ICAO AVIATION AND SUSTAINABLE ALTERNATIVE FUELS WORKSHOP

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Understanding Variability in Life Cycle GHG Inventories of Alternative Jet Fuels

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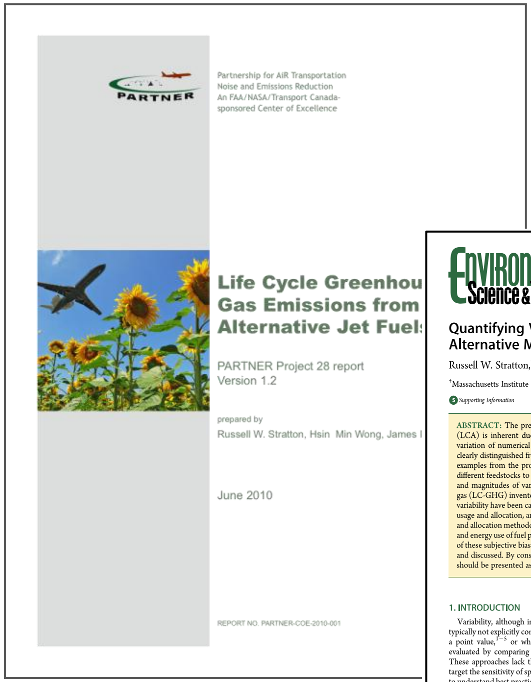
Motivation

- Variability, although inherent in LCA, is often not explicitly considered
- Results are typically reported as a point value
  - These approaches cannot develop new data sets to target the sensitivity of specific factors, which could help understand best practices for reducing LC-GHG emissions
- A new methodological approach was developed using screening level LCAs to understand how variability impacts LC-GHG inventories of transportation fuels
- Screening level analyses provide preliminary assessments of technology alternatives with the intent of informing research funding and decision makers
  - Identify pivotal factors defining the LC-GHG emission profiles of fuel production for each LC step and each feedstock

PARTNER
Project 28 Study

PARTNER Project 28 Report and ES&T Article

- PARTNER Jet Fuel Study
  - Screening level study of next generation alternative jet fuels
  - Examine low, baseline, and high emissions scenarios
  - Emphasize influential aspects of fuel production on GHG emissions
- Results are a range of possible LC-GHG inventories intended to demonstrate variability in fuel production processes.
- Other issues considered: land, water, invasiveness
- Developed analysis into a diesel fuel article for ES&T



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Partnership for AiR Transportation Noise and Emissions Reduction
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Life Cycle Greenhou
Gas Emissions from
Alternative Jet Fuel:

PARTNER Project 28 report
Version 1.2

prepared by
Russell W. Stratton, Hsin Min Wong, James I

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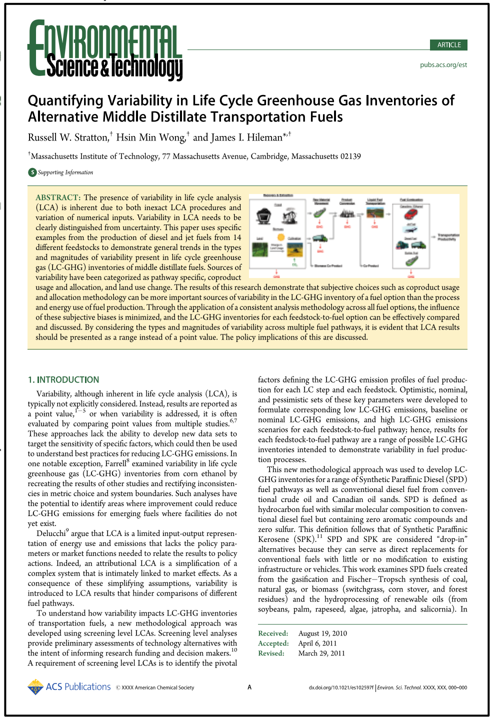

Environmental Science & Technology

ARTICLE

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Quantifying Variability in Life Cycle Greenhouse Gas Inventories of Alternative Middle Distillate Transportation Fuels

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Supporting Information

ABSTRACT: The presence of variability in life cycle analysis (LCA) is inherent due to both inexact LCA procedures and variation of numerical inputs. Variability in LCA needs to be clearly distinguished from uncertainty. This paper uses specific examples from the production of diesel and jet fuels from 14 different feedstocks to demonstrate general trends in the types and magnitudes of variability present in life cycle greenhouse gas (LC-GHG) inventories of middle distillate fuels. Sources of variability have been categorized as pathway specific, coproduct usage and allocation, and land use change. The results of this research demonstrate that subjective choices such as coproduct usage and allocation methodology can be more important sources of variability in the LC-GHG inventory of a fuel option than the process and energy use of fuel production. Through the application of a consistent analysis methodology across all fuel options, the influence of these subjective biases is minimized, and the LC-GHG inventories for each feedstock-to-fuel option can be effectively compared and discussed. By considering the types and magnitudes of variability across multiple fuel pathways, it is evident that LCA results should be presented as a range instead of a point value. The policy implications of this are discussed.

1. INTRODUCTION

Variability, although inherent in life cycle analysis (LCA), is typically not explicitly considered. Instead, results are reported as a point value,[1−5] or when variability is addressed, it is often evaluated by comparing point values from multiple studies.[6,7] These approaches lack the ability to develop new data sets to target the sensitivity of specific factors, which could then be used to understand best practices for reducing LC-GHG emissions. In one notable exception, Farrell[8] examined variability in life cycle greenhouse gas (LC-GHG) inventories from corn ethanol by recreating the results of other studies and rectifying inconsistencies in metric choice and system boundaries. Such analyses have the potential to identify areas where improvement could reduce LC-GHG emissions for emerging fuels where facilities do not yet exist.

Delucchi[9] argue that LCA is a limited input-output representation of energy use and emissions that lacks the policy parameters or market functions needed to relate the results to policy actions. Indeed, an attributional LCA is a simplification of a complex system that is intimately linked to market effects. As a consequence of these simplifying assumptions, variability is introduced to LCA results that hinder comparisons of different fuel pathways.

To understand how variability impacts LC-GHG inventories of transportation fuels, a new methodological approach was developed using screening level LCAs. Screening level analyses provide preliminary assessments of technology alternatives with the intent of informing research funding and decision makers.[10] A requirement of screening level LCAs is to identify the pivotal factors defining the LC-GHG emission profiles of fuel production for each LC step and each feedstock. Optimistic, nominal, and pessimistic sets of these key parameters were developed to formulate corresponding low LC-GHG emissions, baseline or nominal LC-GHG emissions, and high LC-GHG emissions scenarios for each feedstock-to-fuel pathway; hence, results for each feedstock-to-fuel pathway are a range of possible LC-GHG inventories intended to demonstrate variability in fuel production processes.

This new methodological approach was used to develop LC-GHG inventories for a range of Synthetic Paraffinic Diesel (SPD) fuel pathways as well as conventional diesel fuel from conventional crude oil and Canadian oil sands. SPD is defined as hydrocarbon fuel with similar molecular composition to conventional diesel fuel but containing zero aromatic compounds and zero sulfur. This definition follows that of Synthetic Paraffinic Kerosene (SPK).[11] SPD and SPK are considered "drop-in" alternatives because they can serve as direct replacements for conventional fuels with little or no modification to existing infrastructure or vehicles. This work examines SPD fuels created from the gasification and Fischer−Tropsch synthesis of coal, natural gas, or biomass (switchgrass, corn stover, and forest residues) and the hydroprocessing of renewable oils (from soybeans, palm, rapeseed, algae, jatropha, and salicornia). In

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Fuel Pathways

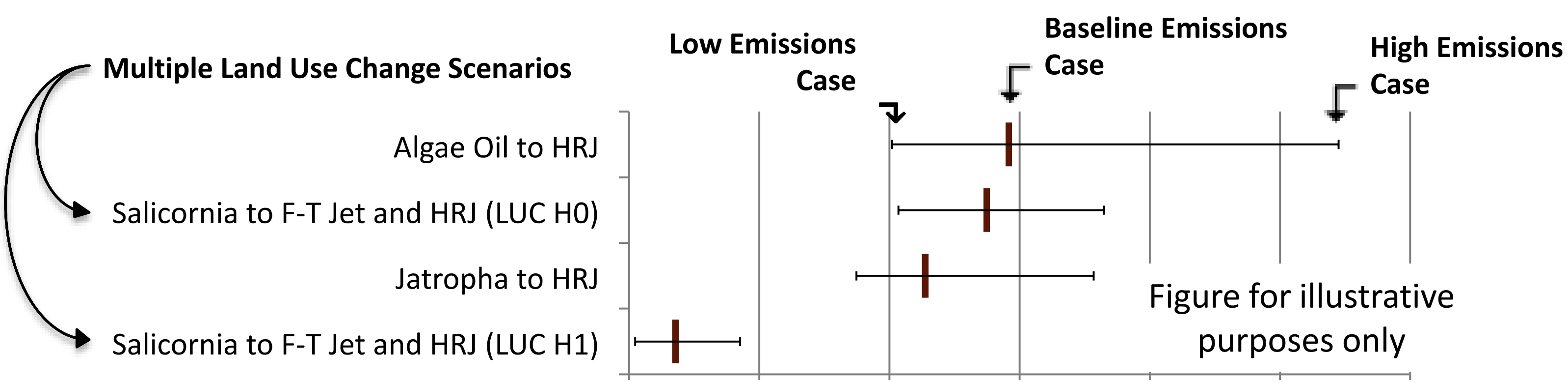
Source	Feedstock	Recovery	Processing	Final Product
Petroleum	Conventional crude	Crude extraction	Crude refining	Jet A
	Conventional crude	Crude extraction	Crude refining	ULS jet fuel
	Canadian oil sands	Bitumen mining/ extraction and upgrading	Syncrude refining	Jet A
	Oil shale	In-situ conversion	Shale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

Variability in LC-GHG Inventories

- LCA is a limited input-output representation of energy use and emissions
  - Attributional LCA is a simplification of a complex system that is intimately linked to market effects.
- The necessity for simplifying assumptions introduces variability into LCA results that hinder comparisons of different fuel pathways.

Types of variability:

Pathway Specific • Co-product Usage and Allocation • Land Use Change Emissions



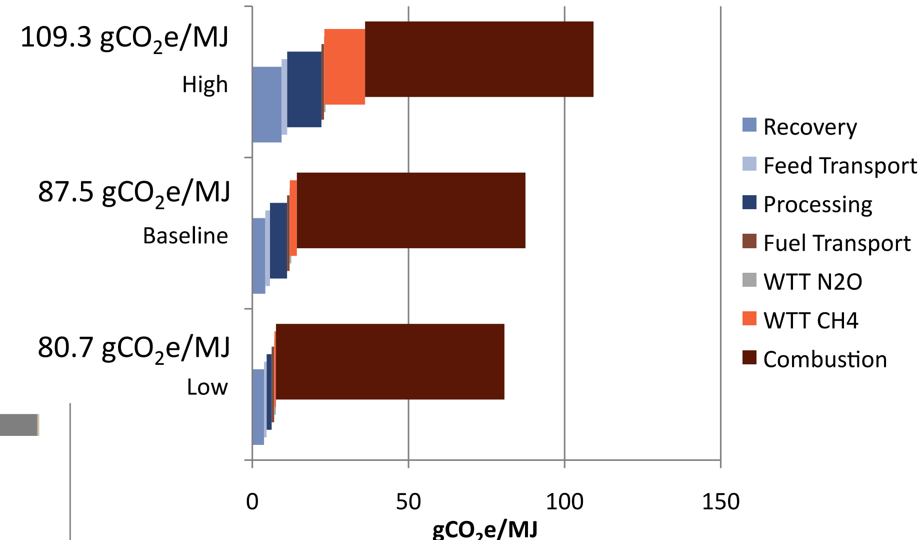
Results for each pathway presented as a range

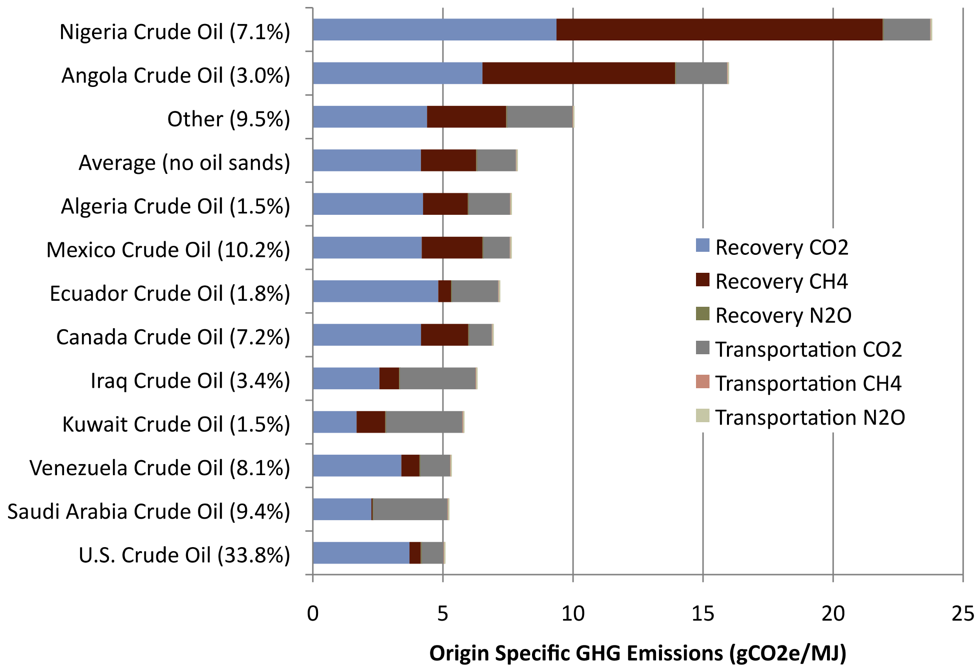
Pathway Specific Variability

Conventional Jet Fuel

- Life cycle analysis is fundamentally a comparative tool

- Jet from conventional crude is the benchmark for alternative fuels





- Consistency between analysis methodologies is essential for comparisons

Average Versus Marginal

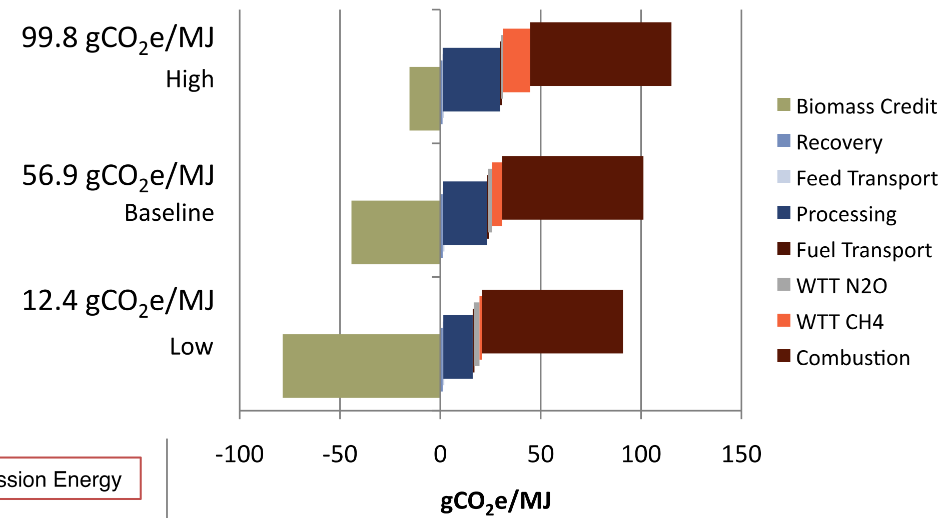
Source: Stratton et al. (2010)

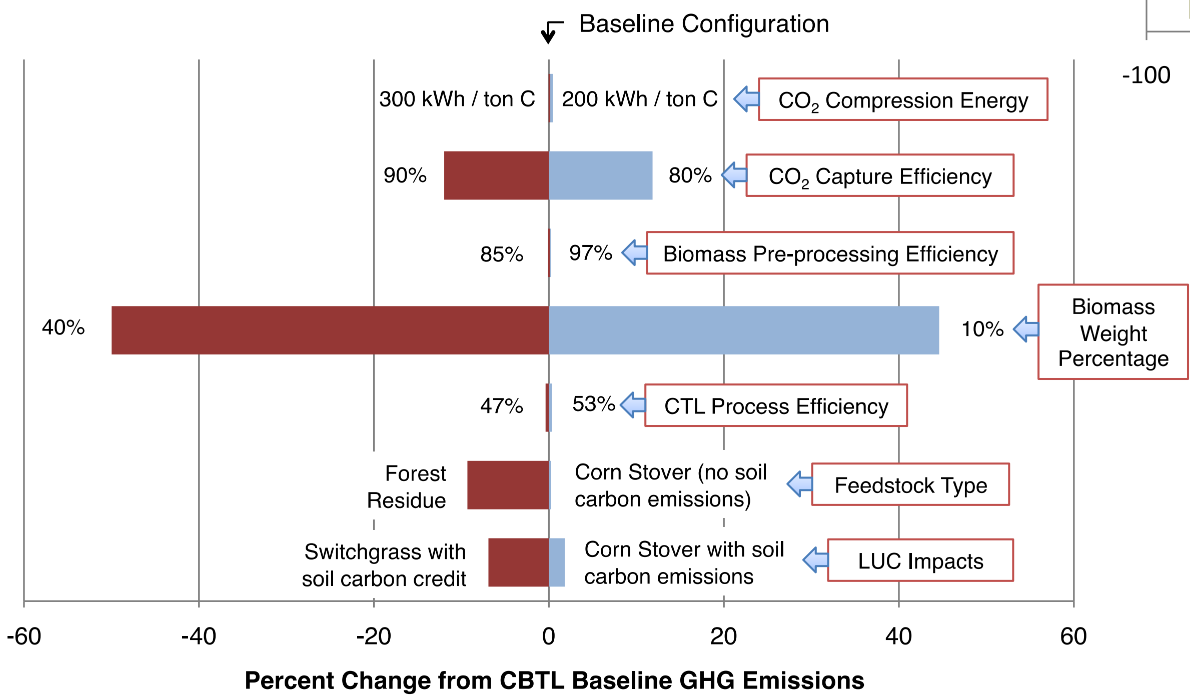
Pathway Specific Variability

Coal and Biomass FT Fuel

- Majority of disparity between cases comes from biomass weight percent and CCS efficiency

- Switchgrass assumed as feedstock





- Feedstock type, biomass weight percent and CCS efficiency → **Very Important for GHG**

- Process Efficiency and energy inputs → **Less important for GHG**

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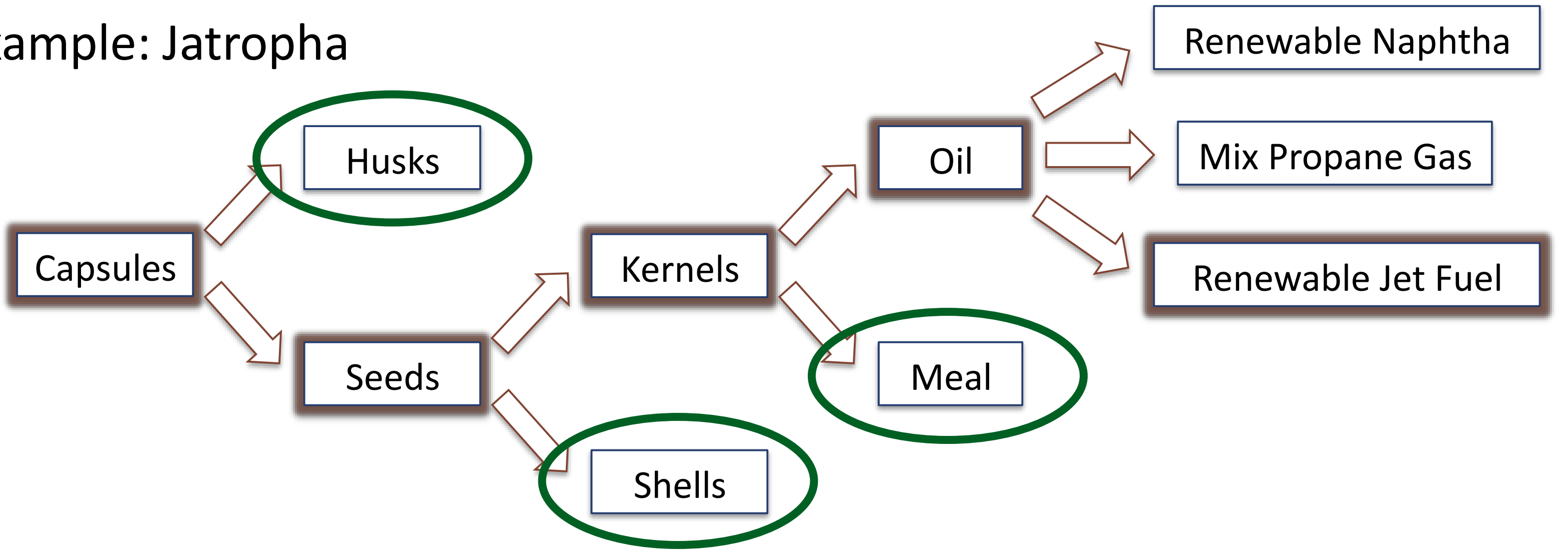
Co-product Usage and Allocation

Jatropha to HRJ (1)

- Allocation methodology between co-products
  - Jet fuel IS the primary product of interest
  - Jet fuel often IS NOT the dominant product created

- Example: Jatropha



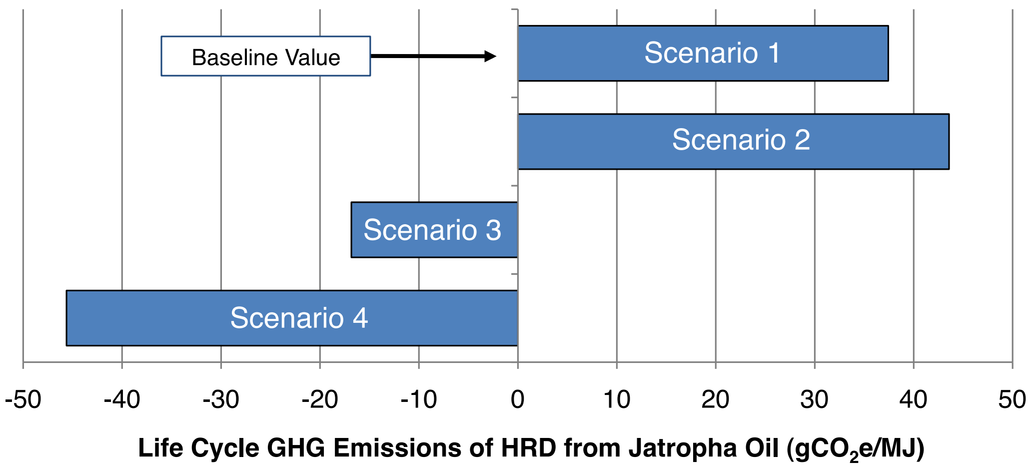
Trade studies were conducted to examine the impacts of different co-product usage assumptions and allocation methodologies

Co-product Usage and Allocation

Jatropha to HRJ (2)

Emissions can be allocated between products using four methods:

- Mass
- Energy
- Economic value
- Displacement (system expansion)



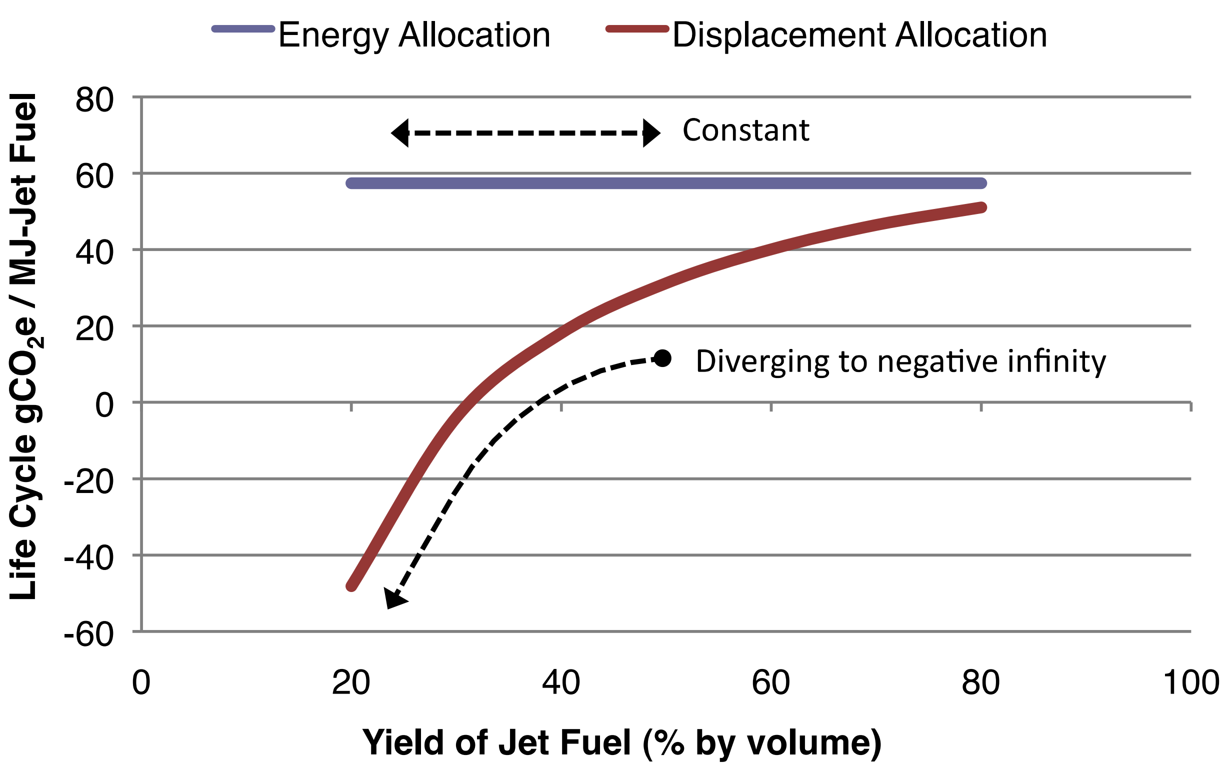
1	**Co-product use:**	Electricity
	Allocation:	Energy
2	**Co-product use:**	Fertilizer
	Allocation:	Displacement
3	**Co-product use:**	Animal feed, Electricity
	Allocation:	Economic value, Displacement
4	**Co-product use:**	Electricity
	Allocation:	Displacement

Subjective allocation and co-product usage choices made by life cycle analyst can be more significant than numerical inputs

Co-product Usage and Allocation

Coal and Biomass FT Fuel

- An F-T facility operator has some control over the product slate of diesel, jet, and naphtha



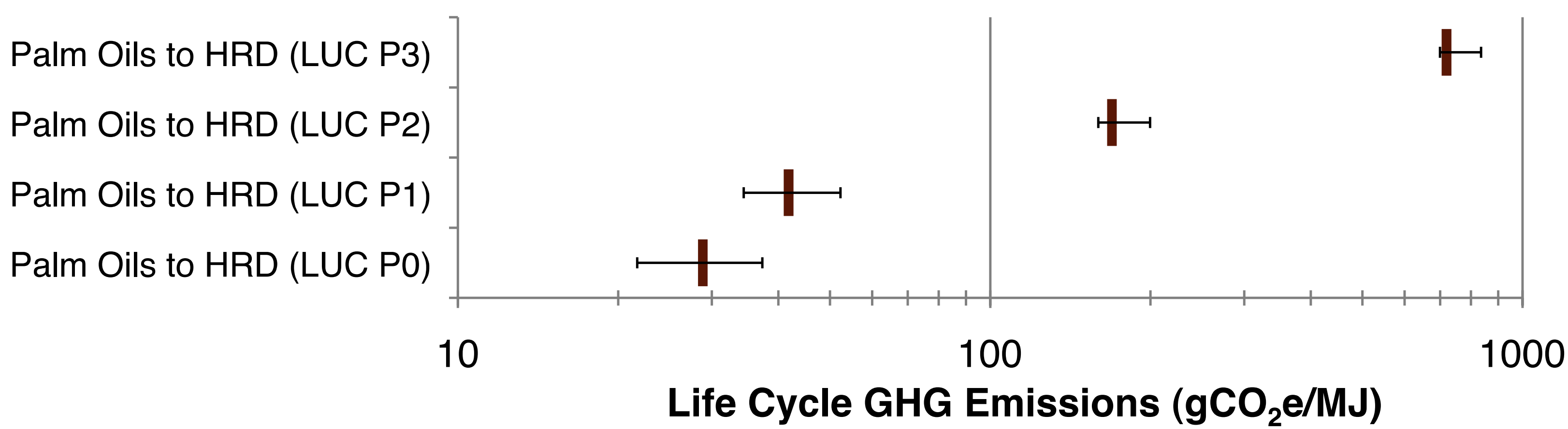
- Displacement allocation makes the LC-GHG inventory of the FT jet fuel VERY sensitive to product slate distribution
- Only meaningful when product of interest IS NOT the primary product (i.e. jet fuel)

Land Use Change Emissions

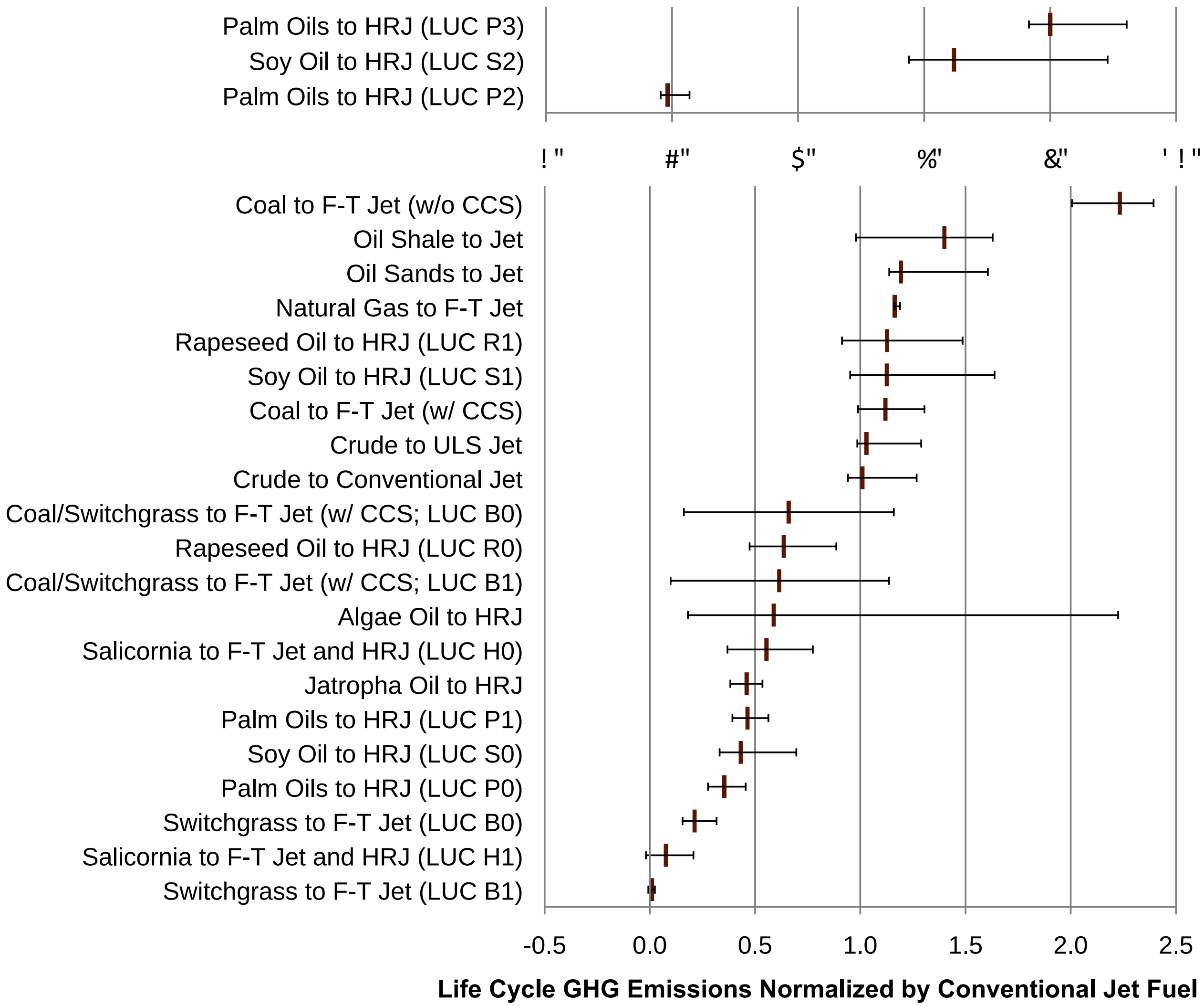
Palm Oil to HRJ

- GHG emissions from LUC can dominate a LC-GHG inventory
- Any given feedstock (i.e. palm oil) could be subject to different types of LUC
- Independent sets of results under select LUC scenarios used to account for the variability of if and when a fuel pathway may be subject to a particular type of LUC

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



Comparison of LC-GHG Inventories



Land Use Change Scenarios

Land use change	LUC Scenario 1	LUC Scenario 2	LUC Scenario 3
Switchgrass (B0, B1)	Carbon depleted soils converted to switchgrass cultivation	n/a	n/a
Soy oil (S0, S1, S2)	Grassland converted to soybean cultivation	Tropical rainforest converted to soybean cultivation	n/a
Palm oil (P0, P1, P2, P3)	Prev. logged over forest converted to palm plantation	Tropical rainforest converted to palm plantation	Peat land rainforest converted to palm plantation
Rapeseed oil (R0, R1)	Set-aside land converted to rapeseed cultivation	n/a	n/a
Salicornia (H0, H1)	Desert land converted to salicornia cultivation	n/a	n/a

Note: In all cases, LUC scenario 0 denotes no land use change

Challenges in Conducting LCA

Multiple Metrics

- Life cycle GHG emissions are only one of many considerations that must be examined when evaluating feasibility and sustainability of alternative fuel options
  - Environmental impacts on global climate change and air quality
  - Efficient usage of fresh water and land resources
  - Invasive characteristics
  - Technical feasibility
  - Economic cost of fuel production.
- While quantifiable comparisons that incorporate these other attributes is ideal, this research has demonstrated the challenges of assessing and comparing different fuel options using only a single attribute, LC-GHG emissions.

Challenges in Conducting LCA

Key Conclusions

- Three key conclusions derive from the potentially dominating influence of variability from co-product usage and allocation and LUC assumptions
  1. Minimizing variability across LCA results by maximizing methodological consistency is essential to making useful comparisons between fuel options
  2. The absolute result from attributional LCA’s may have a diluted physical meaning and are therefore most effective as a comparative tool, given the above condition
  3. Decision makers and the general public should be presented LC-GHG inventories as a range
     - Such an approach emphasizes the importance of understanding the key aspects that determine the LC-GHG emissions from fuel production and use.

Thank you

All results discussed herein are presented in more detail in:

Stratton, R.W.; Wong, H.M.; Hileman, J.I. Quantifying Variability in Life Cycle GHG Inventories of Alternative Middle Distillate Transportation Fuels, *Environ. Sci. Technol.* **2011**, 45 (10), 4637-4644

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