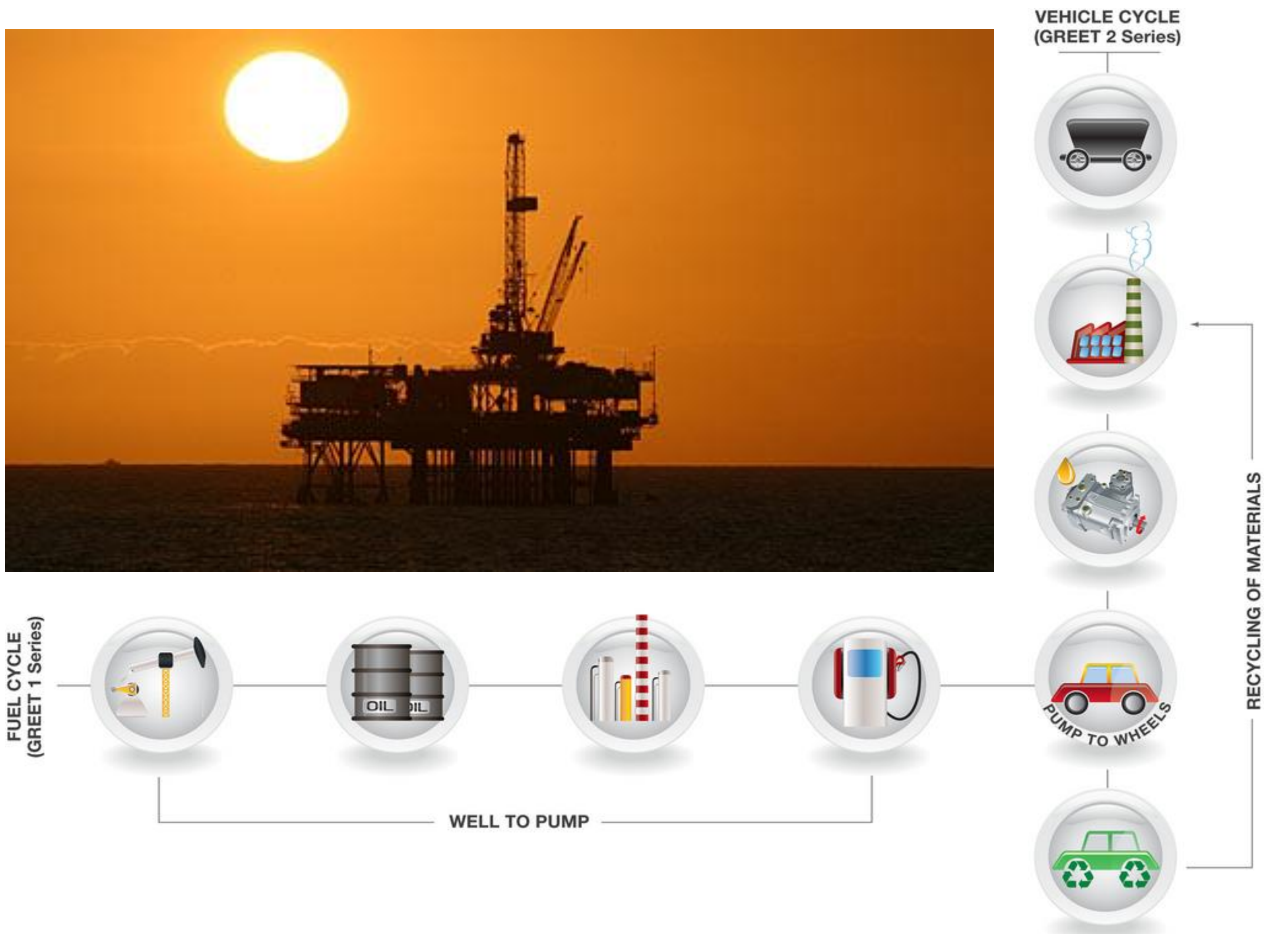
GREET Bioenergy Life Cycle Analysis and Key Issues for Woody Feedstocks

Michael Wang
Systems Assessment Section
Energy Systems Division
Argonne National Laboratory

Biomass 2014
Washington, D.C., July 30, 2014

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

- DOE has been sponsoring GREET development and applications since 1995
  - Vehicle Technology Office (VTO)
  - Fuel-Cell Technology Office (FCTO)
  - Bioenergy Technology Office (BETO)
  - Energy Policy and Systems Analysis (EPSA)
- GREET is available at Argonne's GREET website: greet.es.anl.gov; current version is GREET1_2013



GREET Outputs Include Energy Use, Greenhouse Gases, and Criteria Pollutants for Vehicle/Fuel 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 (in a new release)
  - CO_2e of the three (with their global warming potentials)
- Criteria 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 (in a new release)
- GREET LCA functional units
  - Per mile driven
  - Per unit of energy (million Btu, MJ, gasoline gallon equivalent)
  - Other units (such as per ton of biomass)

GREET includes many biofuel production pathways

- Ethanol via fermentation from
  - Corn
  - Sugarcane
  - Cellulosic biomass
    - Crop residues
    - Dedicated energy crops
    - **Forest residues**

- Renewable natural gas from
  - Landfill gas
  - Anaerobic digestion of animal wastes

- Corn to butanol

- Soybeans to
  - Biodiesel
  - Renewable diesel
  - Renewable gasoline
  - Renewable jet fuel

- Cellulosic biomass via gasification to
  - Fischer-Tropsch diesel
  - Fischer-Tropsch jet fuel

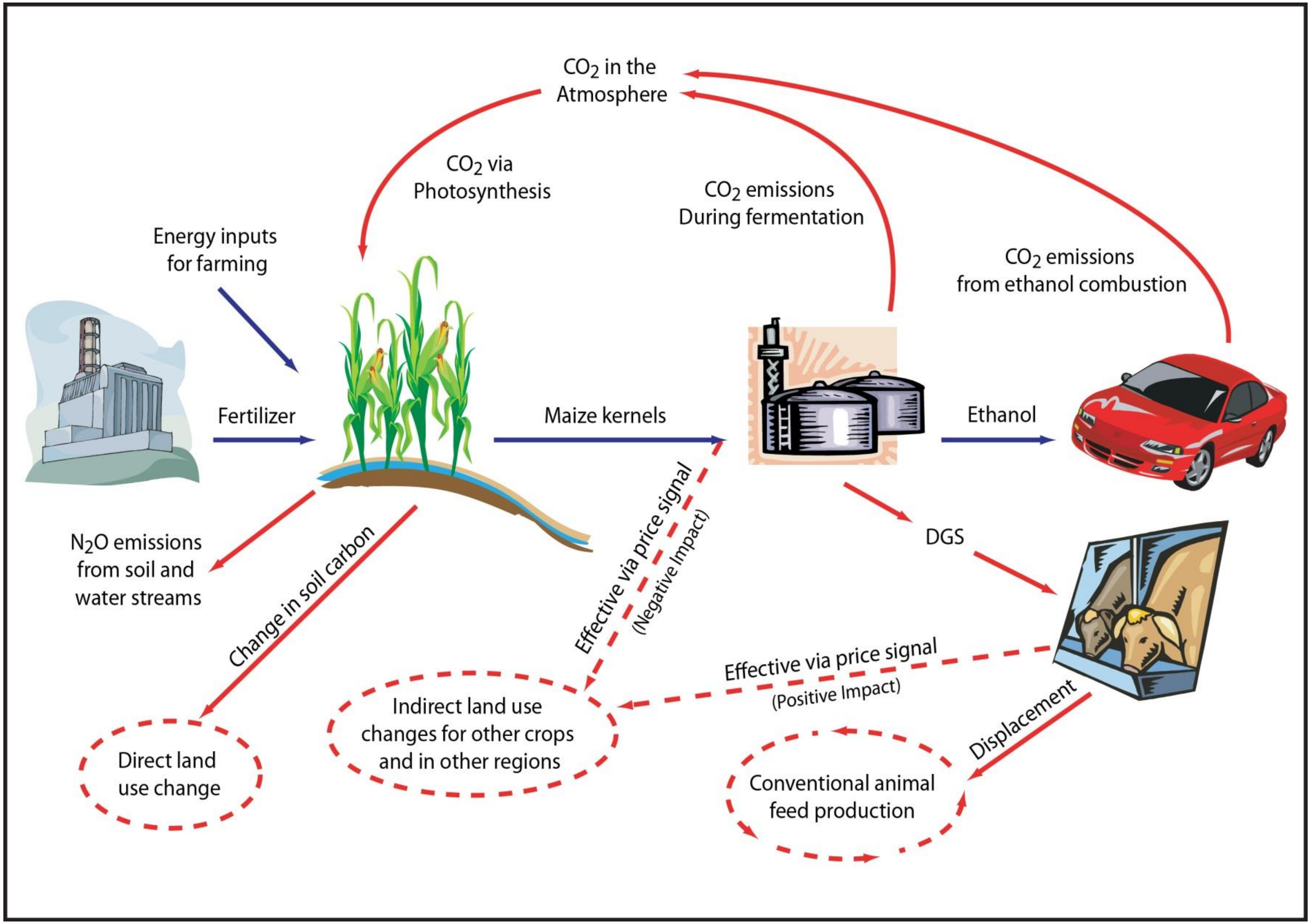
- Algae to
  - Biodiesel
  - Renewable diesel
  - Renewable gasoline
  - Renewable jet fuel

- Cellulosic biomass via pyrolysis to
  - Gasoline
  - Diesel

Key aspects of GREET LCAs

- LCA system boundary – scope of LCA
  - Process-based LCA
  - Attributional vs. consequential LCA
- Co-product methods in LCA
- Data availability and representation
  - Temporal variation
  - Geographic variation
  - Sensitivity of LCA parameters and uncertainty analysis

LCA system boundary: corn to ethanol



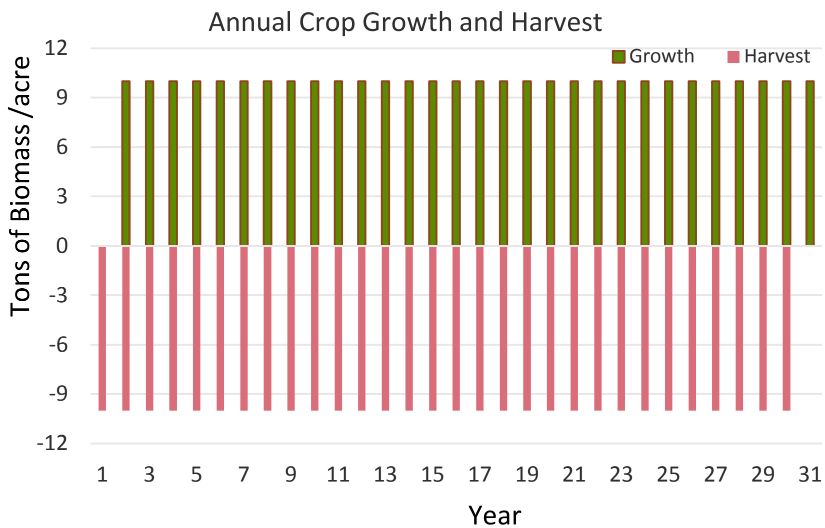
LCA issues of woody feedstocks

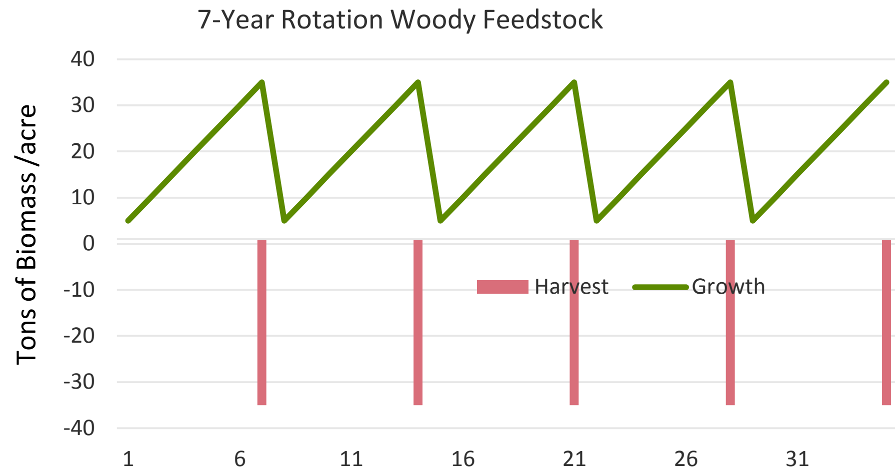
- Difference between short-rotation woody feedstocks and forest feedstocks
  - Management intensity: chemicals use, irrigation, etc.
  - Energy intensities of harvest and transportation logistics
  - Harvest cycle: a few years vs. tens of years
  - Land use change??
    - Above-ground and below ground C stock
- Different uses of forests
  - Multiple uses
    - Wood products for furniture and building materials – carbon fate?
    - Forest residues for bioenergy (currently in GREET)
  - Dedicated growth for bioenergy

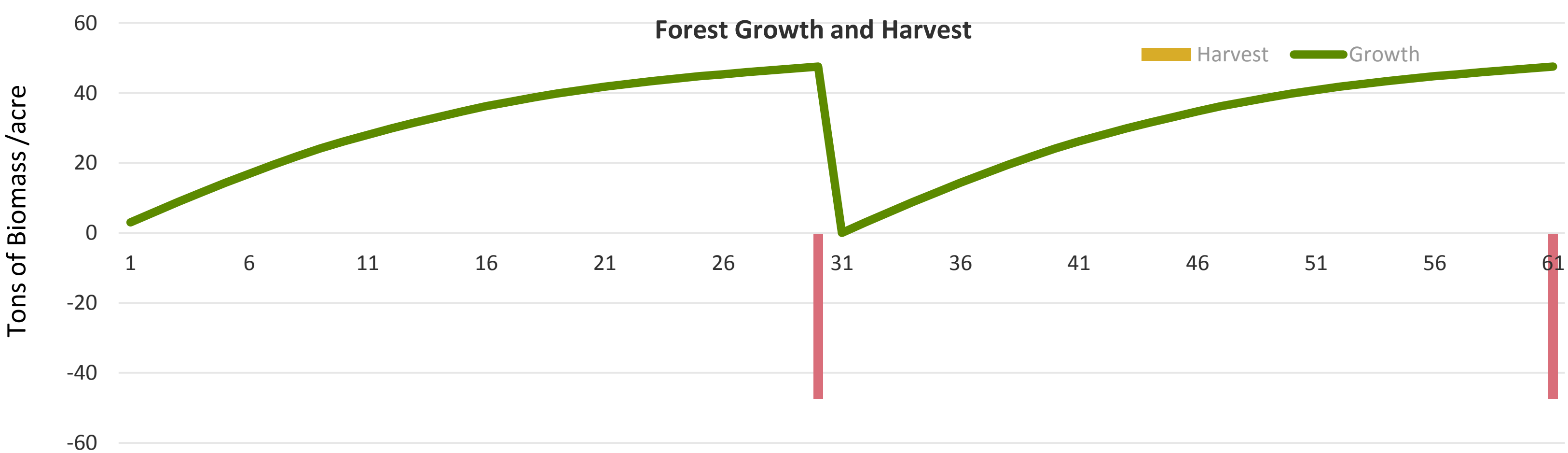
Woody feedstocks in current GREET version: willow, poplar and forest residue

Feedstock	Short-Rotation Willow	Short-Rotation Poplar	Forest residue
Rotations (years in a rotation)	7 (3)	3 (8)	--
Yield (dry ton/acre/year)	4.8	4.5	3.5
Harvesting Energy Use (Btu/dry ton)	154,754	219,200	132,180
Fertilization Use Rate (g/dry ton)			
N	2,584	2,743	0
P_2O_5	0	914	0
K_2O	0	1,828	0
Herbicide Use Rate (g/dry ton)	27	136	0
Elemental Composition (% dry weight)			
C	48.7	50.1	50.3
H	6.0	5.8	6.0
N	0.5	0.4	0.5
O	42.9	40.6	41
S	0.05	0.02	0.04
Ash	1.51	2.02	2.4
Lower Heating Value (mmBtu/dry ton)	15.4	15.9	17.3

Carbon cycle of biomass feedstocks: annual crops, short-rotation woody feedstocks, and forest

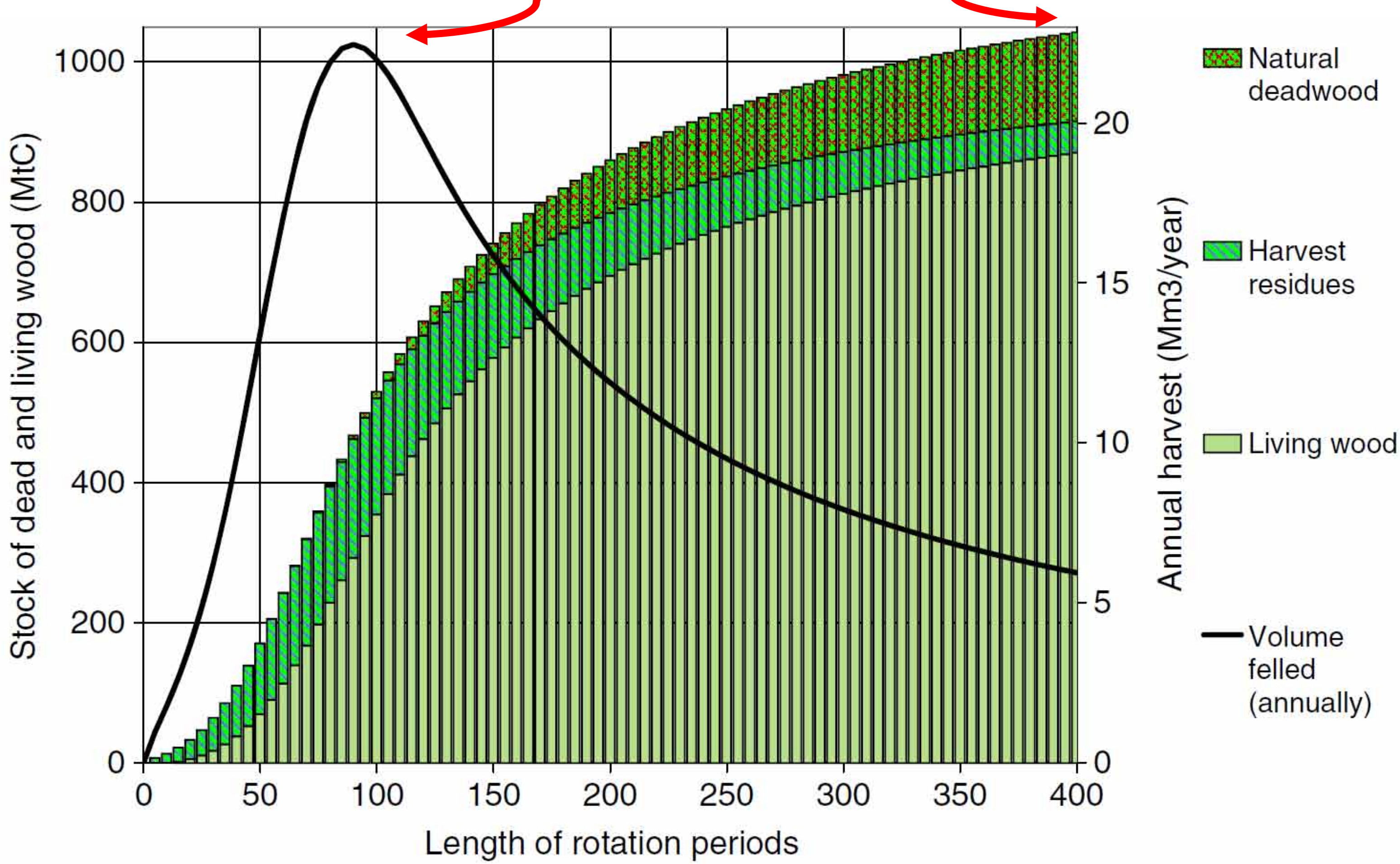






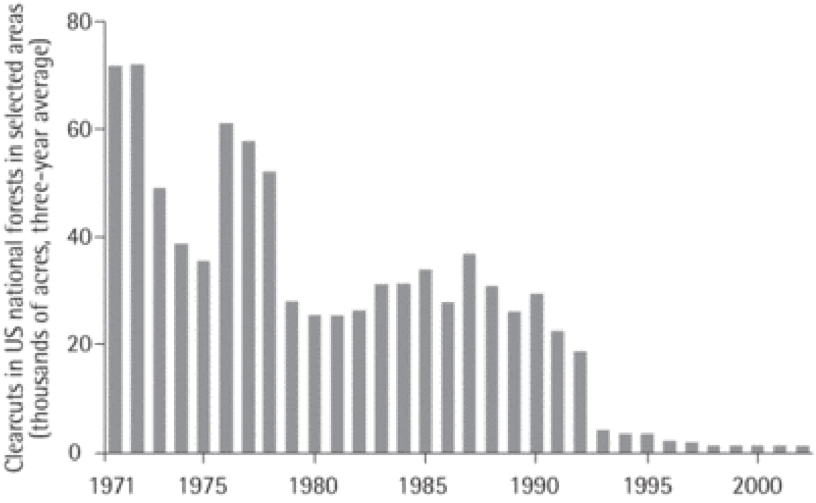
Biomass dynamics of forest residues in the context of entire forest

Maximum yield and maximum carbon stock can occur in different years

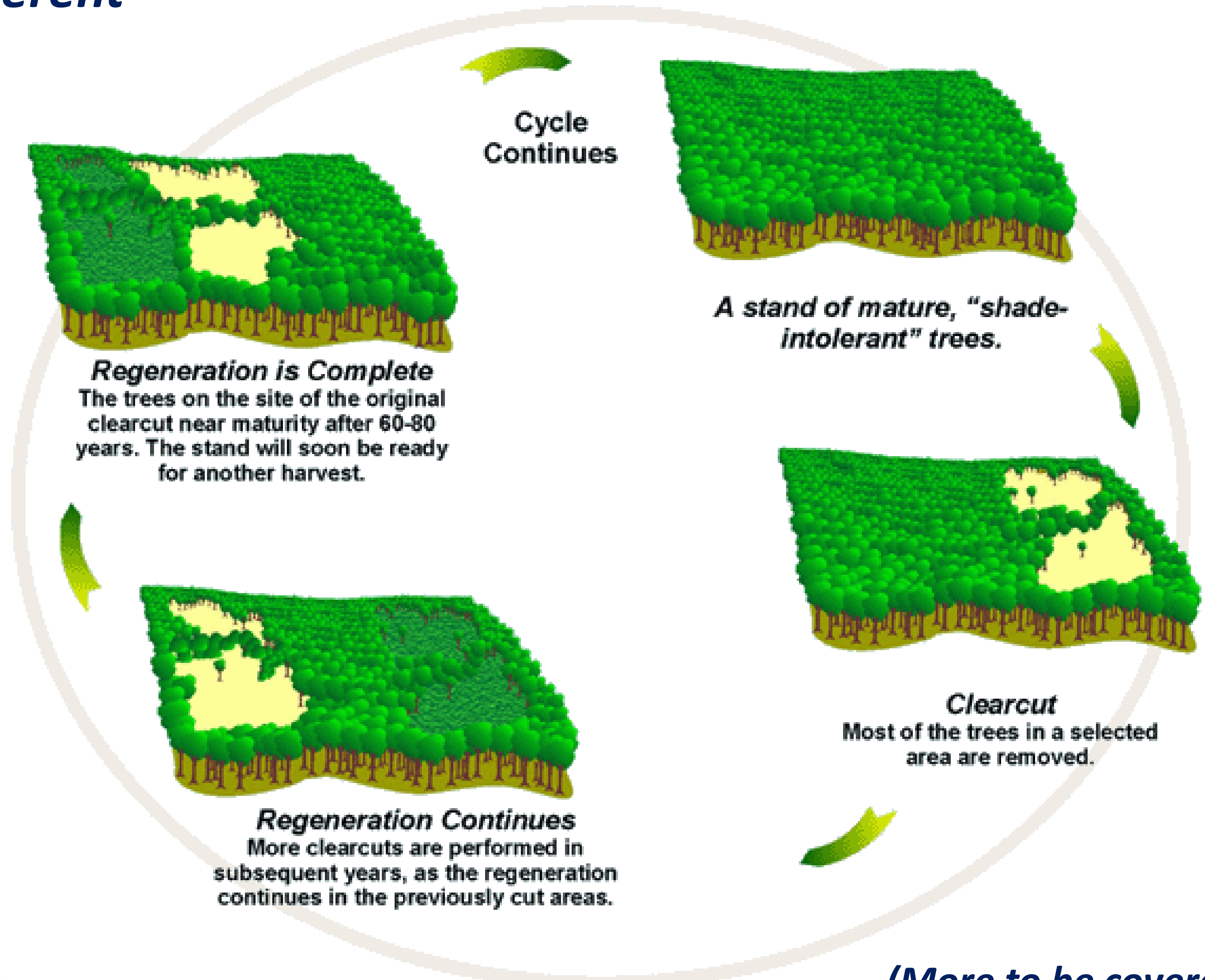


Adapted from Holtsmark (2012) in *Climate Change*.

Forest harvest methods – clear cut vs. thinning: implications on forest regrowth, soil carbon, among other ecological effects



Spatial Boundary of Forest Feedstock LCA: trees vs. forest patches vs. regional forest supply: treatment of carbon stock in LCA can be (very) different



(More to be covered by Reid Miner)

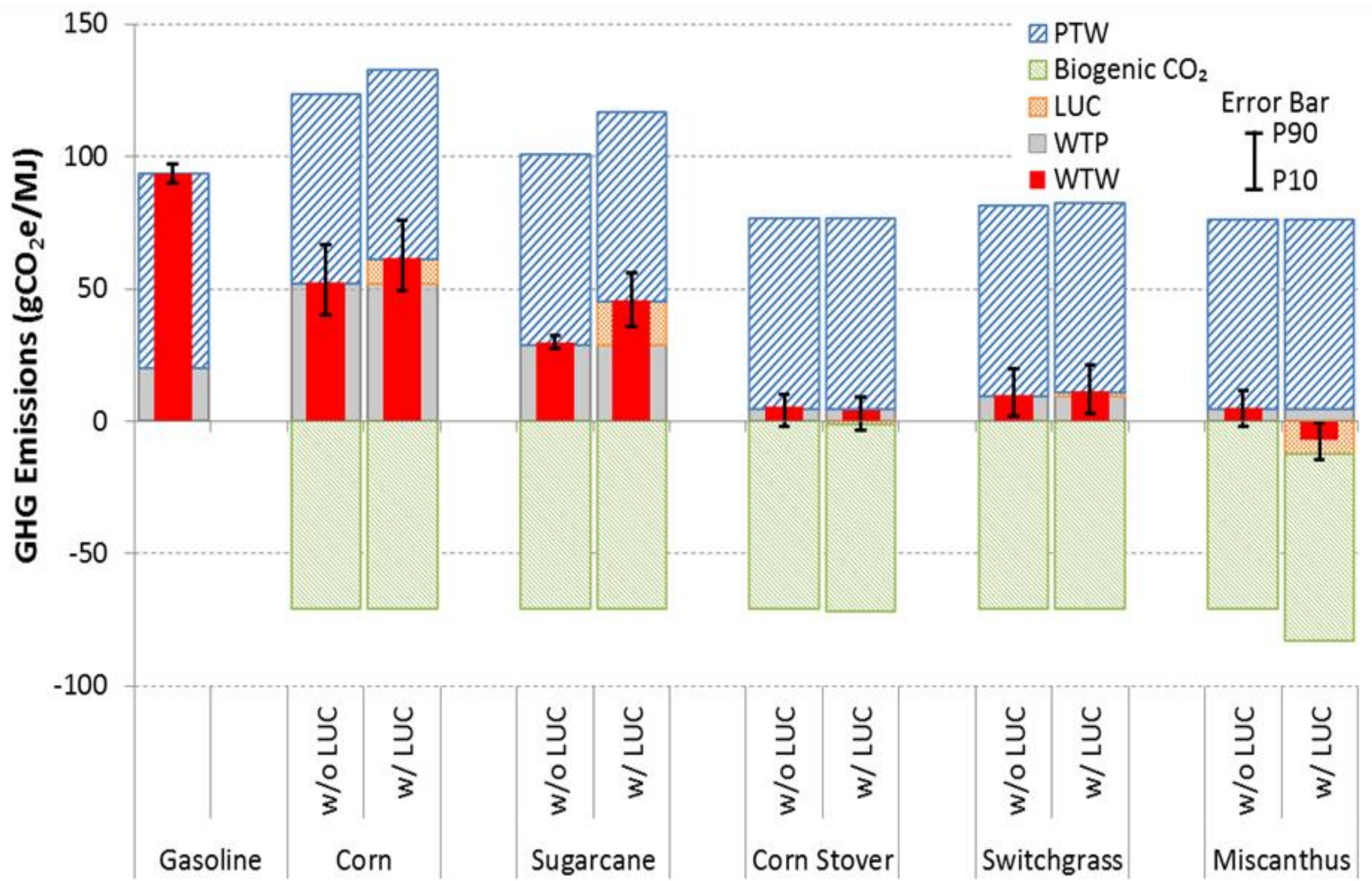
Summary: key LCA parameters for forest as biofuel feestocks

- Forest yield
  - Forest growth model prediction vs. measured data?
- Baseline forest without harvest for bioenergy
  - Biomass growth
  - Carbon cycle dynamics
- Carbon cycle dynamics over time with harvest
  - Carbon absorption predicted from forest growth models
  - Above- and below-ground C after harvest
  - Validity of carbon neutrality assumption for forest feedstocks with long growth cycle
  - Discounting over time of carbon sinks and sources for long growth cycle
  - Impacts of clear cut vs. thinning (and other harvest methods?)
- Feedstock composition of different forest types
  - Cellulose, hemi-cellulose, lignin, etc.
  - Carbon content

For GREET model and technical reports, please visit

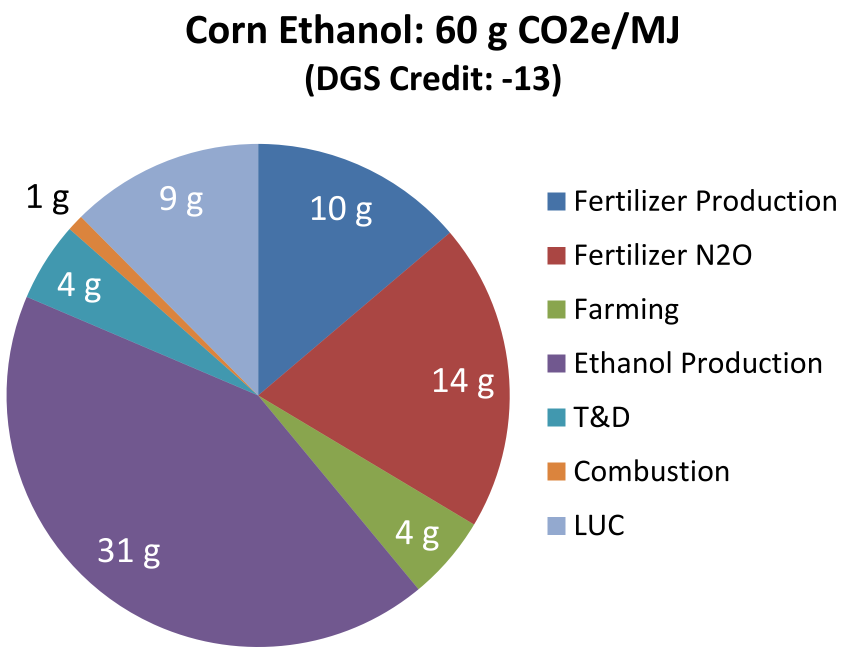
greet.es.anl.gov

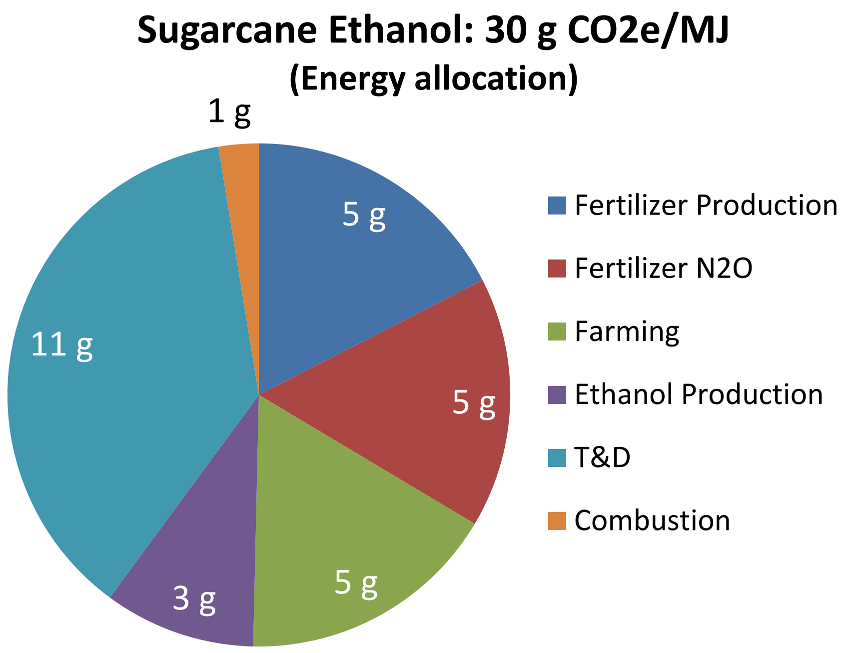
LCA GHG emissions of gasoline and bioethanol pathways from GREET simulations



Wang M., et al., 2012, *Environ. Research Letters*

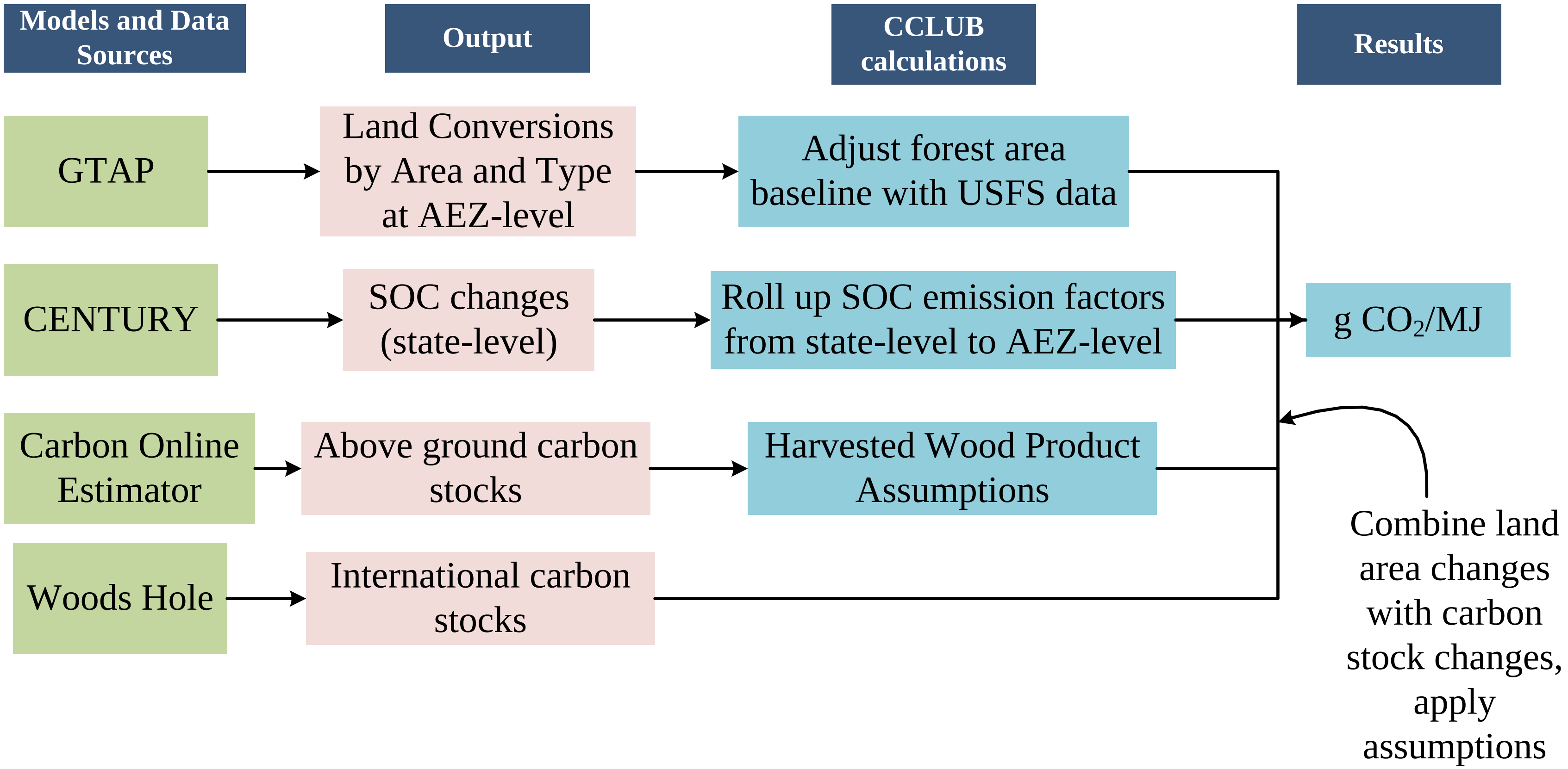
GHG emission sources for corn and sugarcane ethanol





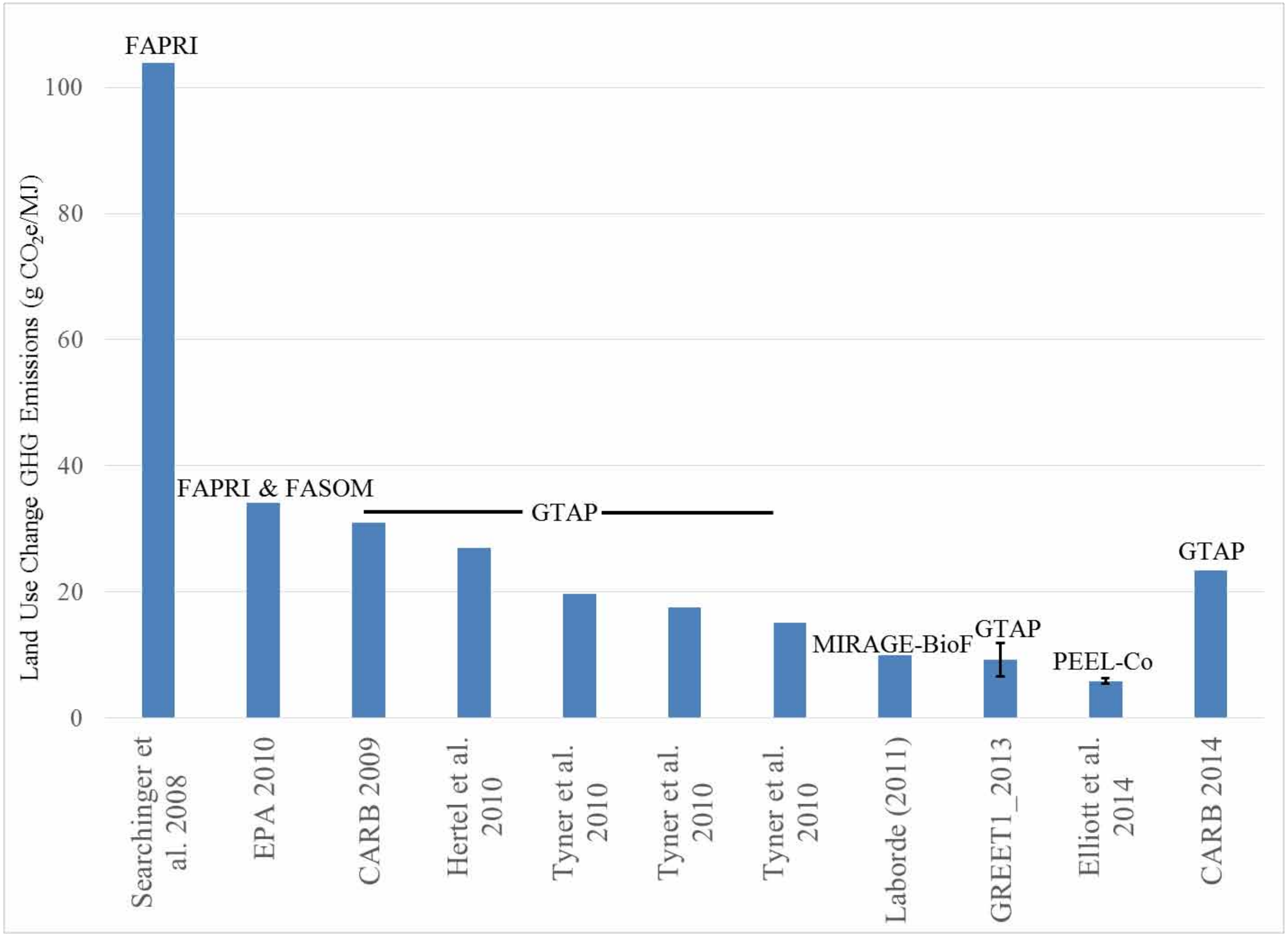
Wang M., et al., 2012, *Environ. Research Letters*

Estimating land-use change GHG emissions incorporates results from several models and data sets

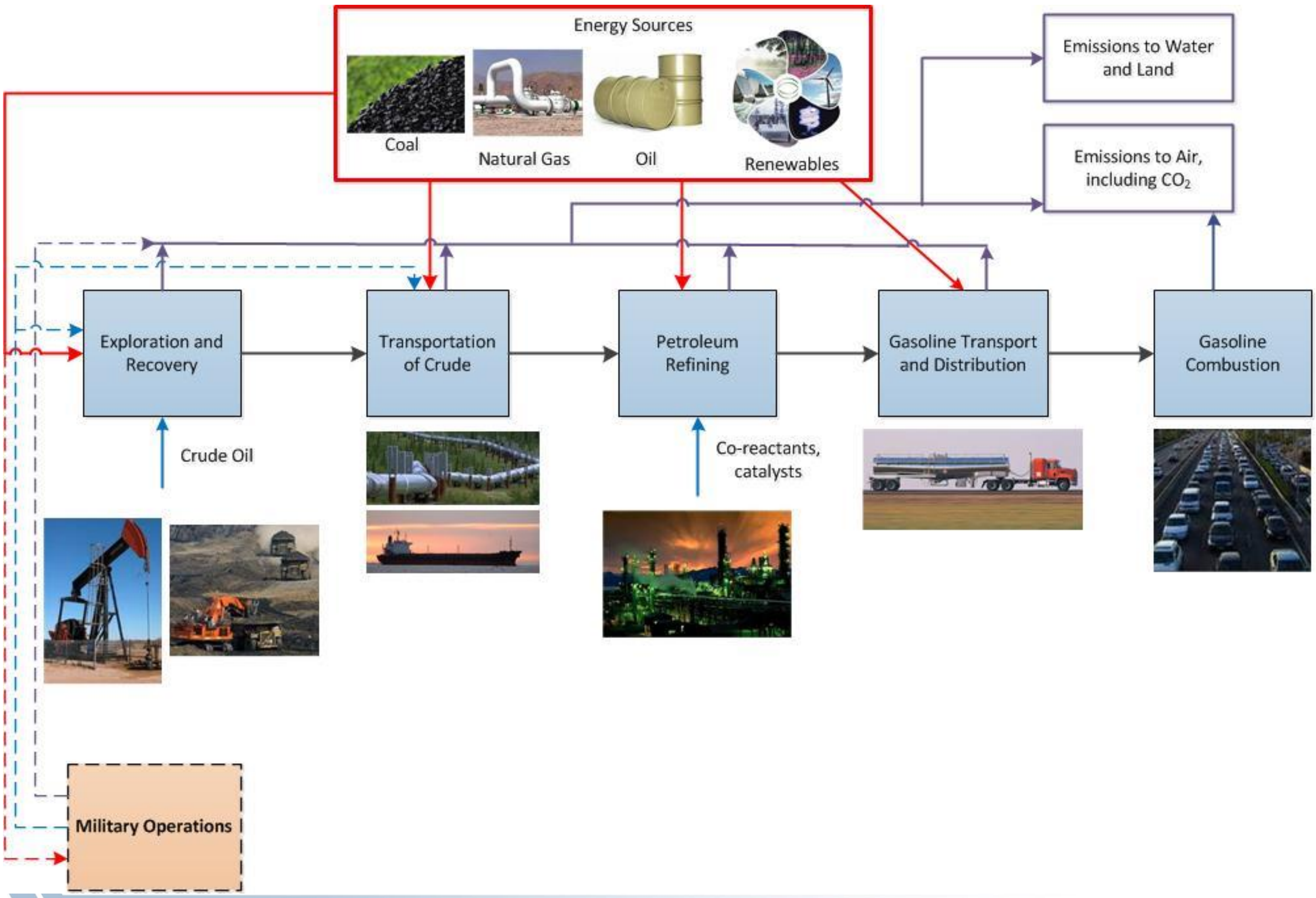


Data and calculations are contained within GREET module: Carbon Calculator for Land Use Change from Biofuels Production (CCLUB)

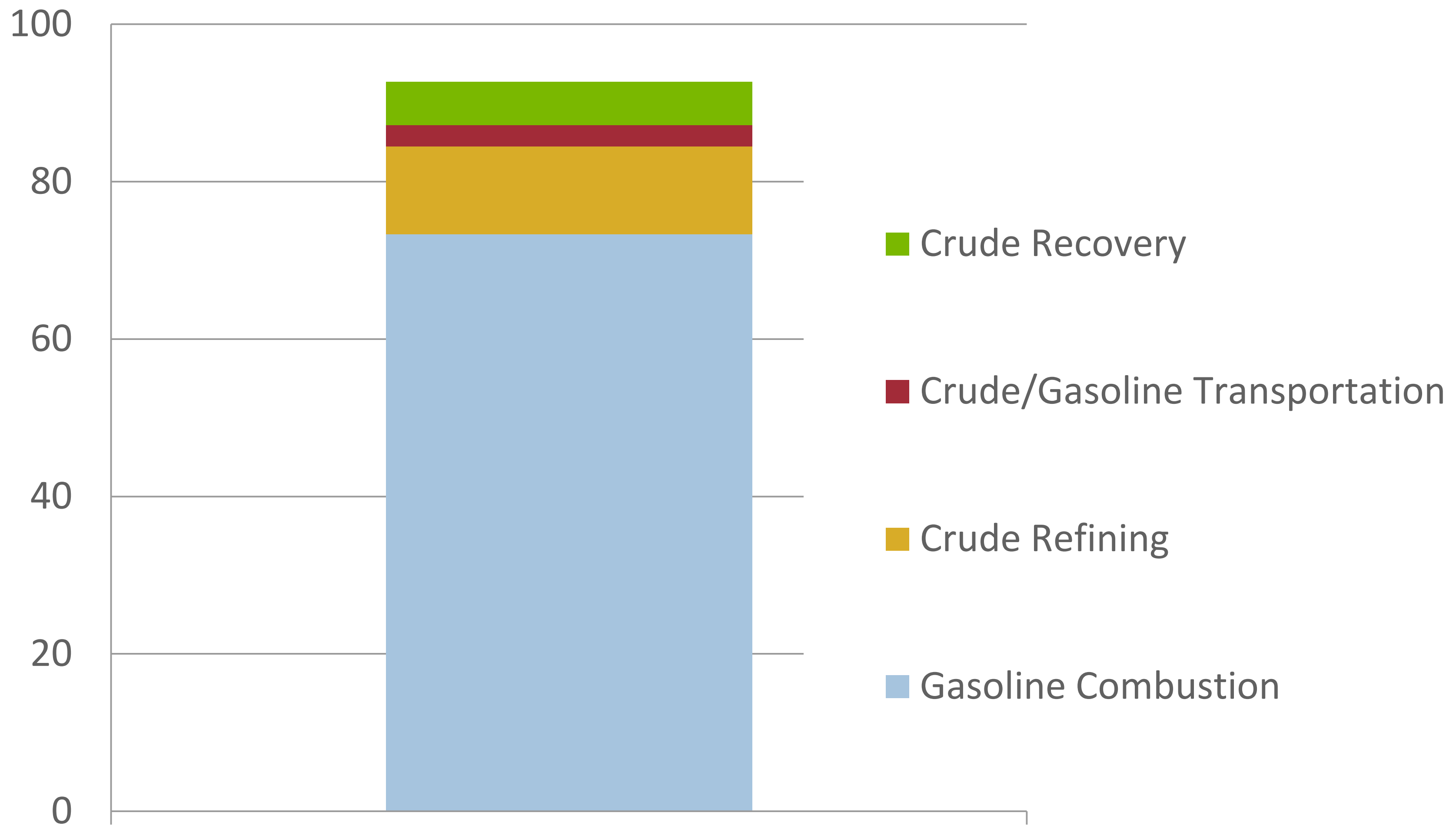
Estimates of LUC GHG emissions for the corn ethanol pathway



LCA System Boundary: Petroleum to Gasoline



Gasoline GHG emissions: grams/MJ



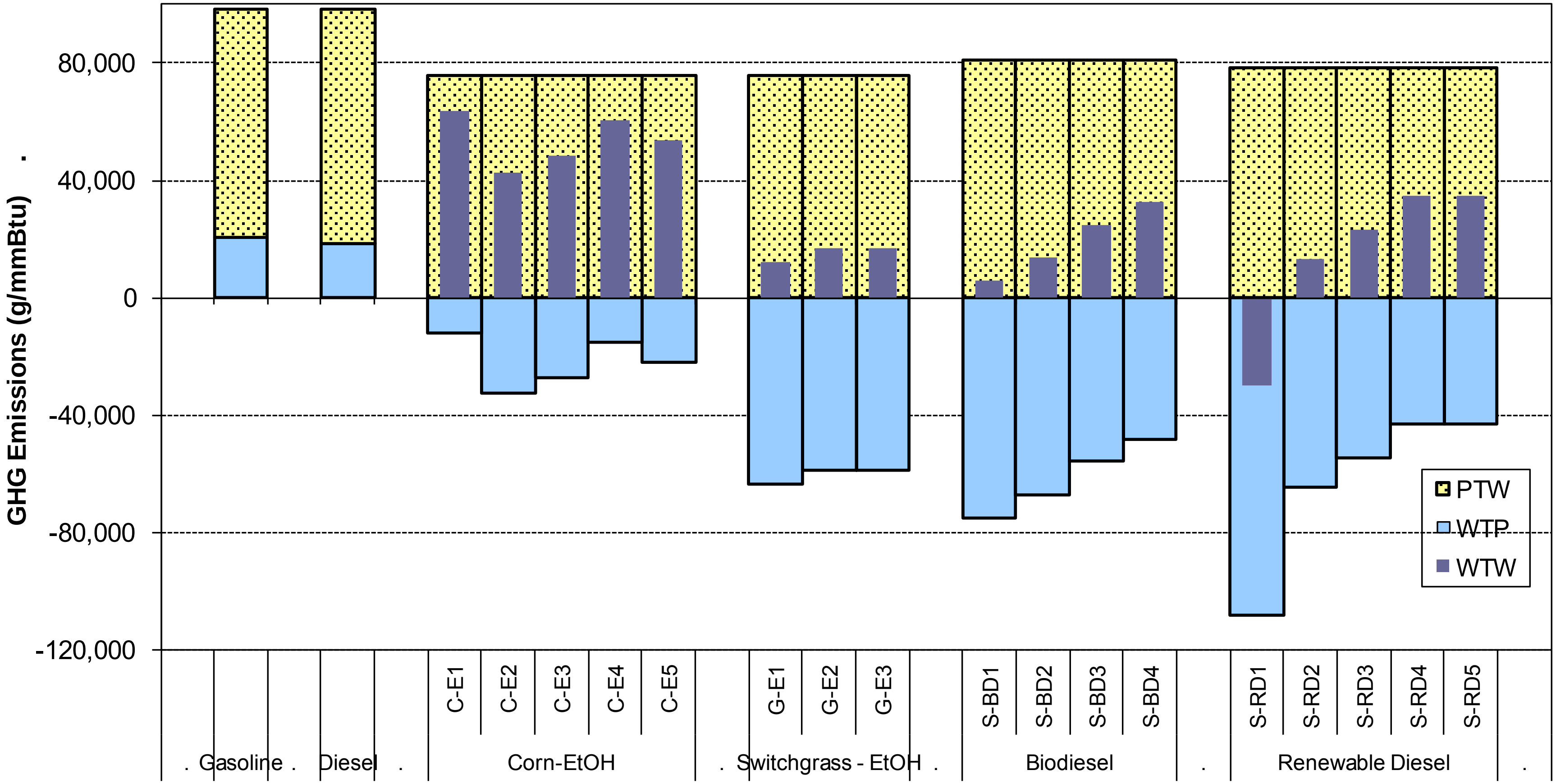
Co-Product Methods: Benefits and Issues

- Displacement method
  - Data intensive: need detailed understanding of the displaced product sector
  - Dynamic results: subject to change based on economic and market modifications
- Allocation methods: based on mass, energy, or market revenue
  - Easy to use
  - Frequent updates not required for mature industry, e.g. petroleum refineries
  - Mass based allocation: not applicable for certain cases
  - Energy based allocation: results not entirely accurate, when coproducts are used in non-fuel applications
  - Market revenue based allocation: subject to price variation
- Process energy use approach
  - Detailed engineering analysis is needed
  - Upstream burdens still need allocation based on mass, energy, or market revenue

Co-Products and Their Treatment in GREET LCAs

Pathway	Co-Product	Displaced Products	LCA Method in GREET	Alternative LCA Methods Available in GREET
Corn ethanol	DGS	Soybean, corn, and other animal feeds	Displacement	Allocation based on market revenue, mass, or energy
Sugarcane ethanol	Electricity from bagasse	Conventional electricity	Allocation based on energy	Displacement
Cellulosic ethanol (corn stover, switchgrass, and miscanthus)	Electricity from lignin	Conventional electricity	Displacement	Allocation based on energy
Petroleum gasoline	Other petroleum products	Other petroleum products	Allocation based on energy	Allocation based on mass, market revenue, and process energy use

Choice of Co-Product Methods Can Have Significant LCA Effects



In Wang et al. (2010)