PARTNER

Partnership for AiR Transportation Noise and Emission Reduction

An FAA/NASA/TC-sponsored Center of Excellence

Alternative Jet Fuels

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The alternative fuels project is being conducted in collaboration with the RAND Corporation with David Ortiz being the Principle Investigator.

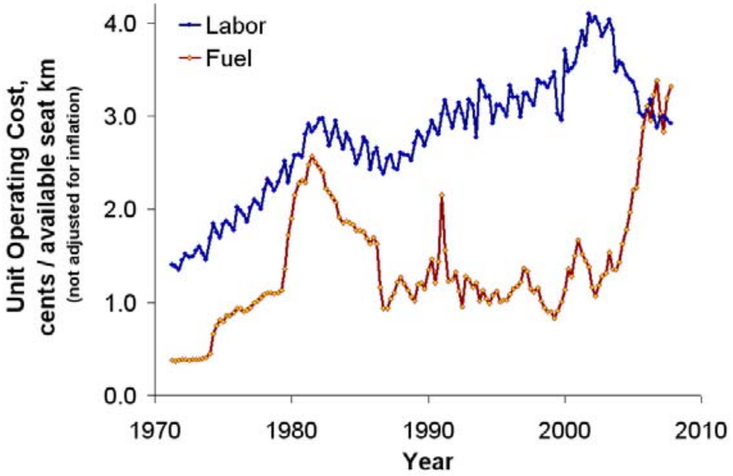
Information about PARTNER and its research: http://partner.aero

Motivation

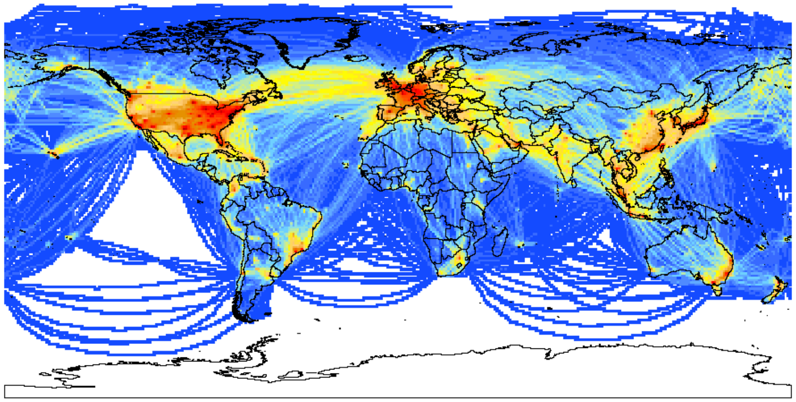
Two primary motivations for the evaluation of alternative fuels:

- The elevated level and volatility of the price of Jet A
- Environmental impacts of aviation on global climate change and air quality.

Airline average unit operating costs for fuel and labor (ATA, 2007)

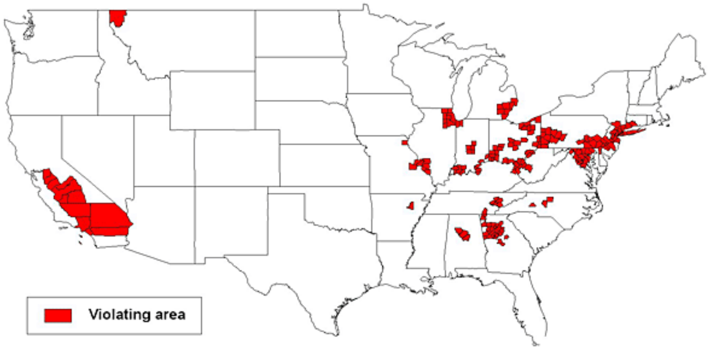


Worldwide Aviation CO_2 Emissions - 2000



Designated PM 2.5 Non-Attainment Areas as of 3-2007

U.S. EPA data interpreted by A.S.L & Assoc. Helena, MT 3/2007



Outline

- Research Overview
- Potential Alternative Jet Fuels
- Environmental Life-Cycle (Well-to-Wake) Analysis
- Alternative Jet Fuel Comparison Matrix
- Summary and Next Steps

Alternative Jet Fuels Research Program

Central Questions:

Are there alternative fuels for commercial aviation that could:

- Reduce price and price volatility of jet fuel?
- Reduce the environmental impact of aviation?

Study Constraints:

- Near-term emphasis, focus on availability in next decade.
- Consider fuels with a consistent set of metrics that focus on climate change, air quality, and production potential.

Extensive Collaboration:

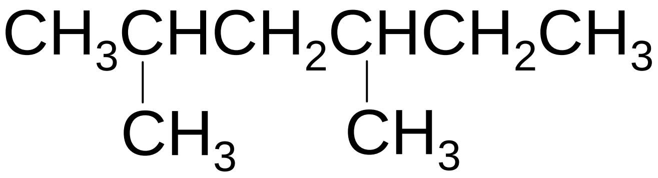
- RAND, CAAFI, AFRL, CSSI, ECG, Cambridge University, Boeing, Air Canada, Pratt & Whitney, and GE.

Jet Fuel Basics

Jet fuel composed of an array of hydrocarbon compounds

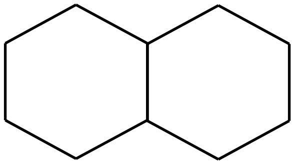
Paraffin – C_nH_{2n+2}

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

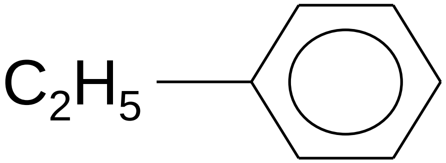


$$CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_2CH_3$$

Naphthene – C_nH_{2n}



Aromatic – C_nH_{2n-6}



Typical Jet Fuel Composition

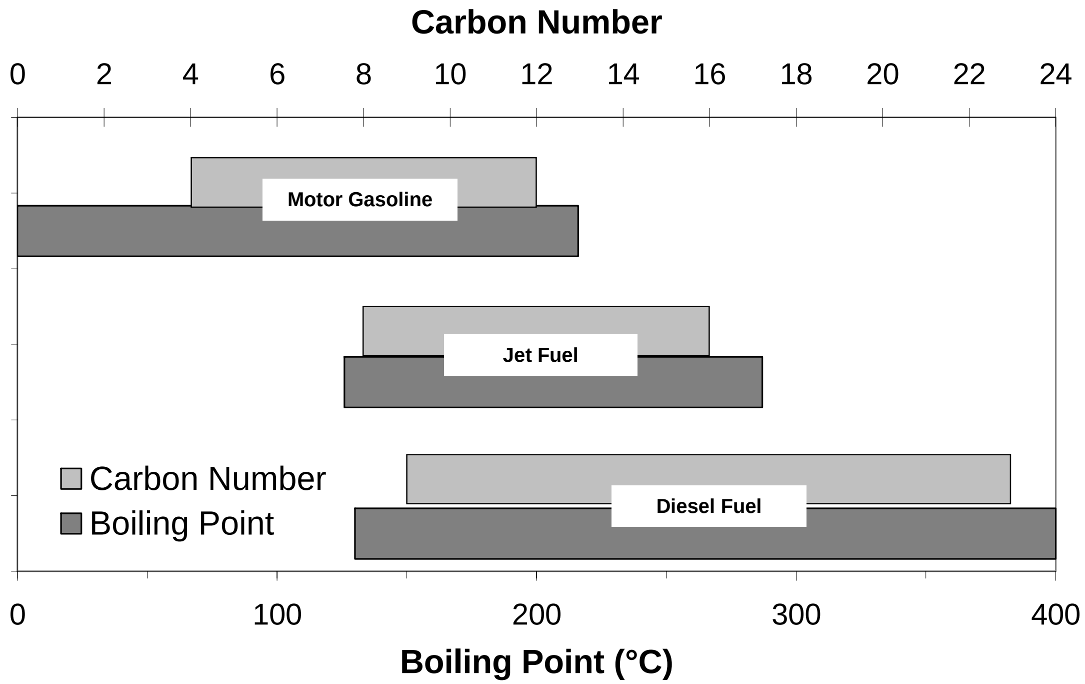
60% Paraffins

20% Napthenes

20% Aromatics (single and double ring)

Similarity of Jet Fuel and Diesel

- Jet fuel and diesel are similar because of similar distillation ranges (key step in fuel refining)



- Refiners can shift fuel production from gasoline and diesel to jet fuel production based on demand
- ***Alternative jet fuels could be alternative diesel fuels***

Fischer-Tropsch (F-T) Fuels

Three major steps in process:

Gasification, F-T Synthesis & Upgrading

- Gasification: biomass, coal, or natural gas reacted with steam and oxygen to form syngas, a mixture of hydrogen and carbon monoxide (pollutants are scrubbed from syngas prior to next step)
- F-T Synthesis: syngas is passed over a catalyst to form a mixture of paraffinic hydrocarbons – reaction results in long paraffin chains
- Upgrading: hydrogen gas is used to “crack” molecules to create desired range of products (diesel, jet, naptha, etc.) – cannot tune system to just produce one type of fuel

Resulting F-T fuel is 100% paraffinic with zero sulfur

Potential Alternative Jet Fuels

Biojet, Biokerosene, and Biodiesel

- At present, no commonly accepted definition of biojet.
- For the PARTNER-RAND study, have distinct definitions.
- Biodiesel:
  - Created via chemical reaction of methanol with vegetable oil (methanol + oil → fuel)
  - Blending limited to 5% - freeze point
  - A.K.A. Fatty Acid Methyl Ester - $C_mH_nO_2CH_3$
- Biokerosene:
  - Biodiesel from lower carbon fuels (such as coconut oil)
  - Lower freeze point -> higher blend percentages (20%)
  - <u>Not</u> a drop-in replacement
- Biojet:
  - Created via hydrotreatment of vegetable oil (H_2 + oil → fuel)
  - Paraffinic fuel with zero oxygen content, similar to F-T fuels
  - Distillation range is similar to jet

Ultra Low Sulfur (ULS) Jet Fuel

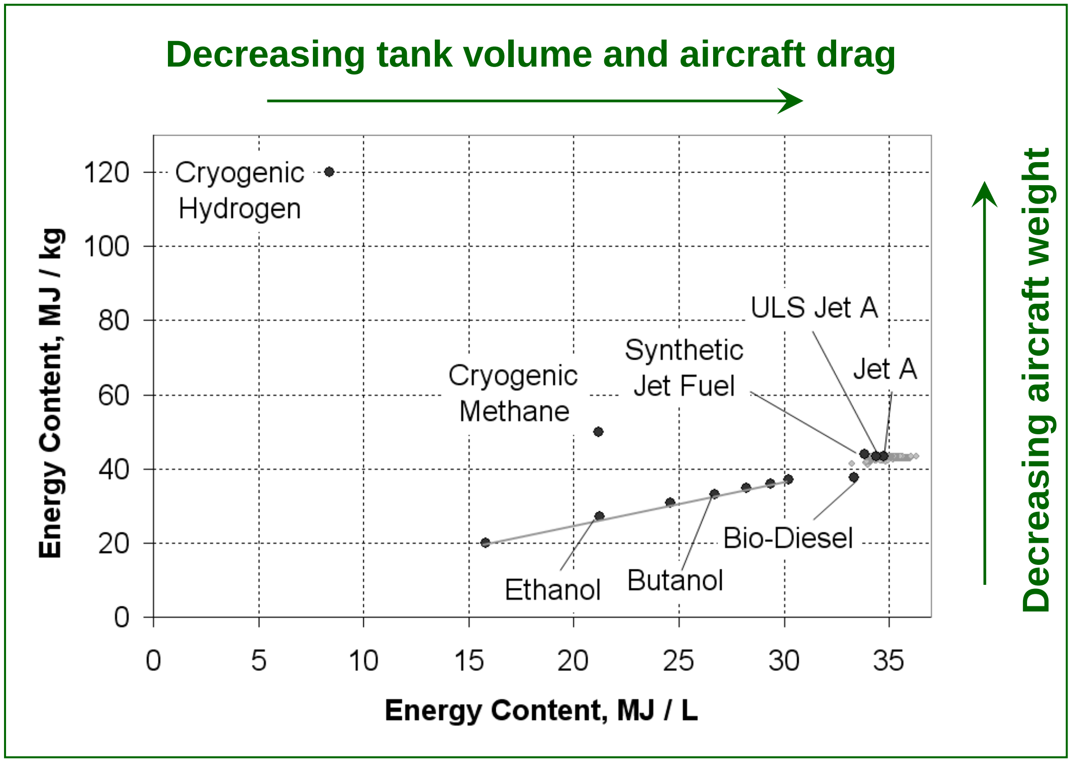
- Not an alternative feedstock – instead, an alternative fuel composition (ultra low fuel sulfur content)
- Current jet fuel sulfur content
  - ~600ppm sulfur (varies by region and year)
- Diesel has an ultra-low sulfur standard
  - EPA requirements for 15 ppm ULS diesel
  - Hydrotreatment used for sulfur removal - Results in 1% loss in volumetric energy content and small gain in gravimetric energy content
  - Added cost of between $0.04 and $0.07 per gallon
- Much of the ULS diesel fuel knowledge is directly transferable due to similarities in diesel fuel and jet fuel

Potential Alternative Jet Fuels

Energy Content Comparison

Potential fuels:

- Conventional Jet-A
- Ultra Low Sulfur (ULS) Jet-A
- Fischer-Tropsch (F-T) fuels created from natural gas, coal, or biomass
- Fuels from bio-based oils: bio-jet and bio-diesel
- Alcohols
- Cryogenic fuels (*not considered further*)



Potential feed stocks:

- Conventional oil, tar sands, very heavy oil, or oil shale → Jet A and ULS Jet A.
- Coal and natural gas → F-T fuels.
- Renewable feed stocks → F-T fuels, bio-diesel, bio-jet, and alcohols.

Potential Alternative Jet Fuels

Compositional Comparison

Potential fuels:	Chemical Composition	Aromatic Content	Sulfur Content
Conventional Jet-A	C_mH_n	~20%	~600 ppm
ULS Jet-A	C_mH_n	~20%	under 15 ppm
Synthetic Paraffinic Kerosene Fuels • F-T fuel from natural gas, coal, biomass • Bio-jet from hydrotreated bio-based oils	C_mH_n	~0	under 15 ppm
Bio-diesel / Bio-kerosene	$C_mH_nO_2CH_3$	0	~50 ppm
Butanol	C_4H_9OH	0	under 15 ppm
Ethanol	C_2H_5OH	0	under 15 ppm

Importance to Air Quality:

Many airports operate in PM2.5 non-attainment areas.

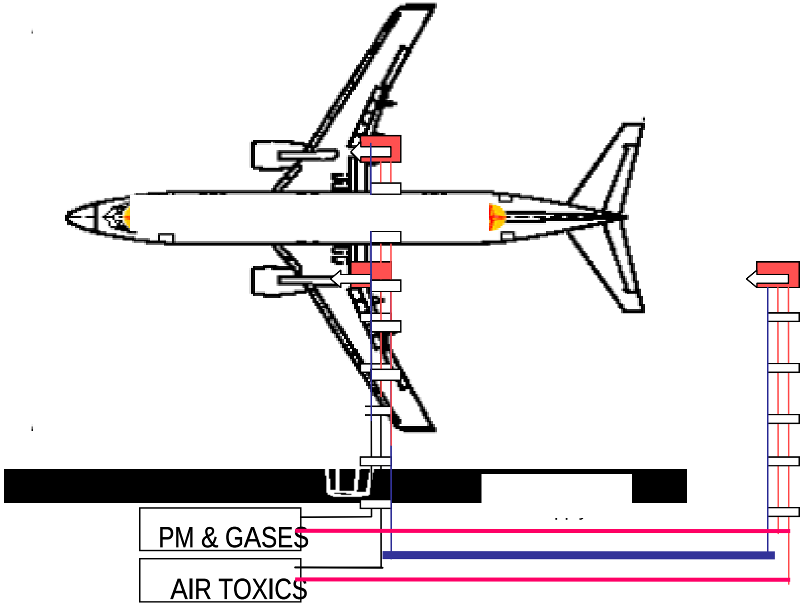
Low aromatic fuels have reduced soot emissions, a component of PM2.5.

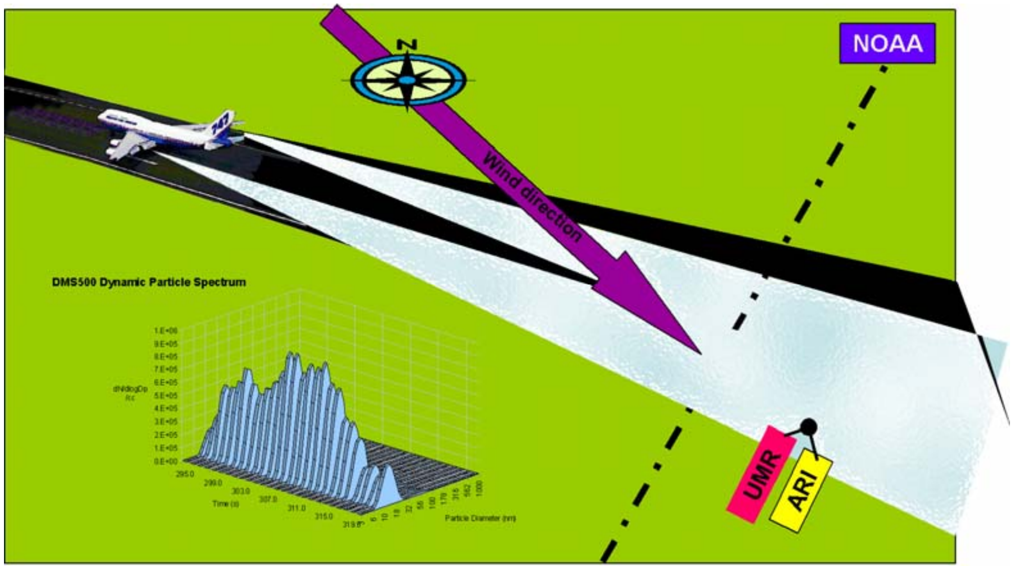
Sulfur oxides (resulting from combustion) result in PM2.5.

PARTNER Research (led by Missouri University of Science and Technology)

Aircraft particulate matter (PM) measurements

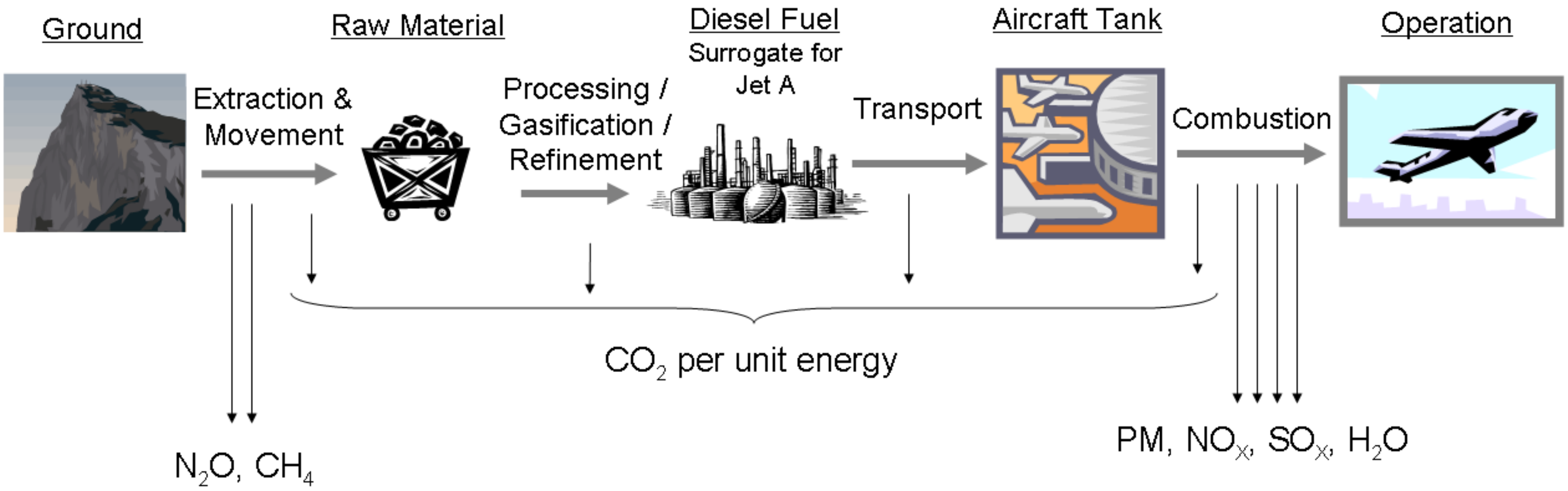
- Measured hundreds of aircraft
  - Operational
  - After hours
- Compared and assessed measurement methods
- Modeled PM and precursor behavior
- Measured and modeled plume behavior
- Analyzing baseline and alternative fuels
- Data will feed into environmental modeling





Overview of Analysis Procedure

- Examine fuel life-cycle from “*well-to-wake*.”



- Analyze fleet-wide alternative fuel use.
- Estimate emissions affecting air quality and climate change.
- Use existing tools:
  - Aircraft analysis via FAA-NASA-TC tool suite (Aviation Environmental Portfolio Management Tool, APMT, and Aviation Environmental Design Tool, AEDT).[1]
  - Fuel analysis via GREET framework (Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) ***with inputs that reflect the range of values found in literature***.[2]

Limited Details of Analysis Procedure

Scale worldwide aircraft fuel use and emissions inventory (AEDT).

Aircraft fuel weight, volume, and energy

- Combine Breguet range equation, fuel energy content, and aircraft performance data to determine fuel use scaling.
- Ignore requisite aircraft and infrastructure modifications.

Well-to-Tank emissions

- Modify GREET framework to examine jet fuel (GREET designed for ground transportation) - results presented here based on diesel fuel.
- Utilize data from literature to place bounds on lifecycle emissions

Tank-to-Wake (combustion) emissions affecting climate change

- Aircraft fuel weight (from above) combined with emission indices to estimate CO_2, H_2O, NO_X, and SO_X.

Tank-to-Wake (combustion) emissions affecting air quality

- Takeoff fuel use scaled by ratio of energy contents.
- Primary particulate matter scaled by change in fuel use, change in fuel sulfur content, and parameterization of soot emissions.
- NO_X scaled by change in fuel use.
- SO_X estimated from change in fuel use and fuel sulfur content.

Fleet-wide Alternative Fuel Use

Jet A:

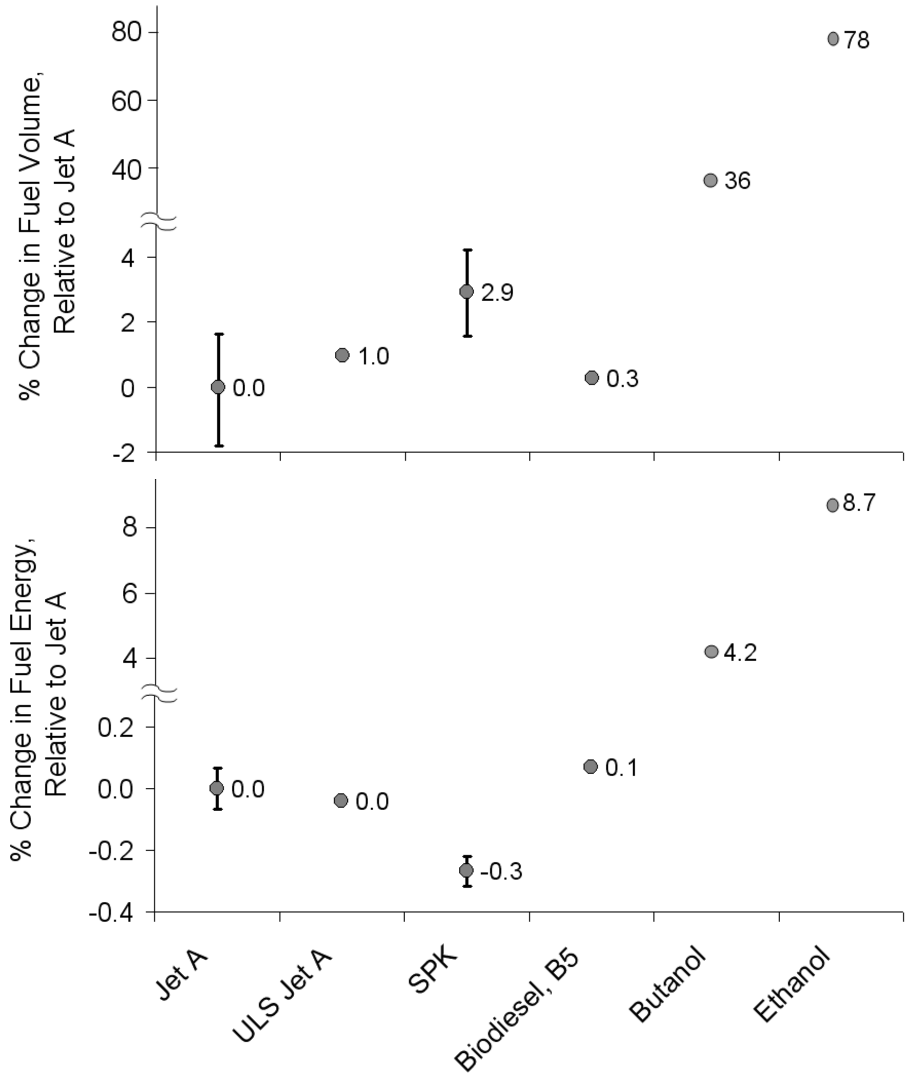
- Variability based on PQIS data.
- ULS within Jet A variability.

Synthetic Paraffinic Kerosene:

- Require more fuel volume but less fuel energy.
- Variability based on measured energy content from literature.

Alcohols

- Require much more energy.
- Better suited for ground transportation.



Preliminary results, do not cite or quote

Fuel Use & Fleet-wide CO_2 Emissions

Life-Cycle CO_2 typically given in g CO_2 / MJ or per distance traveled.

For aviation, need to consider lifecycle carbon dioxide emissions per payload-distance flown

Obtain by combining fuel use change with lifecycle CO_2 emissions.

Definition of CO_2 Intensity:

$$= \left(\frac{\text{Energy Use}}{\text{Payload * Distance}} \right) (\text{Energy Ratio}) (\text{Lifecycle CO}_2)$$

$$= \left(\frac{\text{MJ}_{\text{Jet A}}}{\text{kg} \cdot \text{km}} \right) \left(\frac{\text{MJ}_{\text{Alt Fuel}}}{\text{MJ}_{\text{Jet A}}} \right) \left(\frac{\text{g CO}_2}{\text{MJ}_{\text{Alt Fuel}}} \right) = \frac{\text{g CO}_2}{\text{kg} \cdot \text{km}}$$

Jet A CO_2 Intensity:

U.S. commercial fleet achieved 0.015 MJ / kg-km in 2005

$$= \left(0.015 \frac{\text{MJ}_{\text{Jet A}}}{\text{kg} \cdot \text{km}} \right) (1) \left(87 \frac{\text{g CO}_2}{\text{MJ}_{\text{Jet A}}} \right) = 1.3 \frac{\text{g CO}_2}{\text{kg} \cdot \text{km}}$$

CO_2 Intensity of 1.3 g CO2 / kg-km for U.S. fleet in 2005

Environmental Life-Cycle (Well-to-Wake) Analysis

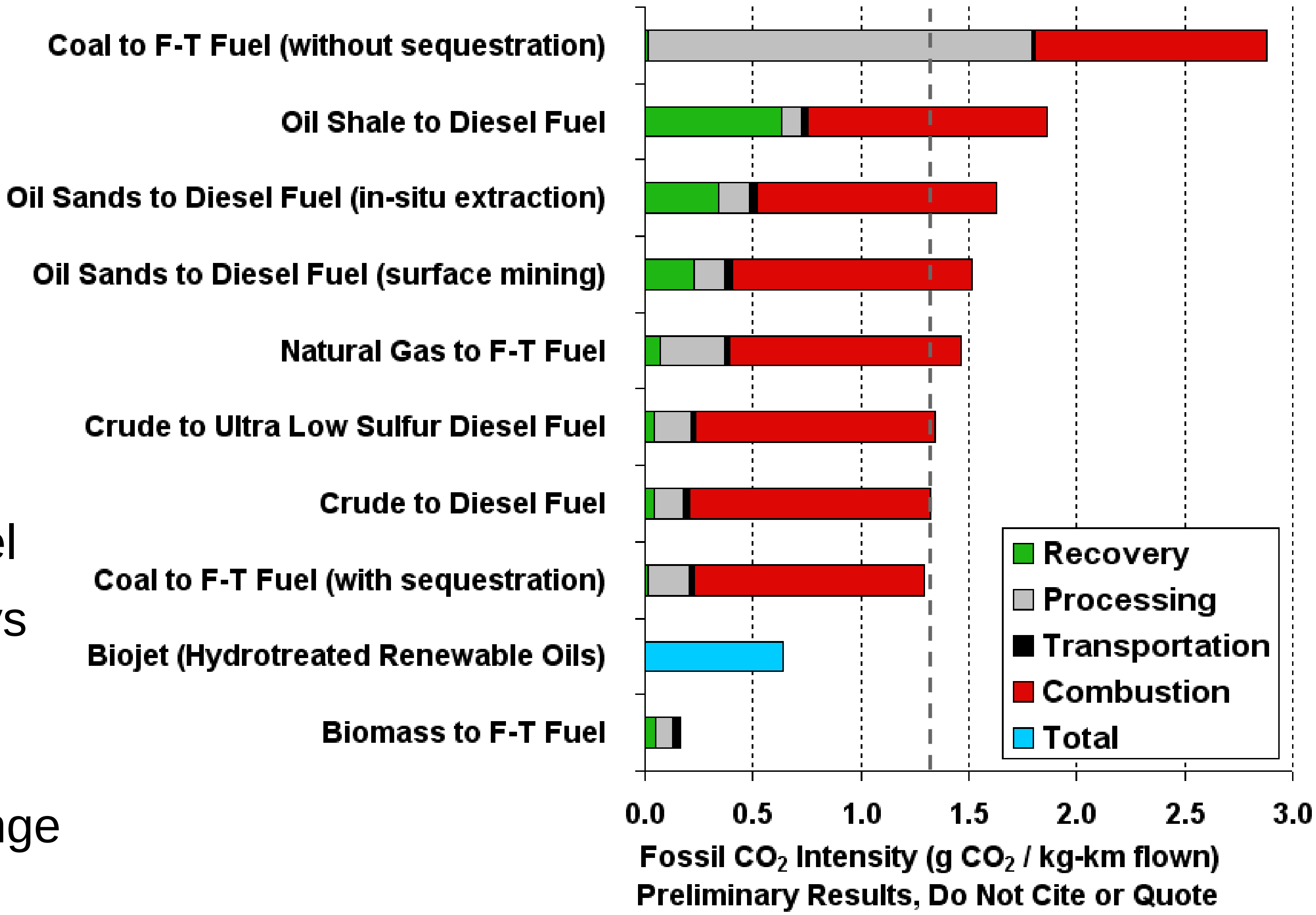
Life-cycle Carbon Dioxide Emissions

Variation due to:

- Recovery technique
- Processing
- Biomass utilization

Ongoing work:

- Analyze jet fuel
- Biojet pathways
- Uncertainty analysis
- Land use change



Preliminary Results, Do Not Cite or Quote

To reduce carbon dioxide emissions, need biofuels created from waste products or harvests from non farm land.

Environmental Life-Cycle (Well-to-Wake) Analysis

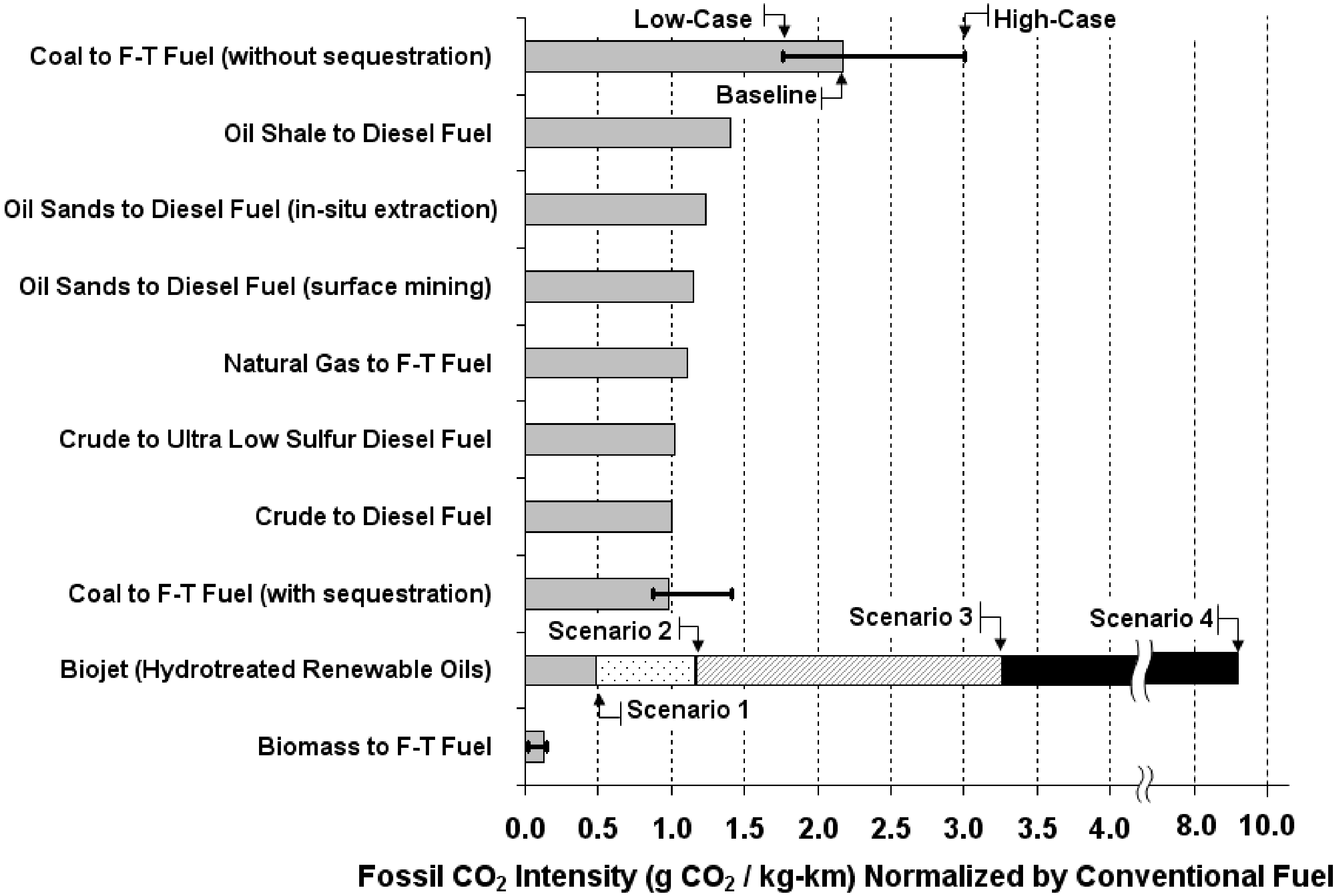
Impact of Uncertainties

Uncertainties:

- Feedstock variation
- Process efficiency
- Carbon capture efficiency

Land use change scenarios:

1. None
2. Cerrado grassland
3. "Large scale" corn ethanol use
4. Peatland rainforest



Preliminary Results, Do Not Cite or Quote

In general, life-cycle emissions are not deterministic, "Point Values." Instead, they are better defined as scenario-dependent ranges.

PARTNER-RAND Alternative Jet Fuel Report

Report presents analysis of multiple fuels and feedstocks

- Compare fuels using a set of metrics that emphasize compatibility, availability, environment, and use.
- Use metrics to create a fuel comparison matrix.
- Use environmental analysis and research by MIT and RAND Corporation.

Received reviews from two external reviewers, members of CAAFI, and FAA.

Present preliminary “Alternative Jet Fuel Comparison Matrix"

Comparison Metrics

Potential fuels compared using common set of metrics:

- Usability in current systems (aircraft and fuel infrastructure) without compromising safety
- Fuel availability within a given timeframe (technology readiness and supply potential)
- Reduced environmental impacts (climate change and air quality)
- Merit of aviation use versus ground transportation use

Comparison metrics for potential alternative fuels for aviation:

Compatibility in Current Systems	***Fuel Readiness Level***	***Production Potential***	***Carbon Dioxide***		***Air Quality***	***Merit of Aviation Use***
			Well-to-Wake	***Tank-to-Wake***		

Fuels and Feed Stocks

- Ultralow Sulfur (ULS) Jet A from:
  - Conventional petroleum
- Conventional Jet A from:
  - Oil sands / very heavy oils
  - Oil shale using in-situ production
- Fischer-Tropsch (F-T) synthetic fuels from:
  - Coal (without and with CO_2 CCS)
  - Natural gas
  - Biomass
- Biodiesel from:
  - Treatment of vegetable oil with methanol
- Biojet from:
  - Hydrotreatment of vegetable oil
- Ethanol from:
  - Fermentation of corn
- Butanol from
  - Fermentation of corn

Fuel
ULS Jet A from conventional petroleum
Current-specification Jet A from oil sands or very heavy oil (VHO)
Current-specification Jet A from shale oil
F-T fuel from coal
F-T fuel from coal with sequestration
F-T fuel from natural gas
F-T fuel from biomass
Biodiesel (5%)
Biojet
Ethanol
Butanol

Alternative Jet Fuel Comparison Matrix

Matrix Structure

Fuel	Characteristics and Desirability in comparison to Current-Specification Jet A Derived from Conventional Petroleum						
	Compatibility in Current Systems	FRL	Production Potential	Carbon Dioxide		Air Quality	Merit of Aviation Use
				Well-to-Wake	Tank-to-Wake		
ULS Jet A from conventional petroleum	-	+++	+++	-	0	++	0
Current-specification Jet A from oil sands or very heavy oil (VHO)	0	+++	+	--	0	0	0
Current-specification Jet A from shale oil	0	--	---	--	0	0	0
F-T fuel from coal	-	++	+	---	+	++	0
F-T fuel from coal with sequestration	-	[illegible]	[illegible]	[illegible]	[illegible]	++	0
F-T fuel from natural gas	-	+++	---	-	+	++	0
F-T fuel from biomass	-	+	-	+++	+	++	0
Biodiesel (5%)	--	+++	-	+	0	0	--
Biojet (20%)	-	+	-	++	+	+	-
Ethanol (100%)	--	+++	+	++	-	- / +	---
Butanol (100%)	--	0	---	++	-	- / +	---

Metrics to characterize fuels

Fuels and feed stocks

Alternative Jet Fuel Comparison Matrix

Matrix Structure

Fuel	Characteristics and Desirability in comparison to Current-Specification Jet A Derived from Conventional Petroleum						
	Compatibility in Current Systems	FRL	Production Potential	Carbon Dioxide		Air Quality	Merit of Aviation Use
				Well-to-Wake	Tank-to-Wake		
ULS Jet A from conventional petroleum	-	+++	+++	-	0	++	0
Current-specification Jet A from oil sands or very heavy oil (VHO)	0	+++	+	--	0	0	0
Current-specification Jet A from shale oil							
F-T fuel from coal							
F-T fuel from coal with sequestration							
F-T fuel from natural gas							
F-T fuel from biomass							
Biodiesel (5%)							
Biojet (20%)							
Ethanol (100%)	--	+++	+	++	-	- / +	---
Butanol (100%)	--	0	---	++	-	- / +	---

Remainder of presentation:

- Fill in matrix entries based on preliminary analysis results.
- Present each column individually – each represents a separate study.
- Columns combined to form matrix.

Usability in Current Systems

- Drop-in replacement fuels
  - Similar properties to conventional Jet A and can be blended with Jet A at high percentages.
  - Examples: ULS Jet A, Jet A from unconventional petroleum, F-T fuels, and biojet.
- Biodiesel
  - Concerns regarding freeze point and thermal stability.
  - If used, would have to be a light blend (<5%)
- Alcohols
  - Concerns regarding corrosiveness, energy content, vapor pressure, water solubility, and flash point.
- **Large installed base of Jet A-specific infrastructure heavily favors drop-in fuels.**

Fuel & Usability

ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	**-**
CURRENT SPEC. JET A FROM TAR SANDS / VHO	**0**
CURRENT SPEC. JET A FROM OIL SHALE	**-**
F-T FUEL FROM COAL	**-**
F-T FUEL FROM COAL W/ SEQUESTRATION	**-**
F-T FUEL FROM NATURAL GAS	**-**
F-T FUEL FROM BIOMASS	**-**
BIODIESEL (5%)	**--**
BIOJET	**-**
ETHANOL	**---**
BUTANOL	**--**

Preliminary Data.
Do not cite or quote.

Alternative Jet Fuel Comparison Matrix Entries

Fuel Readiness Level (FRL)

- Qualitatively assess *current* technological maturity of fuel production process.
- FRL determined by least developed part of fuel production process.

FRL	Description
---	Fuel creation process is undergoing fundamental research and development at laboratory scale to prove viability of fuel creation concept.
--	Fuel creation process is undergoing intermediate research and development to prove viability of individual components.
-	Fuel creation process is undergoing advanced research and development.
0	All relevant technologies that are necessary for fuel production have been proven.
+	Commercial pilot plant is under construction or in operation.
++	The fuel is in limited commercial production using fuel creation process.
+++	The fuel is in large-scale, commercial production using fuel creation process.

Fuel & FRL

ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	+++
CURRENT SPEC. JET A FROM TAR SANDS / VHO	+++
CURRENT SPEC. JET A FROM OIL SHALE	--
F-T FUEL FROM COAL	+++
F-T FUEL FROM COAL W/ SEQUESTRATION	- / +
F-T FUEL FROM NATURAL GAS	+++
F-T FUEL FROM BIOMASS	+
BIODIESEL (5%)	+++
BIOJET	+
ETHANOL	+++
BUTANOL	+

Preliminary Data.
Do not cite or quote.

Production Potential in Ten Years

- **Alternative fuels not likely to be widely available in significant quantities in 10 years.**

Fuel consumption, in millions of barrels per day

	World (2004)	USA (2004)
Motor Gasoline	20.9	9.1
Jet Fuel	4.8	1.6 *
Distillate (Diesel)	22.5	4.1

* 1.6 million barrels per day = 47,000 gallons per minute

Percent of Projected Jet A Demand in 2017 (2.1 mbpd) use North American resources; business as usual

~100%	~50%	~10%	~5%	~1%	~0.5%	~0.1%
+++	++	+	0	-	--	---

Fuel & Production Potential

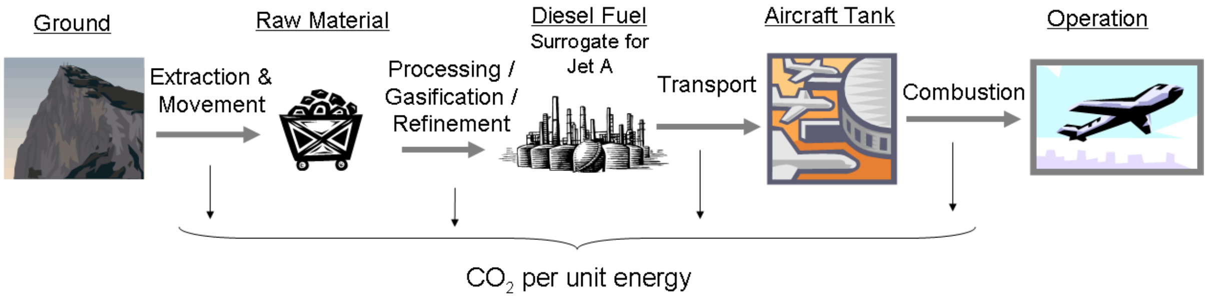
ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	+++
CURRENT SPEC. JET A FROM TAR SANDS / VHO	+
CURRENT SPEC. JET A FROM OIL SHALE	---
F-T FUEL FROM COAL	+
F-T FUEL FROM COAL W/ SEQUESTRATION	+
F-T FUEL FROM NATURAL GAS	---/+
F-T FUEL FROM BIOMASS	-
BIODIESEL (5%)	-/0
BIOJET	-/0
ETHANOL	+
BUTANOL	N/A

**Preliminary Data.
Do not cite or quote.**

Alternative Jet Fuel Comparison Matrix Entries

Lifecycle CO_2 Emissions

- Examined fuel life cycle to determine total carbon dioxide emissions using accepted data from the literature and Argonne National Laboratory GREET model.
- Data are on a per unit energy basis



- **Biomass-based fuels provide potential for substantial carbon dioxide reductions; land use changes add uncertainty.**

Lifecycle CO_2 relative to Jet A from Conv. Petroleum

< 0.5X	0.5X to 0.9X	0.9X to 1.0X	~1.0X	1.0X to 1.1X	1.1X to 1.5X	> 1.5X
+++	++	+	0	-	--	---

Fuel & Lifecycle CO_2

ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	-
CURRENT SPEC. JET A FROM TAR SANDS / VHO	--
CURRENT SPEC. JET A FROM OIL SHALE	--
F-T FUEL FROM COAL	---
F-T FUEL FROM COAL W/ SEQUESTRATION	0
F-T FUEL FROM NATURAL GAS	--
F-T FUEL FROM BIOMASS	+++
BIODIESEL (5%)	--/+
BIOJET	---/+++
ETHANOL	-/+++
BUTANOL	0/+++

Preliminary Data.
Do not cite or quote.

Alternative Jet Fuel Comparison Matrix Entries

Air Quality Emissions

Estimated impact of fuel change on:

- Primary particulate matter
- Secondary particulate matter from sulfur oxide emissions
- Secondary particulate matter from emissions of nitrogen oxides

Pluses/minuses refer to number of above that are reduced/increased by more than 10%.

Alcohols impact uncertain due to NO_X, PM, and aldehydes.

Reducing sulfur / aromatics yields benefit.

Could get local air quality improvement by removing sulfur from Jet A.

Note: ULS Jet A may cost an additional $0.04 to $0.07 per gallon to produce and may suffer 1% reduction in volumetric energy density.

Fuel & AQ Emissions

ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	++
CURRENT SPEC. JET A FROM TAR SANDS / VHO	0
CURRENT SPEC. JET A FROM OIL SHALE	++
F-T FUEL FROM COAL	++
F-T FUEL FROM COAL W/ SEQUESTRATION	++
F-T FUEL FROM NATURAL GAS	++
F-T FUEL FROM BIOMASS	++
BIODIESEL (5%)	0
BIOJET	++
ETHANOL	- / +
BUTANOL	- / +

Preliminary Data.
Do not cite or quote.

Alternative Jet Fuel Comparison Matrix Entries

Merit of Aviation Use of Fuel

Incentives of various transportation sectors to use alternative fuels (beyond shared CO_2 benefits):

- *Octane / Cetane* - ground transportation pays a premium for these properties
- *Energy Content* - aircraft suffer fuel economy penalty when using low energy fuels (fuel economy benefit with high energy)
- *Water Vapor Emissions* - little climate impact when emitted from ground level and troposphere, larger climate impact when emitted into stratosphere
- *Safety* - high vapor pressure and low flash point complicate ground handling

Fuel & Merit of Aviation Use

ULTRA LOW SULFUR JET A FROM CONV. PETROLEUM	**0**
CURRENT SPEC. JET A FROM TAR SANDS / VHO	**0**
CURRENT SPEC. JET A FROM OIL SHALE	**0**
F-T FUEL FROM COAL	**0**
F-T FUEL FROM COAL W/ SEQUESTRATION	**0**
F-T FUEL FROM NATURAL GAS	**0**
F-T FUEL FROM BIOMASS	**0**
BIODIESEL (5%)	**--**
BIOJET	**0**
ETHANOL	**---**
BUTANOL	**---**

Preliminary Data.
Do not cite or quote.

Matrix of Alternative Fuels for Commercial Aviation

Preliminary results,
Do not cite or quote.

PARTNER

Fuel	Characteristics and Desirability in comparison to Current-Specification Jet A Derived from Conventional Petroleum						
	Compatibility in Current Systems	FRL	Production Potential	Carbon Dioxide		Air Quality	Merit of Aviation Use
				Well-to-Wake	Tank-to-Wake		
ULS Jet A from conventional petroleum	-	+++	+++	-	0	++	0
Current-specification Jet A from oil sands or very heavy oil	0	+++	+	--	0	0	0
Current-specification Jet A from oil shale	-	--	---	--	0	++	0
F-T fuel from coal	-	+++	+	---	+	++	0
F-T fuel from coal with sequestration	-	- / +	+	0	+	++	0
F-T fuel from natural gas	-	+++	---/+	--	+	++	0
F-T fuel from biomass	-	+	-	+++	+	++	0
Biodiesel (5%)	--	+++	-/0	--/+	0	0	--
Biojet	-	+	-/0	---/+++	+	++	0
Ethanol	---	+++	+	-/+++	-	- / +	---
Butanol	--	+	N/A	0/+++	-	- / +	---

Summary

- Alcohols are not a viable alternative for aviation and are better suited for ground transportation.
- Low sulfur fuels (e.g., ULS Jet) could improve air quality and ULS Jet A could ease alternative fuel introduction.
- Coal-to-liquid fuels (via F-T process with CCS) have comparable lifecycle CO_2 to conventional fuel and their use could improve air quality. Without CCS, lifecycle CO_2 will double (or triple with low efficiency and poor quality coal).
- Alternative fuels exist that could both reduce lifecycle CO_2 and improve air quality (e.g., biojet and biomass-to-liquids via F-T process), but at present the ability to produce these fuels is limited.
- Uncertainties in inputs and land use changes need to be considered in life-cycle analysis.

Ongoing Alternative Jet Fuels Research

- PARTNER-RAND Alternative Jet Fuels report being completed.
- Refining life-cycle analysis to estimate jet fuel.
- Cost-benefit analysis of alternative fuel use in ground support equipment is underway.
- Emission measurements from aircraft operating on alternative fuels.
- Aviation-specific life-cycle analysis tool being developed (joint effort of FAA AEE and Air Force Research Labs):
  - Well-to-tank analysis of lifecycle emissions of Jet Fuel production using GREET framework
  - Tank-to-wake analysis of Jet Fuel combustion using FAA-NASA-TC modeling tools
  - Impact analysis of well-to-wake emissions on air quality and global climate change using FAA-NASA-TC modeling tools
  - Creation of alternative fuel introduction scenarios
  - Assessment of environmental costs and benefits of fuel introduction scenarios.

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Backup Slides

Backup Slide

Local Air Quality Emissions

Fleet-wide landing and takeoff emissions

Fuel Type	ΔFuel Flow, Weight	ΔNO_X	ΔSO_X	ΔPM
Jet A (90% of JP-8)	0.5% to -0.5%	0.5% to -0.5%	0.5% to -0.5%	0.5% to -0.5%
Ultra Low Sulfur Jet A	-0.3%	-0.3%	-97.5%	-14.5%
Synthetic Fuel	-1.6% to -2.3%	-1.6% to -2.3%	-97.5% to -97.6%	-14.5% to -77%
5% Biodiesel Blend	0.7%	0.7%	-3.9%	-3.2% to -16.2%
Butanol	30.4%	-	-96.7%	-
Ethanol	60.3%	-	-96.0%	-

* Values relative to mean JP-8 values from PQIS
** Results in table are preliminary, do not quote or cite

Several fuel options provide substantial SO_X reductions.

Synthetic fuels (F-T or biojet) offer potential for substantial primary PM reduction in addition to SO_X reductions.

Need to refine PM estimates based on recent measurements.

Cruise Emissions

Fleet-wide cruise emissions (not life-cycle emissions)

Fuel Type	ΔFuel Burn, Weight	ΔCO_2	ΔH_2O	ΔNO_X	ΔSO_X
Jet A (90% of JP-8)	0.5% to -0.6%	1.0% to -1.1%	-2.4% to 2.5%	0.5% to -0.6%	0.5% to -0.6%
Ultra Low Sulfur Jet A	-0.3%	-0.6%	1.4%	-0.3%	-97.5%
Synthetic Fuel	-1.9% to -2.6%	-3.3% to -4.7%	6.9% to 10.3%	-1.9% to -2.6%	-97.5% to -97.6%
5% Biodiesel Blend, B5	0.7%	0.2%	-0.2%	0.7%	-3.9%
Butanol	36%	2.1%	34.2%	-	-96.6%
Ethanol	74%	5.4%	66.1%	-	-95.6%

*** Values relative to mean JP-8 values**
**** Results in table are preliminary, do not quote or cite**

Alcohols are better suited for use in ground transportation because of increased energy requirement and increased water emissions.