Life-Cycle Greenhouse Gas Emissions of Corn Ethanol with the GREET Model

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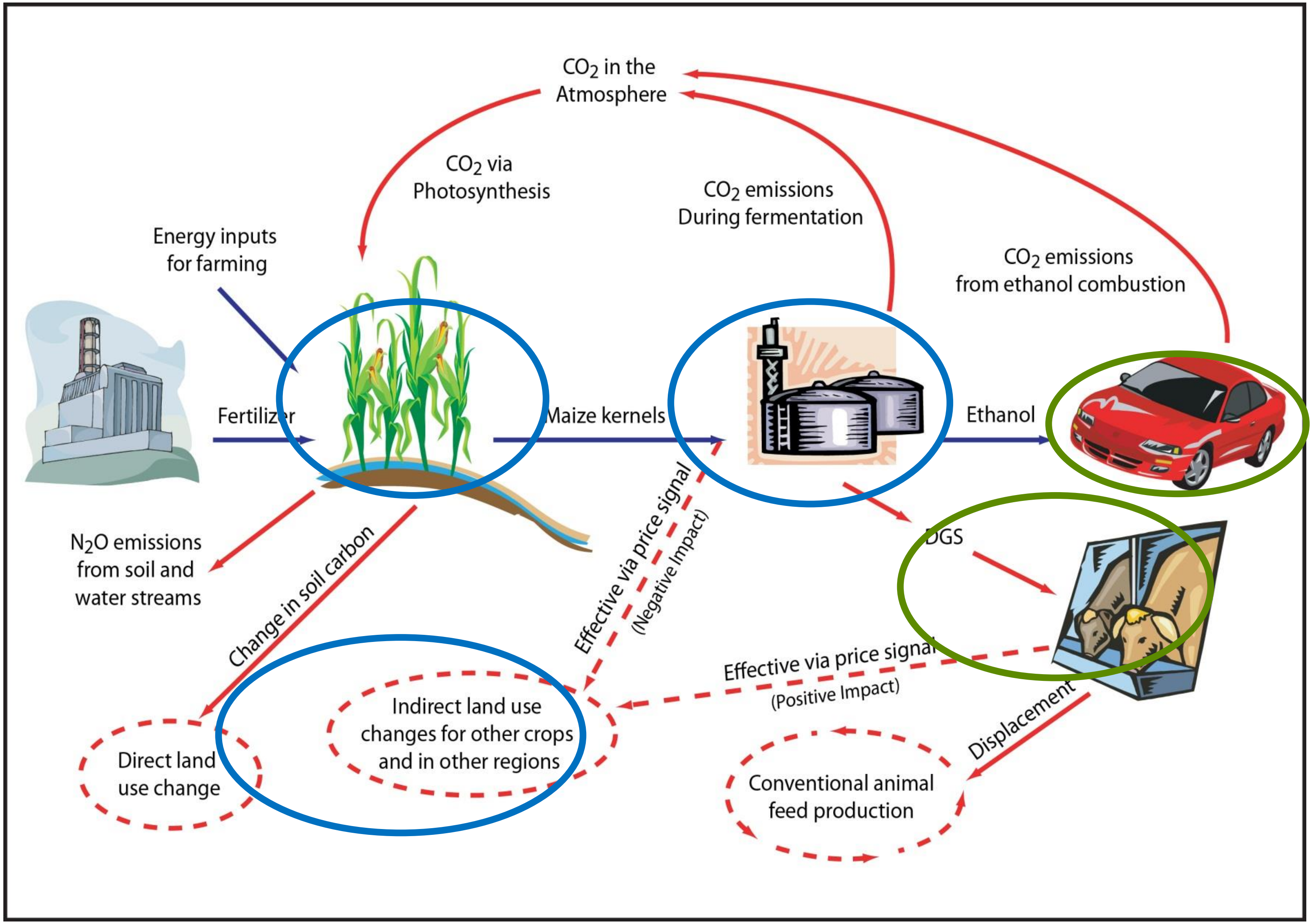
GREET includes more than 100 fuel production pathways from various energy feedstock sources

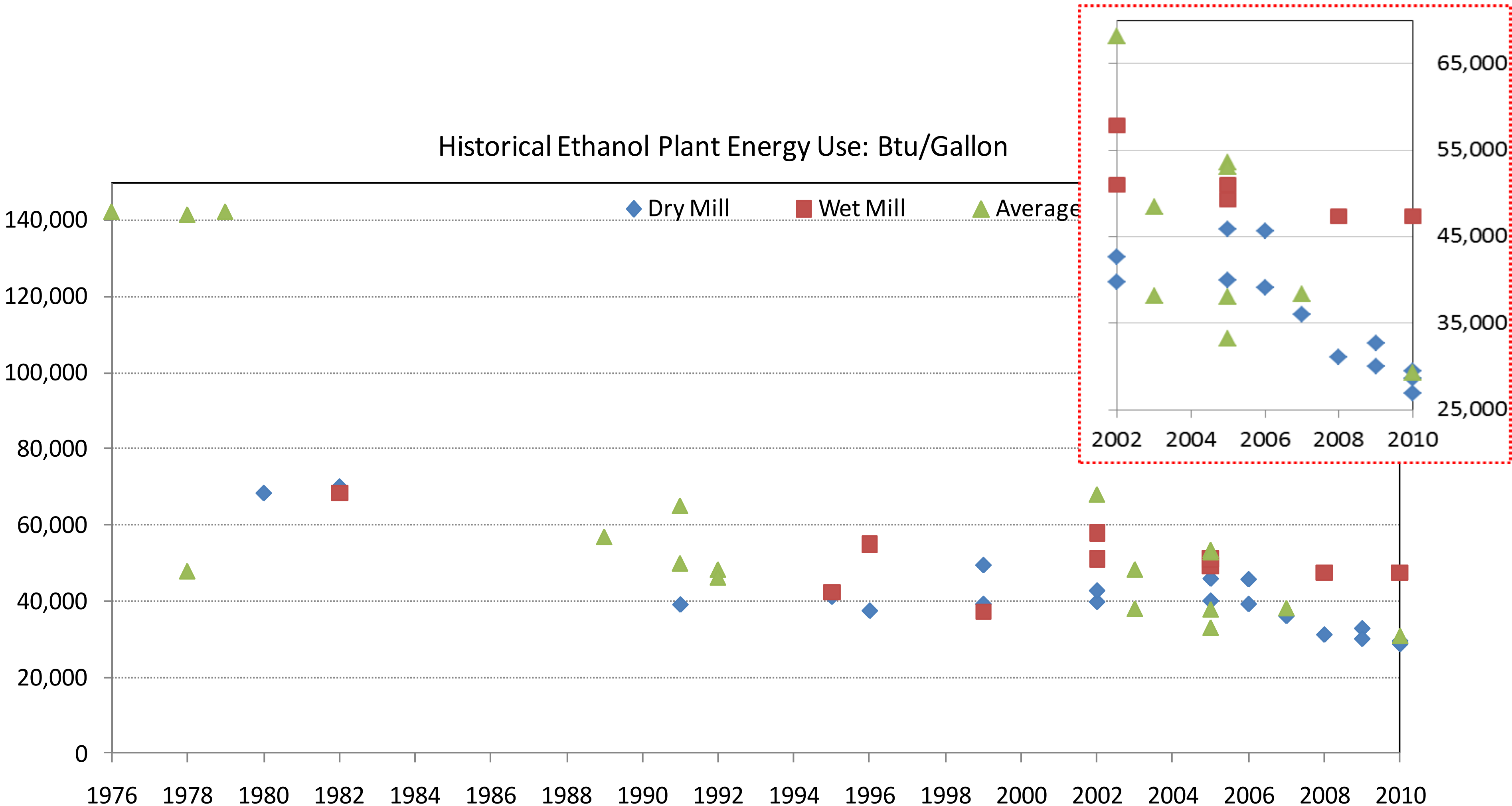
Feedstock	Fuel
Petroleum Conventional Oil Sands	Gasoline Diesel Jet Fuel Liquefied Petroleum Gas Naphtha Residual Oil
Coal	Hydrogen Fischer-Tropsch Diesel Fischer-Tropsch Jet Methanol Dimethyl Ether
Natural Gas North American Non-North American Shale gas **Renewable Natural Gas** Landfill Gas Animal Waste Waste water treatment	Compressed Natural Gas Liquefied Natural Gas Liquefied Petroleum Gas Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fischer-Tropsch Naphtha Hydrogen
Coke Oven Gas Petroleum Coke Nuclear Energy	Hydrogen

Feedstock	Fuel
Corn	Ethanol Butanol
Sugarcane	Ethanol
Soybeans Palm Rapeseed Jatropha Camelina Algae	Biodiesel Renewable Diesel Renewable Gasoline Hydroprocessed Renewable Jet
Cellulosic Biomass Switchgrass Willow/Poplar Crop Residues Forest Residues Miscanthus	Ethanol Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Pyro Gasoline/Diesel/Jet
Residual Oil Coal Natural Gas Biomass Other Renewables	Electricity

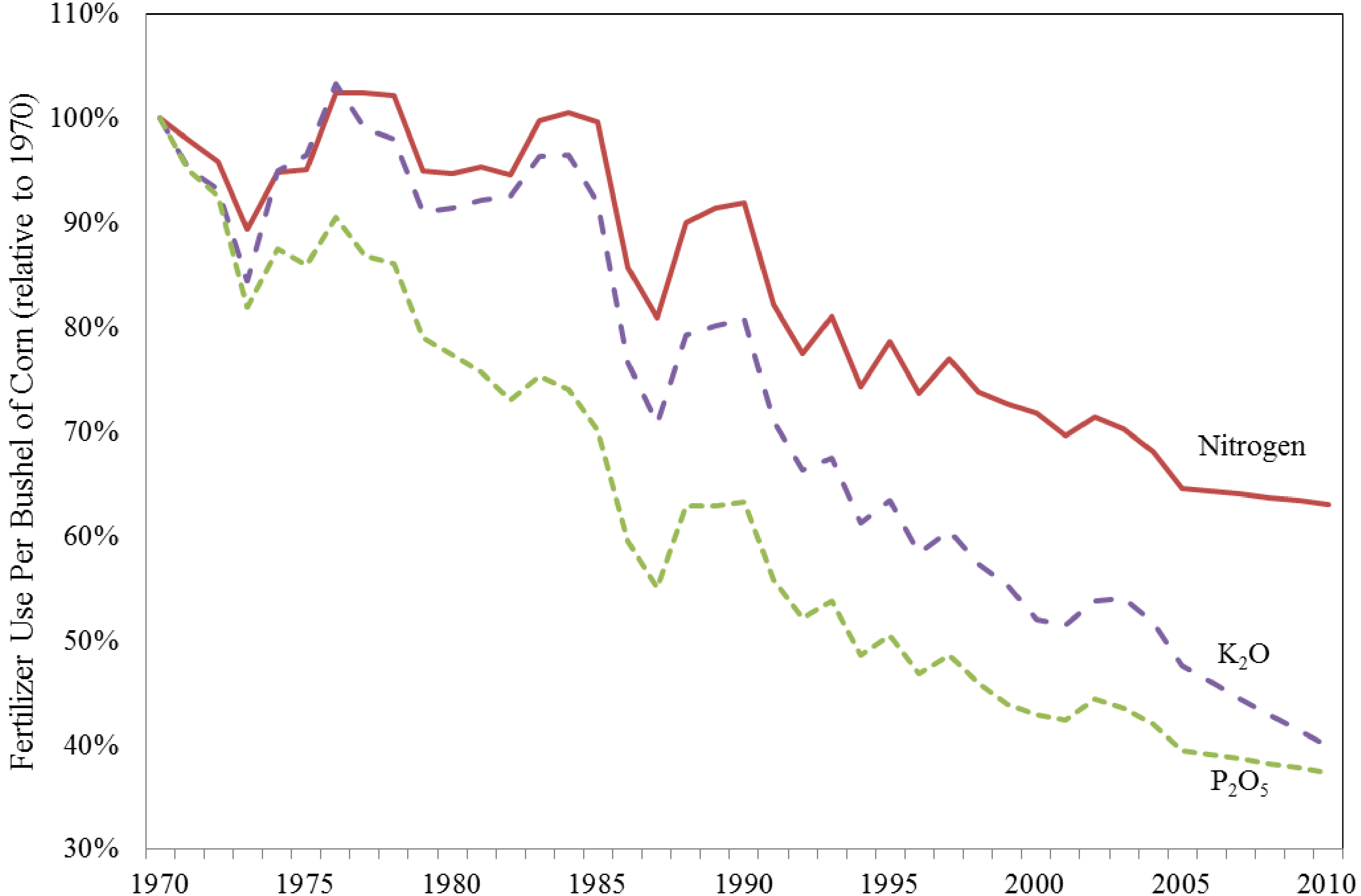
Life-Cycle Analysis System Boundary: Corn to Ethanol



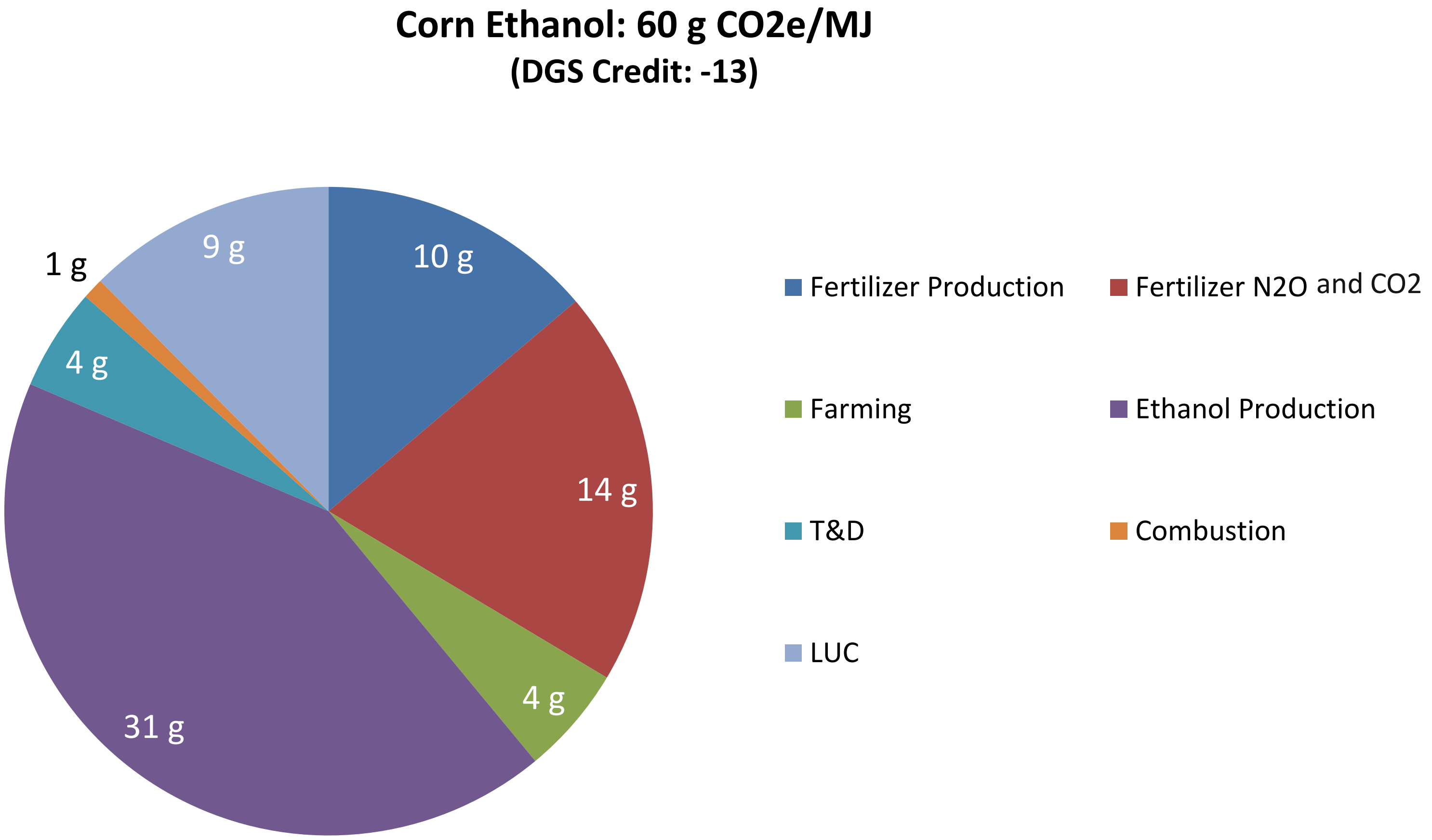
Trend of 35 Studies in the Past 35 Years: Energy Use in U.S. Corn Ethanol Plants Has Decreased Significantly



Fertilizer Use in U.S. Corn Farming Has Reduced Significantly in the Past 40 Years

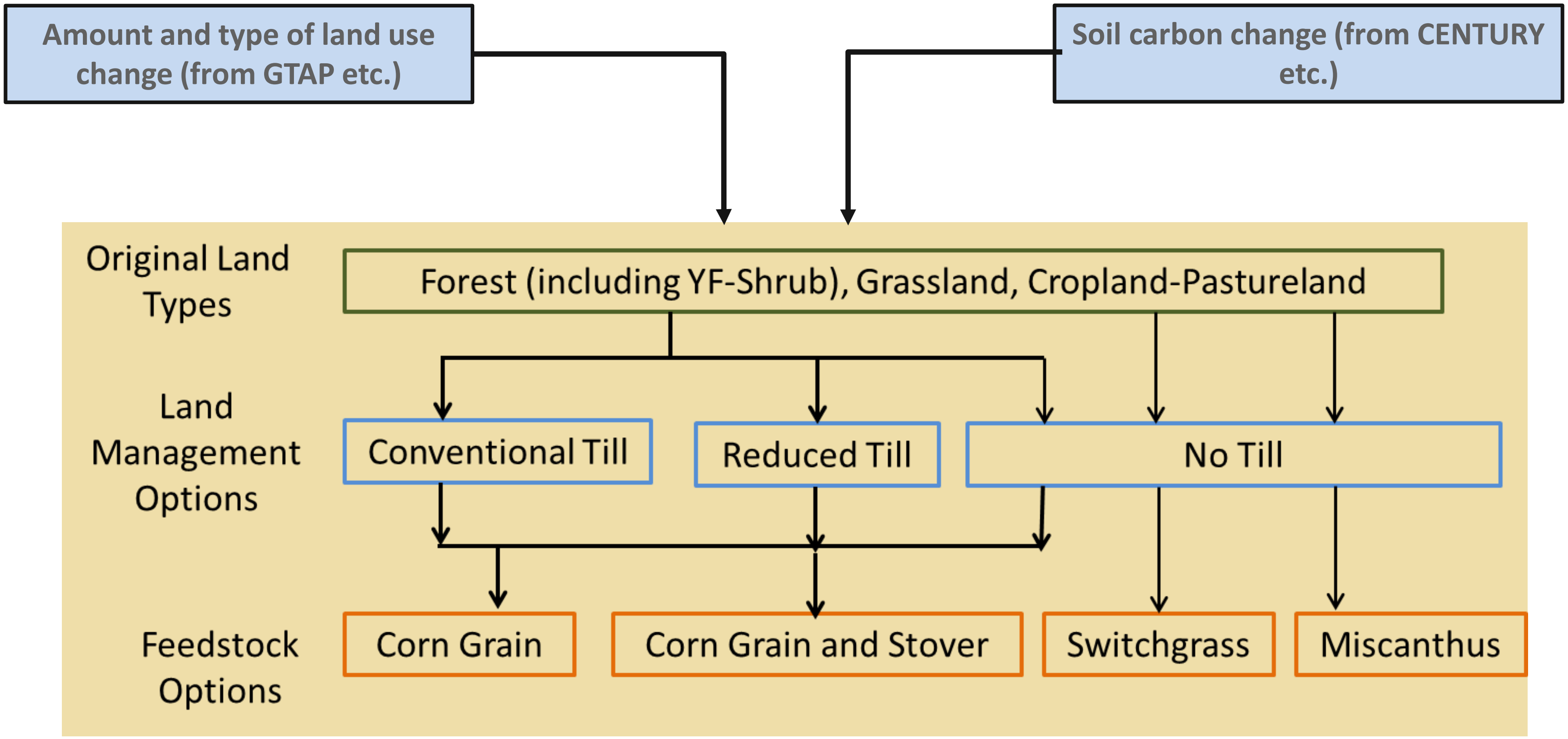


GHG Emission Sources for Corn Ethanol

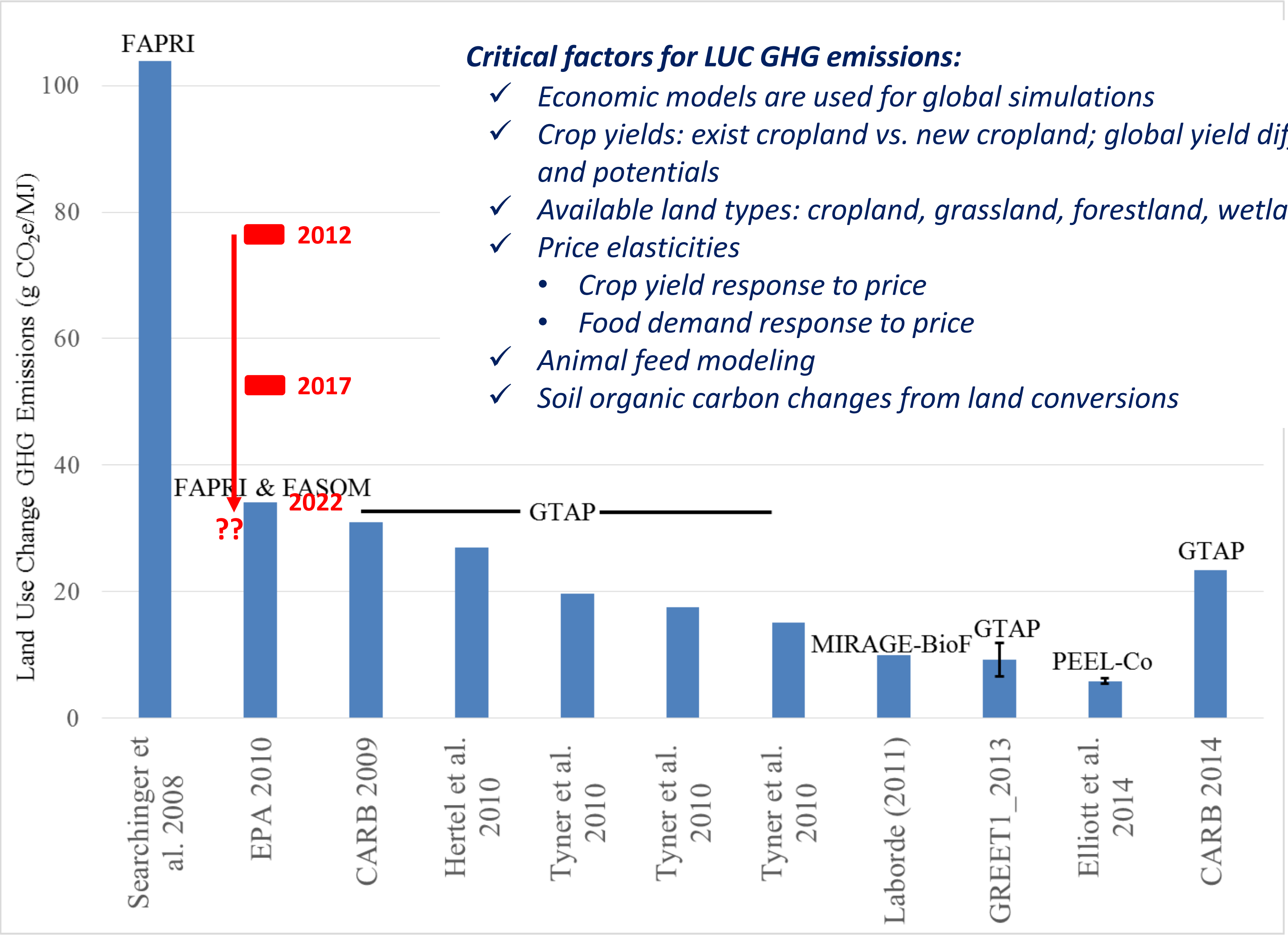


From Wang et al. (2012), *Environ. Research Letters*

Carbon Calculator for Land-Use Change from Biofuels Production (CCLUB) in GREET



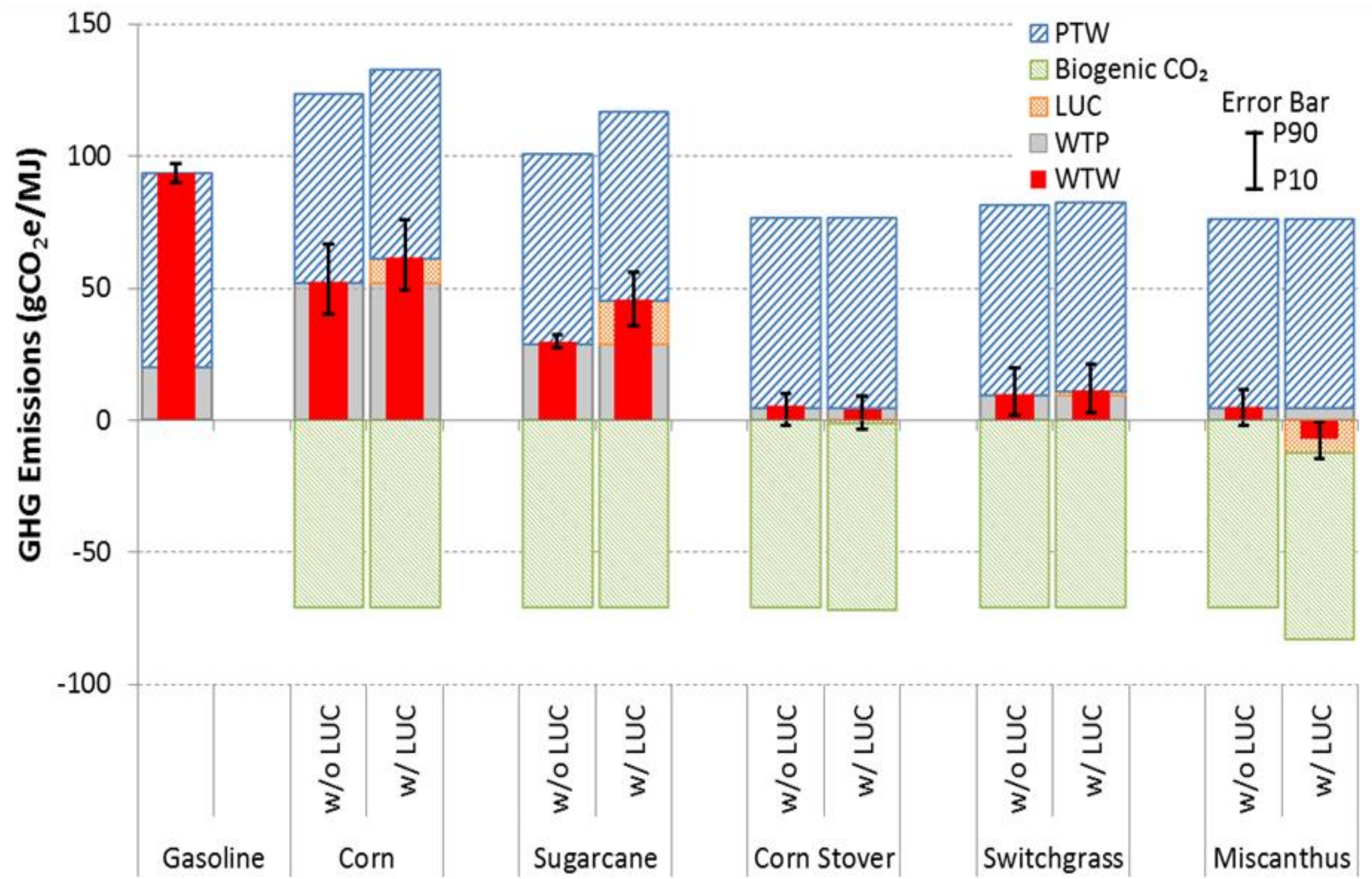
Estimates of LUC GHG emissions for corn-to-ethanol pathway



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*

LCA GHG emissions of gasoline and bioethanol pathways



From Wang M., et al., (2012), *Environ. Research Letters*

Biofuels achieve positive fossil energy balance

Biofuel energy balance = energy output - fossil energy input

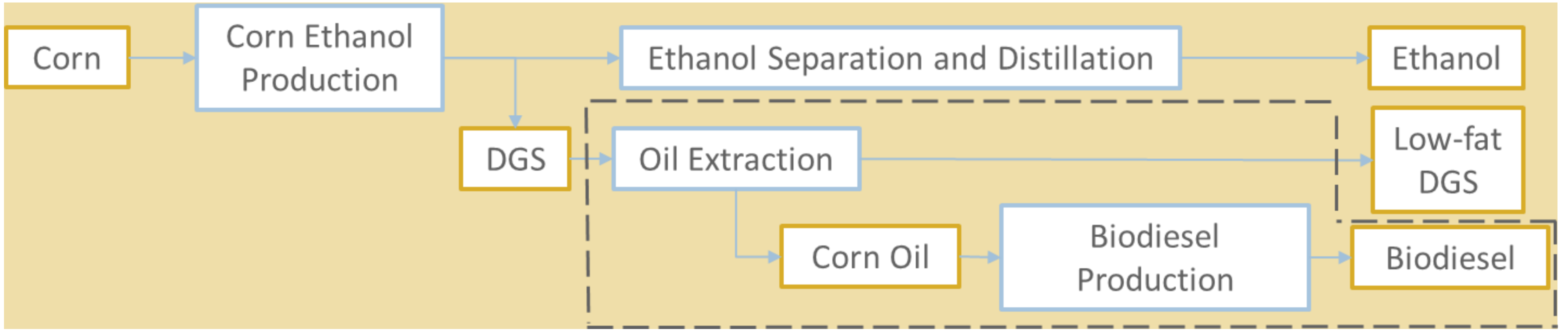
Biofuel energy ratio = energy output/fossil energy input

	Corn	Sugar-cane	Corn Stover	Switch-grass	Miscanthus
Energy balance: MJ/liter[a]	10.1	16.4	20.4	21.0	21.4
Energy ratio	1.61	4.32	4.77	5.44	6.01

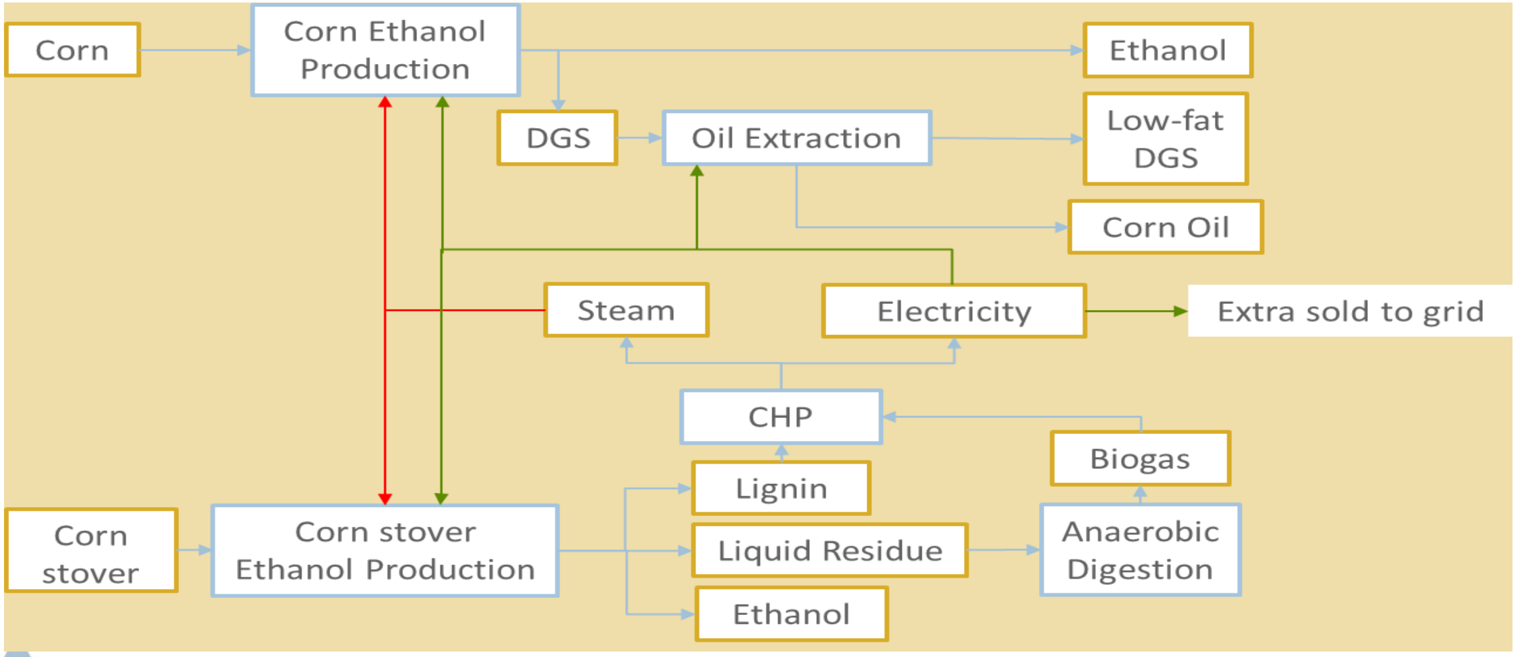
[a] A liter of ethanol contains 21.3 MJ of energy (lower heating value). Values close to or greater than 21.3 MJ are caused by co-produced electricity

New trends of ethanol production

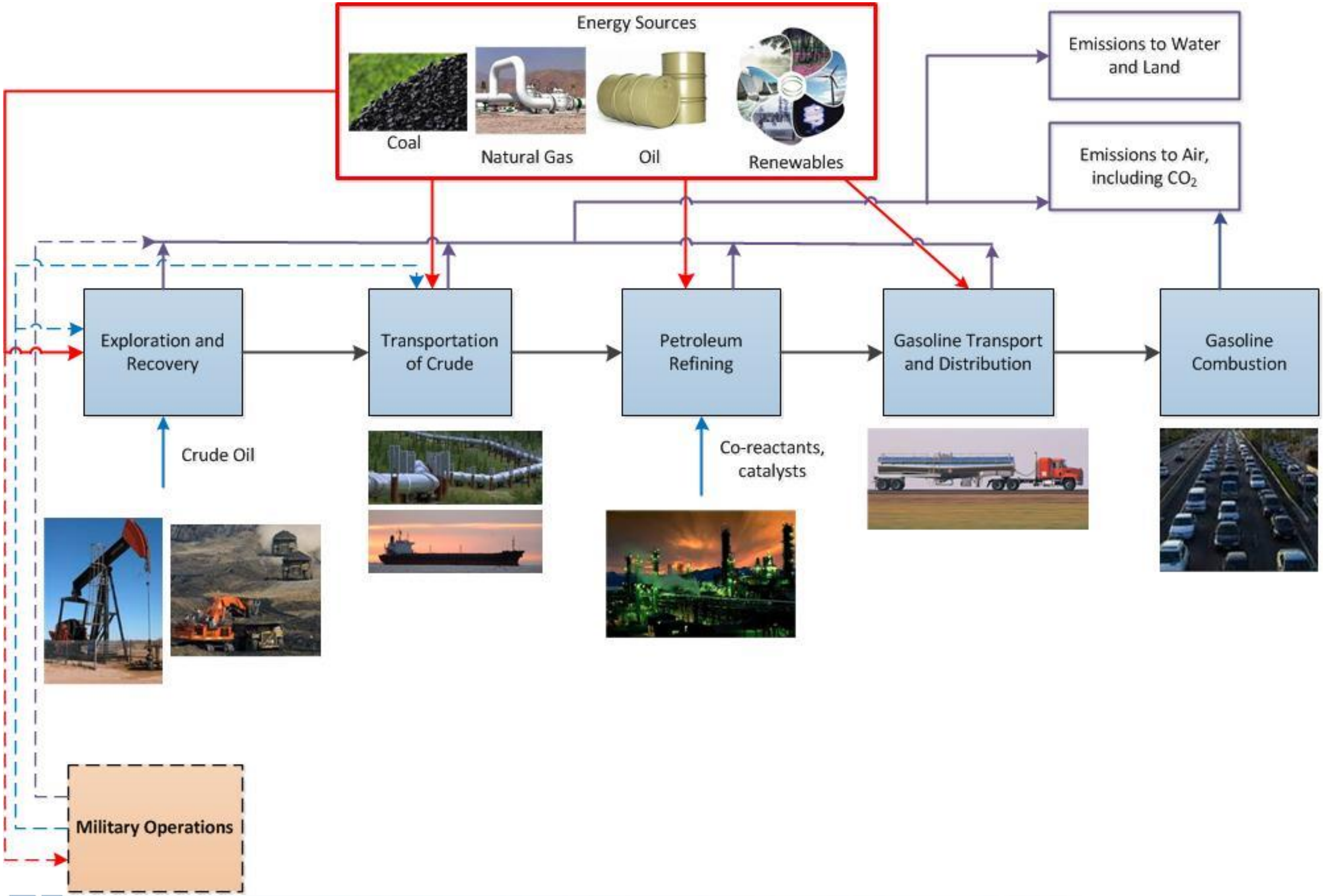
Corn oil extraction for biodiesel production



Co-production of corn grain ethanol and stover ethanol



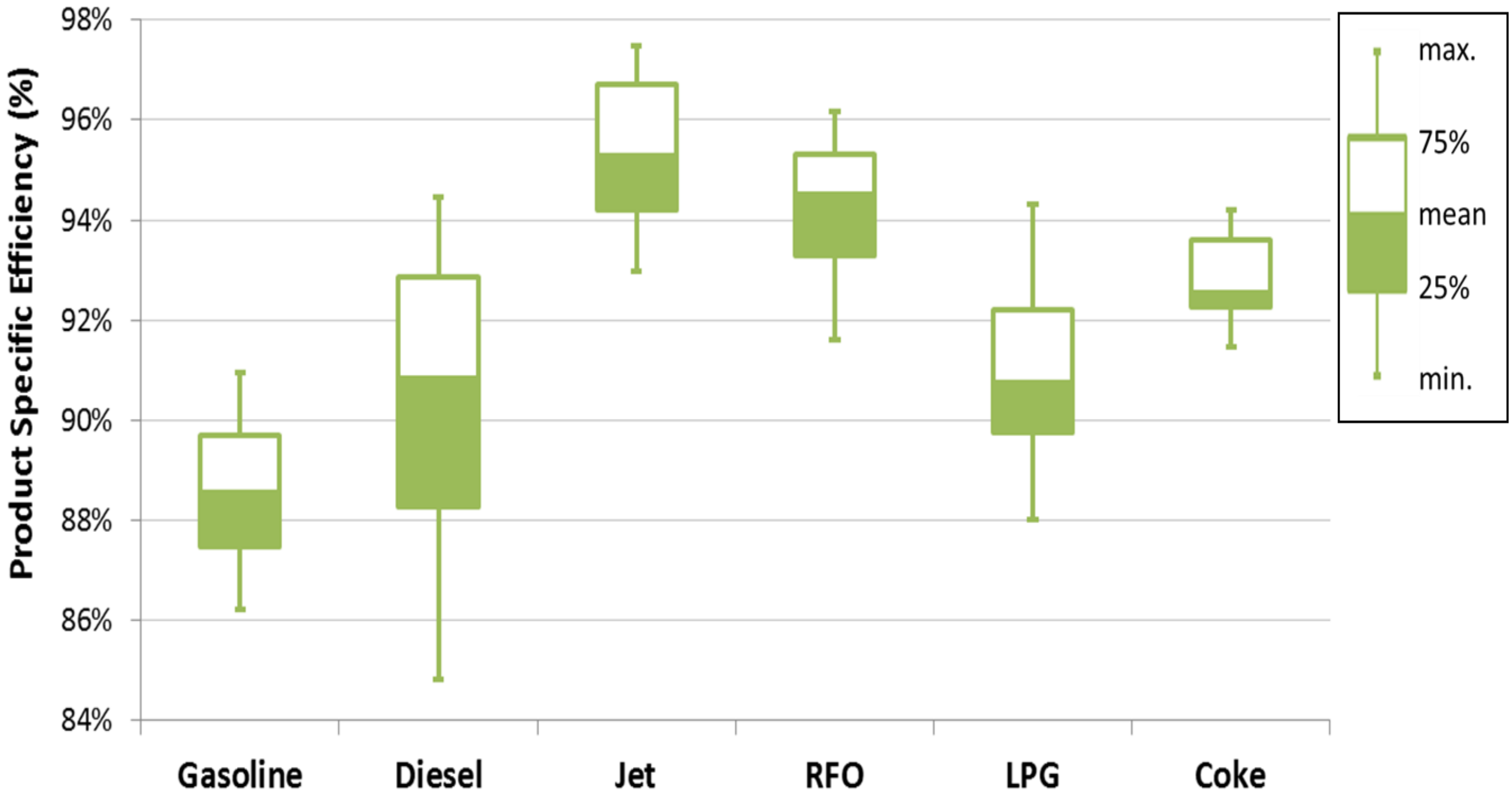
Life-Cycle Analysis system boundary: petroleum to gasoline



Argonne has been addressing petroleum fuel pathways

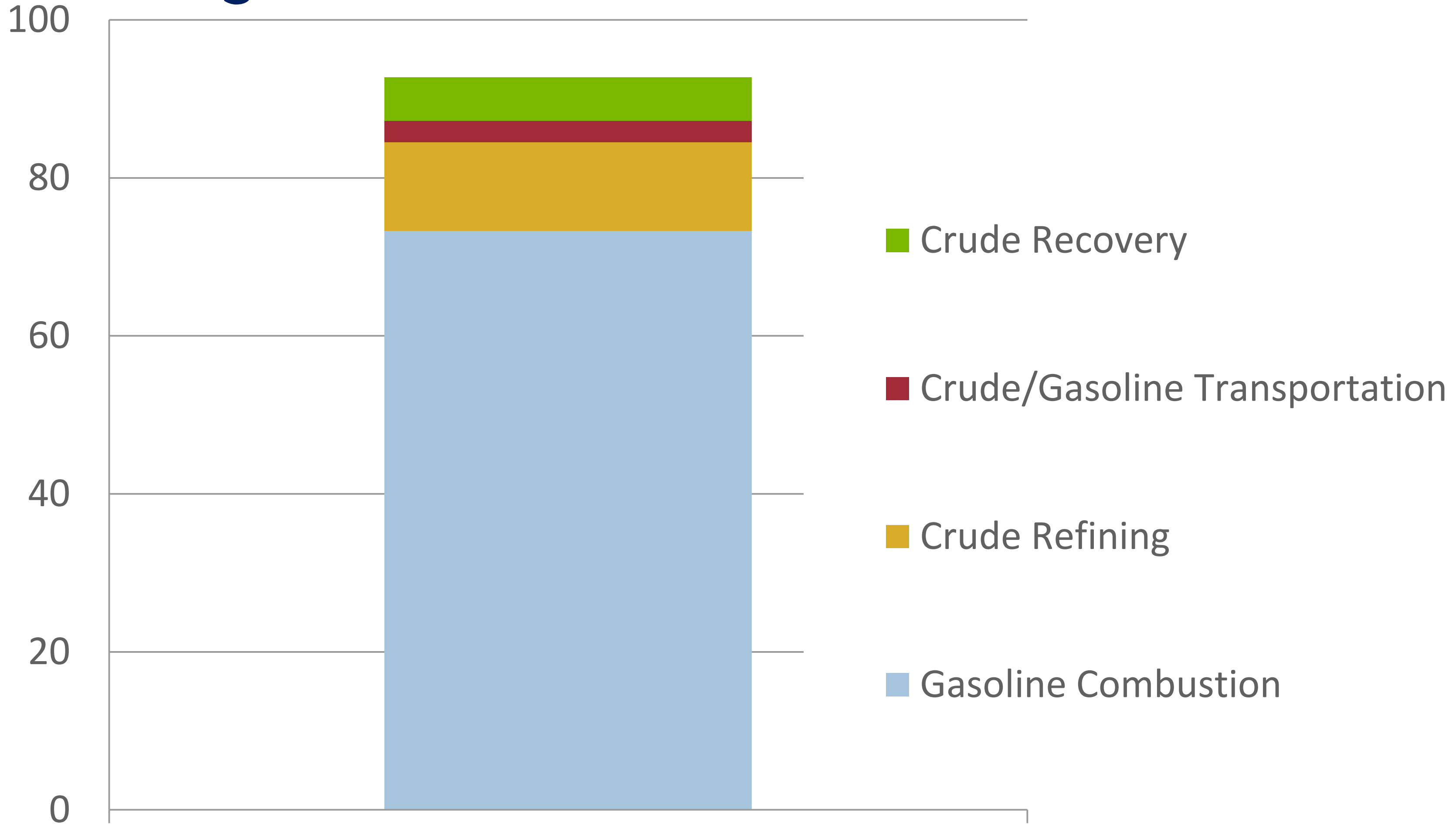
- Petroleum refining to gasoline, diesel, jet fuel, and others with LP modeling to address refinery efficiency and emissions
  - Two journal articles document findings
- Oil sands production
  - Energy use and GHG emissions of recovery activities (with Stanford U.)
  - Land disturbance GHG emissions (with UC Davis)
- Other crude types being analyzed
  - Light crude recovery in Bakken and Eagle Ford Plays

Petroleum product energy efficiencies based on simulations of 43 US refineries



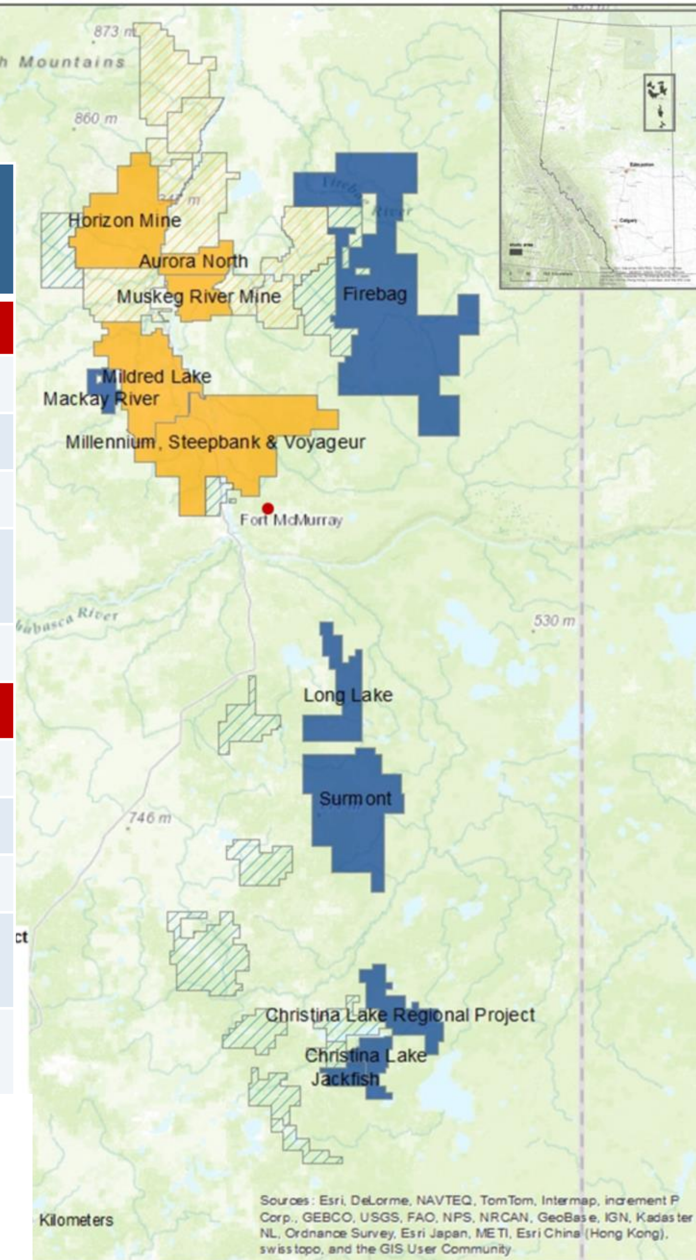
From Elgowainy et al. (2014), *Environ. Science and Tech.*

Gasoline greenhouse gas emissions simulated in GREET: grams/MJ



25 oil sands projects were analyzed for their emissions and land disturbance

	Mining + SCO (58%)	Mining + Bitumen (4%)	In-Situ + SCO (6%)	In-Situ + Bitumen (32%)
GREET2013				
Recovery	14.9		18.0	
Refining	12.7		12.9	
T&D	4.1		4.1	
Land Disturbance	NE		NE	
Total	**31.7**		**35.0**	
GREET2014 Update				
Recovery	24.1	8.1	34.5	20.3
Refining	11.1	17.0	11.6	18.1
T&D	4.1	4.0	4.2	4.1
Land Disturbance	1.9	1.9	0.7	0.7
Total	**41.2**	**31.0**	**51.0**	**43.2**



- NE – not estimated
- Refining GHG emissions for GREET2014 are estimated by assuming API gravity of 32 for SCO and 21 for bitumen
- Combustion GHG emissions are 73.3 g/MJ for gasoline and 75.0 g/MJ for diesel

Based on Englander and Brandt (2014) and Yeh et al. (2014)

Conclusions

- Technology improvements in ethanol production and corn farming have helped reduce corn ethanol GHG emissions
- Land use change modeling for corn ethanol has improved in the past 6 years with reduced modeled LUC GHG emissions, but uncertainties and confusions remain and debate continues
- Transition to cellulosic biofuels will result in greater GHG reductions

Additional Information:

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