Partnership for AiR Transportation Noise and Emission Reduction

An FAA/NASA/TC-sponsored Center of Excellence

Environmental Viability of Alternative Jet Fuels

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Background and Acknowledgments

- Full Research Team: Russell Stratton, Matthew Pearlson, Nicholas Carter, Kristy Bishop, Hsin Min Wong, Pearl Donohoo, Christoph Wollersheim, Malcolm Weiss, Ian Waitz, and James Hileman, mostly of MIT Aero Astro
- Finishing fourth year of research on alternative jet fuels with funding from FAA, U.S. Air Force (PARTNER Project 28) and National Academies (ACRP Project 02-07)
- In next two-year phase of PARTNER research, will collaborate with:
  - MIT Joint Program on Global Change
  - Woods Hole Marine Biological Lab
  - Argonne National Labs (GREET)
  - U.S. Department of Transportation Volpe Transportation Center
  - Environmental Law Institute
- PARTNER cost share partners:
  - DLR, U. of Cambridge, Boeing, Pratt & Whitney, and Shell

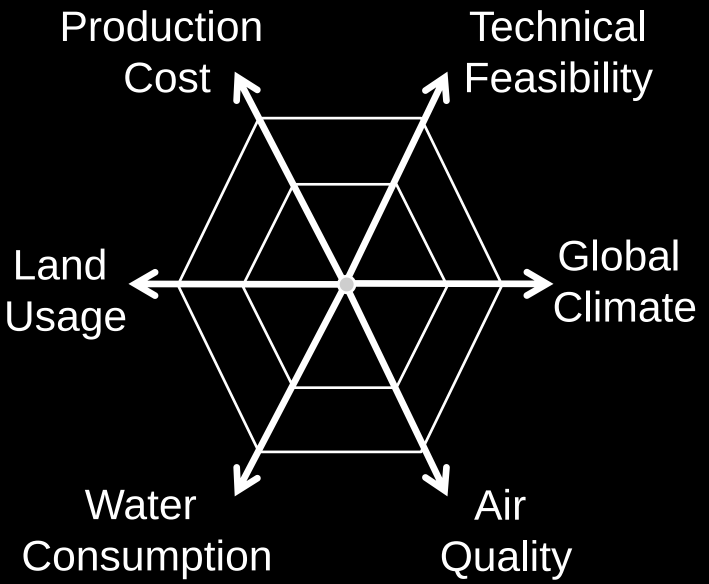
Motivation

Examining Potential of Alternative Fuels to:

- Reduce emissions that impact global climate change and air quality thus improving the environment.
- Expand and diversify energy supplies beyond conventional petroleum.
- Be produced in large quantities without adverse impacts on our land and water resources.

Study Uniqueness:

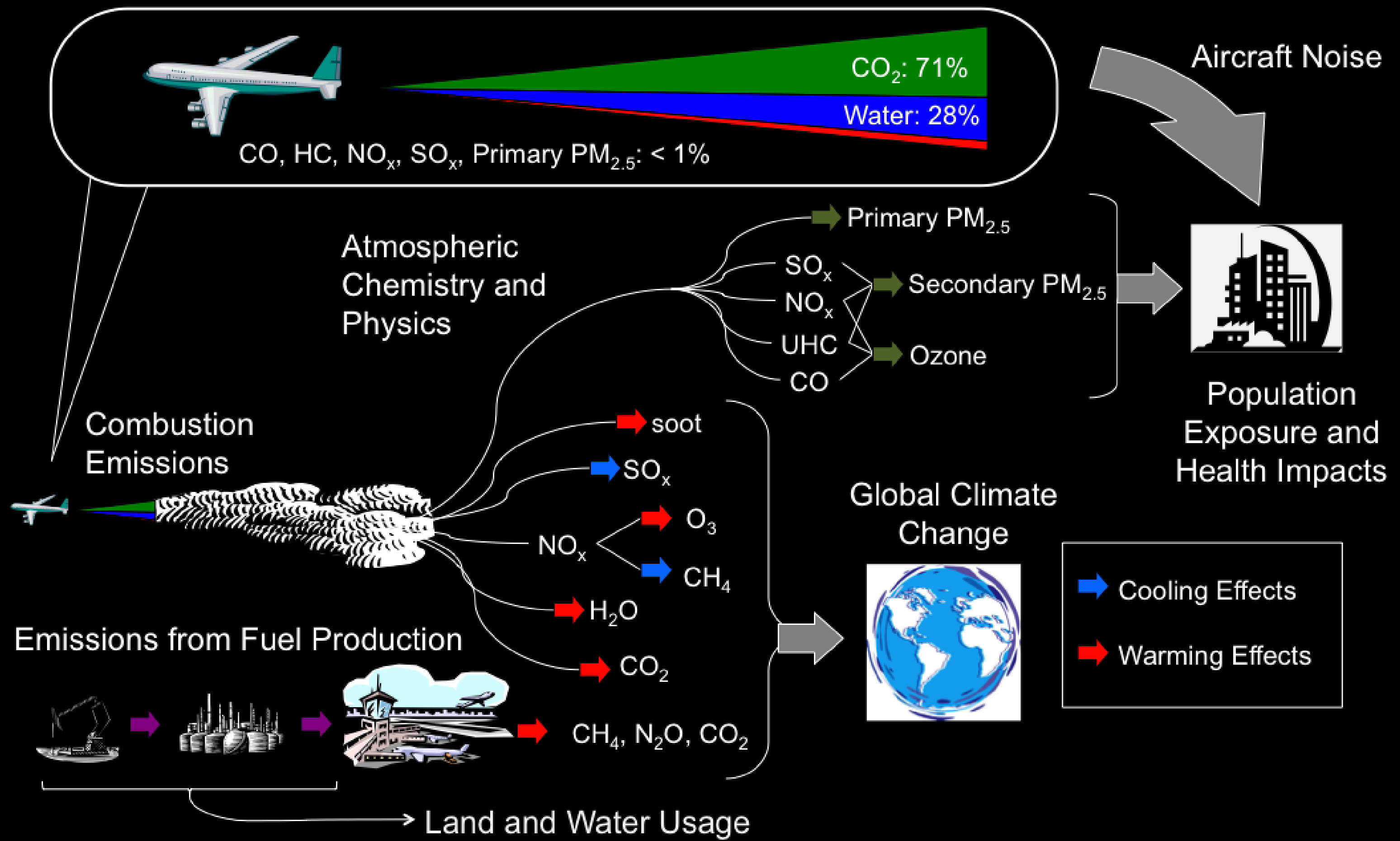
- Focus on SPK fuels - compatible with existing aviation infrastructure
- Compare wide range of alternative fuel options using consistent set of metrics and assumptions.
- Considering multiple uses for alternative jet fuel feedstocks.



Alternative Fuel Viability

- Viability of Fuel Composition
  - Is the fuel compatible with the current fleet of transportation vehicles?
- Viability of Fuel Pathway
  - Fuel pathway comprised of feedstock, processing technique and fuel composition
  - Are fuel feedstock and processing techniques amenable to large-scale production?
  - Determined (in no particular order) by life cycle GHG emissions, land usage, impact on local environment, fresh water withdrawal and consumption, air quality impacts, economics…

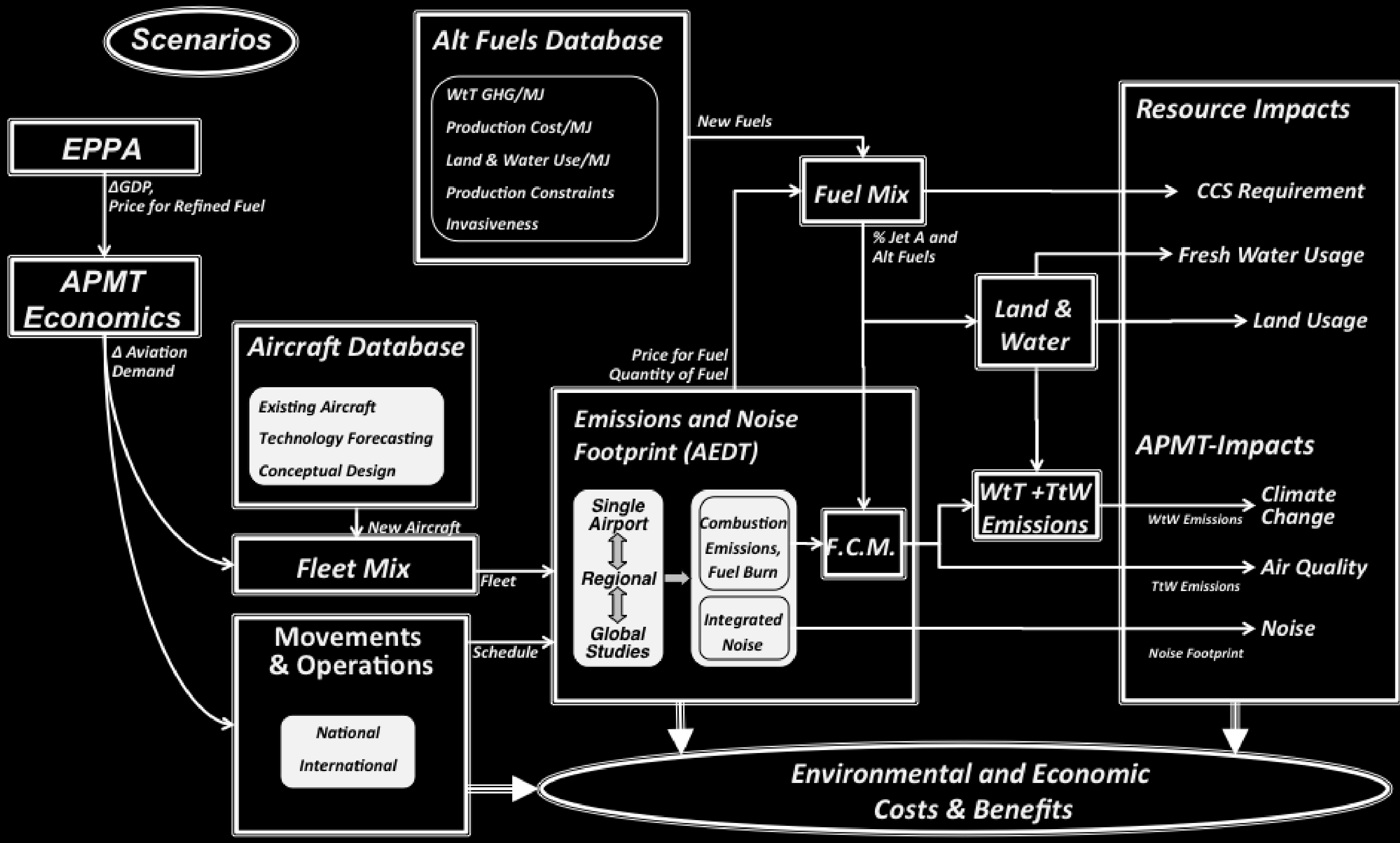
Environmental Impacts of Aviation



Approach

http://www.apmt.aero

Include alternative fuels within Aviation Environmental Tool Suite.



Some Alternative Transportation Fuels

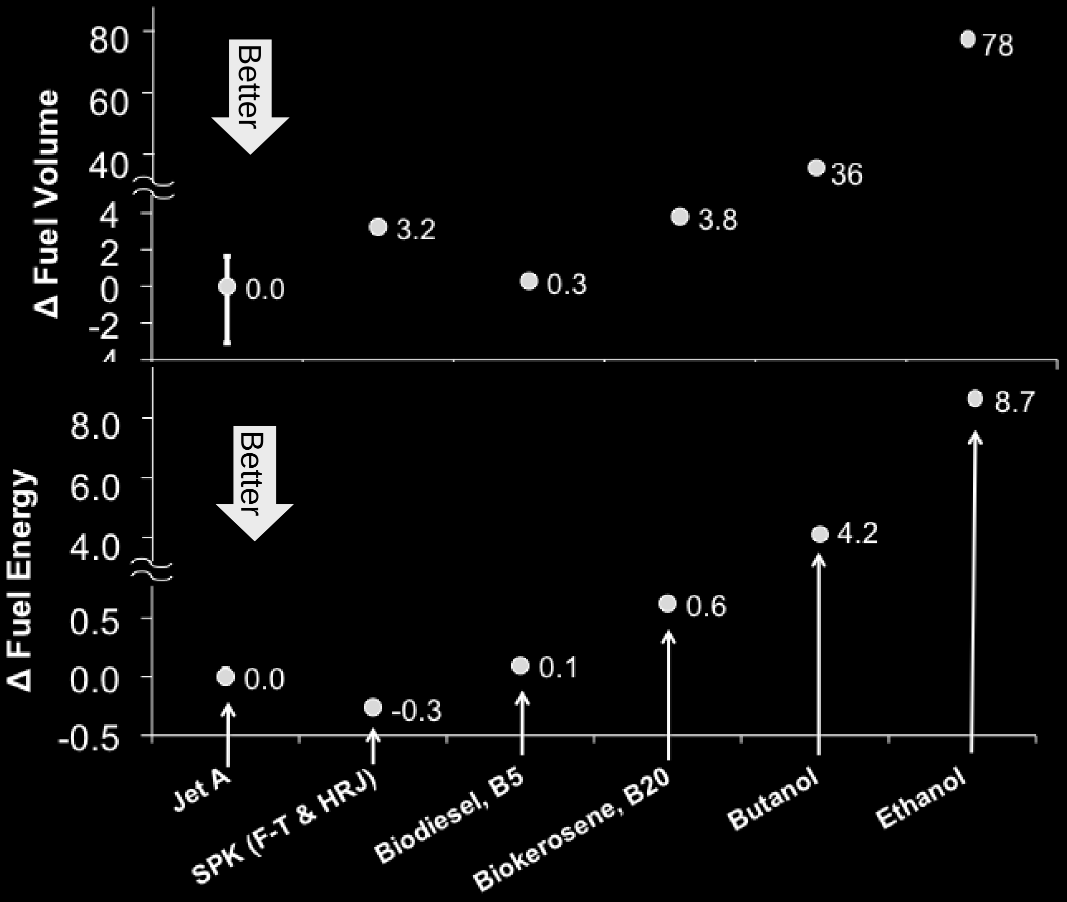
- Fuels “better suited to ground transportation”
  - Alcohols (ethanol, butanol, etc.) and FAME (biodiesel / biokerosene)
  - Reduced energy content
  - Incompatibility concerns exist for all of these fuels
  - Thermal stability concerns for biodiesel and biokerosene
- Jet fuel from unconventional crude
  - Created from oil sands and oil shale
  - Heavier and higher sulfur content than conventional crude
  - Requires additional pre-processing (higher GHG)
- Drop-in, synthetic jet fuels
  - Functionally similar to Jet A, but created from non-petroleum sources
  - Can be renewable, with a potential for sustainability
- Cryogenic fuels derived from natural gas
  - Requires new aircraft design and infrastructure changes
  - Need to examine infrastructure, engine, aircraft, and fuel cycle
  - Conducted work during NASA N+3 study – publications forthcoming

Considerable additional information on these in Hileman et al. PARTNER Report 2009-001.

Fleet-wide Alternative Jet Fuel Use

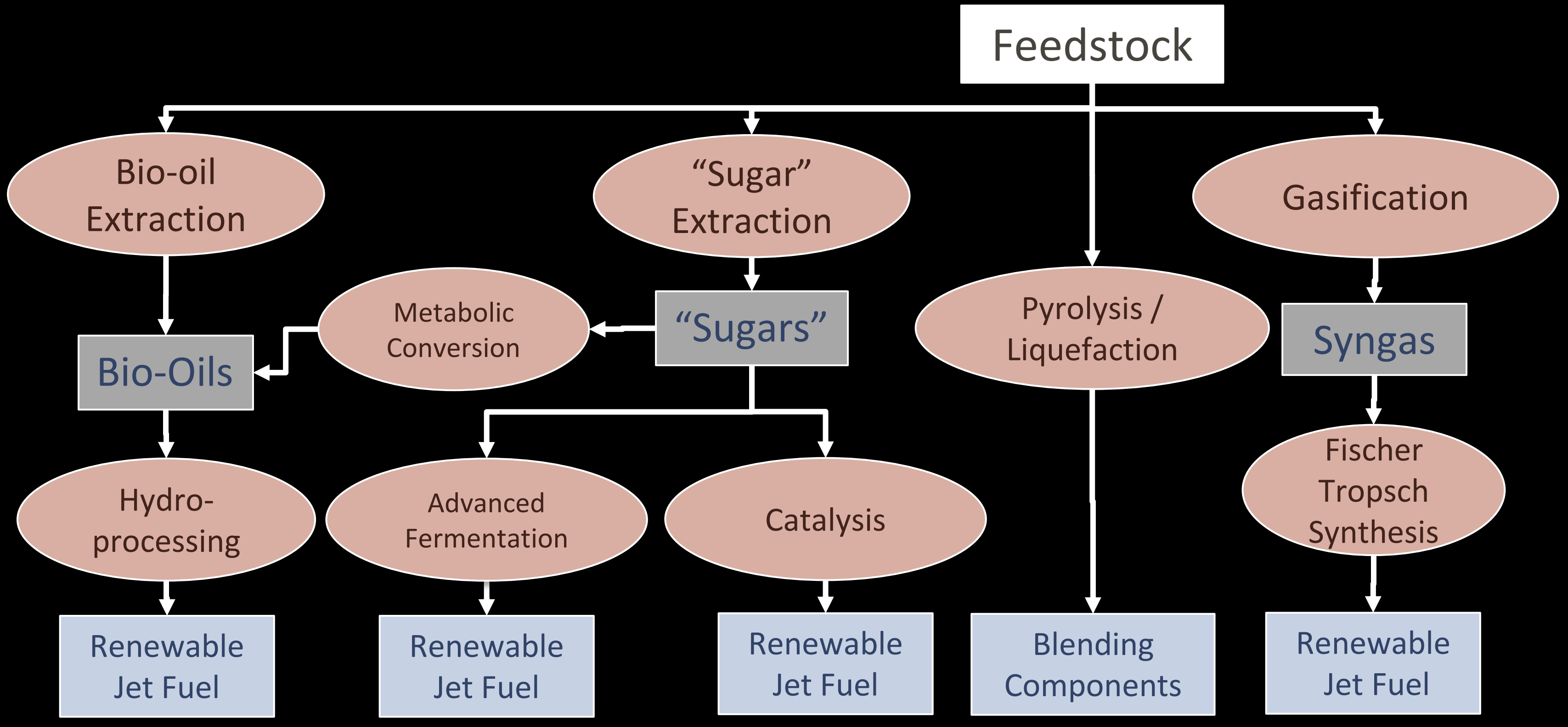
Alcohols, biodiesel, and biokerosene better suited for ground transport.

Focus on synthetic fuels.



Hileman, Stratton and Donohoo, accepted to JPP (April 2010)

Pathways to Drop-In "Bio" Jet Fuels

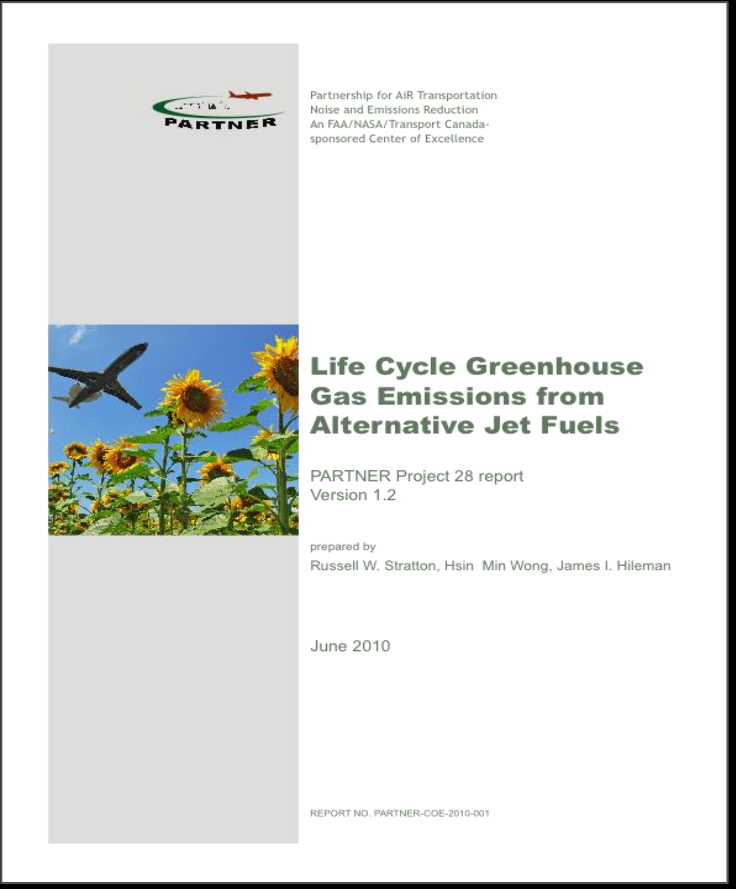


These pathways all result in a hydrocarbon fuel (no oxygen) that would have similar properties to conventional jet fuel.

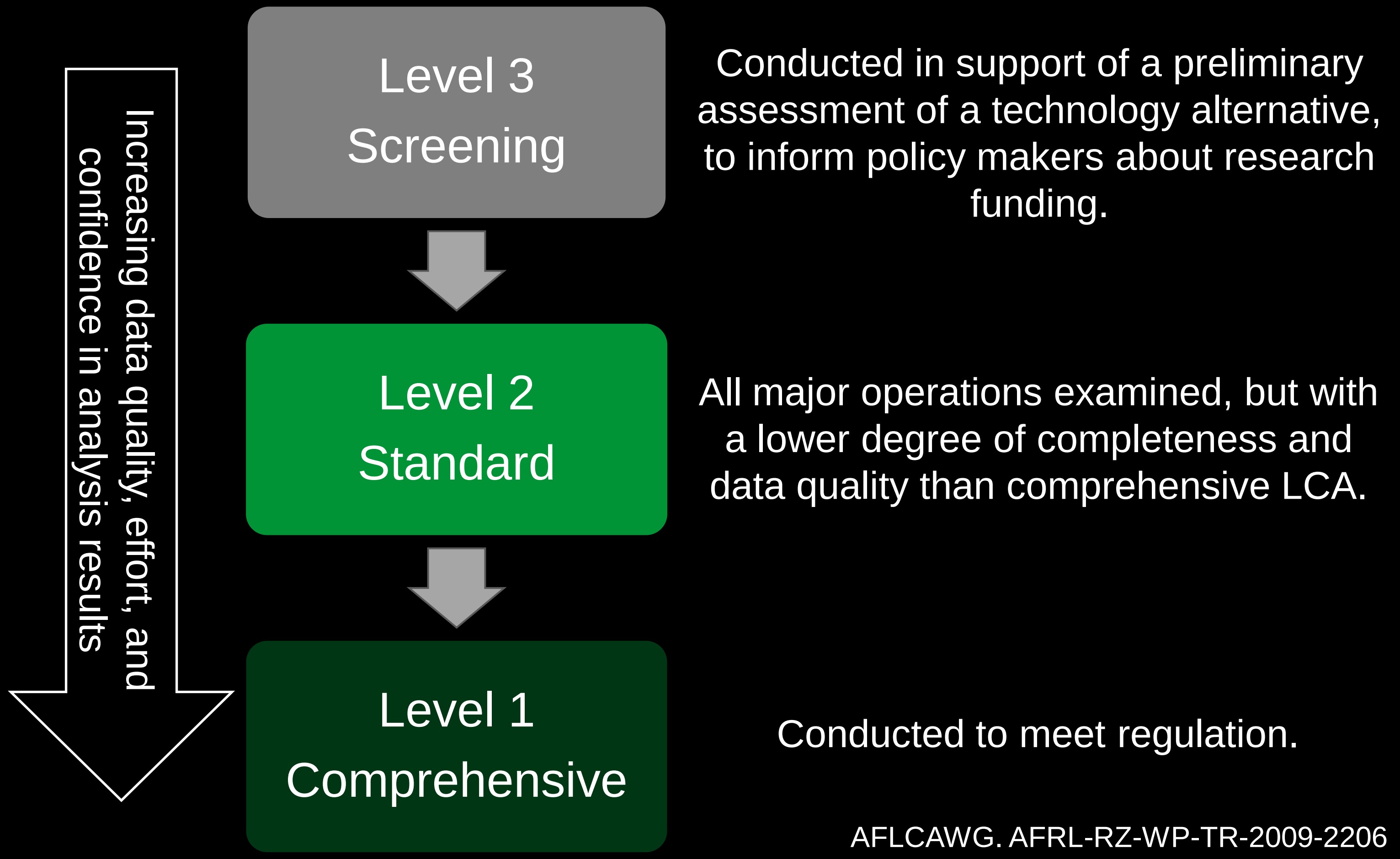
Alt Jet Fuel Life Cycle GHG Emissions

Referred to as Stratton et al. (2010) herein

- LCA of 16 different feedstocks
  - Screening level study of next generation alternative jet fuels
  - Examined low, baseline, and high emissions scenarios
  - Emphasized influential aspects of fuel production on GHG emissions
- Other issues considered: land, water, invasiveness
- Review by Shell, Chevron, NETL, UOP, and Michigan Tech
- Will update Version 1.2 with new feedstock-to-jet pathways



LCA Resolution Levels

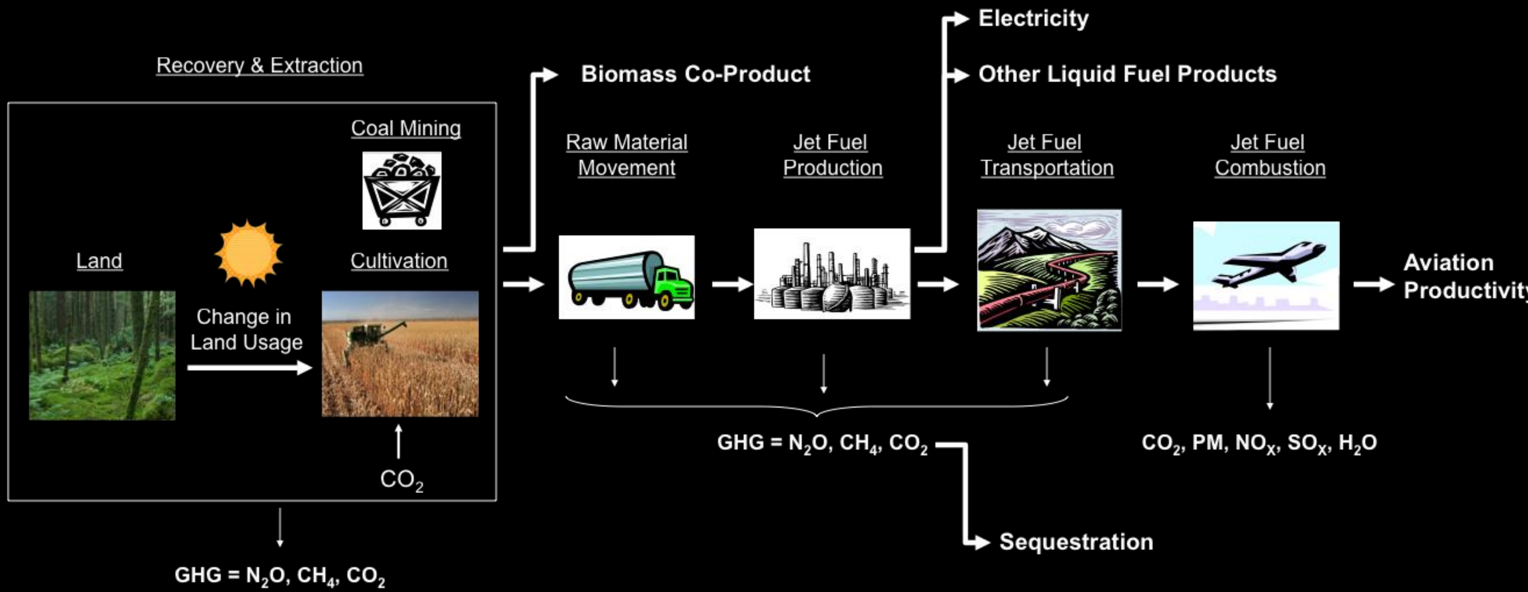


Fuel Pathways Considered for GHG

within Stratton et al. (2010)

<table>
<tr><th>Source</th><th>Feedstock</th><th>Recovery</th><th>Processing</th><th>Final Product</th></tr>
<tr><td rowspan="3">Petroleum</td><td>Conventional crude</td><td>Crude extraction</td><td>Crude refining</td><td>Jet A / ULS Jet A</td></tr>
<tr><td>Canadian oil sands</td><td>Bitumen mining/extraction & upgrading</td><td>Syn-crude refining</td><td>Jet A</td></tr>
<tr><td>Oil shale</td><td>In-situ conversion</td><td>Shale oil refining</td><td>Jet A</td></tr>
<tr><td>Natural gas</td><td>Natural gas</td><td>Natural gas extraction & processing</td><td rowspan="4">Gasification, F-T reaction and upgrading (with and without carbon capture)</td><td rowspan="4">SPK Jet Fuel
(F-T)</td></tr>
<tr><td>Coal</td><td>Coal</td><td>Coal mining</td></tr>
<tr><td>Coal and Biomass</td><td>Coal and Biomass</td><td>Coal mining & biomass cultivation</td></tr>
<tr><td rowspan="2">Biomass</td><td>Biomass
switchgrass
corn stover
forest waste</td><td>Biomass cultivation</td></tr>
<tr><td>Renewable oil
soybeans
palm
algae
jatropha
rapeseed
salicornia</td><td>Biomass cultivation & extraction of plant oils</td><td>Hydroprocessing</td><td>SPK Jet Fuel (HRJ)</td></tr>
</table>

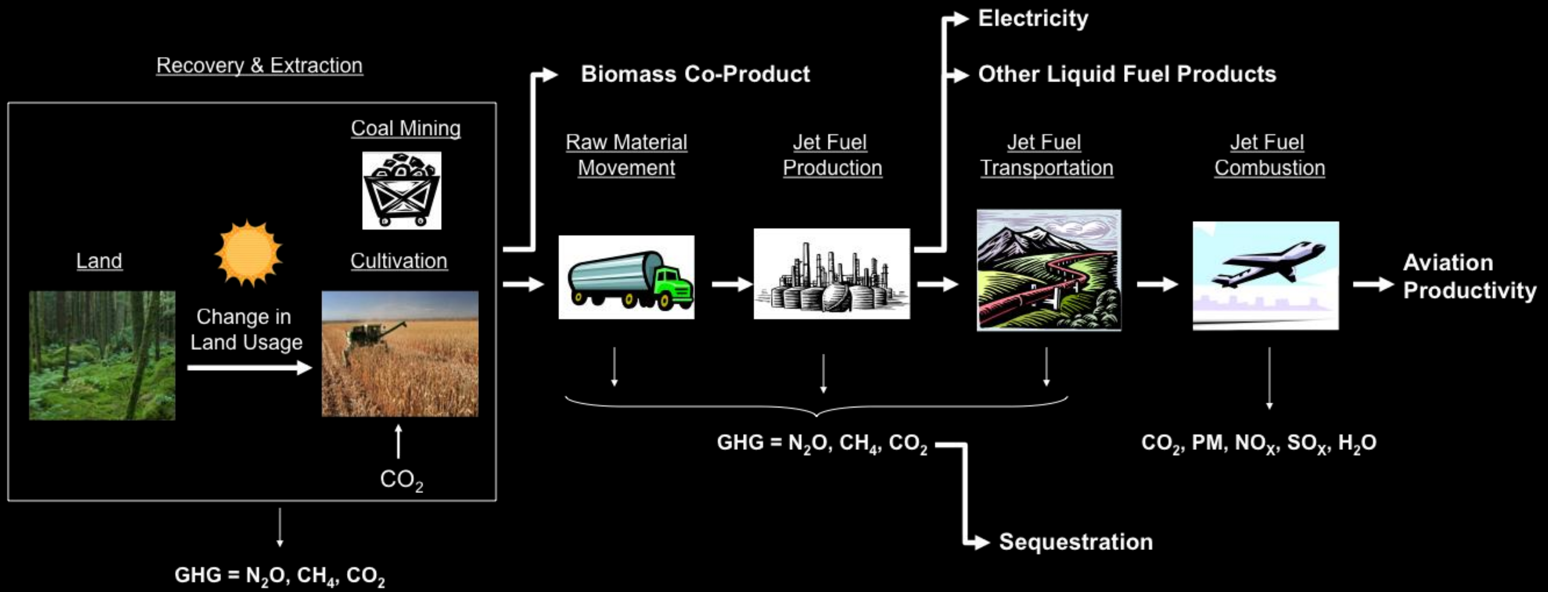
Life Cycle GHG Emissions Inventory – 1 of 3



Key Issues in creating a life cycle GHG emissions inventory:

- System Boundary Definition
- Allocating Emissions among Co-products
- Data Quality and Uncertainty

Life Cycle GHG Emissions Inventory – 2 of 3

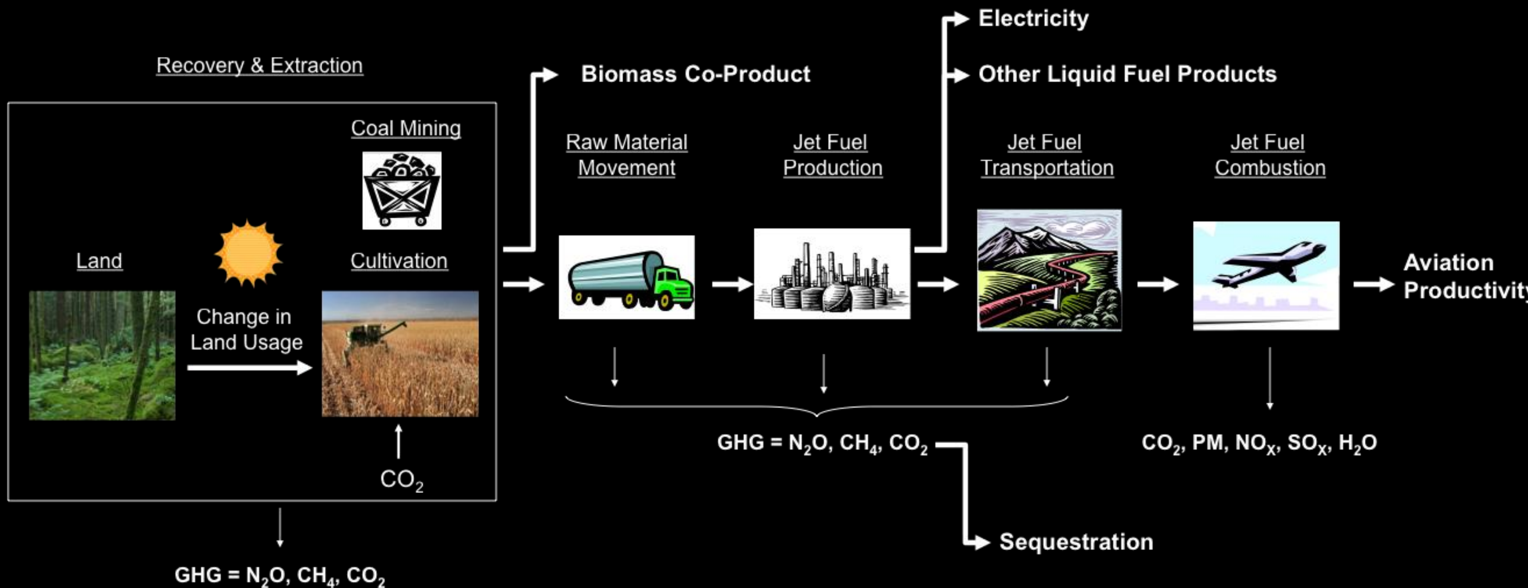


Developed inventories using GREET database and computing framework

- GREET designed for ground transportation fuels – modified to reflect jet fuel
- Created many new feedstock-to-fuel pathways (e.g., oil shale, palm, jatropha, salicornia, algae) that are not in GREET

GREET Website: http://www.transportation.anl.gov/modeling_simulation/GREET/

Life Cycle GHG Emissions Inventory – 3 of 3

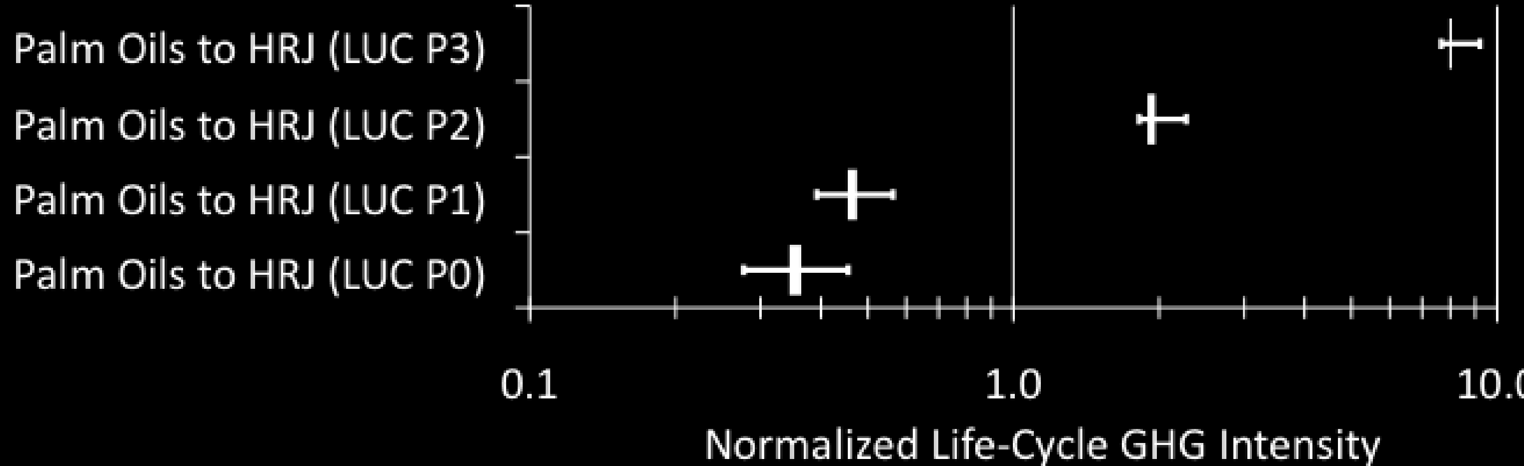


Land Use Change (LUC) Emissions

- Can be positive or negative depending on land involved
- Magnitude depends primarily on land type being converted and crop type
- LUC can be direct (due to land conversion) or indirect (consequence of a price signal in agricultural products)

Impact of LUC on Palm HRJ Emissions

LUC P0: No land use change
LUC P1: Conversion of logged over forest
LUC P2: Conversion of tropical rainforest
LUC P3: Conversion of peat land rainforest



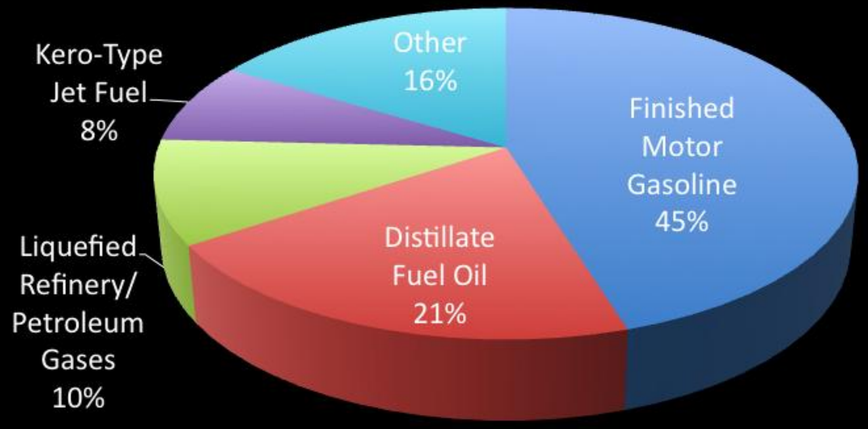
- Extremes vary by factor of 30
- International measures are needed to prevent large Land Use Change

Data from Stratton et al. (2010)

Petroleum Usage

Fully loaded 747-400 consumes ~1200 barrels of jet fuel to fly Boston to Dubai

Boston Logan uses ~25,000 barrels per day (bpd)



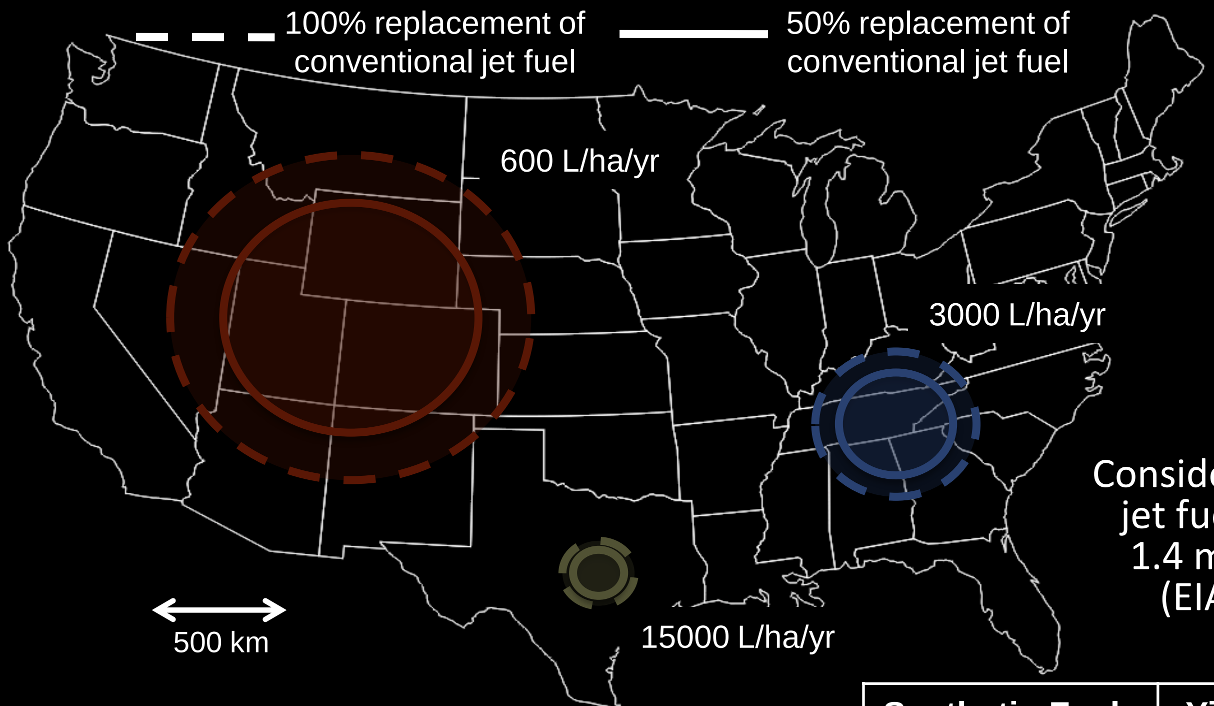
SOURCE: EIA (2009)*

Petroleum Usage (2007):

- U.S. Jet consumption of 1.6 million bpd
- U.S. oil consumption of 20.5 million bpd
- Total worldwide oil consumption of 86.0 million bpd

*** http://www.eia.doe.gov/neic/infosheets/petroleumproductsconsumption.html**

Biofuel Land Requirements



Considered current jet fuel usage of 1.4 million bpd (EIA, 2009).

Synthetic Fuel	Yield (L/ha/yr)
Soy HRJ	400
Palm HRJ	3300
Algae HRJ	17000

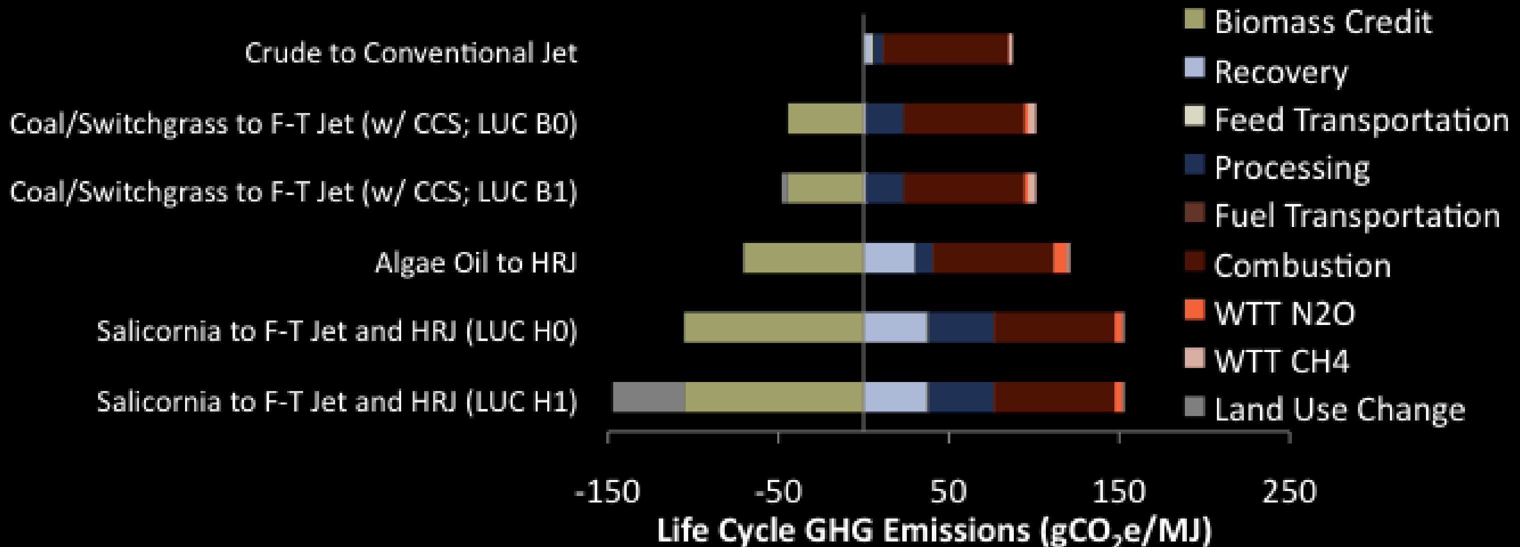
Need feedstocks with high yield and low life cycle emissions that require minimal arable land and water usage.

Data from Stratton et al. (2010)

Some Promising Pathways

1) Fossil Fuel & Biomass to F-T Fuel
2) Algae to HRJ Fuel
3) Salicornia to HRJ / F-T Fuel

Salicornia Land Use Change Scenarios	
LUC-H0	No land use change
LUC-H1	Desert converted to salicornia cultivation
Switchgrass Land Use Change Scenarios	
LUC-B0	No land use change
LUC-B1	Carbon depleted land converted to switchgrass cultivation



Data from Stratton et al. (2010)

Assessing Pathway Variability

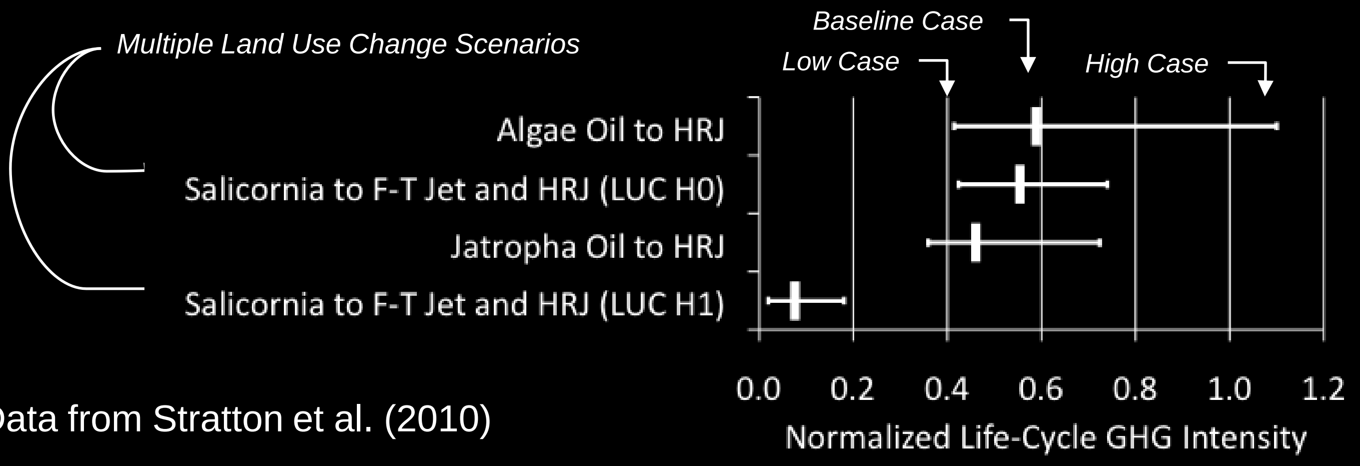
Variability considered using scenarios with consistent assumption sets

Sources of variability:

- Feedstock type
- Conversion technology
- Process efficiency
- Cultivation and harvesting
- Carbon capture efficiency

Sample land use change scenarios:

- Use marginal land or waste product
- Conversion of Brazilian cerrado
- Destruction of rain forest
- Salicornia soil carbon sequestration
- Switchgrass soil carbon sequestration



Data from Stratton et al. (2010)

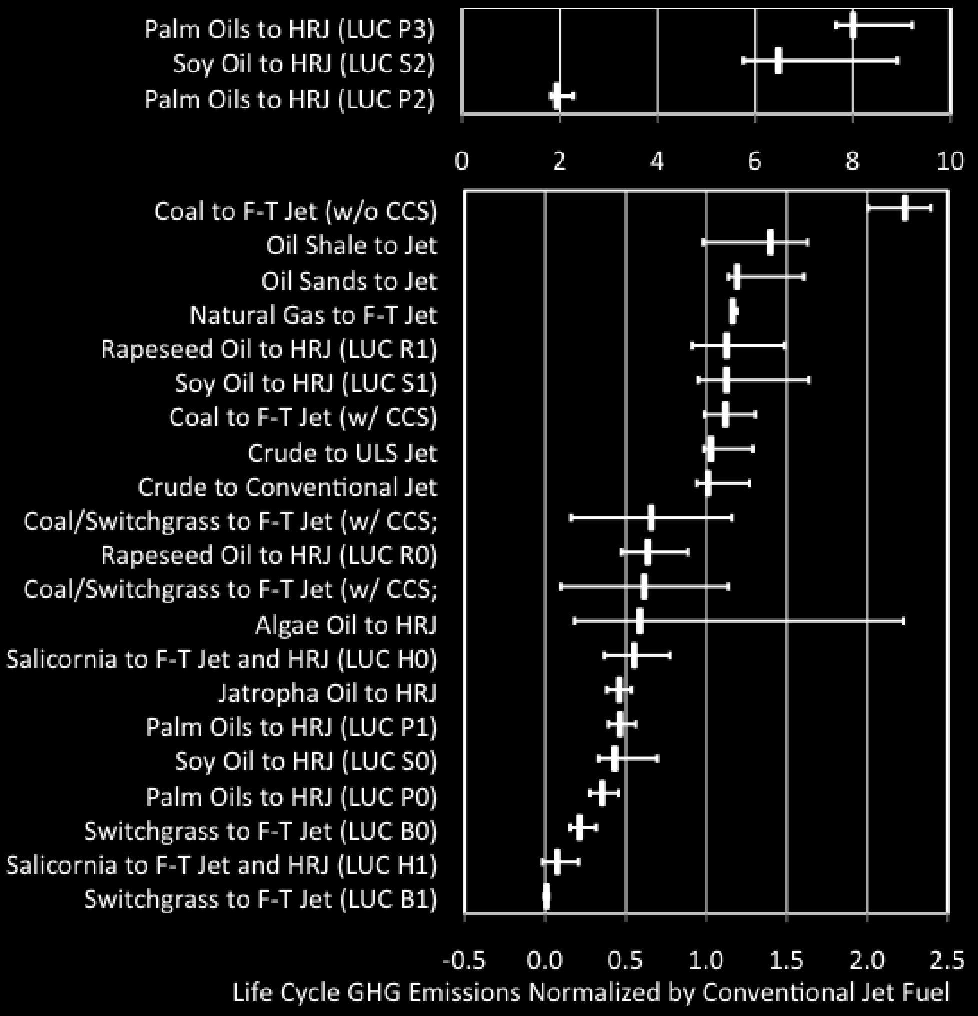
Full Life Cycle GHG Inventory Results

Key Points:

- Screening level study
- Not all fuel options covered
- Large variability
- Few biofuels have zero GHG
- Conv. petroleum has lowest emissions among fossil fuels
- Land use change emissions have large impact on results

Next on the list:

1) Sugars to Jet Fuel
2) Pyrolysis oils to Jet Fuel Blend Stock
3) Camelina oil to Jet Fuel
4) Other F-T Pathways



Data from Stratton et al. (2010)

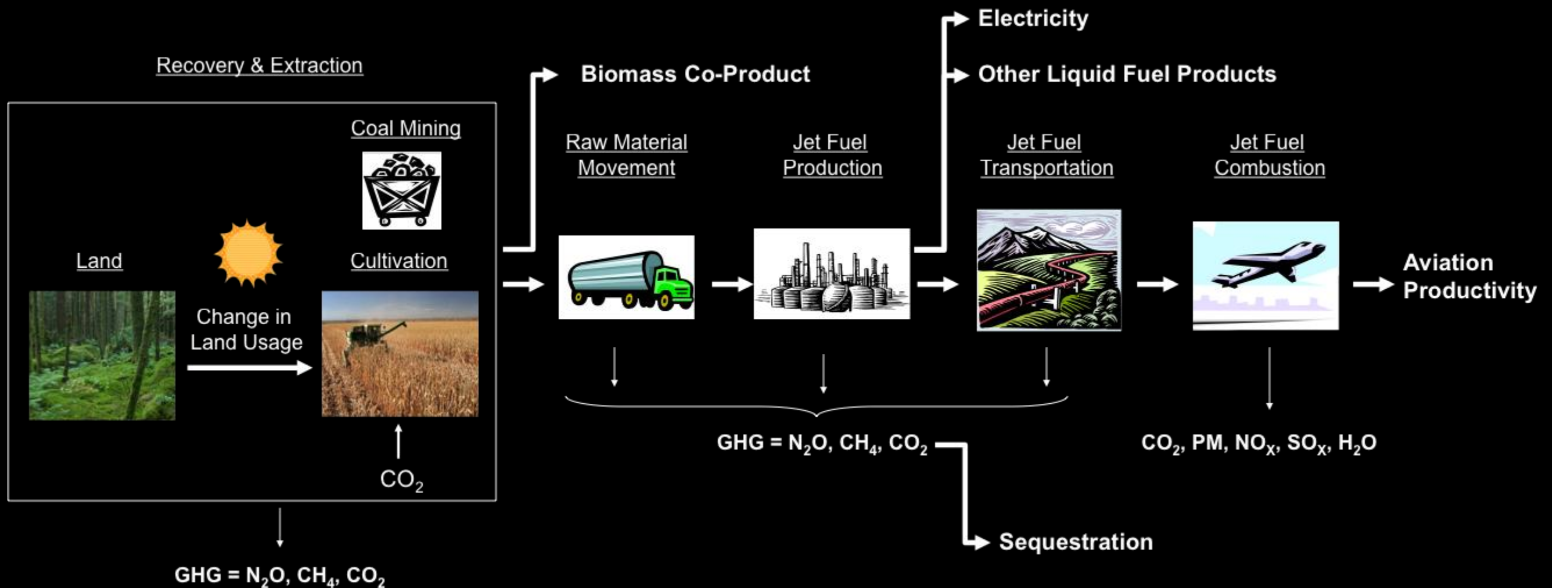
Summary

- Life cycle assessment is critical to determine whether a potential alternative jet fuel will reduce GHG emissions
- Alternative fuels exist that could both reduce life cycle GHG emissions and improve air quality (e.g., HRJ and CBTL fuels w/CCS), but at present the ability to produce these fuels is limited
- If land use changes are incurred, biofuels can have life-cycle GHG emissions that are many times worse than conventional jet fuel – *international measures needed to mitigate iLUC*
- Feedstocks are needed that have low life-cycle emissions and high yield with minimal arable land usage and water consumption – *avoid biofuel feedstock irrigation*
- Work continues on the evaluation of alternative jet fuel sustainability and feasibility

Questions? ***Jim Hileman: hileman@mit.edu***

Backup Charts

Allocation & Life Cycle GHG Inventory



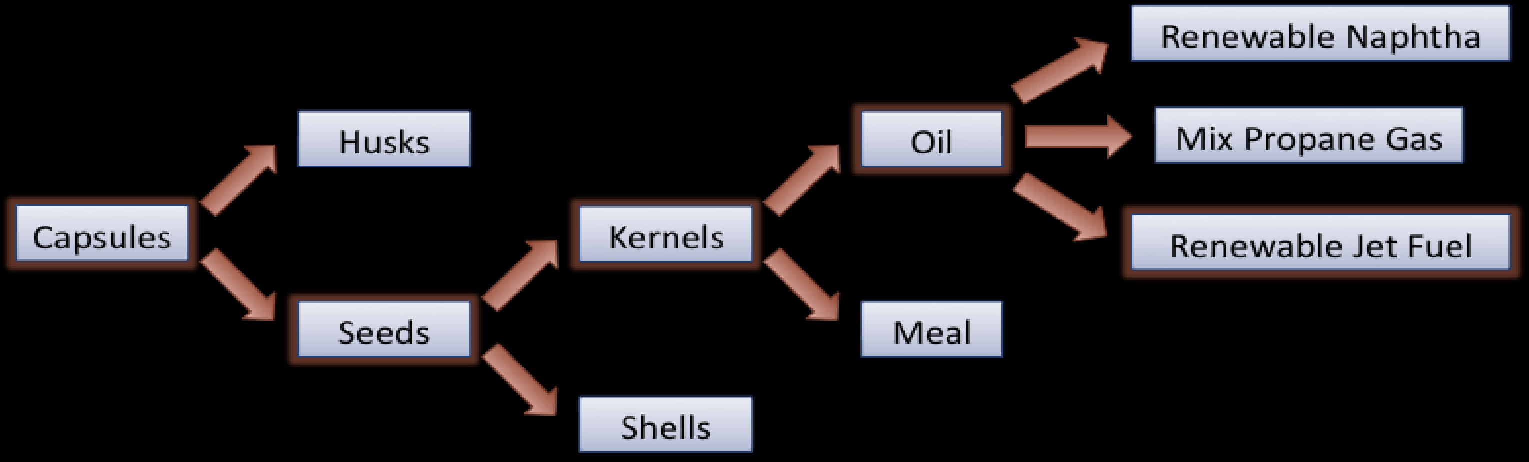
Upstream emissions need to be assigned to co-products

- Simple example is soy oil and meal that come from soybeans
- Expand system to displace equivalent product
- Allocate based on property - mass, energy, economic value

Allocating GHG among Co-products

Jatropha to HRJ (1 of 2)

- Need both co-product usage and allocation methodology
- Example: Jatropha Hydroprocessed Renewable Jet (HRJ) fuel



Trade studies were conducted to examine the impacts of different co-product usage assumptions and allocation methodologies

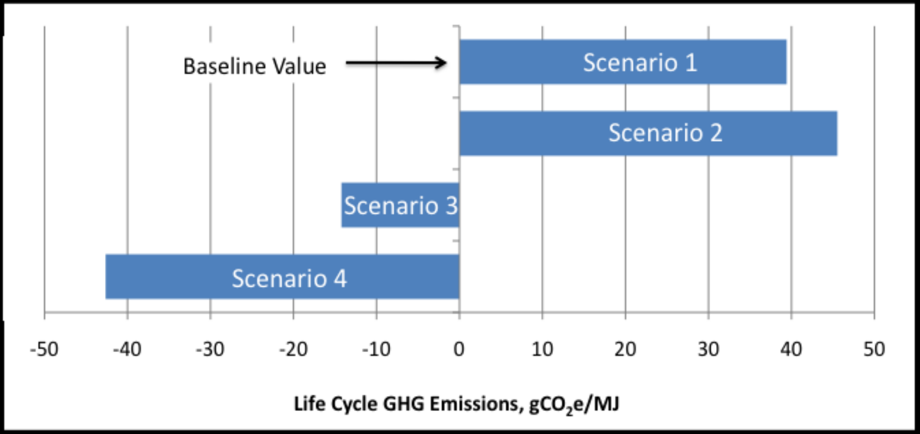
Allocating GHG among Co-products

Jatropha to HRJ (2 of 2)

Co-product usage should be linked to the allocation method:

Mass	Economic value
Energy	Displacement (system expansion)

1	**Co-product use:**	Electricity
	Allocation:	Energy
2	**Co-product use:**	Fertilizer
	Allocation:	Displacement
3	**Co-product use:**	Animal feed, Electricity
	Allocation:	Economic value, Displacement
4	**Co-product use:**	Electricity
	Allocation:	Displacement



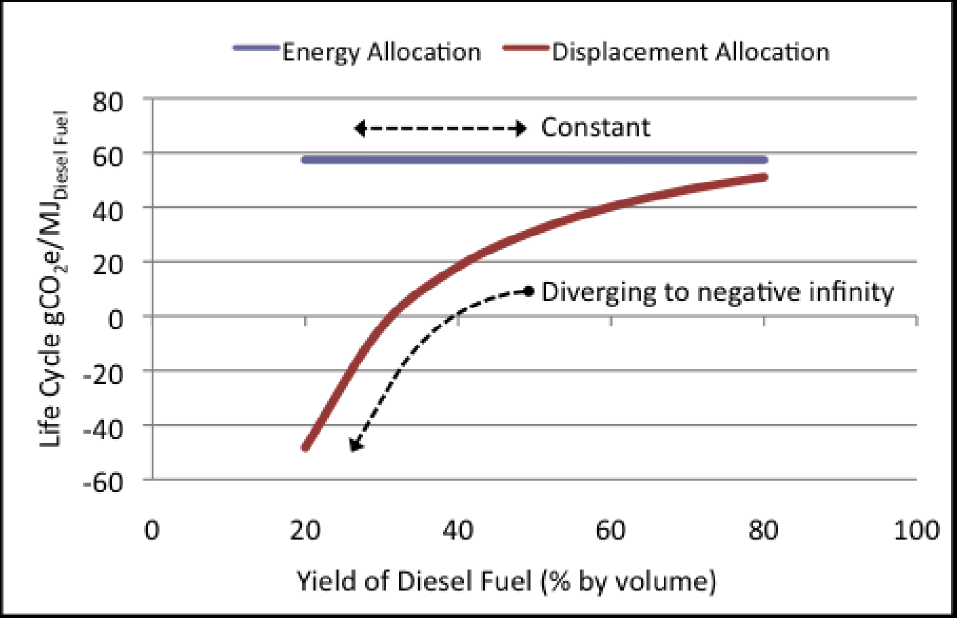
Subjective allocation and co-product usage choices can be more significant than numerical inputs

Data from Stratton, Wong, & Hileman (2010)

Allocating GHG among Co-products

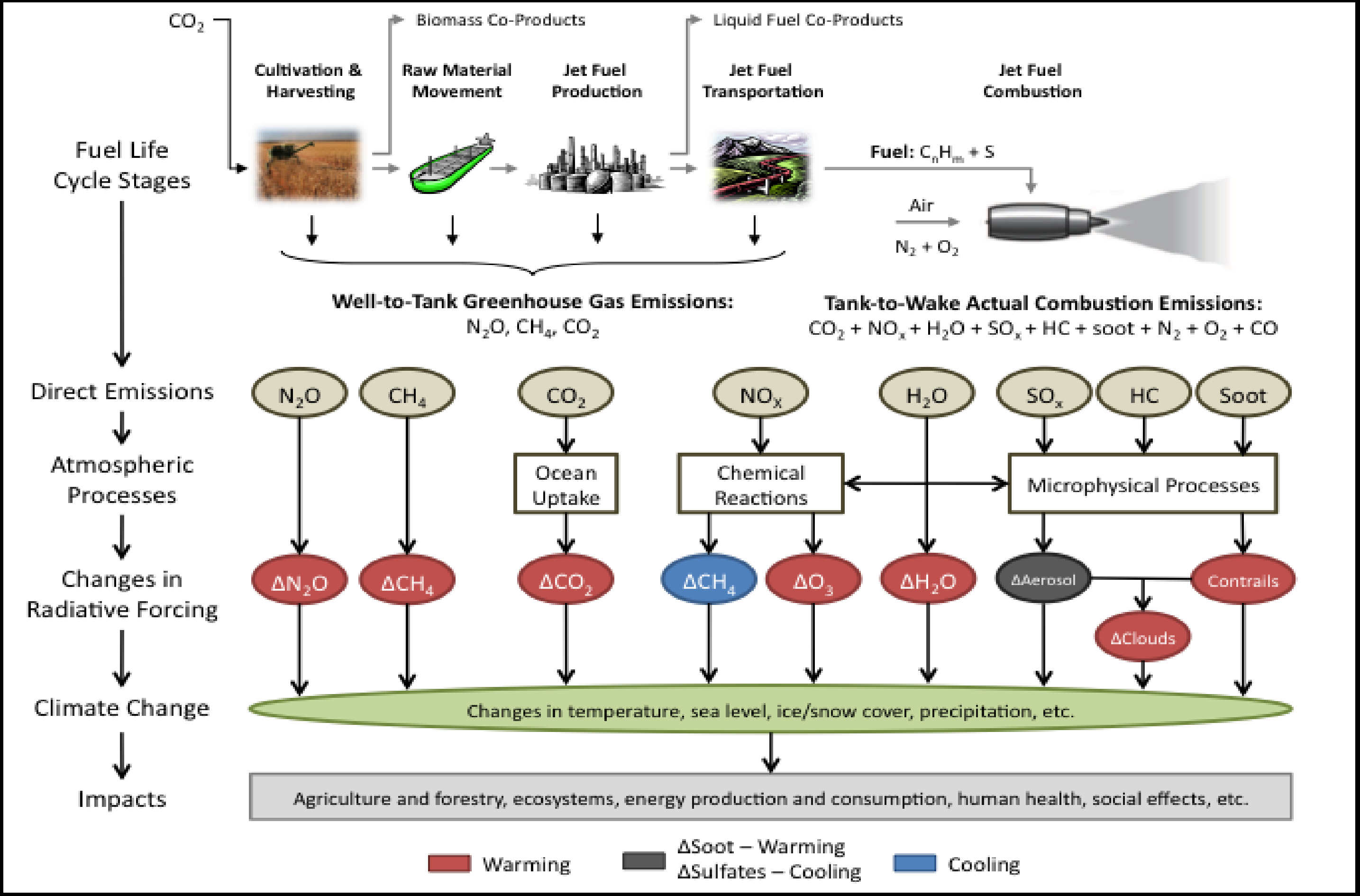
Coal & Biomass To Liquids (CBTL via F-T)

- CBTL product slate:
  - 25% F-T jet fuel,
  - 55% F-T diesel
  - 20% F-T naphtha
  - No export electricity
- If jet fuel given “biomass credit” for all CBTL fuels, then max GHG reduction for jet fuel corresponds to min jet fuel production
- Allocating by energy content overcomes this issue

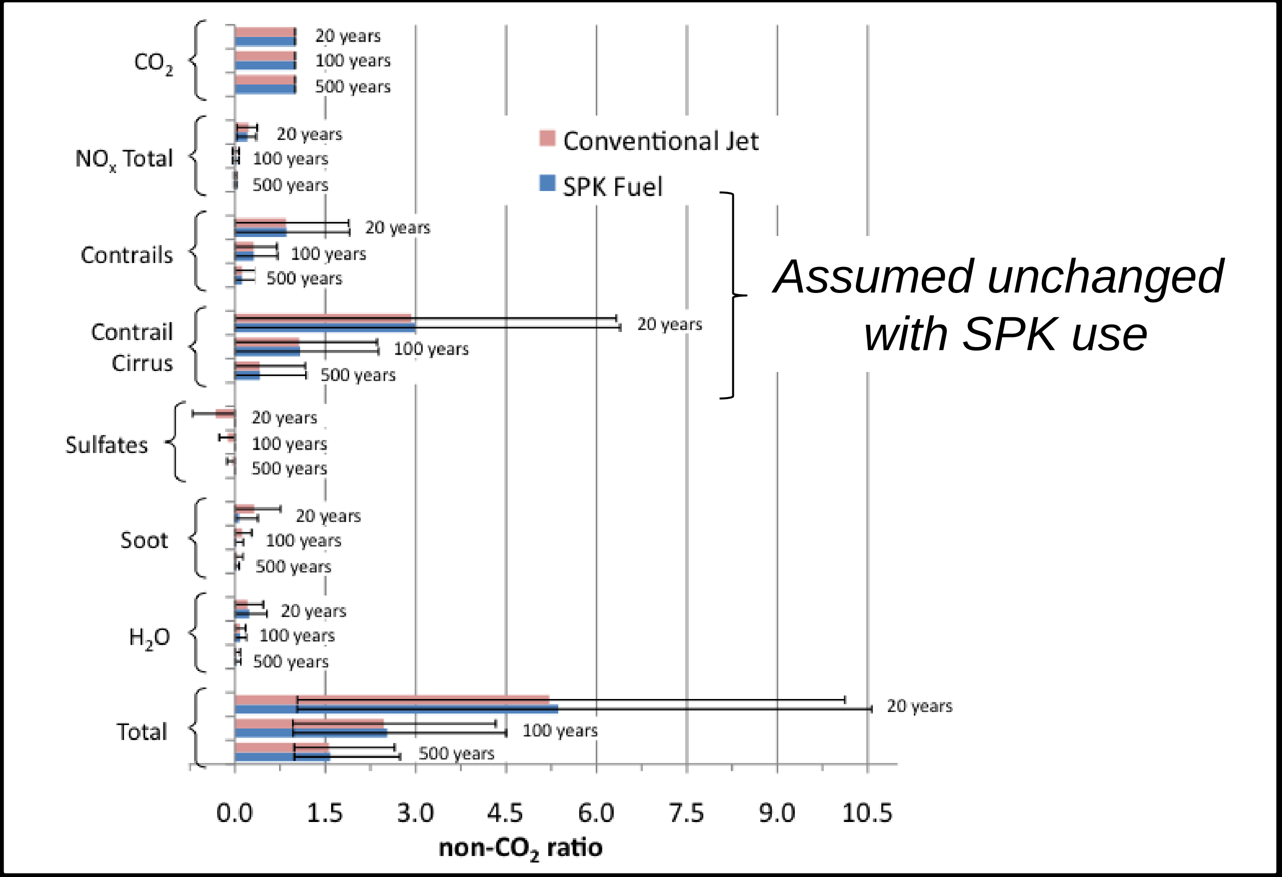


Data from Stratton, Wong, & Hileman (2010)

Impact of Non-CO_2 Combustion Effects



Impact of Non-CO_2 Combustion Effects



Data from Stratton & Hileman (submitted to ES&T, 2010)