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Well-to-Wheels Energy and Greenhouse Gas Emission Results and Issues of Fuel Ethanol

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Workshop on The Lifecycle Carbon Footprint of Biofuels

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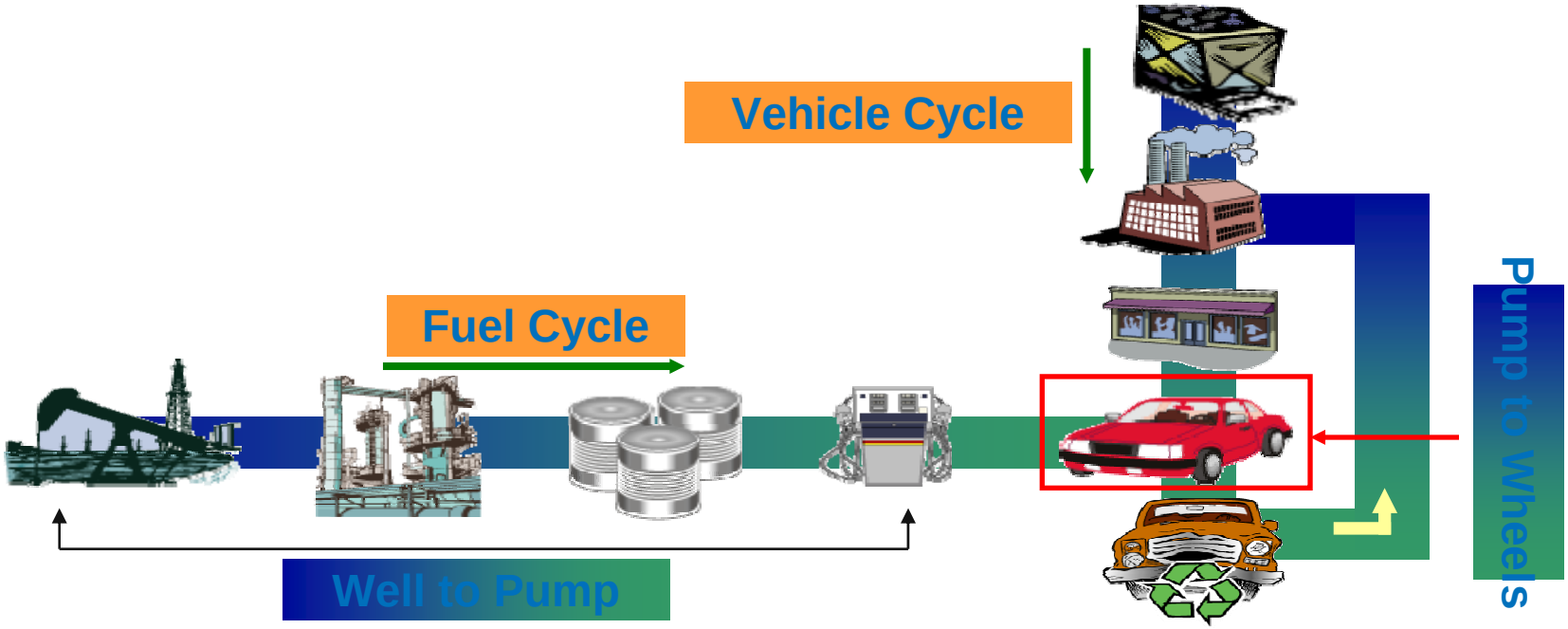
Several Life-Cycle Analysis (LCA) Models Are Available to Examine Vehicle/Fuel Systems

- The lifecycle emission model (LEM) at University of California at Davis
- The GREET model at Argonne National Laboratory
- Canadian GHGenius model (a derivative of the LEM)
- LBST's E3 database in Europe
- The Ecobalance model by PriceWaterhouseCooper in Europe
- Other generic LCA models that can be applied to examine transportation fuels and vehicle technologies

WTW Analysis In the GREET Model Covers Feedstock Production, Fuel Production and Fuel Use



- With DOE support, Argonne has been developing the GREET model since 1995
- It is available at *http://www.transportation.anl.gov/software/GREET/(or simply Google GREET on the Web)*
- There are more than 4,000 registered GREET users worldwide
- It contains more than 100 fuel production pathways and 80 vehicle/fuel systems

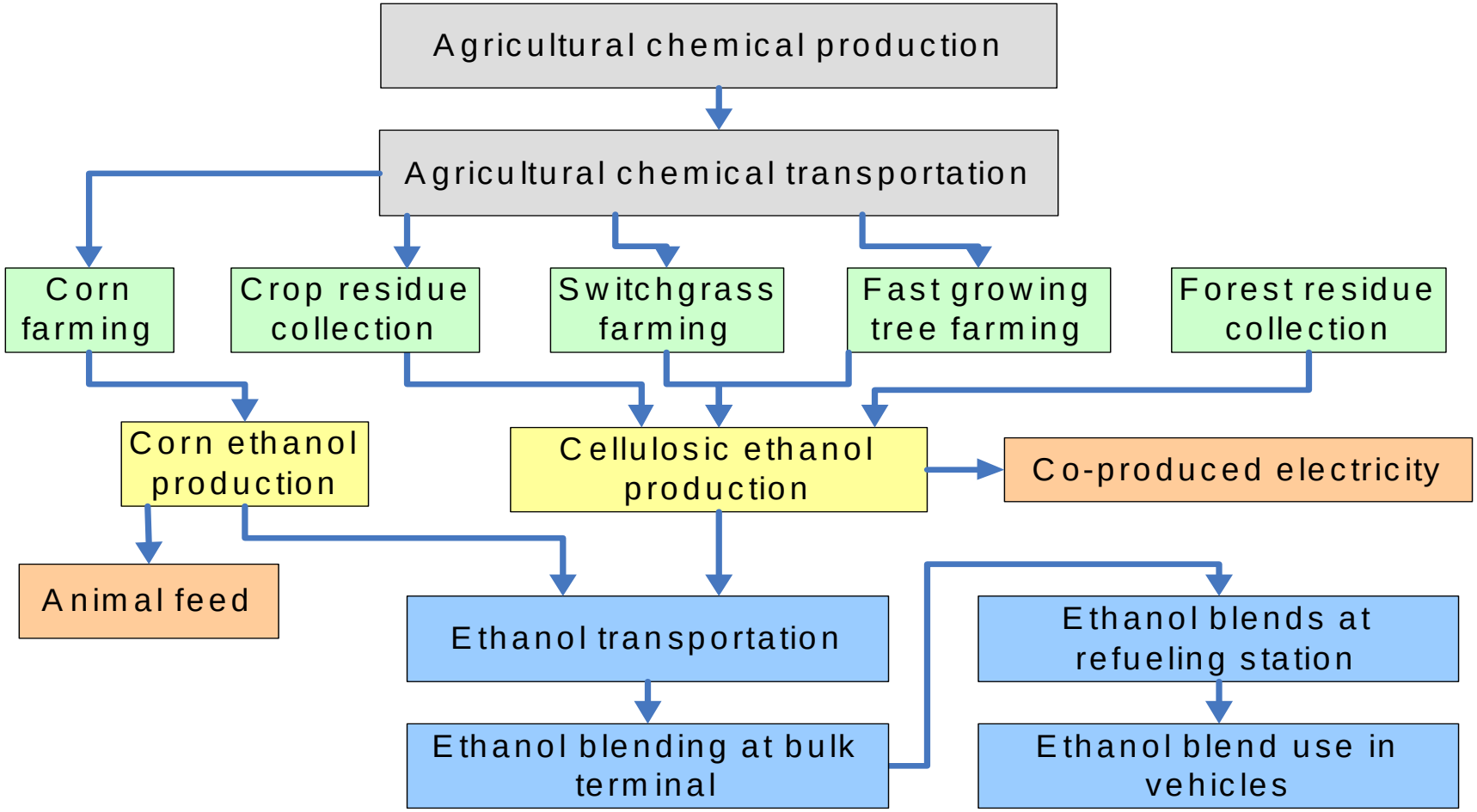
GREET Includes Some of the Potential Biofuel Production Pathways

- Sugar Crops for EtOH
  - **Sugar cane**
  - Sugar beet
  - Sweet sorghum
- Starch Crops for EtOH
  - **Corn**
  - Wheat
  - Cassava
  - Sweet potato
- Butanol Production
  - **Corn**
  - Sugar beet
- Cellulosic Biomass via Gasification
  - **Fitscher-Tropsch diesel**
  - **Hydrogen**
  - Methanol
- Oils for Biodiesel/Renewable Diesel
  - **Soybeans**
  - Rapeseed
  - Palm oil
  - Jatropha
  - Waste cooking oil
  - Animal fat
- Cellulosic Biomass for EtOH
  - **Corn stover**, rice straw, wheat straw
  - **Forest wood residue**
  - Municipal solid waste
  - **Energy crops**
  - Black liquor

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

GREET Ethanol Life-Cycle Analysis Includes Activities from Fertilizer Production to Ethanol Use in Vehicles

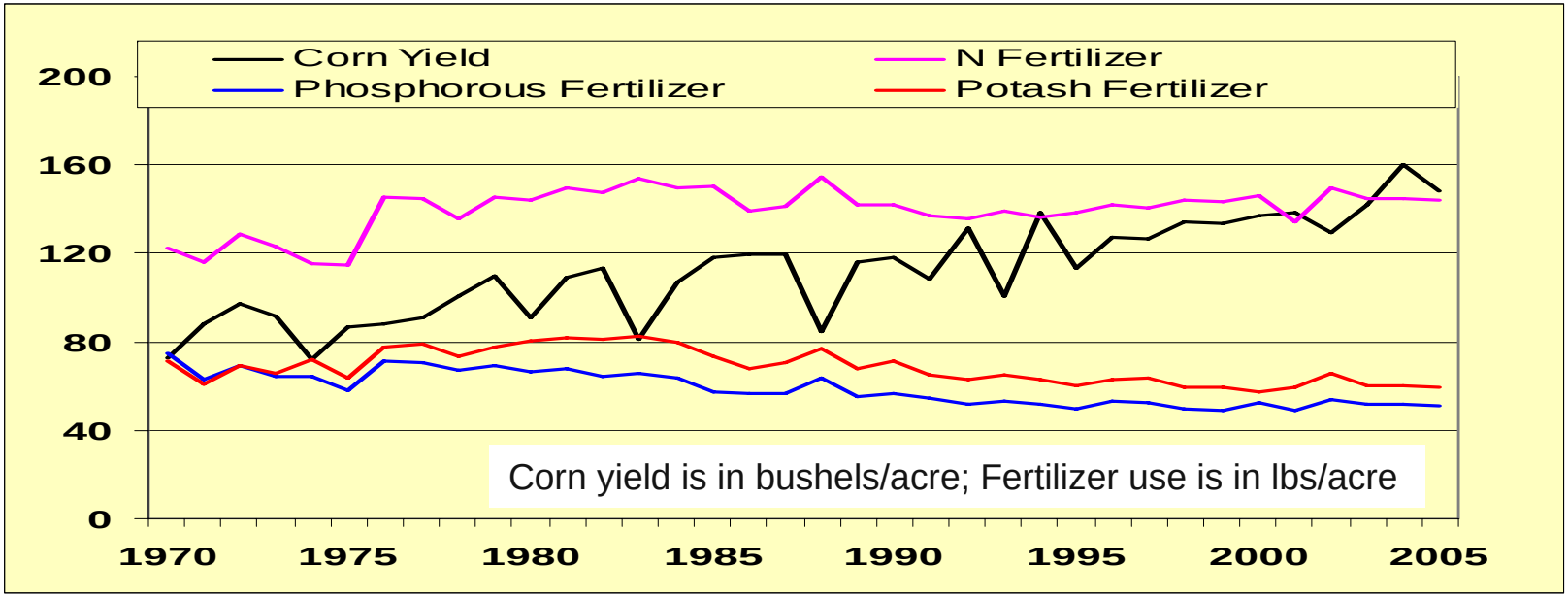
The Bioethanol Pathways Included in This Paper

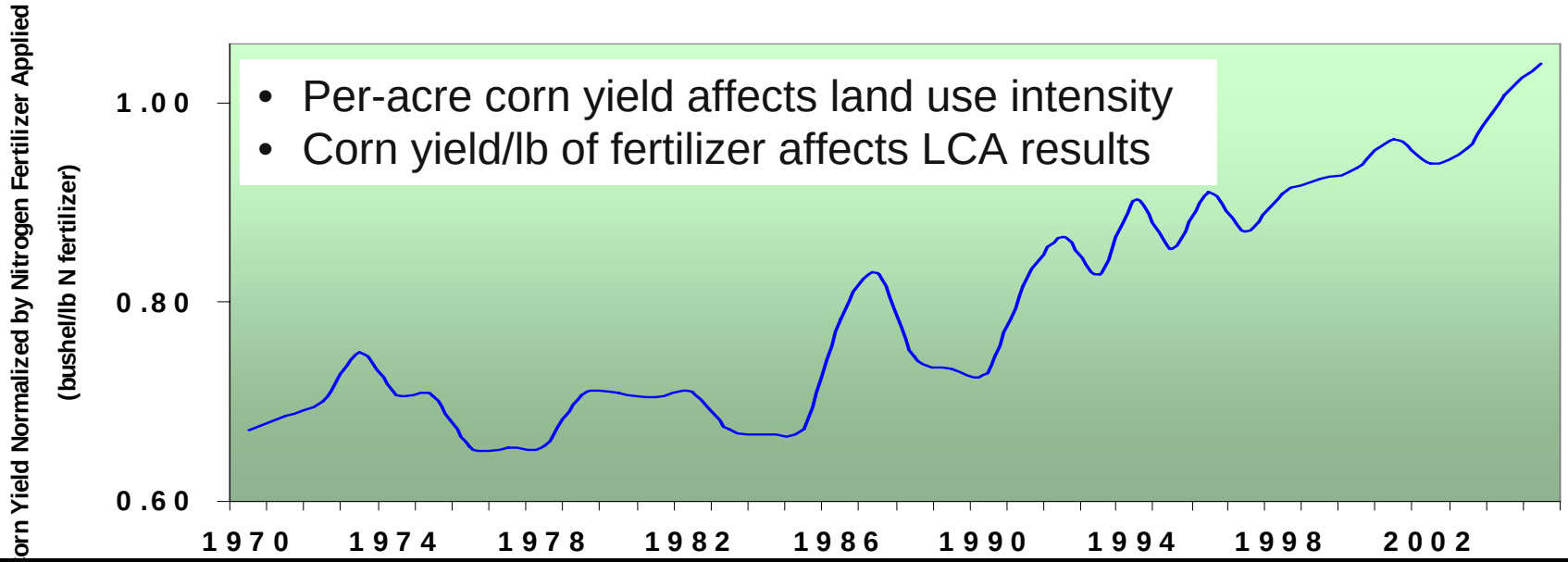


Key Issues Affecting Biofuel WTW Results

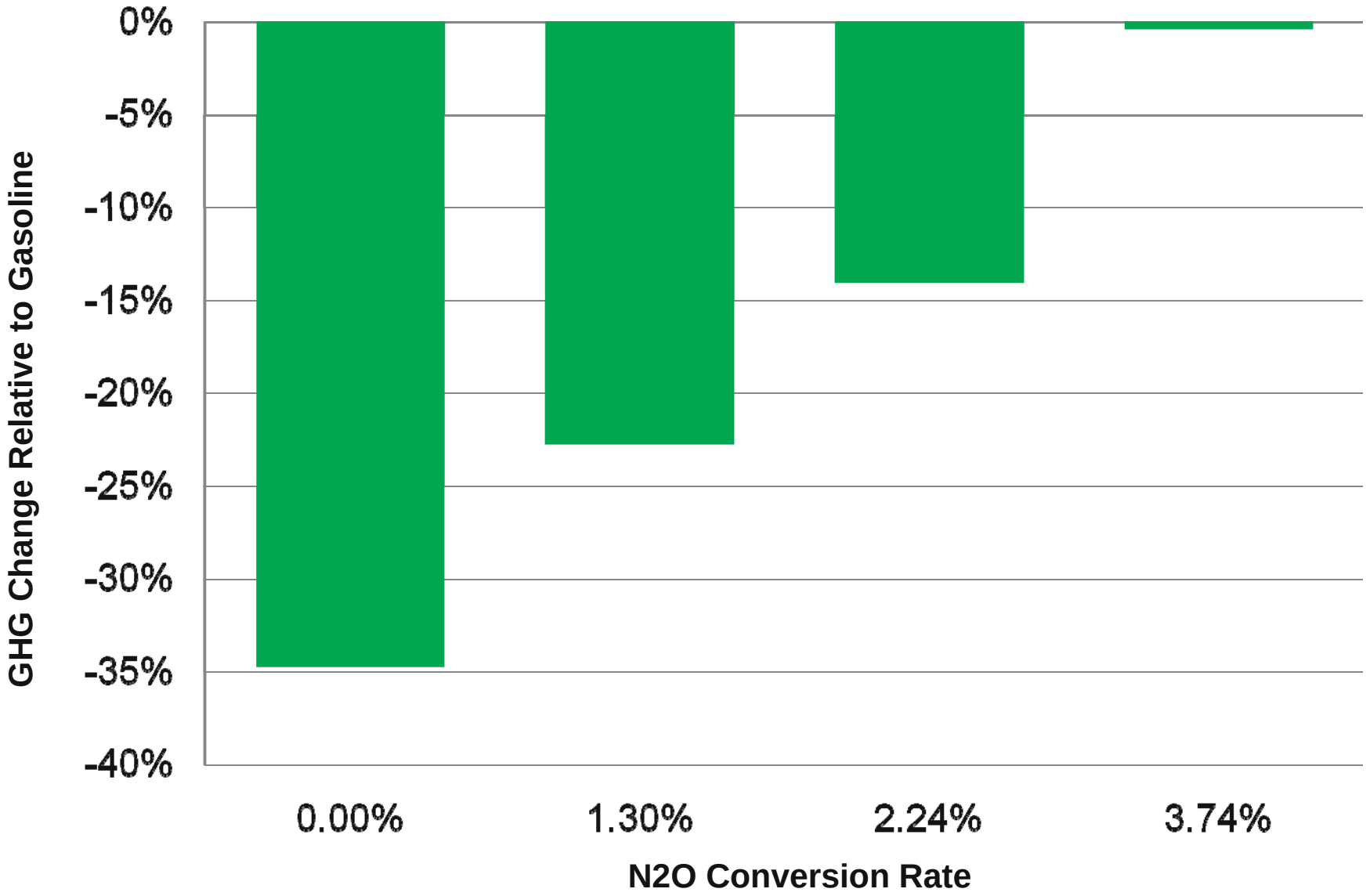
- Nitrogen fertilizer plants
  - Energy use
  - Natural gas vs. coal as feedstock
- Farming
  - Crop and biomass yields
  - Energy and chemical inputs
- Energy use in biofuel plants
  - The amount of process fuels
  - The type of process fuels
- Credits of co-products of biofuels
  - Distillers grains and solubles for corn ethanol: 0-50%
  - Electricity for cellulosic and sugarcane ethanol
  - Soy meals and glycerin for biodiesel
  - Acetone for butanol
- N2O conversion factors of nitrogen fertilizer
  - IPCC: 1.325% (GREET adopts it; equivalent to 1.77% of Crutzen factor)
  - Crutzen et al.: 3-5% (equivalent to 2.24-3.74% of IPCC factor)
  - Background vs. N fertilizer-induced N2O emissions in fields
- Land use changes and resulted CO2 and CH4 emissions
- Some of the issues are affected heavily by the scale of biofuel production

US Corn Production Has Been Improving in the Past 35 Years





Corn Ethanol GHG Reductions Under Different N2O Conversion Factors



Energy Use in Ethanol Plants Has Reduced by More Than 50% in the Past 20 Years

Corn ethanol plants in early 1980s consumed 70,000 Btu per gallon of ethanol produced.

Current and Near-Future Ethanol Plant Energy Use (per gallon of ethanol)

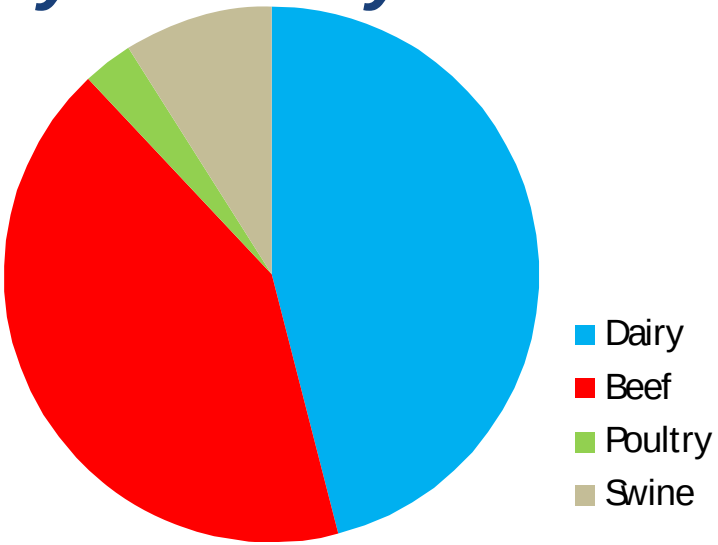
Ethanol Plant Type	Natural Gas (Btu)	Coal (Btu)	Renewable Process Fuel (Btu)	Electricity (kWh)
1. Plant with natural gas (NG)	33,330	None	None	0.75
2. Plant with NG and wet DGS	21,830	None	None	0.75
3. Plant with coal	None	40,260	None	0.90
4. Plant with coal and wet DGS	None	26,060	None	0.90
5. Plant with wood chips	None	None	40,260	0.90
6. Plant with DGS as fuel	None	None	40,260	0.75

Co-Products with Biofuels

- Types of co-products
  - Corn ethanol: animal feeds (distillers grains and solubles, DGS)
  - Sugarcane ethanol: electricity
  - Cellulosic ethanol: electricity
  - Biodiesel and renewable diesel from soybean and rapeseed: animal feeds, glycerin, and other chemicals
- Ways of dealing with co-products
  - Displacement method (or the system boundary expansion approach)
  - Allocation methods
    - *Mass based*
    - *Energy content based*
    - *Economic revenue based*
  - Production plant process purpose based
- Scale of biofuel production (and resultant scale of co-product production) can affect the choice of methods

Proper Accounting for Animal Feed Is Key to Corn Ethanol's Lifecycle Analysis

DG S Market Shares In 2006



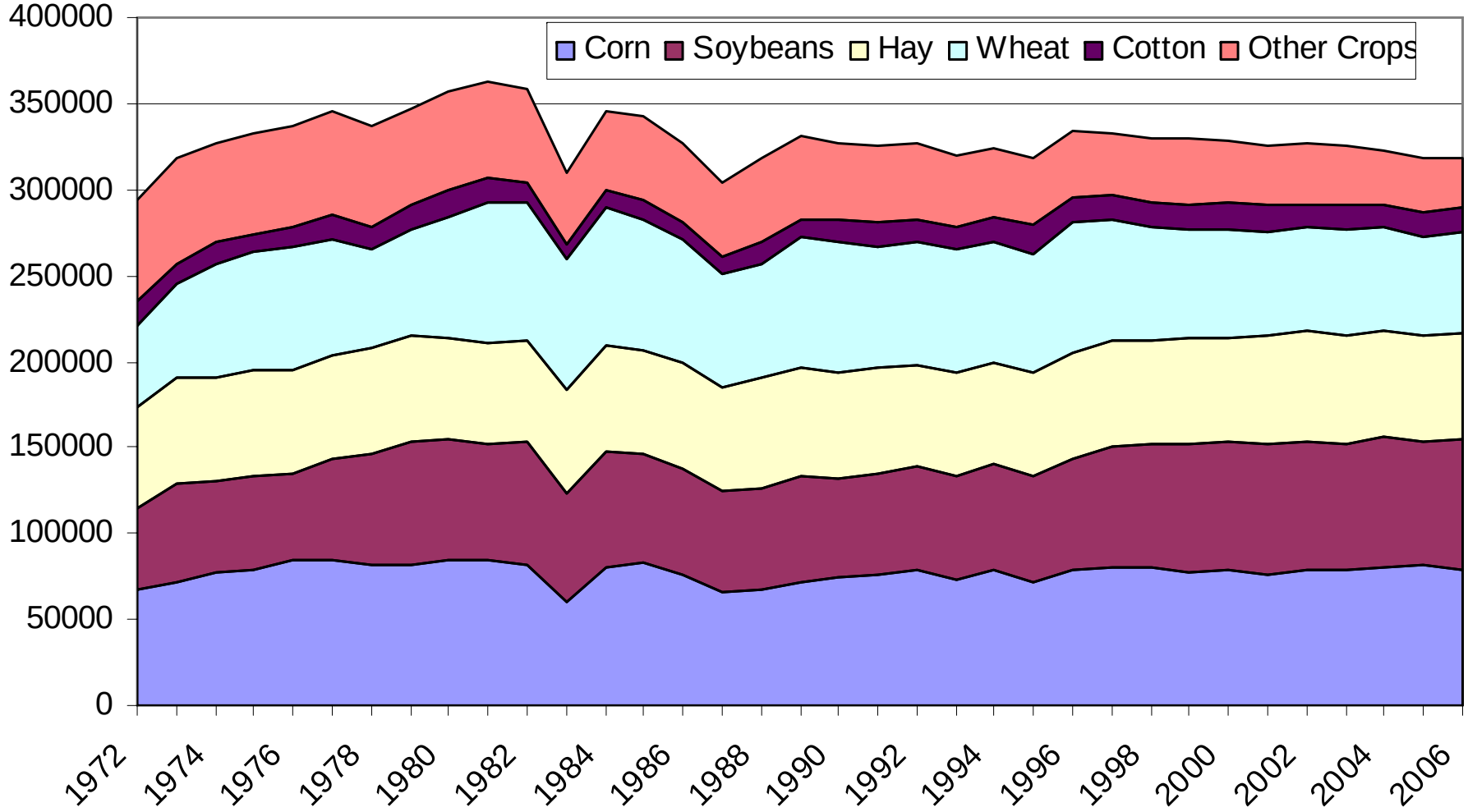
Allocation Method	Wet milling	Dry milling
Weight	52%	51%
Energy content	43%	39%
Process energy	36%	41%
Market value	30%	24%
Displacement	~16%	~20%

Argonne uses the displacement method.

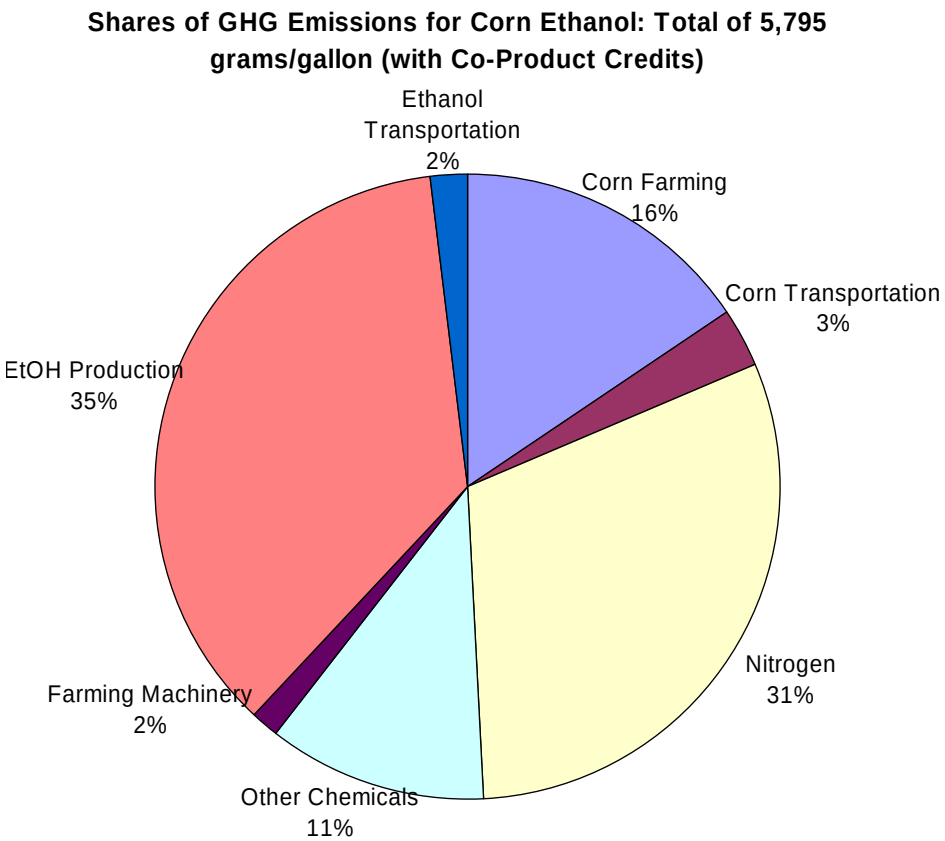
GHG Emission Implications of Potential Land Use Change by Large-Scale Biofuel Production Needs to Be Examined

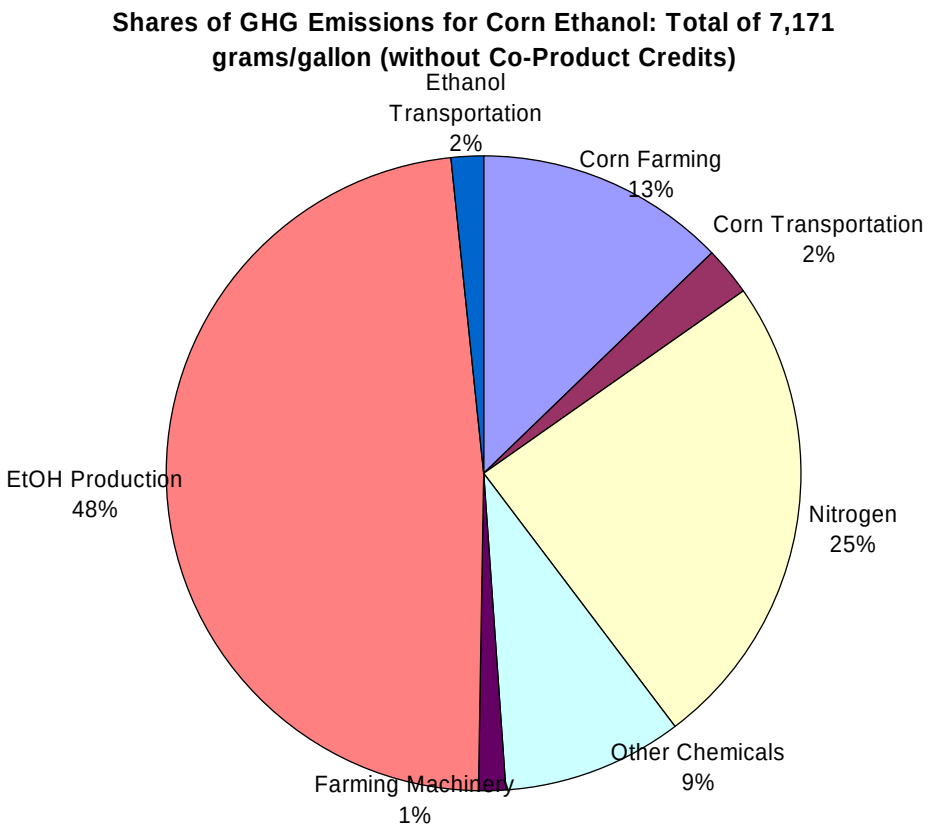
- Potential land use changes
  - Direct land use change: regional or national scale
  - Indirect land use change: global scale
  - Both can be simulated with global general equilibrium models
  - The resolution level of global GE models could be a key factor
- Carbon profiles of major land types
  - Models in the U.S. and Europe are available
  - Carbon profiles of land types in other parts of the world (South America, Asia, Africa) may be less understood
- Time horizon of biofuel programs; "for-ever biofuels" can mathematically result in zero GHG emission changes from land use changes
- There are no reliable simulation results yet; some new efforts in this area started very recently
- At present, GREET includes the following soil CO2 sources/sinks for ethanol
  - Corn ethanol: CO2 <u>source</u> of 73 grams/gal. EtOH from soil C reduction
  - Cellulosic ethanol
    - *Fast growing trees: CO2 <u>sink</u> of 1,250 g/gal. EtOH from soil C increase*
    - *Switchgrass: CO2 <u>sink</u> of 540 g/gal. EtOH from soil C increase*

Historical Trend of U.S. Crop Land (based on NASS/USDA)

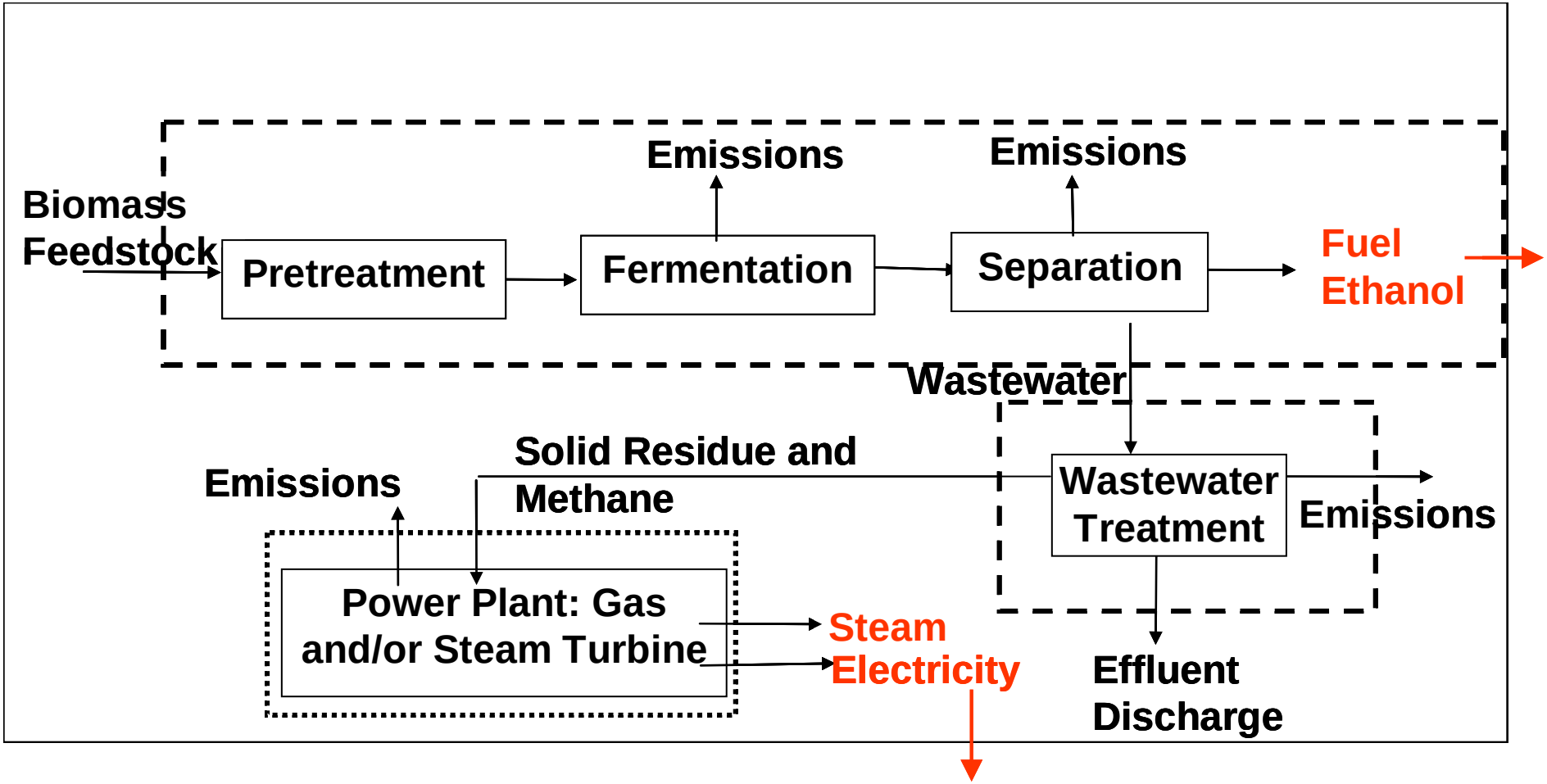


Fuel-Cycle GHG Emission Shares for Corn-Based Ethanol





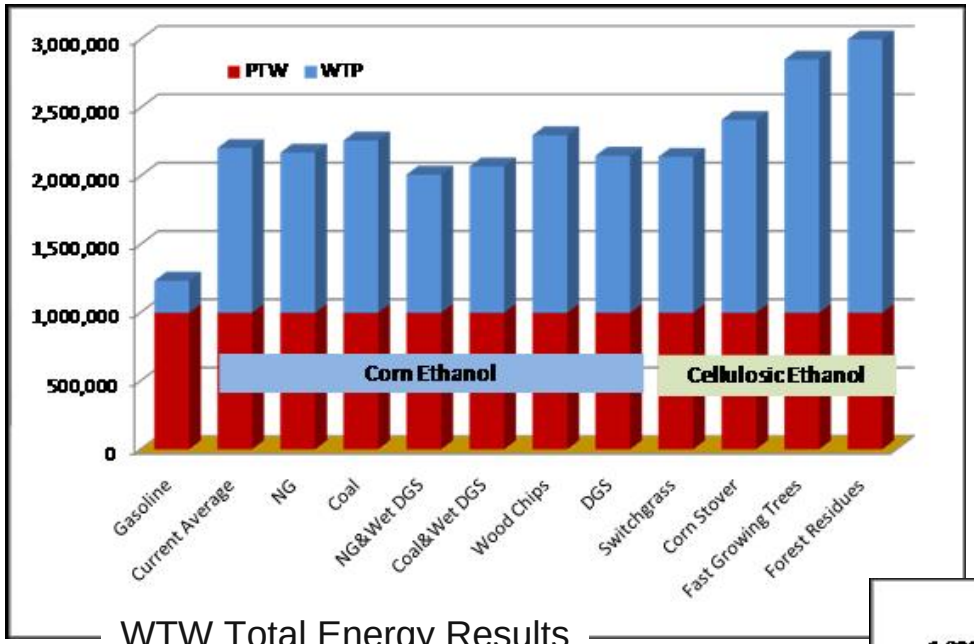
Cellulosic Ethanol Plants Potentially Produce Electricity Together With Ethanol



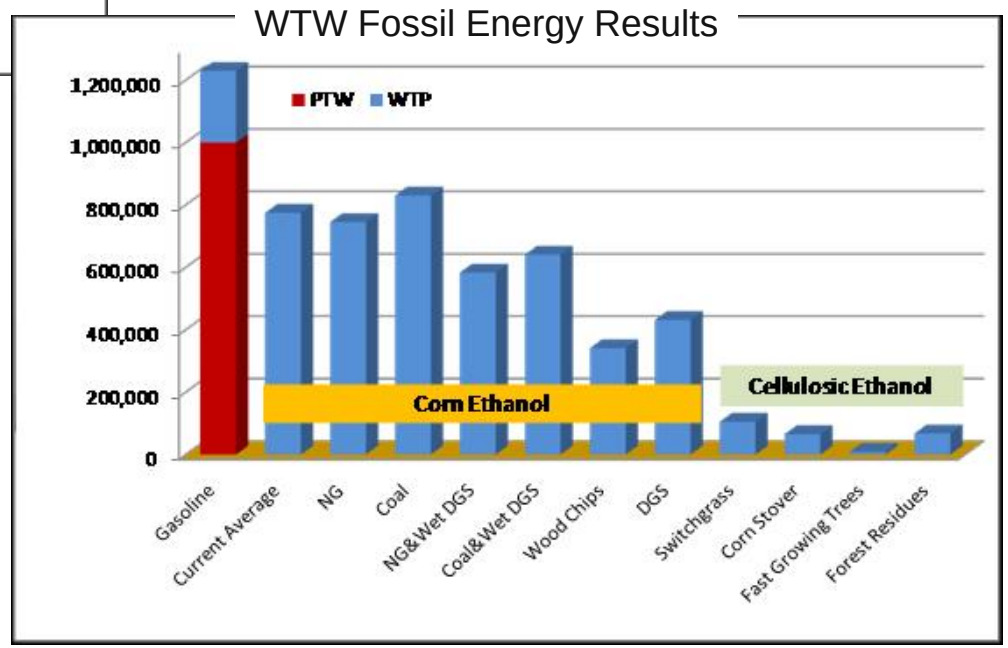
Key Issues Affecting Cellulosic Ethanol Results

- Cellulosic biomass feedstock types
  - Fast growing trees
    - *Soil carbon could increase*
    - *Fertilizer may be applied*
    - *Irrigation to be needed?*
  - Switchgrass and other native grass
    - *Soil carbon could increase*
    - *Fertilizer will be applied*
    - *Irrigation to be needed?*
  - Crop residues
    - *soil carbon could decrease*
    - *Additional fertilizer will be needed to supplement nutrient removal*
  - Forest wood residues: collection effort could be extensive
- Co-production of ethanol and electricity
  - The amount of electricity produced
  - The types of conventional electric generation to be displaced
- Land use changes could have less effects on cellulosic ethanol's GHG results

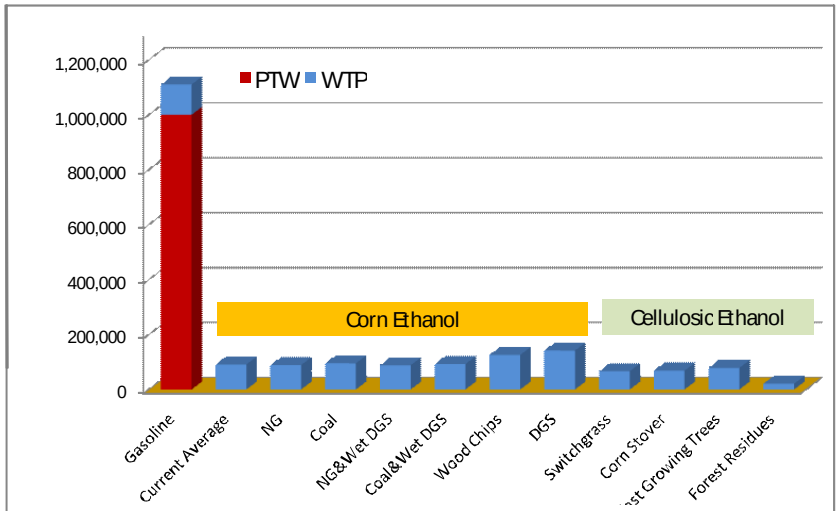
Energy Benefits of Ethanol Lie in Fossil Energy and Petroleum Energy



WTW Total Energy Results

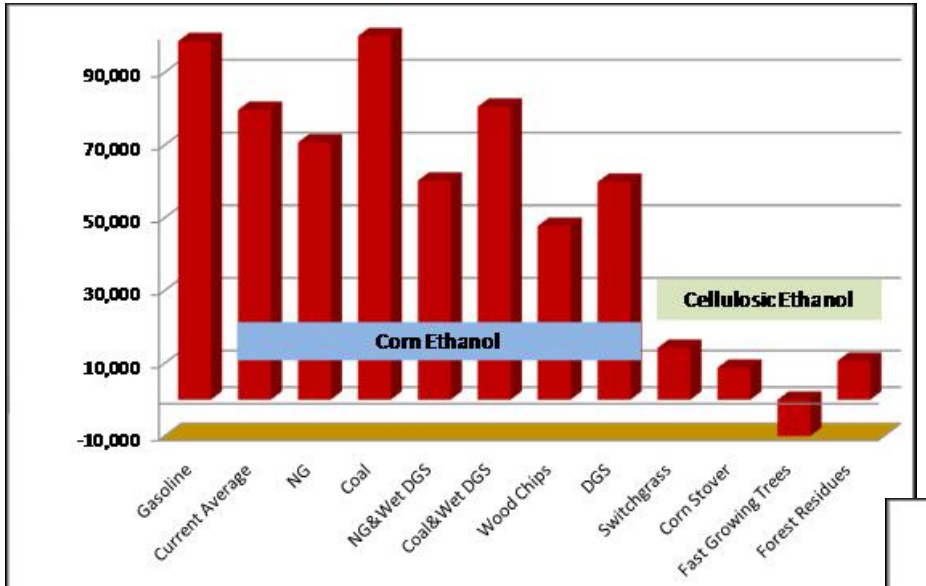


WTW Fossil Energy Results



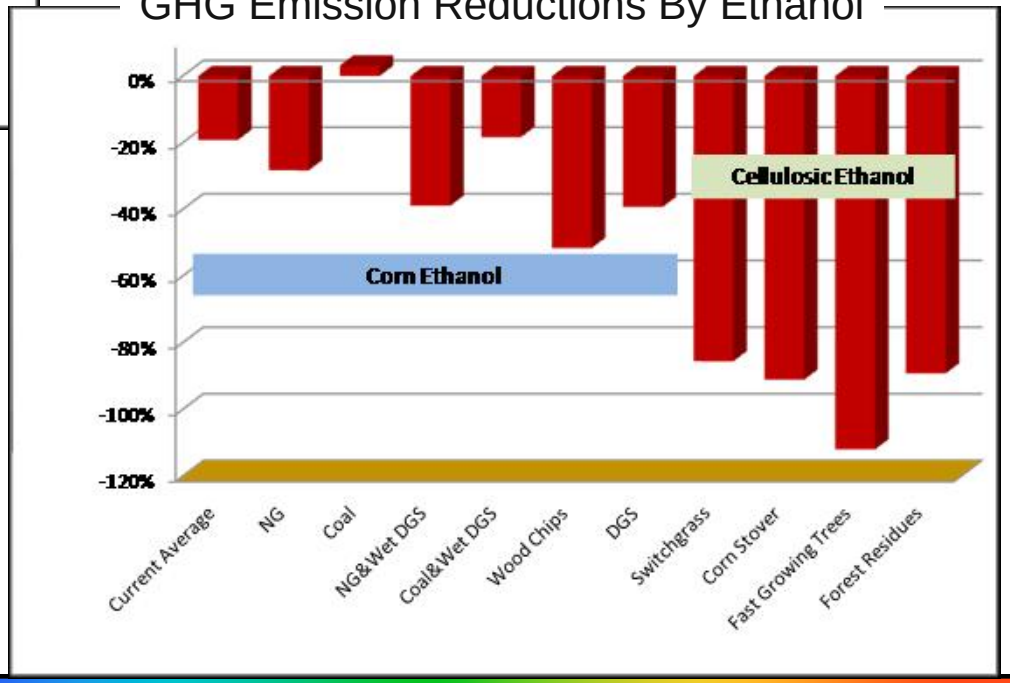
WTW Petroleum Energy Results

GHG Emissions of Corn Ethanol Vary Considerably Among Process Fuels in Plants



WTW GHG Emissions Per Million Btu

GHG Emission Reductions By Ethanol



Summary and Other Sustainability Issues

- Corn ethanol was examined here with different process fuels in corn ethanol plants, it could be examined with different corn farming practices
- So far, corn ethanol has achieved moderate GHG reductions; future GHG effects of corn ethanol are unclear
- The unclear future of corn ethanol's GHG effects is from the potential land changes by the rapid expansion of U.S. corn ethanol production
- Cellulosic ethanol achieves significant GHG reductions
- Water issues of biofuel production
  - Consumptive water requirements: Argonne recently began to address these for biofuels and petroleum fuels
  - Waste water discharge and water quality issues
- Criteria air pollution problems
- Other ecological issues
  - Soil erosion and soil quality impacts
  - Adverse biodiversity effects of monoculture