ARGONNE NATIONAL LABORATORY

TRANSPORTATION TECHNOLOGY R&D CENTER

Fuel-Cycle Energy and Greenhouse Emission Impacts of Fuel Ethanol

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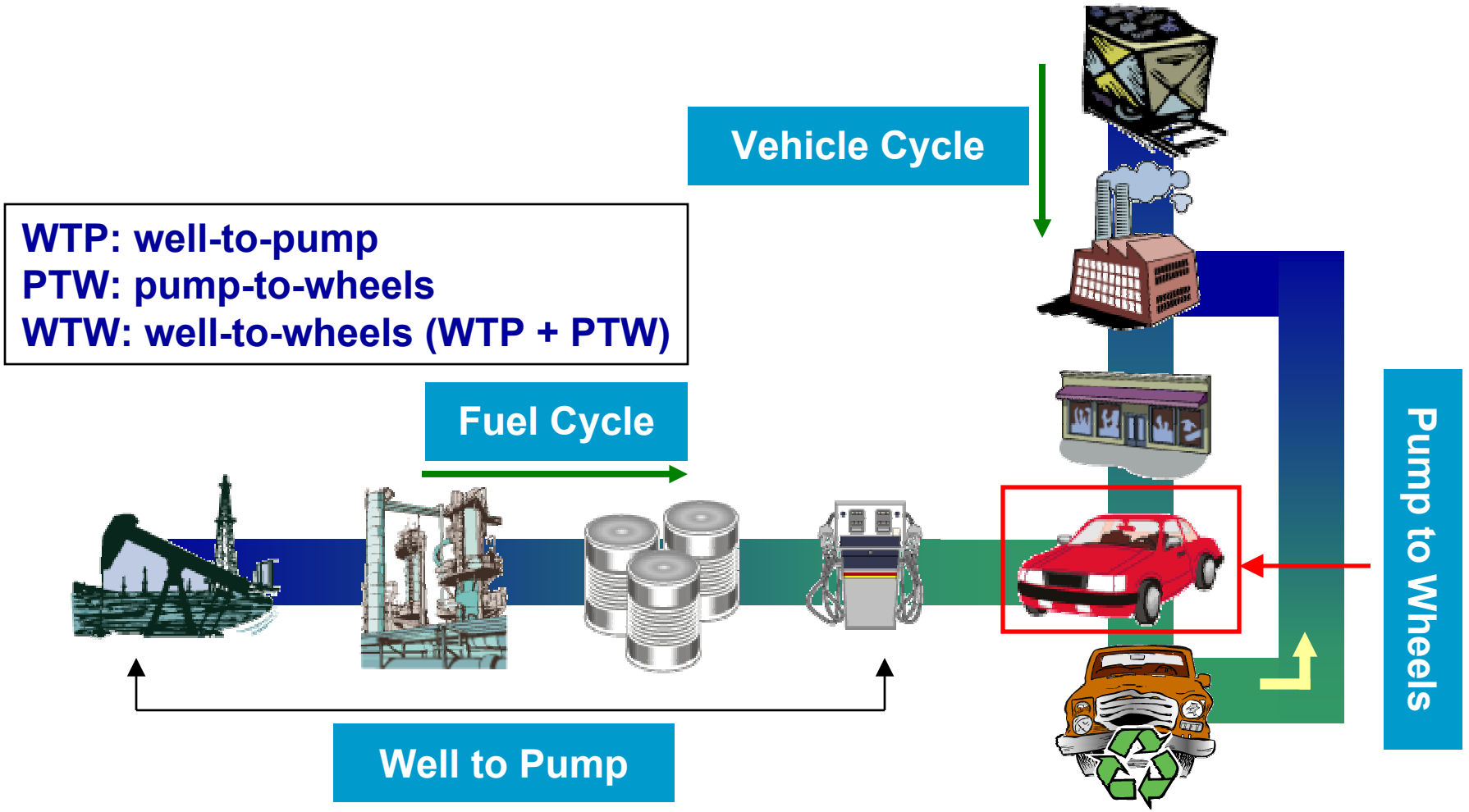
Cycles for Vehicle/Fuel Systems

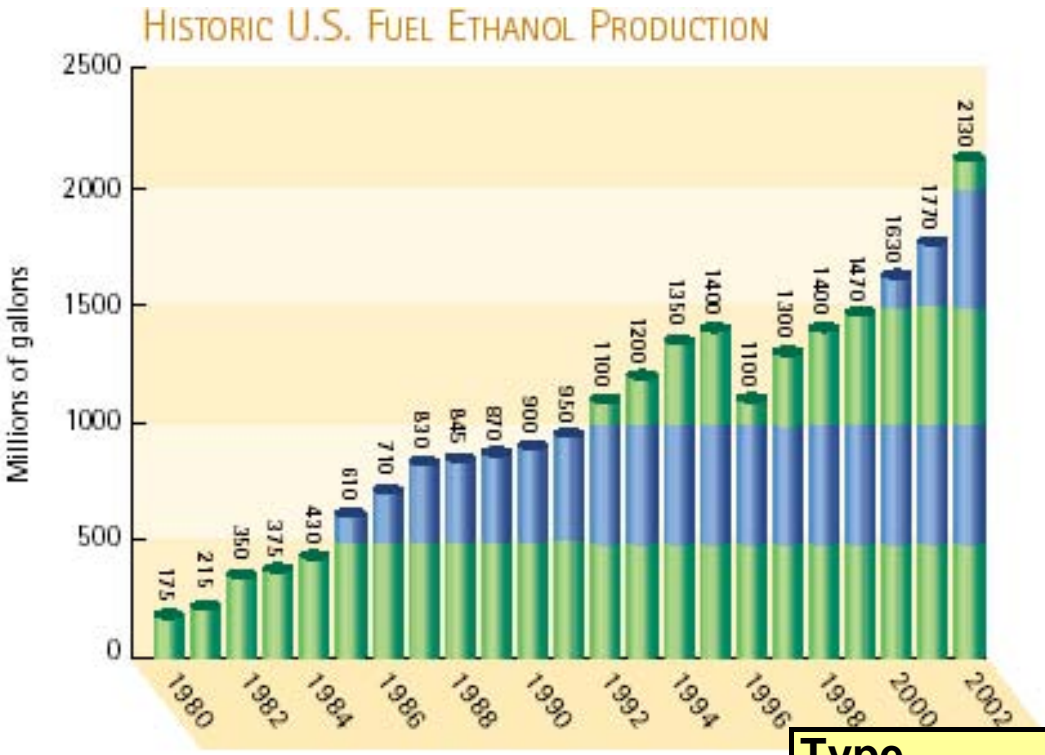
The Illustration is for Petroleum-Based Fuels



The GREET (*G*reenhouse gases, *R*egulated *E*missions, and *E*nergy use in *T*ransportation) Model

- **GREET includes emissions of greenhouse gases**
  - CO_2, CH_4, and N_2O
  - VOC, CO, and NO_x as optional GHGs
- **GREET estimates emissions of five criteria pollutants**
  - VOC, CO, NO_x, PM_{10}, and So_x
  - Total and urban emissions separately
- **GREET separates energy use into**
  - All energy sources
  - Fossil fuels (petroleum, natural gas, and coal)
  - Petroleum
- **The GREET model and Its documents are available at http://greet.anl.gov; there are about 800 registered GREET users**

U.S. Fuel Ethanol Production and Use Have Increased Steadily



In 2002, the U.S. used 2.1 billion gallons of fuel ethanol

Type	Purpose	Mil. Gal.
FRFG	Oxygenate (E6-E10)	700
F.Winter Oxy. Fuels	Oxygenate (E10)	250
MN Oxy. Fuels	Oxygenate (E10)	250
Conv. Gasoline	Octane/Extender	900
Total		**2,100**

Source: Renewable Fuels Association's 2003 Ethanol Industry Outlook Report.

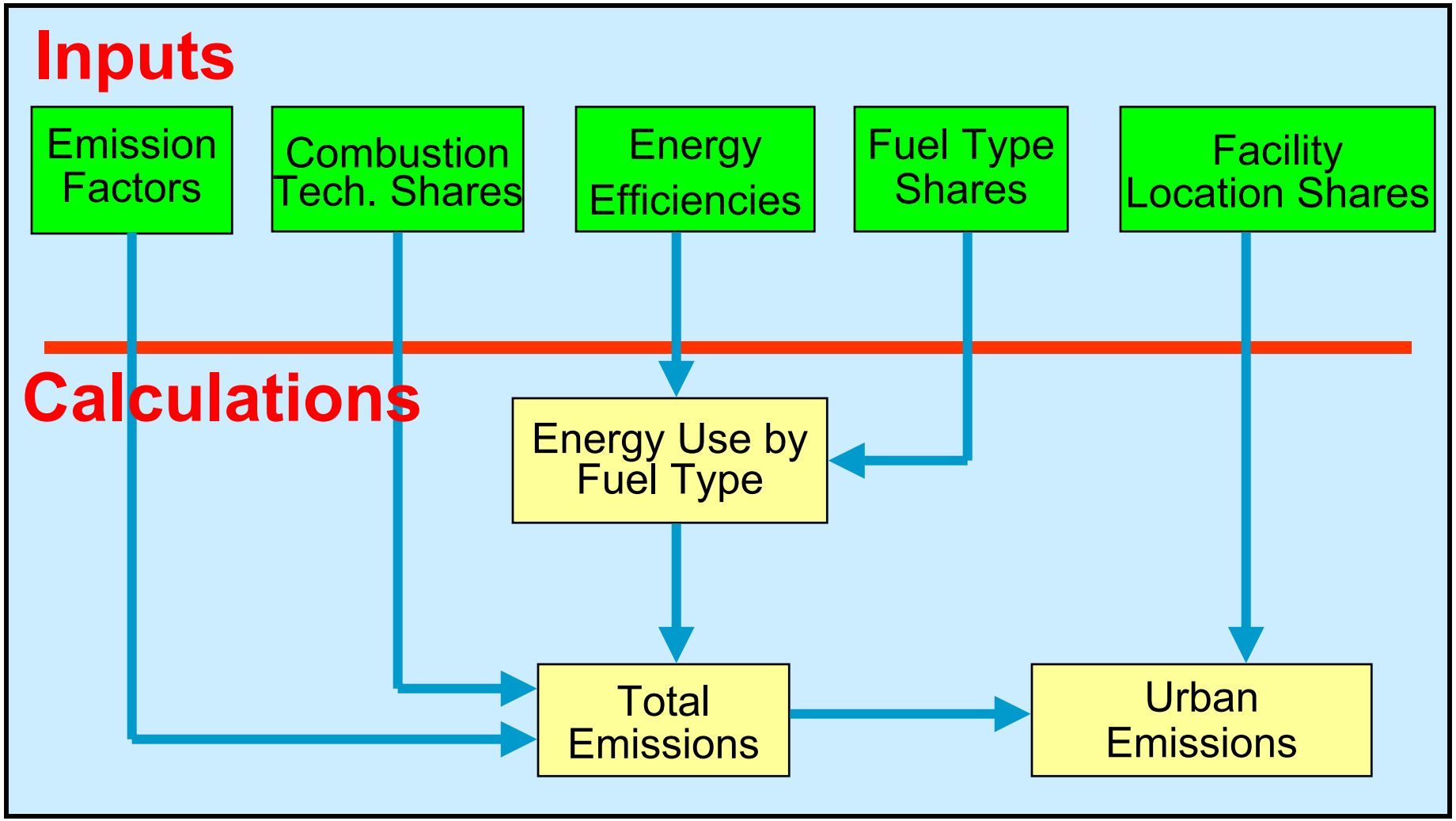
Energy Effects of Fuel Ethanol Have Been Subject to Debate

- Some studies, especially those completed between late 1980s and early 1990s, concluded negative energy balance value of ethanol
- Those past studies basically examined energy use of producing ethanol
- Though self evaluation of ethanol's energy balance is easy to understand, it may not be useful to fully understand true energy benefits of fuel ethanol
- A more complete way is to compare fuel ethanol with the fuels to be displaced by ethanol (i.e., gasoline)
- The GREET model has been applied to conduct a comparative analysis between ethanol and gasoline

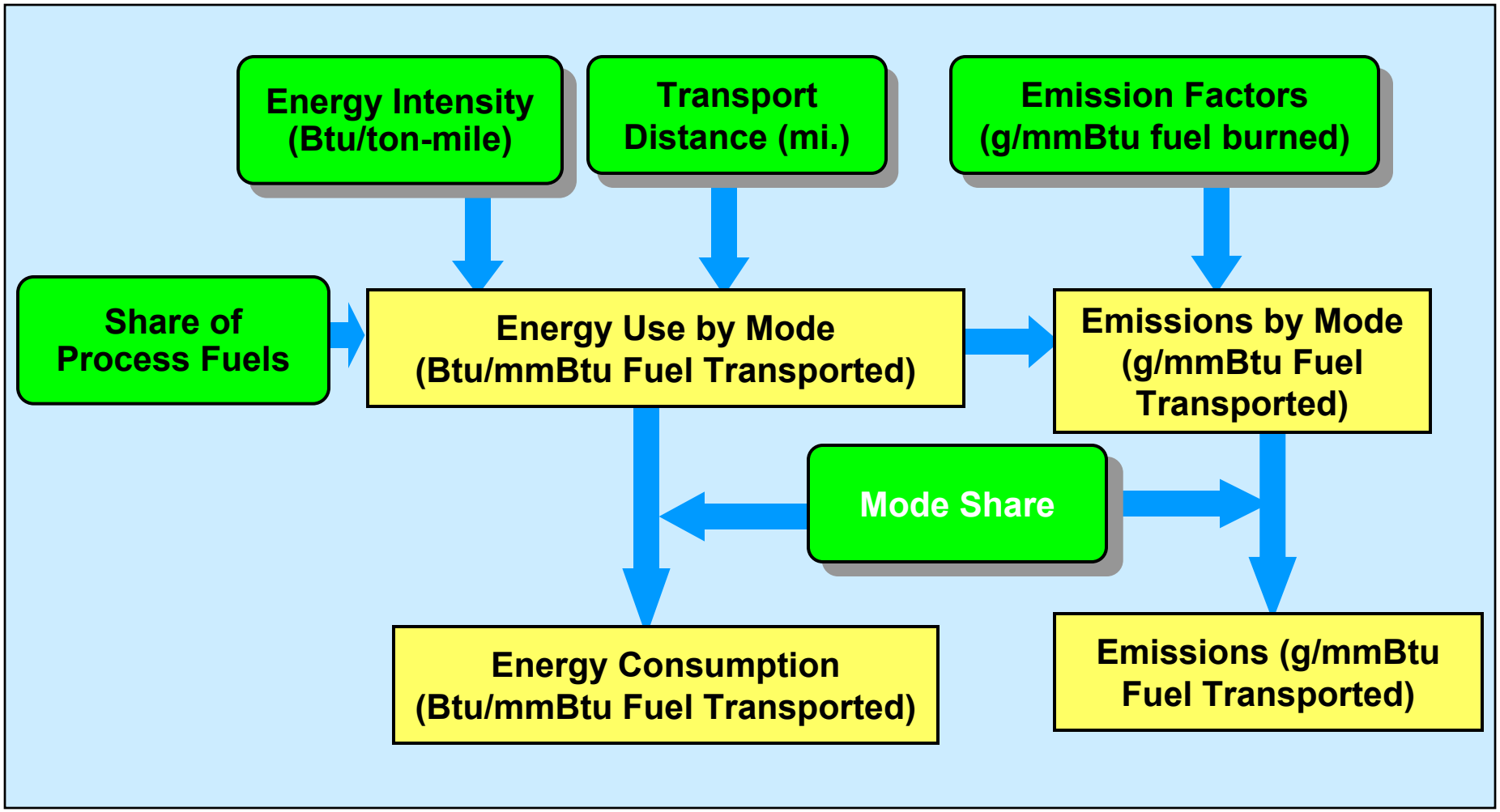
Emission Effects of Fuel Ethanol Were Not Addressed on the Fuel-Cycle Basis

- Past emission studies focused mainly on ethanol's evaporative emissions and its effects on vehicle tailpipe emissions
- Well-to-pump emissions were identified for ethanol and gasoline only in a piece-meal way
  - Petroleum refinery emissions
  - Ethanol plant emissions
- GHG emissions were simply ignored in some debatable studies
- Emissions of fuel ethanol need to be evaluated in a holistic and comparative way
- For criteria pollutant emissions, future emission controls for WTP and vehicle activities are important

GREET Calculation Logic for Production Activities

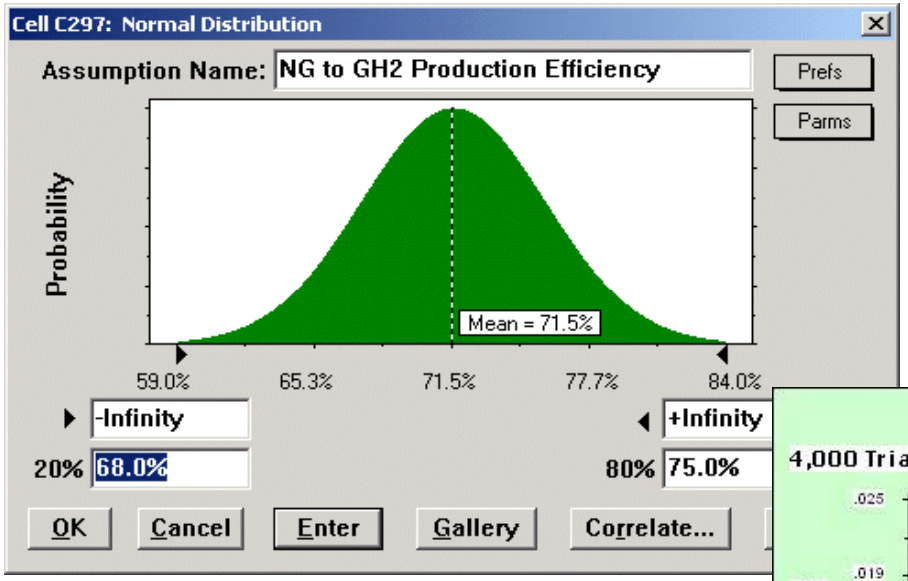


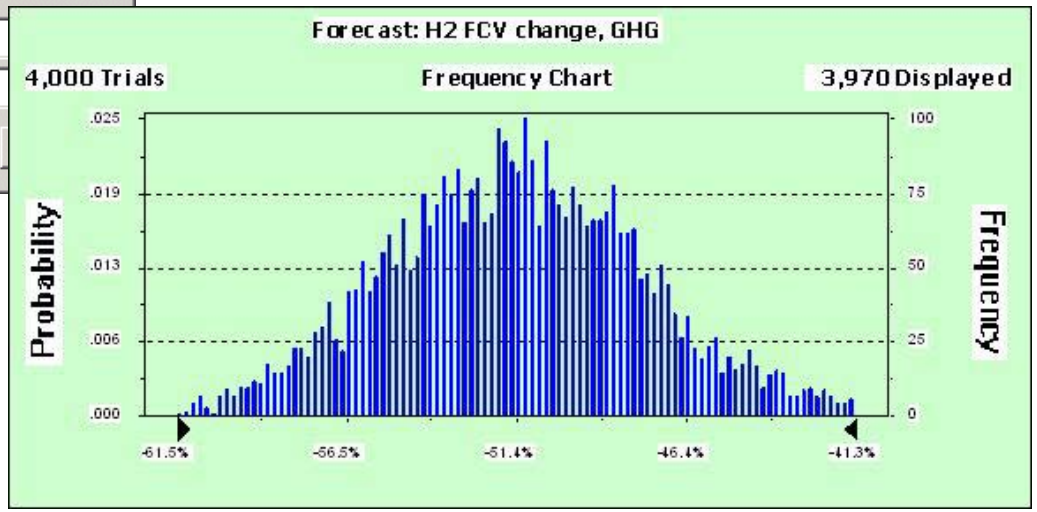
GREET Calculation Logic for Transportation Activities



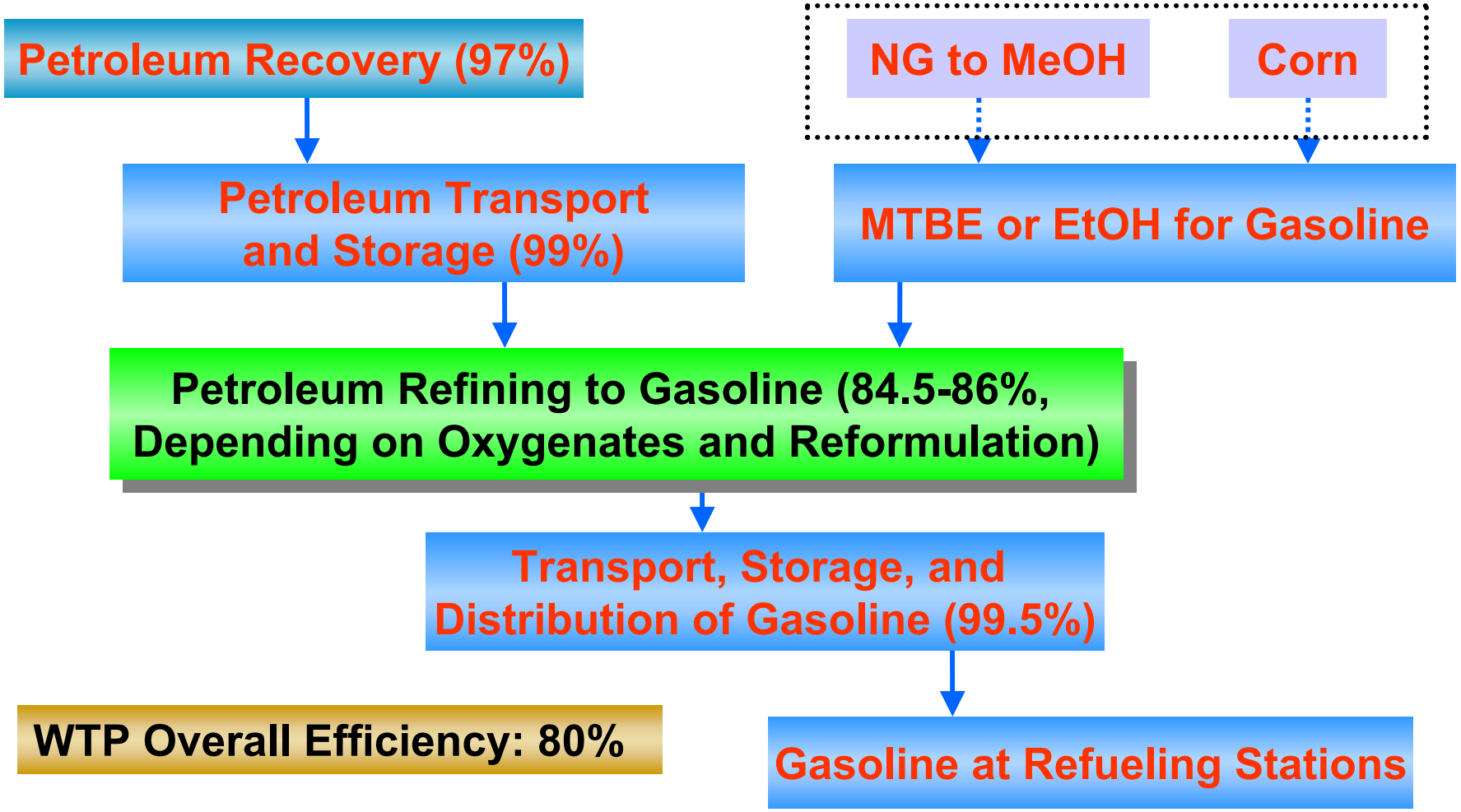
GREET Is Designed to Conduct Stochastic Simulations

Distribution-Based Inputs Generate Distribution-Based Outputs





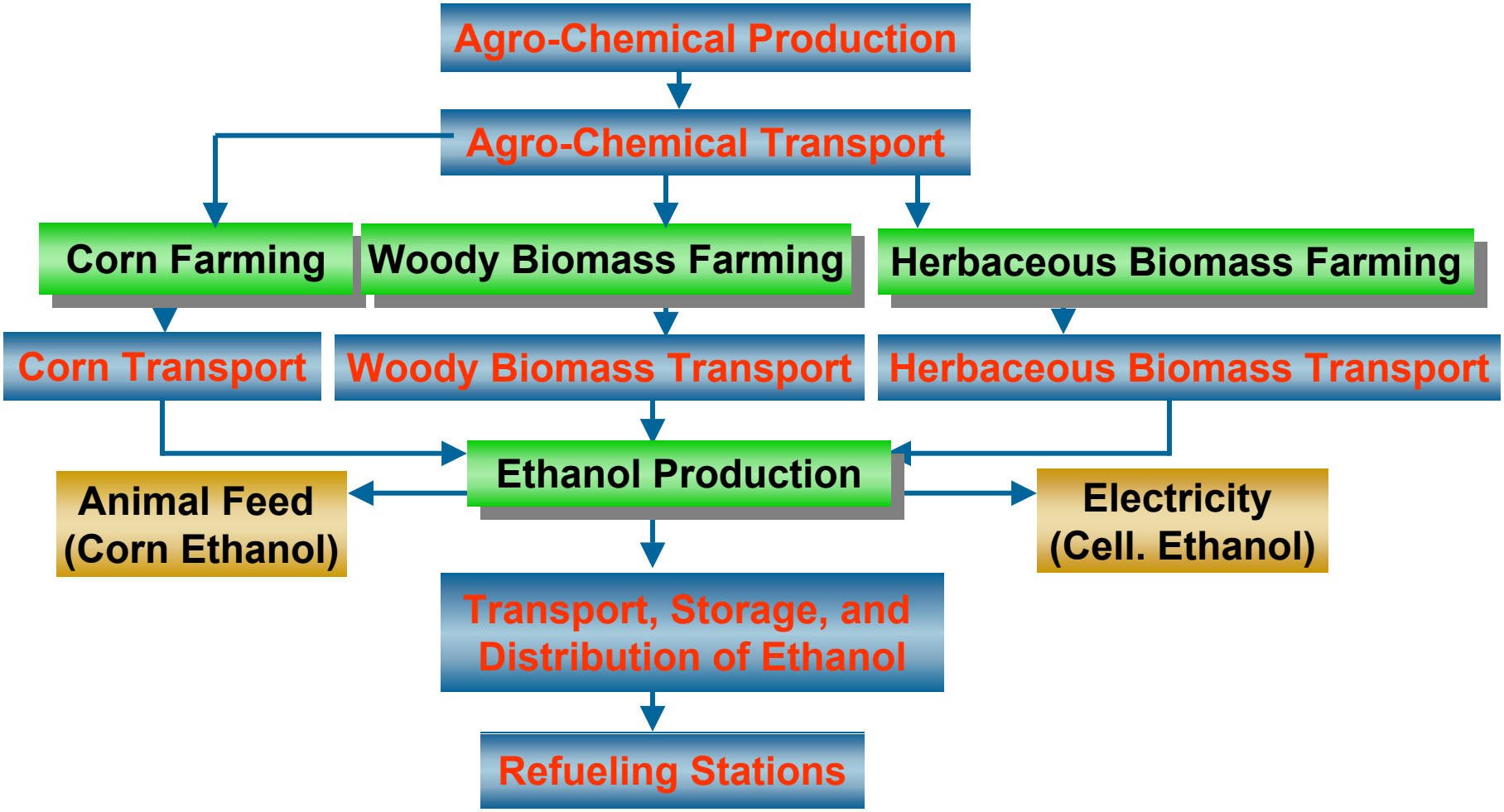
Petroleum Refining Is the Key Energy Conversion Step for Gasoline



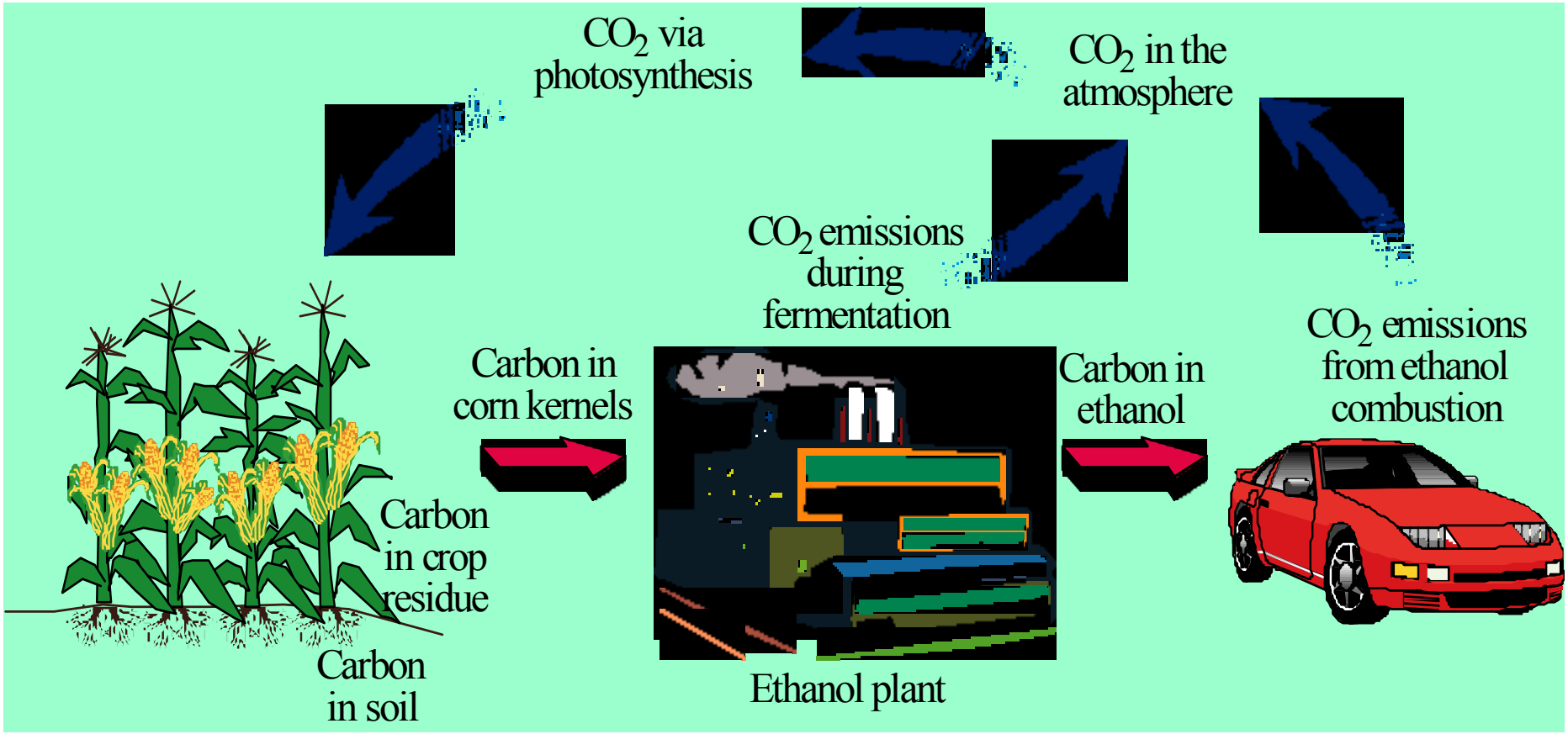
Key Issues for Simulating Petroleum Fuels

- Beginning in 2004, gasoline sulfur content will be reduced nationwide from the current level of 150-300 ppm to 30 ppm
- In addition, marginal crude has high sulfur content
- Desulfurization in petroleum refineries adds stress on refinery energy use and emissions
- Ethanol could replace MTBE in RFG nationwide
  - Energy and emission differences in MTBE and ethanol
  - Differences in gasoline blend stocks for MTBE and ethanol

Ethanol WTP Pathways Include Activities from Fertilizer to Ethanol at Stations



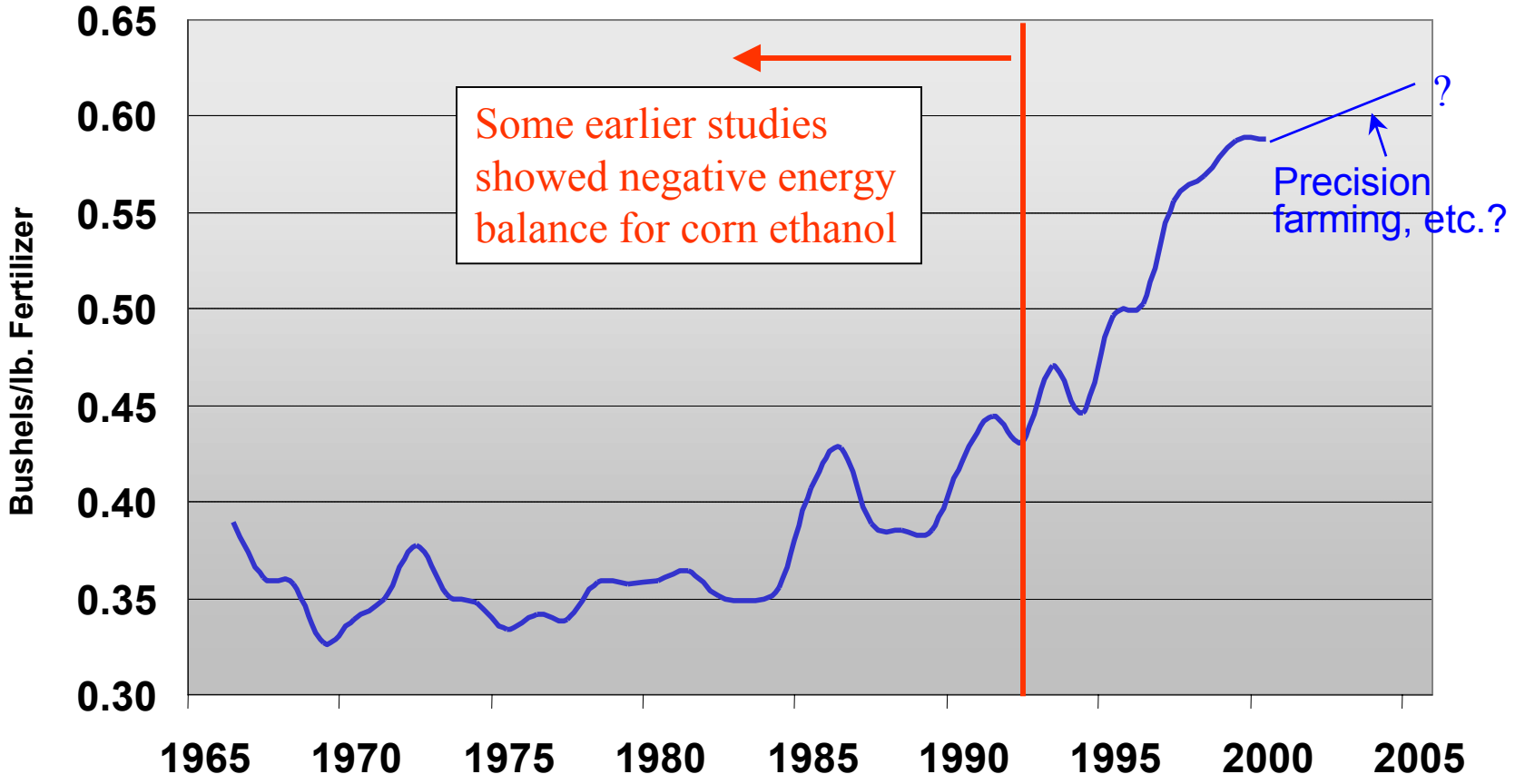
Recycling of Carbon by Ethanol Fuel Results in Large CO_2 Benefits for It



Key Parameters for Ethanol's Energy and Emission Effects

- **Energy use for chemicals production**
  - Fertilizers (N, P_2O_5, K_2O)
  - Herbicides
  - Insecticides
- **Farming**
  - Corn and biomass yield
  - Chemicals use intensity
  - Energy use intensity
  - Soil N_2O and NO_x emissions
  - Soil CO_2 emissions or sequestration
- **Ethanol production**
  - Corn ethanol: wet vs. dry milling
  - Ethanol yield
  - Energy use intensity
  - Co-product types and yields
- **Vehicle fuel economy**
  - Gasoline vehicles with E10
  - Flexible-fuel vehicles with E85

U.S. Corn Output Per Pound of Fertilizer Used Has Risen (3-yr Moving Average)

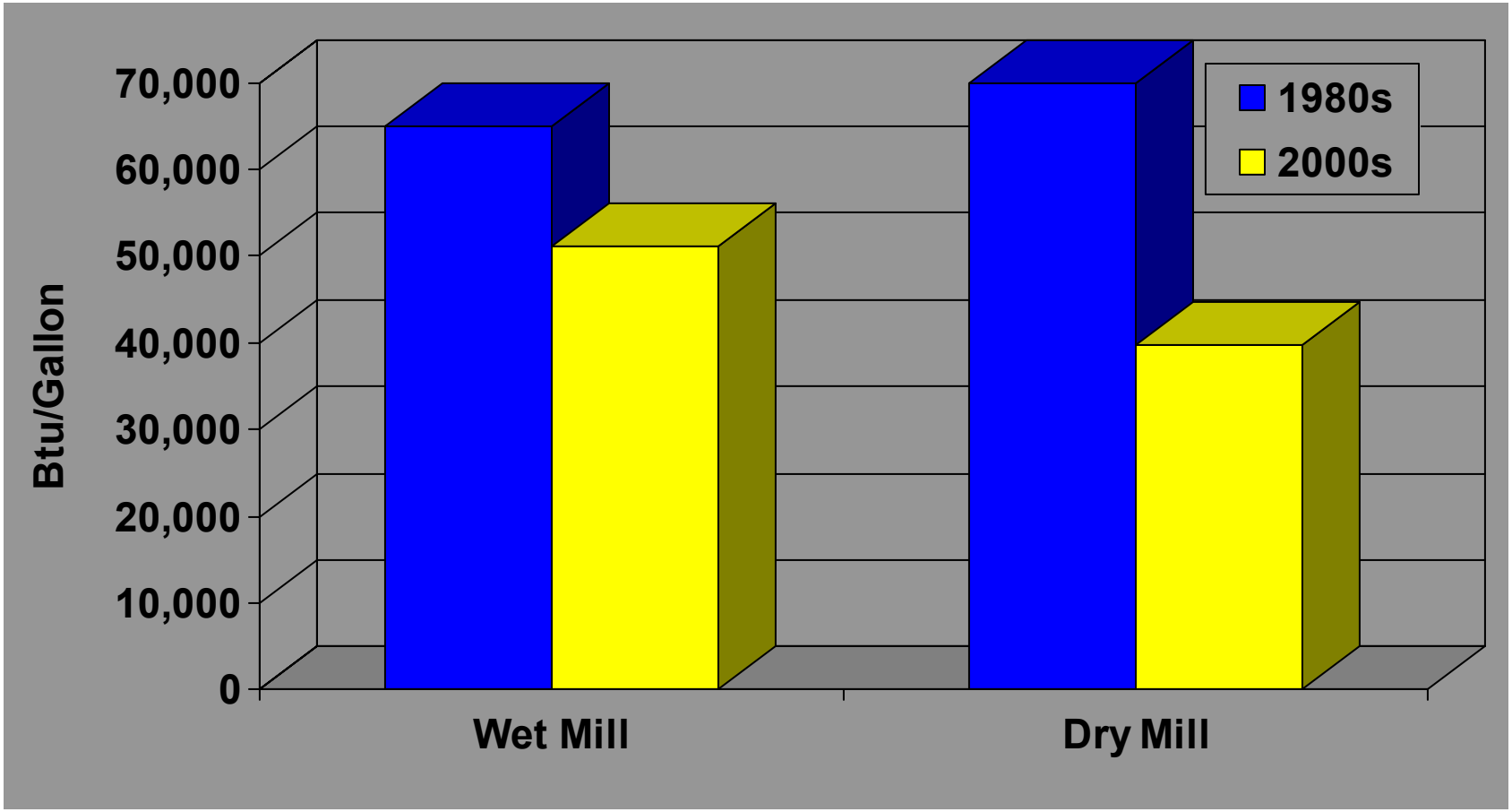


Source: from USDA data.

N_2O and NOx Emissions from Nitrogen Fertilizer Are a Major Emission Source

- Some nitrogen fertilizer is converted into N_2O and NOx via nitrification and denitrification in farmland
- Depending on soil type and condition, 1-3% of N in nitrogen fertilizer is converted into N in N_2O
- On the well-to-wheels basis, N_2O emissions from nitrogen fertilizers could account for up to 25% of total GHG emissions from corn ethanol

Technology Has Reduced Energy Use Intensity of Ethanol Plants



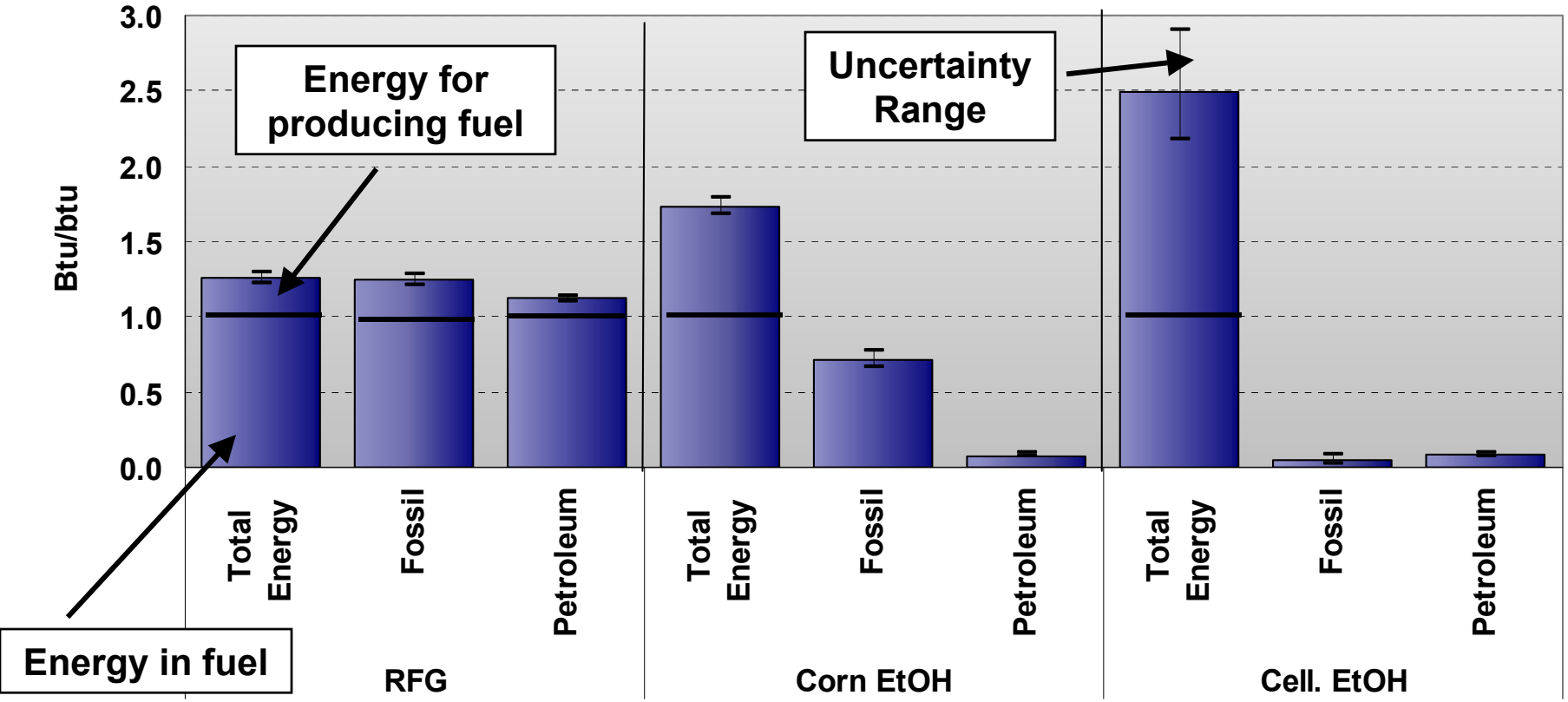
Source: from Argonne's discussions with ethanol plant designers and recent USDA data.

Well-to-Gate Energy and Emissions Allocated to Co-Products (Animal Feed) Vary by Allocation Method

Allocation Method	Wet milling	Dry milling
Weight	52%	51%
Energy content	43%	39%
Process energy	31%	34%
Market value	30%	24%
Displacement	~16%	~20%

- Weight and energy methods no longer used
- Some studies did not consider co-products at all

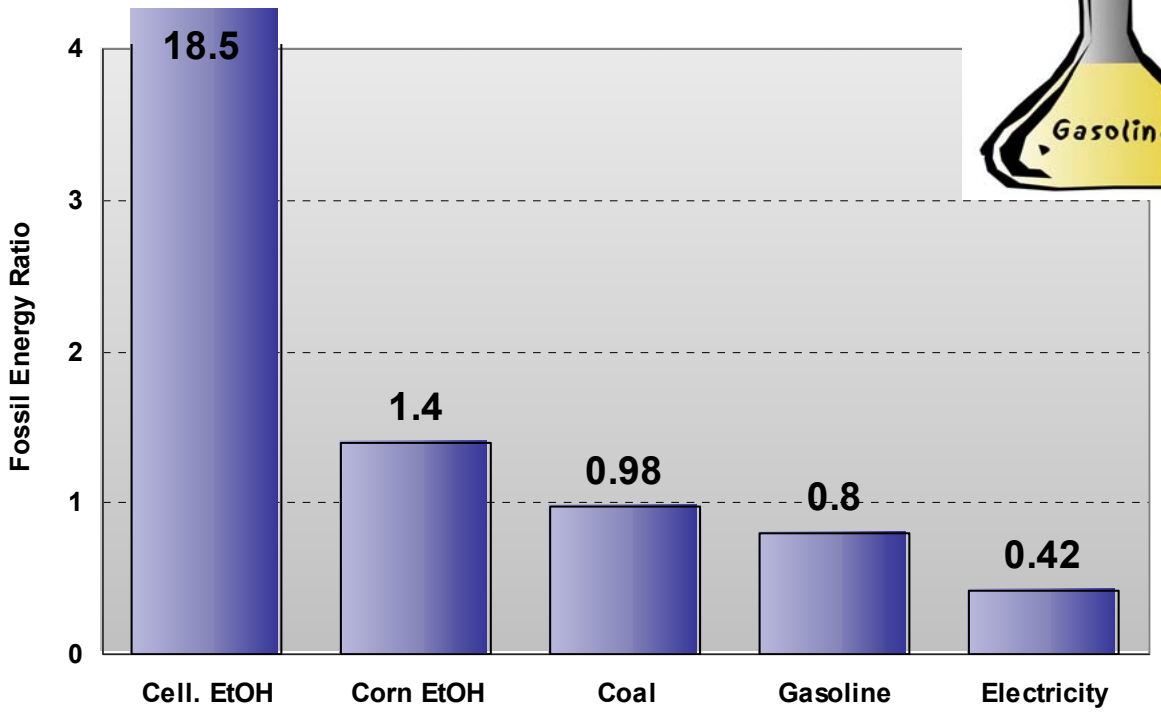
Energy Benefits of Fuel Ethanol Lie in Fossil Energy and Petroleum Use

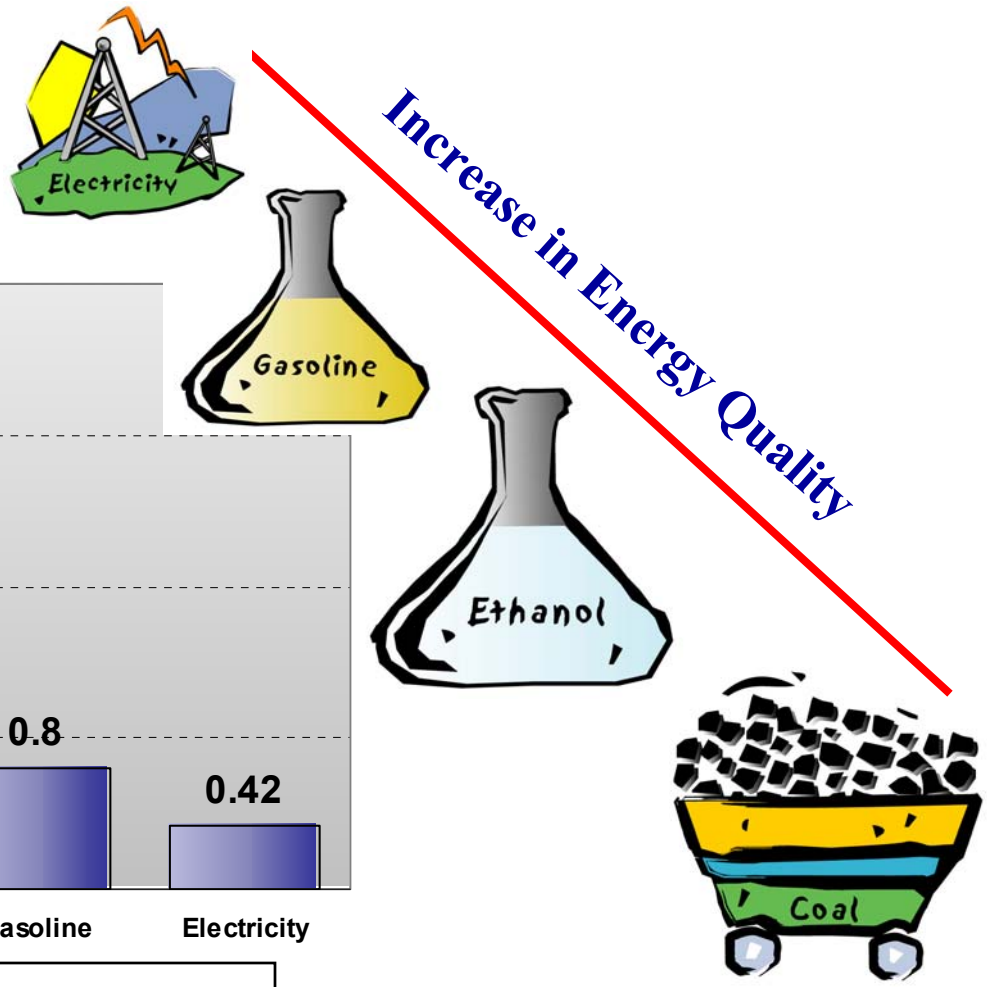


Energy Use for Each Btu of Fuel Used

Energy in Different Fuels Can Have Very Different Qualities

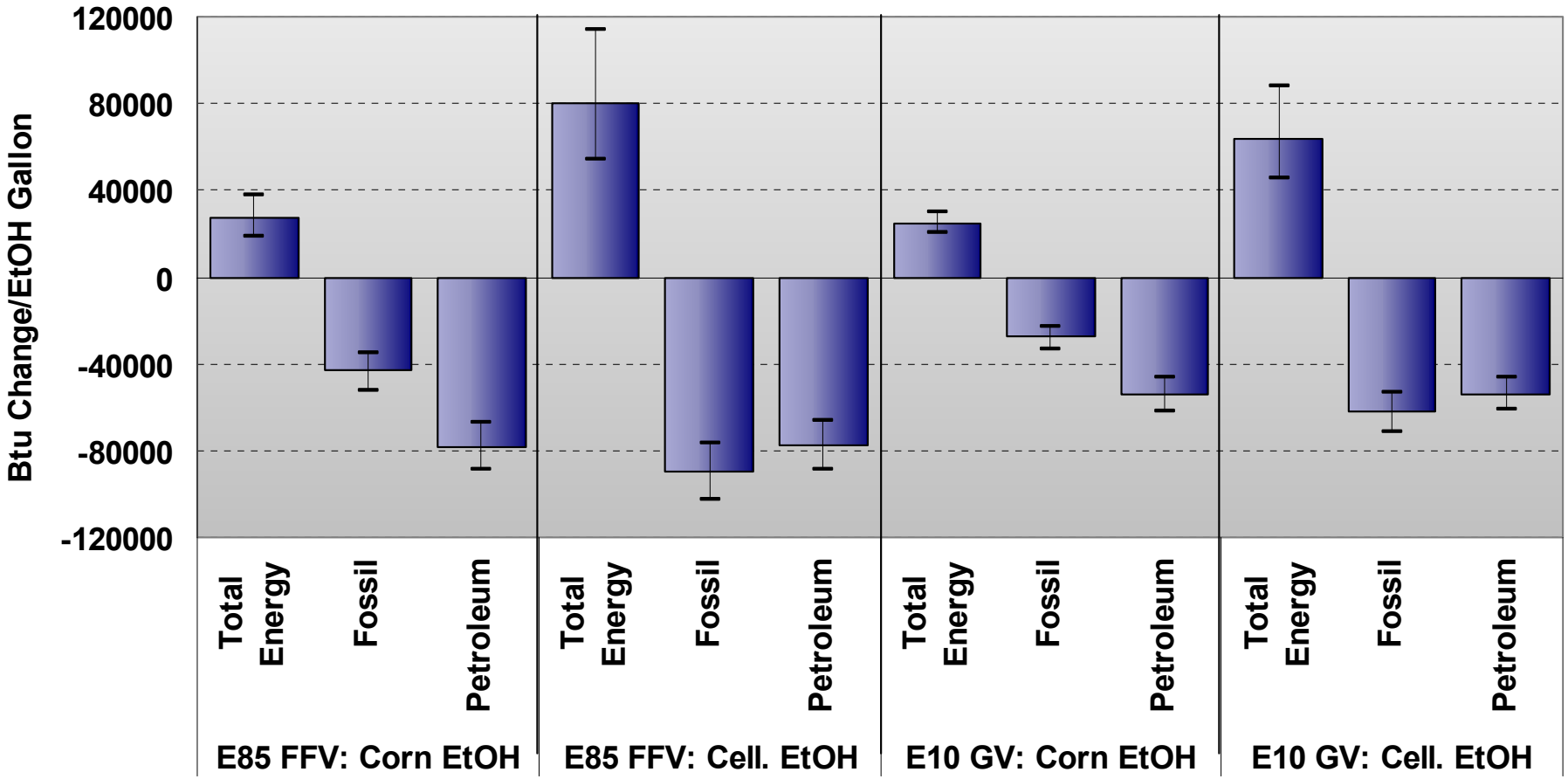
Fossil Energy Ratio (FER) = energy in fuel/fossil energy input



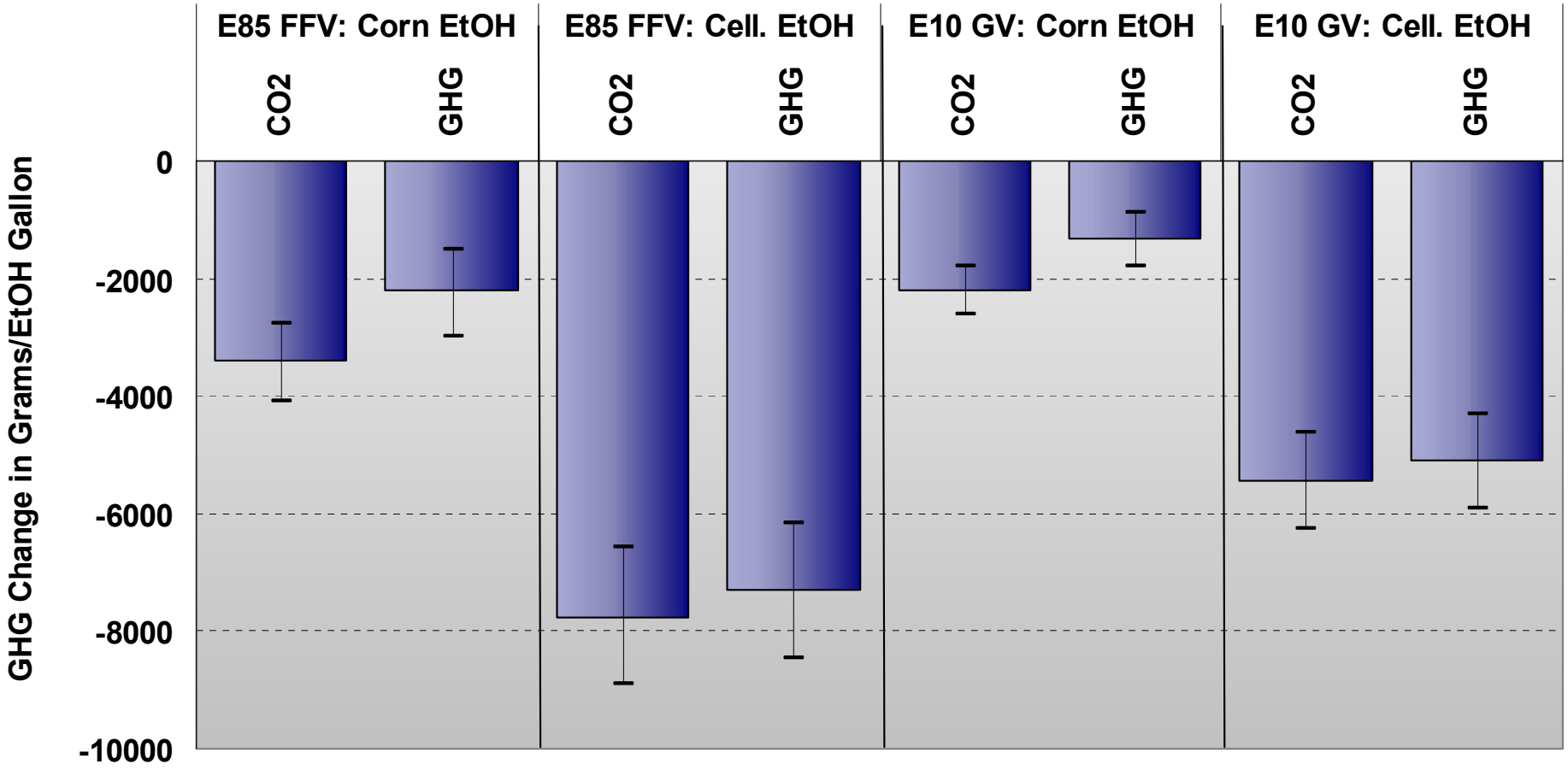


Petroleum energy ratios for ethanol, coal, and electricity are much greater than one.

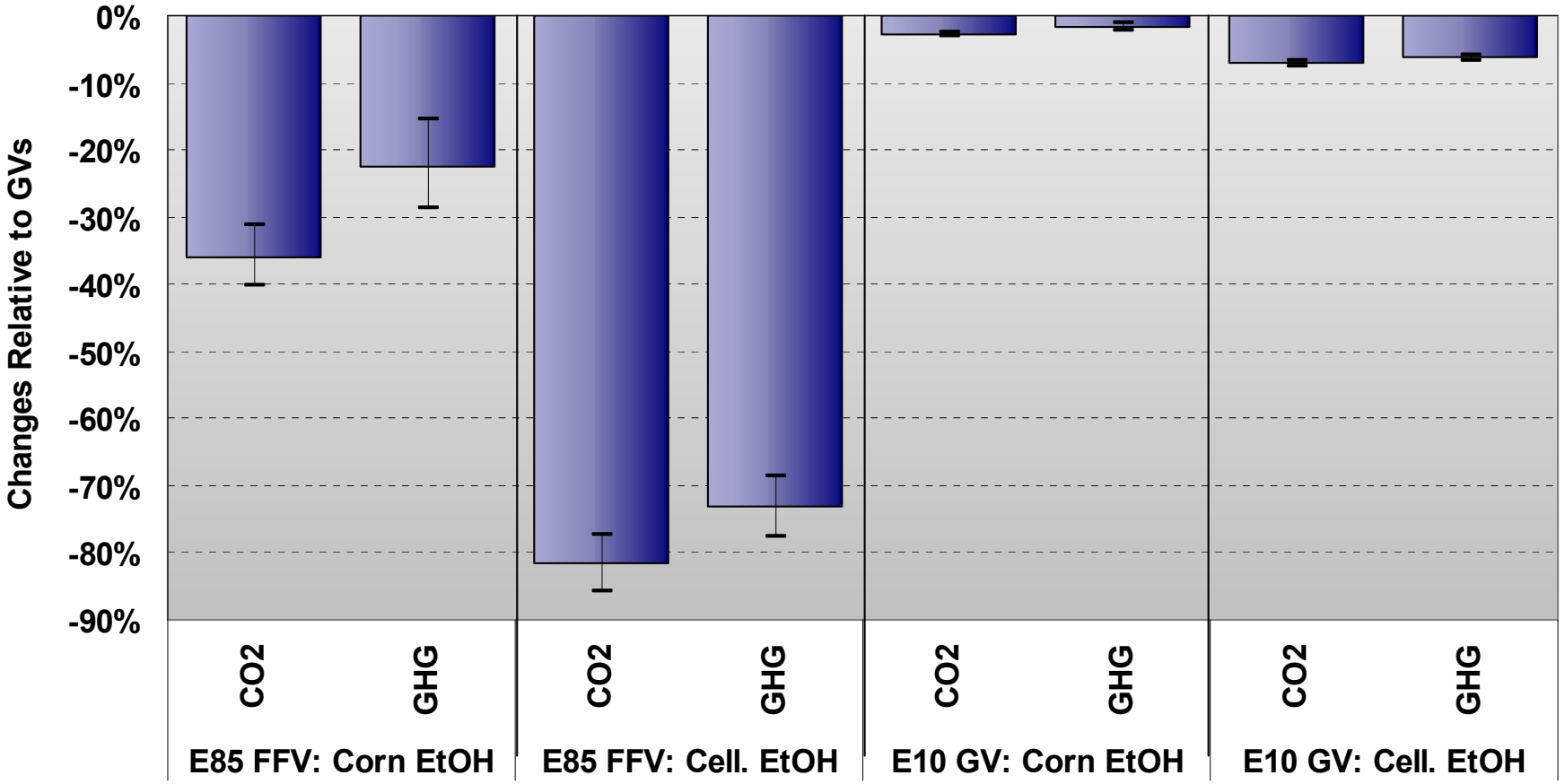
Changes in Energy Use Per Gallon of Ethanol Used (Relative to Gasoline)



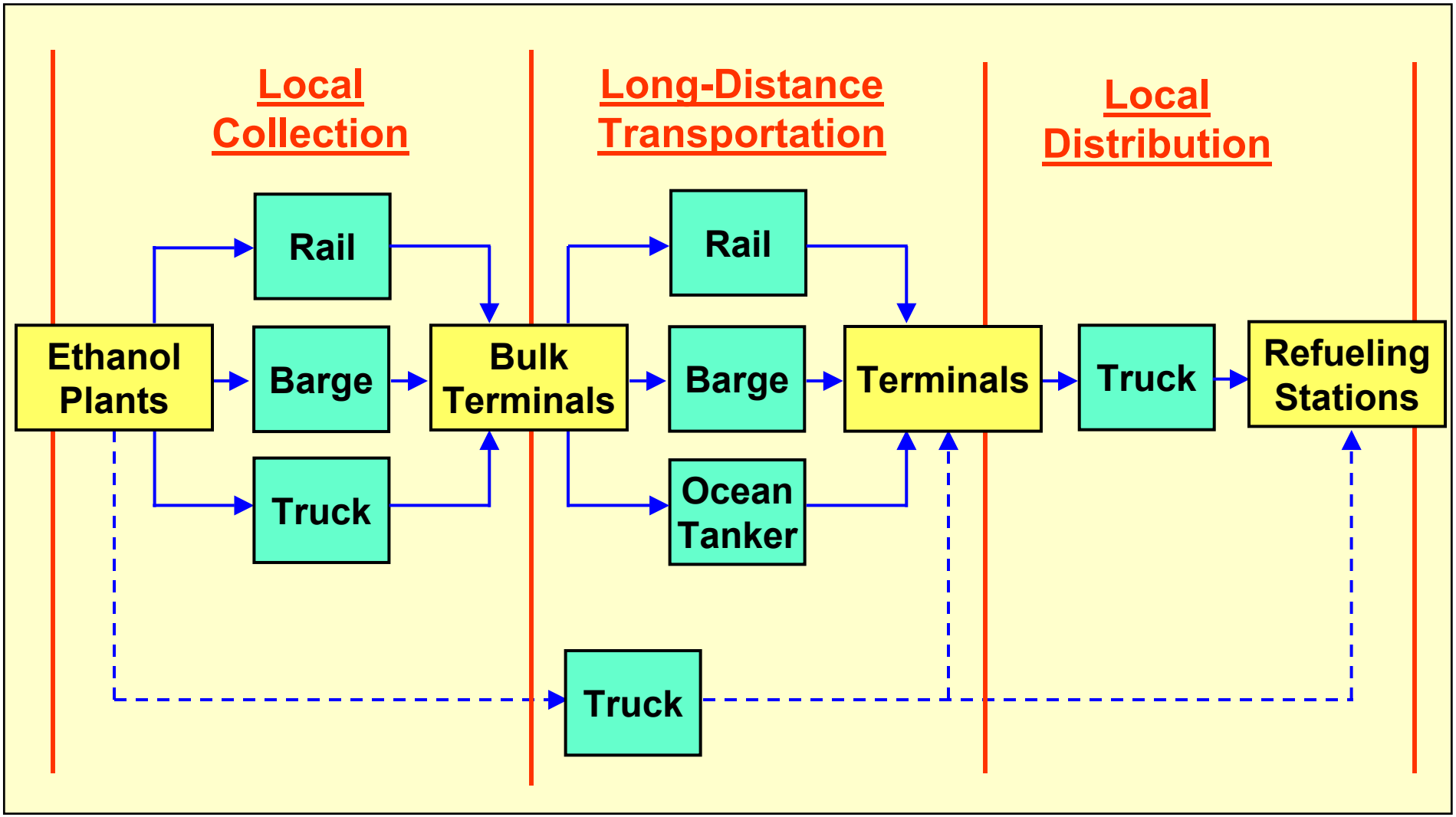
Changes in Greenhouse Gas Emissions per Gallon of Ethanol Used (Relative to Gasoline)



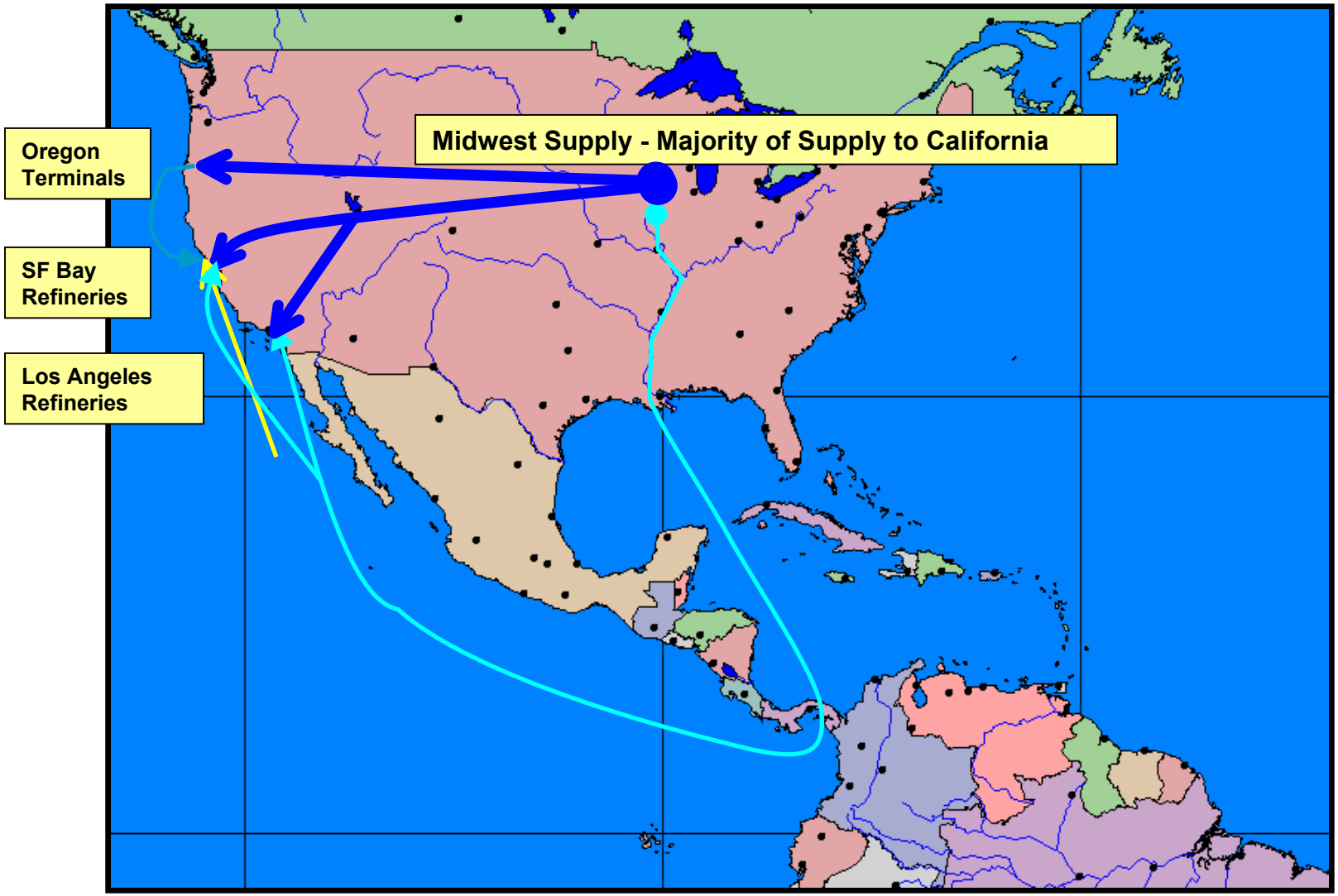
Changes in Greenhouse Gas Emissions per Mile Driven (Relative to GVs)



Transportation Logistics Can Affect Ethanol Emissions

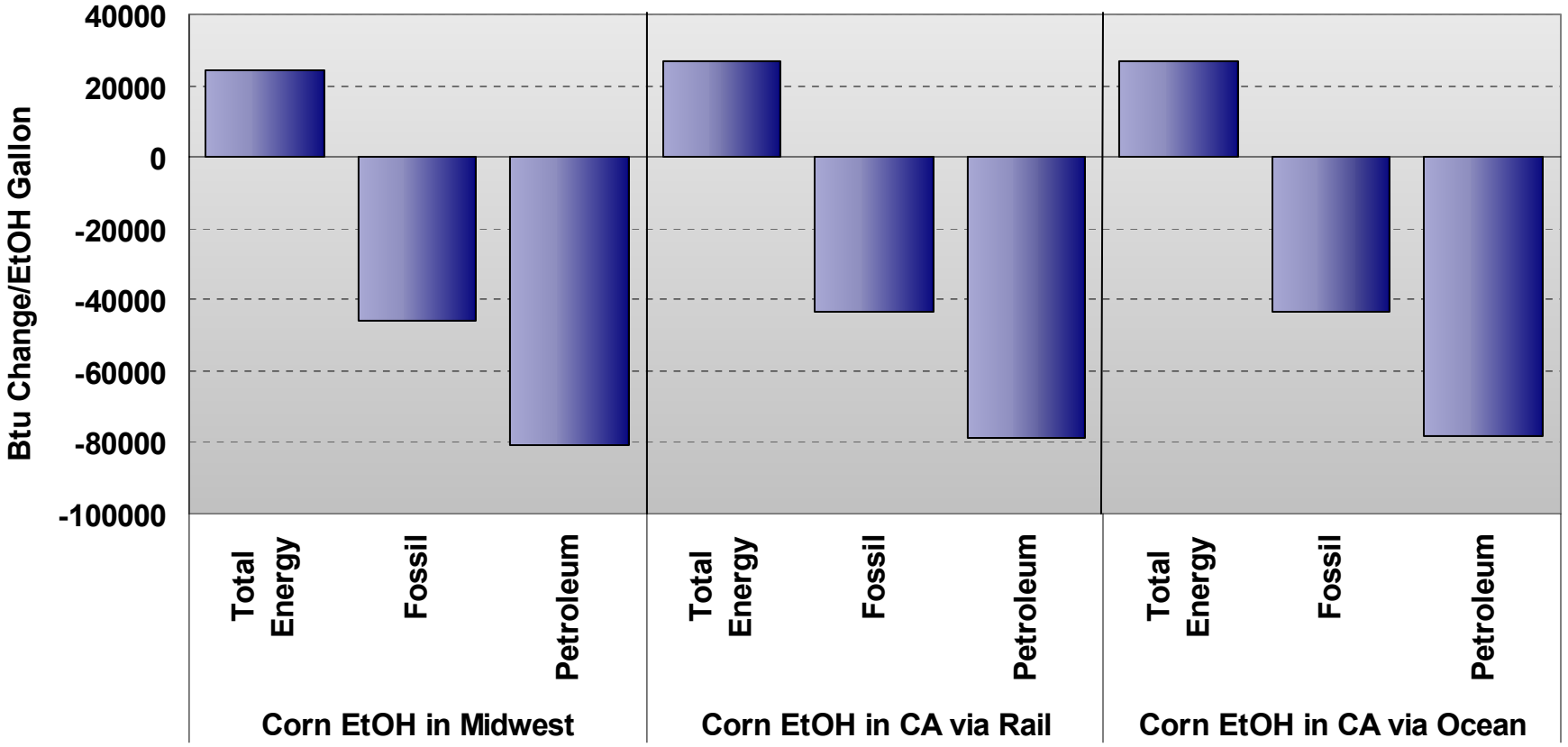


Transportation of Midwest Ethanol to California is Accomplished via Rail and Ocean



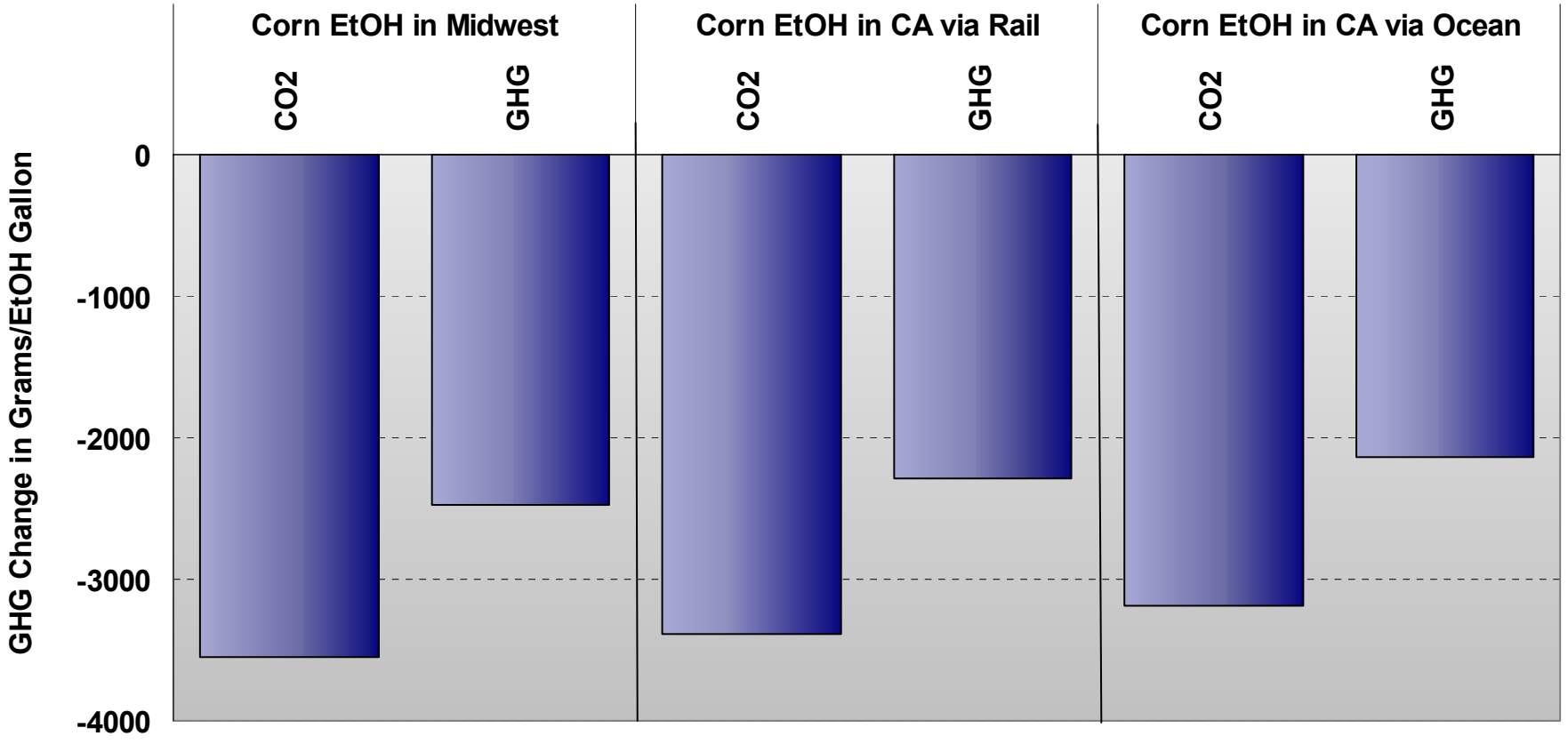
Based on Pat Perez of CEC.

Changes in Energy Use by Corn Ethanol: Midwest Use vs. California Use



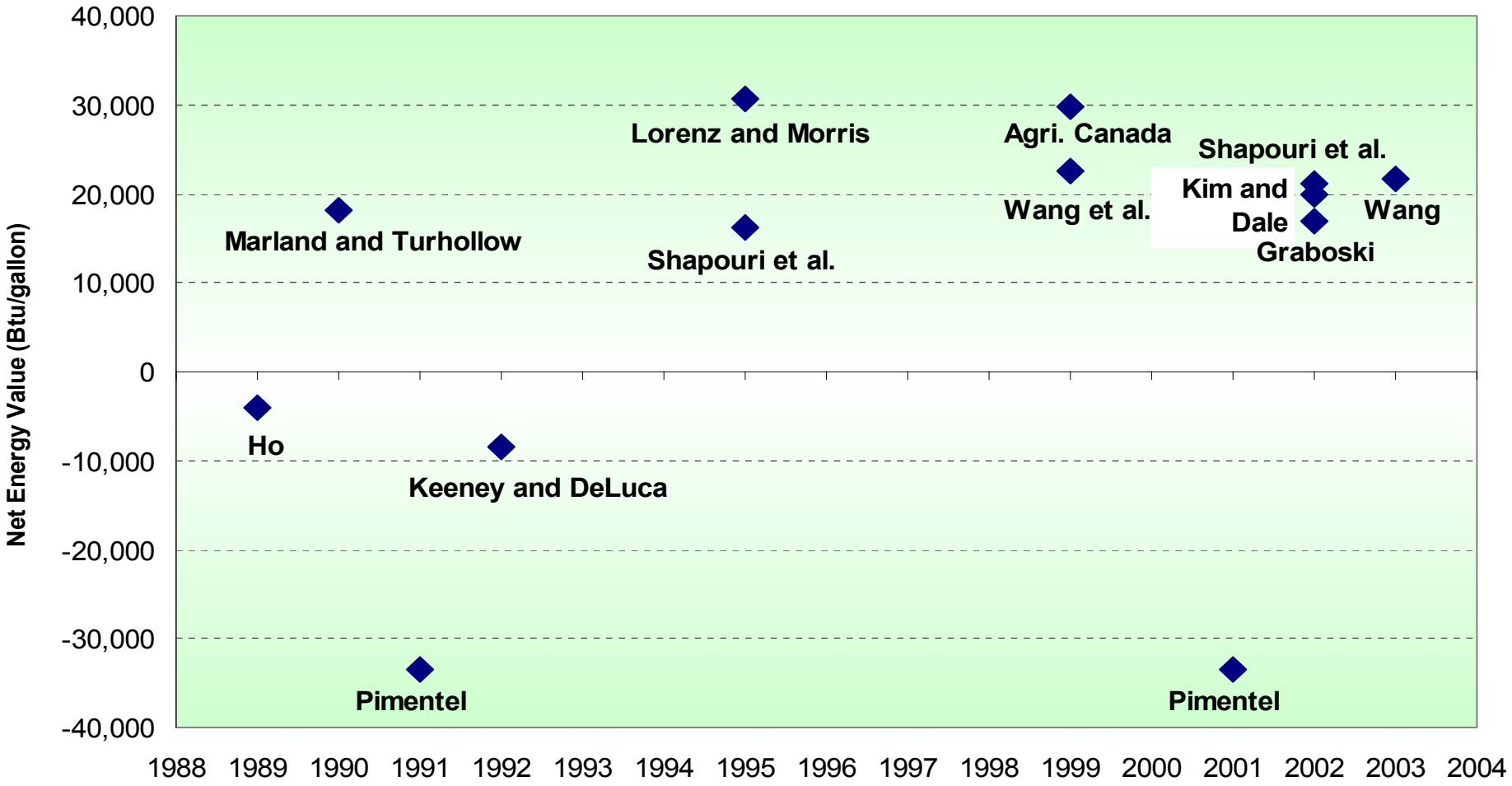
Results are based ethanol in E85

Changes in Greenhouse Gas Emissions by Corn Ethanol: Midwest Use vs. California Use

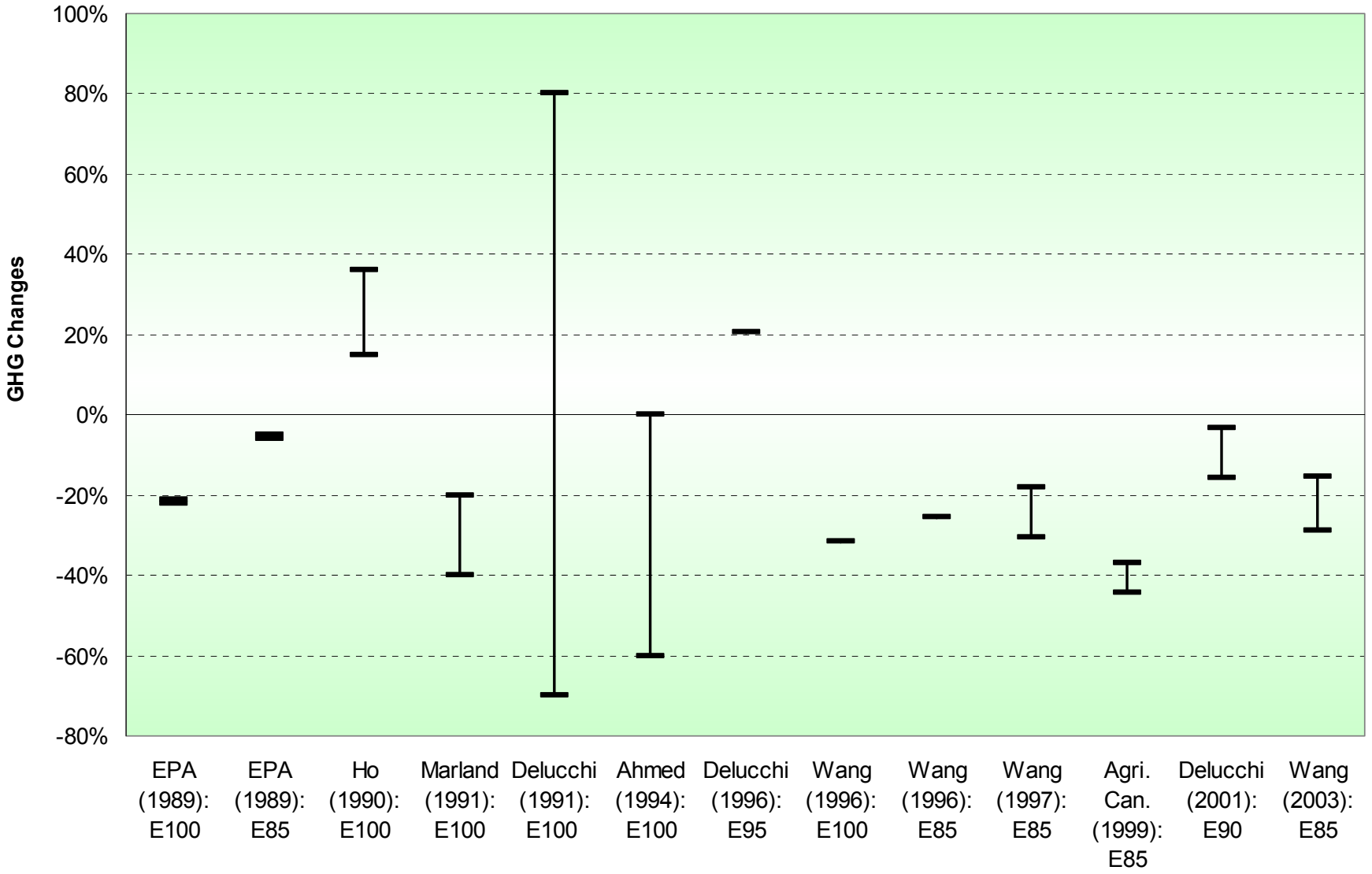


Results are based ethanol in E85

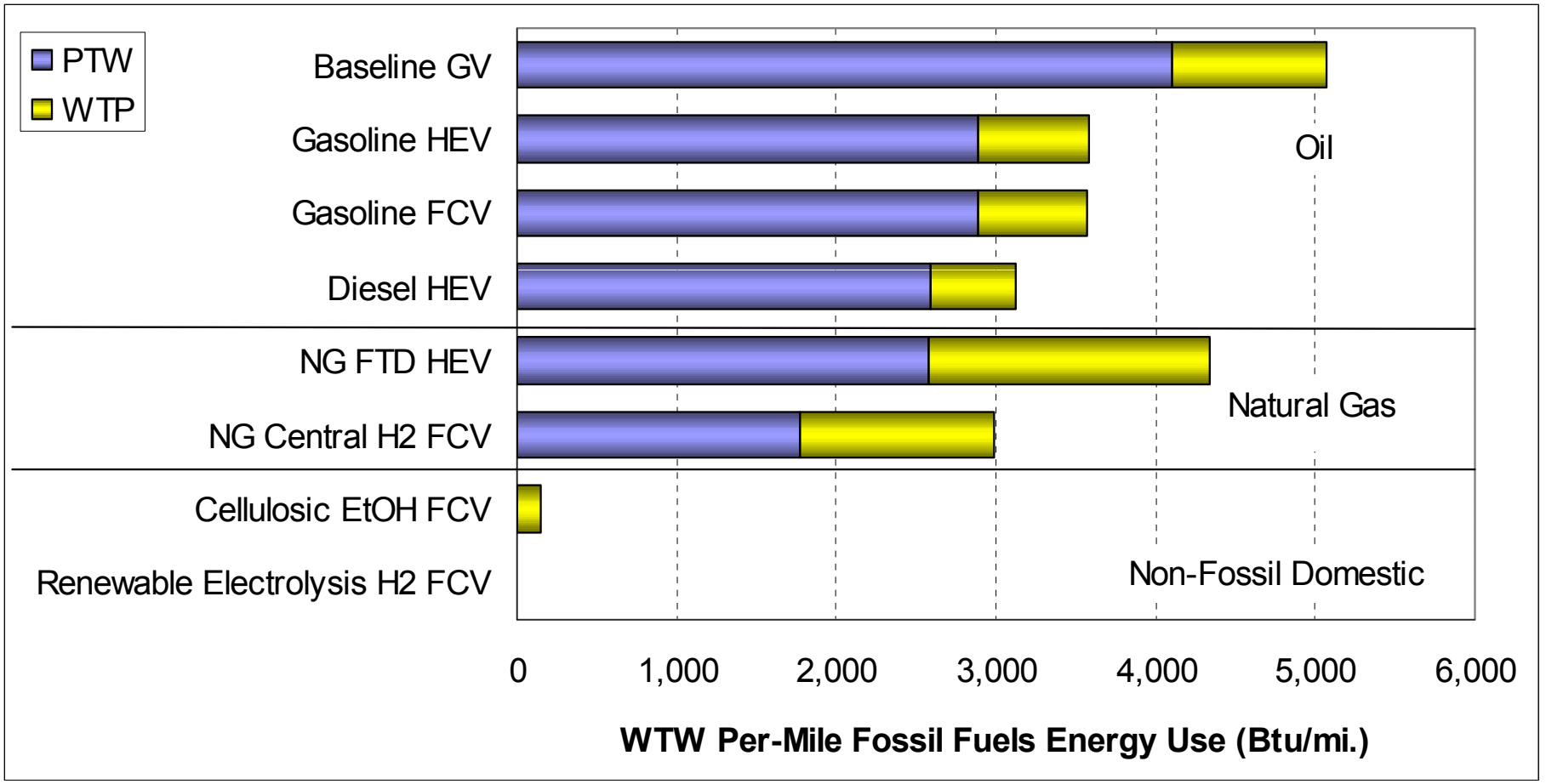
Energy Balance of Ethanol Results Among Studies



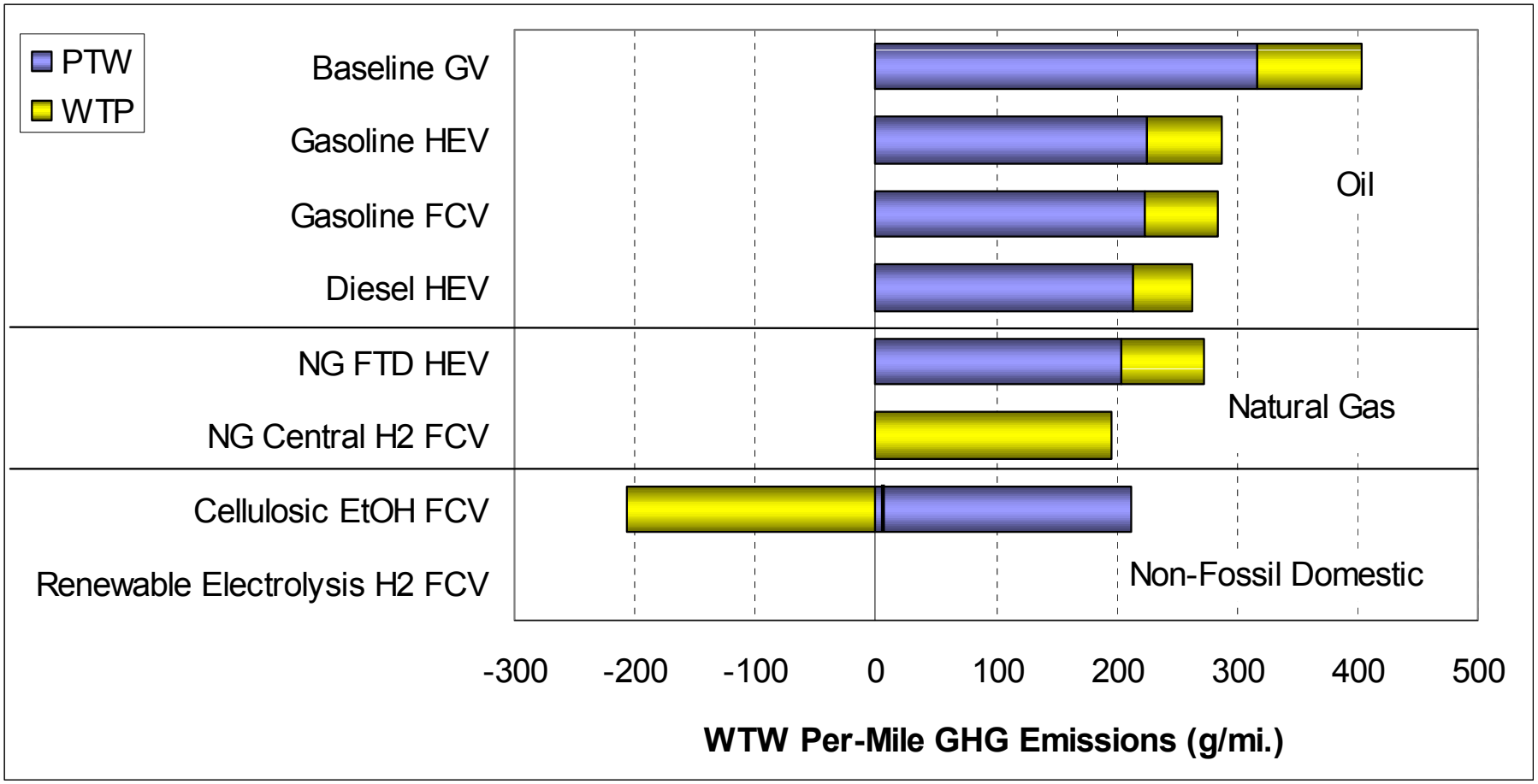
Ethanol GHG Emission Changes Among Studies



In long Run, Cellulosic Ethanol Could Play an Important Role in Energy Benefits



Cellulosic Ethanol Could Also Play an Important Role in GHG Reductions



Conclusions

- Any type of fuel ethanol helps substantially reduce transportation's fossil energy and petroleum use
- Though studies now show that ethanol has positive energy balance values, energy balance values alone are not meaningful
- Corn-based fuel ethanol achieves moderate reductions in GHG emissions
- Cellulosic ethanol will achieve much greater energy and GHG benefits

Some WTW Analysis Issues Need to Be Noted

- Multiple products
  - System expansion vs. allocation (GREET takes both)
  - System expansion: allocation vs. attribution of effects
- Technology advancement over time
  - Current vs. emerging technologies – leveling comparison field
  - Static snap shot vs. dynamic simulations of evolving technologies and market penetration over time
- Dealing with uncertainties
  - Risk assessment vs. sensitivity analysis
  - Regional differences, e.g, CA vs. the rest of the U.S.
- Trade-offs of impacts
- WTW results are better for identifying problems than for giving the answers