ALTERNATIVE JET FUEL LCA WITH THE GREET® MODEL

MICHAEL WANG AND JEONGWOO HAN

Systems Assessment Group
Energy Systems Division
Argonne National Laboratory

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The GREET™ (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems

Stochastic Simulation Tool
Carbon Calculator for Land Use Change from Biofuels (CCLUB)

GREET 2 model:
Vehicle-cycle modeling for vehicles

VEHICLE CYCLE (GREET 2 Series)
RECYCLING OF MATERIALS
WELL TO PUMP
GREET outputs include energy use, greenhouse gases, criteria pollutants and water consumption for vehicle and energy systems

- **Energy use**
  - Total energy: fossil energy and renewable energy
    - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
    - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy

- **Greenhouse gases (GHGs)**
  - CO₂, CH₄, N₂O, and black carbon
  - CO₂e of the three (with their global warming potentials)

- **Air pollutants**
  - VOC, CO, NOₓ, PM₁₀, PM₂.₅, and SOₓ
  - They are estimated separately for
    - Total (emissions everywhere)
    - Urban (a subset of the total)

- **Water consumption**
Aviation fuel and aircraft options in GREET

Fuels and Feedstocks

- **Petroleum Jet Fuel**
  - Conventional Crude
  - Oil Sand

- **Pyrolysis Oil Jet Fuel**
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops

- **Fischer-Tropsch Jet Fuel**
  - North American Natural Gas
  - Non-North American Natural Gas
  - Renewable Natural Gas
  - Shale Gas
  - Biomass via Gasification
  - Coal via Gasification
  - Coal/Biomass via Gasification
  - Natural Gas/Biomass via Gasification

- **Hydrotreated Renewable Jet Fuel**
  - Soybeans
  - Palm Oil
  - Rapeseeds
  - Jatropha
  - Camelina
  - Algae

- **Ethanol-To-Jet**
  - Corn
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops

- **Sugar-To-Jet**
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops

- **Pyrolysis Oil Jet Fuel**
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops

- **Fischer-Tropsch Jet Fuel**
  - North American Natural Gas
  - Non-North American Natural Gas
  - Renewable Natural Gas
  - Shale Gas
  - Biomass via Gasification
  - Coal via Gasification
  - Coal/Biomass via Gasification
  - Natural Gas/Biomass via Gasification

Aircraft Types

- **Passenger Aircraft**
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad
  - Regional Jet
  - Business Jet

- **Freight Aircraft**
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad

LCA Functional Units

- Per MJ of fuel
- Per kg-km
- Per passenger-km

With data from DOT Volpe Center
Key factors for alternative jet fuel LCA

- Feedstocks
  - Oil seeds
  - Cellulosic biomass
  - Starch/sugar via ATJ/STJ
  - Algae

- Conversion technologies
  - HEFA
  - FT synthesis/pyrolysis
  - Advanced fermentation

- System boundary

- Co-product methods

- Land use changes and other indirect effects
Bio-oil-based jet fuels (HRJ) pathway system boundary
(Soybean feedstock shown as example)

Carbon cycle via photosynthesis provides key CO2 benefits with biofuel pathways
Co-products in the bio-aviation fuel pathways

- **Oil Crops**
  - Algae
  - Waste Oil
  - Oil Extraction
  - Meal
  - Bio-Oil
  - Hydroprocessing
  - Other fuels
  - Hydroprocessed Renewable Jet

- **Starch and Sugar Crops**
  - Adv. Fermentation
  - DGS
  - Electricity
  - Alcohol (e.g., ethanol)
  - Oilgomerization
  - Other fuels
  - Alcohol-To-Jet

- **Cellulosic Biomass**
  - (e.g., Herbaceous, Woody, Ag. and Forest Residue, etc.)
  - Gasification
  - Syngas
  - Fischer-Tropsch Synthesis
  - Electricity
  - Other fuels
  - Fischer-Tropsch Jet
  - Pyrolysis
  - Pyro-Oil
  - Hydroprocessing
  - Other fuels
  - Pyrolysis Renewable Jet

**Note**: DGS denotes Distillers’ Grains with Solubles. Other fuels include fuel gas, naphtha and distillates.
Choice of co-product methods can have significant LCA effects for biofuels

Displacement method
- Fuel
- Energy & Emission Burden
- Production of displaced product
- Fuel (Credit)
- Main Product
- Co-product

Allocation method
- Fuel
- Energy & Emission Burden
- Main Product
- Co-product
- Displacing conv. product

Displacing conv. product

- 100%
- 80% 20%

The hybrid method (GREET default) applies market value allocation between meal and energy products, and energy value allocation among energy co-products

Soybean-based HRJ

- Combustion minus
- Biogenic CO\textsubscript{2} in Fuel
- Transportation
- Distribution
- HRJ Production
- Oil Extraction
- Feedstock (Farming & Fertilizer)
WTWa GHG emissions of alternative jet fuels
LCA functional unit: per MJ of fuel consumption

- LUC-related emissions are not included
- Other key factors: Technology readiness level (TRL), production costs, resource availability and fuel types
Land use change GHG emissions modeling in GREET

Biofuel production increases

Lands transition to feedstock production

Change in carbon stocks in lands

Aboveground carbon

Belowground carbon, including soil organic carbon

Computational General Equilibrium (CGE) Model: GTAP

Carbon Stock Model: Century Winrock Woods Hole

Carbon Calculator for Land Use Change from Biofuels (CCLUB)
CCLUB estimates LUC CO₂ emissions for corn and herbaceous biomass

-60  -40  -20  0  20  40  60  80  100

- GREET dLUC + iLUC

Multiple points by a study represent estimates for different scenarios

- GTAP + Century/Winrock/Woods Hole = CCLUB
- Production assumptions
  - Corn ethanol: 15 billion gallons/year
  - Corn stover ethanol: 9 billion gallons/year
  - Herbaceous ethanol: 7 billion gallons/year

- Petroleum Jet’s WTWa GHG: ~ 86 gCO₂e/MJ

Coal/Biomass FTJ
Herbaceous FTJ
Palm HRJ
Soybean HRJ
Canola/Rapeseed HRJ
Algae HRJ
Camelina HRJ
Salicornia FTJ/HRJ
Corn ATJ
Corn stover ATJ
Conclusions

- Feedstock is a key driver of LCA results for RJF
- LCA system boundary has been expanded in the past 8 years to include indirect effects
- Co-product issue is related to functional unit of LCA; co-product method is an accounting issue (artifact??)
- How to treat trade-offs among energy, GHG, air emissions, and water use attributes for different fuel systems?
- LUC emission modeling continue to advance
- Biomass additionality and carbon neutrality for biofuels are hotly debated now