Applying Phycology to Aviation Biofuel

Presentation to:

Carbon Recycling Forum (APS)

Phoenix, AZ

by:

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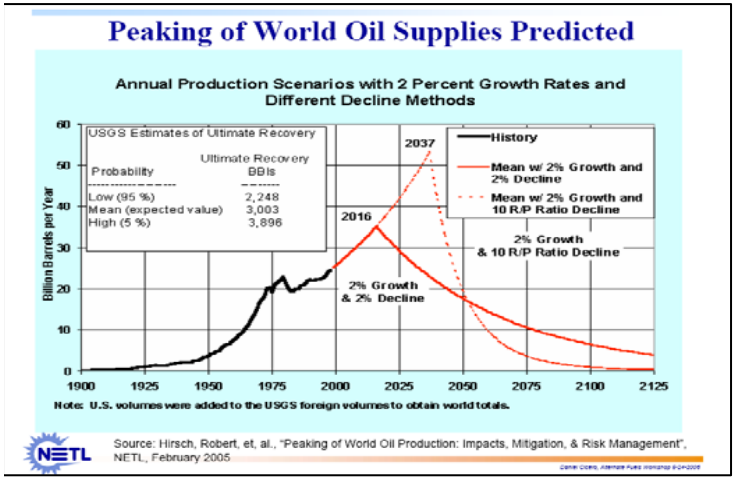
Technology Leader,
Energy & Emissions

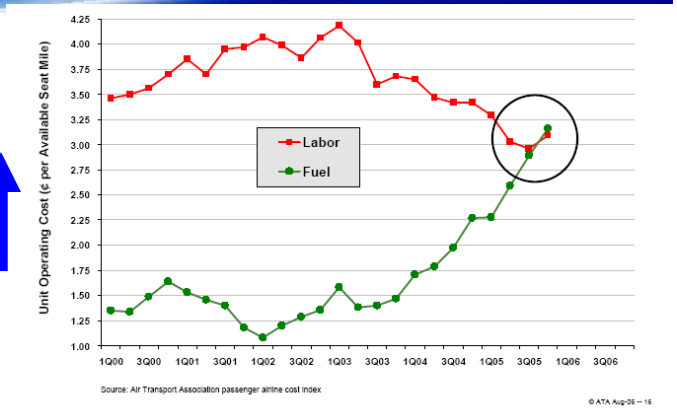
17-18 September, 2008

Aviation Alternative Fuel Drivers

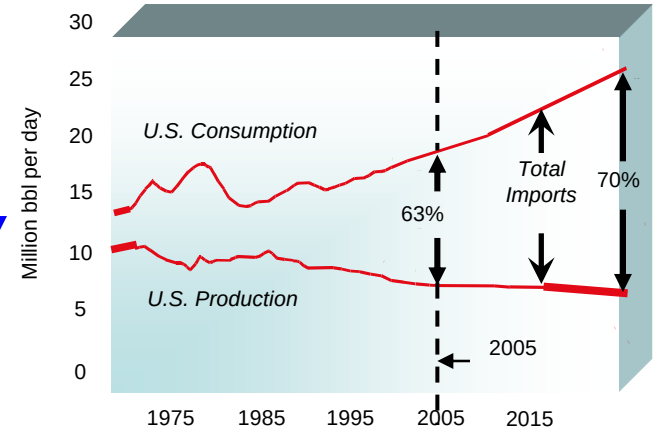


Availability

Price



Energy Independence



Environmental Issues

….. and must meet specification for safety

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The challenge

How can we most effectively minimize aviation's impact on the environment – specifically CO_2 emissions?

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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

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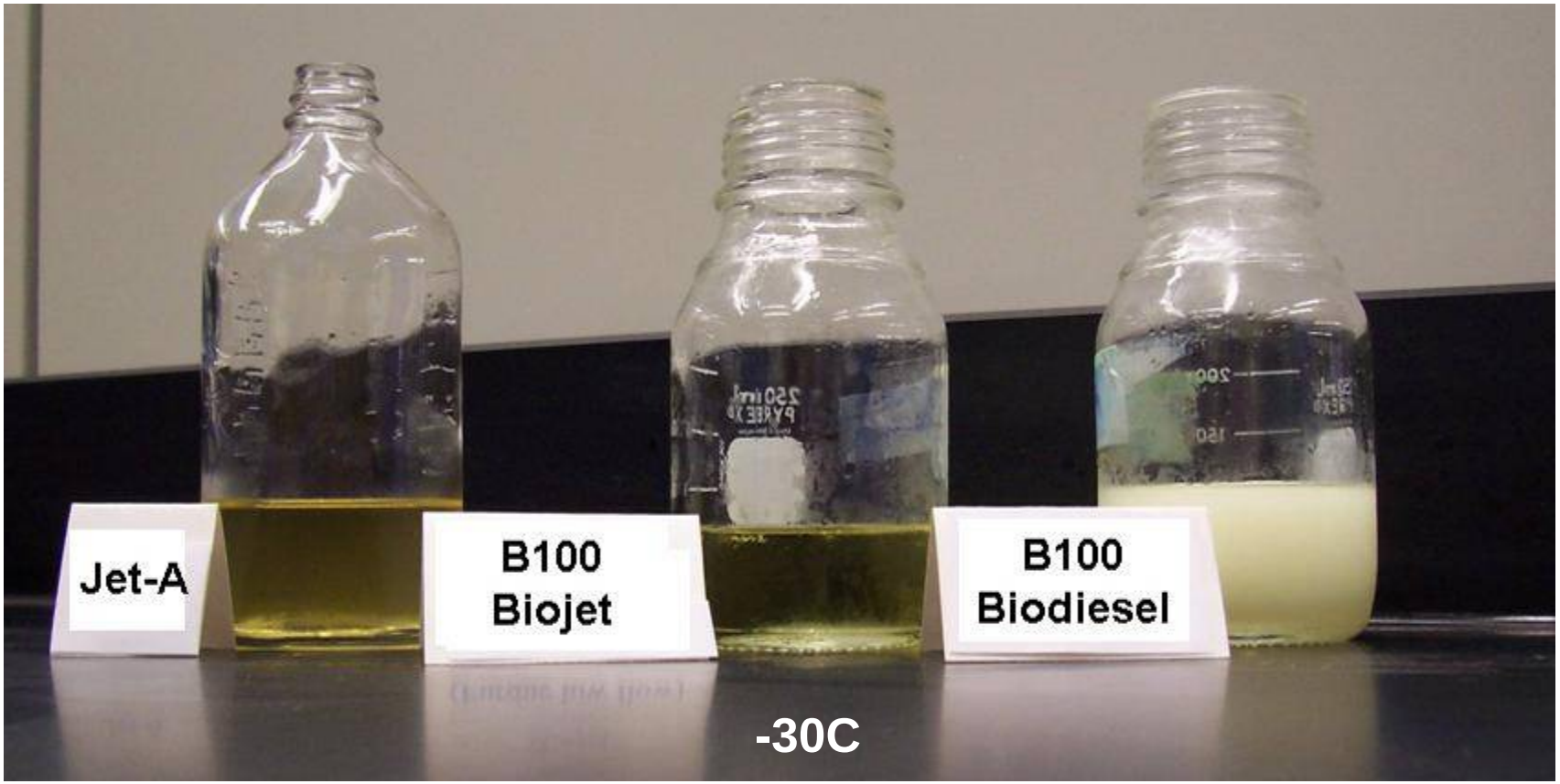
Biojet should perform similarly to Jet-A

Fuel performance requirements:

- Freezing point (-40C)
- High temperature thermal stability
- Energy density
- Storage stability
- Elastomeric compatibility
- Must be a “drop-in” solution



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Things that make for a low freezepoint hydrocarbon fuel:

- **Lower carbon number HC chains**
- **Molecular weight**
- **Branched structures**
- **Weak intermolecular forces between atoms**
- **Non-heteroatomic molecules**

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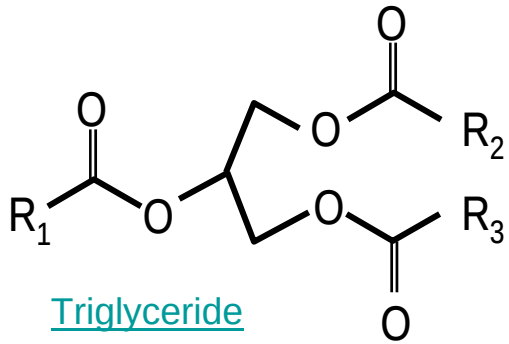
Hydroprocessing and isomerization of vegetable oils improves freezepoint and energy content

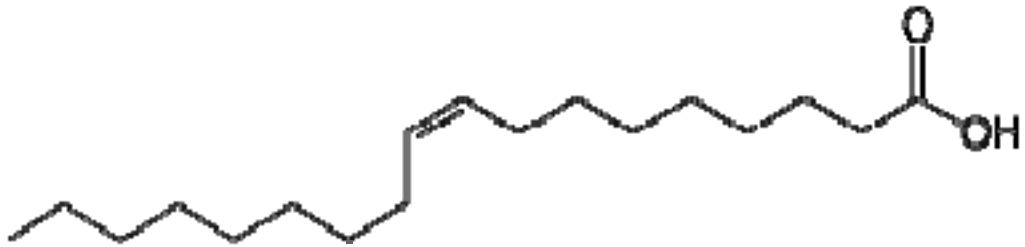
Vegetable oil



Triglyceride

$CH\ (C_{18}H_{33}O_2)3$

Oleic Acid



monounsaturated fatty acid

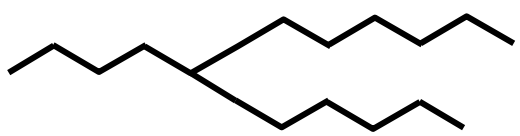
$CH_4 + (C_{18}H_{34}O_2)3$

Alkane (pariffin)

Linear saturated hydrocarbon

$nCO_2 + nH_20^{+}\ (C_{18}H_{36})3$

Low Freezepoint Alkane



Branched saturated hydrocarbon

$C_{18}H_{35}$

Koivusalmi, et al., "Process for Processing a Saturated Hydrocarbon Component", US Patent 2007/0131579 A1, June 14, 2007

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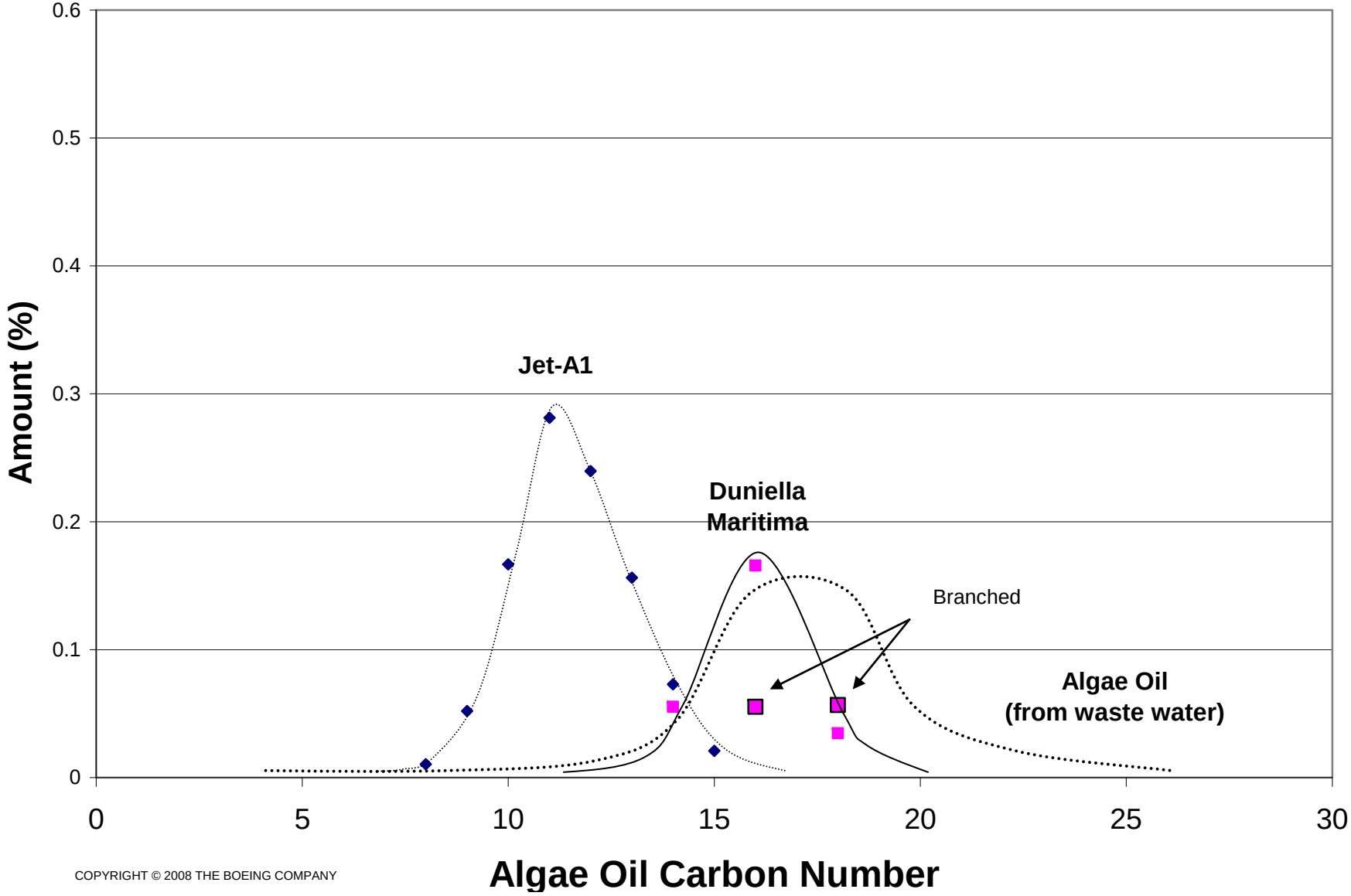
Would algae oil work for low temperature biojet fuel needs?

Algae oil appears to have about the same long HC chain length as palm oil, but not as many branched molecules for good freezepoint performance



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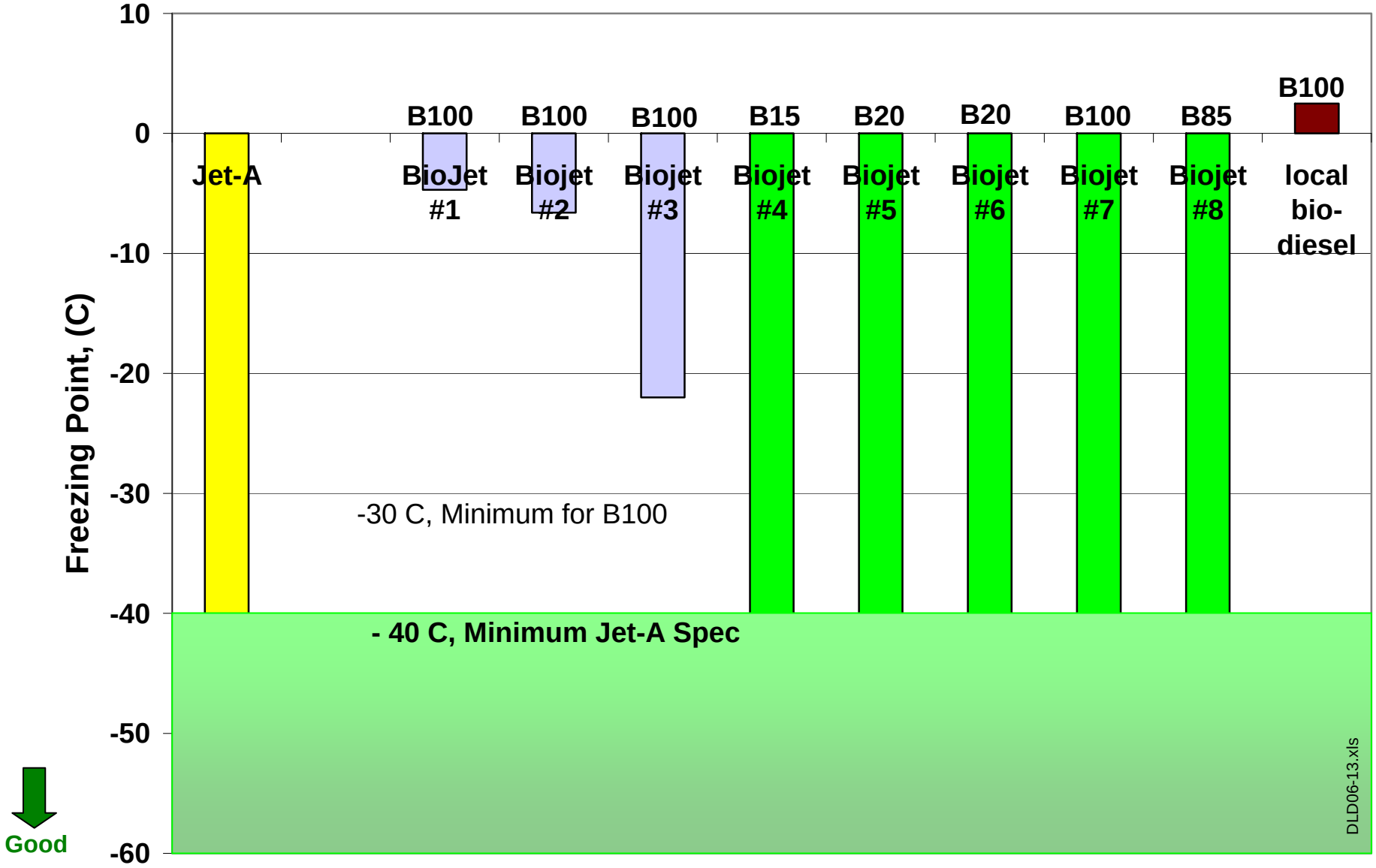
Several bio-jet fuels are meeting freeze point requirements*



*using 1st generation feedstocks

*per ASTM D 5972 method as required in ASTM D 1655 Jet-A specification

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The strategy

Be a catalyst in the biofuel industry

(how we can help accelerate algae technology?)

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What Boeing is doing

- **Working with fuel suppliers and customers**
- **Focusing on biojet fuel to address industry concerns about: CO_2, environmental, fuel availability and cost issues**
- **Created an industry "vision" by flight demonstrating biojet fuel.**

Evaluate bio feedstocks

Identify required processing methods

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

Demonstrate use of biojet fuel

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Use biojet fuel in a flight demonstration

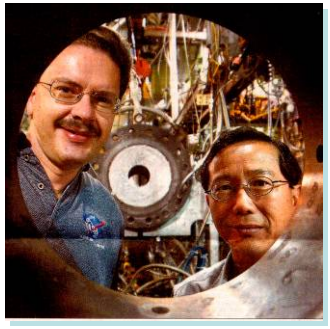
Gather
Biojet samples

Boeing screening tests

NASA lab tests

Engine company tests

Biojet fuel flight
demonstration



NASA flame tube tests

2007											2008

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Imperium
renewables
HOT
FLAMMABLE LIQUID
3

Cosmic Girl
Re-born December 2001

virgin atlantic

virgin atlantic

What we learned from the literature about algae:
(from closeout report of Aquatic Species Program)

- **Work on basic biology**
- **Take advantage of plant biology**
- **Start with what works in the field**
- **Maximize photosynthetic efficiency**
- **Set realistic expectations**
- **Look for near term opportunities (e.g. waste water treatment)**

Close-Out Report

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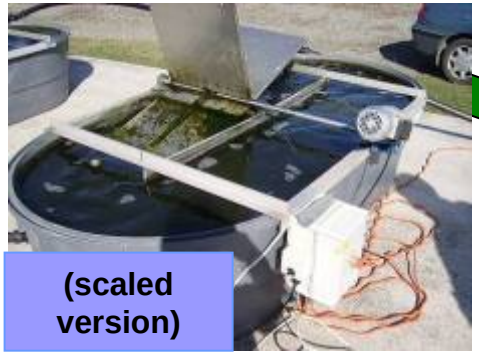
Algae from waste water might make for a sustainable biojet fuel

Use waste water output

+ flue gas



(scaled version)

Encourage further algae growth in racetrack ponds

Harvest

Discharge Clean Water

Algae

Biocrude

Refining Process

Sustainable BioFuel

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Boeing is engaged in algae research to learn and also to stimulate the industry

Strain Selection
(salt & fresh watger)

Growing Conditions

Growing Method

Open system

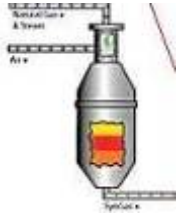
or?

Closed system

Harvesting

Dewatering

Oil Extraction



Oil Cleanup

Life Cycle Assessment

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Demonstration projects enable a great learning experience

Prototype flue gas algae open ponds in operation by Seambiotic (Israel)

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Overall time scale

Feasibility

- Biojet is looking promising ☑
- Receive more fuel samples ☐
- More lab tests yet to complete ☐

Sustainability

- High yield feedstocks will be needed ☑
- Future of algae needs to be researched ☐

Costs/Benefits

- Need to gather costs and benefits ☐
- Evaluate business case for airlines ☐

2006 **2007** **2008** **2009** **2010**

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Conclusions

- **“Drop-in” alternate fuels presently work best for commercial aviation**
- **Alternatives need to be environmentally attractive and sustainable**
- **Algae feedstock looks promising**
- **Governments, industry and academia need to work together**

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Thank You!

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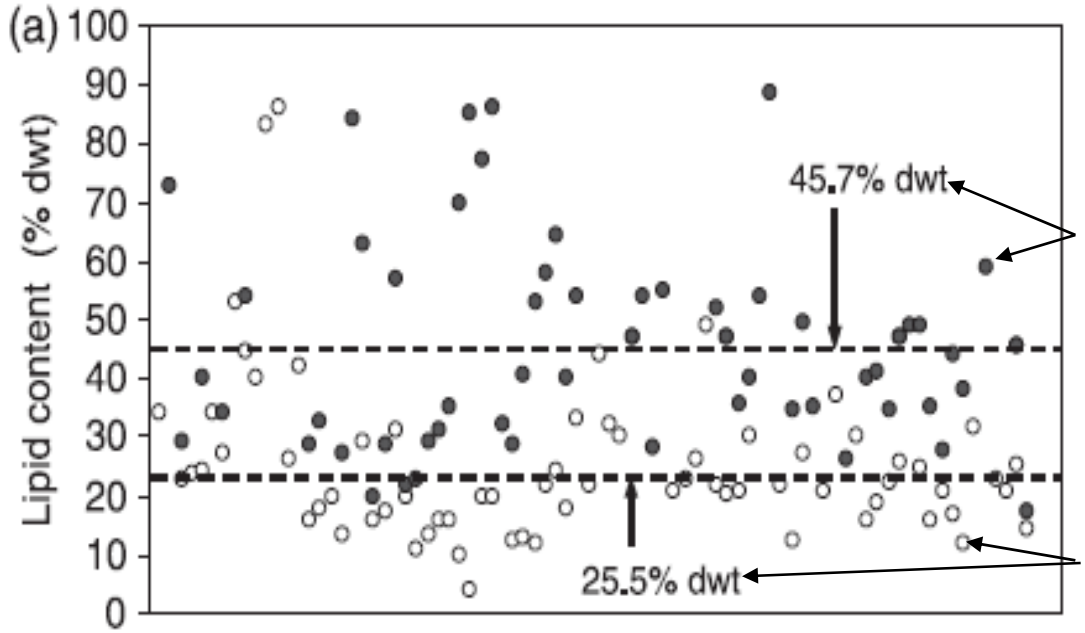
One argument in favor of a closed system:

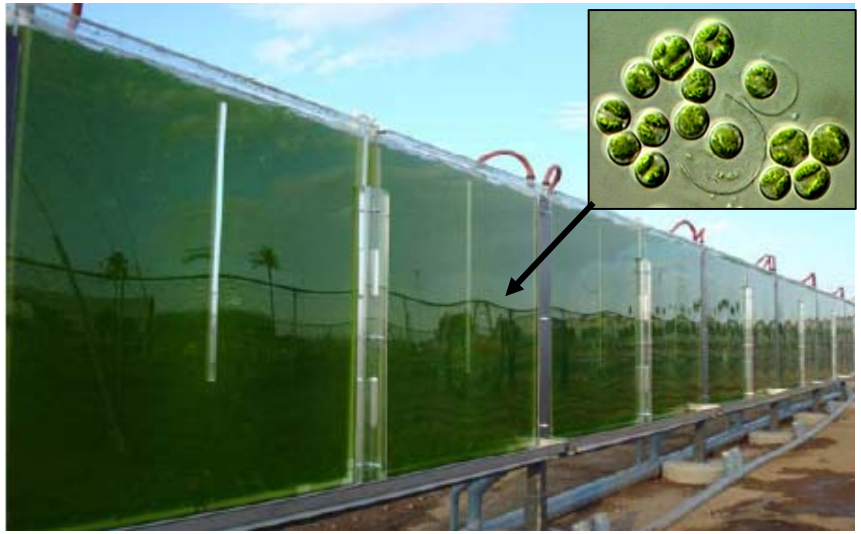
Can significantly increase yield and lipid content of algae

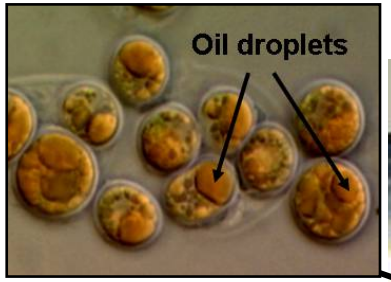


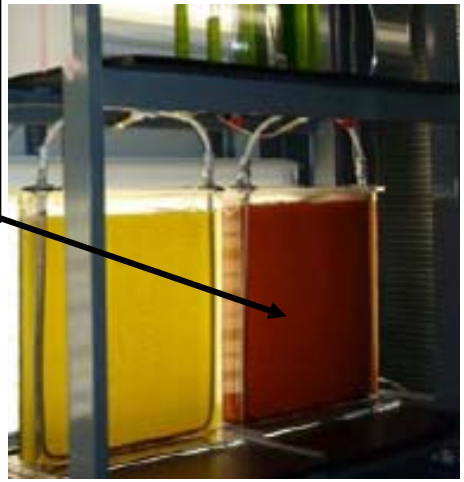
Conditioned Algae

Unstressed Algae

Source: Q. Hu. Et. Al., "The Plant Journal", 2008, pg 621-639

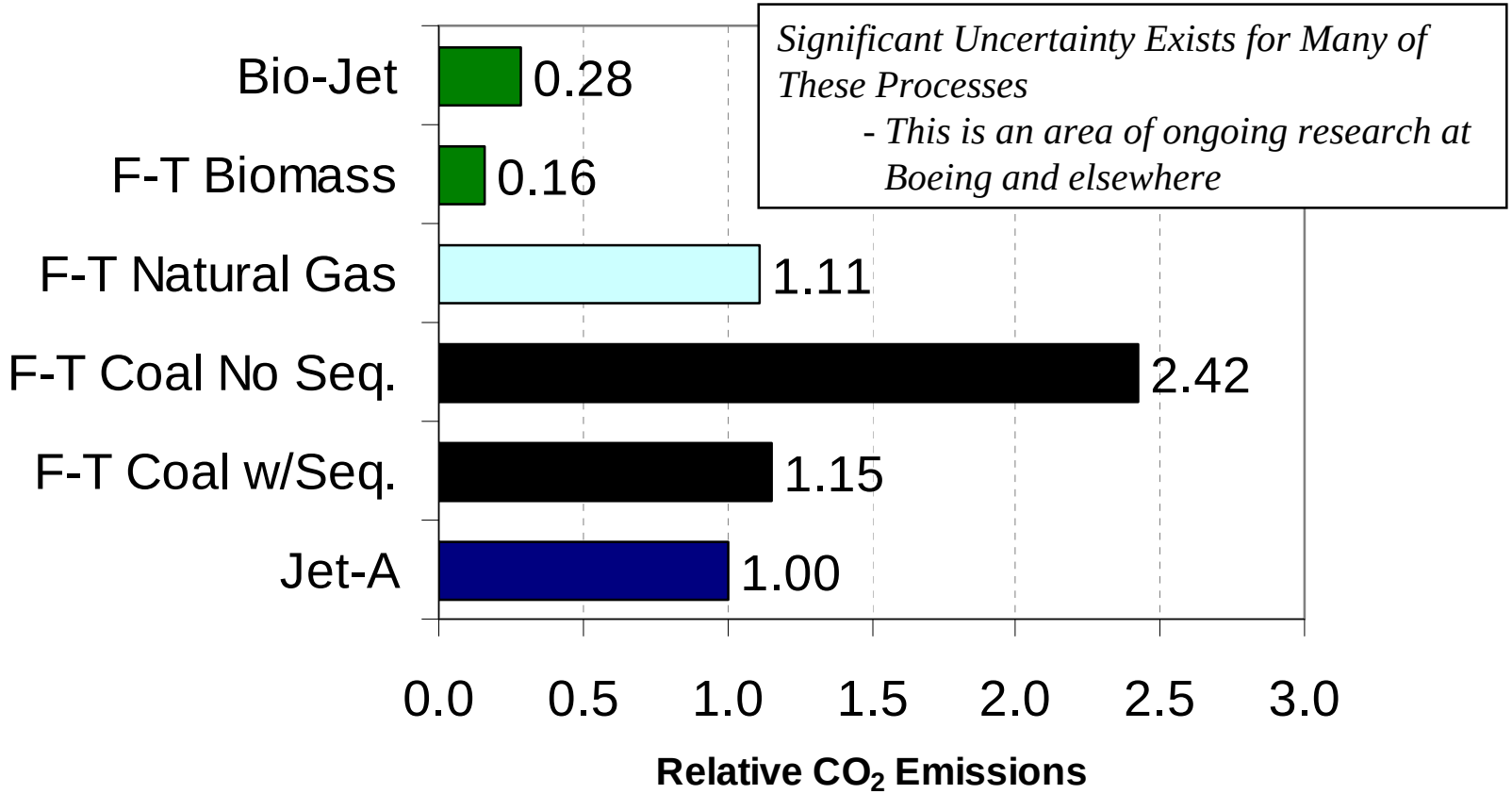






Oleaginous green algae at ASU

Aviation desires to have a lower carbon fuel (over life cycle) than present Jet fuel.



Significant Uncertainty Exists for Many of These Processes
- This is an area of ongoing research at Boeing and elsewhere

Biojet from Soybeans
F-T Biomass from Woody Biomass
Results sensitive to biomass source, co-generation, and other efficiency assumptions (ongoing research and analysis)

Results Using GREET 1.8b: Greenhouse gases, Regulated Emissions, and Energy use in Transportation

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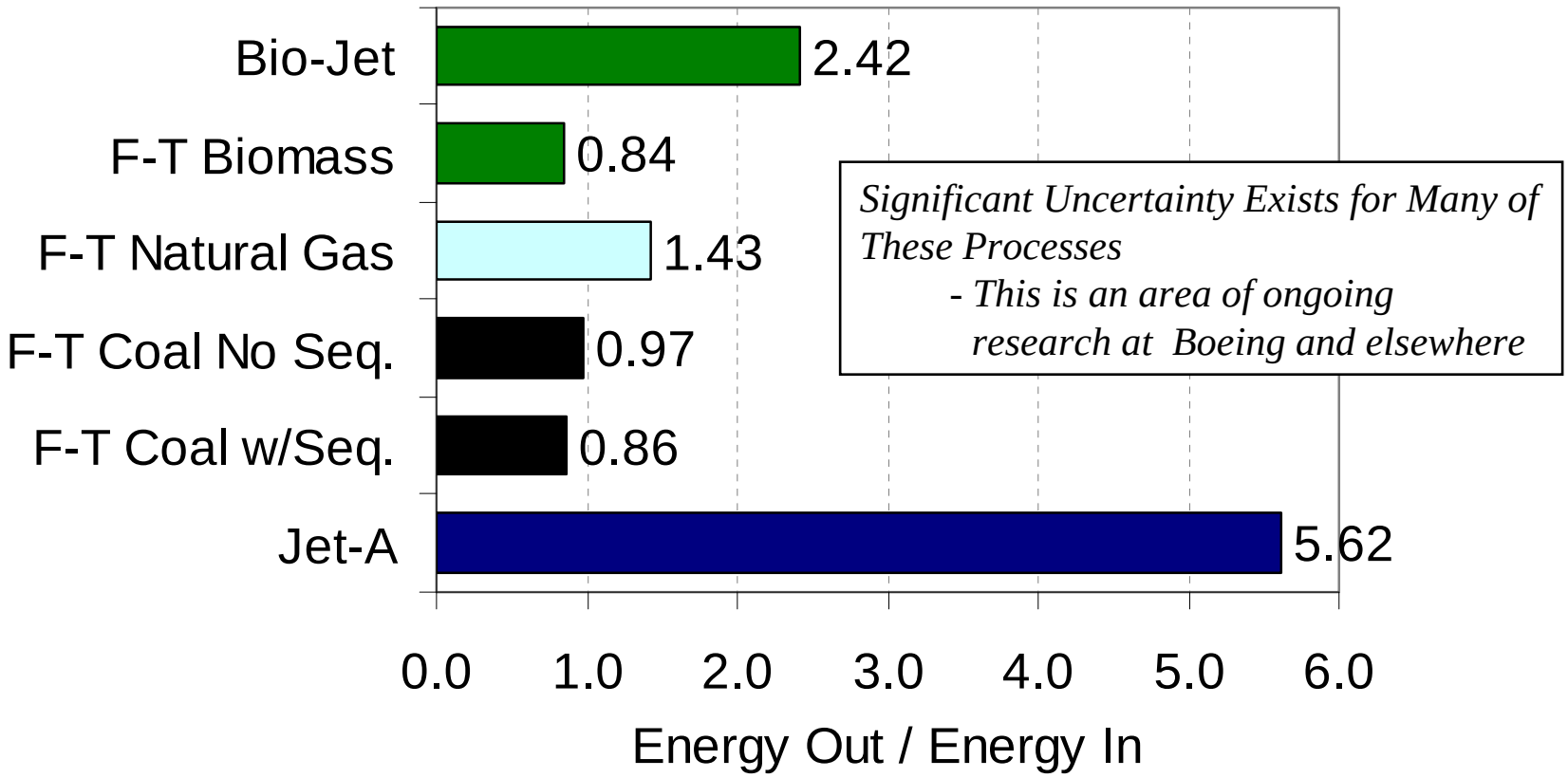
We believe biojet fuel is a comparatively energy efficient process

Process Efficiencies Affect Net Energy Consumption



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