Sustainable Biofuels For Aviation

Royal Aeronautical Society
Wellington, New Zealand
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Technology Solutions Present Opportunities

Aerodynamics

Structures and Materials

Systems

Engines

The Industry Is Supporting Many Technology Solutions

Next-Generation Biofuels...

Of All the Non Business As Usual Solutions, Sustainable Biofuels have the Largest Potential Impact
Alternate fuel drivers

- Airlines are seeking to:
  - Reduce exposure to fuel price volatility
  - Position for future fuel policies
  - Reduce aviation’s impact on global warming
Types of Alternative Fuels

Synthetic (from gas, coal or bio)

Other (ethanol, methane, liquid hydrogen)

Biofuels (from oil-based feedstock such as halophytes, algae, jatropha)
First-generation biofuels

- Inefficient and unsustainable sources of energy
- Require large landmasses and mostly grown for human consumption

**Examples:**
Ethanol produced from corn and soybean feedstocks

Second-generation biofuels

- Derived from *non-food crops* utilizing *new biomass-to-fuel-conversion technologies*
- Exponentially more efficient and sustainable sources of energy
- Require small landmasses and proportionately less fertilizer and water

**Examples:**
New fuels from algae, jatropha, switchgrass and other feedstocks

Soybean

Babassu

Algae
Widespread deforestation (Haiti & Madagascar pictured) is driven by lack of economically & environmentally sustainable options. Jatropha for biofuel will be one of the first solutions.
Feedstocks Which Can Mitigate Deforestation Will Have Positive Impact

Global CO₂ emissions that cause global warming

- Deforestation: 25%
- Petroleum: 31%
- Coal: 26%
- Natural Gas: 15%
- Other: 3%


Slash and burn deforestation
Soybean versus algae: comparing first- and second-generation biofuels

Supplying the worldwide commercial airline fleet with 100% 1st-gen biofuel from soybeans would require a landmass nearly the size of the entire continental United States.

Supplying the worldwide commercial airline fleet with 100% 2nd-gen biofuel from algae might require a landmass as small as the size of West Virginia.

Estimates assume a yield of 10,000 gallons of oil per acre of algae, or about 150X more than soybeans.
Boeing is pursuing alternate fuels that have low life-cycle CO₂ emissions.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Relative CO₂ Emissions</th>
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<tbody>
<tr>
<td>Jet fuel from crude oil</td>
<td>1</td>
</tr>
<tr>
<td>Liquid hydrogen from water and nuclear power</td>
<td>2</td>
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<tr>
<td>Biojet fuel</td>
<td>3</td>
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<tr>
<td>Liquid methane from natural gas</td>
<td>4</td>
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<tr>
<td>Methanol from natural gas</td>
<td>5</td>
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<tr>
<td>Jet fuel from coal with CO₂ sequestration</td>
<td>6</td>
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<tr>
<td>Jet fuel from coal</td>
<td>7</td>
</tr>
<tr>
<td>Liquid methane from coal</td>
<td>8</td>
</tr>
<tr>
<td>Liquid hydrogen from coal</td>
<td>9</td>
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Sustainable biojet fuel development timeline

Establish Feasibility
• Biojet fuel technical performance demonstrated

Research and Development
• Second-generation biojet fuel research & development
• Infrastructure integration challenges identified & worked

Commercial Viability
• Cost-effective, environmentally progressive options move forward

2006 2007 2008 2009 2010 2011
Commercial aviation fuel performance criteria

- Low freezing point
- High temperature thermal stability
- Energy density
- Storage stability
- Elastomeric compatibility
- Compatible when mixed with Jet-A

Must be a replacement solution
Several non Fischer-Tropsch Fuels Are Very Promising

Freezing Point, (C) per ASTM D 5972

-30 C, Minimum Jet-A Spec (for blending)
-40 C, Minimum Jet-A Spec

Jet-A
BioJet #1
Biojet #2
Biojet #3
Biojet #4
Biojet #5
Biojet #6
Local biodiesel

Better
Feedstock to Fuel Conversion: Many emerging and efficient methods

In order for GTL/BTL to be Viable in Long Run, You Must Assume:
1) None of the enzymatic/microbial conversion technologies will be viable
2) Stranded natural gas is best used for transport, not LNG to powergen
Several marine operators have been running biodiesel in their aero-derivative engines.
What Boeing is Doing

Evaluate bio feedstocks

Identify required processing methods

Help create “drop-in” carbon neutral Bio-Jet fuel

Demonstrate use of biojet fuel

<table>
<thead>
<tr>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<tbody>
<tr>
<td>Feasibility</td>
<td>Production Viability</td>
<td>Commercial Capability</td>
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Biojet test flights
Sustainable biofuel demo flights are designed to highlight the viability of low carbon life-cycle alternative fuels by:

- Demonstrating technical feasibility
- Identifying sustainable biofuel sources
- Promoting the development of viable commercial markets

Algae feedstock
The first sustainable biofuel demonstration flight with Virgin Atlantic and GE

February 24, 2008
Making Progress: The 2nd Sustainable Biofuel Demonstration

Scheduled 2008
First North American Sustainable Biofuel Demonstration

Scheduled 2009
Market Viability Will Enable Much Greater Levels of Innovation and Adoption

Timing of Market Viability for SUSTAINABLE Fuels Influenced By:

- Aviation industry willingness to help innovate
- Aviation industry ability to spur investment
- Ability to build coalitions with entities outside aviation
- Future oil prices

Boeing Strategy is to accelerate timing of this inflection point (Market Viability)

Quantity of Sustainable Aviation Fuel

Time

2008

2014/15
Conclusions

- Identify sustainable alternative fuels that work in today’s airplanes

- Emerging low cost production technology and sustainable bio-feedstocks offer economically viable and environmentally attractive options in near term

- Fischer Tropsch fuels are by no means the only game

- Algae-based fuel sources, jatropha, halophytes, and other cellulose perennials all hold great promise and some are affordable today

- Governments, academia and industry need to continue to work together