Ethanol Life Cycle Analysis: Consideration of System Boundary Expansion and Technology Improvements

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Background

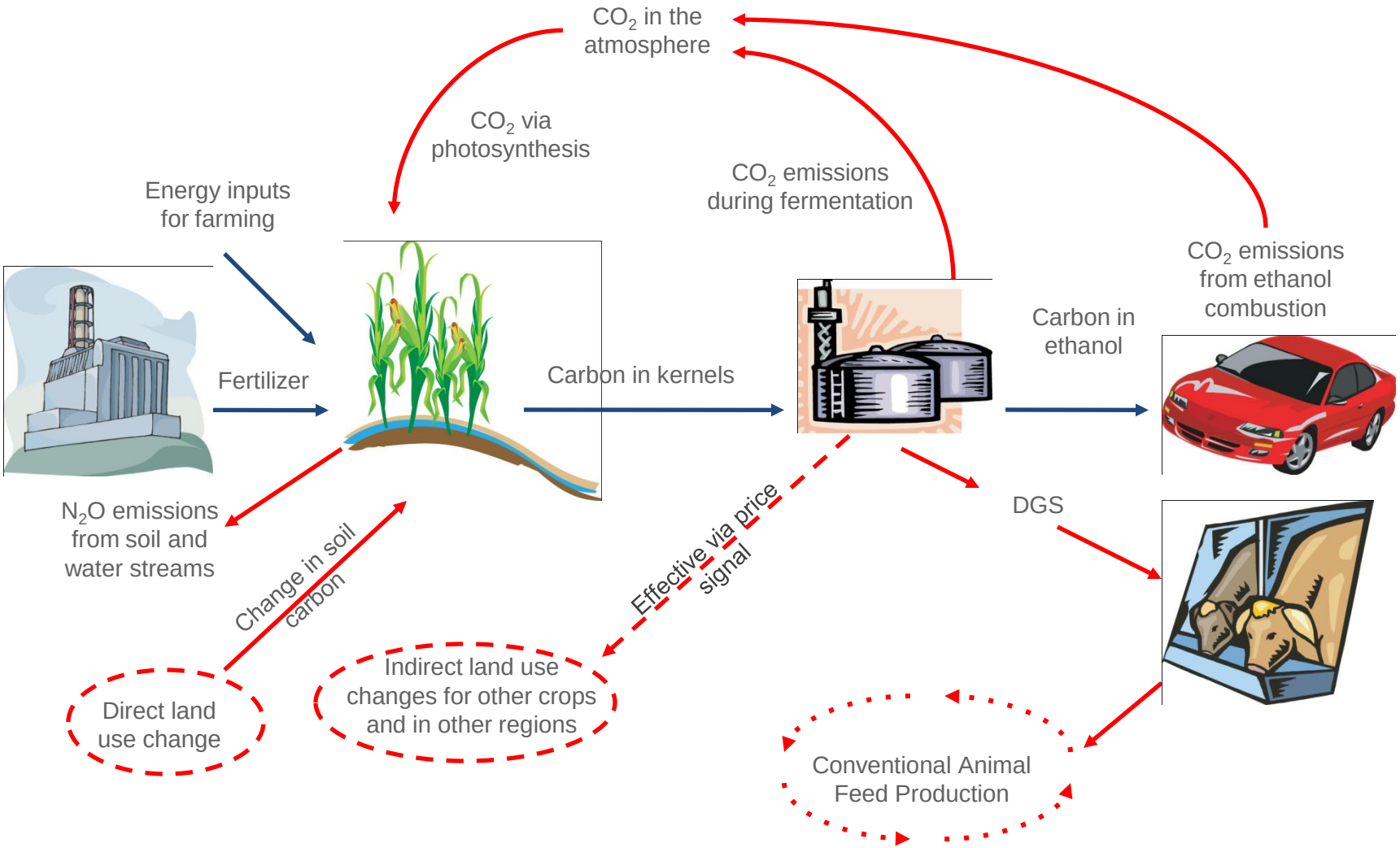
- U.S. corn ethanol production in 2009
  - 10.6 billion gallons
  - 5.4% of US gasoline market (on the energy basis)
  - Has this caused international land use changes and other unintended consequences? Maybe not
- Will continuous growth of corn ethanol to 15 B gallons cause unintended consequences? Nobody knows with certainty
- Have technologies in farming and corn ethanol production improved?

GREET Includes Many Potential Biofuel Production Pathways

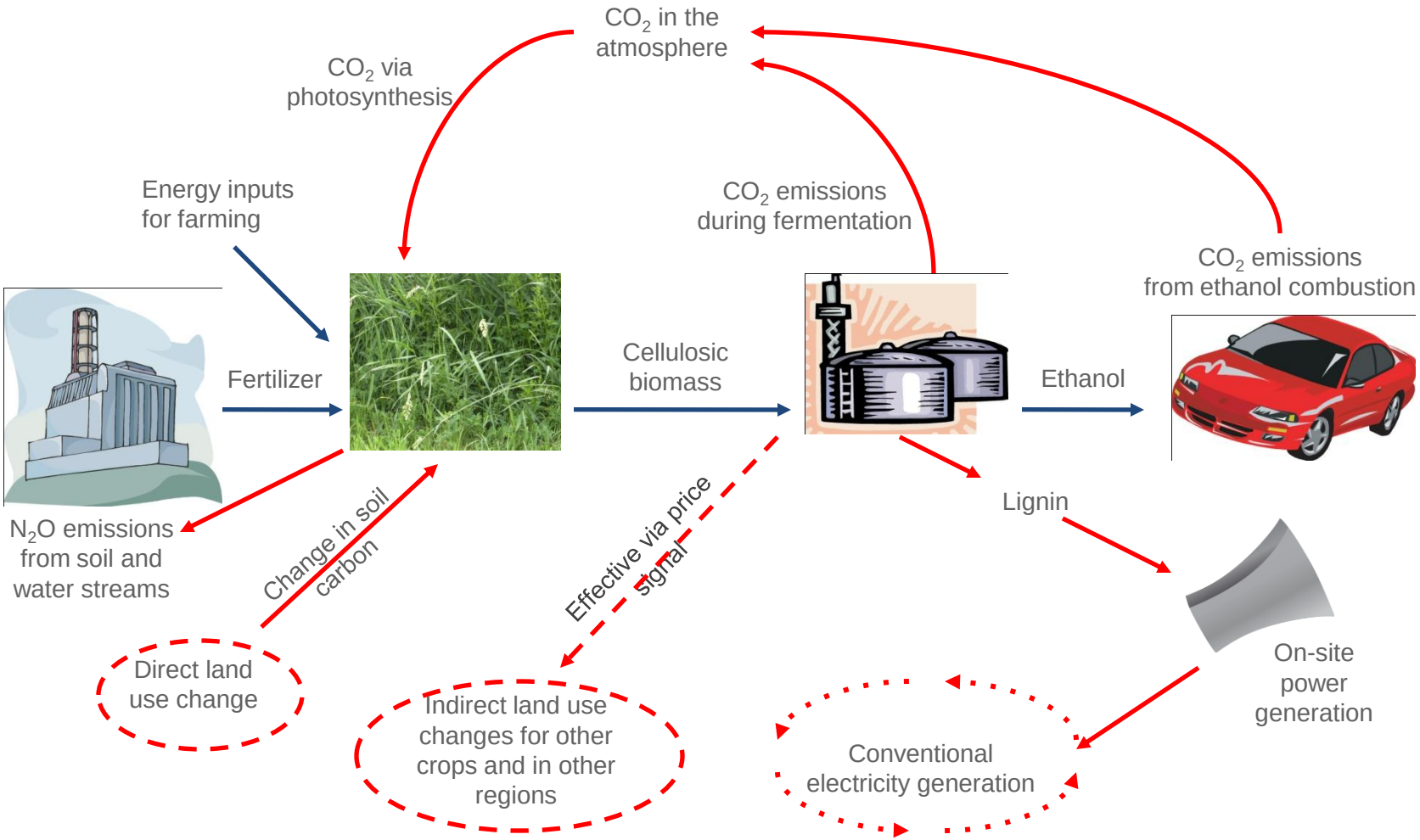
- **Sugar Crops for EtOH**
  - Sugar cane
  - Sugar beet
  - Sweet sorghum
- **Starch Crops for EtOH**
  - Corn
  - Wheat
  - Cassava
  - Sweet potato
- **Cellulosic Biomass for EtOH**
  - Corn stover, rice straw, wheat straw
  - Forest residues
  - Municipal solid waste
  - Dedicated energy crops
  - Black liquor
- **Landfill Gas**
  - CNG/LNG
  - Fischer-Tropsch diesel
  - Hydrogen
  - Methanol
  - DME
  - Fischer-Tropsch jet fuel
- **Oils for Biodiesel/Renewable Diesel/Renewable Jet Fuel**
  - Soybeans
  - Rapeseed
  - Palm oil
  - Jatropha
  - Waste cooking oil
  - Animal fat
- **Butanol**
  - Corn
  - Sugar beet
- **Cellulosic Biomass via Gasification**
  - Fischer-Tropsch diesel
  - Hydrogen
  - Methanol
  - DME
  - Fischer-Tropsch jet fuel
- **Algae**
  - Biodiesel
  - Renewable diesel

The feedstocks and fuels that are underlined are already included in the GREET model.

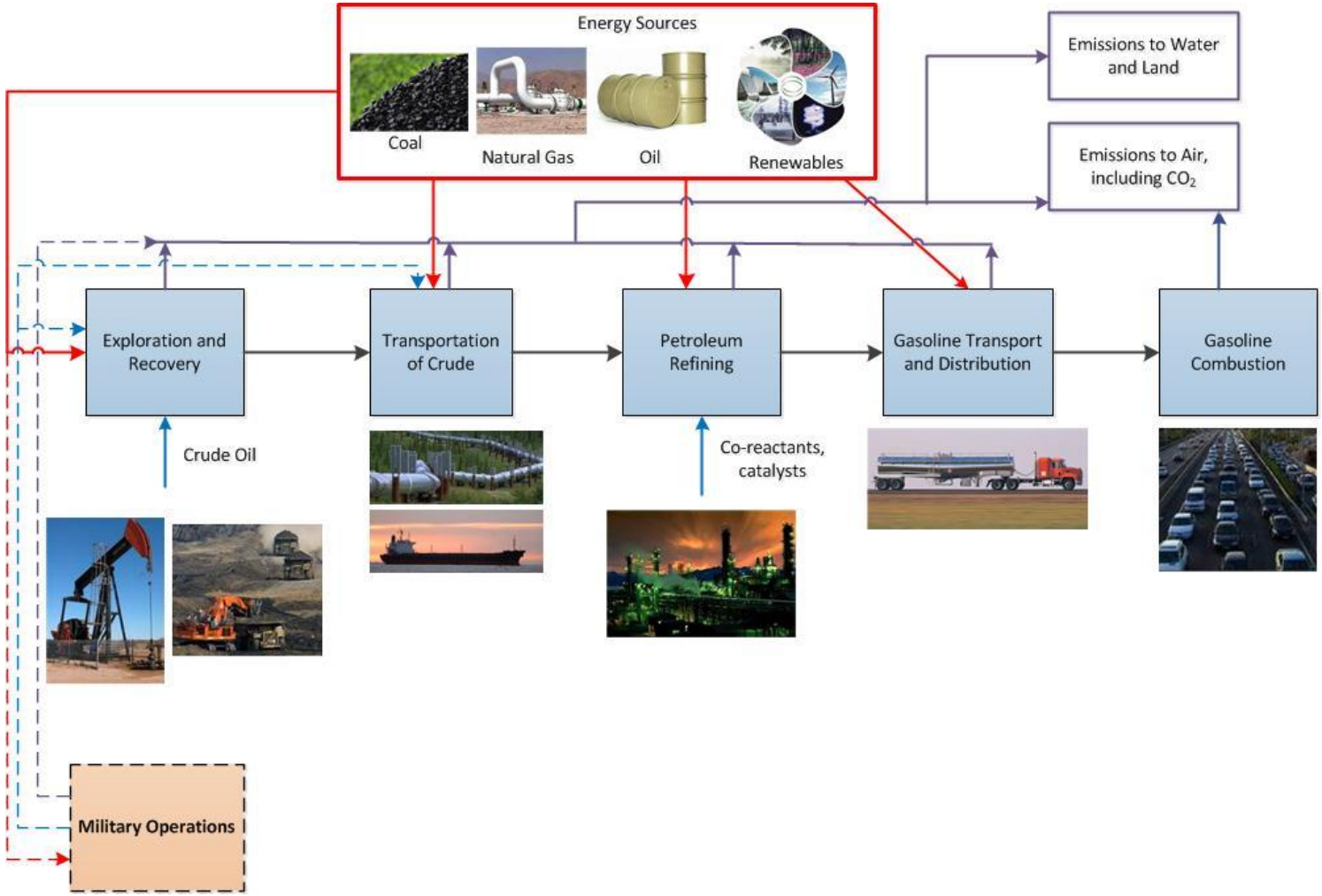
Life-Cycle Analysis System Boundary: Corn to Ethanol



Life-Cycle Analysis System boundary: Switchgrass to Cellulosic Ethanol



Life-Cycle Analysis System Boundary: Petroleum to Gasoline



Key Issues Affecting Biofuel WTW Results

- Continued technology advancements
  - Agricultural farming: continued crop yield increase and resultant reduction of energy and chemical inputs per unit of yield
  - Energy use in ethanol plants: reduction in process fuel use and switch of process fuel types
- Methods of estimating emission credits of co-products of ethanol
- Direct and indirect land use changes and resulted GHG emissions
- Life-cycle analysis methodologies
  - Attributional LCA
  - Consequential LCA

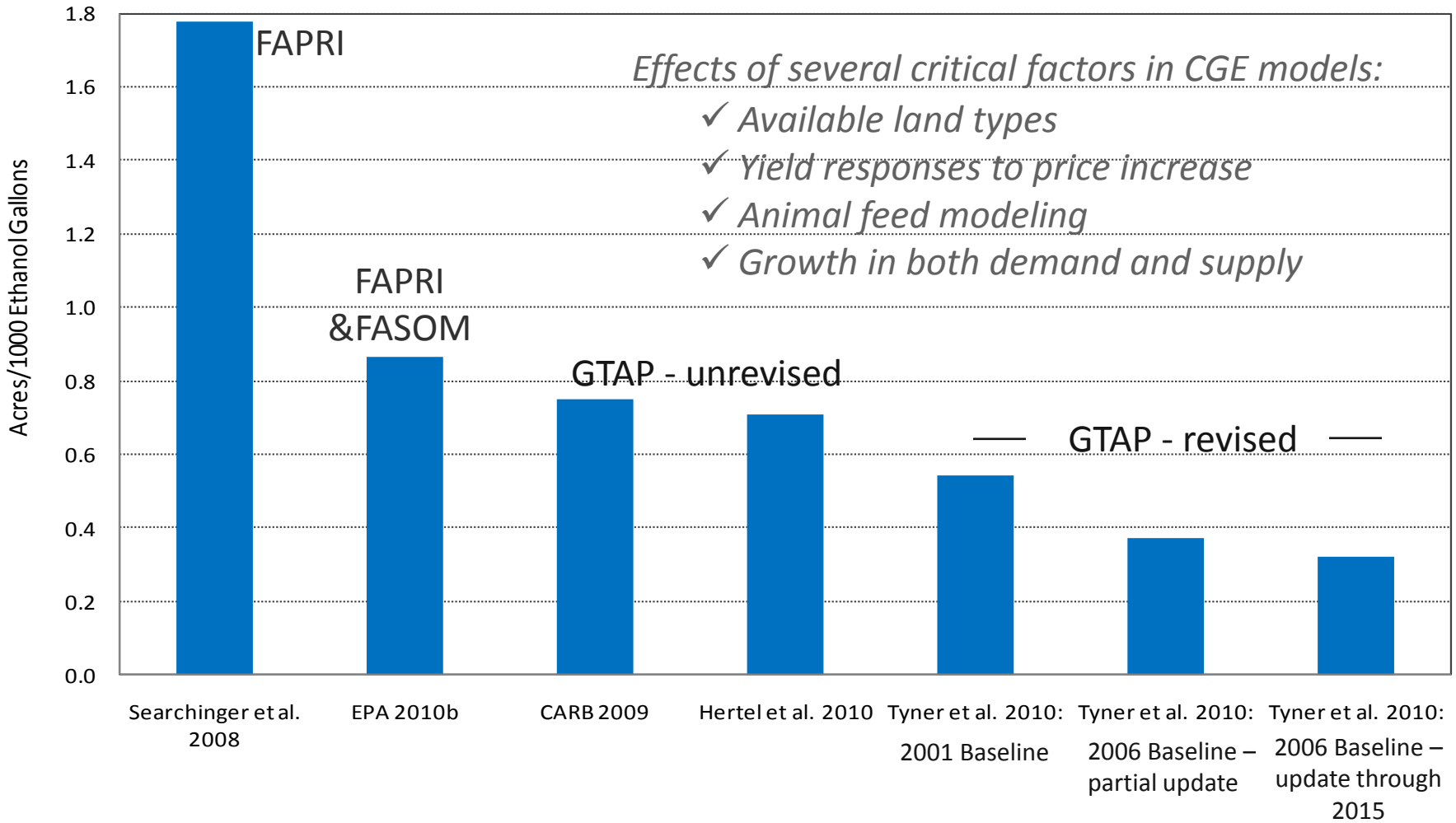
U.S. Efforts on Modeling LUCs of Biofuel Production

- Searchinger et al. with FAPRI for corn ethanol
- CARB/UCB/Purdue with GTAP for corn ethanol
- EPA/Texas A&M/Iowa State U. with FASOM and FAPRI for corn ethanol, biodiesel, sugarcane ethanol, and cellulosic ethanol
- DOE/ANL/Purdue with GTAP for corn ethanol and cellulosic ethanol
- Others have been applying models to examine LUCs

Direct and Indirect Land Use Change Modeling: ANL and Purdue Collaboration on GTAP Upgrade

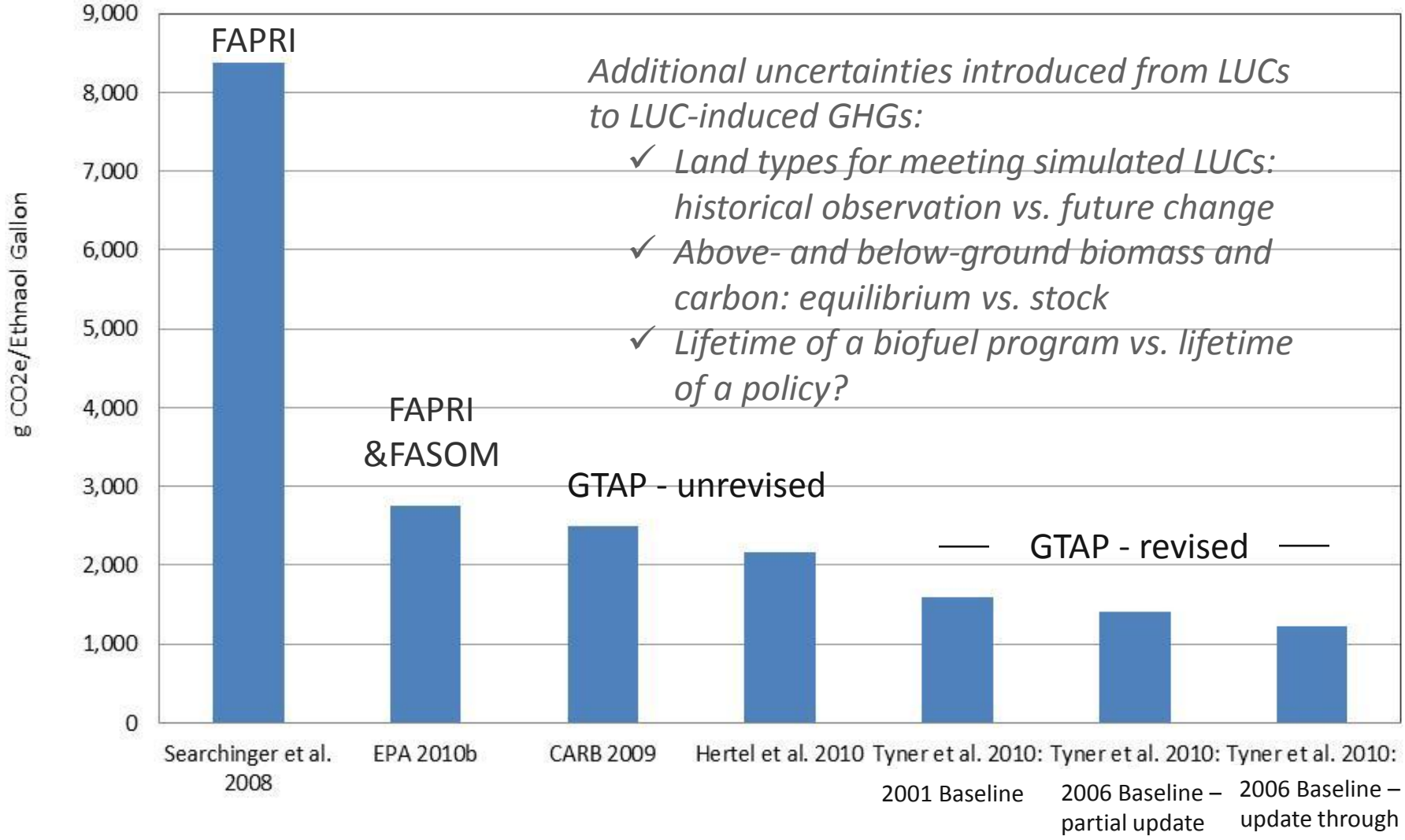
- Land availability in key countries
- Increases in yields in response to elevated commodity price
- Future grain supply and demand trends without ethanol production
- Substitution of conventional animal feed with by-products of ethanol manufacturing (DGS)
- Updated GHG emissions from direct and indirect land use change impacts

Land Use Change Simulated for US Corn Ethanol Production from Completed Studies



FAPRI – Food and Agricultural Policy Research Institute (Iowa State)
FASOM – Forest and Agricultural Sector Optimization Model (Texas A&M)

Greenhouse Gas Emissions of Land Use Changes of Corn Ethanol from Completed Studies



Additional uncertainties introduced from LUCs to LUC-induced GHGs:

- ✓ *Land types for meeting simulated LUCs: historical observation vs. future change*
- ✓ *Above- and below-ground biomass and carbon: equilibrium vs. stock*
- ✓ *Lifetime of a biofuel program vs. lifetime of a policy?*

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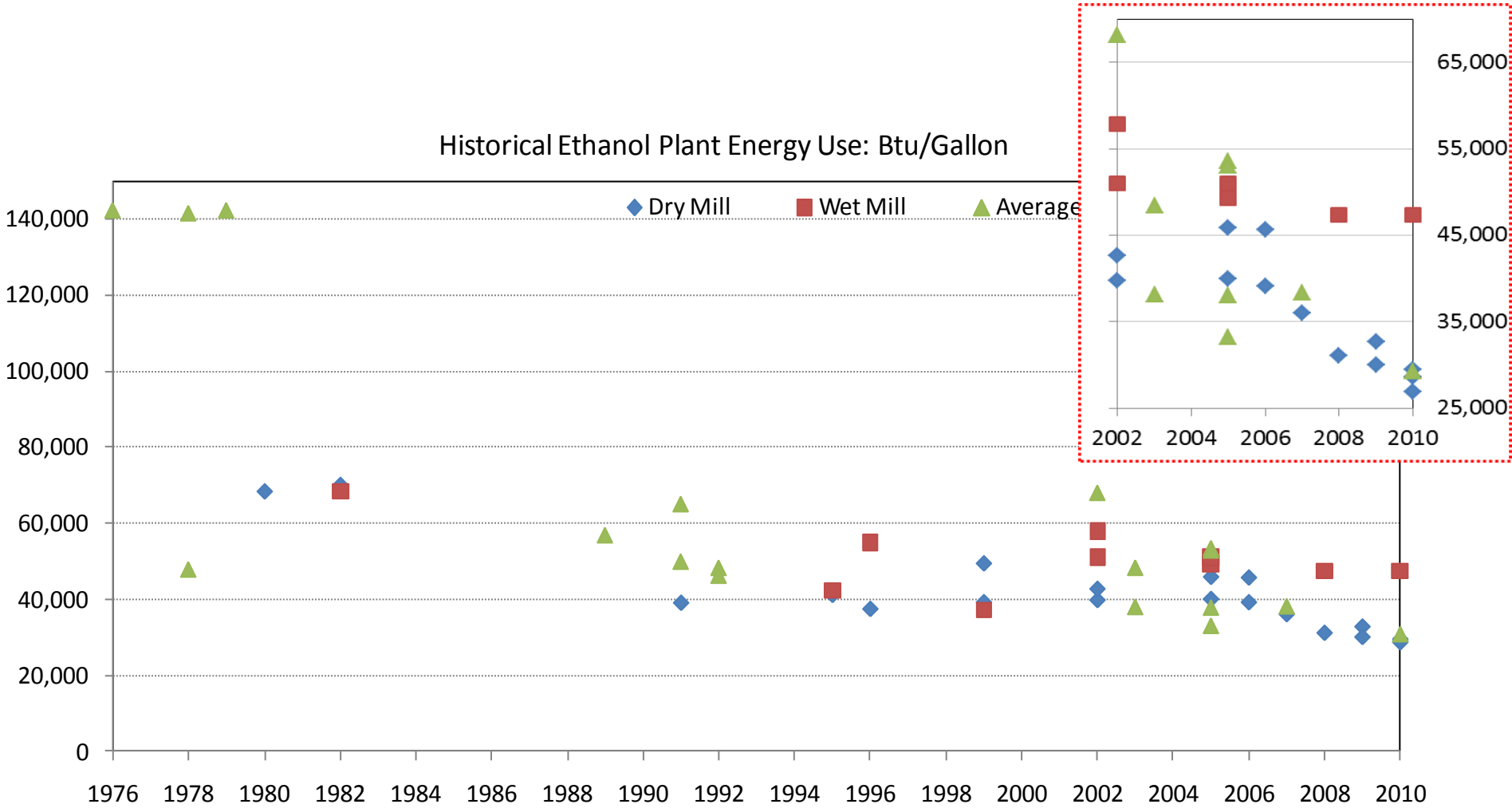
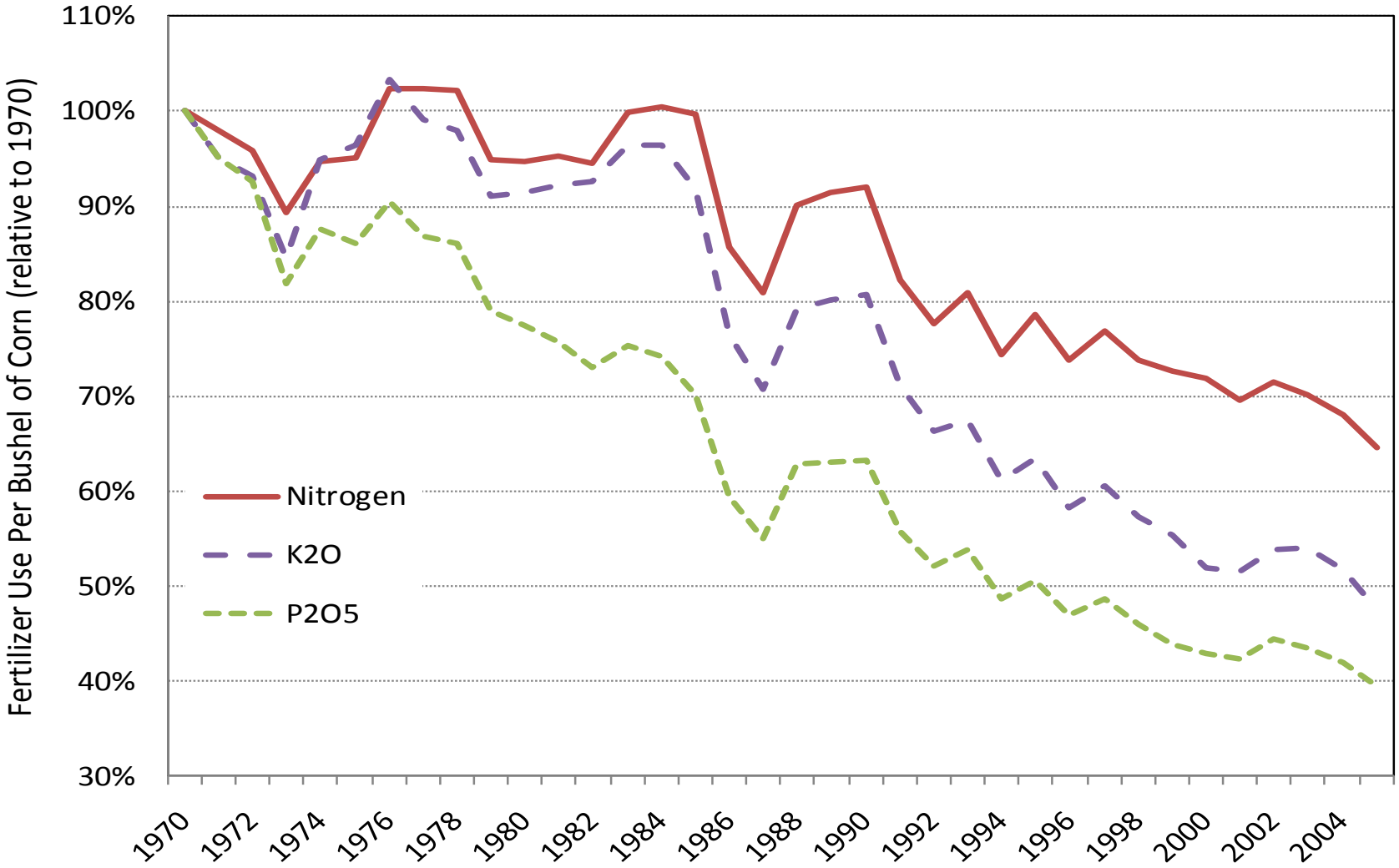
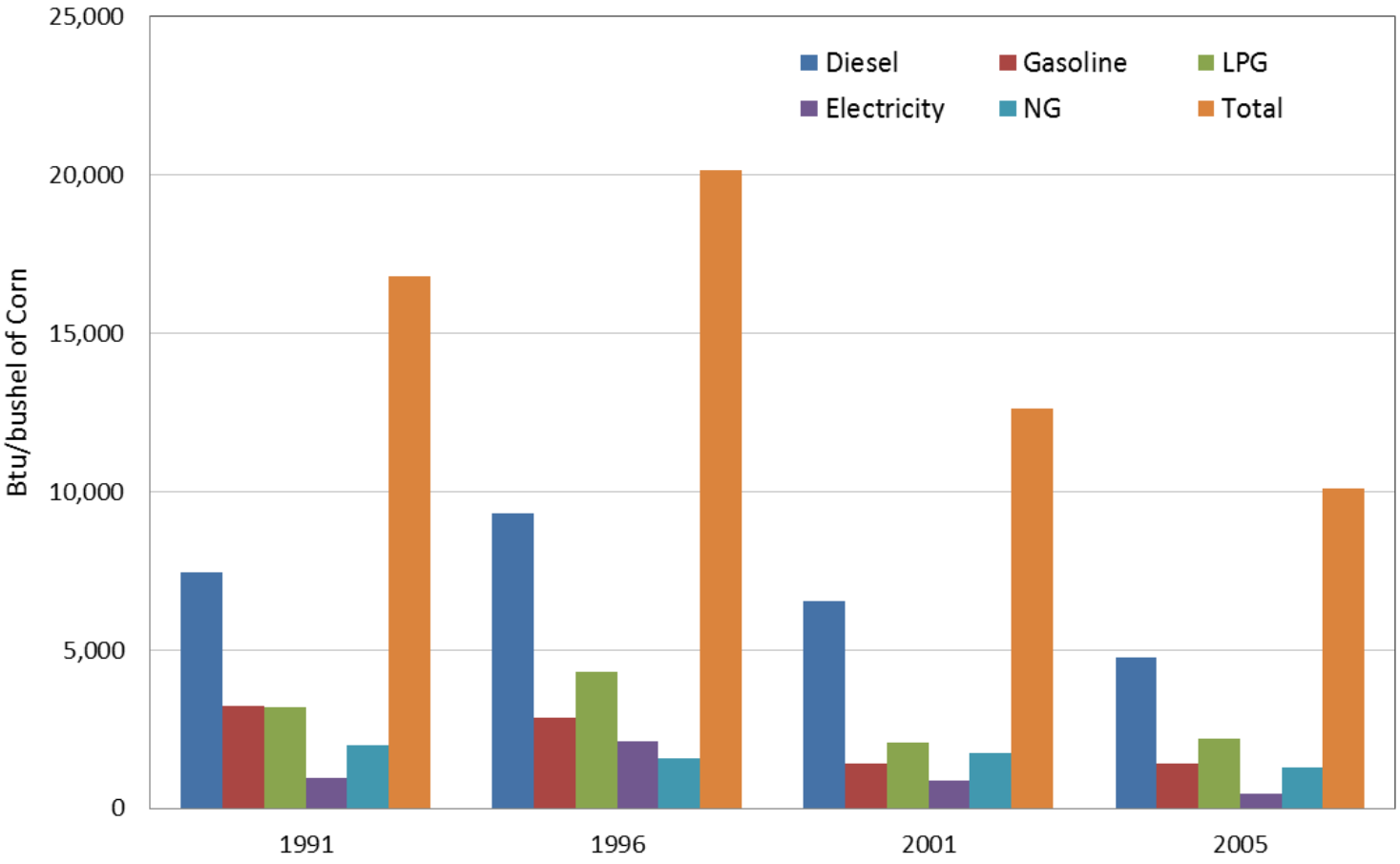
Trend of 35 Studies in the Past 35 Years: Energy Use in U.S. Corn Ethanol Plants Has Decreased Significantly



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



Energy Use for Corn Farming Has Been Reduced



The unusual high farming energy use in 1996 may be caused by the wet weather in that year in the Midwest.

Intensity of Fertilizer Use in U.S. Corn Farming and Energy Use and GHG Emissions of Fertilizer Production and Use

	Nitrogen	Phosphate	Potash	Lime
Fertilizer Use Intensity: lb of nutrient per bushel of corn	0.96	0.34	0.40	2.44
Energy Use for Fertilizer Production: Btu/lb of nutrient	20,741	5,939	3,719	3,398
GHG Emissions of Fertilizer Production: g CO_{2e}/lb of nutrient	1,359	460	302	274
GHG Emissions from Fertilizer in Field: g CO_{2e}/lb of nutrient	2,965[a]	0	0	200[b]
Total GHG Emissions: g CO2e/lb of fertilizer	4,324	460	302	474
Total GHG Emissions: g CO2e/bushel of corn	4,151	156	121	1,157

[a] This is CO_{2e} emissions of N_2O from nitrification and denitrification of nitrogen fertilizer in cornfields.
[b] This is CO_2 emissions of converting calcium carbonate (limestone) to calcium oxide (burnt lime) in cornfields.

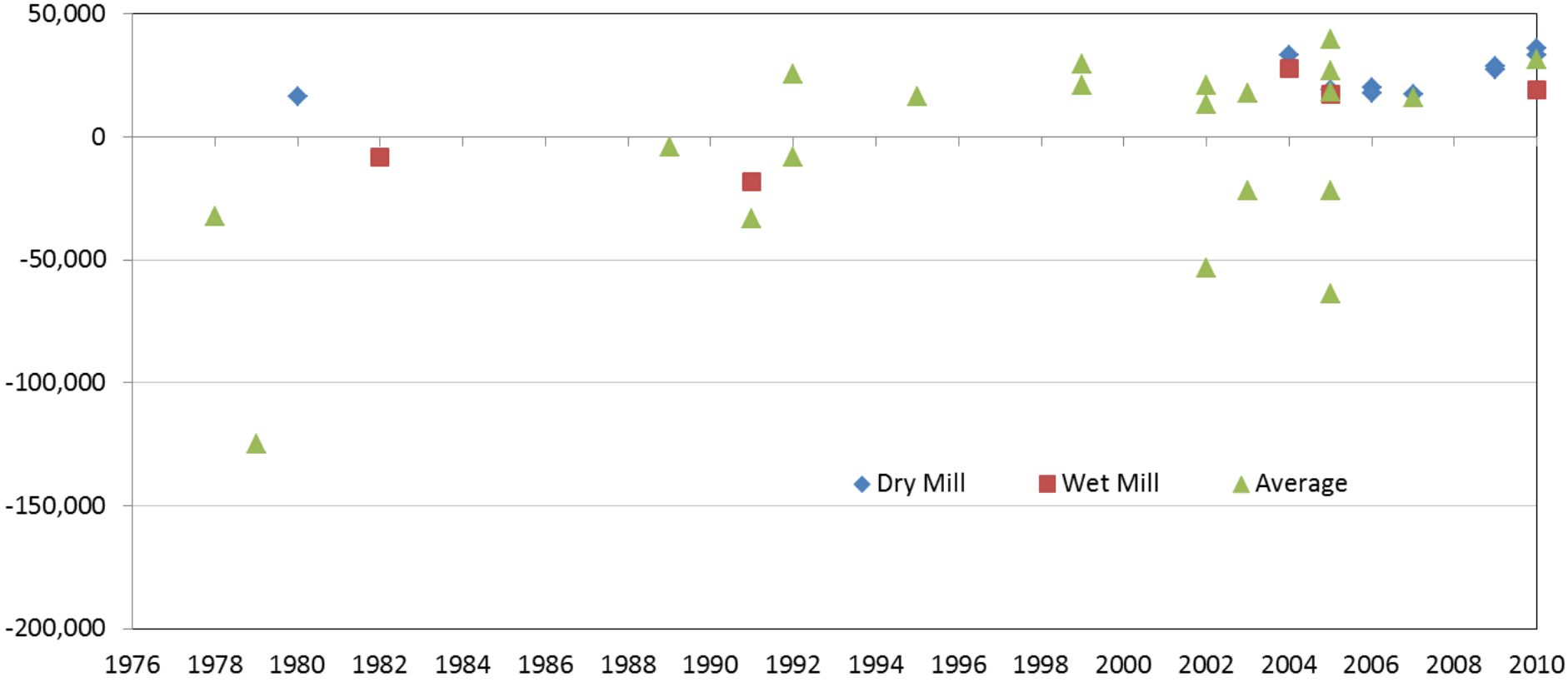
GHG Emissions Benefits of Animal Feed By-Products

- Distillers' Grains Solids (DGS) can offset animal feeds of corn, soybeans, and urea
- Conventional feed displacement yields GHG "credits" for ethanol that are simulated in GREET
- Reduction in LUCs also results from conventional feed displacement
  - Displacement of corn
  - Displacement of soy meals

Displacement Ratios between DGS and Conventional Animal Feeds

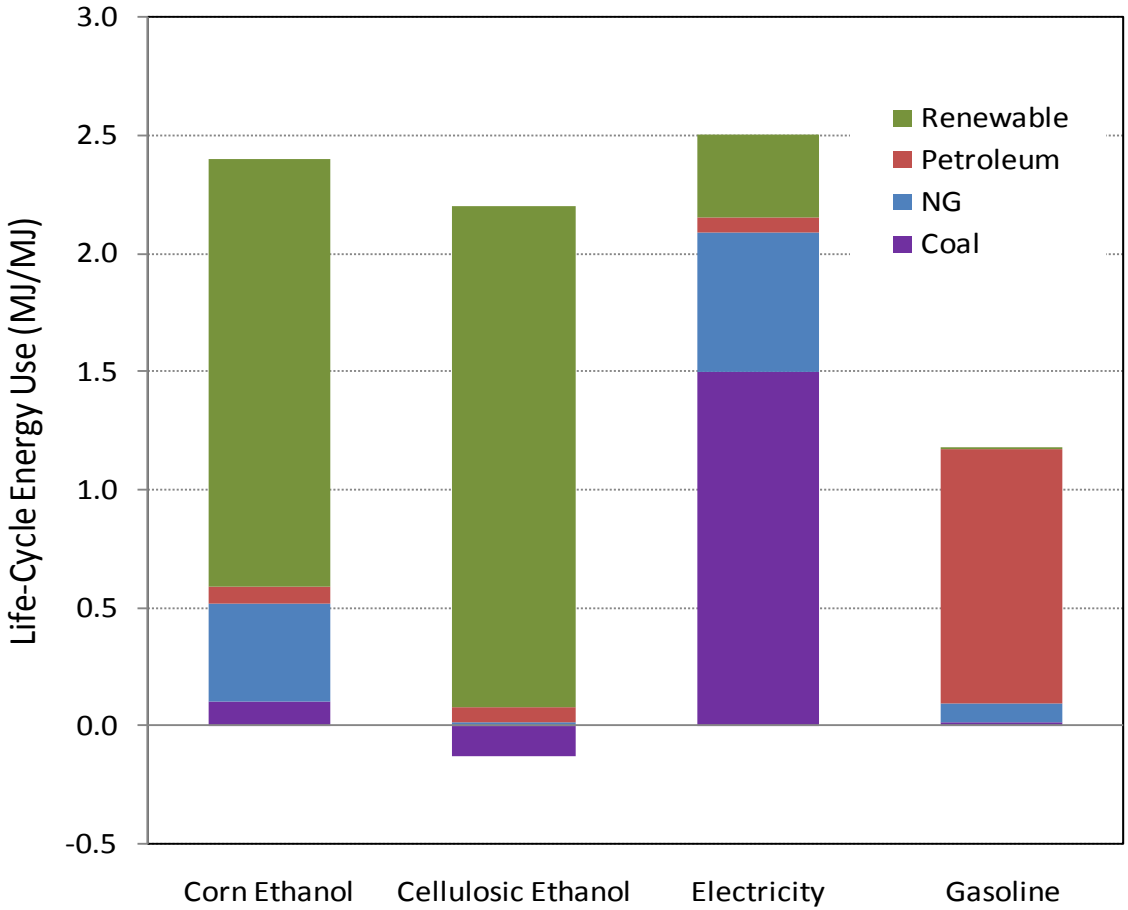
	DDGS and WDGS US Market Share	DDGS Dispalcement Ratio (kg/kg DDGS)				WDGS Displacement Ratio (kg/kg WDGS)			
Feedlot Level		Market Share (%)	Corn	Soybean meal	Urea	Market Share (%)	Corn	Soybean meal	Urea
Beef Cattle	40.6%	35.7%	1.203	0.000	0.068	50.0%	1.276	0.000	0.037
Dairy Cattle	40.6%	35.7%	0.445	0.545	0.000	50.0%	0.445	0.545	0.000
Swine	12.8%	19.5%	0.577	0.419	0.000				
Poultry	6.0%	9.2%	0.552	0.483	0.000				
Average			0.751	0.320	0.024		0.861	0.273	0.019
		DDGS and WDGS Displacement Ratio (kg/kg DDGS&WDGS)							
			Corn	Soybean meal	Urea				
U.S. Consumption Level[a]			0.788	0.304	0.022				
U.S. and Export Market Combined[b]			0.781	0.307	0.023				

Most Recent Studies Show Positive Net Energy Balance for Corn Ethanol

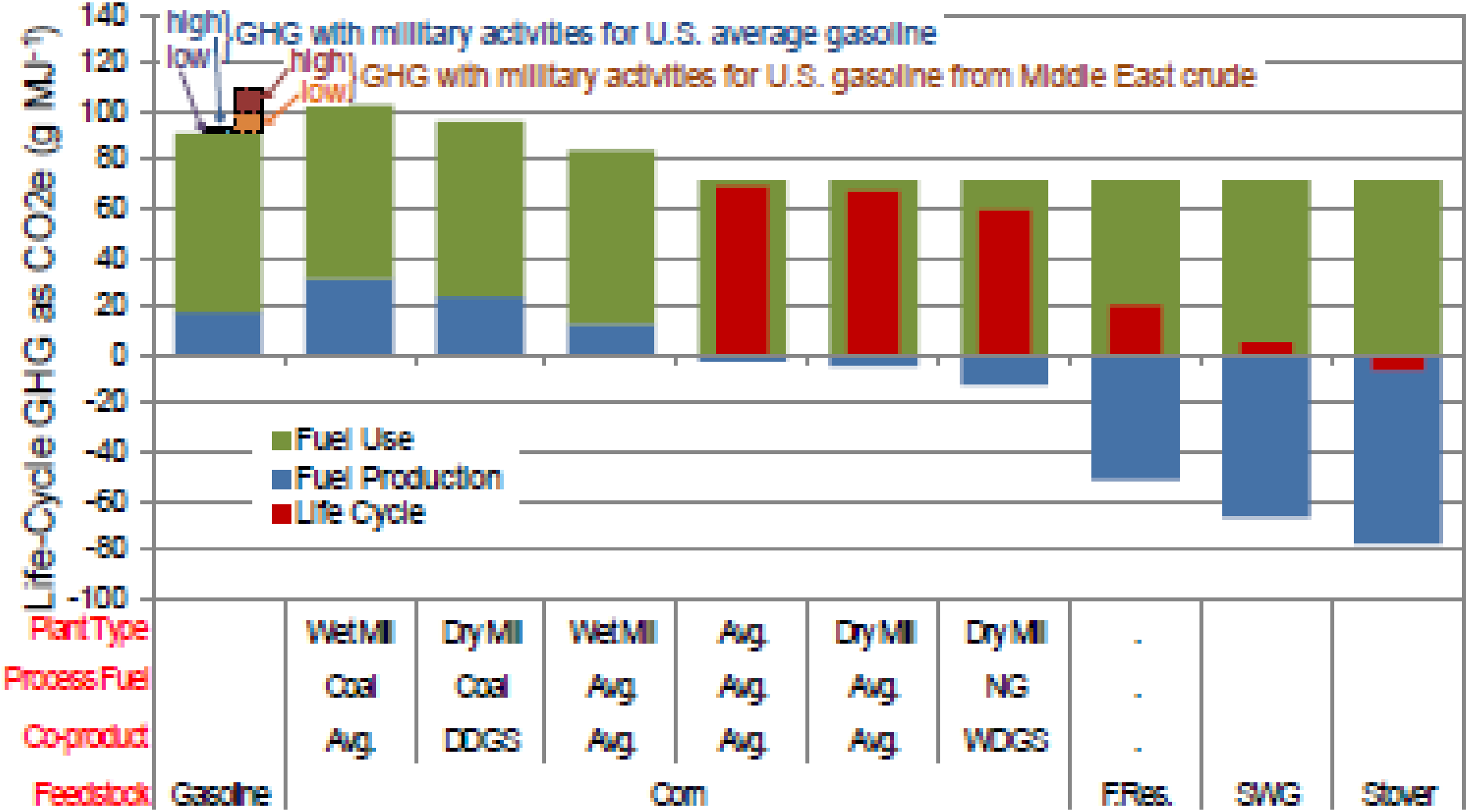


Energy balance here is defined as Btu content a gallon of ethanol minus fossil energy used to produce a gallon of ethanol

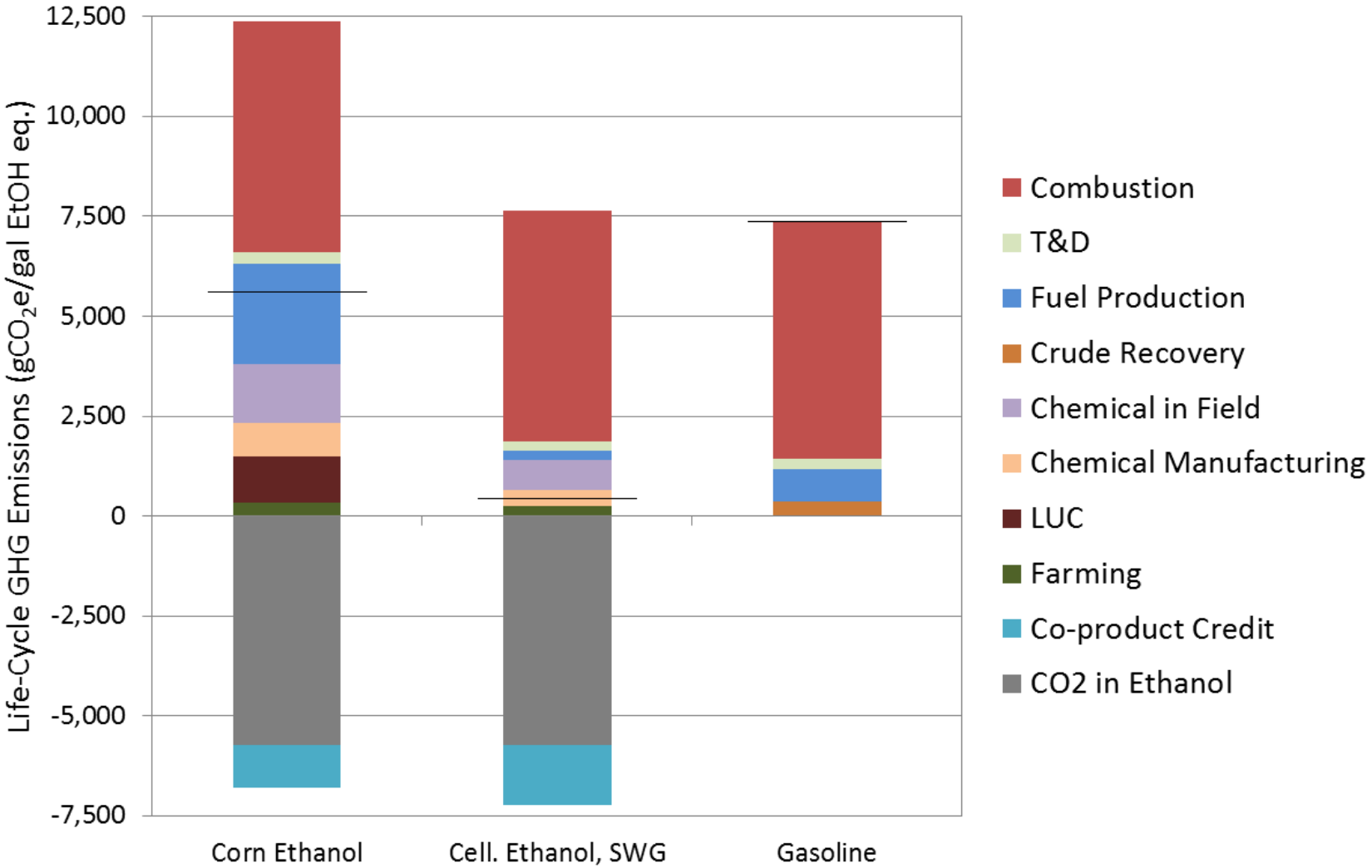
Energy Use by Type Varies Considerably Among Energy Products



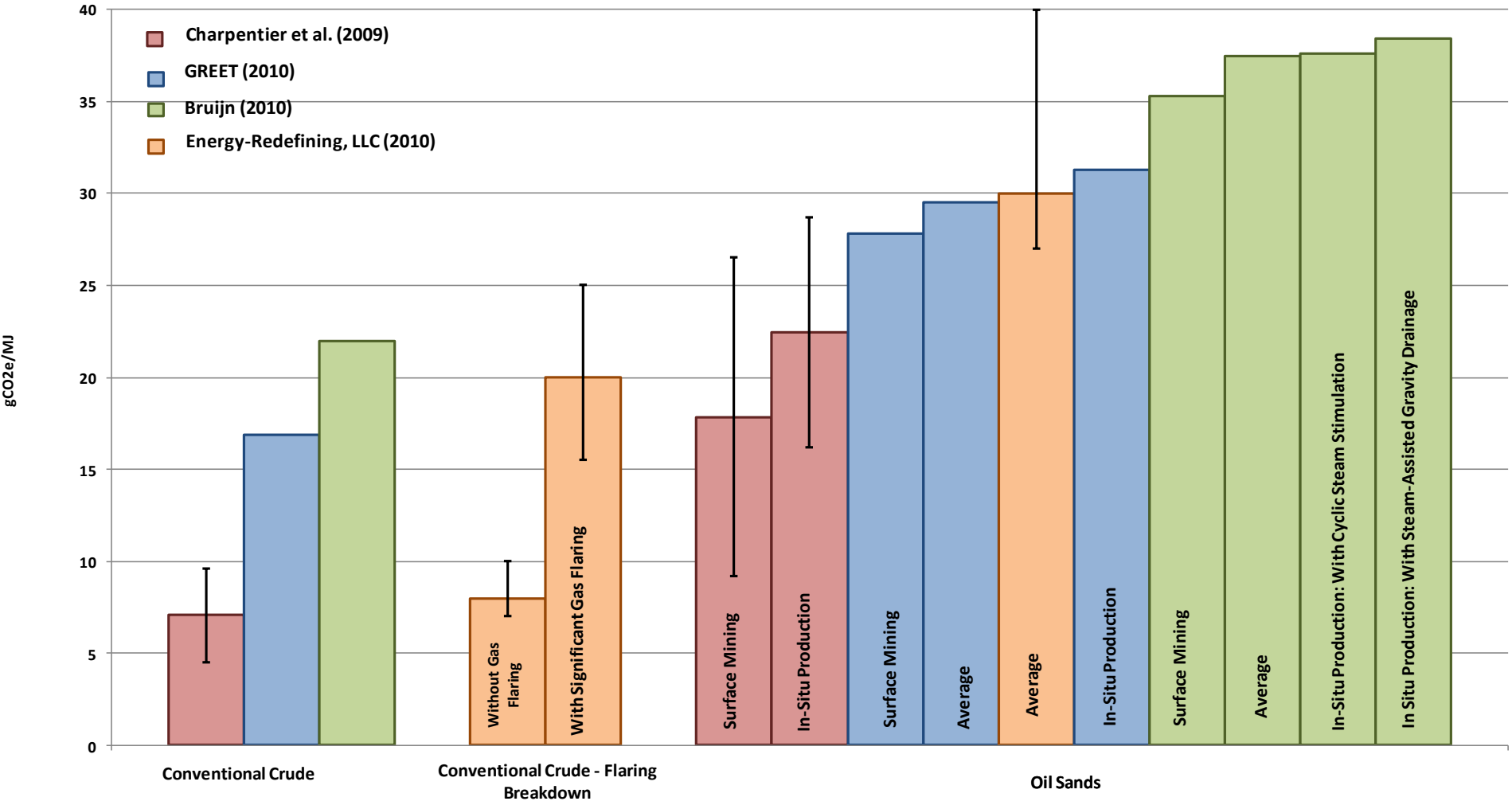
GHG Emissions of Corn Ethanol Vary Considerably Among Process Fuels in Plants; Cellulosic Ethanol Consistently Achieve Large Reductions



GHG Emission Sources of Ethanol and Gasoline



Well-to-Pump GHG Emissions of Petroleum Gasoline



Gasoline combustion: about 75 g/MJ GHG emissions

Conclusions

- Corn ethanol life cycle GHG emissions are approximately 24% below those of gasoline
- Cellulosic ethanol life cycle GHG emissions could achieve close to 100% below those of gasoline
- It is critical to consider evolving technology and feedstock types in biofuel LCAs
- A philosophic issue in ethanol LCAs in the past several years:
  - If we are not certain about the magnitude of certain risks, should we assign somewhat high negative values to manage them?
  - However, doing so may indeed generate other risks
    - ✓ Lost opportunities of achieving GHG reductions immediately (though moderate and incremental)
    - ✓ High-carbon fuels may seize the opportunity
- To use analysis results for policy making, should we pursue underlined causes to address uncertainties, or should we aggregate old and new results all together to address "perceived" uncertainties/risks?