAA Review

**FFP Property Testing – Conformance with Conventional Fuels**
- ✓ Hydrocarbon #, Type, Distribution
- ✓ Trace Components
- ✓ Bulk Physical, Thermodynamics, Solubility
- ✓ Electrical Properties
- ✓ Ground Handling And Safety
- ✓ Compatibility With Fuels/Additives s, elastomers

**Component And Engine Testing To Ensure No Anomalies**
- ✓ Turbine Hot Section
- ✓ Fuel System, Combustor Rig
- ✓ Engine Test At OEM
- ✓ Compatibility with Aircraft Parts
- ✓ Test Flight

All Future Testing per Guidance from the OEM’s

Courtesy Mark Rumizen

Sept 22, 2016
Hydrocarbon Class of Lanzatech Jet Fuel Neat and Blended

### Neat fuel

<table>
<thead>
<tr>
<th>Carbon number</th>
<th>Iso-paraffins by GCxGC, mass%</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
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<tr>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
</tr>
</tbody>
</table>

### Blended fuel

- n-paraffins
- iso-paraffins
- aromatics
- cycloparaffins

### Table: D2425 (mass %)

<table>
<thead>
<tr>
<th>Component</th>
<th>Spec</th>
<th>D7566 SPK</th>
<th>Neat ATJ Fuel Lab</th>
<th>GRE ATJ</th>
<th>LZ ATJ Demo</th>
<th>Typical Jet A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffins (normal + iso)</td>
<td>96</td>
<td>97</td>
<td>97</td>
<td>97</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Cycloparaffins</td>
<td>≤15</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Alkylbenzenes</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Indans and Tetralins</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Indenes and C_{n}H_{2n-10}</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Naphthalene</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Naphthalenenes</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>2</td>
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<tr>
<td>Acenaphthenes</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>0.2</td>
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</tr>
<tr>
<td>Acenaphthylenes</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td></td>
</tr>
<tr>
<td>Tricyclic Aromatics</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td></td>
</tr>
<tr>
<td>Total Aromatics</td>
<td>≤0.5</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

**Sept 22, 2016**
### ASTM 7566 Table A5.1 Detailed Batch Requirements for Alcohol to Jet (ATJ-SPK)

<table>
<thead>
<tr>
<th>Property</th>
<th>Limit</th>
<th>ATJ-SPK spec</th>
<th>ATJ Lab</th>
<th>GRE ATJ Demo</th>
<th>LZ ATJ Demo</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity, KOH mg/g</td>
<td>Max</td>
<td>0.015</td>
<td>0.008</td>
<td>0.001</td>
<td>0.001</td>
<td>D3242</td>
</tr>
<tr>
<td>Distillation Temp, °C</td>
<td>Max</td>
<td>205</td>
<td>172</td>
<td>168</td>
<td>162</td>
<td>D86</td>
</tr>
<tr>
<td>10% recovery, Temp (T10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% recovery, Temp (T50)</td>
<td>None</td>
<td>Report</td>
<td>197</td>
<td>185</td>
<td>185</td>
<td>D86</td>
</tr>
<tr>
<td>90% recovery, Temp (T90)</td>
<td>None</td>
<td>Report</td>
<td>239</td>
<td>221</td>
<td>217</td>
<td>D86</td>
</tr>
<tr>
<td>Final boiling point, Temp</td>
<td>Max</td>
<td>300</td>
<td>260</td>
<td>257</td>
<td>240</td>
<td>D86</td>
</tr>
<tr>
<td>T90-T10, °C</td>
<td>Min</td>
<td>21</td>
<td>67</td>
<td>53</td>
<td>55</td>
<td>D86</td>
</tr>
<tr>
<td>Distillation Residue, %</td>
<td>Max</td>
<td>1.5</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>D86</td>
</tr>
<tr>
<td>Distillation Loss, %</td>
<td>Max</td>
<td>1.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>D86</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>Min</td>
<td>38</td>
<td>44</td>
<td>42</td>
<td>40</td>
<td>D56</td>
</tr>
<tr>
<td>Density @ 15 °C, kg/m³</td>
<td>Range</td>
<td>730-770</td>
<td>761</td>
<td>763</td>
<td>759</td>
<td>D4052</td>
</tr>
<tr>
<td>Freezing Point, °C</td>
<td>Max</td>
<td>-40</td>
<td>&lt;75</td>
<td>-61</td>
<td>-56.5</td>
<td>D2386</td>
</tr>
<tr>
<td>Thermal Stability Temperature, °C</td>
<td></td>
<td>325</td>
<td>&gt;340</td>
<td>&gt;340</td>
<td>&gt;340</td>
<td>D3241</td>
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<tr>
<td>Filter pressure, mm Hg Tube Rating</td>
<td>Min</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less than</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Both Grain ethanol (GRE) and Lanzanol (LZ) Neat Fuel meet ATJ-SPK specifications
### D7566 Table A5.2 Other Detailed Requirements; Alcohol to Jet (ATJ-SPK)

<table>
<thead>
<tr>
<th>Property</th>
<th>Limit</th>
<th>ATJ-SPK spec</th>
<th>ATJ Lab</th>
<th>GRE ATJ Demo</th>
<th>LZ ATJ Demo</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydrocarbon Composition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycloparaffins, mass%</td>
<td>Max</td>
<td>15</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>D2425 ✓</td>
</tr>
<tr>
<td>Aromatics, mass%</td>
<td>Max</td>
<td>0.5</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>D2425 ✓</td>
</tr>
<tr>
<td>Paraffins, mass%</td>
<td>None</td>
<td>Report</td>
<td>96</td>
<td>97</td>
<td>97</td>
<td>D2425 ✓</td>
</tr>
<tr>
<td>Carbon &amp; Hydrogen mass%</td>
<td>Min</td>
<td>99.5</td>
<td>99.5</td>
<td>99.5</td>
<td>99.5</td>
<td>D5291 ✓</td>
</tr>
<tr>
<td><strong>Non-hydrocarbon Composition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen, mg/Kg</td>
<td>Max</td>
<td>2</td>
<td>0.3</td>
<td>&lt;0.1</td>
<td>&lt;0.3</td>
<td>D4629 ✓</td>
</tr>
<tr>
<td>Sulfur, mg/kg</td>
<td>Max</td>
<td>15</td>
<td>&lt;1.0</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>D5453 ✓</td>
</tr>
<tr>
<td>Water, mg/kg</td>
<td>Max</td>
<td>75</td>
<td>55</td>
<td>63</td>
<td>20</td>
<td>D6304 ✓</td>
</tr>
<tr>
<td>Metals( Al, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Sn, Sr, Ti, V, Zn), mg/kg</td>
<td>Max</td>
<td>0.1 per metal</td>
<td>&lt;0.1 per metal</td>
<td>&lt;0.1 per metal</td>
<td>&lt;0.1 per metal</td>
<td>D7111 ✓</td>
</tr>
<tr>
<td>Halogens, mg/kg</td>
<td>Max</td>
<td>1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>D7359 ✓</td>
</tr>
</tbody>
</table>

Both Grain ethanol (GRE) and Lanzanol (LZ) Neat Fuel meet ATJ-SPK specifications

Sept 22, 2016
### ASTM 7566 Table 1 Detailed Requirements of Aviation Fuel Containing SPK(50% ATJ/50% Jet A)

<table>
<thead>
<tr>
<th>Property</th>
<th>Limit</th>
<th>Jet A/A-1 spec</th>
<th>50% ATJ Lab /50%Jet A</th>
<th>50%GRE Demo /50% Jet A</th>
<th>50%LZ Demo /50% Jet A</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity, KOH mg/g</td>
<td>Max</td>
<td>0.1</td>
<td>0.008</td>
<td>0.002</td>
<td>0.002</td>
<td>D3242</td>
</tr>
<tr>
<td>Aromatics, vol%</td>
<td>Max</td>
<td>25</td>
<td>8.7</td>
<td>8.8</td>
<td>8.6</td>
<td>D1319, D6379</td>
</tr>
<tr>
<td>Sulfur, mercaptan mass%</td>
<td>Max</td>
<td>0.003</td>
<td>0.000</td>
<td>0.001</td>
<td>0.001</td>
<td>D3227</td>
</tr>
<tr>
<td>Sulfur, total mass%</td>
<td>Max</td>
<td>0.30</td>
<td>0.021</td>
<td>0.027</td>
<td>0.027</td>
<td>D5453, D2622</td>
</tr>
<tr>
<td>Distillation Temp, °C 10%, Temp (T10)</td>
<td>Max</td>
<td>205</td>
<td>173</td>
<td>177</td>
<td>173</td>
<td>D86</td>
</tr>
<tr>
<td>50 %, Temp(T50) °C</td>
<td>None</td>
<td>Report</td>
<td>201</td>
<td>204</td>
<td>203</td>
<td>D86</td>
</tr>
<tr>
<td>90 %, Temp(T90) °C</td>
<td>None</td>
<td>Report</td>
<td>243</td>
<td>244</td>
<td>241</td>
<td>D86</td>
</tr>
<tr>
<td>Final boiling point, °C</td>
<td>Max</td>
<td>300</td>
<td>265</td>
<td>270</td>
<td>264</td>
<td>D86</td>
</tr>
<tr>
<td>Distillation Residue,%</td>
<td>Max</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>1.2</td>
<td>D86</td>
</tr>
<tr>
<td>Distillation Loss, %</td>
<td>Max</td>
<td>1.5</td>
<td>1.0</td>
<td>0.3</td>
<td>0.1</td>
<td>D86</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>Min</td>
<td>38</td>
<td>44</td>
<td>45</td>
<td>42</td>
<td>D56</td>
</tr>
<tr>
<td>Density @ 15 °C, kg/m³</td>
<td>Range</td>
<td>775-840</td>
<td>782</td>
<td>782</td>
<td>787</td>
<td>D4052</td>
</tr>
<tr>
<td>Viscosity@-20 °C mm²/sec</td>
<td>Max</td>
<td>8.0</td>
<td>4.4</td>
<td>4.7</td>
<td>4.5</td>
<td>D445</td>
</tr>
<tr>
<td>Net Heat of Combustion, MJ/kg</td>
<td>Min</td>
<td>42.8</td>
<td>43.3</td>
<td>43.8</td>
<td>43.6</td>
<td>D4809</td>
</tr>
</tbody>
</table>

**Both Grain ethanol (GRE) and Lanzanol (LZ) Blended with 50% Jet A meet D7566 specifications**

Sept 22, 2016
### ASTM 7566 Table 1 Detailed Requirements of Aviation Fuel Containing SPK (50% ATJ SPK/50% Jet A)

<table>
<thead>
<tr>
<th>Property</th>
<th>Limit</th>
<th>Jet A/A-1 spec</th>
<th>50% ATJ Lab /50% Jet A</th>
<th>50% GRE Demo /50% Jet A</th>
<th>50% LZ Demo /50% Jet A</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoke Point, mm</td>
<td>Min</td>
<td>25.0</td>
<td>31.4</td>
<td>29.1</td>
<td>29.1</td>
<td>D1322</td>
</tr>
<tr>
<td>Copper Strip, 2h 100°C</td>
<td>Max</td>
<td>No 1</td>
<td>1a</td>
<td>1a</td>
<td>1a</td>
<td>D130</td>
</tr>
<tr>
<td>Thermal Stability Temperature, °C</td>
<td>Min</td>
<td>260</td>
<td>&gt;325</td>
<td>&gt;325</td>
<td>&gt;325</td>
<td>D3241</td>
</tr>
<tr>
<td>Filter pressure, mm Hg</td>
<td>Max</td>
<td>25</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Tube Rating</td>
<td>Less than</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Existent Gum, mg/100ml</td>
<td>Max</td>
<td>7</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>D381</td>
</tr>
<tr>
<td>Microseparometer Rating W/O additive</td>
<td>Min</td>
<td>85</td>
<td>99</td>
<td>100</td>
<td>97</td>
<td>D3948</td>
</tr>
</tbody>
</table>

### ASTM 7566 Table 1 Part 2 Extended Requirements of Aviation Fuel Containing SPK (50% ATJ /50% Jet A)

<table>
<thead>
<tr>
<th>Property</th>
<th>Limit</th>
<th>Jet A/A-1 spec</th>
<th>50% ATJ Lab /50% Jet A</th>
<th>50% GRE Demo /50% Jet A</th>
<th>50% LZ Demo /50% Jet A</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aromatics, vol%</td>
<td>Min</td>
<td>8, 8.4</td>
<td>8.7</td>
<td>8.8</td>
<td>8.6</td>
<td>D1319, D6379</td>
</tr>
<tr>
<td>Distillation T50-10, °C</td>
<td>Min</td>
<td>15</td>
<td>28</td>
<td>27</td>
<td>30</td>
<td>D86</td>
</tr>
<tr>
<td>Distillation T90-10, °C</td>
<td>Min</td>
<td>40</td>
<td>70</td>
<td>67</td>
<td>68</td>
<td>D86</td>
</tr>
<tr>
<td>Lubricity, mm</td>
<td>Max</td>
<td>0.85</td>
<td>0.59</td>
<td>0.70</td>
<td>0.70</td>
<td>D5001</td>
</tr>
<tr>
<td>Viscosity@-40 °C mm²/sec</td>
<td>Max</td>
<td>12</td>
<td>9.1</td>
<td>9.9</td>
<td>9.3</td>
<td>D445</td>
</tr>
</tbody>
</table>

Both Grain ethanol (GRE) and Lanzanol (LZ) Blended with 50% Jet A meet D7566 specifications.
Demonstration Fuel  Next Steps

- On-going OEM data analysis and review to determine required Tier 3 & 4 components
  - Engine, materials compatibility, and flight demonstration data for inclusion in Phase 2 Report
- Completion of OEM review process and balloting to the ASTM membership for eventual incorporation into D7566 specification for drop-in jet fuel

Goal: Add ethanol to isobutanol as an approved ATJ feedstock in D7566 Annex 5
CAAFI Biennial General Meeting
Washington, D.C.
Oct 26th, 2016
Forward-Looking Statements

Certain statements within this presentation may constitute “forward-looking statements” within the meaning of the Private Securities Litigation Reform Act of 1995. Such statements relate to a variety of matters, including but not limited to: the timing and costs associated with and the availability of capital for Gevo’s scheduled retrofits of existing ethanol production facilities, its future isobutanol production capacity, the timing associated with bringing such capacity online, the availability of additional production volumes to seed additional market opportunities, the expected applications of isobutanol, including its use to produce renewable paraxylene, PET, isobutanol-based fuel blends for use in small engines, and ATJ bio-jet, production costs and sensitivities, capital costs and sensitivities, tax credits and RIN pricing and availability, addressable markets, and market demand, Gevo’s ability to produce commercial quantities of isobutanol from cellulosic feedstocks, the suitability of Gevo’s iDGs™ for the animal feed market, the expected cost-competitiveness and relative performance attributes of isobutanol and the products derived from it, the strength of Gevo’s intellectual property position and other statements that are not purely statements of historical fact. These forward-looking statements are made on the basis of the current beliefs, expectations and assumptions of Gevo’s management and are subject to significant risks and uncertainty. All such forward-looking statements speak only as of the date they are made, and Gevo assumes no obligation to update or revise these statements, whether as a result of new information, future events or otherwise. Although Gevo believes that the expectations reflected in these forward-looking statements are reasonable, these statements involve many risks and uncertainties that may cause actual results to differ materially from what may be expressed or implied in these forward-looking statements. For a discussion of the risks and uncertainties that could cause actual results to differ from those expressed in these forward-looking statements, as well as risks relating to the business of the company in general, see the risk disclosures in Gevo’s Annual Report on Form 10-K for the year ended December 31, 2014, and in subsequent reports on Forms 10-Q and 8-K and other filings made with the Securities and Exchange Commission by Gevo.

This presentation has been prepared solely for informational purposes and is neither an offer to purchase nor a solicitation of an offer to sell securities.
Gevo integrated fermentation technology (GIFT®)

Alcohol to Jet (ATJ)
How We Produce Isobutanol (GIFT®)

START: Feedstock

Fresh & Recycled Water

Jet Cooker

Steam

Enzymes

Fermentation

CO₂

Beer

Thin Stillage

Evaporation System

Syrup

Wet Grain

Drum Dryer

Animal Feed

Finished Product

Molecular Sieves

Isobutanol Recovery

Isobutanol

Water

Syrup

Animal Feed

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Proprietary processing based on standard unit operations leads to high yields, with minimum of co-products.

Gevo has been producing jet fuel and isoctane since 2011.

Simple product mix of isoctane and jet, yields at 98% of theoretical.
ASTM D7566 Annex 5

Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

This standard is intended to be used as a standard in describing the quality of aviation turbine fuels and synthetic blending components at the place of manufacture but can be used to describe the quality of aviation turbine fuels for contractual transfer at all points in the distribution system.

1. Scope

This specification covers the manufacture of aviation turbine fuel that contains conventional and synthetic blending components.

2. Referenced Documents

2.1 ANSI/ASTM Standards.

2.2 Gevo Test Method for Flash Point by Tag Closed Cup Toner

3. Summary of Changes since approval of this standard

A summary of changes is given at the end of this standard.
NARA – Northwest Advanced Renewables Alliance (Gevo is the technology supplier for fermentation and Renewable Jet) has been conducting a demonstration project to convert wood waste to jet fuel.
Sustainability – Short Term Carbon Cycle

**Carbon Cycle**

- **Long-term unbalanced cycle**
  - $\text{CO}_2$

- **Short-term balanced cycle**
  - $\text{CO}_2$
  - Months

- **Biofuel**
  - Millions of years and geological processes needed

- **Fossil Fuel**

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The large size of the jet fuel market means large scale feedstocks are important. Carbohydrates are significantly more abundant and cost less to obtain than other feedstocks used.

---

**Feedstock Availability (000’s MT)**

- Carbohydrates: 756,354
- Vegetable Oils: 147
- Rendered Fats: 9

**Feedstock Cost per Ton ($/MT)**

- Carbohydrate: $283
- Vegetable Oil: $1,154
- Rendered Fats: $1,199

*Based on updated Nexant Models and engineering projections. Assumed $3.60/bu corn, average tallow/grease price from NRA market report.

Source: 2010/2011 USDA Foreign Agriculture Service (FAS), NRA 2015
Building Out Luverne

- Strategy: Leverage installed assets at Luverne and adding the capability to produce 7-10 MGPY of hydrocarbons.
- Luverne is a proving ground for products and supply chain development.
- Currently completing FEL2 (Front-end loading) engineering for construction which includes robust planning and design.

Potential Buildout Overview

- 13 MGPY Hydrocarbon Production ~10 MGPY
- 8 MGPY Jet Fuel
- 2 MGPY Isooctane
- Not publicly announced yet

Isobutanol Production ~14-16 MGPY

~1-3 MGYP IBA

~65-70 kt Animal feed

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Building Out – Plant 2 and beyond

- Link term sheets of Luverne build-out to commercial build-out
- Those participating at Luverne will be advantaged for future volumes

Commercial Buildout Overview (Beyond Luverne)

- Isobutanol Production 48 MGPY
- Hydrocarbon Production ~30 MGPY
  - 24 MGPY Jet Fuel
  - 6 MGPY Isooctane
- Animal feed ~223 kt
- IBA ~10 MGPY
Thank you

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Email - gjohnston@gevo.com