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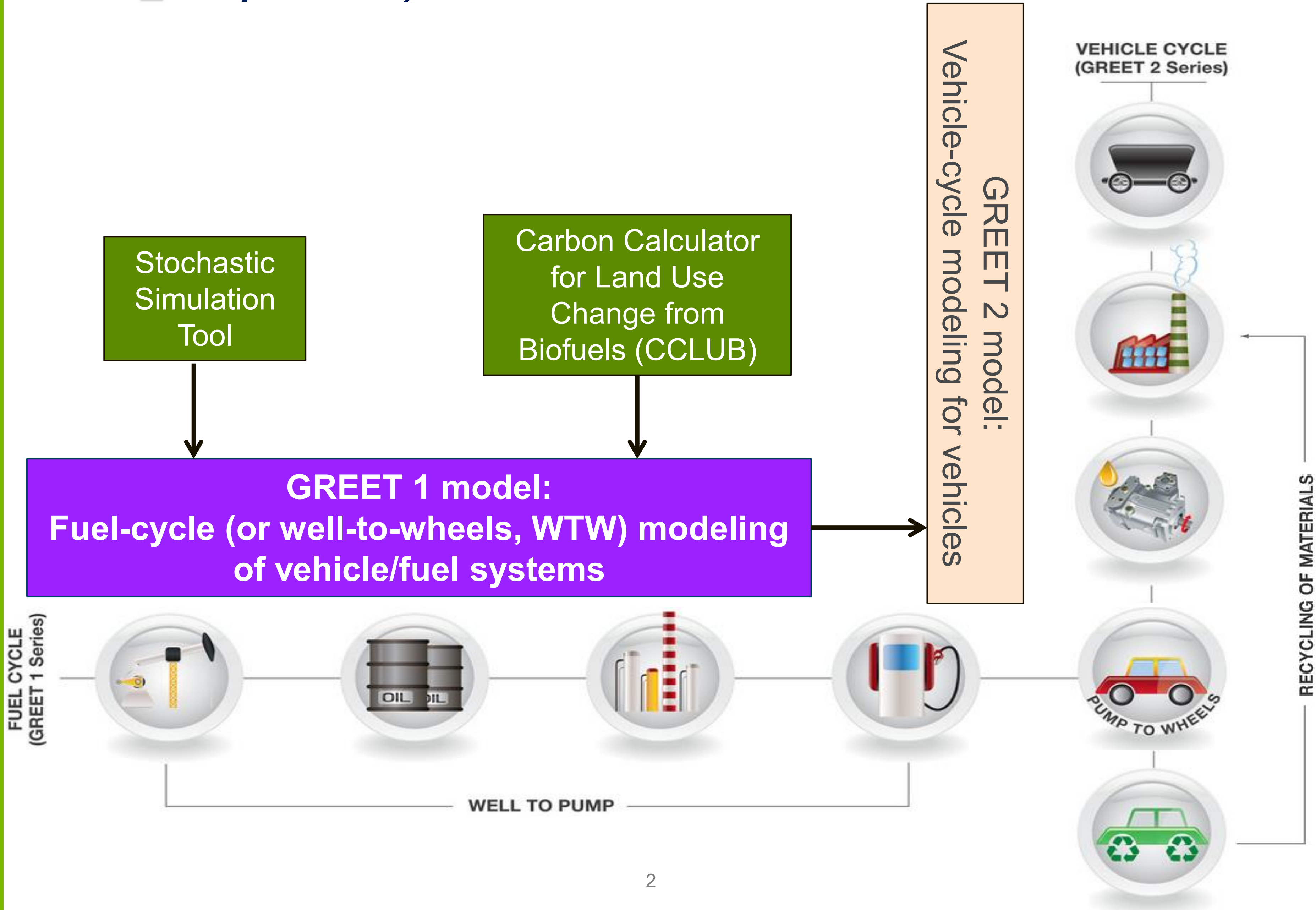
The GREET™ (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model



GREET 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)**
  - CO_2, CH_4, N_2O, and black carbon
  - CO_{2e} of the three (with their global warming potentials)
- **Air pollutants**
  - VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
  - 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
- Hydrotreated Renewable Jet Fuel
  - Soybeans
  - Palm Oil
  - Rapeseeds
  - Jatropha
  - Camelina
  - Algae
- Pyrolysis Oil Jet Fuel
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops
- Ethanol-To-Jet
  - Corn
  - 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
- Sugar-To-Jet
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops

Aircraft Types

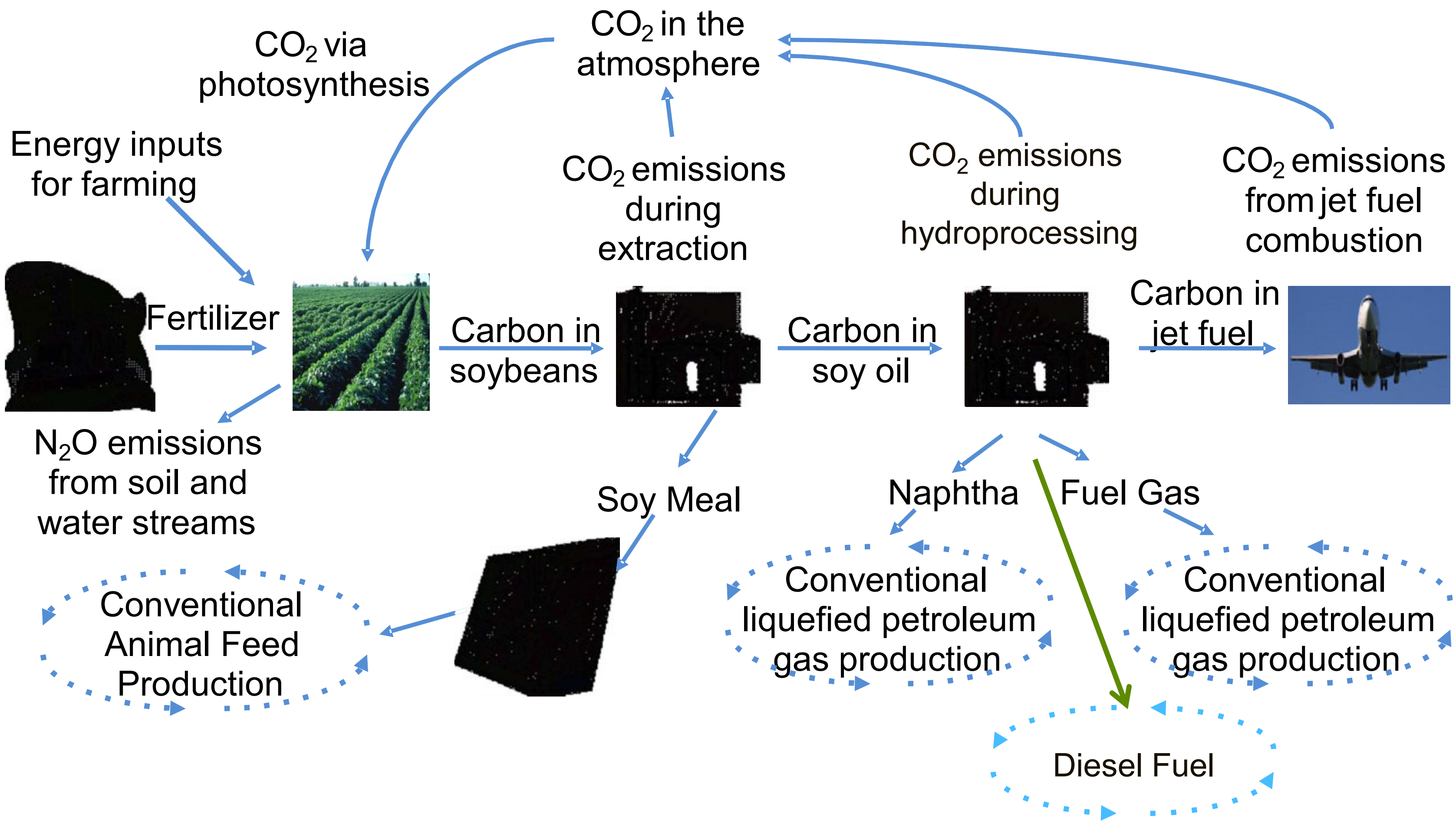
- Passenger Aircraft
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad
  - Regional Jet
  - Business Jet
- Freight Aircraft
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad
- LCA Functional Units
  - Per MJ of fuel
  - Per kg-km
  - Per passenger-km

With data from DOT Volpe Center

Key factors for alternative jet fuel LCA

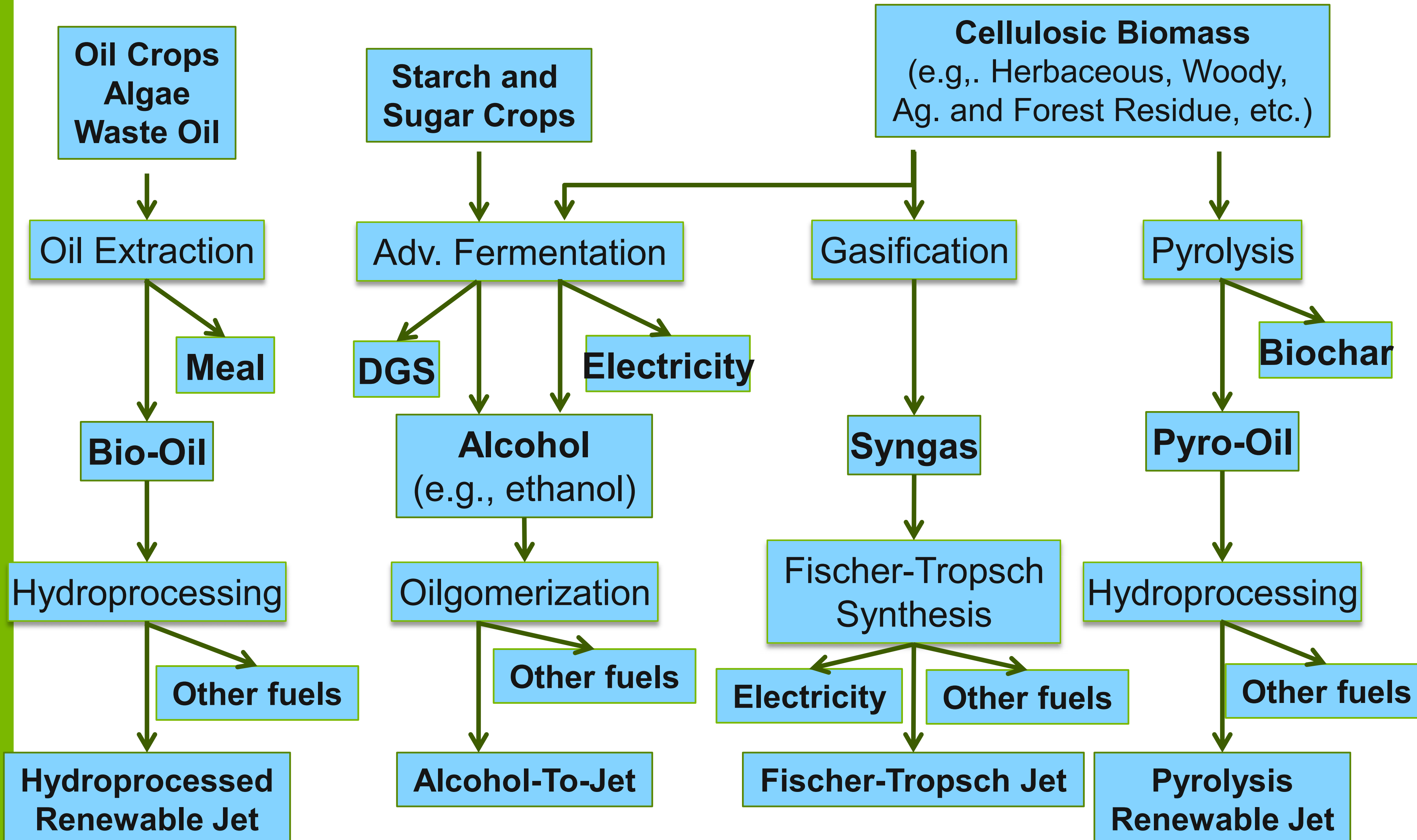
- Feedstocks
  - ✓ Oil seeds
  - ✓ Cellulosic biomass
  - ✓ Starch/sugar via ATJ/STJ
  - ✓ Algae
- Conversion technologies
  - ✓ HEFA
  - ✓ FT synthesis/pyrolysis
  - ✓ Advanced fermentation
- System boundary
- Co-product methods
- Land use changes and other indirect effects

Bio-oil-based jet fuels (HRJ) pathway system boundary
(Soybean feedstock shown as example)



Carbon cycle via photosynthesis provides key CO_2 benefits with biofuel pathways

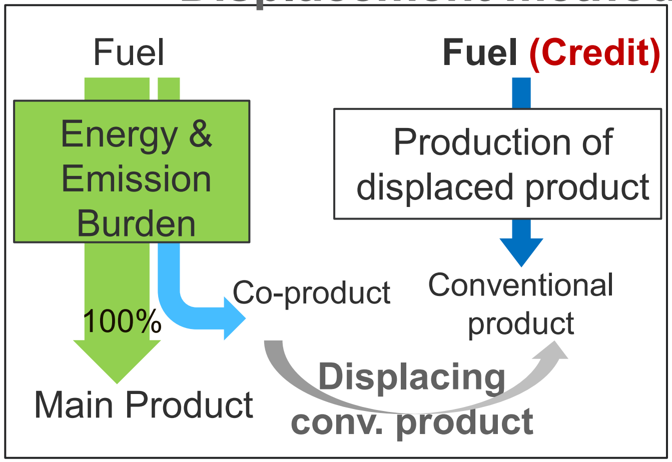
Co-products in the bio-aviation fuel pathways



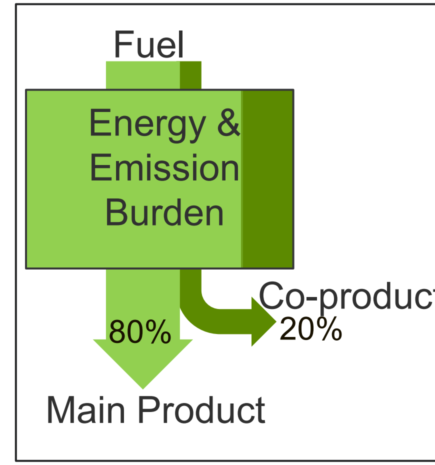
<u>Note</u>: DGS denotes Distillers' Grains with Solubles. Other fuels include fuel gas, naphtha and distillates

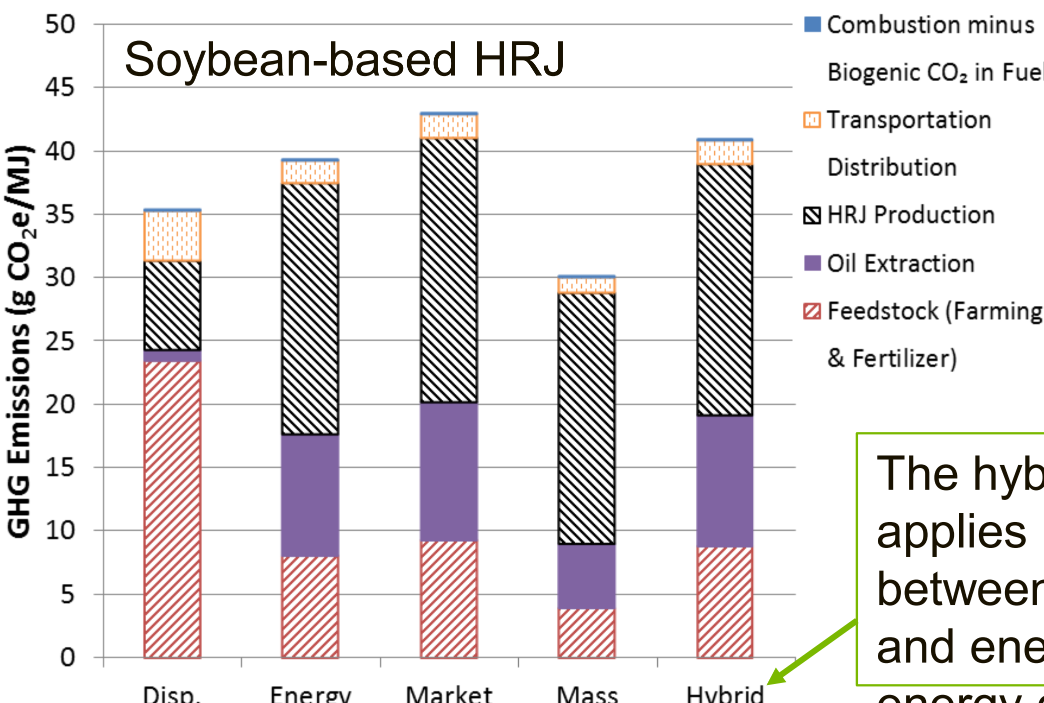
Choice of co-product methods can have significant LCA effects for biofuels

Displacement method



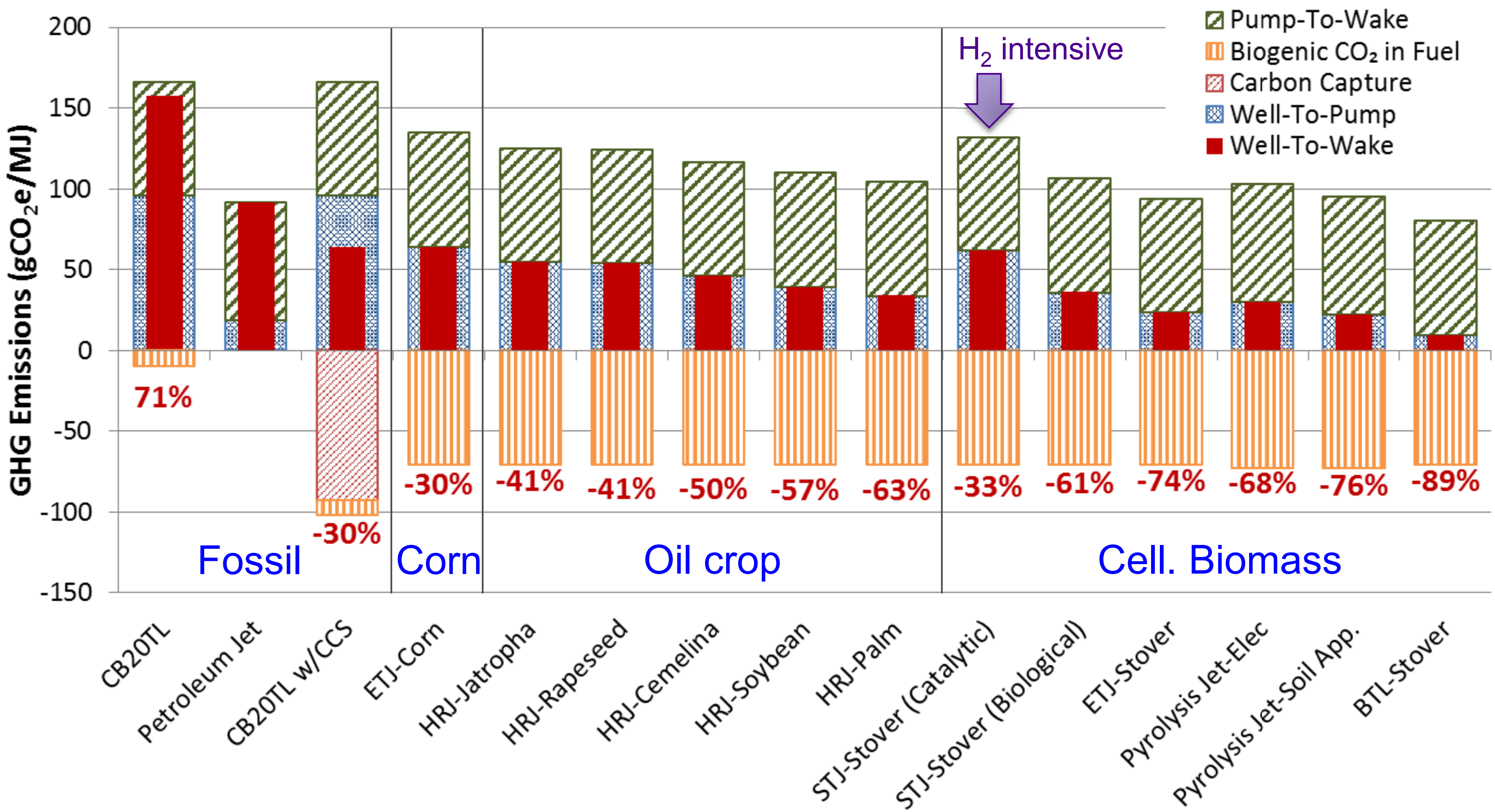
Allocation method





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

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

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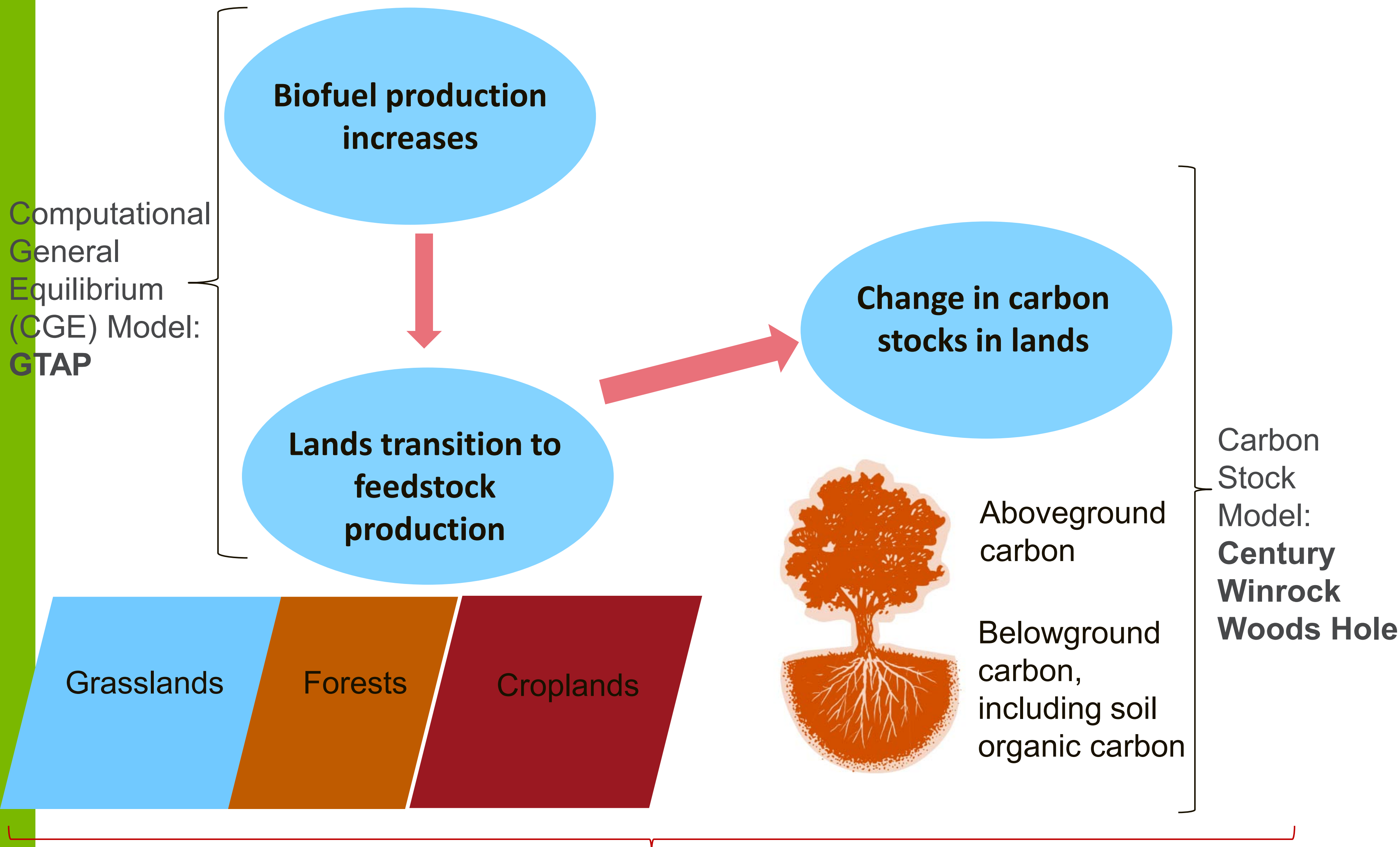
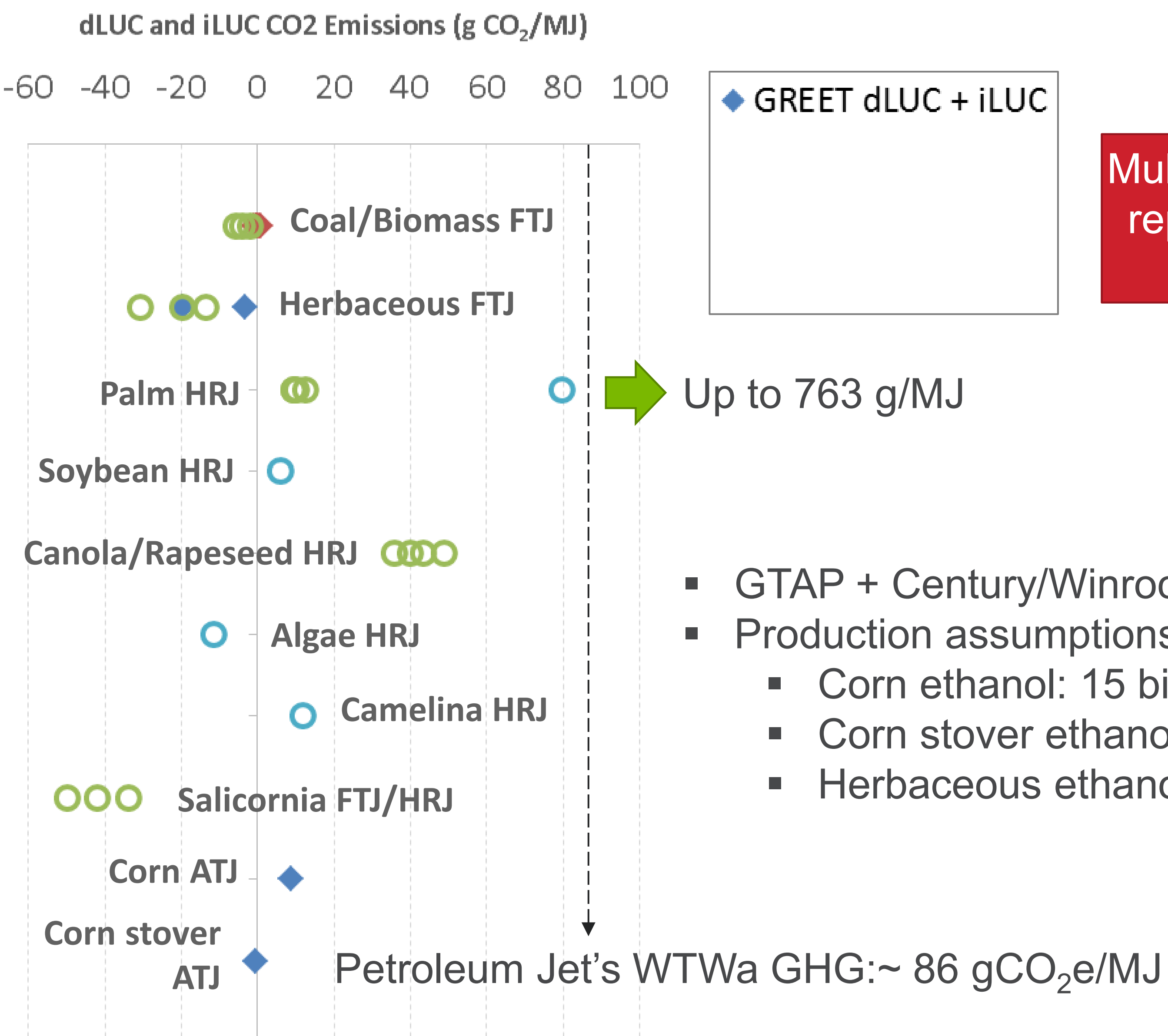
Land use change GHG emissions modeling in GREET



Carbon Calculator for Land Use Change from Biofuels (CCLUB)

CCLUB estimates LUC CO_2 emissions for corn and herbaceous biomass



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

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