Alternative Jet Fuel Supply Chain Analysis

Regional Supply Chain Approaches

Supply Chain for Sustainable Aviation
Fuel from Oilseeds in the Inland Northwest

Project Manager: Nathan Brown, FAA
Lead Investigators: M. Wolcott, K. Brandt, N. Martinkus
Graduate Student: Dane Camenzind, WSU

[December 4, 2018]

Opinions, findings, conclusions and recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ASCENT sponsor organizations.
SUPPLY CHAIN MODEL

ENTRY NODES

PROCESSING & STORAGE NODES

EXIT NODES
NORTH AMERICAN
BRASSICA OILSEEDS

2016 Crops
Compatible Small Grain Rotations
Brassica Crops

USDA NASS, Cropland Data Layer
Agriculture and Agri-Food Canada, Annual Crop Inventory
COMMON CROPS

SMALL GRAINS
- Winter Wheat
- Spring Wheat
- Barley

PULSES
- Peas
- Lentils
- Garbanzo Beans

BRASSICA OILSEEDS
- Canola/Rapeseed
- Mustard
- Camelina
- Carinata
AGROECOLOGICAL CLASSES

GRAIN FALLOW
• >40% fallow

Rotations:
• WW-F
• WW-F-WC-F

TRANSITION
• 10-40% fallow

Rotations:
• WW-SW-F
• WC-SW-F
• WW-SC-F

ANNUAL CROP
• <10% fallow

Rotations
• WW-SW-Pulse
• WW-Pulse
• WW-SW-SC
FATS, OILS, & GREASES

<table>
<thead>
<tr>
<th>Type</th>
<th>Annual Production (Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used Cooking Oil</td>
<td>33,000</td>
</tr>
<tr>
<td>Beef Tallow</td>
<td>86,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>119,000</strong></td>
</tr>
</tbody>
</table>
### FEEDSTOCK PRODUCTION SCENARIOS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Feedstock</th>
<th>Plant Oil</th>
<th>FOGs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Production</strong></td>
<td>807,600</td>
<td>687,750</td>
<td>119,850</td>
</tr>
<tr>
<td><strong>50% Production</strong></td>
<td>463,725</td>
<td>343,875</td>
<td>119,850</td>
</tr>
</tbody>
</table>
The Pacific Northwest is known for its “territorial” storage structure. Unlike other parts of the United States, storage is controlled by many companies, each functioning in a relatively small and homogeneous area. Especially farmer-owned cooperatives control a large portion of the region's country elevators, shuttle elevators, and barge terminals.
# Crusher Techno Economic Analysis

<table>
<thead>
<tr>
<th>Type</th>
<th>Annual Capacity (ton/day)</th>
<th>Capital Cost ($/yr)</th>
<th>Electricity (kWh/ton)</th>
<th>Natural Gas (MMbtu/ton)</th>
<th>Other OPEX ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>1,500</td>
<td>31,900,000</td>
<td>126.1</td>
<td>0.1871</td>
<td>5.258</td>
</tr>
<tr>
<td>Mechanical</td>
<td>1,000</td>
<td>35,950,000</td>
<td>90.06</td>
<td>0.1897</td>
<td>10.16</td>
</tr>
</tbody>
</table>
OILSEEDS (HARVEST)

IMPORTED OILSEEDS

OILSEED CRUSHER

OILSEED STORAGE

FATS, OILS & GREASES

OILSEED MEAL MARKETS

OILSEED MEAL MARKETS

BIODIESEL & GREEN DIESEL

GREEN JET FUEL

BIODIESEL PLANT

HEFA REFINERY
ANACORTES, HOQUIAM
MAXIMUM OILSEED PRODUCTION

LINK TYPE
- Oilseeds at harvest
- Oilseeds post harvest
- Lipid feedstocks
- Oilseed Meal

LINK USE (tons)
- 25k
- 50k
- 200k
- 400k
- 800k

PRODUCTION NODES
- Oilseeds Harvest
- Fats, Oils, & Greases

INTERMEDIATE NODES
- Elevator
- Oilseed Crusher

Elevator Storage Capacity (Tons)
- 10k
- 50k
- 100k
- 250k

EXIT NODES
- HEFA Refinery
- Biodiesel Plant
- Oilseed Meal Market
Regional Supply Chain Analysis for Alternative Jet Fuel Production in the Tropics

Scott Turn
University of Hawaii

James Hileman, FAA Program Manager
Nathan Brown, FAA Program Manager
Dan Williams, FAA Program Manager

December 5, 2018

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Alternative Jet Fuel Supply Chain, Tropical Region Analysis -- Motivation

• The tropics account for 36% of the world’s land mass

• Tropics are home to unique biomass materials, production practices/systems, and temporal availabilities

Adapted from https://commons.wikimedia.org/wiki/File:World_map_indicating_tropics_and_subtropics.png
https://creativecommons.org/licenses/by-sa/3.0/deed.en
Jet Fuel Use in Hawaii, 2015
Commercial Airports and Military (million gallons)

Honolulu, 481.9, 71%
Kauai, 22.8, 3%
Maui, 71, 11%
Kona, 27.6, 4%
Hilo, 2.7, <1%
Military, 73.3, 11%

Total Use in 2015
678.4 M Gallons
Tropical Bioresources and Pathways to AJF

Bioresource Intermediate Products & Conversion Technologies

Blue – Commercial elsewhere
Pink – Commercial in Hawaii
Orange – Under Development

Bioresource
Sugarcane
Fiber Sorghum
Sesbania
Glyricidia
Energy cane
Banagrass
Eucalyptus
Leucaena
Rice Residues
Jatropha
Kamani
Pongamia
Croton megalocarpus

Extraction

Hydrolysis

Fiber

Pretreatment

Urban Solid Waste

Extraction

Oil

Bioprocessing

Gasification & Gas Clean Up

Synthesis Gas

Pyrolysis

Catalytic Hydrothermolysis

Synthesis

Bio-Oil

Fischer Tropsch Synthesis

Hydro-processing

Catalytic Hydrothermolysis

Hydro-processing

Hydro-processing

Synthesized Paraffinic Kerosene

Synthesized Paraffinic Kerosene w/ Aromatics

Hydro-processed Depolymerized Cellulosic Jet

Catalytic Hydrothermolysis

Hydrotreated Esters & Fatty Acids

Sugars

Thermo-processing

Hydro-processing

Hydro-processing

Synthesized Iso-Paraffins

Synthesized Kerosene & Aromatic Kerosene

Sugars

Methanol

Gas

Pyrolysis

Hydro-processing

Synthesized Iso-Paraffins

Synthesized Paraffinic Kerosene

Synthesized Paraffinic Kerosene w/ Aromatics

Hydro-processed Depolymerized Cellulosic Jet

Catalytic Hydrothermolysis

Hydrotreated Esters & Fatty Acids

Waste FOG

Synthesized Iso-Paraffins

Synthesized Paraffinic Kerosene

Synthesized Paraffinic Kerosene w/ Aromatics

Hydro-processed Depolymerized Cellulosic Jet

Catalytic Hydrothermolysis

Hydrotreated Esters & Fatty Acids
Tropical Bioresources and Pathways to AJF

**Bioresource**
- Sugarcane
- Fiber Sorghum
- Sesbania
- Glyricidia
- Energycane
- Banagrass
- Eucalyptus
- Leucaena
- Rice Residues
- Jatropha
- Kamani
- Pongamia
- Croton megalocarpus

**Intermediate Products & Conversion Technologies**

- Extraction
- Bioprocessing
- Hydrolysis
- Hydroprocessing
- Alcohol
- Gasification & Gas Clean Up
- Fischer Tropsch Synthesis
- Pyrolysis
- Catalytic Hydrothermalysis
- Oil
- Urban Solid Waste
- Synthesis Gas
- Bio-Oil
- Catalytic Hydrothermolysis
- Waste FOG

**Conversion Technologies**
- Synthesized Kerosene & Aromatic Kerosene
- Synthesized Iso-Paraffins
- Synthesized Paraffinic Kerosene
- Synthesized Paraffinic Kerosene w/ Aromatics
- Hydroprocessed Depolymerized Cellulosic Jet
- Catalytic Hydrothermolysis
- Hydrotreated Esters & Fatty Acids

**Pathways**
- Blue – Commercial elsewhere
- Pink – Commercial in Hawaii
- Orange – Under Development

**Jet Fuel**

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5
Tropical Bioresources and Pathways to AJF

Bioresource Intermediate Products & Conversion Technologies Alternative Jet Fuel

- Sugarcane
- Fiber Sorghum
- Sesbania
- Glyricidia
- Energycane
- Banaggrass
- Eucalyptus
- Leucaena
- Rice Residues
- Jatropha
- Kamani
- Pongamia
- Croton megalocarpus

Extraction → Sugars → Bioprocessing

Hydrolysis → Fiber → Pretreatment

Urban Solid Waste → Extraction

Waste FOG → Extraction

Bioresource Intermediate Products & Conversion Technologies

Synthesis

Gasification & Gas Clean Up

Thermo-processing

Alcohol

Hydro-processing

Bio-Oil

Pyrolysis

Catalytic Hydrothermalysis

Urban Solid Waste

Synthesis Gas

Fischer Tropsch Synthesis

Hydro-treated Depolymerized Cellulosic Jet

Hydro-processed

Synthesized Paraffinic Kerosene

Synthesized Paraffinic Kerosene w/ Aromatics

Hydro-processing

Synthesized Kerosene & Aromatic Kerosene

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Synthesized Paraffinic Kerosene

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Pyrolysis

Catalytic Hydrothermolysis

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Tropical Bioresources and Pathways to AJF

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Extraction → Sugars → Bioprocessing → Alcohol → Thermo-processing → Hydro-processing

- Synthesized Kerosene & Aromatic Kerosene
- Synthesized Iso-Paraffins
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- Synthesized Paraffinic Kerosene w/ Aromatics

Extraction → Oil → Bioprocessing → Catalytic Hydrothermolysis → Hydro-processing

- Synthesized Paraffinic Kerosene
- Synthesized Paraffinic Kerosene w/ Aromatics
- Hydro-processed Depolymerized Cellulosic Jet
- Catalytic Hydro-thermalysis
- Hydrotreated Esters & Fatty Acids

Extraction → Hydrolysis → Fiber → Bioprocessing → Alcohol → Thermo-processing → Hydro-processing

- Fischer Tropsch Synthesis
- Bio-Oil
- Pyrolysis
- Catalytic Hydrothermolysis
- Hydro-processing

Pretreatment → Fiber → Bioprocessing → Alcohol → Thermo-processing → Hydro-processing

- Synthesis Gas

Hydrolysis → Fiber → Bioprocessing → Alcohol → Thermo-processing → Hydro-processing

- Gasification & Gas Clean Up

Urban Solid Waste → Extraction → Pyrolysis → Catalytic Hydrothermolysis → Hydro-processing

- Waste FOG

Blue – Commercial elsewhere
Pink – Commercial in Hawaii
Orange – Under Development

Alternative Jet Fuel
Tropical Bioresources and Pathways to AJF

Bioresource Intermediates Products & Conversion Technologies

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<tr>
<th>Bioresource</th>
<th>Intermediate Products &amp; Conversion Technologies</th>
<th>Alternative Jet Fuel</th>
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<tbody>
<tr>
<td>Sugarcane</td>
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<td>Pongamia</td>
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<td></td>
</tr>
<tr>
<td>Croton megalocarpus</td>
<td>Bioprocessing</td>
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Synthesized Paraffinic Kerosene

Hydro-treated Esters & Fatty Acids

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Orange – Under Development
Construction enjoys unexpected growth

Industry spending is forecast to achieve a decade high in ’18, but jobs remain static

By Andrew Gomes
agomes@staradvertiser.com

Hawaii’s construction industry should provide a little more oomph to the local economy this year than previously expected, according to a report by economists released Friday.

The analysis by the University of Hawaii Economic Research Organization projects that statewide construction spending will reach a decade high of $9 billion this year.

That figure represents a 7 percent increase over $8.4 billion in 2017 — a gain that UHERO last year didn’t expect would happen.

A year ago, UHERO researchers forecast that Hawaii construction spending would be flat this year. However, the new forecast for industry growth is in part due to a smaller-than-expected gain last year.

Essentially, more spending on construction is getting stretched out over two years; and a leveling off of work remains on the horizon for an industry that is a major driver of the state’s economy.

Spending by contractors building homes, renovating hotels, improving public infrastructure and other work should remain at $9 billion for the next three years, the report forecasts.

“The description is one of relative stability or flatness,” said Carl Bonham, UHERO executive director.

Hawaii’s peak for construction spending adjusted for inflation was $10.6 billion in 2007. If spending reaches $9 billion this year as UHERO forecasts, it would be the most since $10.2 billion in 2008.

Bonham said construction is particularly difficult to forecast because time frames between when permits are issued and
PVT Land Company
Nānākuli, Hawaii
http://www.pvtland.com

• PVT is the only construction & demolition landfill on Oahu
• Current intake 1,775 tons C&D waste per day
• ~50% of intake converted to feedstock, up to 900 tpd
• Waste-in-place also “mined” for additional “feedstock”
• Feedstock: wood, plastic, cloth, paper, and other organics
• Tipping fee $50 per ton, or $54 per ton for LEED certified
Possible Locations of Value Chain Participants

- PVT Land Company
- Campbell Industrial Park
- PVT and CIP
- Island Energy Refinery
- Kalaeloa Airport
- Par Hawaii Refinery
- Joint Base Pearl Harbor-Hickam
- Daniel K. Inouye Airport

Map data ©2017 Google
Construction & Demolition Waste-Based AJF Assessment

- Feedstock characterization
  - Fuel properties, physical properties, temporal variability
- Greenhouse gas implications
- Technoeconomic analysis
- Gasification benchscale testing
Summary

• Tropics provide unique biorenewable resources for AJ F feedstocks

• Modeling tools provide guidance for locating dedicated energy crops on available land to support regional supply development

• Construction & demolition waste stream characterization and supply chain analysis ongoing
University of Hawaii Contributors

Sharon Chan, Taha Elwir, Curtis Daehler, Jinxia Fu, Kyle Marcelino, Trevor Morgan, Richard Ogoshi, Lloyd Paredes, Sabrina Summers, Leia Tashiro, Adel Youkhana

Questions?
Real World Supply Chain Development
Southeastern United States

Lead investigator: Tim Rials
Project manager: Nate Brown

December 5, 2018
Washington, DC

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Supply Chain: Lignocellulosic

Country’s Largest Energy Crop Acreage
- High yielding, native grass, growing on marginal cropland
- Production contracts with >60 farmers, within 50 miles of Vonore, TN
- In production since 2008, yielding 8 tons/acre today
- Over 90% success in first year stand establishment
- Developed and improving innovations in supply chain logistics

Developed & Operate Unique Biomass RD&D Campus
- Integrated research campus for biomass handling, processing, storage, densification, transportation
- 22-acre campus adjacent to demonstration scale biorefinery
- Considerable flexibility in range of energy crops and processing systems
- Driving efficiencies and innovations between farm gate & biorefinery gate
- Extensive technology partnership and scale-up opportunities

World-Class, Demo-Scale Cellulosic Ethanol Biorefinery
- Demonstration-scale plant, Process Development Unit (PDU), and lab facilities located in Vonore, TN
- Started operations January 2010, processing corn cob, stover, and switchgrass
- Designed to develop technology and engineering packages for the construction of commercial facilities
- Collaboration with DuPont Cellulosic Ethanol, serving as HQ for DuPont’s CE business
Additional conversion pathways available for AJF
- HEFA, pyrolysis, Fischer-Tropsch, etc.

Introduces opportunity to broaden feedstock portfolio
- Valuable in meeting diverse landowner goals

ASCENT has enabled initial evaluation of oilseed yield potential
- Camelina, pennycress, carinata, etc.
The Aviation Sustainability Center at the University of Tennessee is pleased to announce a workshop on “Sustainable Aviation In the Southeast: Moving From Strategic to Tactical”. The 1-½ day meeting will be held in Knoxville, TN. The program will gather information on logistical challenges to building a complete and flexible supply chain for the industry. Topics to be addressed include:

- Fuel production technology pathways
- The resource base for biomass and oilseed crops
- Feedstock supply chain limitations and required developments
- Product distribution infrastructure barriers

April 24-25, 2019

The University of Tennessee
Institute of Agriculture
Knoxville, Tennessee
“Real World” East Coast Supply Chain Initiatives

December 5, 2018
CAAFI Biannual General Meeting
Washington D.C.

Richard Altman – CAAFI Executive Director Emeritus,
East Coast State Project lead
East Coast Project Development Approach

Strong State / Regional Teams and Local Leaders

+ Public / Gov’t, Ag. Sector Engagement

+ High value resilient co-products suite + jet fuel

+ Quantified/Maximized Economic and Environmental (Air and Water) Value

Facilitate Supply Chain Development for Processors / End Customers
SPARC – Supply Chain Team

Southeast Partnership for Advanced Renewables from Carinata

- **Project Lead** - UFL (David Wright), NIFA CAP
- **Key Partners** - ARA, Agrisoma, USF, UGA, Auburn, DOT Volpe
- **Objectives**: Enable Maximize Sustainable Development in SE Partner States
- **Innovative Elements** -
  - Implement bottoms up FTOT
  - Engage State support
  - Monetize runoff control gain

Oyster bed water quantity

Red tide threat to water quality
SASSCA – Forest Industry

Southcentral Atlantic State Supply Chain Alliance

- Project Lead - Clemson (Pat Layton), NIFA Mini CAP proposal
- Key Partners - NCSU, UVA, VaTech, Regional Forest Industry
- Objectives: Facilitate sustainable fuel supplies, to east coast, fill slack demand for forest products
- Innovative Elements -
  - Wood supply precision analysis
  - multiple proven process access
  - cellulosic ethanol / lignin co-prod

Growing sawmill waste

Lignin 30% of tree
CCAT– MSW to Fuel in CT

Connecticut Center for Advanced Technology

- Project Lead – CCAT (Tom Maloney), Multiple USDA RD, Business Dev. grants

- Key Partners - multiple processors, CT legacy Waste to power facility MIRA

- Objectives: Facilitate conversion of aging RFD facility from electricity production. Enhance revenue 6 X

- Innovative Elements -
  - Publicly available MSW
  - Refuse Derived fuel facility
  - new action needed within 2 – 5 yrs.
Dairy Waste – A 3rd 24/7 Feedstock

- Project Lead - GSR (Krivov), Todd Campbell (ex-USDA) USDA Rural Dev (RBEG and VAPG)
- Key Partners - UVM, Cornell, Newtrient, Canadian Interests,
- Objectives: Cross border technology scale up, support dairy industry, monetize value.
- Innovative Elements -
  - Strongest co-product potential
  - Organized feedstock industry
  - Environmental NGO support for lake pollution mitigation
TCERDA – Citrus Replacement

Sustainable Fuels Feasibility Study

- Project Lead - TCERDA (Devries)
  USDA RBDG grant

- Key Partner/ Customers - Amyris, Lanzatech, Gevo, Jet Blue, American, Fedex, Tropicana

- Objectives: Energy Crop to replace, Citrus lost to Greening

- Innovative Elements -
  - Research park run / County focal
  - Cattle feed co-product w/ranchers
  - Citrus grower engagement
SAFE – Sustainable Ethanol

Sustainable Aviation Fuel from Ethanol

- Project Lead - GA Tech (Thomas) USDA NIFA LOI focus

- Key Partners / Customers - Lanzatech, UGA, USF, UFL

- Objectives: Resilient rotation for sustainable ethanol supplies from agricultural sources for ATJ

- Innovative Elements -
  - Solely sustainable ethanol focus
  - Multiple southeast crop focus
  - Processor demand in place