# *Quantifying Energy and Environmental Effects of Biofuels*

**Presentation to the Biomass Research and Development Technical Advisory Committee**

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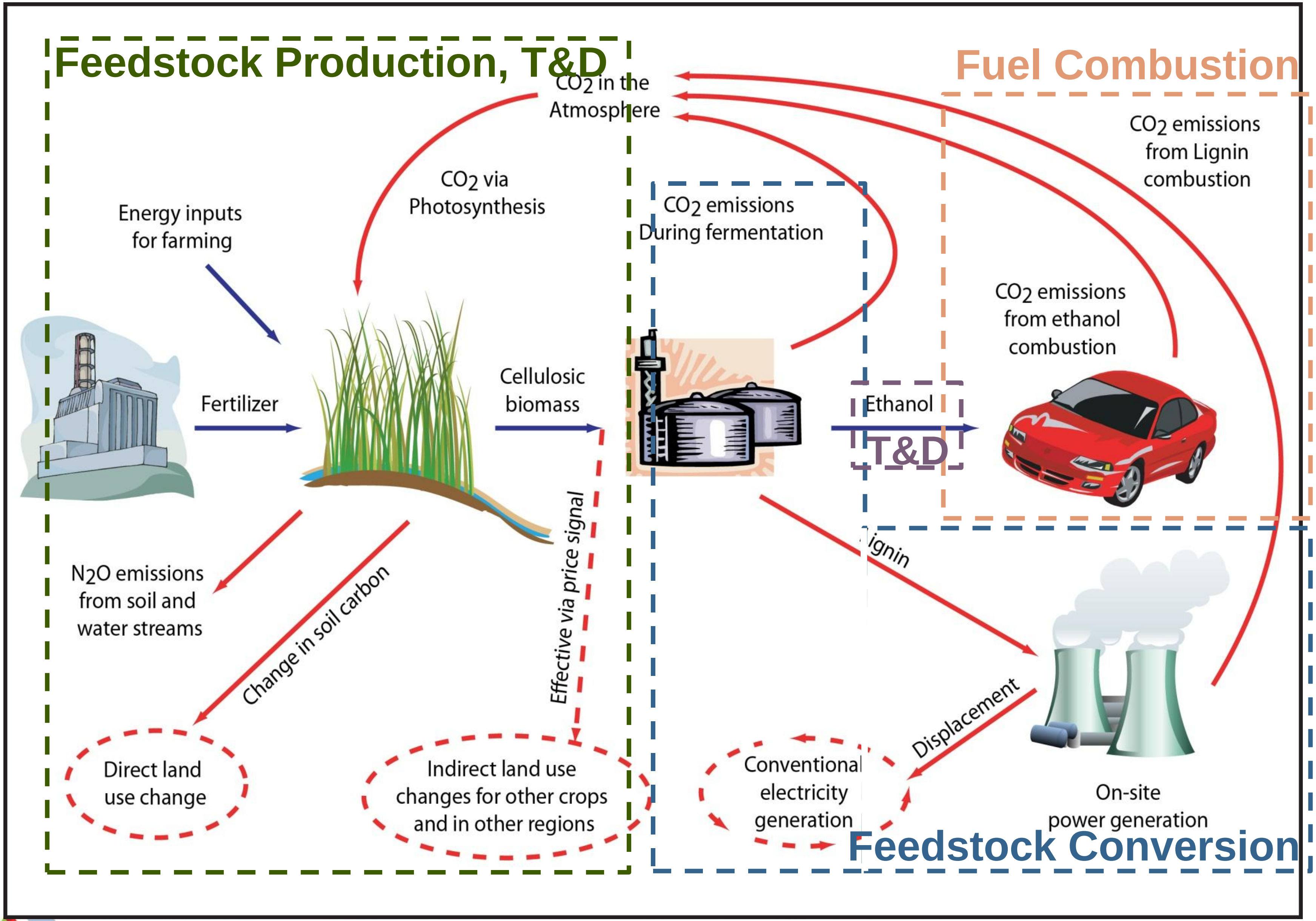
# Biofuel life cycle system boundary example: switchgrass to ethanol

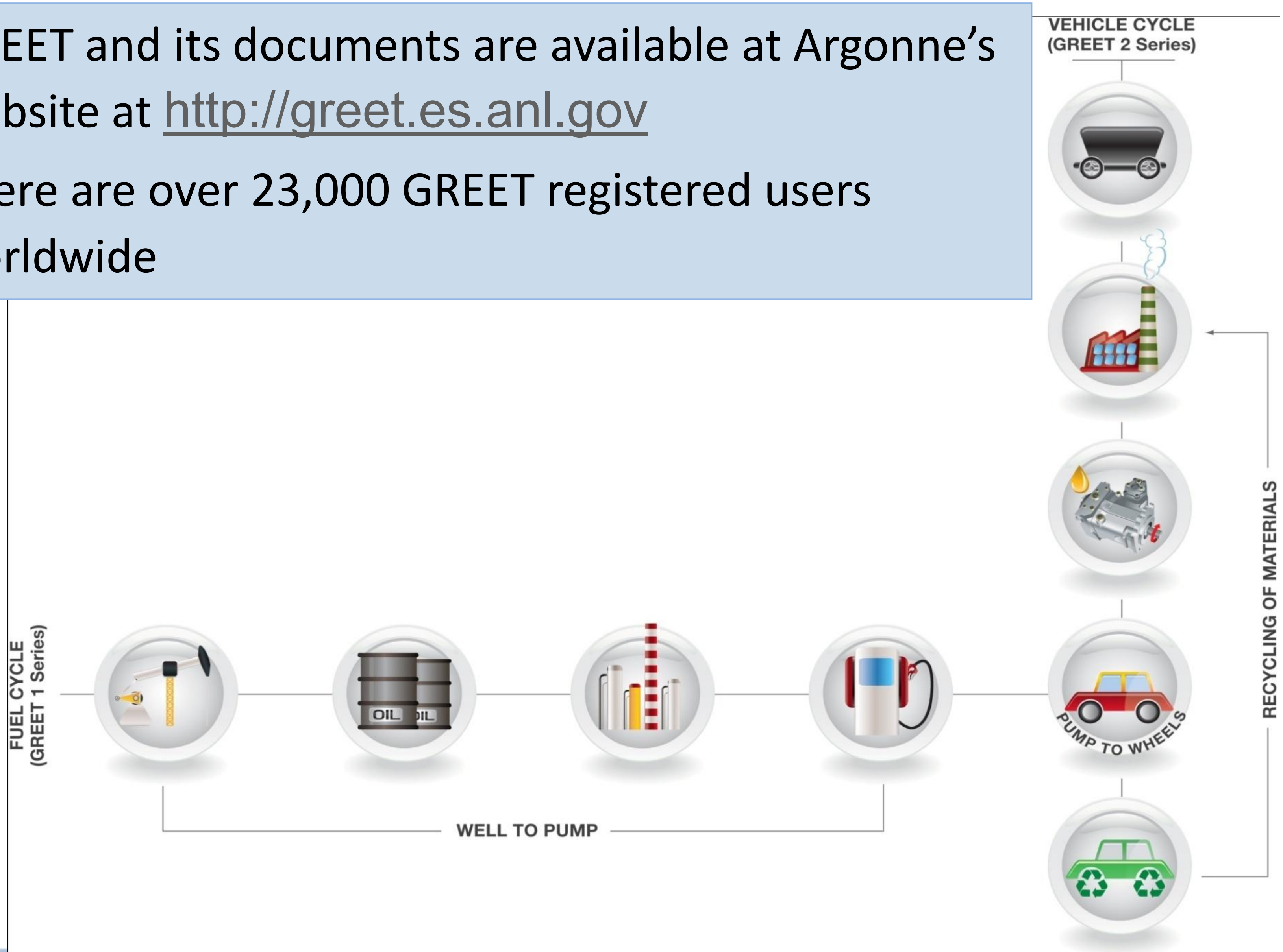


# Biofuel life cycle analysis addresses key biofuel sustainability questions

- Does producing biofuels consume more energy than the fuel contains?
- What quantity of fossil fuels are consumed to make biofuels?
- Over their lifecycle, do biofuels emit or sequester carbon on net? If they emit carbon, do they emit less carbon than fossil fuels?
- How water intensive are biofuels to produce?
- What amount of air pollutants are emitted over the course of a biofuel's life cycle?
- Which life-cycle stages contribute the most to GHG emissions and other impacts?
- How do biofuel co-products share the energy and emissions burdens of the biofuels?
- What indirect effects are associated with biofuels and how can they be quantified?

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

- GREET and its documents are available at Argonne's website at http://greet.es.anl.gov
- There are over 23,000 GREET registered users worldwide



# GREET Transportation Applications

- GREET includes more than 100 fuel production pathways
  - Petroleum fuels: conventional crude and oil sands
  - Natural gas: conventional gas and shale gas
  - Coal: to various liquid fuels
  - $H_2$ and electricity production from different feedstocks
  - Renewable fuels: corn, sugarcane, cellulosic biomass, oil crops, algae, biogas

- Ground transportation
  - Conventional gasoline and diesel vehicles
  - Hybrid electric vehicles and plug-in hybrid electric vehicles
  - Battery electric vehicles
  - Fuel cell vehicles

- Aviation transportation
  - Passenger and freight transportation
  - Various alternative fuels blending with petroleum jet fuels

- Rail transportation

- Marine transportation
  - Ocean transportation
  - Inland water transportation

# GREET includes many biofuel production pathways

- Ethanol via fermentation from
  - Corn
  - Sugarcane
  - Sorghum (grain, juice, cane)
  - Cellulosic biomass
    - Crop residues
    - Dedicated energy plants: switchgrass, miscanthus, willow, poplar
    - Forest residues

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

- Cellulosic biomass via pyrolysis to
  - Renewable gasoline
  - Renewable diesel
  - Renewable jet fuel

- Renewable natural gas from
  - Landfill gas
  - Anaerobic digestion of animal wastes, municipal solid waste, and other feedstocks

- Corn to butanol

- Soybeans, other oil seeds, and corn oil to
  - Biodiesel
  - Renewable diesel
  - Renewable gasoline
- Soybeans and other oil seeds
  - Renewable jet and marine fuel

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

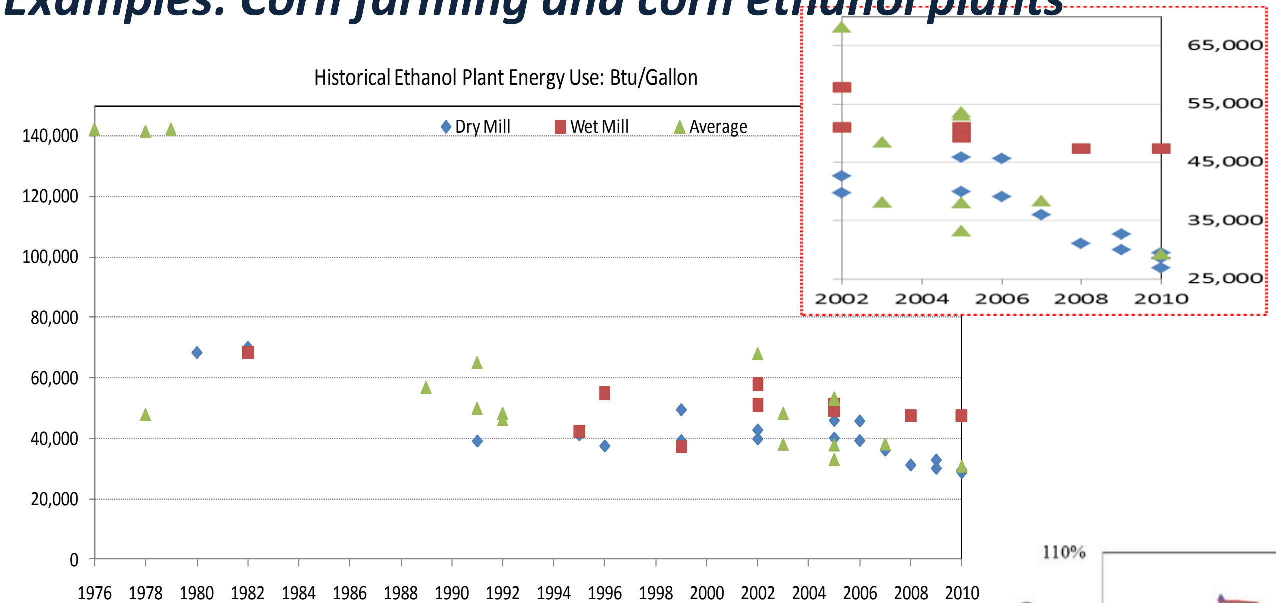
- Ethanol to jet fuel

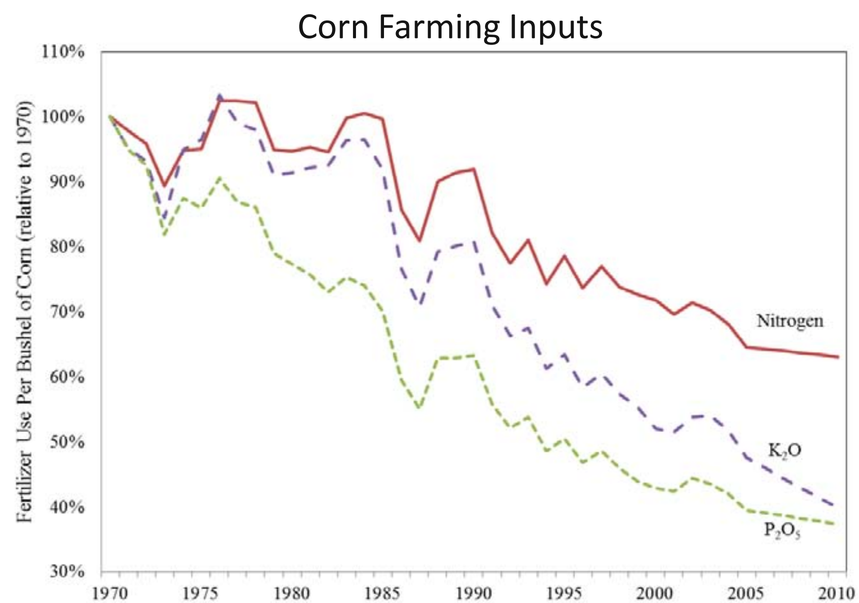
# *Feedstock production*

- Harvesting equipment fuel consumption
- Fertilizer application
- Nitrogen fertilizer conversion to $N_2O$
- Storage technique
- Transportation to biorefinery
- Soil organic carbon changes resulting from land management change
- Carbon stock changes as a result of land use change

# Life cycle analysis must take into account technology advancements

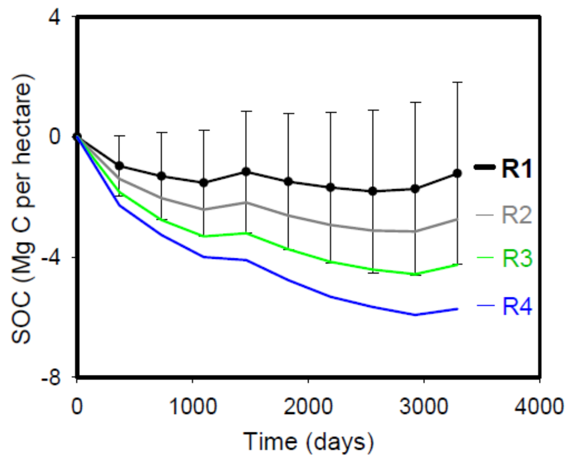
## *Examples: Corn farming and corn ethanol plants*

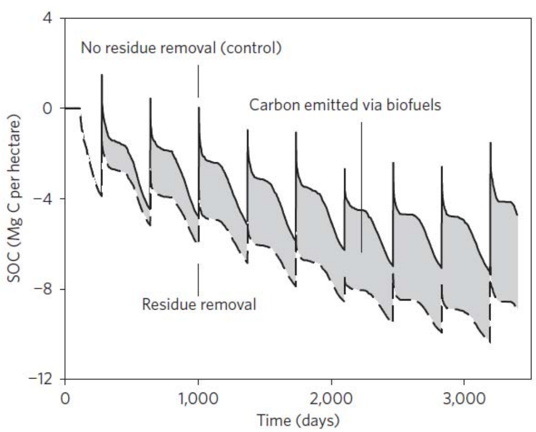



Wang M. et al., 2011, *Biomass and Bioenergy*

# Does harvesting corn stover as a biofuel feedstock reduce soil organic carbon (SOC) and increase $CO_2$ emissions ?



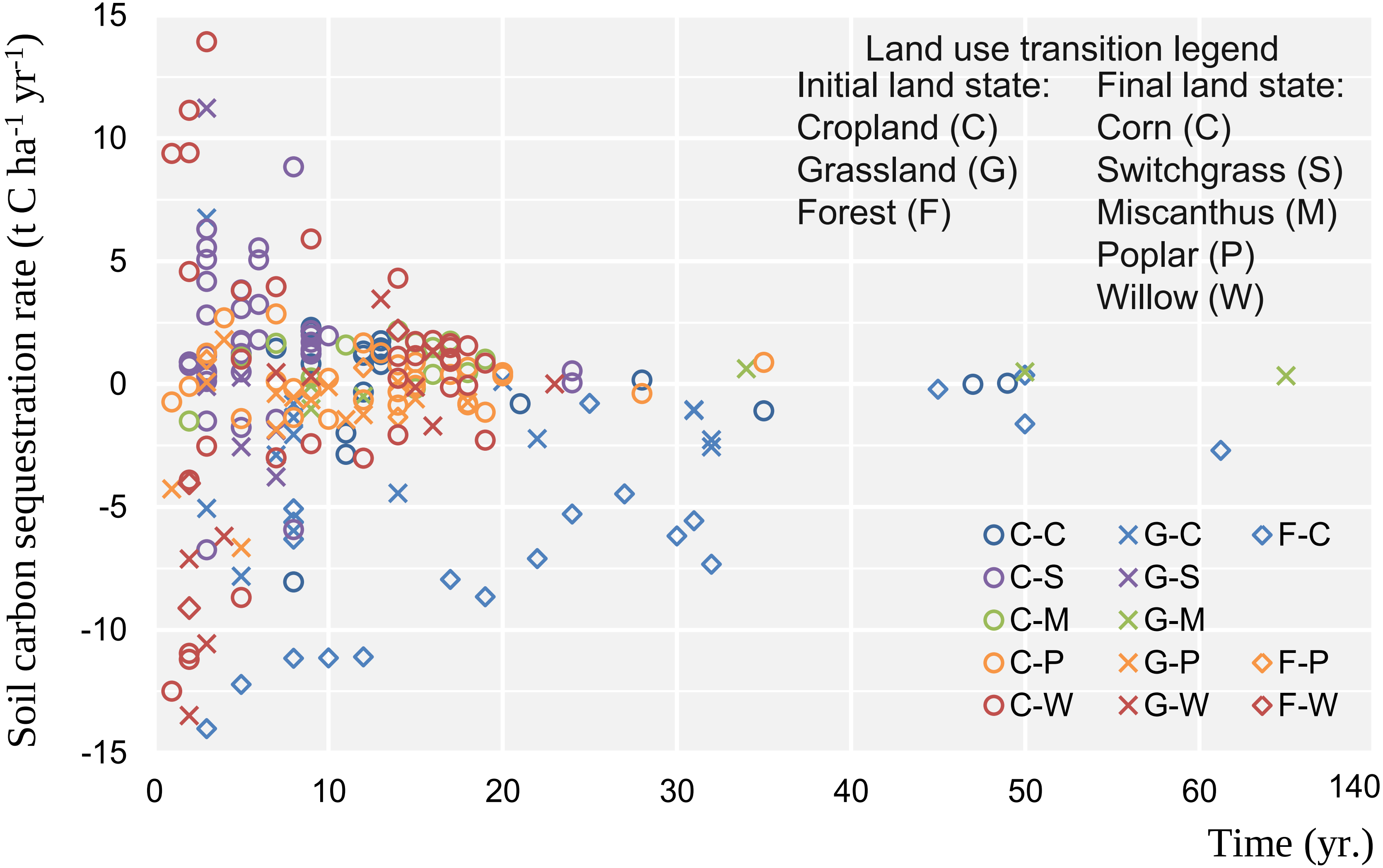




Liska *et al*. 2014 ***Nature CC***

- **100% residue removal?**
  - "we **are not aware of any management practices** for corn grain production that prescribe 100% stover removal." (Robertson et al., 2014 ***NCC***)
- **SOC trend**
  - "…almost universally predict **stable or increasing SOC** with full residue retention under no-till management in Midwest soils". (Robertson et al., 2014 ***NCC***)
- **Time horizon**
  - **5-10** (Liska 2014), or
  - >**20**, even **100** years ("dilutes the average annual carbon emissions"). (Bentsen et al., 2014 ***NCC***) (Sheehan et al., 2014 ***NCC***)

**How do practices such as manure application and cover crops influence SOC and overall GHG emissions?**

# SOC change rates for LCAs should be based on a time horizon of 20 to 30 years in most cases




Qin et al., *GCB Bioenergy*, 2015

# *Critical LCA issues for woody bioenergy*

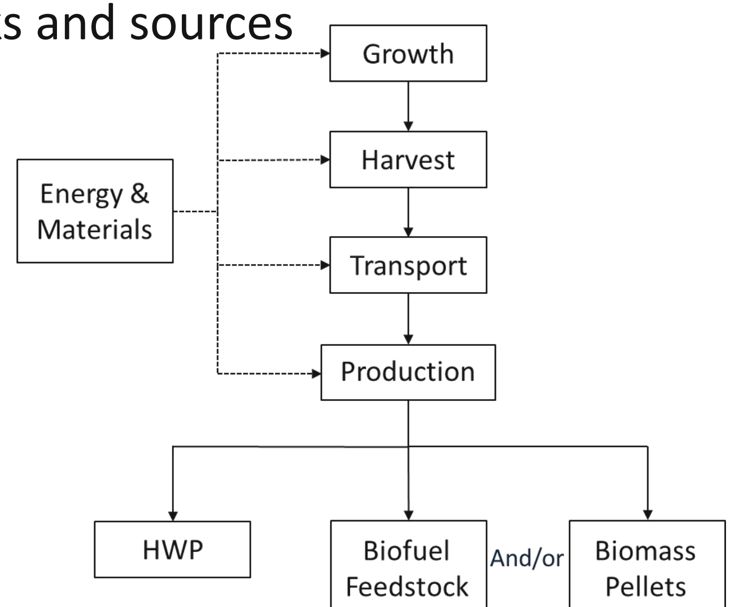
- Current debate on carbon neutrality and biomass additionality for biofuels

- Carbon cycle dynamics over time
  - Carbon absorption from forest growth model
  - Above- and below-ground biomass after harvest

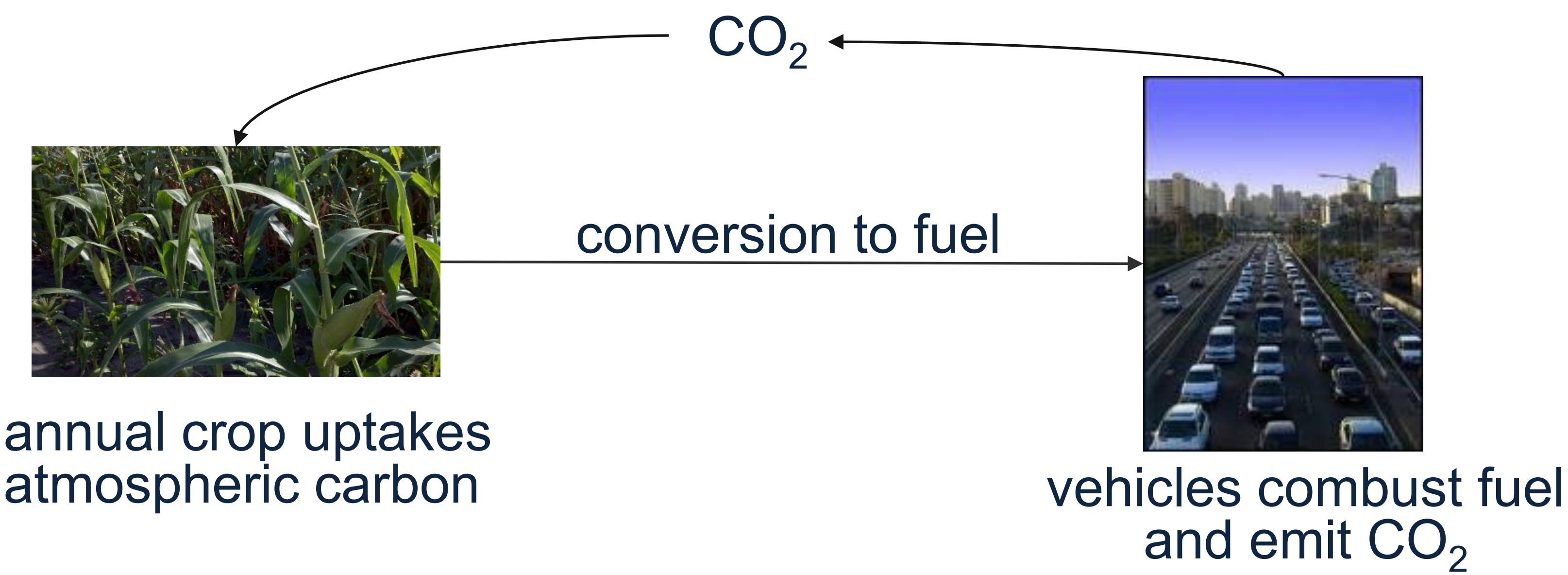
- Forest carbon sinks and sources
  - Validity of carbon neutrality assumption for different forest types and different woody feedstock types
  - Discounting over time of carbon sinks and sources

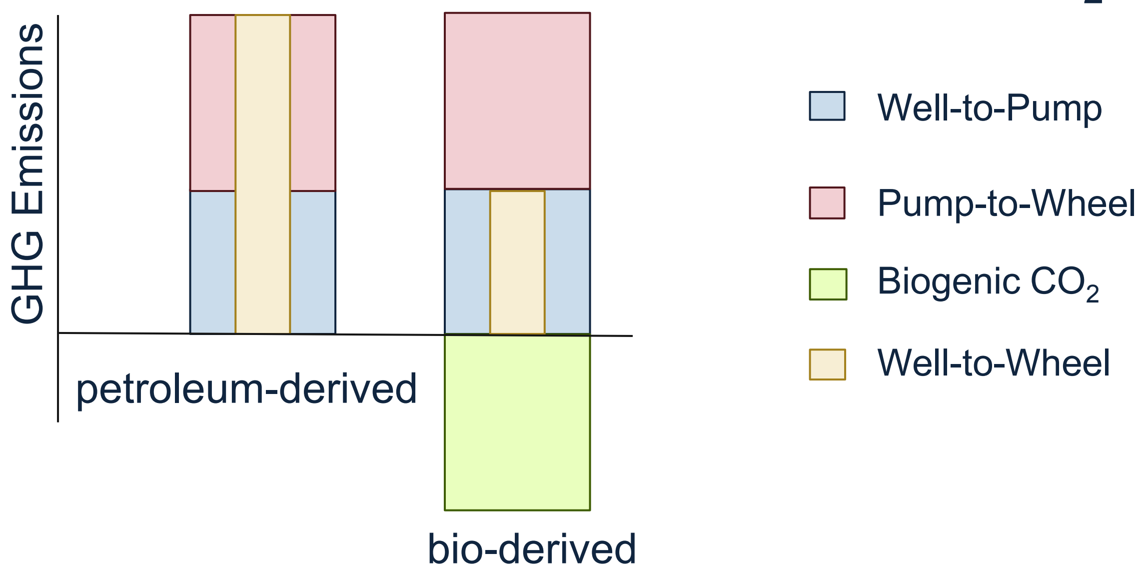
- Counterfactual scenarios

Credit: National Renewable Energy Laboratory



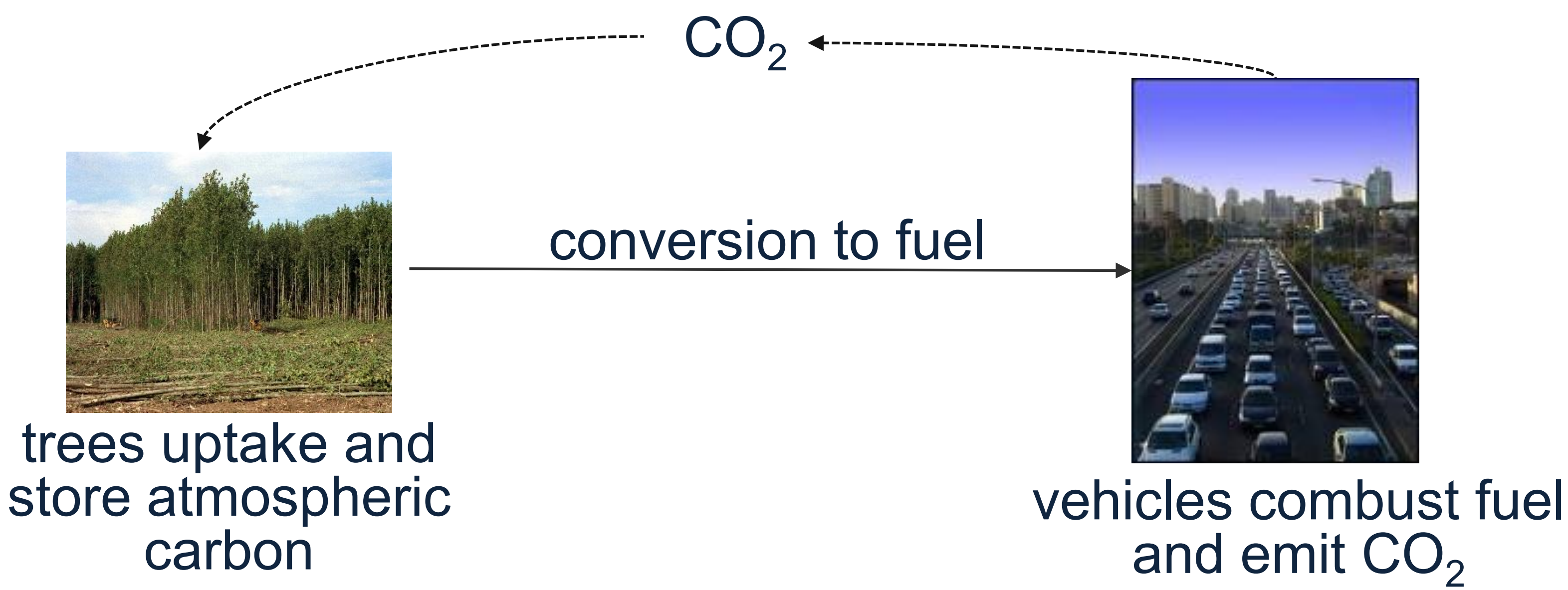
# How carbon neutral is biofuel combustion?

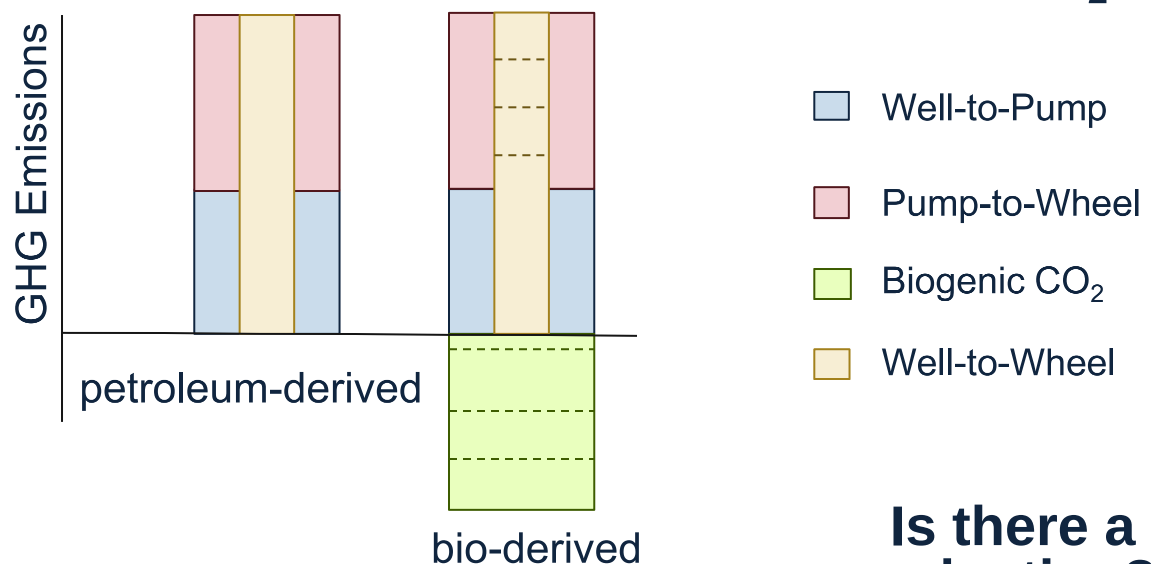



**Carbon cycle is fast**

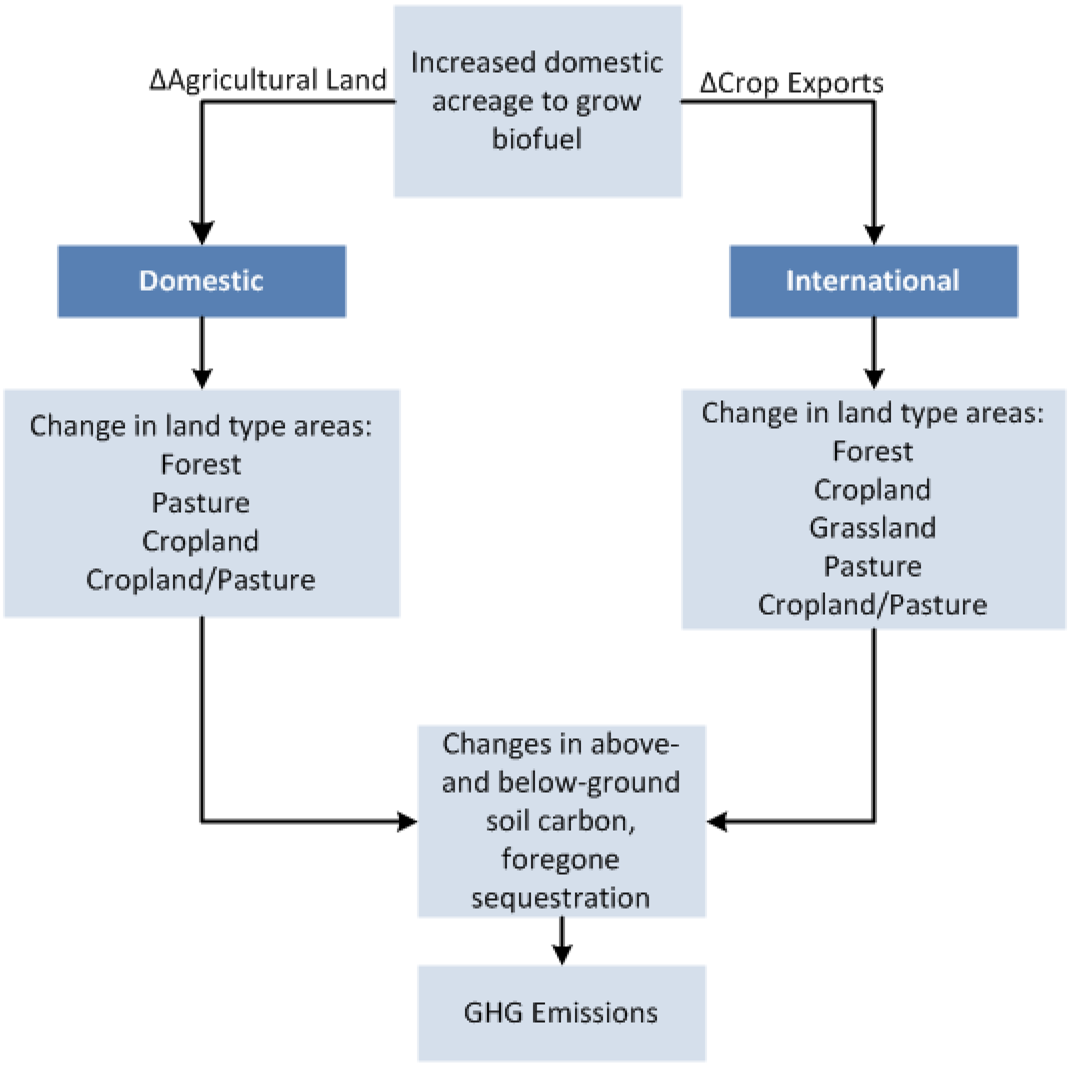
# How carbon neutral is biofuel combustion?



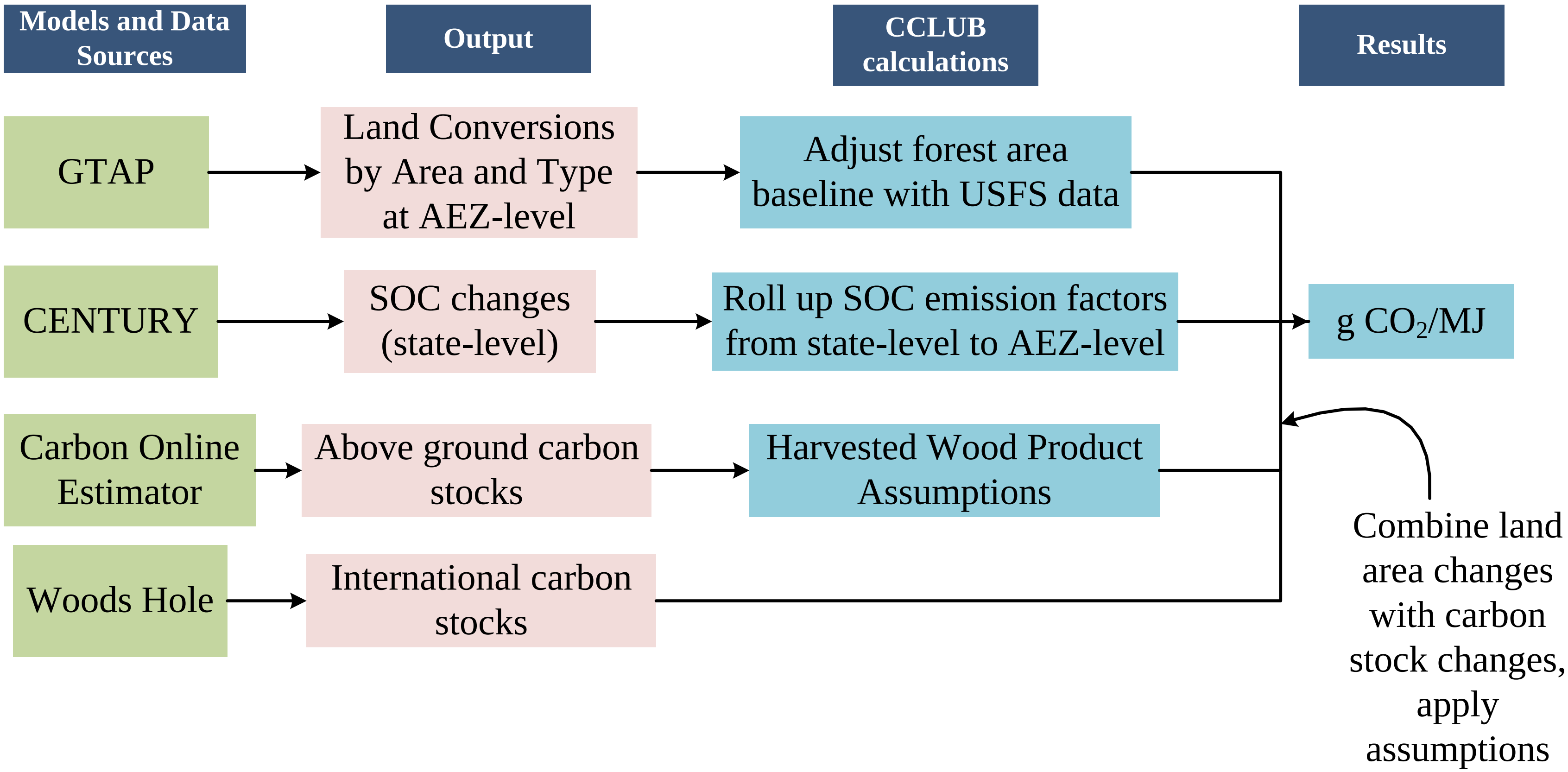




**Is there a reduction?**

# *Land-Use Change Overview*

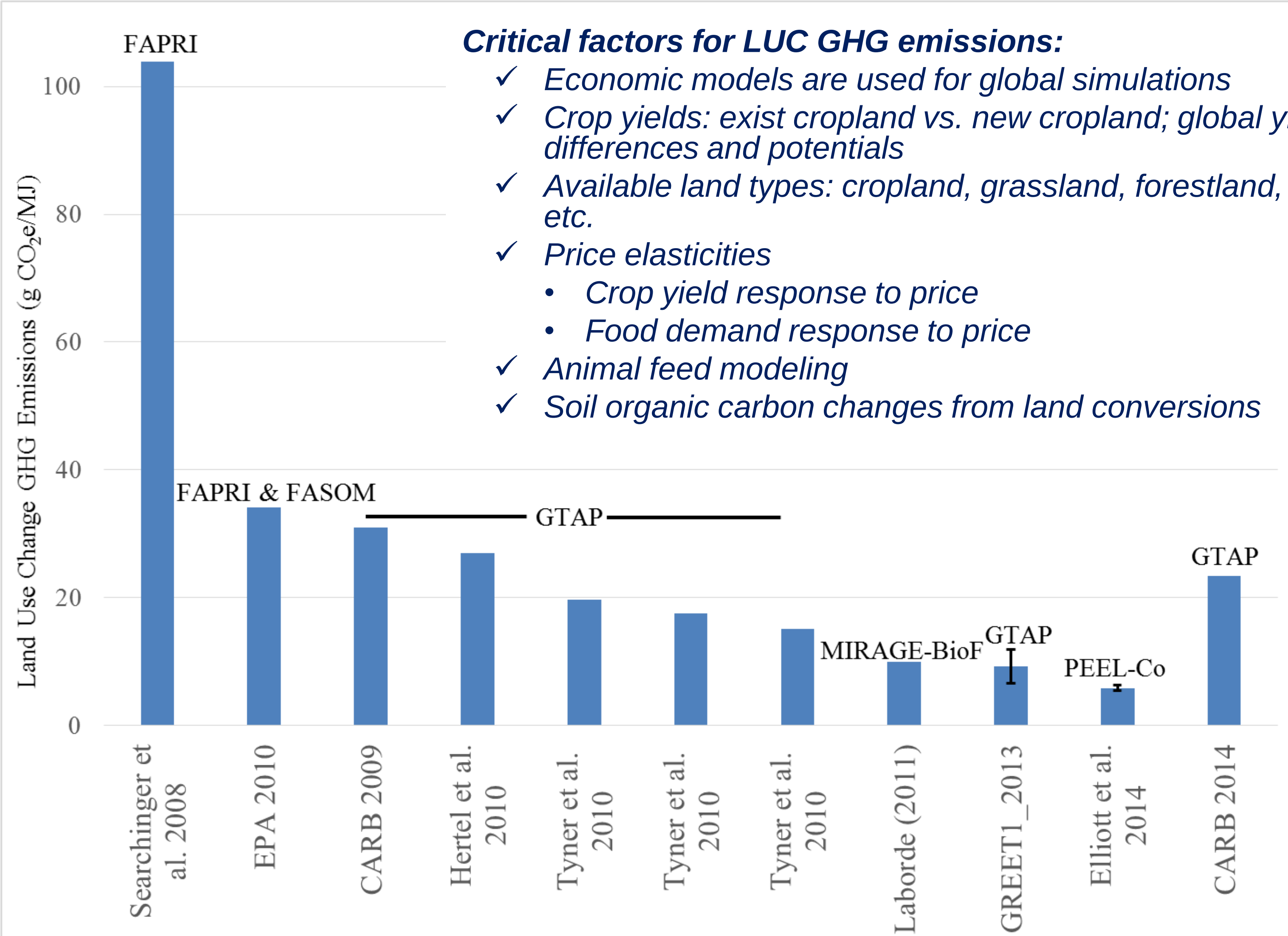


# *Estimating land-use change GHG emissions incorporates results from several models and data sets*




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

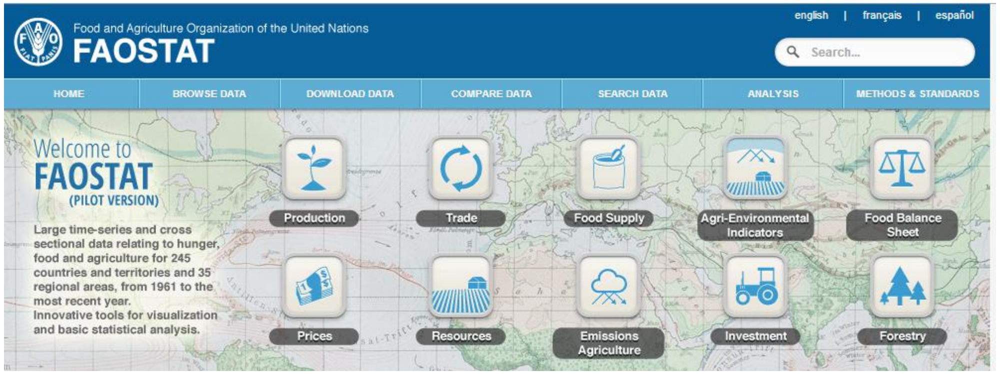
# Estimates of LUC GHG emissions for corn-to-ethanol pathway




***Critical factors for LUC GHG emissions:***

- ✓ *Economic models are used for global simulations*
- ✓ *Crop yields: exist cropland vs. new cropland; global yield differences and potentials*
- ✓ *Available land types: cropland, grassland, forestland, wetland, etc.*
- ✓ *Price elasticities*
  - *Crop yield response to price*
  - *Food demand response to price*
- ✓ *Animal feed modeling*
- ✓ *Soil organic carbon changes from land conversions*

# *GTAP modifications to reflect historical land use patterns improve LUC estimates*




Assess land allocation patterns and agricultural land use in period 1990-2010.

Low land transition | Intermediate land transition | High land transition

Unique elasticity assigned to each category

Pastureland

Conversion cost: $C_P$ →

Cropland

← Conversion cost: $C_F$

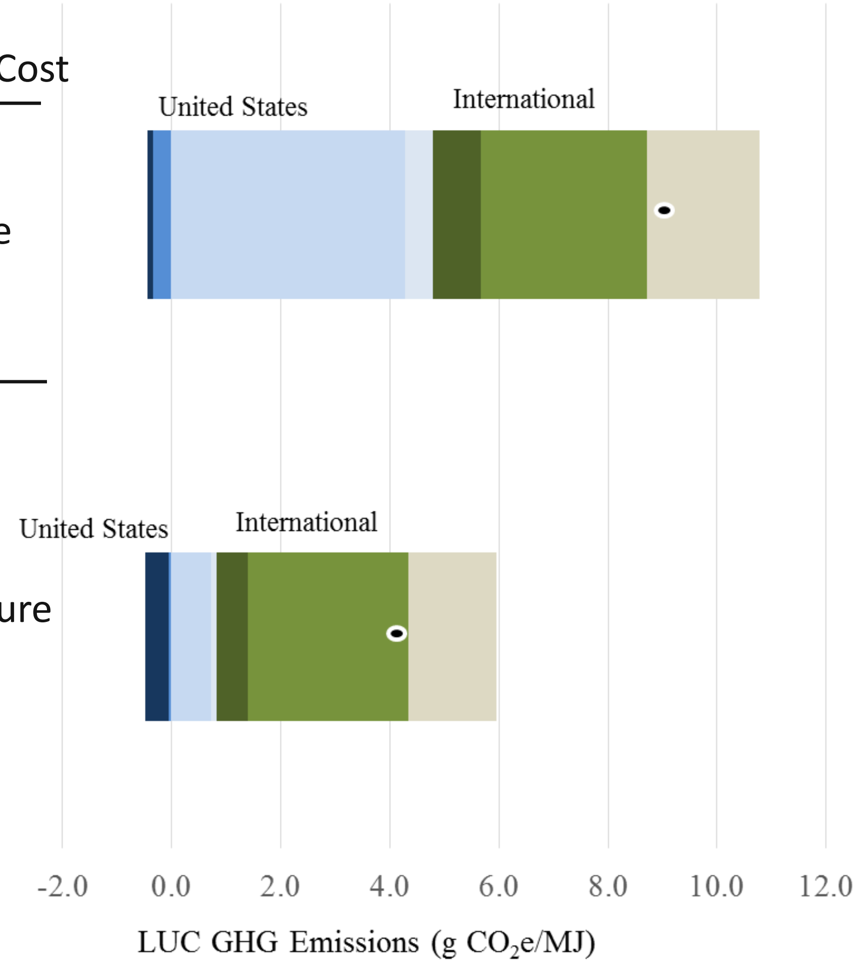
Forest

$C_F > C_P$

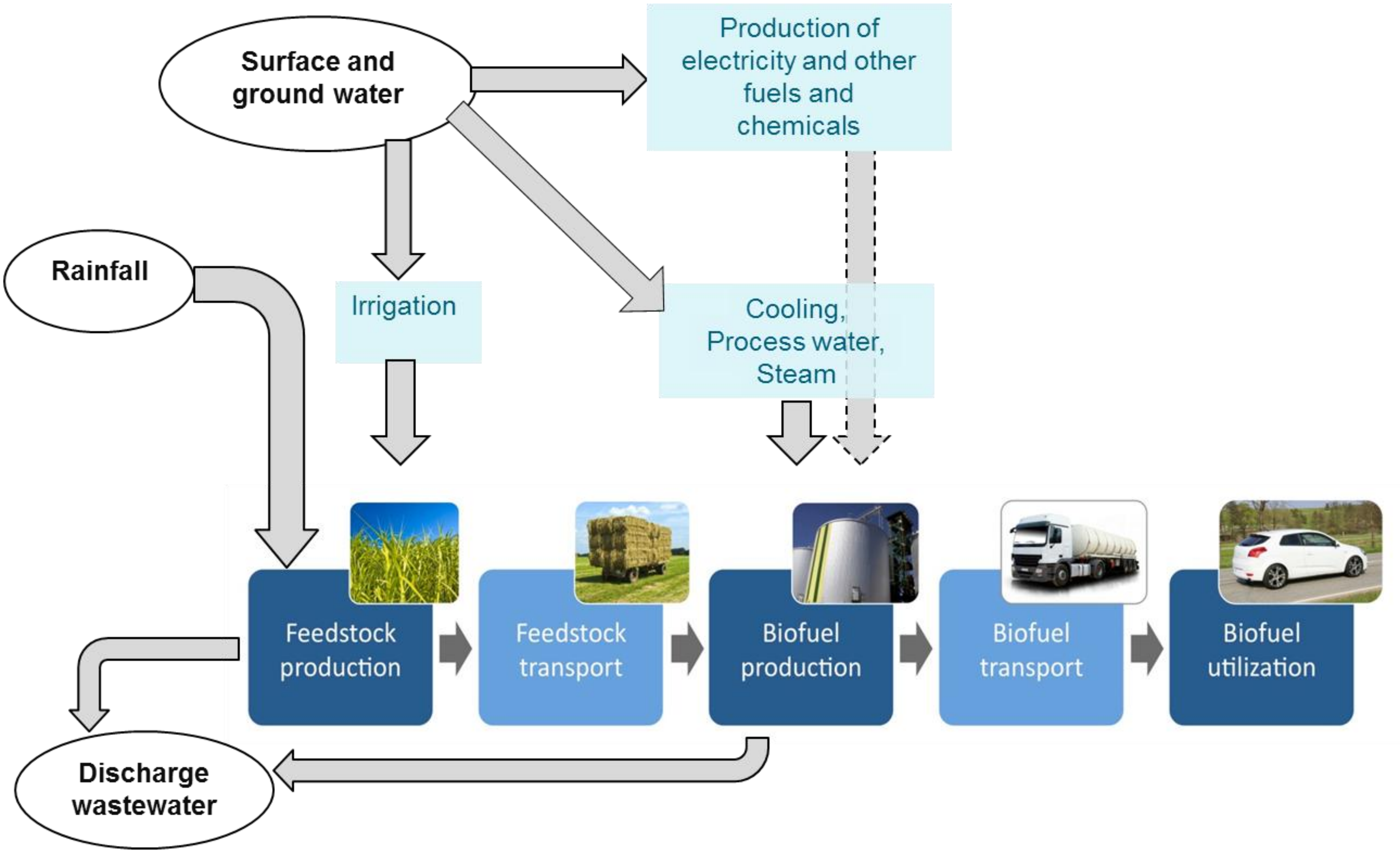
Taheripour and Tyner, *Applied Science*, **2013**, 3:14-38.

# GTAP modeling improvements reduce anticipated LUC GHG emissions associated with corn ethanol

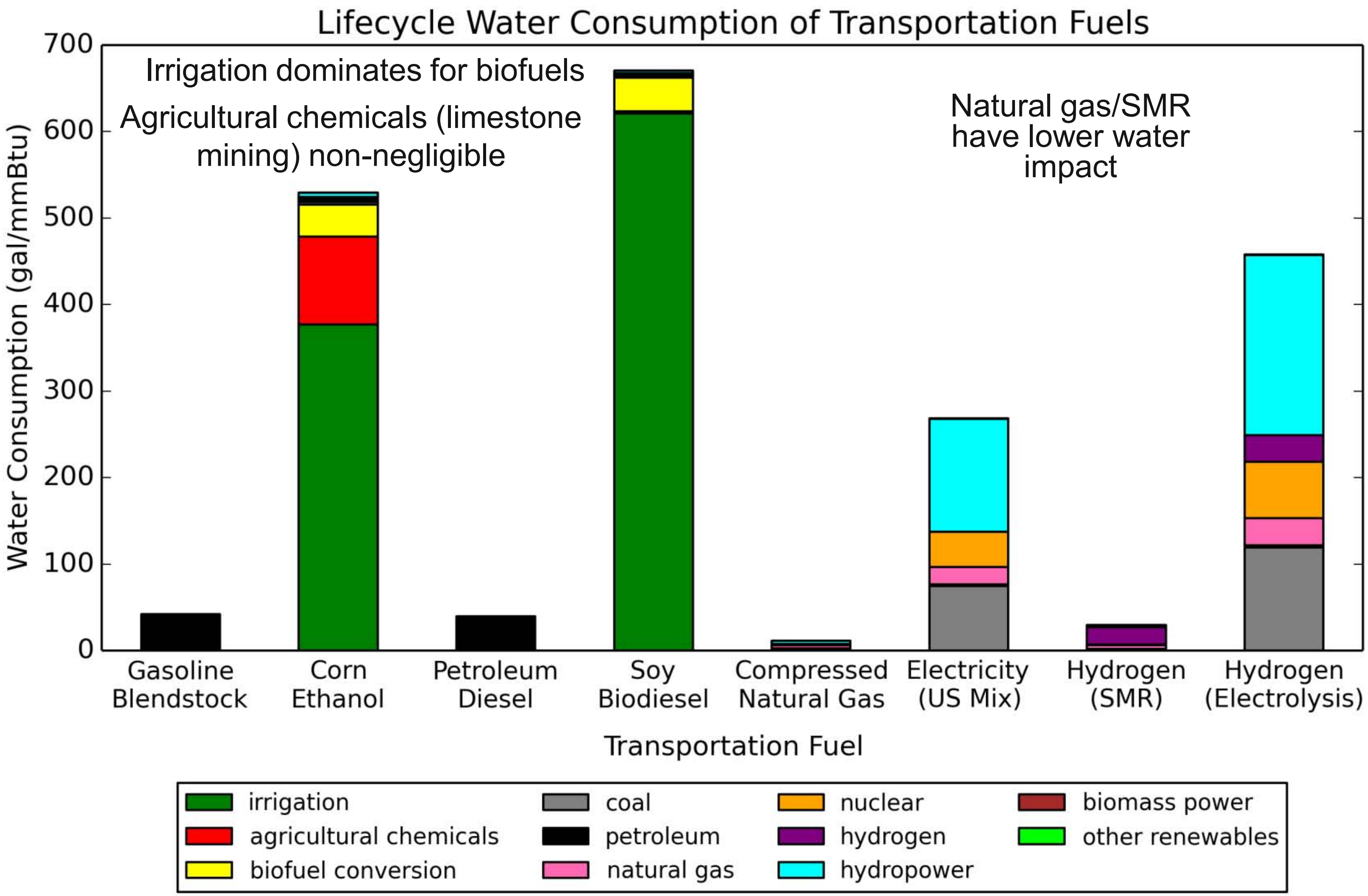
| Ease of Land Conversion | Forest Conversion Cost |
|---|---|
| Uniform | Equal to Pasture |
| Tuned | Greater than Pasture |



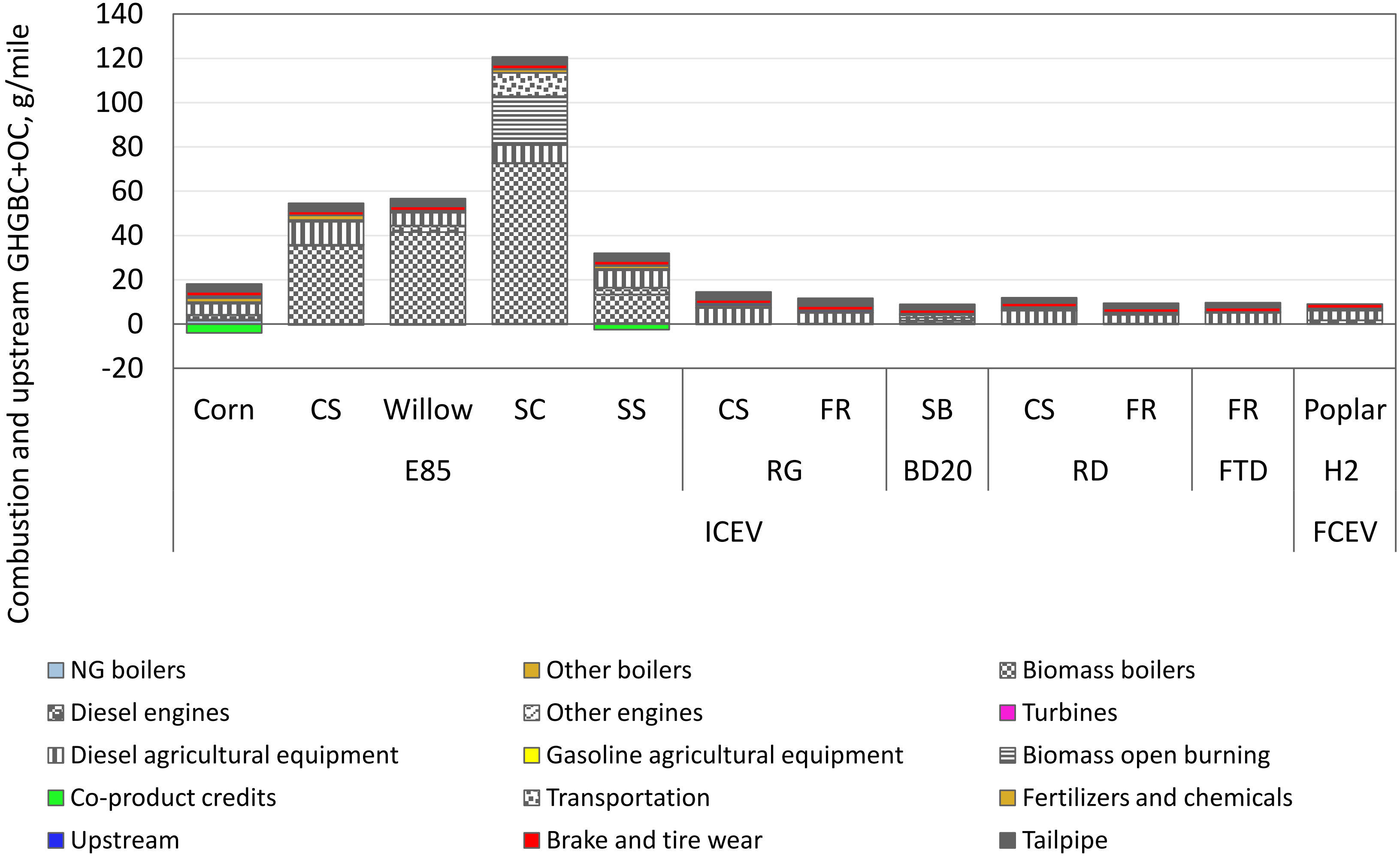
# Biofuel water use accounting



# Detailed water life-cycle analysis of fuel pathways



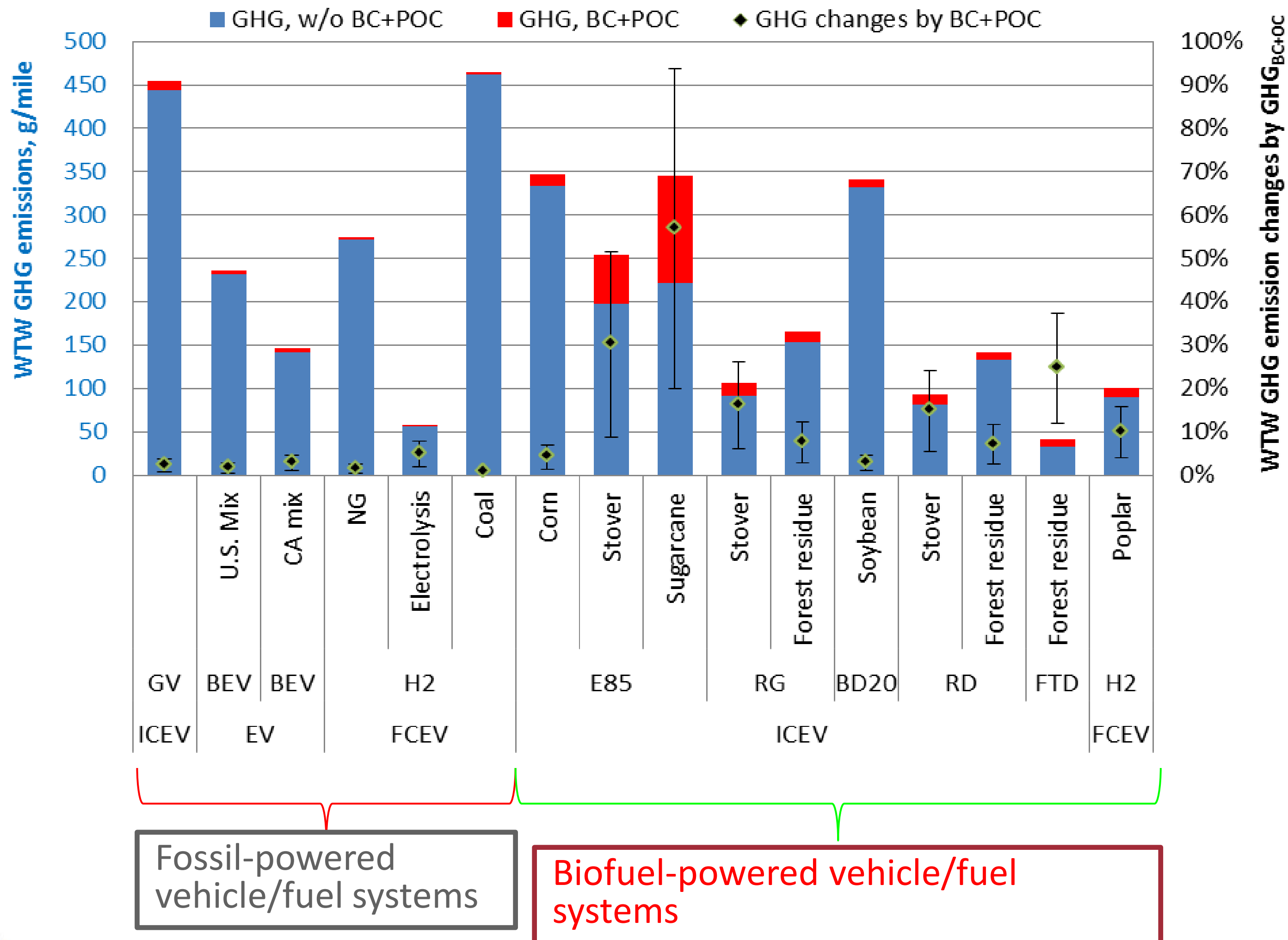
# *Biomass combustion was identified to be a key contributor to black carbon emissions (g/mi in FFVs)*




CS: Corn stover ; SC: sugarcane; SS: Sweet sorghum; FR: Forest residue; SB: Soybean; RG: Renewable gasoline; FTD: Fischer-Tropsch diesel; RD: Renewable diesel; FCEV: Fuel cell electric vehicle

Cai and Wang, *Environmental Science and Technology*, 2014

# Black and organic carbon significantly influence sugarcane and cellulosic ethanol, but minimally affect fossil- and electricity-powered vehicle systems




Cai and Wang, *Environmental Science and Technology*, 2014

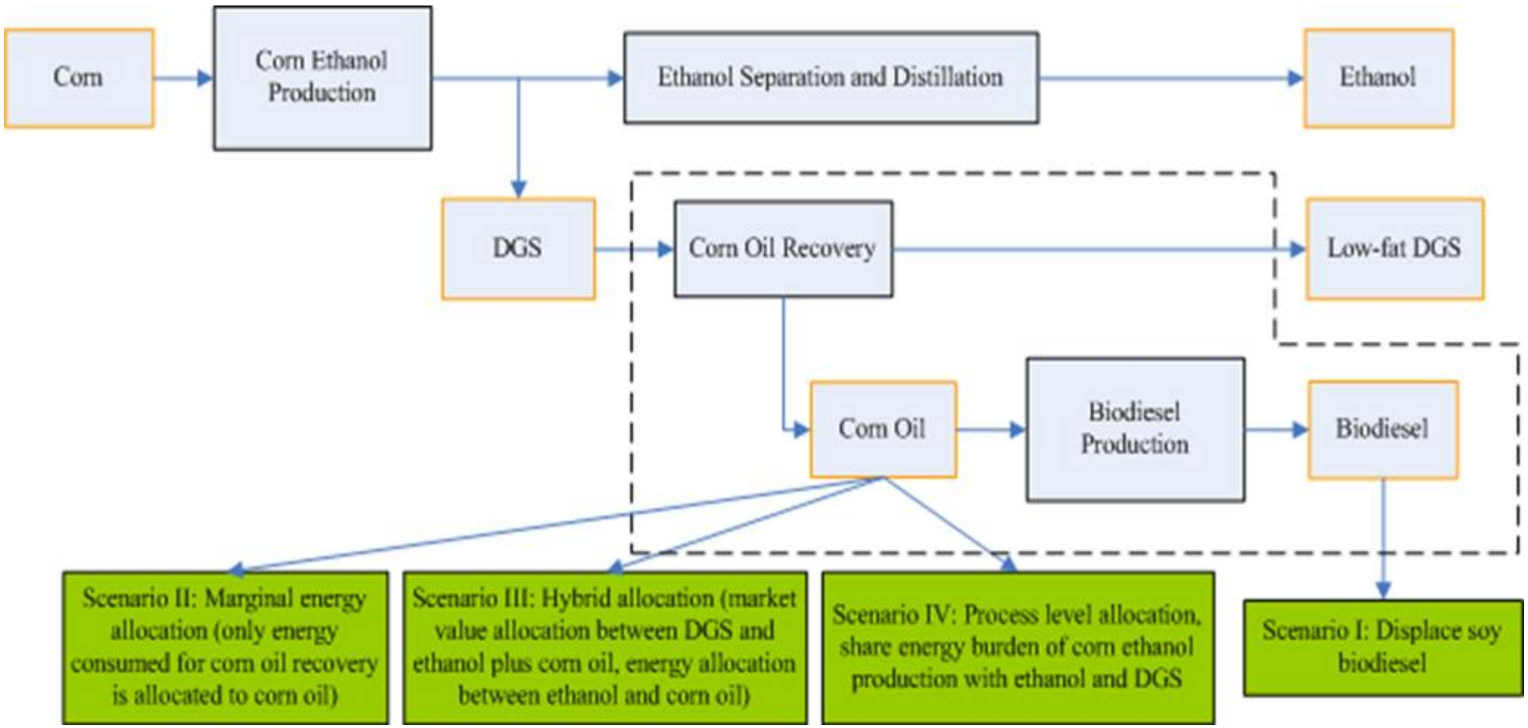
# *Evaluation of air pollutants emitted over a biofuel's life cycle*

- During farming influenced by type of farming equipment, sulfur level of fuel
- During conversion, electricity grid will influence emissions as will process chemistry
- At the biorefinery, combustion equipment will also influence emissions
- Combustion emissions depend on process fuel and type of equipment
- Pollution control regulations influence expected changes in air pollution from combustion equipment and farming equipment over time

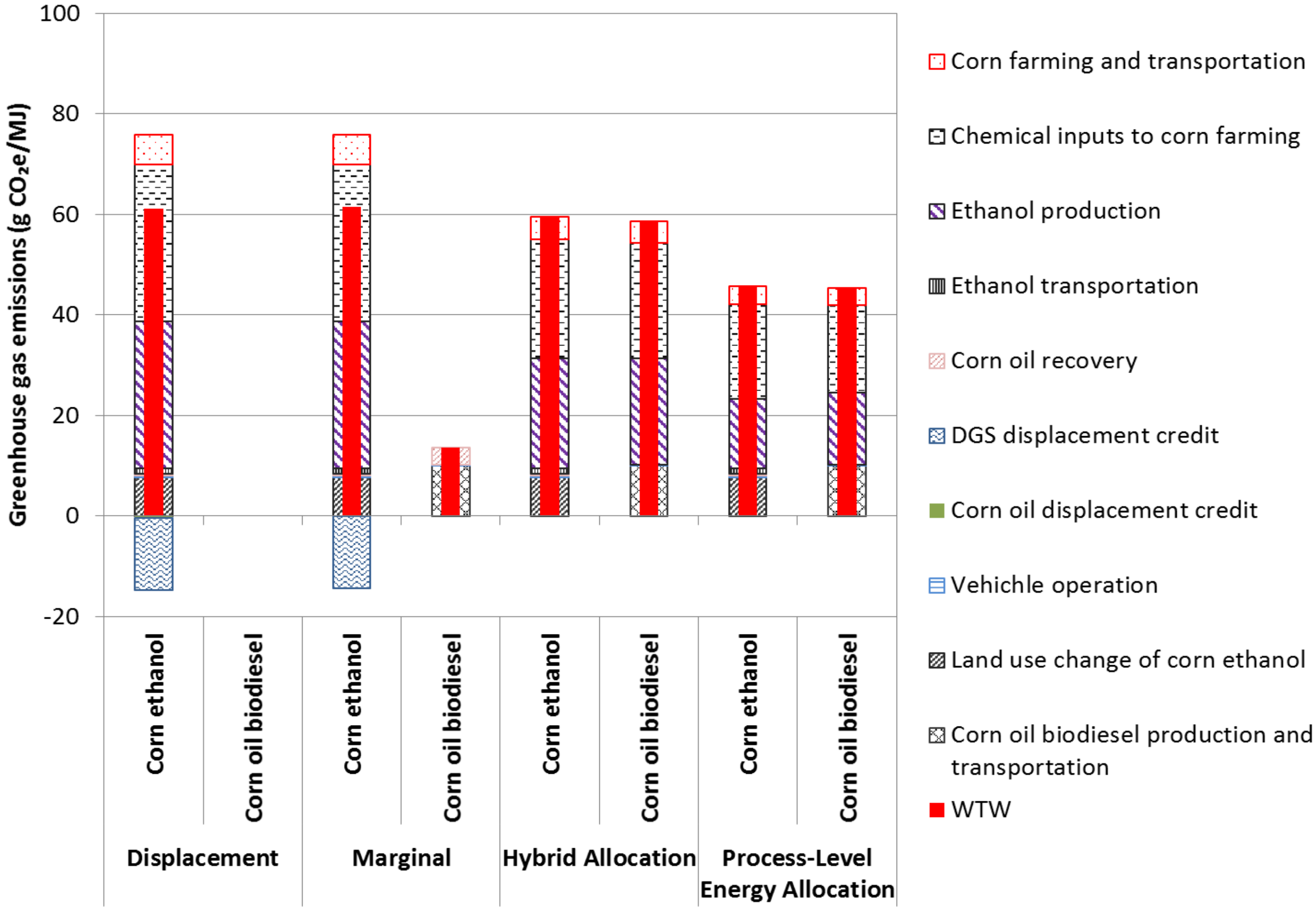
# *Co-Product Methods: Benefits and Issues*

- 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

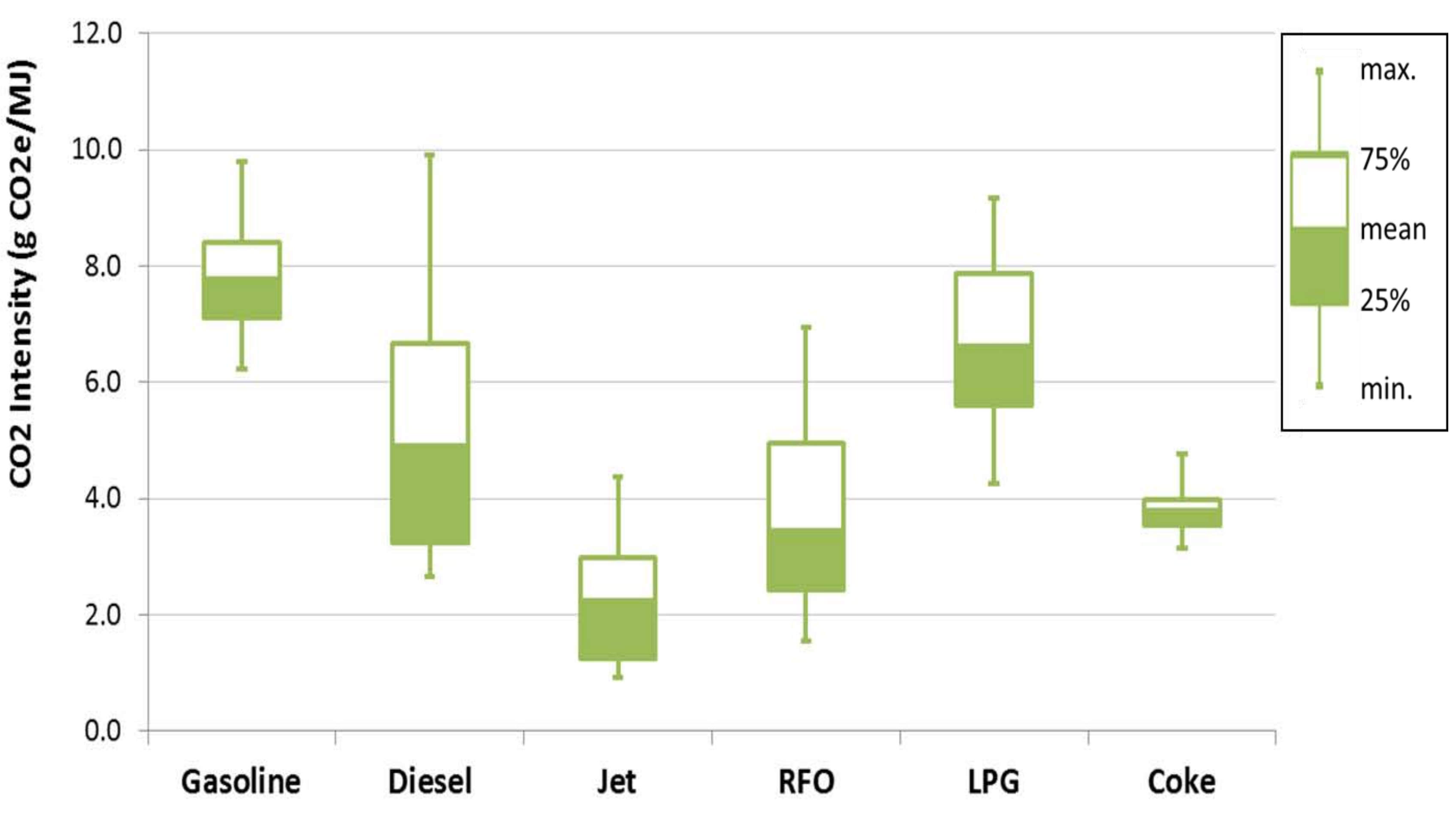
# Corn ethanol-corn oil biodiesel system is a case study in choosing a co-product allocation technique



# Co-product allocation choice influences life-cycle GHG emissions of both fuels

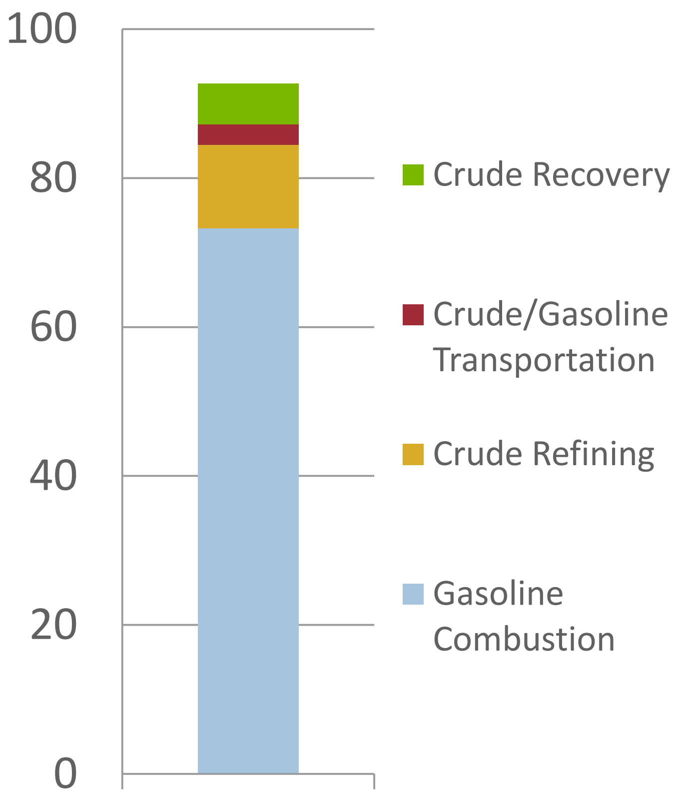


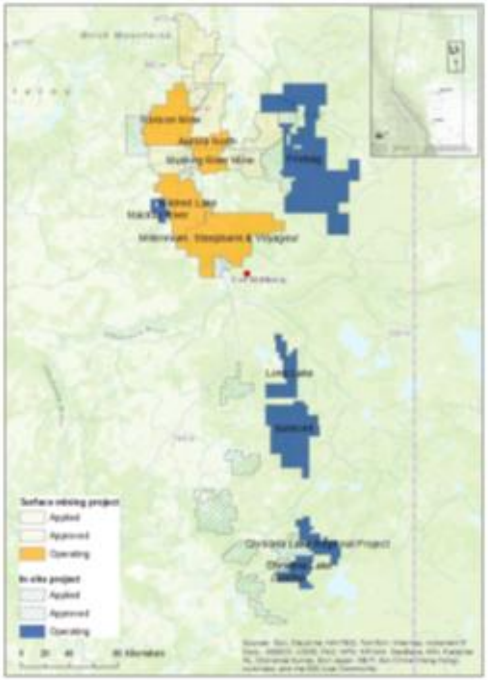
# $CO_2$ intensity of petroleum refinery products differ depending on level of processing




Elgowainy et al. *Environmental Science and Technology*, 2014
Forman et al. *Environmental Science and Technology*, 2014

# Gasoline Well-to-Wheel GHG emissions: grams/MJ



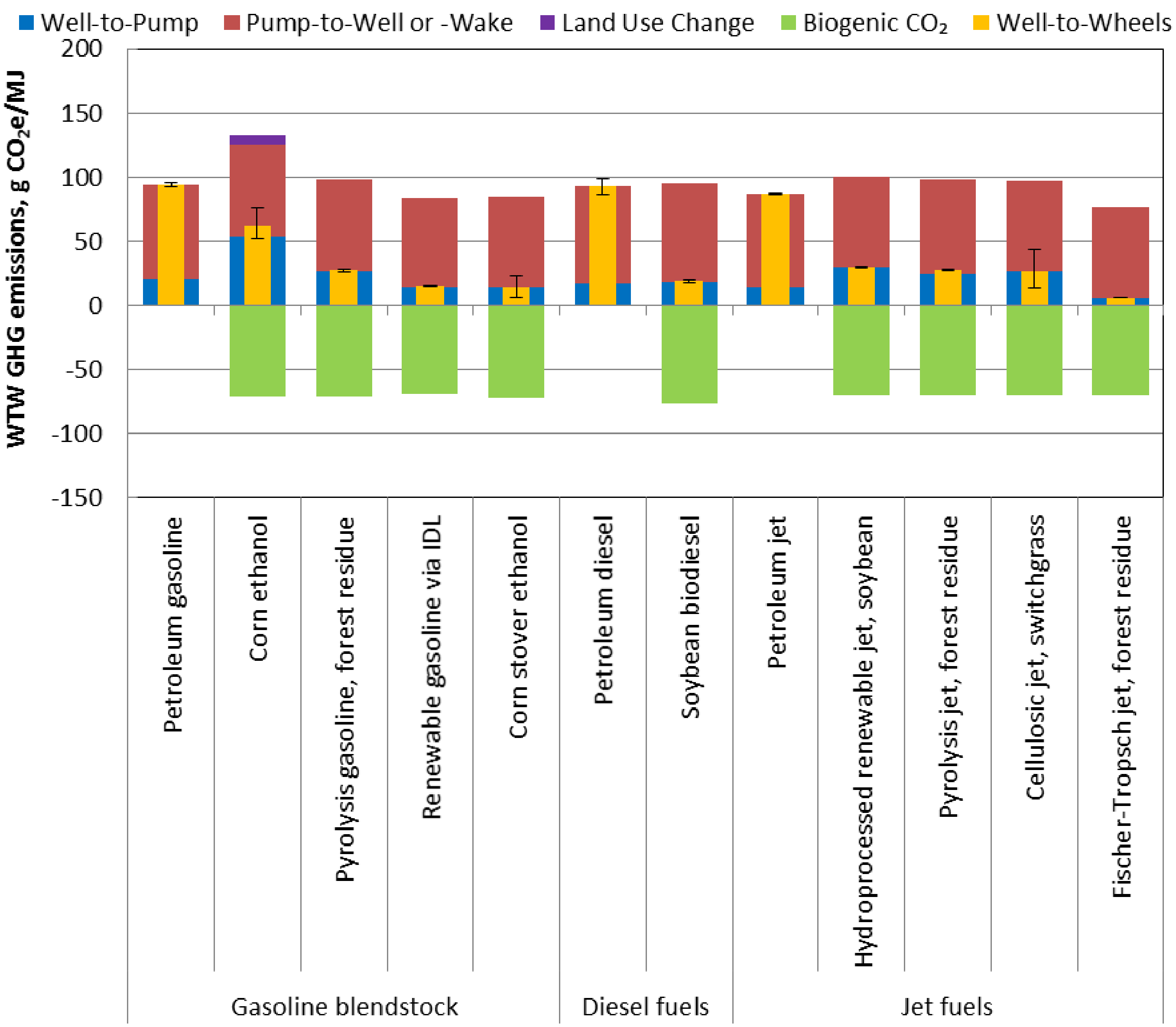
**Oil sand land disturbance GHG (Yeh et al. 2014)**

Pay-as-you –go
- ✓3.4-3.4 g/MJ for surface mining
- ✓1.8-2.8 g/MJ for in-situ

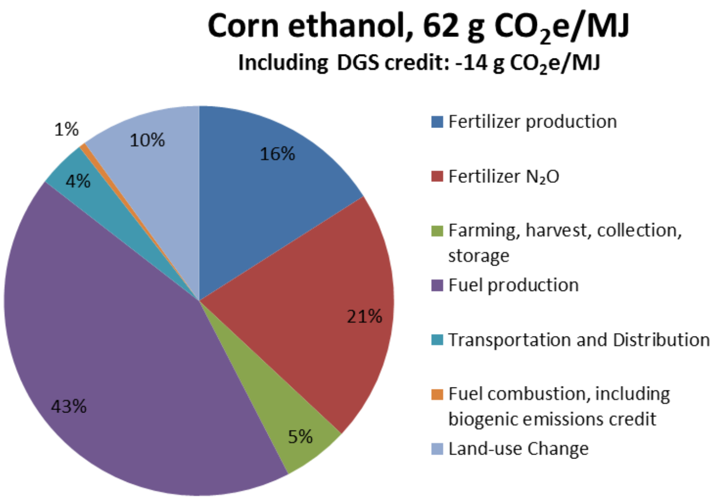
Amortization
- ✓1.9 g/MJ for surface mining
- ✓0.56-0.89 g/MJ for in-situ

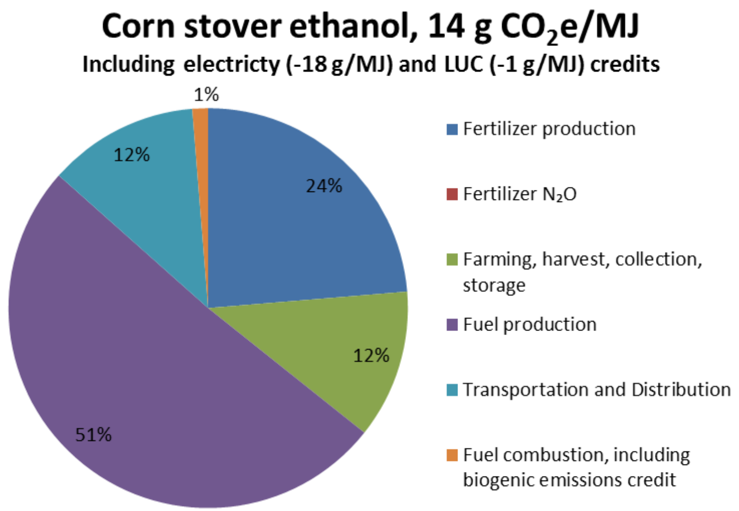
| | Conventional Crude | Mining SCO (53%) | Mining Dilbit (4%) | In-Situ SCO (8%) | In-Situ Dilbit (35%) |
|---|---|---|---|---|---|
| **Recovery** | 4.1 | 20 | 7.0 | 24 | 13 |
| **Land Disturbance** | — | 1.9 | 1.5 | 0.70 | 0.56 |
| **Refining** | 15 | 18 | 17 | 19 | 19 |
| **Transport. & Distribution** | 2.3 | 3.7 | 3.9 | 3.7 | 3.9 |
| **Total Well-to-Pump** | **21** | **44** | **29** | **47** | **36** |

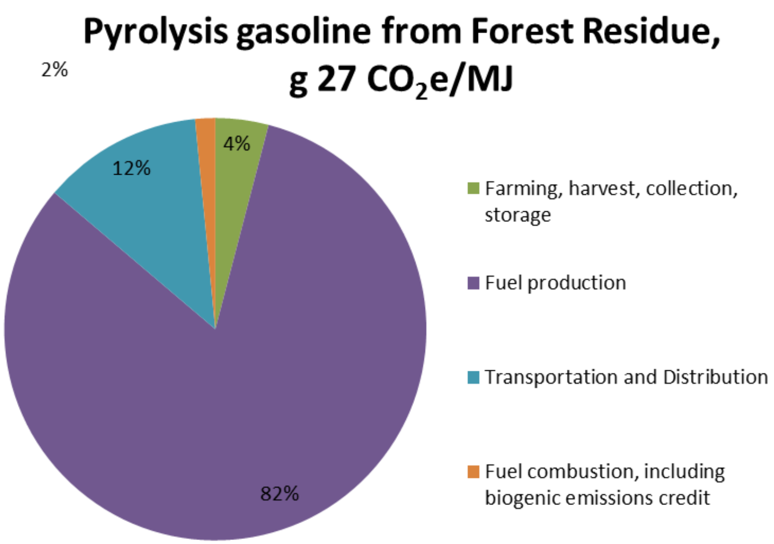
# Overview of life-cycle GHG emissions of selected biofuels

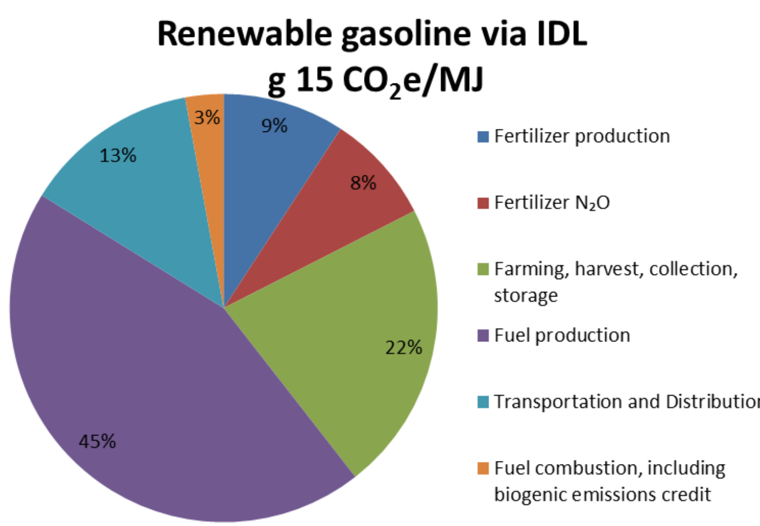


# *Emissions breakout for different biofuels*



# *Externalities: an undeveloped area of analysis*

- Feedstock production can offer environmental services including reduced nitrogen run-off
- Additional air, water, and soil quality issues merit further exploration and are likely to be spatially- and feedstock-dependent
- Fossil fuel externalities and indirect effects – double standard?
  - Catastrophic events
  - Biodiversity and other influences on ecosystems where drilling occurs
- Existing tools could quantify externality effects on life-cycle metrics, but data availability is likely limited

# *Biofuel and petroleum-derived fuel LCA areas for development*

- Carbon neutrality of woody feedstocks
- Improved accounting of biofuel life-cycle air emissions
- Better accounting for soil chemistry changes that influence GHG emissions from soils
- Advances in conversion processes and feedstock production
- Spatial-temporal resolution
- Land-use change effects beyond C stock (albedo, surface water, etc.)
- Improved handling and quantification of indirect effects and externalities

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