PARTNER

Partnership for AiR Transportation Noise and Emission Reduction

An FAA/NASA/TC-sponsored Center of Excellence

Life Cycle Analysis
Background and Current Progress

James Hileman, Hsin Min Wong, Pearl Donohoo, Russell Stratton, Malcolm Weiss, and Ian Waitz

Massachusetts Institute of Technology

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CRC Aviation Meeting
Emerging Fuels Session

Information about PARTNER and its research: http://partner.aero
Contact information for James Hileman: hileman@mit.edu

This presentation covers a work-in-progress and is subject to modification.

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Alternative Jet Fuels Research

Examining Potential of Alternative Fuels to:

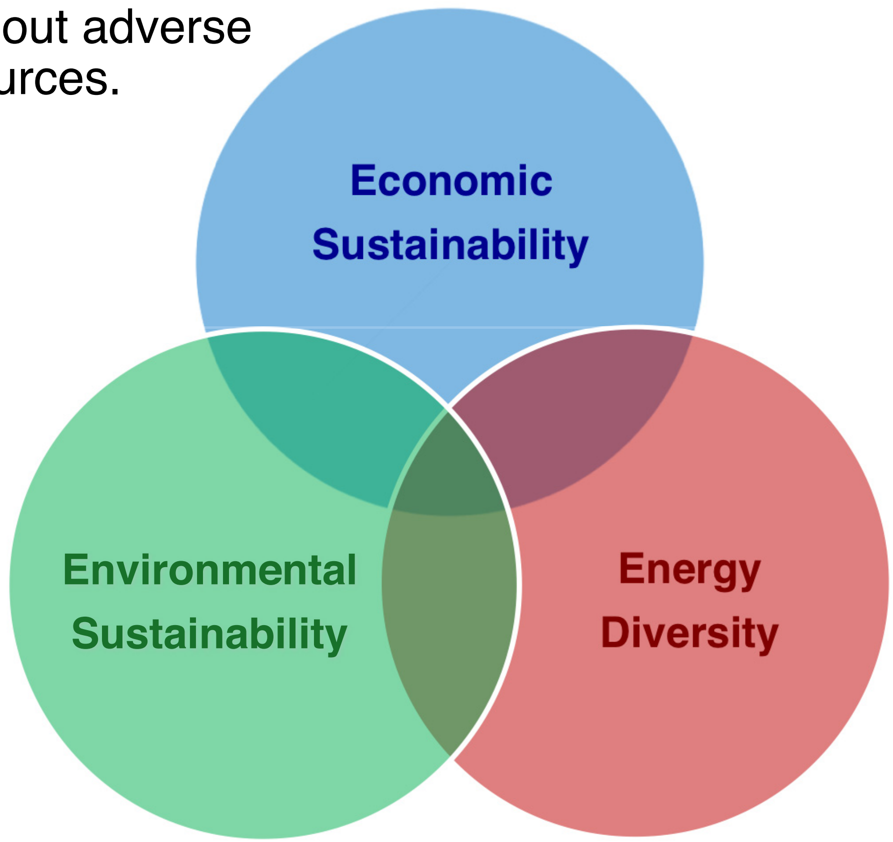
- Reduce emissions that impact global climate change and air quality thus improving the environment.
- Expand and diversify energy supplies beyond conventional petroleum.
- Be produced in large quantities without adverse impacts on our land and water resources.

Study Constraints:

- Fuel needs to be compatible with existing infrastructure.
- Using consistent set of metrics that focus on climate change, air quality, and production potential.

Extensive Collaboration:

- FAA, AFRL, TRB, CAAFI, RAND, CSSI, ECG, Cambridge University, Omega, Boeing, Shell, and Pratt & Whitney.



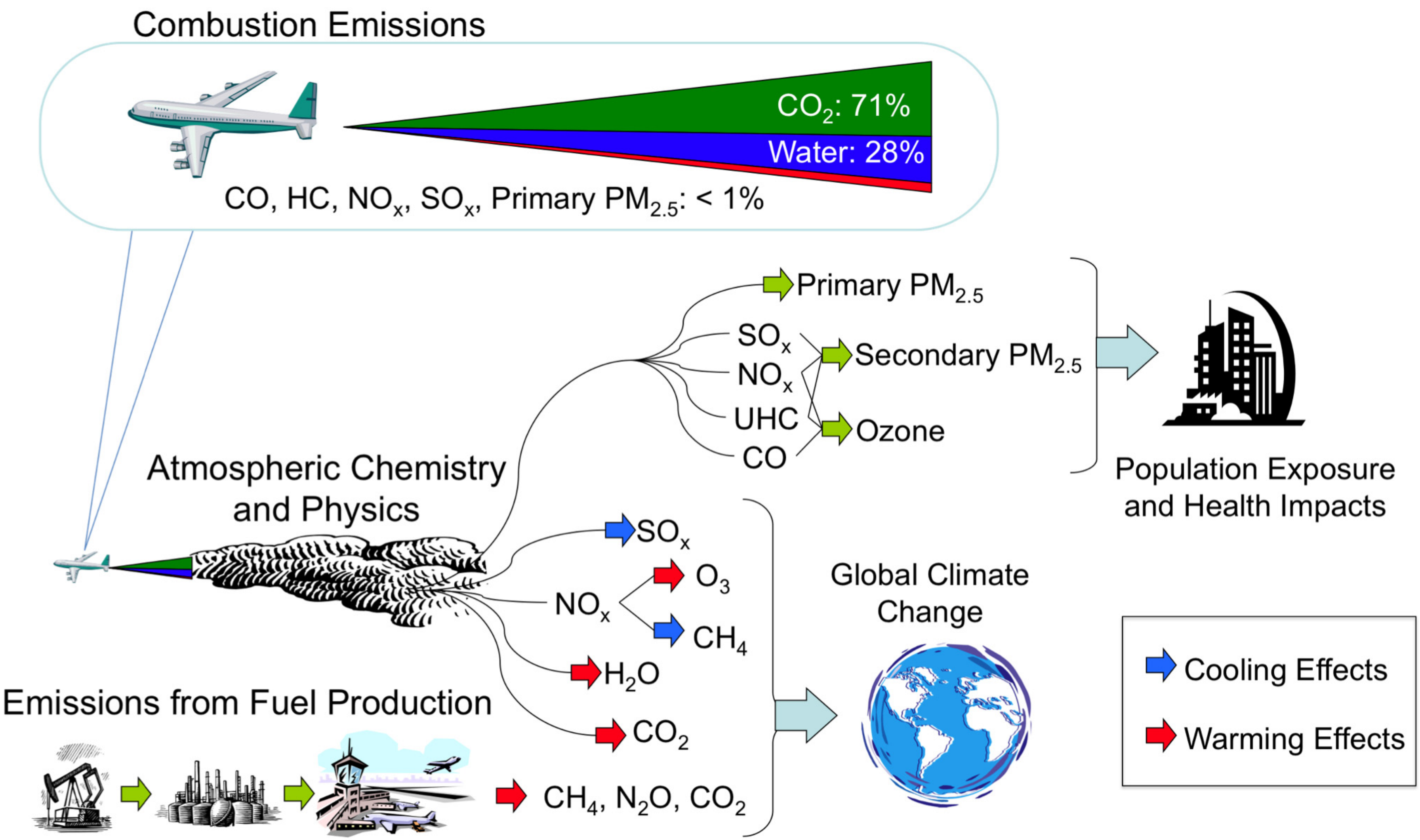
Alternative Fuel Viability

- Viability of Fuel Composition
  - Is the fuel compatible with the current fleet of aircraft?
- 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 by production potential and life-cycle GHG emissions
- Aspects that should also be considered:
  - Impact on food production
  - Land usage and impact on local environment
  - Fresh water usage
  - Air quality
  - Economics

  … but these are not covered during this short briefing

Emissions and Environmental Impacts

(an extraordinarily simplified view)



"Well-to-Wake" Life Cycle CO_2 Emissions

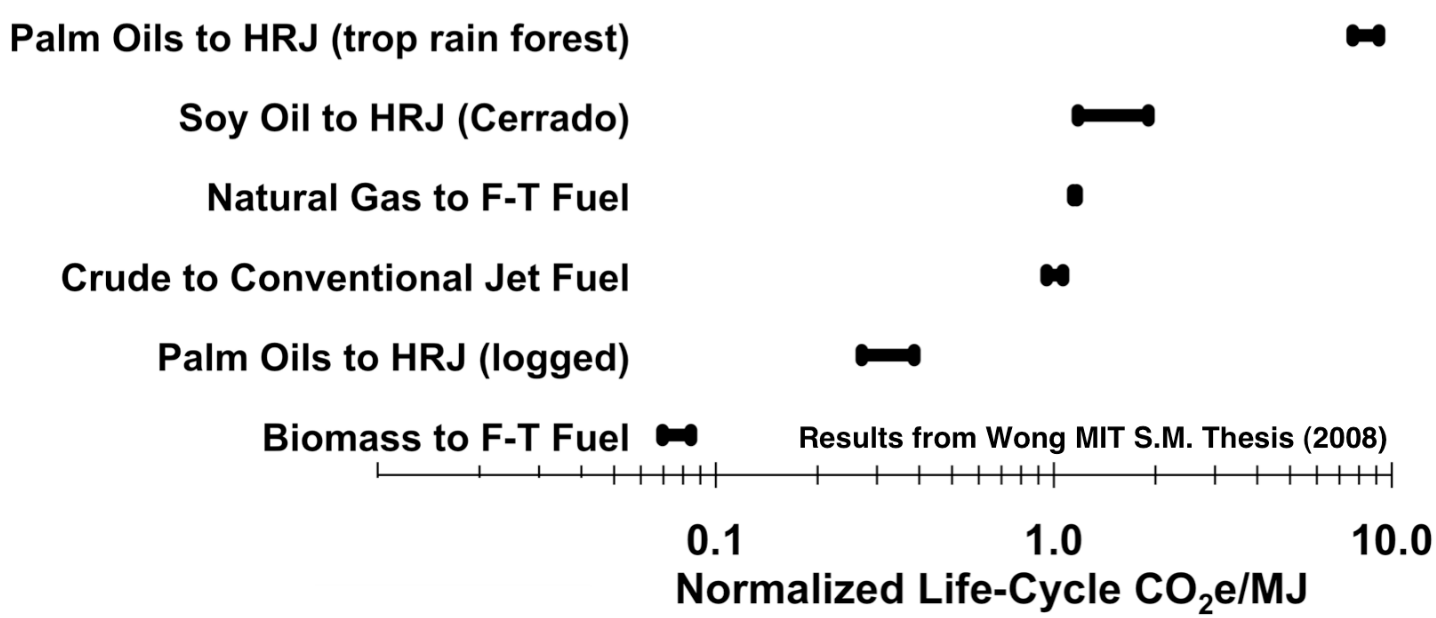
Combustion CO_2 emissions

- Jet fuel varies by less than +/-1% g CO_2/MJ (DESC PQIS)
- SPK has ~4% lower g CO_2/MJ than nominal jet fuel
- These variations are miniscule compared to life cycle variations

Life cycle CO_2e emissions

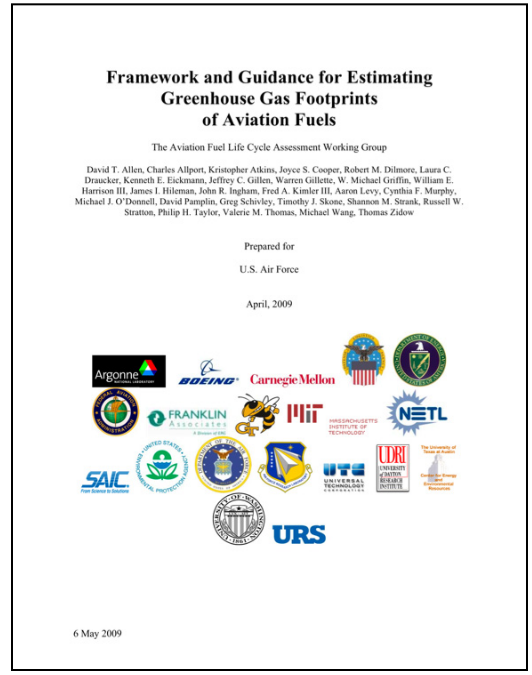
- Examining CO_2 equivalent per MJ (LHV) of fuel consumed by aircraft:

  $LC\ CO_2e = (CO_2 + GWP_{CH4} * CH_4 + GWP_{N2O} * N_2O)_{WtT} + (CO_2)_{TtW}$
- Ongoing research will consider non-CO2 combustion emissions



Information Sources

- Ongoing PARTNER research
- Wong, H.M., MIT S.M. Thesis, 2008
- "Rules and Tools" Guidance document being developed under AFRL leadership



Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels

The Aviation Fuel Life Cycle Assessment Working Group

David T. Allen, Charles Allport, Kristopher Atkins, Joyce S. Cooper, Robert M. Dilmore, Laura C. Draucker, Kenneth E. Eickmann, Jeffrey C. Gillen, Warren Gillette, W. Michael Griffin, William E. Harrison III, James I. Hileman, John R. Ingham, Fred A. Kimler III, Aaron Levy, Cynthia F. Murphy, Michael J. O'Donnell, David Pamplin, Greg Schivley, Timothy J. Skone, Shannon M. Strank, Russell W. Stratton, Philip H. Taylor, Valerie M. Thomas, Michael Wang, Thomas Zidow

Prepared for

U.S. Air Force

April, 2009

6 May 2009

- Argonne National Labs GREET model

http://www.transportation.anl.gov/software/GREET/

- CARB Low Carbon Fuel Standard

http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

- EPA Renewable Fuel Standard

http://www.epa.gov/otaq/renewablefuels/index.htm

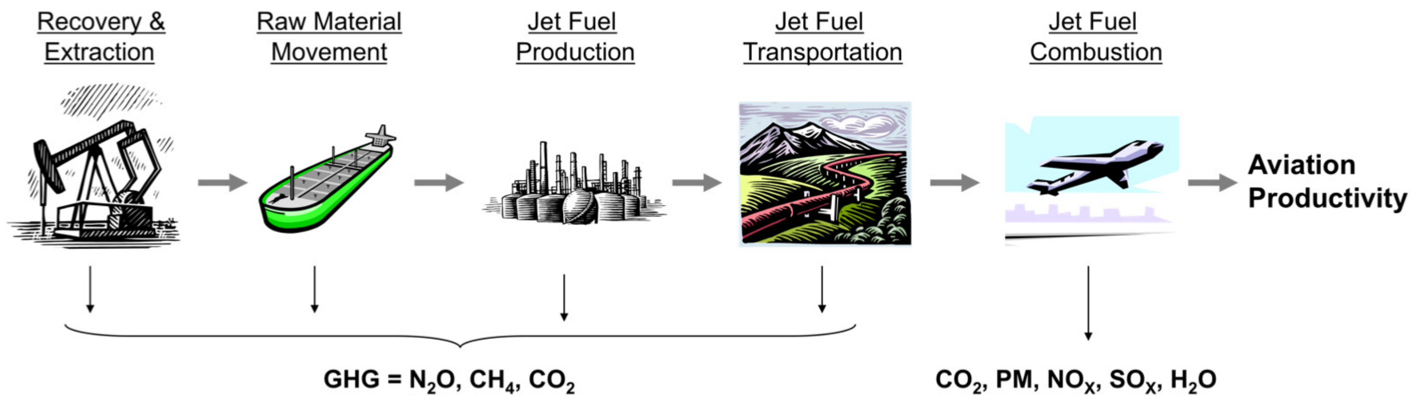
Life Cycle Stages

- Stage #1: Raw Material Acquisition
- Stage #2: Raw Material Transport
- Stage #3: Fuel Production
- Stage #4: Product Transport and Refueling
- Stage #5: Vehicle / Aircraft Operation
- Stage #6: End of Life

Consistent with ISO Standard for Life Cycle Analysis

- ISO 14040 (ISO, 2006), Framework, Principles and Requirements for Conducting and Reporting LCA studies.

Well-to-Wake GHG Emissions Fossil-based Jet Fuels



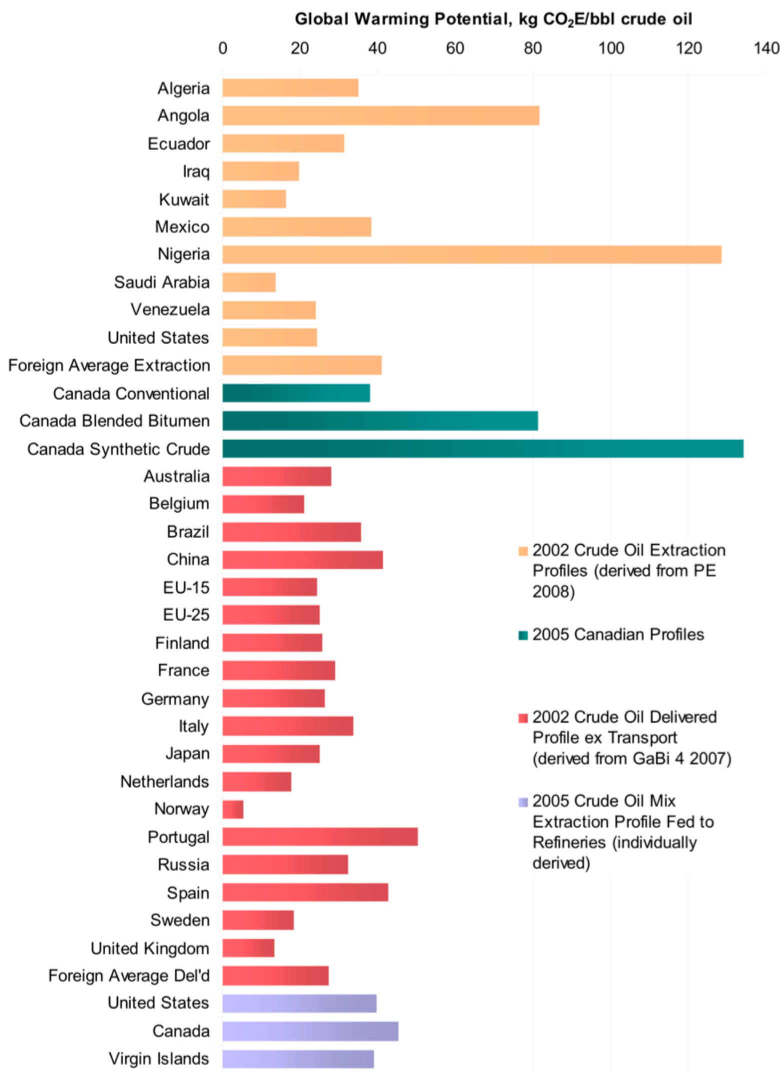
- Stage #1: Extraction of fossil resource from domestic and foreign sources (e.g., crude oil)
- Stage #2: Pipeline, tanker, rail and truck transport to refinery
- Stage #3: Refinement to produce transportation fuel (e.g., gasoline, diesel, and jet fuel)
- Stage #4: Pipeline transportation, blending with additives, transport to bulk storage, and loading into aircraft fuel tank
- Stage #5: Combustion (only discussing CO_2 today)

Key Issues in Life Cycle Analysis

- System Boundary Definition
  - System boundary captures all processes used in jet fuel creation
  - Goal is to account for all process-associated flows (materials, energy, etc.) and activities
  - System boundary cut-off criteria should strike a balance between capturing impacts and modeling scope
- Allocating Emissions among Co-products
  - Processes that ultimately result in fuel often have multiple outputs (e.g., electricity, other fuels, animal feed, commodity chemicals)
  - Options for allocating emissions:
    1. Expand system boundaries to "offset" co-product creation
    2. Allocate emissions based on mass, energy, market value
- Data Quality and Uncertainty
  - The old adage of "Garbage In, Garbage out" is true
  - Data quality and uncertainty depend on time frame and scale
  - Easier to get good data for an existing product (conventional jet fuel from crude oil) than from a non-existent industry (algal HRJ)

Scale of Analysis

Figure 2-5. Crude Oil Extraction GWP, kg CO_2E per Barrel of Crude Oil



Skone and Gerdes, NETL 2008.

- Life cycle analysis needs to reflect study goal.
  - Analysis of an industry to define a “baseline” for comparison
  - Analysis of a single facility to meet regulatory requirement
  - Analysis of future industries for GHG mitigation potential
- Temporal Scale:
  - Existing industry
  - New industry
- Production Scale:
  - Average GHG from all barrels?
  - GHG from a barrel from a particular facility
  - Marginal GHG from one more barrel?

Life-Cycle Analysis Resolution Levels

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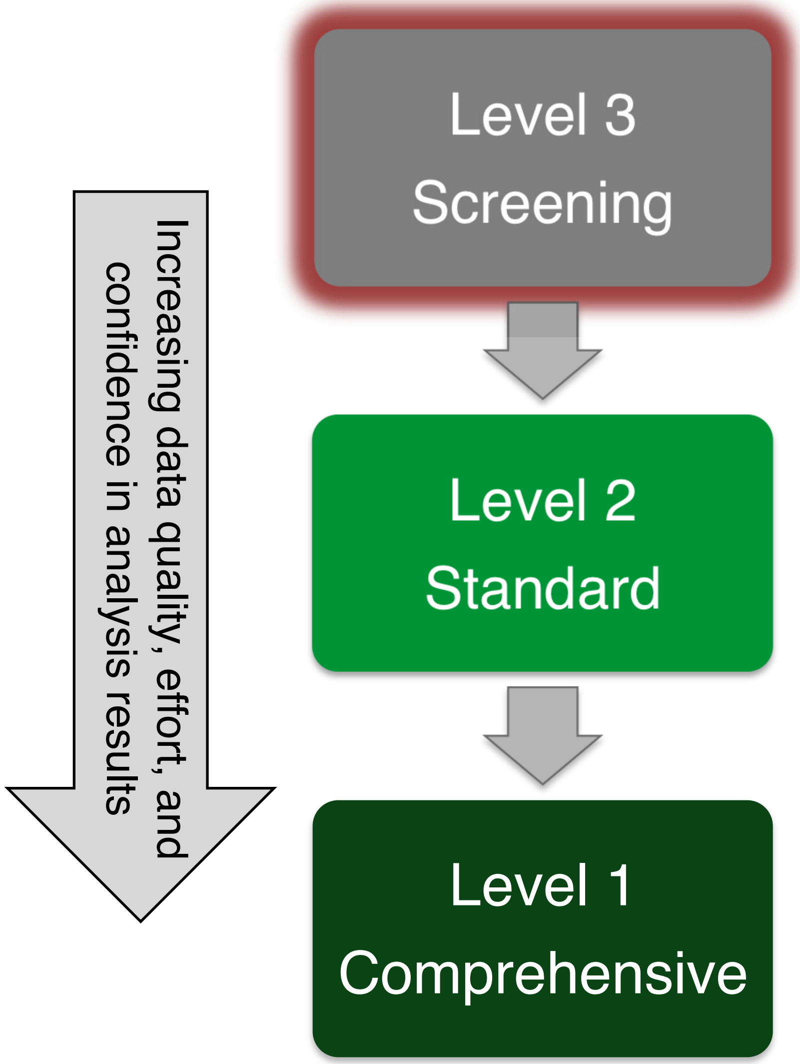


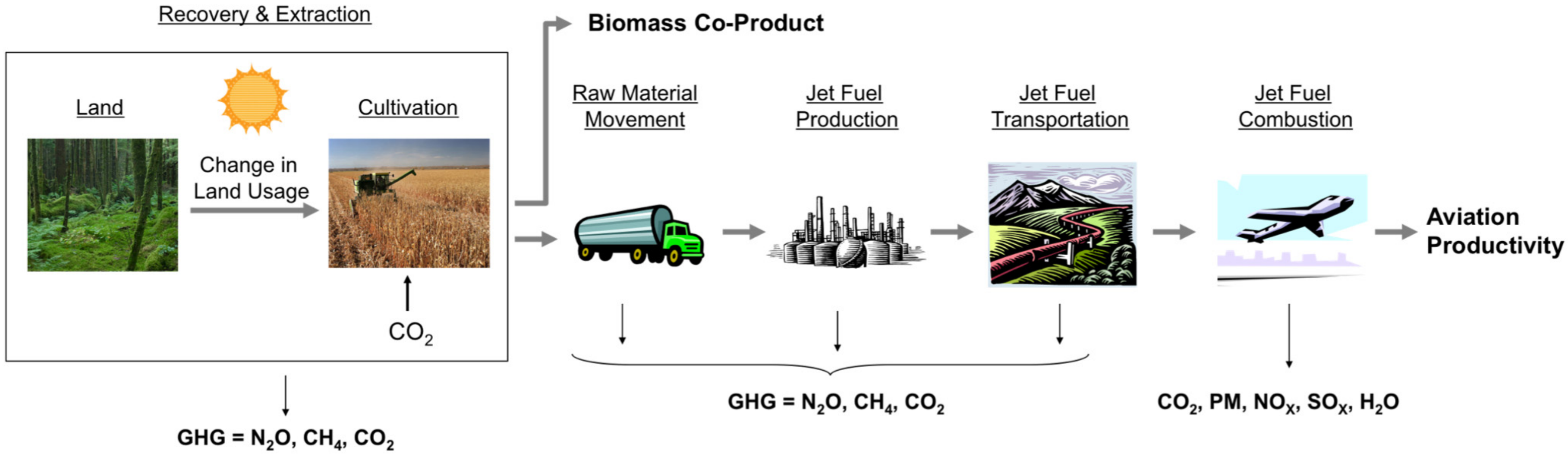
Conducted in support of a preliminary assessment of a technology alternative, to inform policy makers about research funding.

All major operations examined, but with a lower degree of completeness and data quality than comprehensive LCA.

Conducted to meet regulation, such as Section 526 of EISA 2007.

Concepts developed as part of IAWG “Rules and Tools” Workshop (Feb 9-13, 2009).

Well-to-Wake GHG Emissions
Bio-based Jet Fuels



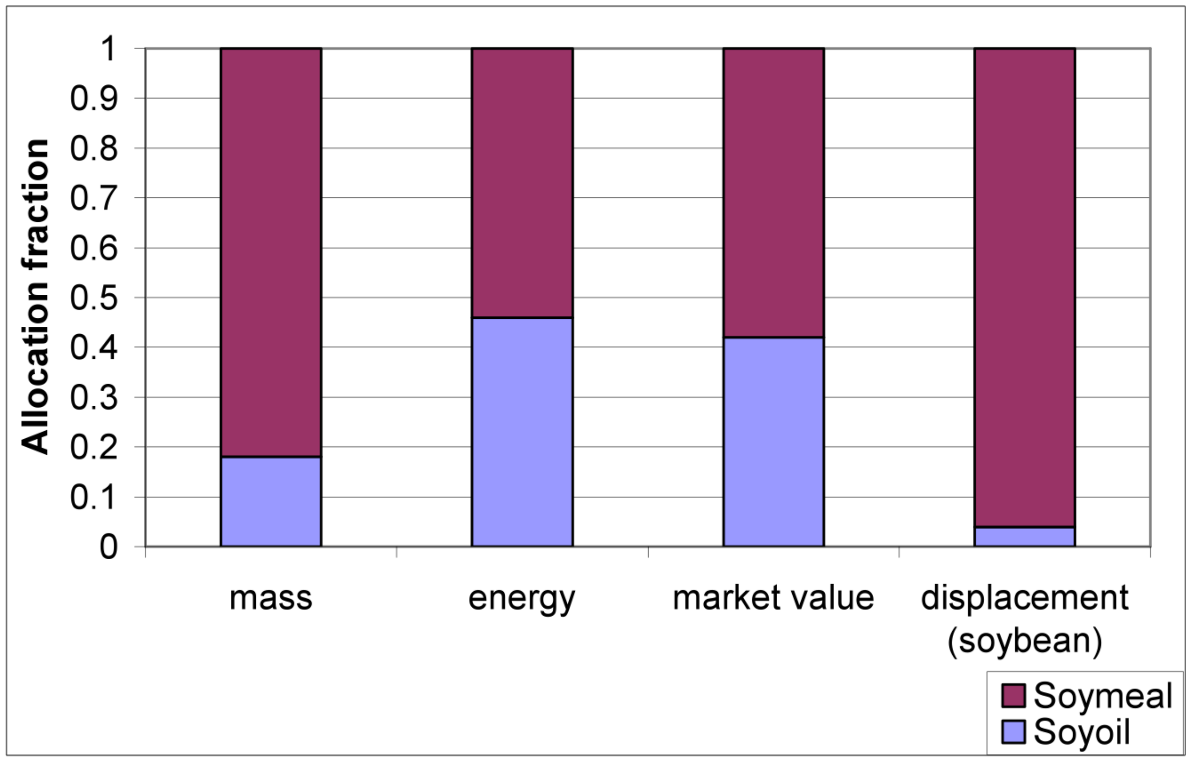
- Biofuels require modifications to analysis:
  - Farming energy and fertilizers
  - Water utilization
  - Land use changes
  - CO_2 extracted from atmosphere to grow biomass feedstock
- Emissions allocation between crop oil and co-product
- Represents soy, rapeseed, palm, camelina, and jatropha.

Soy Oil / Soy Meal Allocation

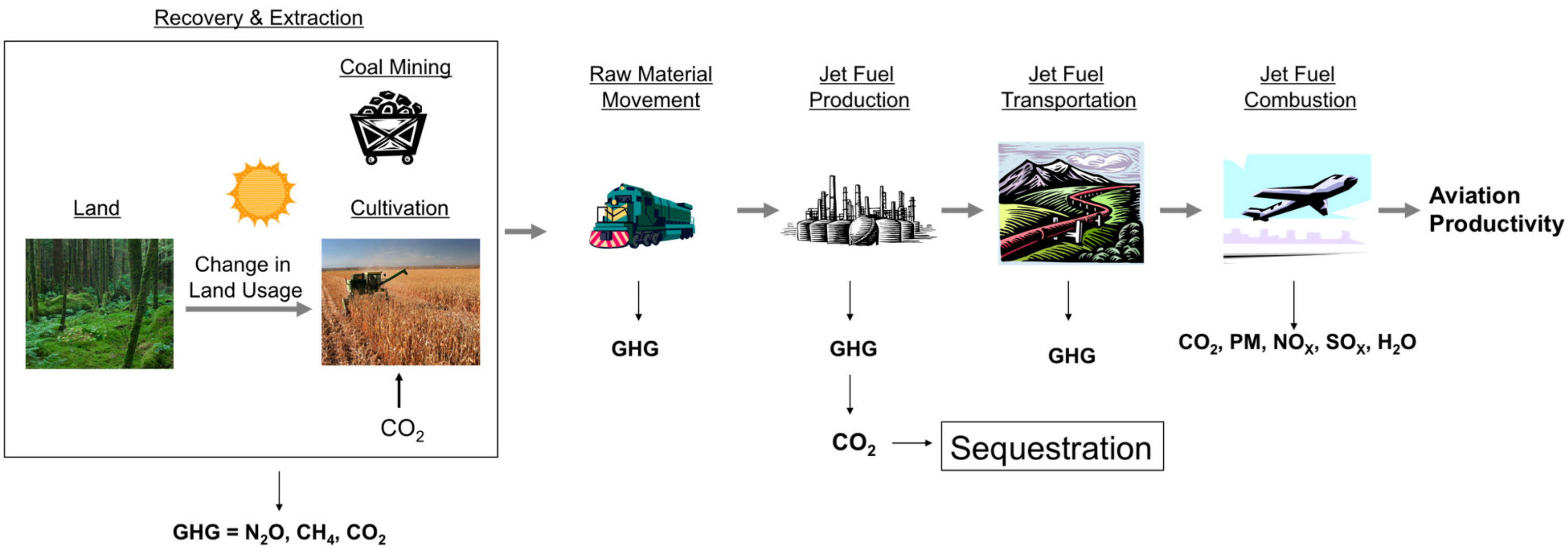
- Emissions need to be allocated between soy oil and soy meal
- Different allocation approaches result in substantial variation
- Energy and market based methods comparable

Source: Wong (2008)

Method / Allocation of emissions	Soyoil (%)	Soymeal (%)
Mass	18	82
Energy	46	54
Market value	42	58
System expansion to displace soybeans	4	96
System expansion to displace barley	-5	105
System expansion to displace corn	-233	333

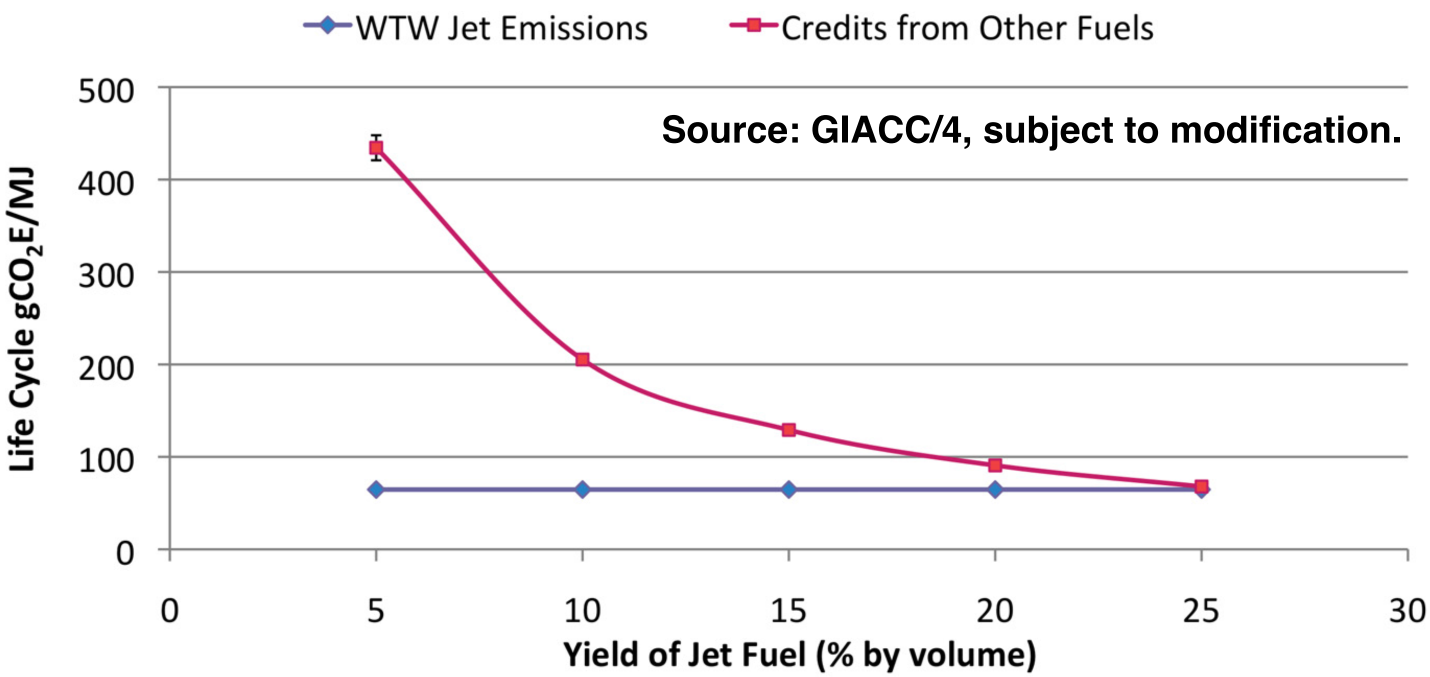


Well-to-Wake GHG Emissions of CBTL Fuel



- Represents F-T synthesis of coal and biomass
- Have potential for partial capture and sequestration of CO_2 from fuel production
- Possible co-products of biomass, electricity, chemicals

Allocating GHG among CBTL fuels



- Examined CBTL product slate of 25% F-T jet fuel, 55% F-T diesel and 20% F-T naphtha – no electricity for export.
- 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

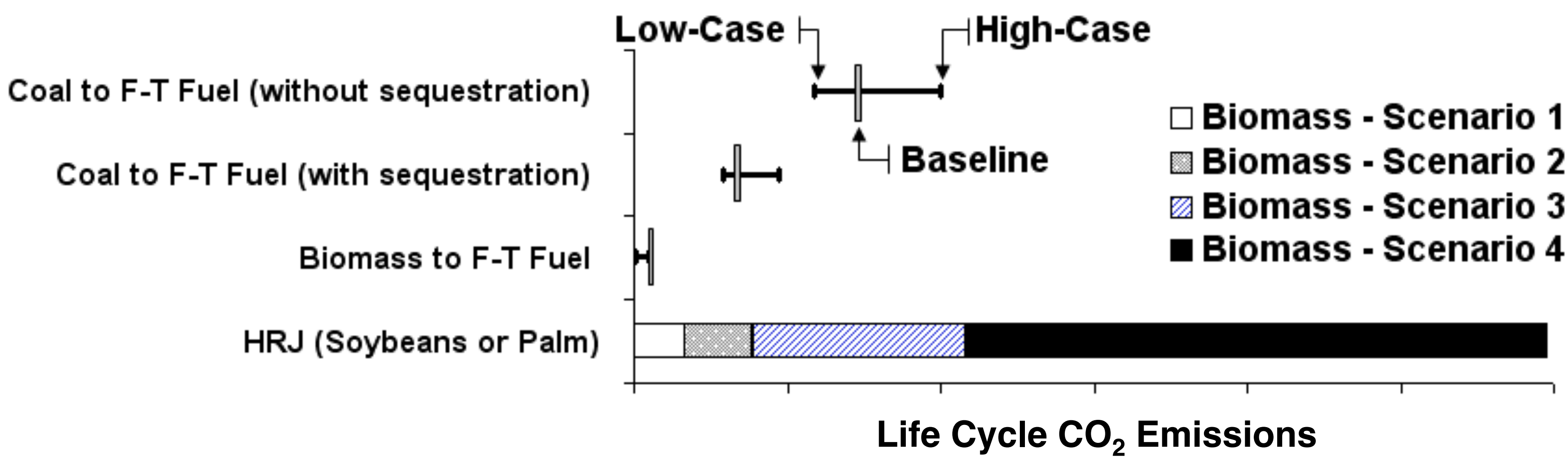
Assessing Uncertainties

Uncertainties:

- Feedstock variation
- Process efficiency
- Carbon capture efficiency

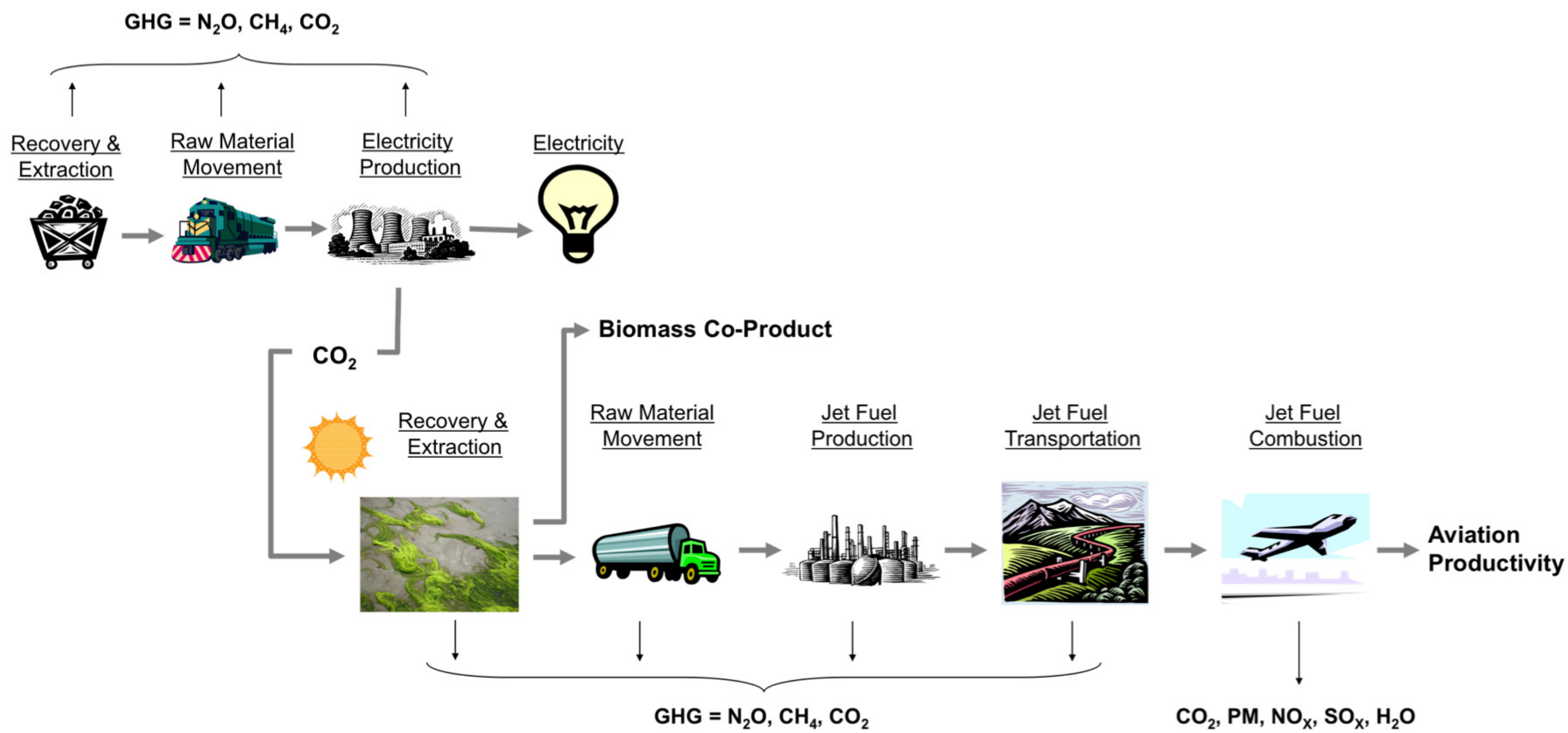
Land use change scenarios:

1. Use Marginal Land or Waste Product
2. Conversion of Brazilian Cerrado
3. Wide-Spread Agricultural Changes
4. Destruction of Peatland Rain Forest



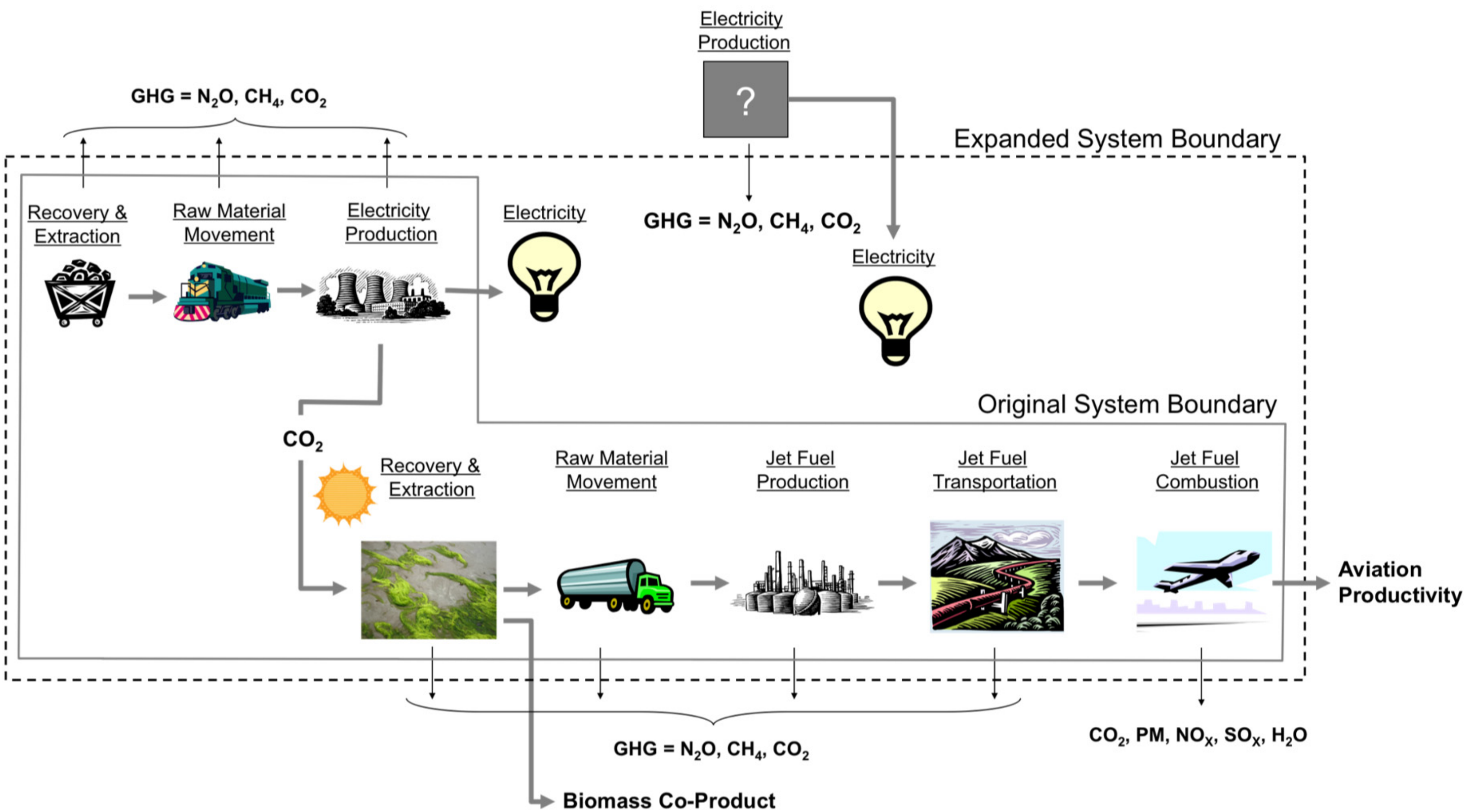
Source: Wong (2008) and Hileman et al. (2008)

Well-to-Wake GHG Emissions Algal-based Jet Fuels (1 of 2)



- To achieve commercial growth rates, algae must be “fed” carbon dioxide from another source (beyond ambient).
- Have electricity, aviation, and biomass co-product output.

Well-to-Wake GHG Emissions Algal-based Jet Fuels (2 of 2)



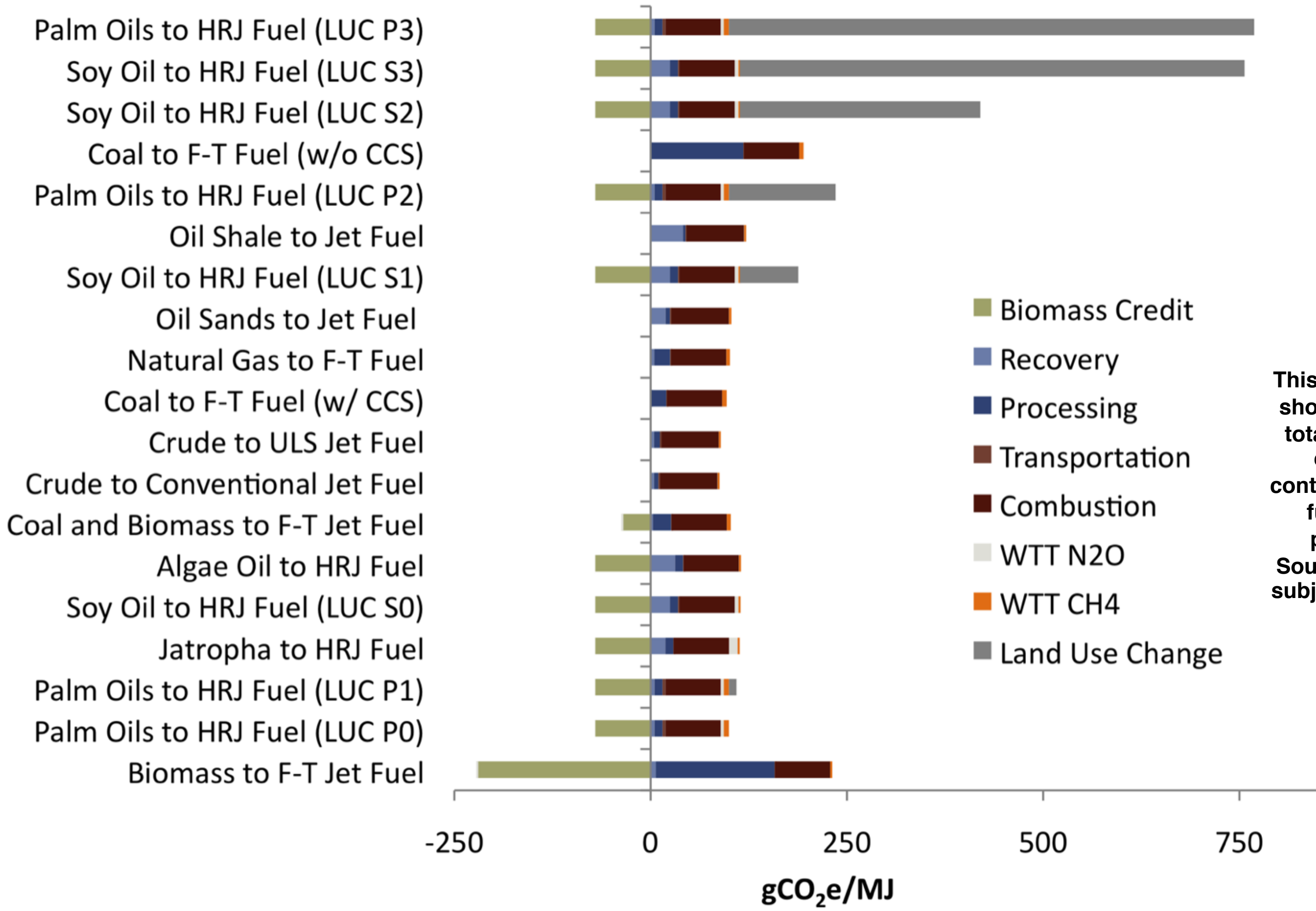
- To enable analysis of jet fuel, expand system boundary to displace similar electricity production.
- Resulting algal HRJ could have low GHG electricity, but electricity GHG are unchanged – both do not get 'credit'

Fuel Pathways Examined by MIT PARTNER

Source	Feedstock	Recovery	Processing	Final Product
Petroleum	Conventional crude	Crude extraction	Crude refining	Jet A
	Conventional crude	Crude extraction	Crude refining	ULS jet fuel
	Canadian oil sands	Bitumen mining/ extraction and upgrading	Syncrude refining	Jet A
	Oil shale	In-situ conversion	Shale oil refining	Jet A
Natural gas	Natural gas	Natural gas extraction and processing	Gasification, F-T reaction and upgrading	SPK Fuel (F-T)
Coal	Coal	Coal mining	Gasification, F-T reaction and upgrading (with and without carbon capture)	SPK Fuel (F-T)
Coal and Biomass	Coal and Biomass	Coal mining and biomass cultivation	Gasification, F-T reaction and upgrading (with and without carbon capture)	SPK Fuel (F-T)
Biomass	Biomass	Biomass cultivation	Gasification, F-T reaction and upgrading	SPK Fuel (F-T)
	Renewable oil – soybeans – palm – algae – jatropha – to be determined	Biomass cultivation and extraction of plant oils	Hydroprocessing	SPK Fuel (HRJ)

Additional pathways currently being examined as part of ongoing research, (e.g., halophytes and camelina to HRJ).

Life-Cycle GHG Emissions



This plot does not show cumulative total, it displays emissions contributions from fuel making processes. Source: GIACC/4, subject to change.

To reduce GHG emissions, need biofuels created from waste products or harvested from non farm land.

Land use change scenarios

Soy oil to biojet pathway scenarios		Palm oil to biojet pathway scenarios	
LUC-S0	No land use change	LUC-P0	No land use change
LUC-S1	Grassland conversion to soybean field	LUC-P1	Logged over forest conversion to palm plantation field
LUC-S2	World wide conversion of non-cropland	LUC-P2	Tropical rainforest conversion to palm plantation field
LUC-S3	Tropical rainforest conversion to soybean field	LUC-P3	Peatland rainforest conversion to palm plantation field

Life-Cycle GHG Emissions with Uncertainty Bands

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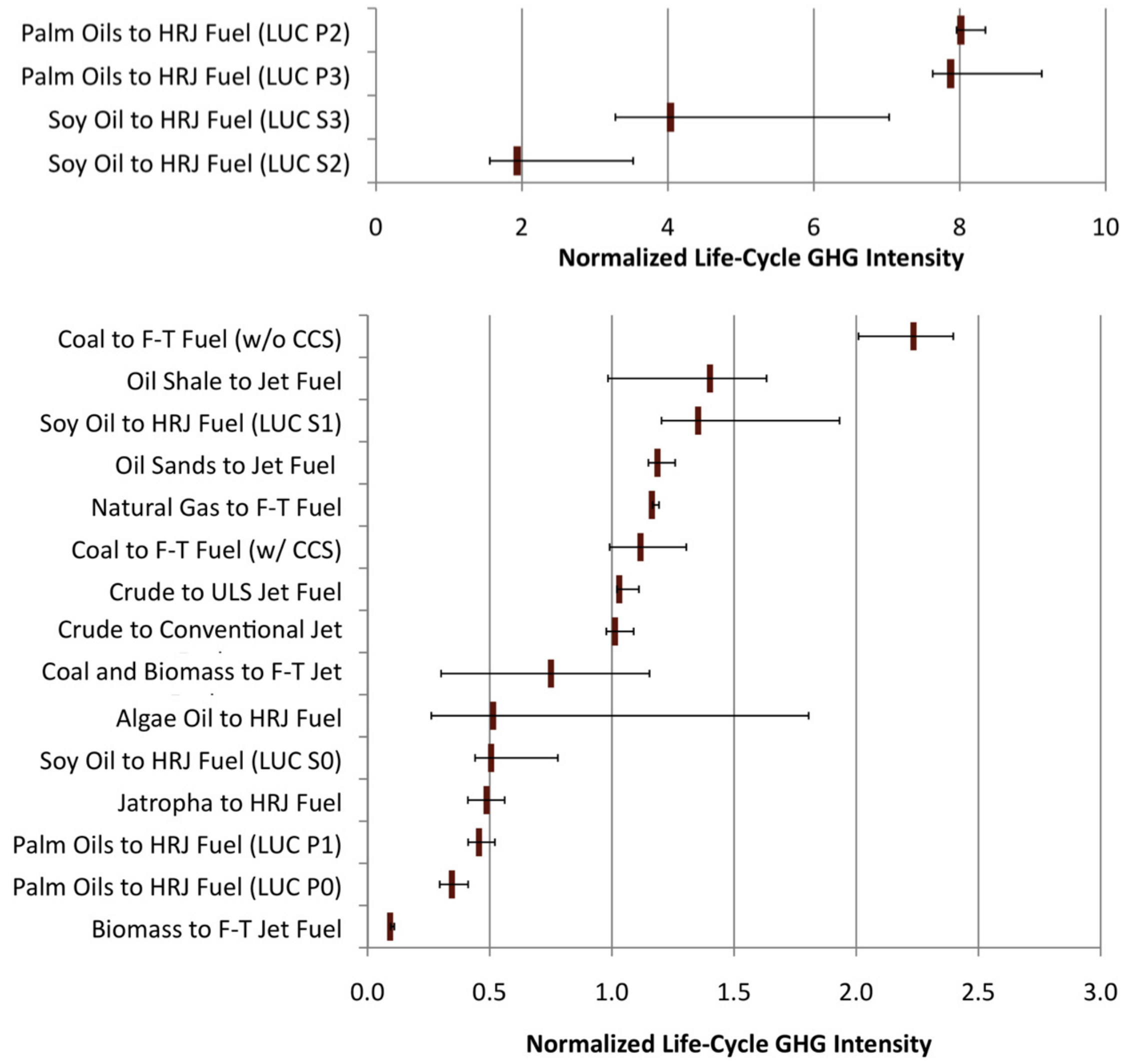
Summary

- Fossil based pathways do not lead to carbon reduction
- Soy and Palm pathways crippled by land use change
- BTL limited by production and delivery of biomass

Three pathways which merit additional analysis:

1) Coal-Biomass to F-T Fuel
2) Algae to Biojet (HRJ)
3) Jatropha to Biojet (HRJ)

… additional fuel pathways being considered as part of our ongoing research (e.g., halophytes to HRJ).



Source: GIACC/4, subject to change.

Biomass Fuel Yields
Land Requirements for Fuel Production

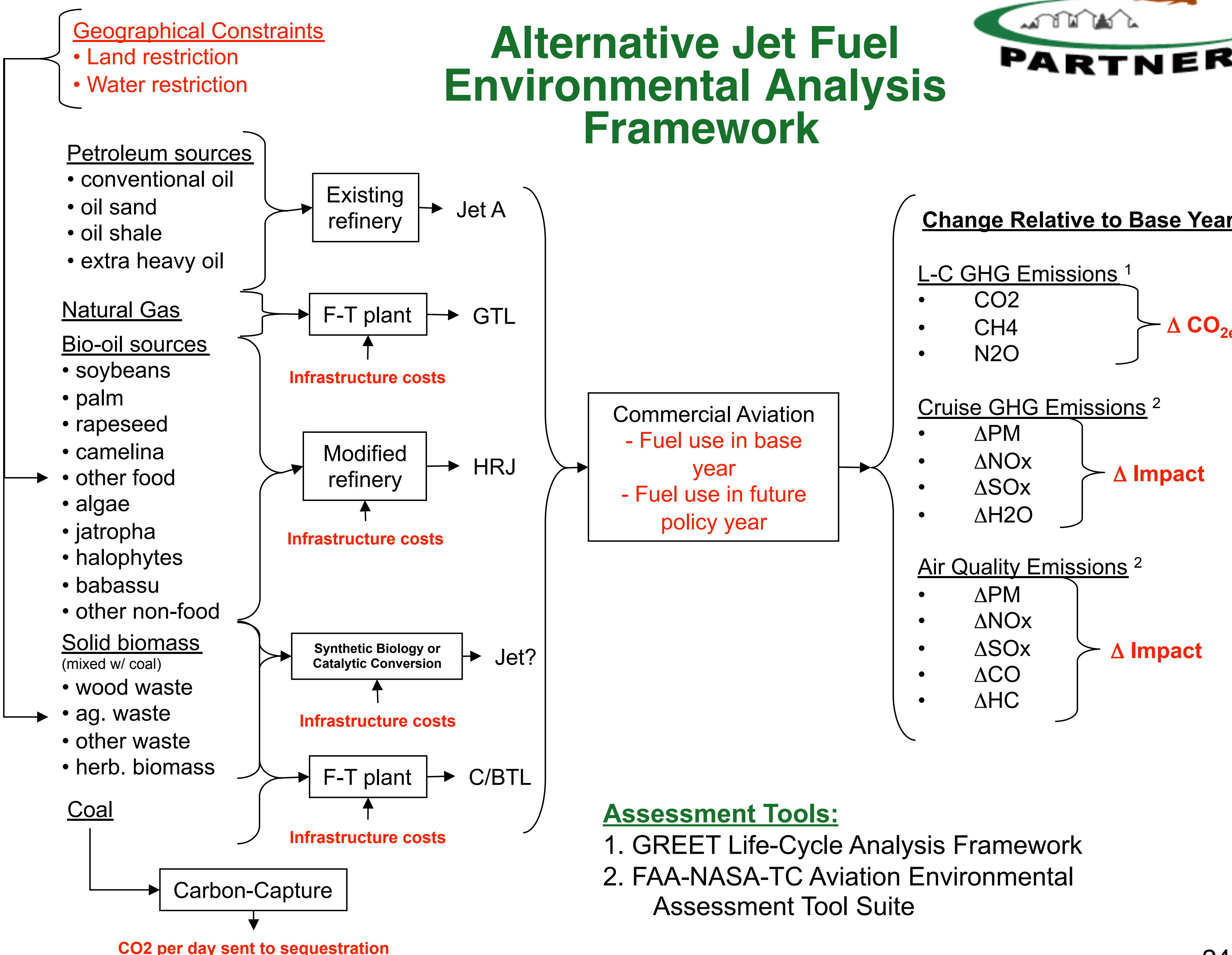
Process	Biomass Type	Biomass Requirements ($kg_{Biomass}/MJ_{Jet\ Fuel}$)	Biomass Yield ($kg_{Biomass}$/ha/year)	Jet Fuel Yields ($L_{Jet\ Fuel}$/ha/year)	Other Fuel Yields[3] ($L_{diesel\ equivalent}$/ha/year)
BTL via Fisher Tropsch[1]	Corn Stover	0.542	4434	244	682
CBTL via Fisher Tropsch[1]	Corn Stover	0.090	4434	1464	4094
UOP via Hydroprocessing[2]	Jatropha	0.115	2500	649	275
UOP via Hydroprocessing[2]	Soybeans	0.220	2993	406	172
UOP via Hydroprocessing[2]	Palm FFB	0.174	19228	3301	1400
UOP via Hydroprocessing[2]	Algae	0.161	91250	16919	7176

Notes:
(1) F-T calculations assume a product slate of 25% jet fuel, 55% diesel and 20% naphtha by volume; May be lower.
(2) Hydro-renewable jet fuels produce renewable naphtha and mix propane gas as by products. Only renewable naphtha is counted as a liquid fuel but production of mix propane gas is minimal by comparison.
(3) Diesel equivalent is total energy of all liquid fuel byproducts represented as a volume of conventional diesel

Source: GIACC/4, subject to modification.

CBTL and Algae to HRJ are promising in terms of biomass production and land usage but Jatropha to HRJ has limited yield.

Alternative Jet Fuel Environmental Analysis Framework



Assessment Tools:

1. GREET Life-Cycle Analysis Framework
2. FAA-NASA-TC Aviation Environmental Assessment Tool Suite

Land Requirements for 2050 Aviation Biofuels

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- Assessed fuel usage projections - 2050 usage varied by factor of two.
- Compared 2050 biofuel life cycle GHG emissions relative to 2006 and 2050 emissions using conventional jet fuel.
- Assessed land requirements to replace conventional jet fuel with 50/50 biofuel blend and 100% biofuel.

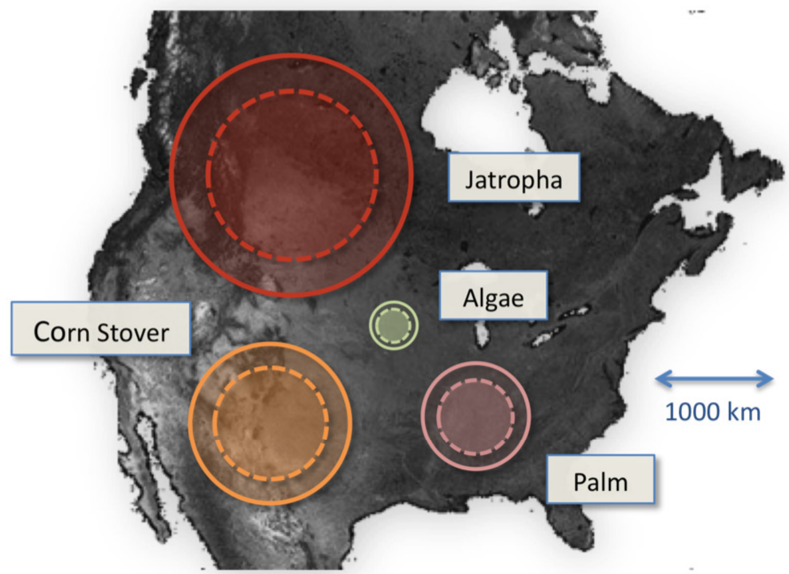
Need feedstocks with high yield and low life cycle emissions that do not require arable land.

Feedstock-to-Fuel Pathway	Fraction of 2006 Emissions(1)	Fraction of BAU 2050 Emissions(2)	Other Fuels Created
Jet Fuel(3)	2.3	1.0	
Algae HRJ(4)	1.2	0.5	• 69 billion kg Naphtha • 13 billion kg MPG(6)
Coal & Biomass F-T Jet Fuel(4,5)	1.7	0.7	• 448 billion kg Diesel • 163 billion kg Naphtha
Jatropha HRJ(4)	1.1	0.5	• 69 billion kg Naphtha • 13 billion kg MPG(6)

(1) Life cycle emissions in 2006 from conventional jet fuel
(2) Life cycle emissions in 2050 with conventional jet fuel
(3) 100% of 2050 jet fuel need is supplied by conventional jet fuel
(4) 100% of 2050 jet fuel need is supplied by biofuel
(5) F-T slate of 25% jet fuel, 55% diesel and 20% naphtha; based on corn stover
(6) Mix Propane Gas

Notes:
- Assumed no land use change emissions with all of the feedstocks.
- Land areas are given relative to continental U.S. for illustrative purposes (e.g., palm trees do not grow in Tennessee).
- Increased aircraft tech development could allow for carbon neutrality with algae HRJ (2050 emissions = 2006 emissions).

US Alternative Fuel Land Requirements in 2050 Compared to the United States



Note: Dashed circles correspond to replacement of conventional jet fuel with 50/50 (vol%) blend of the respective biofuel with conventional jet fuel; solid circles correspond to replacement of conventional jet fuel with 100% mix of the respective biofuel

Source: GIACC/4 (2009). Subject to modification.

Summary

- Life cycle analysis is critical to determine whether a potential alternative jet fuel will reduce GHG emissions
- Alternative fuels exist that could both reduce life cycle CO_2 and improve air quality (e.g., HRJ and CBTL fuels), 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.
- Carbon neutrality appears to be physically possible, but…
  - Considerable land mass will be needed and costs could be prohibitive.
  - Aviation will need to compete with other sectors for these limited biomass resources.
  - Solutions that use feedstocks with low life-cycle emissions and high yield that do not require arable land appear reasonable and these are currently being examined as part of PARTNER research.

Select References:

1. U.S. Federal Aviation Administration, Office of Energy and Environment, *Aviation Environmental Models,* May 2007. http://www.faa.gov/about/office_org/headquarters_offices/aep/models/
2. Argonne National Laboratory, "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model Version 1.7."
3. Wong, H.M., *Life-cycle Assessment of Greenhouse Gas Emissions from Alternative Jet Fuels,* S.M. thesis, Massachusetts Institute of Technology, Engineering Systems Division, Technology and Policy Program, 2008.
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5. GIACC/3-IP/4, "Opportunities for mitigating climate impacts," presented to the 3rd Meeting of the Group on International Aviation and Climate Change (GIACC/3), Feb 17-19, 2009. http://www.icao.int/env/meetings/2009/GIACC_3/GIACC_3.html
6. GIACC/4, In Preparation for the 4th Meeting of the Group on International Aviation and Climate Change (GIACC/4).
7. Skone, T. and Gerdes, K., "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," DOE/NETL-403/101008, 2008. http://www.netl.doe.gov/energy-analyses/trend.html

Backup Slide

PARTNER Alternative Fuels Projects

PARTNER Project 17: Alternative Jet Fuels (Oct 2006 to Dec 2008)

- Examine potential near-term alternative jet fuels
- Working in collaboration with RAND Corporation to create report

PARTNER Project 20: Emissions Characteristics of Alternative Aviation Fuels

PARTNER Project 27: ULS Jet Fuel Environmental Cost Benefit Analysis

PARTNER Project 28: Alternative Jet Fuel Environmental Cost Benefit Analysis (Sept 2008 to Aug 2010) – joint AFRL-FAA project

- Expand to wider range of fuel pathways with longer time horizon
- Examine potential for carbon-neutral growth and a zero-carbon future
- Create and use aviation-specific life-cycle analysis tool
- Perform environmental cost benefit analysis of alternative jet fuels in commercial aircraft

ACRP Project 02-07: Handbook for Analyzing the Costs and Benefits of Alternative Turbine Engine Fuels at Airports (Nov 2007 to May 2009)

- Airport-level examination of alternative jet fuel use in ground service equipment and commercial jet aircraft
- Working in collaboration with CSSI and ECG