

Critical Issues of Biofuel Life-Cycle Analysis

Michael Wang
Center for Transportation Research
Argonne National Laboratory

CRC Workshop on Life Cycle
Analysis of Biofuels
Argonne National Laboratory
Oct. 18-19, 2011



GREET Includes Many Biofuel Production Pathways

(GREET.1.2011 is available at <http://greet.es.anl.gov/>)

- 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

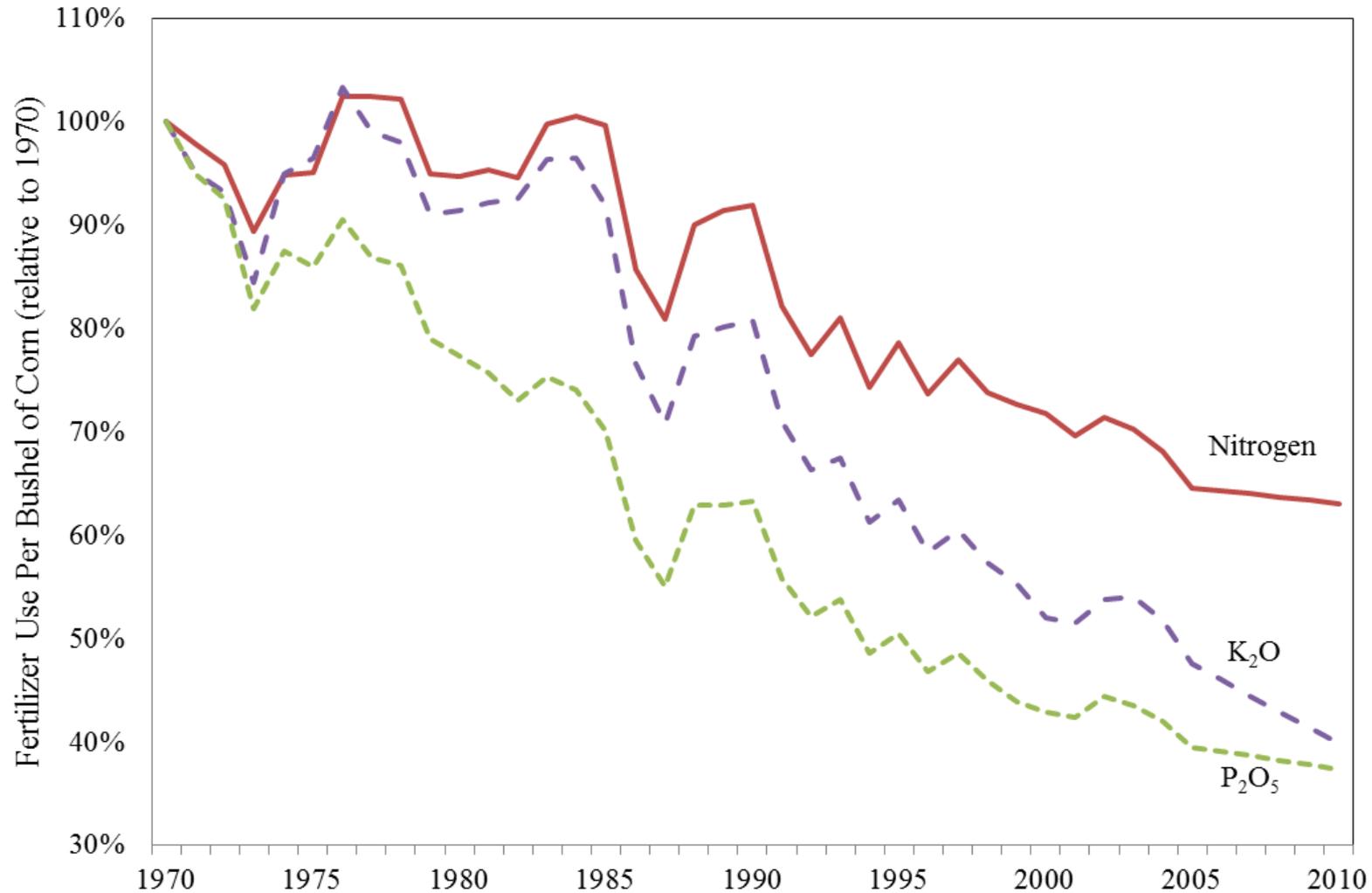
- Cellulosic biomass via pyrolysis to
 - Gasoline
 - Diesel

Key Issues Affecting Biofuel WTW Results

- ❑ Technology advancements
 - Agricultural farming: crop yield increase vs. chemical input decrease
 - Energy use in biofuel plants: primary target of CARB LCFS approvals
- ❑ Direct and indirect land use changes and resulted GHG emissions (two sessions in this workshop)
- ❑ Methods of estimating emission credits of co-products of ethanol (Don O'Connor's presentation)
 - Displacement method (system boundary expansion)
 - Allocation methods
- ❑ Life-cycle analysis methodologies (John DeCicco's presentation)
 - Consequential LCA (EPA RFS2, to a large extent)
 - Attributional LCA (CA LCFS and EU RED and FQD, with supplement of CLCA on LUCs)



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



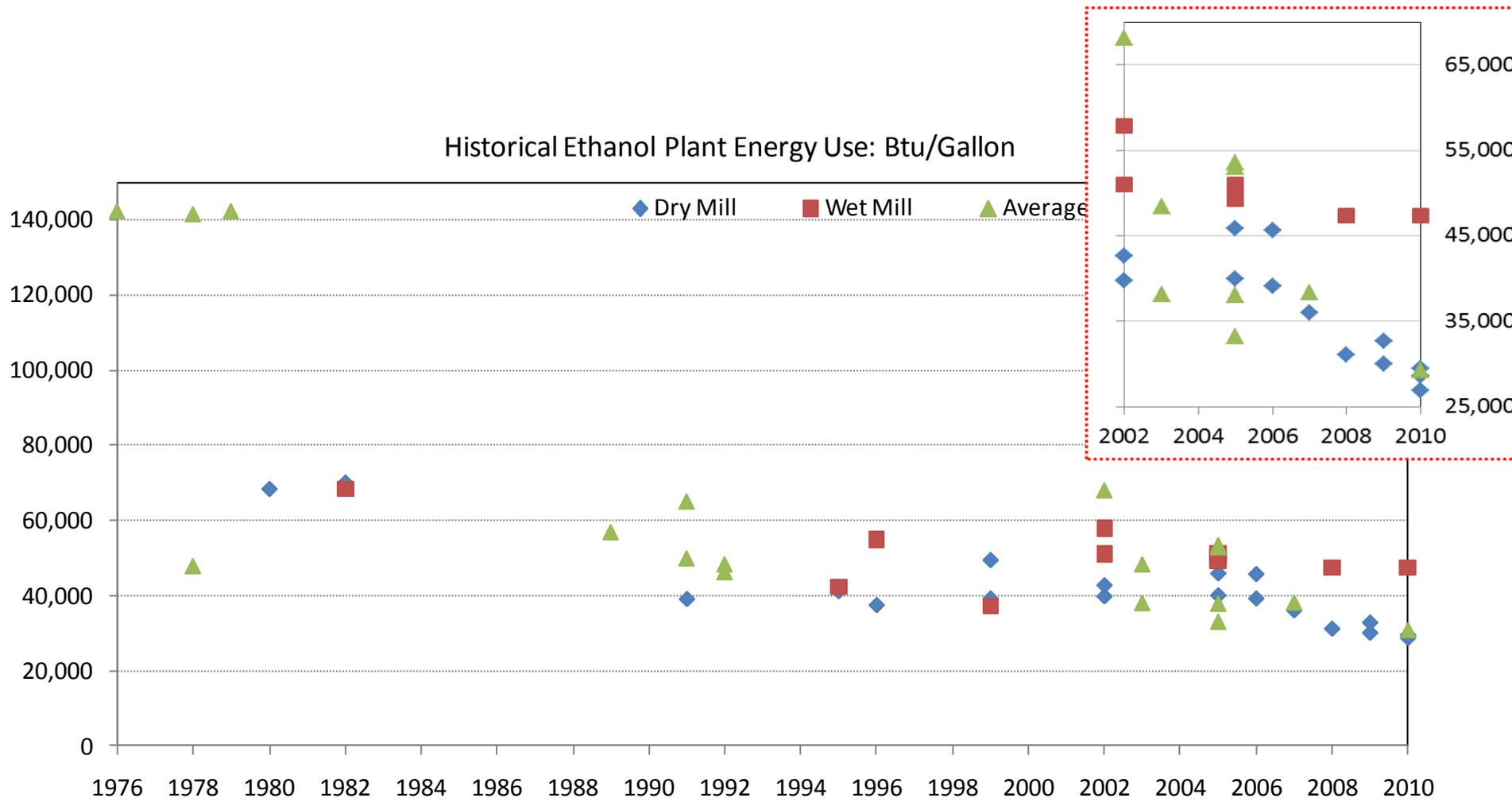
Intensity of Fertilizer Use in U.S. Corn Farming and Energy Use and GHG Emissions of Fertilizer Production and Use

	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 CO_{2e}/lb of fertilizer nutrient	4,324	460	302	474
Total GHG Emissions: g CO_{2e}/bushel of corn	4,151	156	121	1,157

^a This is CO_{2e} emissions of N₂O from nitrification and denitrification of nitrogen fertilizer in cornfields.

^b This is CO₂ emissions of converting calcium carbonate (limestone) to calcium oxide (burnt lime) in cornfields.

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



In Wang et al. (2011), Biomass and Bioenergy Journal

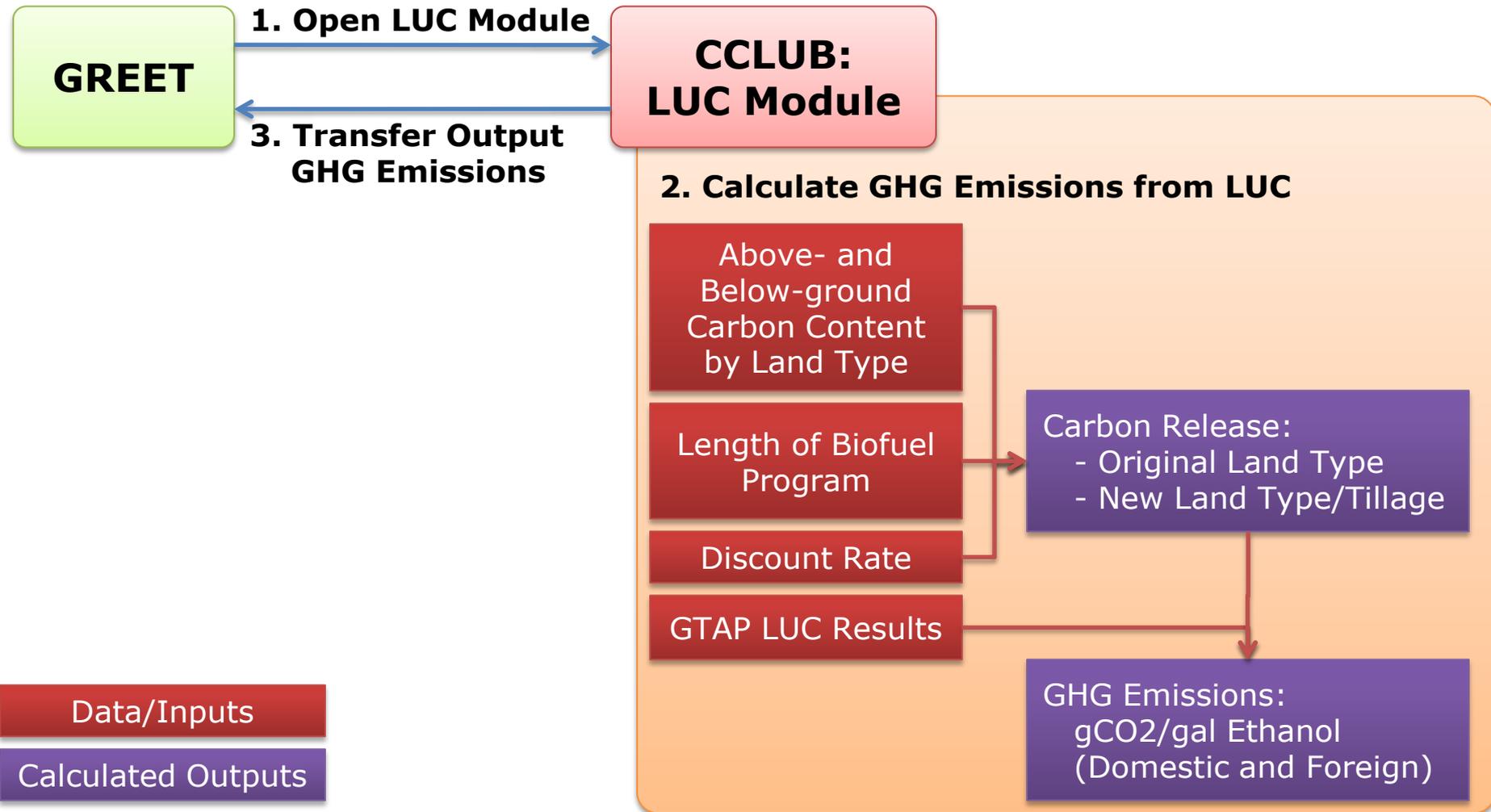


Key Issues Affecting Biofuel WTW Results

- ❑ Technology advancements
- ❑ **Direct and indirect land use changes and resulted GHG emissions**
- ❑ Methods of estimating emission credits of co-products of ethanol
- ❑ Life-cycle analysis methodologies



Interface between GREET and Biofuel LUC Module



CCLUB was developed by Dr. Steffen Mueller of University of IL at Chicago and Argonne National Laboratory



Direct and Indirect Land Use Changes and Their Emissions: ANL's Collaborative Efforts

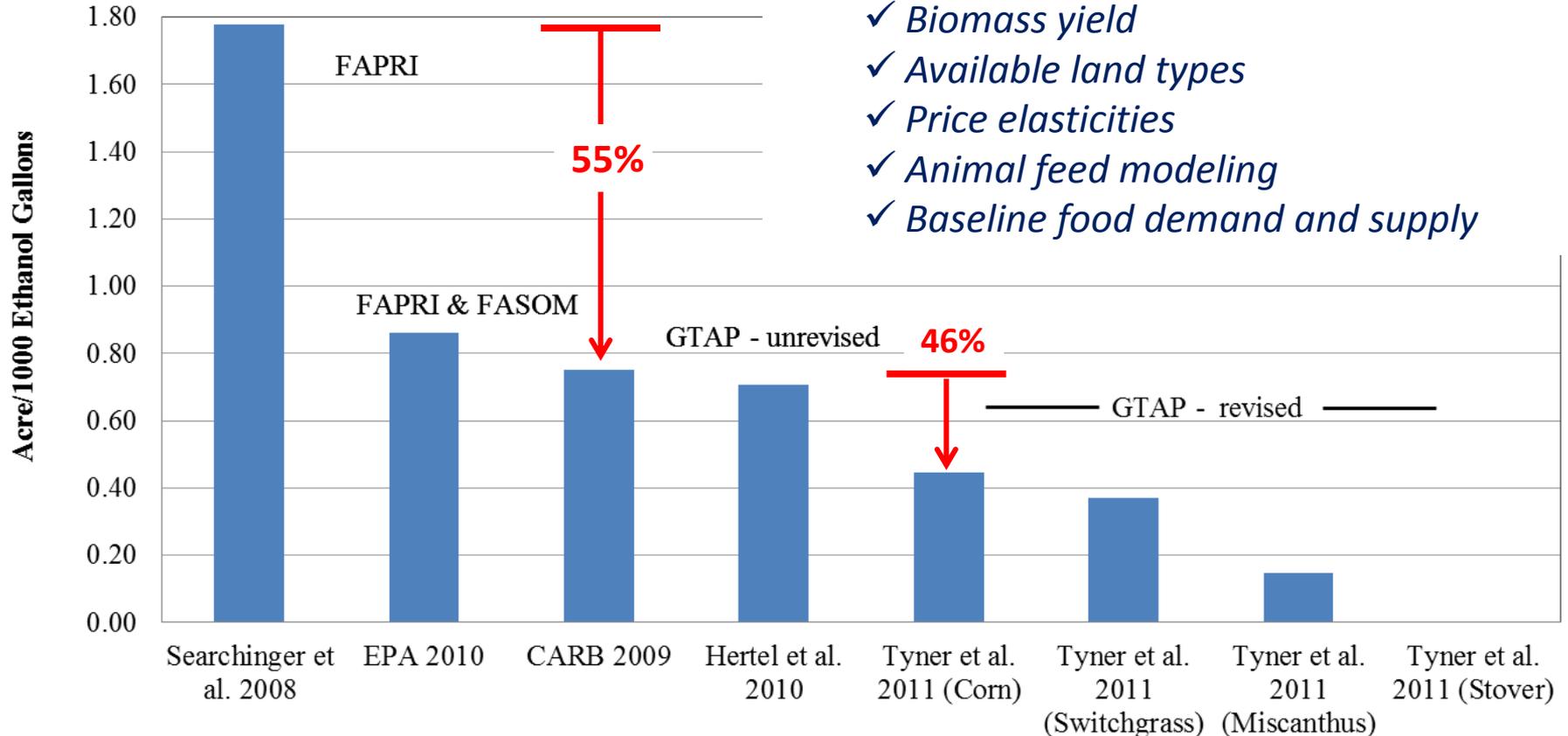
- ❑ GTAP upgrading and expansion by Purdue
 - Land availability in key countries
 - Yields in response to elevated commodity price
 - Future grain supply and demand trends without ethanol production
 - Substitution of conventional animal feed with by-products of ethanol manufacturing (DGS)
 - Inclusion of cellulosic biomass (stover, switchgrass, and miscanthus)
- ❑ GHG emissions of different land types with University of Illinois at Chicago (UIC) and at Urbana-Champaign (UIUC)



Land Use Change Simulated for US Biofuel Production from Some Completed Studies

Effects of several critical factors in CGE models:

- ✓ Biomass yield
- ✓ Available land types
- ✓ Price elasticities
- ✓ Animal feed modeling
- ✓ Baseline food demand and supply



CGE – Computable General Equilibrium

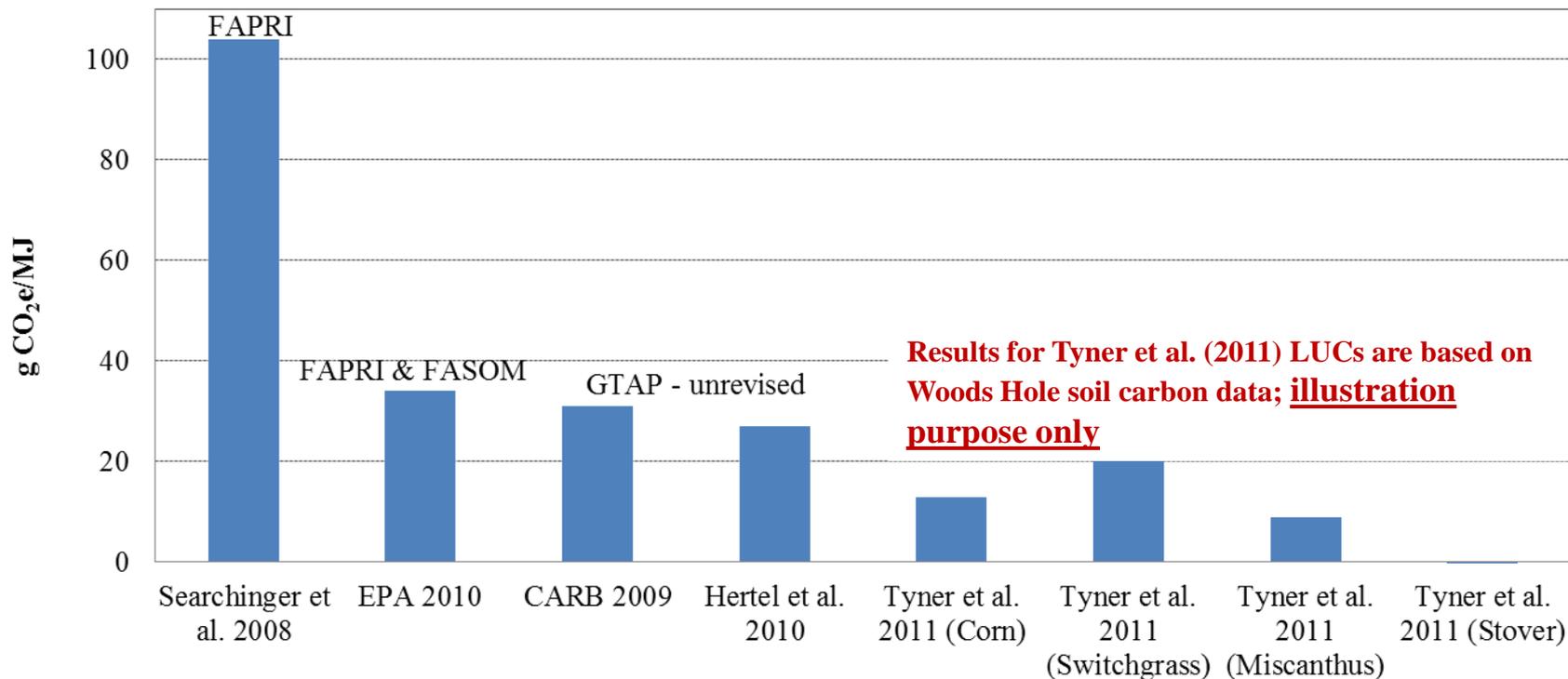
GTAP – Global Trade Analysis Project (Purdue University)

FAPRI – Food and Agricultural Policy Research Institute (Iowa State)

FASOM – Forest and Agricultural Sector Optimization Model (Texas A&M)



GHG Emissions of LUCs Estimated for US Biofuel Production from Some Completed Studies



GTAP 2011 LUC Results: Pasture vs. Forest Conversion

	Corn	Miscanthus	Switchgrass
Pasture	89%	50%	20%
Forest	11%	50%	80%

GTAP 2011 LUC Results: U.S. vs. Rest of the World

	Corn: pasture	Miscanthus	Switchgrass: forest
U.S.	35%	33%	93%
ROW	65%	67%	7%

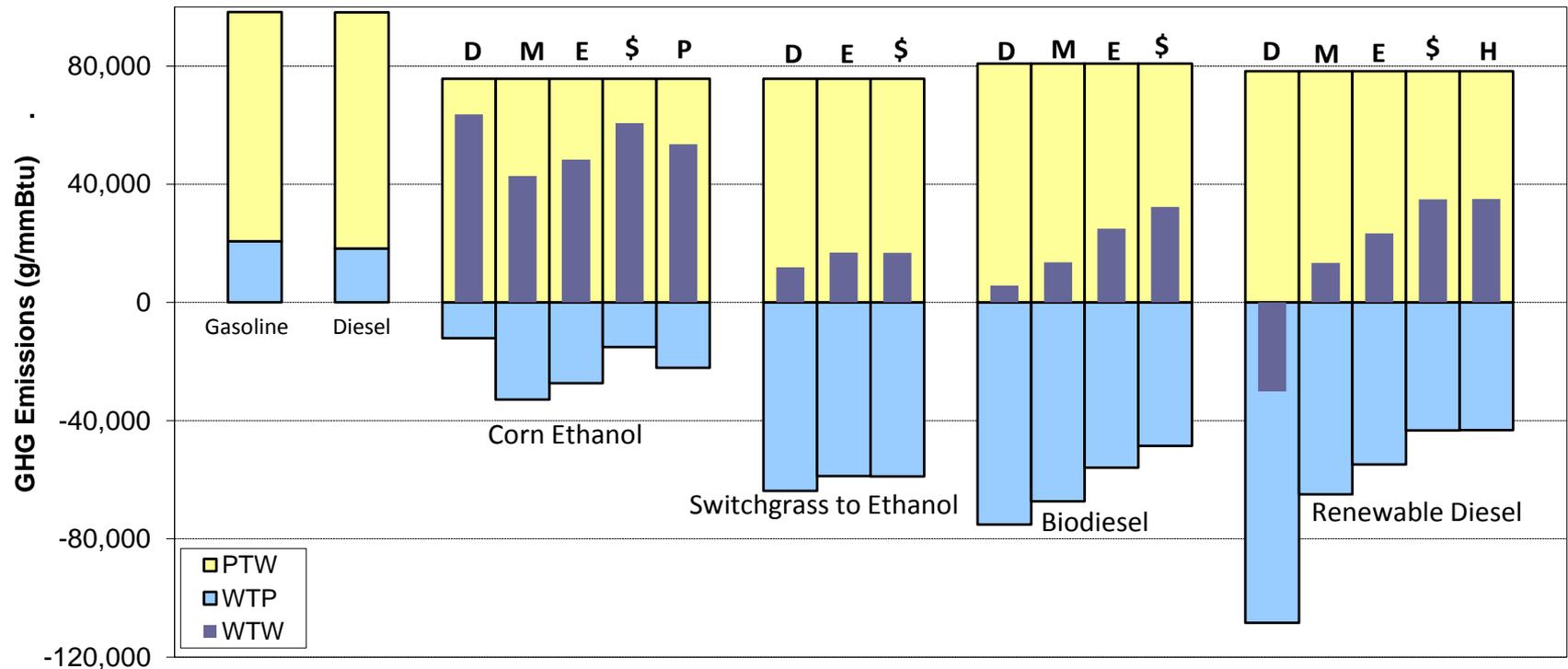


Key Issues Affecting Biofuel WTW Results

- ❑ Technology advancements
- ❑ Direct and indirect land use changes and resulted GHG emissions
- ❑ **Methods of estimating emission credits of co-products of ethanol**
- ❑ Life-cycle analysis methodologies



Choice of Co-Product Methods Can Have Significant LCA Effects for Biofuels



D: Displacement M: Mass based E: Energy Based
 \$: Market Value P: Process Purpose H: Hybrid Allocation

Mathematics for the Displacement Method

$$\text{GHG}_{\text{fuel}} = (\text{GHG}_{\text{total}} - \text{GHG}_{\text{convproduct}}) \times \frac{\text{Output}_{\text{nonfuel}}}{\text{Output}_{\text{fuel}}}$$

Concluding Paragraph in Wang, Huo and Arora (Energy Policy 39 (2011) 5726-5736)

*It is important to take into account co-products in life-cycle evaluation of the energy use and environmental effects of biofuels. Most LCA studies do so. However, this study shows that the choice of co-product method can significantly influence the WTW results of biofuels. Of the five methods examined in this study, ISO 14040 advocates use of the displacement method. As we discussed in principle and simulated in practice, the displacement method can generate distorted LCA results if the co-products are actually main products (for the cases of biodiesel and renewable diesel from soybeans). It is far from settled whether use of a given method should be uniformly and automatically recommended for LCA studies. We suggest that a generally agreed-upon method should be applied for a given fuel production pathway. Consistency in choice of co-product method may not serve the purpose of providing **reliable** LCA results. On this note, the transparency of LCA method(s) selected is important in given LCA studies, and sensitive cases with multiple co-product methods may be warranted in LCA studies where co-products can significantly impact study outcomes.*



Key Issues Affecting Biofuel WTW Results

- ❑ Technology advancements
- ❑ Direct and indirect land use changes and resulted GHG emissions
- ❑ Methods of estimating emission credits of co-products of ethanol
- ❑ **Life-cycle analysis methodologies**



Two Distinctly Different Uncertainties in LCAs

❑ System uncertainties

- LCA methodology inconsistency: attributional vs. consequential
- System boundary selection: moving target?
- Treatment of co-products

❑ Technical uncertainties related to data availability and quality: variations in input parameters and output results

❑ Purpose and usefulness of LCAs (John DeCicco)

1. Guide fuels R&D and investment
2. Understand environmental impacts of fuel systems
3. Regulate GHG emissions of fuels

Moving into Area 3 has been a gratifying experience for those of us working in the field of LCAs,
BUT increasingly with anxiety

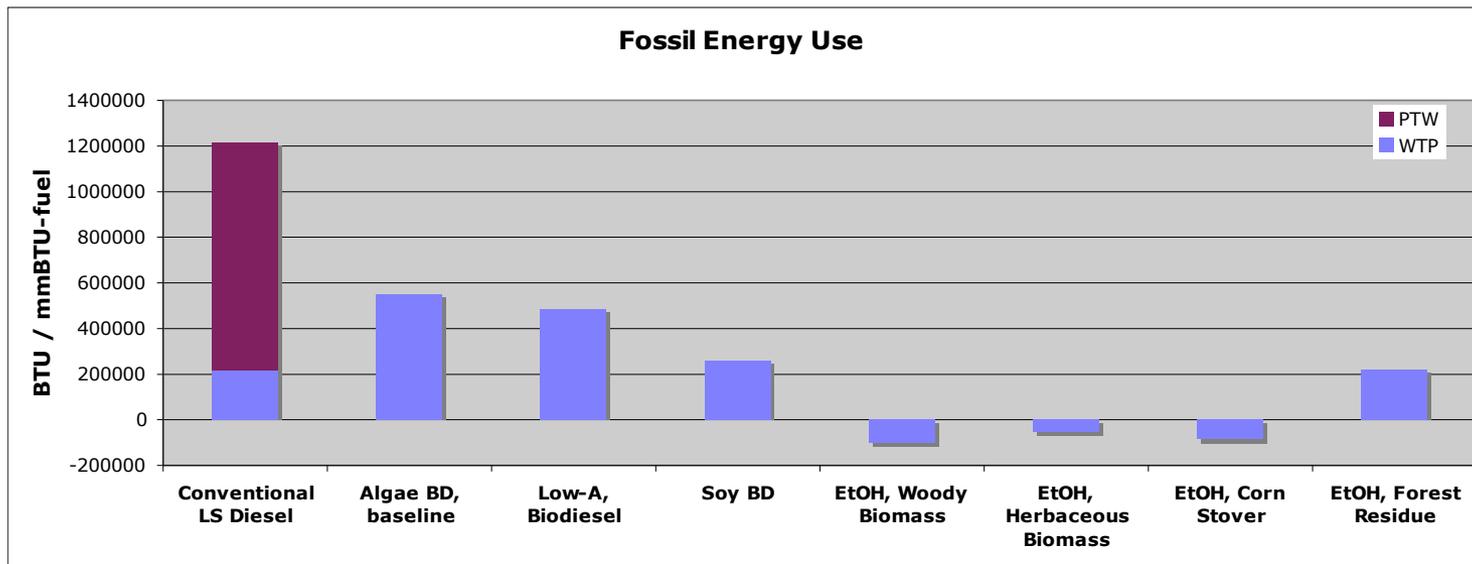
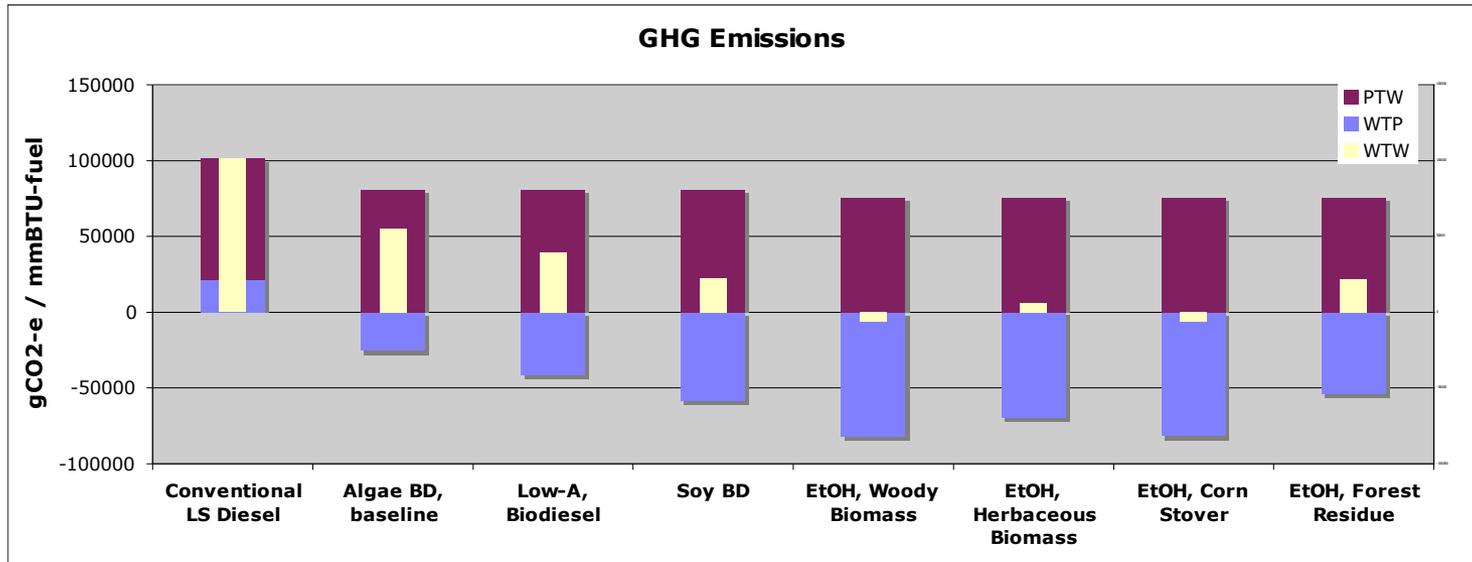


LCA in a Broad Philosophic Debate Context

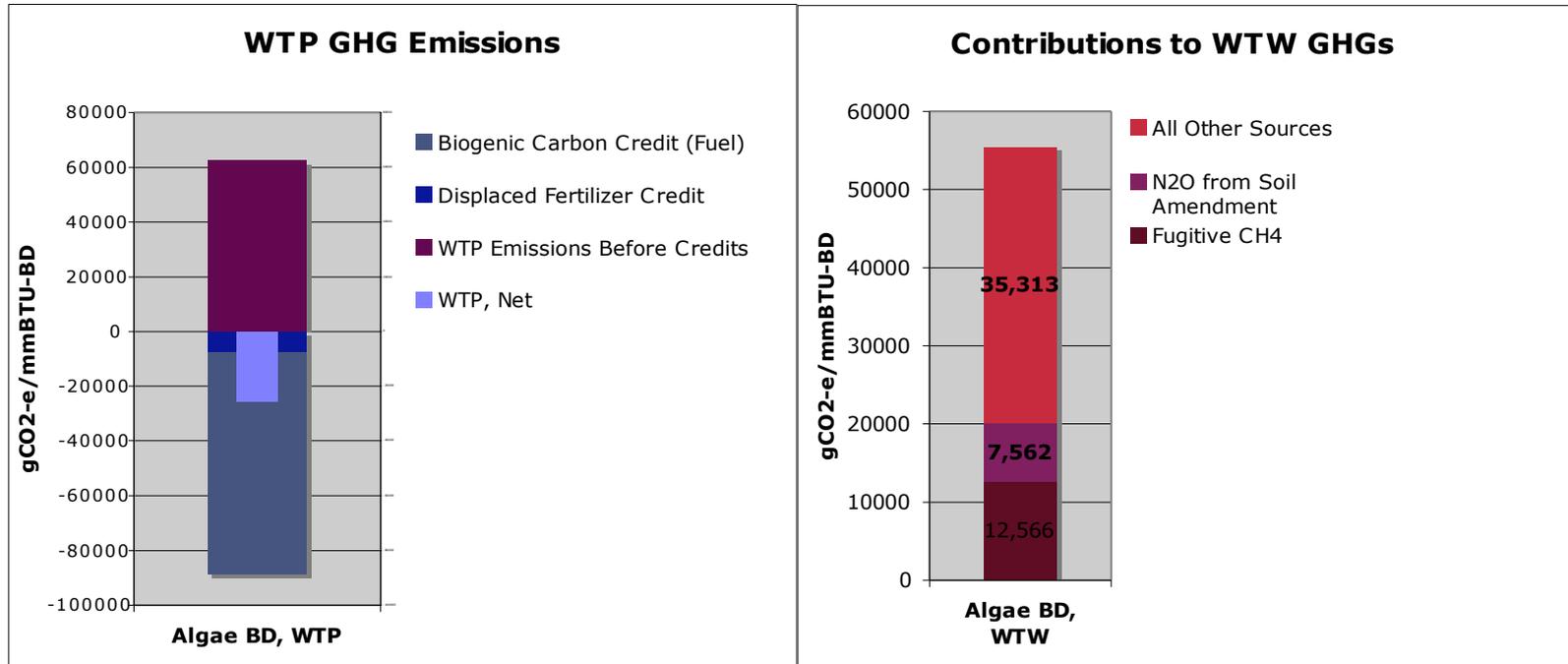
- ❑ LCA has been used by some to address an overarching philosophic issue:
 - Land exclusively for food/fiber?
 - For food/fiber and carbon?
 - Or for food/fiber, carbon, and energy?
- ❑ Another philosophic issue in biofuel policy formulation:
 - If the society is not certain about the magnitude of risks, should it assign somewhat high negative values for the purpose of managing them?
 - However, doing so may indeed generate other risks; lost opportunities of GHG reductions?
- ❑ Trade-offs among different energy/environmental attributes of given technologies (and environmental policies) are a reality
- ❑ Result of mixing philosophic concerns with LCA
 - Collateral damage to LCA credibility?



Energy and GHG Results: Algae vs. Other Fuels



Breakdowns of GHG Emissions



- ❑ Biogenic credit cancels substantial emissions from growth and processing
- ❑ Substantial direct CH₄ from AD + biogas clean-up
 - Technology choice, operations and maintenance are important
 - Beware of shortcuts for CAPEX, OPEX reduction here
- ❑ Also, significant amount of N₂O emissions from AD residues in AD sites and farming fields

What Type of Land Use Changes for Algae Biofuels?

