Status of Sustainable Biofuel Efforts for Aviation

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Agenda

- Motivations
- Fuel Development
- Commercial Aircraft Approach
- The Path Forward

Why Boeing is concerned about sustainable biofuels?

Customers & Alternative Fuels

- Airline customers are hopeful about alternative fuels for 3 reasons:

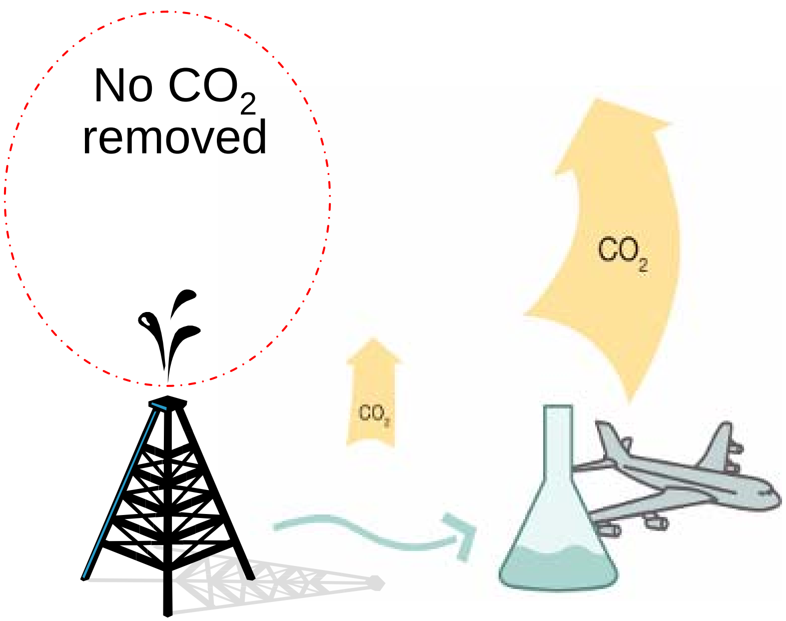
1. Environmental: CO_2 emissions
2. Fuel availability
3. Potential benefit to fuel costs

DoD customers are interested in these as well

Boeing's approach is to demonstrate feasibility, identify sustainable biofuel sources, and promote viable commercial markets

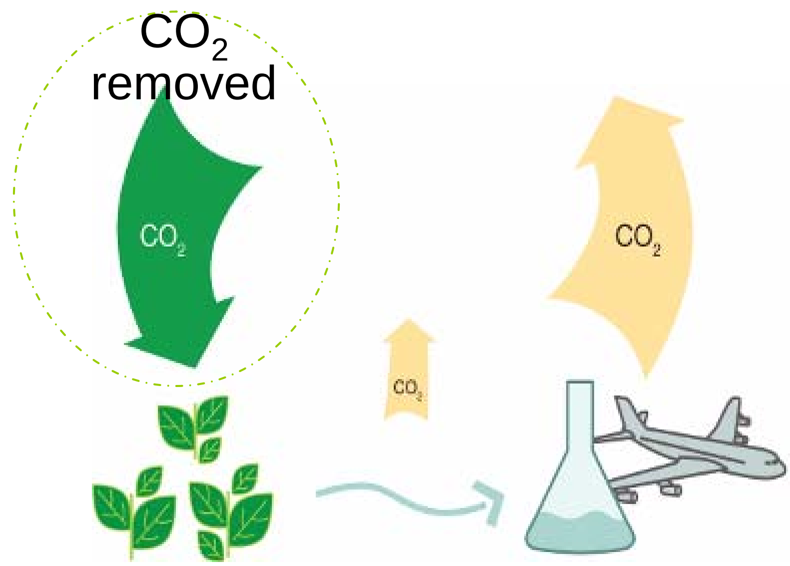
Plant-based feedstocks naturally remove CO_2 from the atmosphere

Petroleum releases CO_2 that has been locked underground



Petroleum-based fuel

Plant feedstocks re-absorb CO_2 emissions as they grow



Plant-based fuel

Fuel

Development

Viable and sustainable feedstock alternatives

Jatropha — ready: 2-4 years

Benefits
- Uses marginal land
- Agronomy is sufficiently advanced

Challenges
- Warm climates only
- Mechanical harvesting not yet mature

Algae — ready: 8-10 years

Benefits
- High productivity
- Potential for scale

Challenges
- Major process tech. innovation needed
- GMO risks

Halophytes — ready: 2-4 years

Benefits
- Uses desert land and salt water
- Part of system designed for GHG reduction

Challenges
- Proven at pilot scale to-date
- Improve agronomy for cost reduction

Camelina — ready: now

Benefits
- Ready-to-go
- Can integrate with traditional agriculture

Challenges
- Limited total potential owing to yield
- Somewhat tied to grain market swings

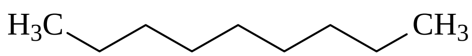
- *Viability is based on timing, technology and local resources.*
- *Sustainability criteria guides acceptable feedstock selection.*

Typical Jet Fuel

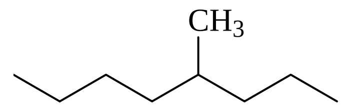
Ideal Carbon Length C8-C16

Paraffin's

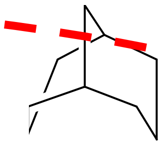
70%-85%



Normal Paraffin's



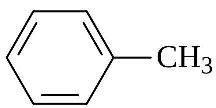
Iso-paraffin's

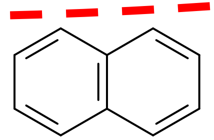


Cyclic Paraffin's

Aromatic's

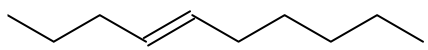
< 25%





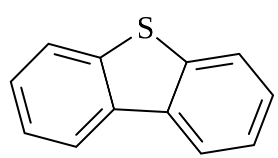
Olefin's

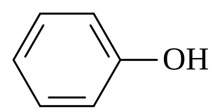
(<5%)



For biofuel flights & engine tests:
Paraffins were produced from plant oils and blended with Jet A at 50% ratio.

Sulfur, Nitrogen, Oxygen Containing Compounds



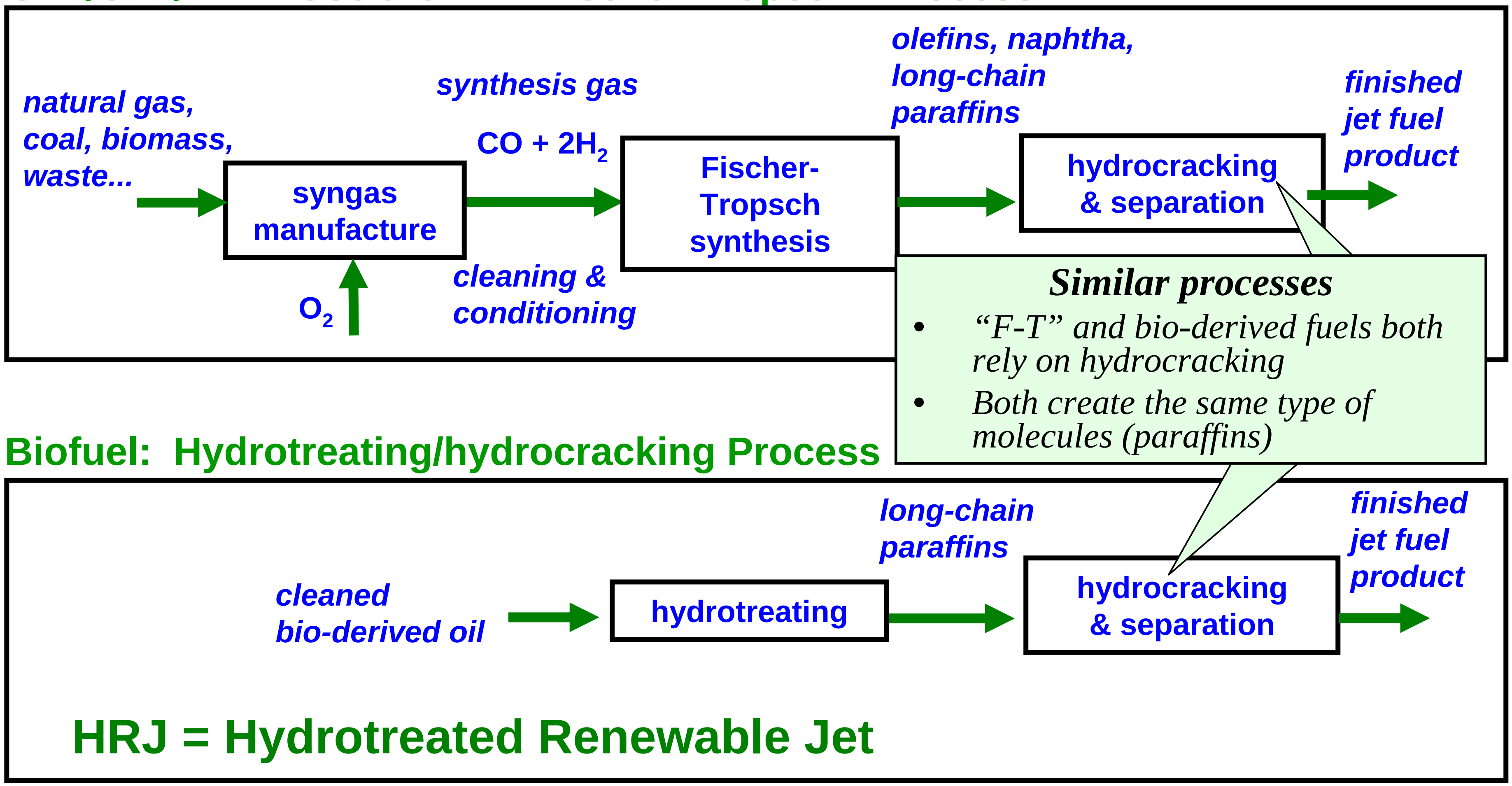


Acids, phenols, etc

The industry needs fuels with composition similar to above (i.e. a replacement or "drop-in" fuel)

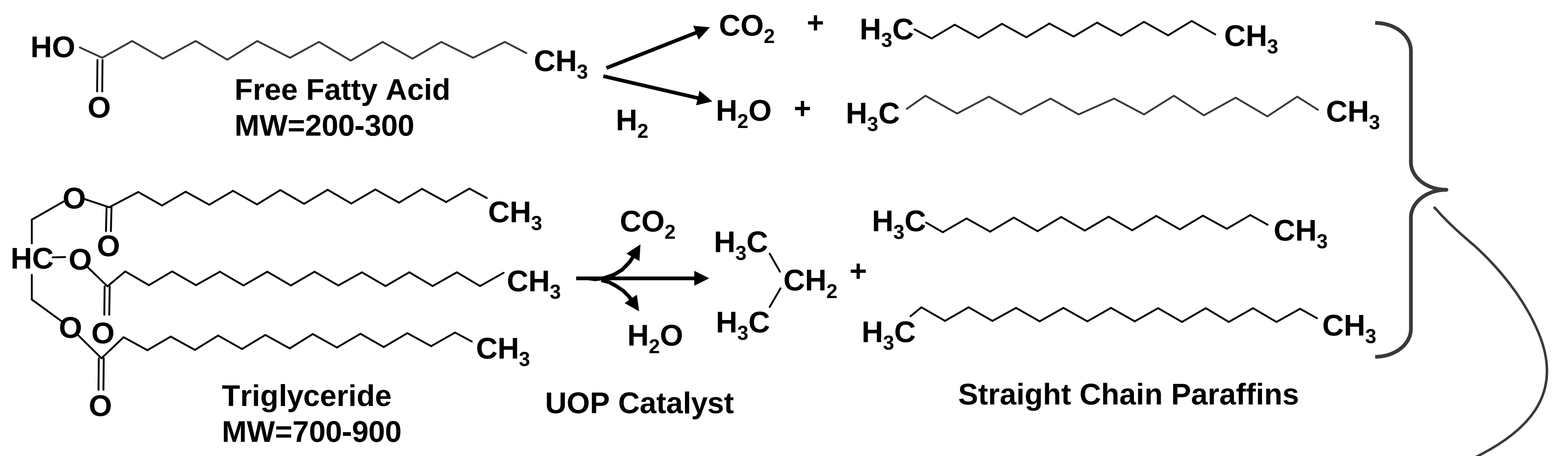
Processes that create Synthetic Paraffinic Kerosene (SPK)

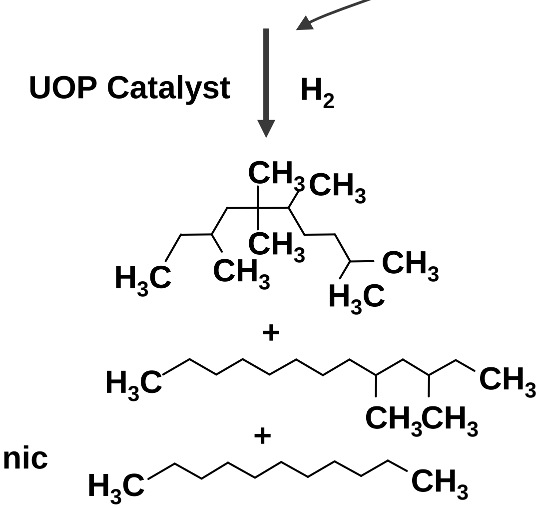
GTL/CTL/BTL: Use the F-T “Fischer-Tropsch” Process



Jet fuel can be produced with the same class of compounds (paraffin's) whether the starting material was made via a FT process or a bio-derived oil.

UOP's Renewable Jet Process Chemistry





- **Natural oils contain oxygen, have high molecular weight.**
- **First reaction removes oxygen – product is diesel range waxy paraffins**
- **Second reaction "cracks" diesel paraffins to smaller, highly branched molecules**
- End product is same as molecules already present in aviation fuel
- End product is independent of starting oil

Feedstock flexible, but with consistent product properties

Boeing Commercial Aircraft approach to sustainable biofuels

Boeing has partnered to enable sustainable biofuel flight tests

- Demonstrate technical feasibility
- Identify sustainable biofuel sources
- Promote development of viable commercial markets

BOEING | Air Force Research Laboratory | UOP A Honeywell Company

Virgin atlantic	Air New Zealand	Continental Airlines	JAL
GE	Rolls-Royce	cfm	Pratt & Whitney
Imperium renewables	terasol energy	Sapphire Energy	Sustainable Oils Your trusted energy growth partner.
Coconut & Babassu	**Jatropha**	**Algae & Jatropha**	**Camelina, Jatropha, & Algae**

Fuel Property Testing

	ASTM D 1655 Table 1	ICP for metals	GC-MS	Materials Compatibility	Other
Boeing	Neat & Blend			Neat	Dielectric
UOP		Neat	Neat		2D-GC
AFRL	Neat & Blend	Neat	Neat & Blend	Blends	
Outside Labs	Neat & Blend				
Engine Companies	Blend				

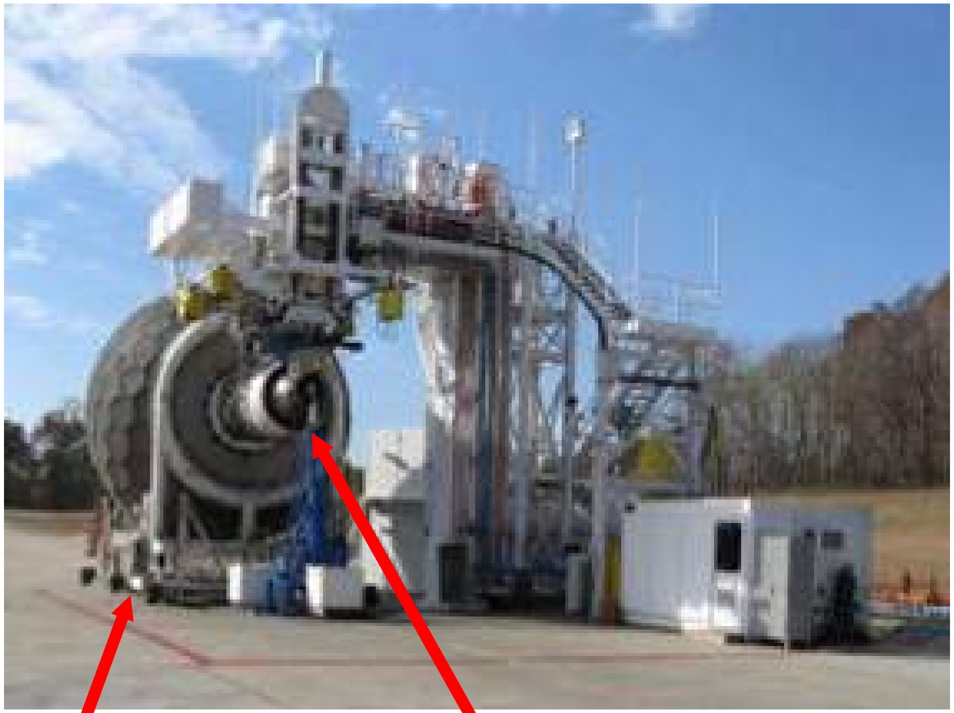
Interesting Results for all 50% SPK blends:

- Heat of Combustion: On a mass basis are ~1% higher than typical jet fuel
- Density: A key parameter limiting higher blends under current specification
  - (e.g. renewable aromatics are possible fix for this)
- Dielectric: A fit-for-use property with ramifications to Fuel Quantity Indication Systems (FQIS)

3 fuels met all performance specifications
at a 50% blend with jet fuel.

The CFM Engine Technical Program

- Ground testing at Peebles, OH
- CFM56-7B development engine
  - Back-to-back runs comparing Jet A, 50%, and 25% biofuel blends
- Performance testing consisted of measuring SFC at several power settings from ground idle to take-off
- Operability testing
  - Start times, Lean-blow out margin, and accel/decel times are within expected variation
  - Specific Fuel Consumption (SFC) improvement noted.
  - No engine deterioration noted.
- Emissions testing also conducted for regulated emissions species
  - Results mainly within expected variation of jet fuel, but some benefit is possible



Inlet Turbulent Control Structure

Emissions Probe

Pratt & Whitney Technical Program

- Ground testing in Mississauga, Ontario, Canada
- PW615 tested with Jet A-1, 50% and a 100% blends
- Engine performance
  - Controllability, engine start, flame-out, and fuel flows within expected variation
  - No engine degradation evident via performance or hardware inspection
- Emissions
  - Emissions of each species were compared for all 3 fuels used
  - No significant change in Hydrocarbon (HC), Carbon Monoxide (CO), or Nitrogen Oxides (NOx)
  - Smoke number decreased as the percentage of alternate fuel to Jet A-1 was increased

Commercial Biofuel Program Summary

- Encouraging sustainable biofuel development for aviation
- Demonstrating biofuel production, test, and operability
- Working with fuel suppliers, engine companies, & customers
- A team effort is underway to address industry concerns about:
  - CO_2 , fuel availability and cost

Evaluate & select 2^{nd} generation feedstocks

Identify & pilot processing methods

Help create "drop-in" lower CO_2 lifecycle, sustainable biofuel

Flights & Engine Tests

The Path Forward

Bio-derived jet fuel certification in work

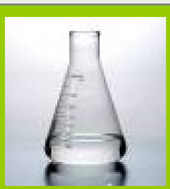
ASTM D 1655

- BTL fuels likely to be certified up to 50% blend
  - Data shows chemical equivalence between F-T fuels from different feedstocks (CTL, GTL, CBTL, BTL)
  - Certification possibly in 2009

- HRJ fuel samples have been evaluated from many sources
  - Results are very similar to F-T fuels
  - Certification possibly in 2010

Sustainable biofuels – Boeing's plan and approach

Achieve near-term market viability
of sustainable biofuels
for commercial aviation

Demonstrate Technical Capability			Drive Commercial Viability		
 **Flight and Engine Tests**	 **Fuels Development**	 **Feedstock Feasibility**	 **Demand Driven**	 **Education**	 **Public Policy**