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Aviation Biofuels: Enhancing Technical & Economic Competitiveness

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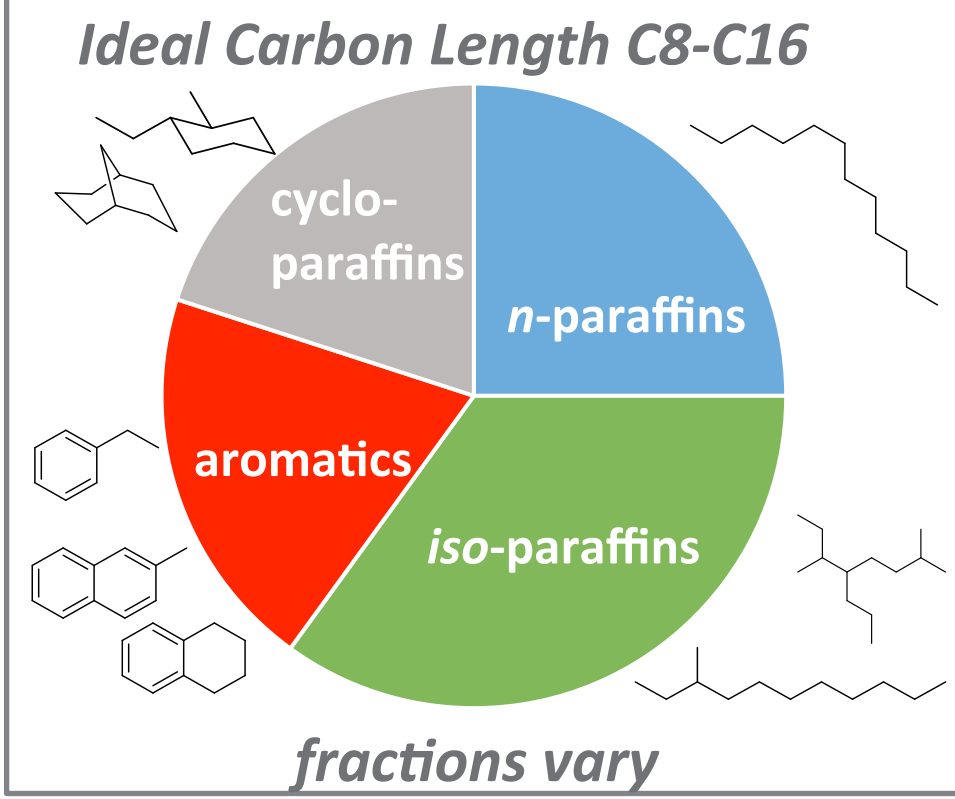
Aviation fuels contain different hydrocarbon families



- Paraffins (70 -85%) (iso, normal, and cyclic, provide Btu content)
- Aromatics (less than 25%) (poor combustion; but ~7% needed to ensure seal swell)
- Olefins (<1%) (gum formation)
- S, N, O containing (limited allowance)

From renewables, make the most valuable hydrocarbons

What should we be producing?

Isoparaffins have high energy content and high combustion quality even at low temps

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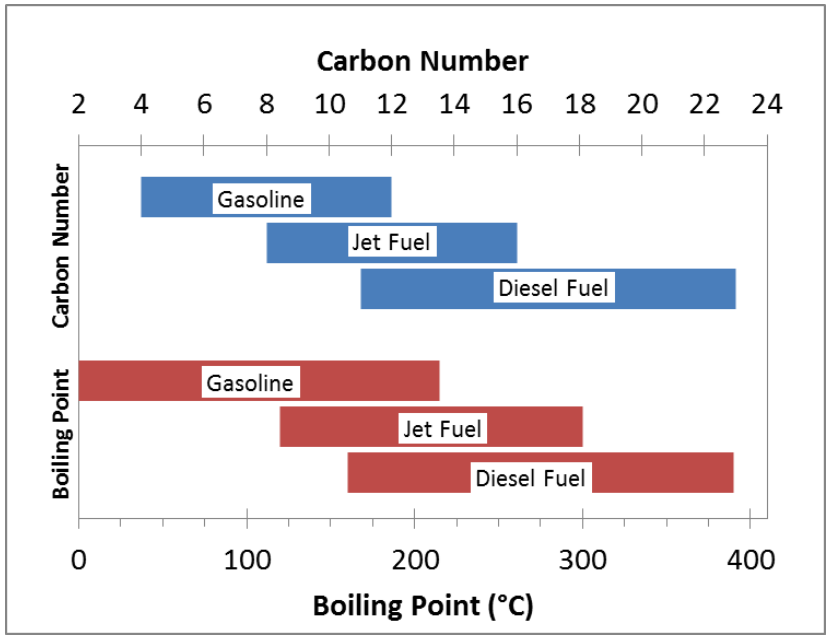
jet fuel property	n-paraffin	isoparaffin	naphthene	aromatic
Energy content				
gravimetric	+	+	0	–
volumetric	–	–	0	+
combustion quality	+	+	+	–
low-temp fluidity	– –	0/+	+	0/–

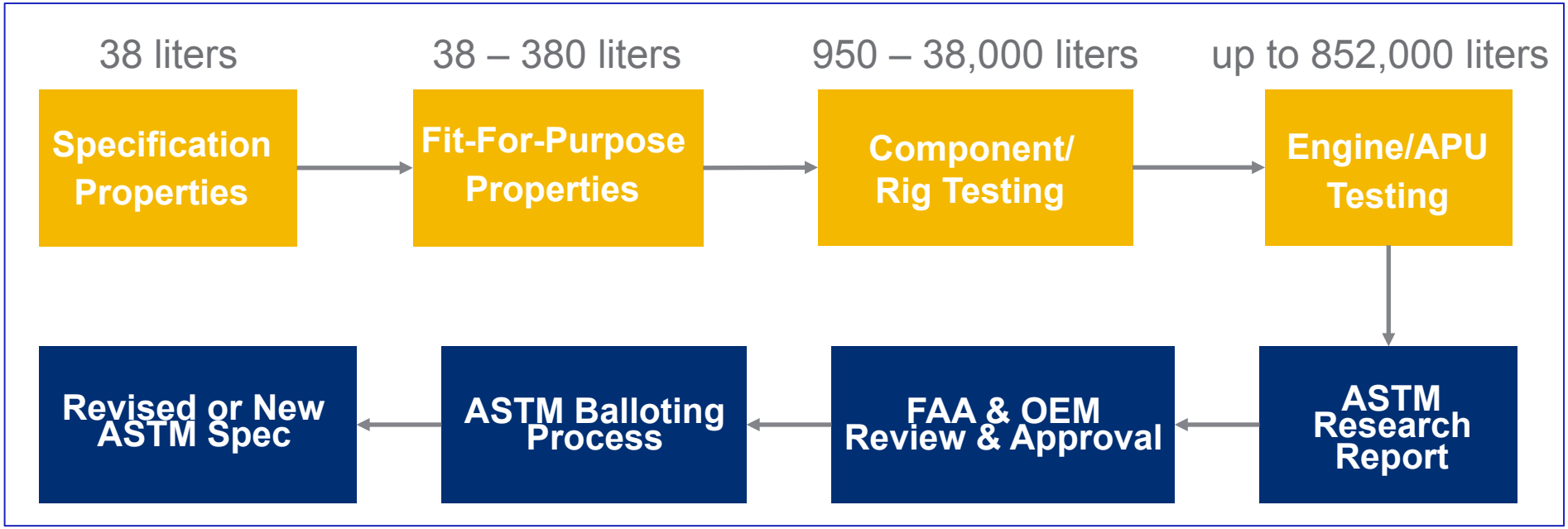


Ideal Carbon Length C8-C16

Paraffins	70 - 85%
Aromatic	< 25%*
Olefins	< 1%
S, N, O containing	< 5%

* Only ~7% aromatics is needed

Through the ASTM process increasingly larger amounts of fuel are required



What are the costs to fuel producers?

- Fuel specification and Fit-For-Purpose testing may be provided at no cost to the producer
- 38 liters can take weeks/months to produce in a laboratory setting
- Component and Rig, and Engine testing is significant cost to the producer
- Now, fuel production requires CapEx and OpEx for piloting

Economic viability – A TEA perspective

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Three Main Cost Drivers

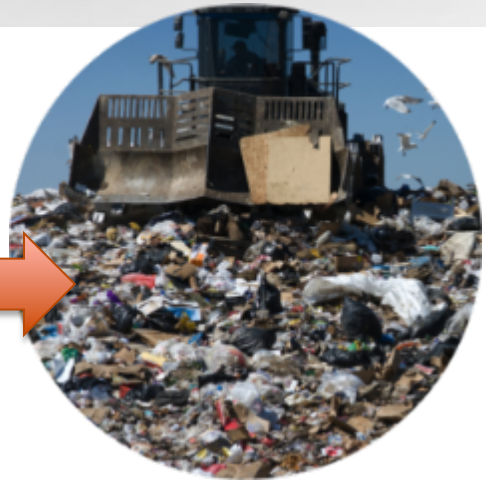
- Feedstock Cost
- Capital Investment
- Yield

Feedstock and Capital are the main issues

Solutions:

Waste feedstocks

- Industrial & municipal sludges
- Waste gases
- MSW



Reduce hydrogen demand and pressure

- Alkylation (e.g., alcohols, ketones)
- Ketonization, oligomerization

Leverage existing infrastructure

- Refinery integration

How might existing infrastructure be leveraged?

Refinery operations germane to biofuels

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Hydrotreating

- Remove heteroatoms (such as S, N, O) via catalytic reaction with H_2
  - Allow finished products to meet spec or to protect sensitive units
- Hydrotreating does not materially impact carbon chain length
  - Renewable feedstocks need to be introduced with a compatible chain length to allow on-spec production of fuels
- Trickle bed reactors contain fixed bed of sulfided NiMo- or CoMo/Al_2O_3 catalyst particles
  - Sensitive to fouling via solids deposition, coking or polymerization
  - Deactivation via metals, alkali, bio-heteroatoms (e.g., P)
  - May have challenges with heat gain across “standard” refinery hydrotreaters (e.g., may exceed allowable temperature limits)

Isomerization

- Converts n-paraffins to isomers (higher octane or alkylation feed)
- Fixed bed of metal/acid catalyst at lower temp than reforming

Alkylation (not likely for bio-derived intermediates going to jet)

- Converts isobutane & isobutylene to isooctane
- HF or H_2S acid catalyst (containment!!), sensitive to feed carbon number

Hydrocracking

- Converts and saturates heavy wide-boiling feeds to lighter fuels
- Similar issues to hydrotreating

How might existing infrastructure be leveraged?

A refiner's perspective

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– safety, reliability, predictability, profitability –

Risk	Type of Bio-oil Intermediate	Insertion	Refinery Challenges
Lowest	Well defined, consistent quality, such as single molecules (e.g., ethanol, butanol, farnesene)	Blending units	• Blending, product performance and distribution of products that include the bio-component • Evaluating and managing potential stability, toxicity and environmental issues
Medium	Intermediates requiring only minor treating (e.g. triglycerides, some direct liquefaction oils, some catalytically derived sugar oils)	Hydrotreating followed by blending	Challenges identified above, plus: • Understanding process performance on new feeds, and also blends with petroleum-based feeds • Enabling larger fractions of bio-oil blending stocks while still meeting product specs. • Providing sufficient hydrogen to meet hydrotreating demands (for reducing oxygen or aromatic contents)
Highest	Intermediates needing boiling range & composition changes for acceptable gasoline, diesel and jet fuel blending stocks (e.g. fast pyrolysis oils, some hydrothermal liquefaction oils, some catalytic pyrolysis oils)	Off-site or dedicated on-site hydrotreating followed by cat- or hydro-cracking	Challenges identified above, plus: • Understanding the impact of bio-oils on all refinery processes • Meeting product quantity and quality needs with feedstocks with less data on conversion behavior

Vertical integration

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Source: NRDC 2016 Scorecard

Motivation: Regulatory pressures and fuel price volatility

Result: Investment upstream in the supply chain

- Fuel purchase agreements
- Direct airline investments in fuel production facilities
- Development of alternative fuel feedstock sources

Trends unique to aviation biofuels

TABLE I: LEADING AIRLINES' ENGAGEMENT IN SUPPLY CHAIN DEVELOPMENT

	RSB-Certified Contract Placed	Firm targets	Supply chain/ Research & Development investment	ASTM process
Air France/KLM	yes	yes	yes	yes
Scandinavian Airlines (SAS)	yes	yes		
British Airways	yes	yes	yes[8]	yes
South African Airways	yes	yes	yes	
United Airlines	yes	yes	yes	yes
Cathay Pacific Airways	yes	yes	yes	yes

TABLE II: ADVANCING AIRLINES ENGAGEMENT IN SUPPLY CHAIN DEVELOPMENT

	RSB-certified contract placed	Firm targets	Supply chain/ R&D investment	ASTM process
Air New Zealand			yes	
Alaska Airlines		yes	yes	yes
Etihad Airways			yes	
Qantas Airways			yes	
Thomson Airways		yes		
Virgin Atlantic Airways	yes			yes
Virgin Australia Airlines		yes	yes	

Public commitment to purchase/use biofuels

- Leading Airlines – broad involvement in creating sustainable fuel supply chains, as well as solid commitments to use and purchase
  - Air France/Royal Dutch Airlines (KLM)*
  - British Airways
  - Cathay Pacific Airways
  - Scandinavian Airlines (SAS)*
  - South African Airways
  - United Airlines
- Advancing Airlines – engaged in advancing supply chain development
  - Air New Zealand*
  - Alaska Airlines
  - Etihad Airways
  - GOL Airlines
  - Japan Airlines
  - Qantas Airways*
  - Virgin Atlantic
  - Virgin Australia Airlines

*Airlines that have publically committed to eliminating fuels made from coal or natural gas when other options are available

Source: NRDC 2016 Scorecard

Effective, stable policy

- *"Rate the probability that aviation biofuel production will scale to levels that allow the aviation industry to reach its 2020 carbon-neutral-growth goals in conjunction with more efficient fleets and improved airspace management"*
  - >10%: 2 airlines
  - 10-30%: 6 airlines
  - 30-60%: 2 airlines
  - 60-90%: 7 airlines
- *"Do you believe airlines can meet 2020 carbon-neutral-growth goals without purchasing carbon offsets?"*
  - Yes: 4 airlines
  - No: 12 airlines
- *"Is your airline considering offsets as a means to achieve carbon neutrality goals?"*
  - Yes: 13 airlines
  - No: 3 airlines

Source: NRDC 2016 Scorecard

What is the U.S. working toward?

Working links between DOE, Labs, DOD, FAA and Industry provides a winning path

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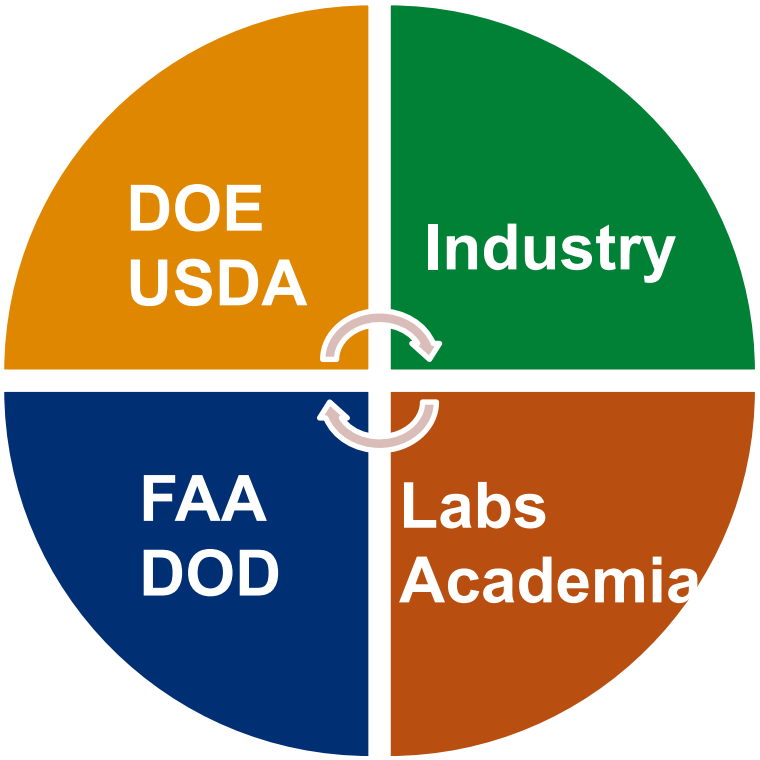
- ✓ Resource assessments
- ✓ R&D funding
- ✓ Tech transfer funding



- ✓ Technology
- ✓ Vision (fuel type)
- ✓ Business case
- ✓ Scale-up

- ✓ Fuel characterization
- ✓ Navigate ASTM
- ✓ Ascent (FAA center of excellence)
- ✓ Early adopter (DOD)

- ✓ Catalyst/organism discovery
- ✓ Process integration
- ✓ Demonstrate on real feeds

Summary

Technical competitiveness

- Biofuels should comprise the right molecules:
  - Importance of n- and iso-paraffins (e.g., freezing and boiling points)
  - Targeted properties (e.g., cloud and pour points, gum)
  - Meet performance and storability criteria

Economic competitiveness

- Waste & low/no-cost feedstocks
- Reduce conversion severity and hydrogen demand
- Leverage existing infrastructure
- Vertical integration of supply chain
- Transparent airline market signals – full disclosure of
  - Goals/timing, volumes, sustainable-certified biofuels, LCA/GHG monitoring
- Effective policy – e.g., small levy on global aviation GHG emissions

Thank you to our colleagues and partners!

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Branching greatly improves low temperature properties

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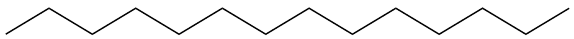
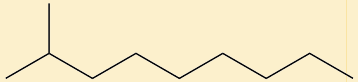
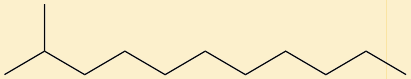
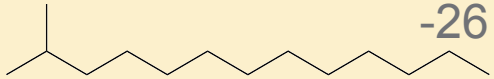
Freeze Point, °C

$C_{10}H_{22}$	FP	$C_{12}H_{26}$	FP	$C_{14}H_{30}$	FP
	-30		-10		-5.5
	-72		-46		-26
Jet A	-40 (max)	Jet A1	-47 (max)		