



Sustainable Biofuels For Aviation

Royal Aeronautical Society
Wellington, New Zealand
March 28, 2008

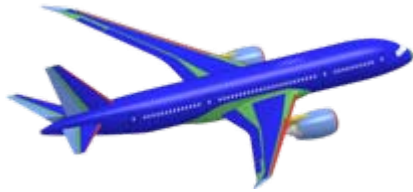
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Technology Solutions Present Opportunities



Aerodynamics



**Structures and
Materials**



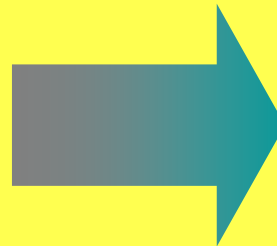
Systems



Engines

The Industry Is Supporting Many Technology Solutions

Next-Generation Biofuels...

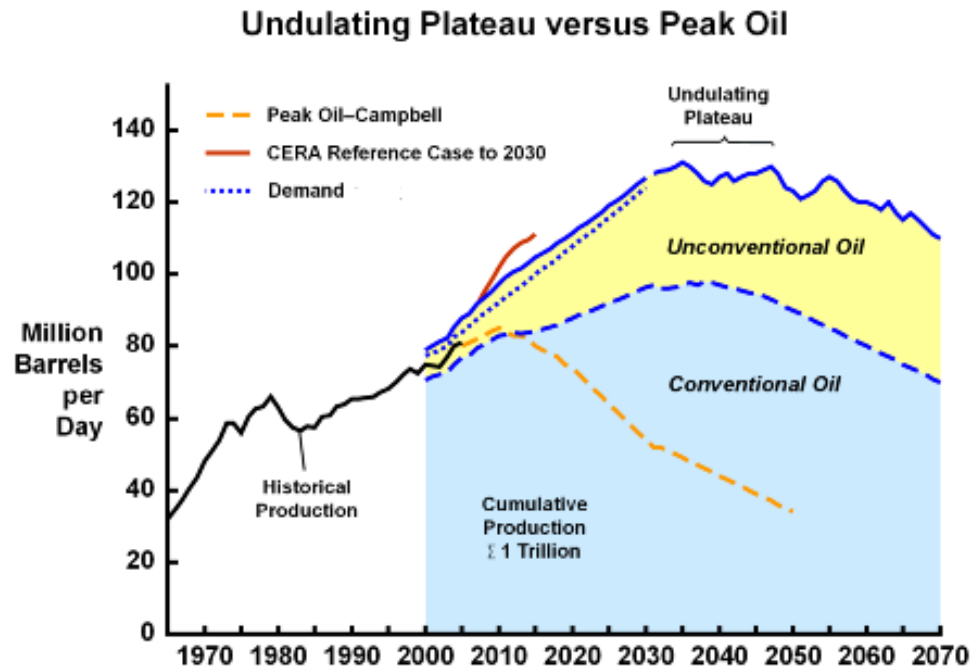


Of All the Non Business As Usual Solutions, Sustainable Biofuels have the Largest Potential Impact

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

Future oil availability



Source: Cambridge Energy Research Associates.

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)

Second-generation biofuels are efficient and sustainable

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



Soybean

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

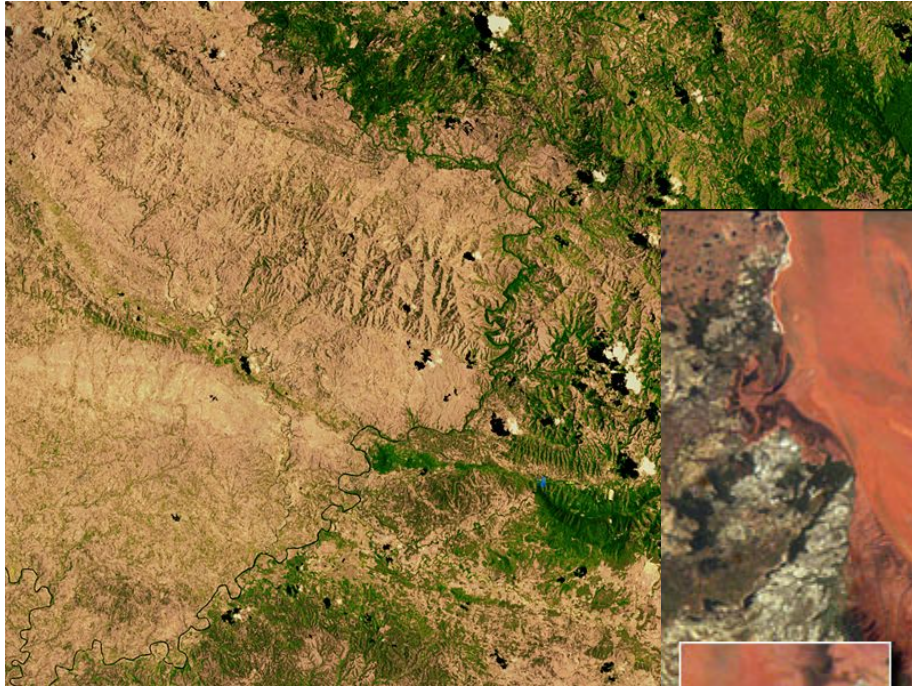


Babassu



Algae

Sustainable Biofuels Are Being Tapped to Create Economic Engines to Mitigate Deforestation

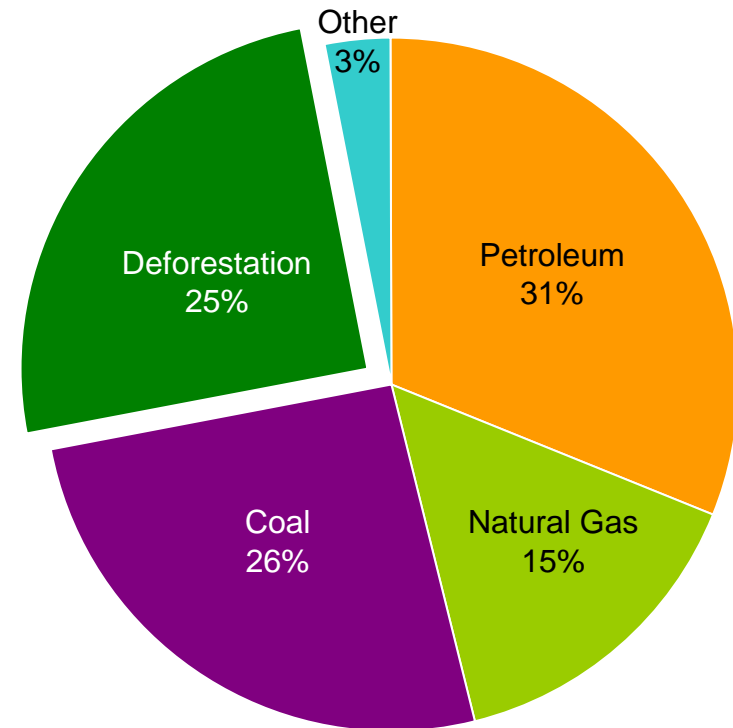


Widespread deforestation (Haiti & Madagascar pictured) is driven by lack of economically & environmentally sustainable options. Jatropha for biofuel will be one of the first solutions

Feedstocks Which Can Mitigate Deforestation Will Have Positive Impact



Global CO₂ emissions that cause global warming



Slash and burn deforestation

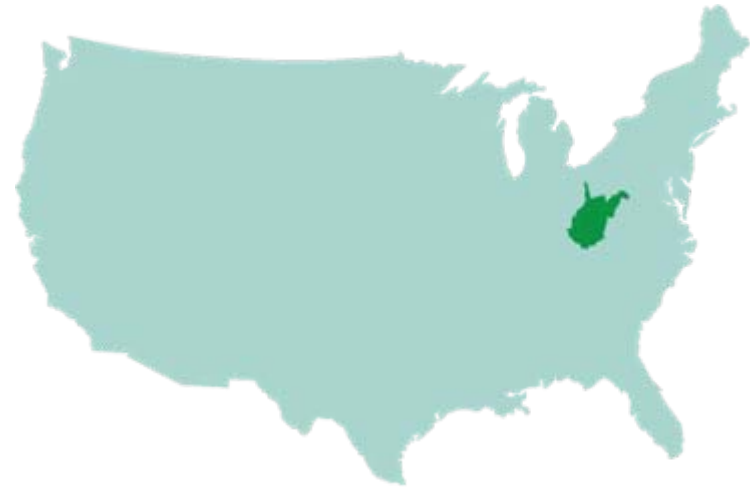
Source: www.Nature.org, 2007



Soybean versus algae: comparing first- and second-generation biofuels



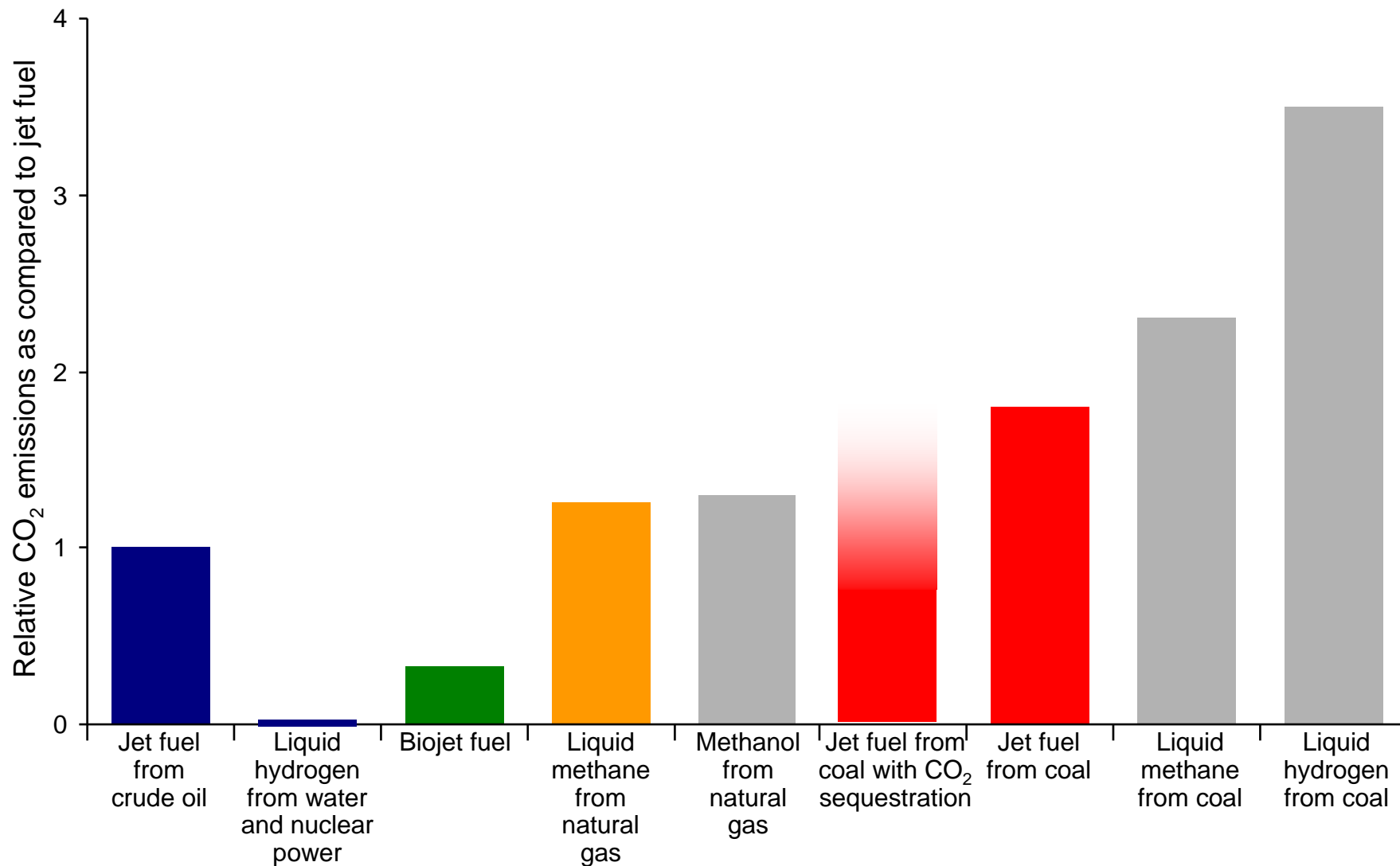
Supplying the worldwide commercial airline fleet with 100% 1st-gen biofuel from soybeans would require a landmass nearly the size of the entire continental United States.



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



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

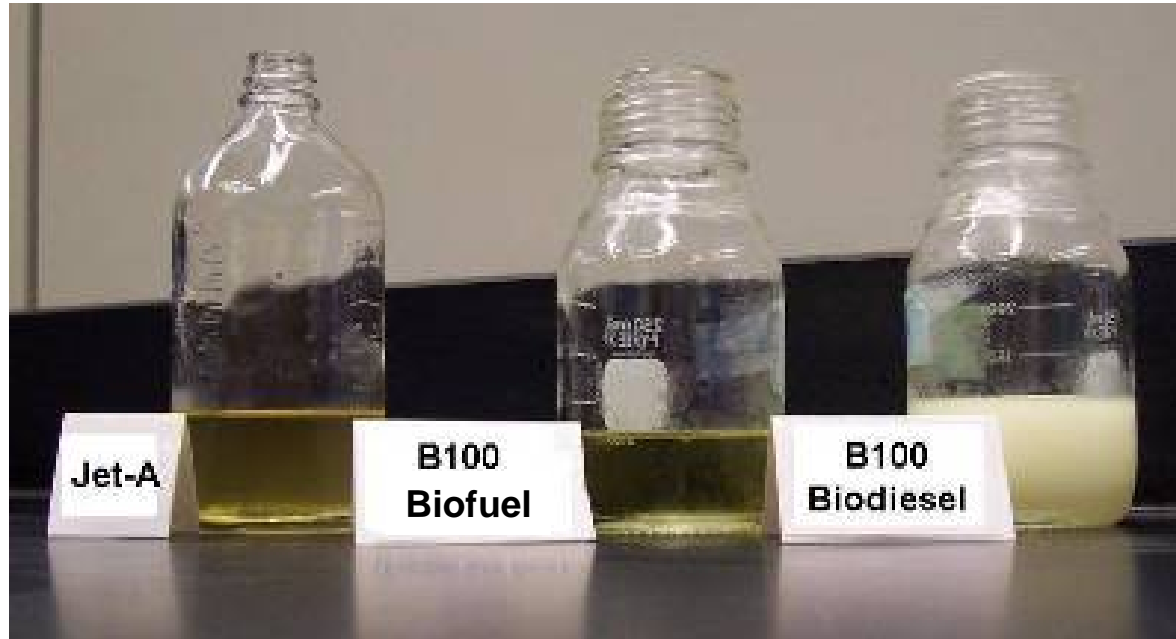
2009

2010

2011

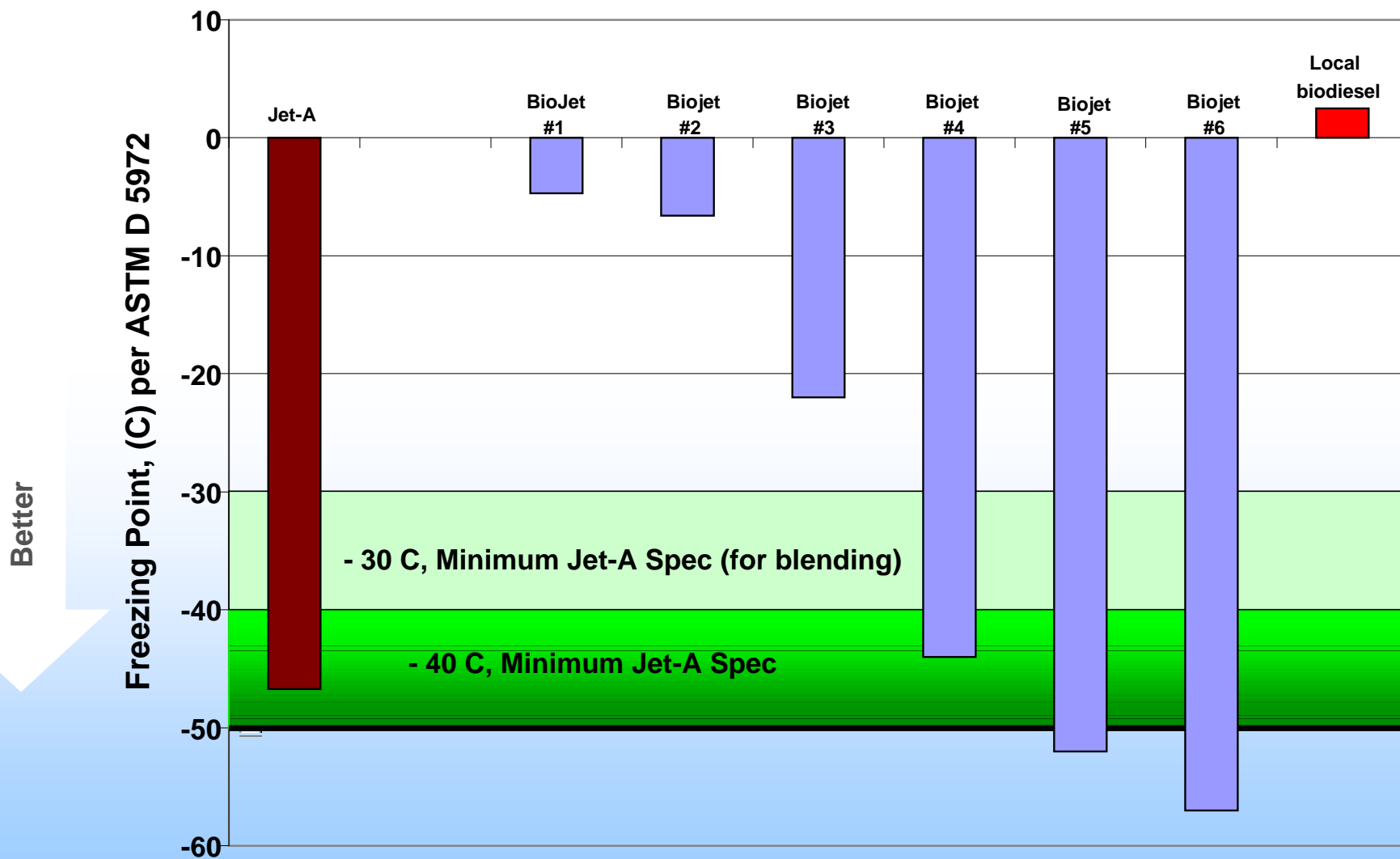
Commercial aviation fuel performance criteria

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

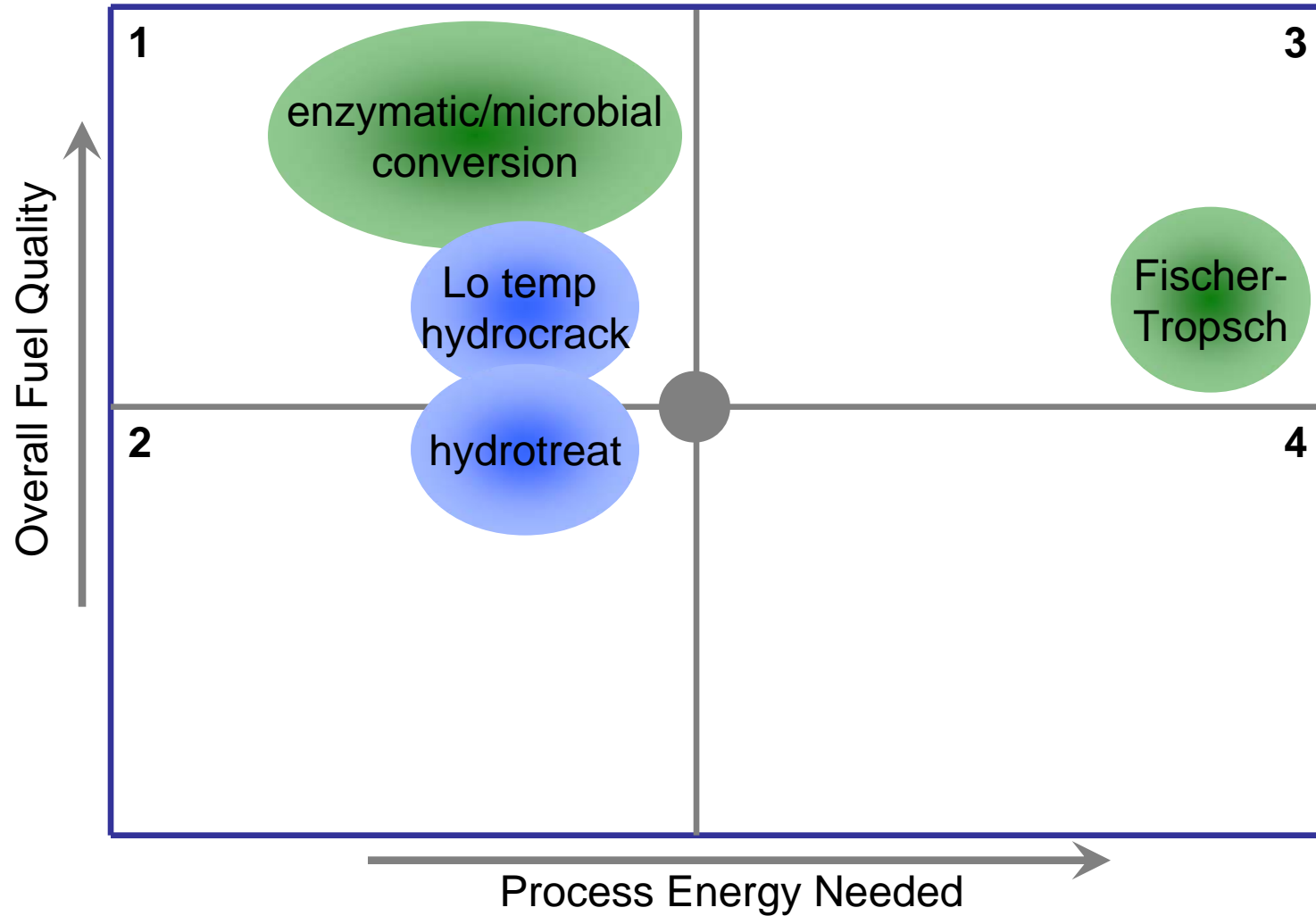


Must be a replacement solution

Several non Fischer-Tropsch Fuels Are Very Promising



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



CF6 Aero Engine (core of LM2500 engine)



Aero-derivative LM2500 Cruise Ship Engine



What Boeing is Doing



Evaluate bio feedstocks



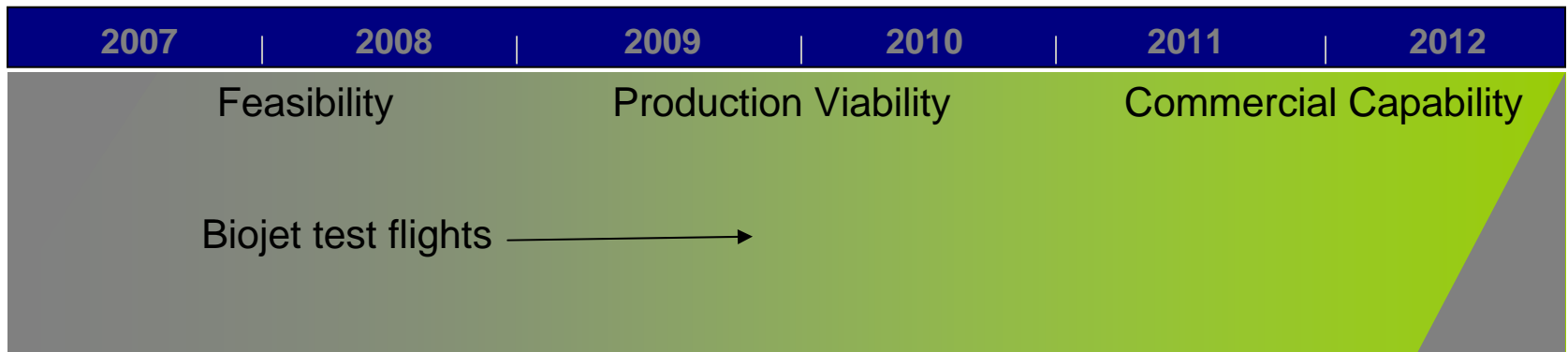
Identify required processing methods



Help create "drop-in" carbon neutral Bio-Jet fuel



Demonstrate use of biojet fuel



Sustainable biofuel demonstrations take flight

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



Rolls-Royce



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

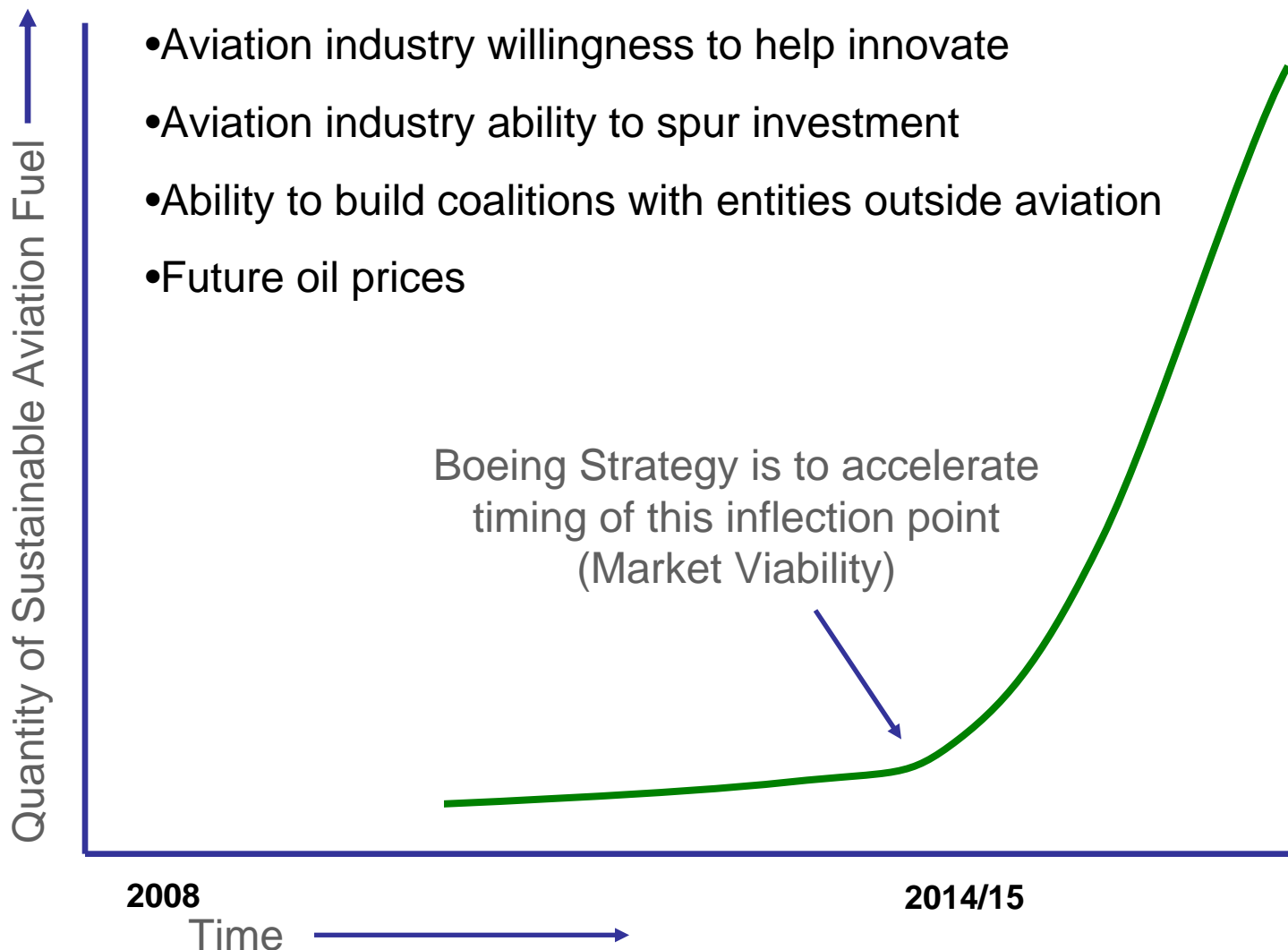


Scheduled 2009

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



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**