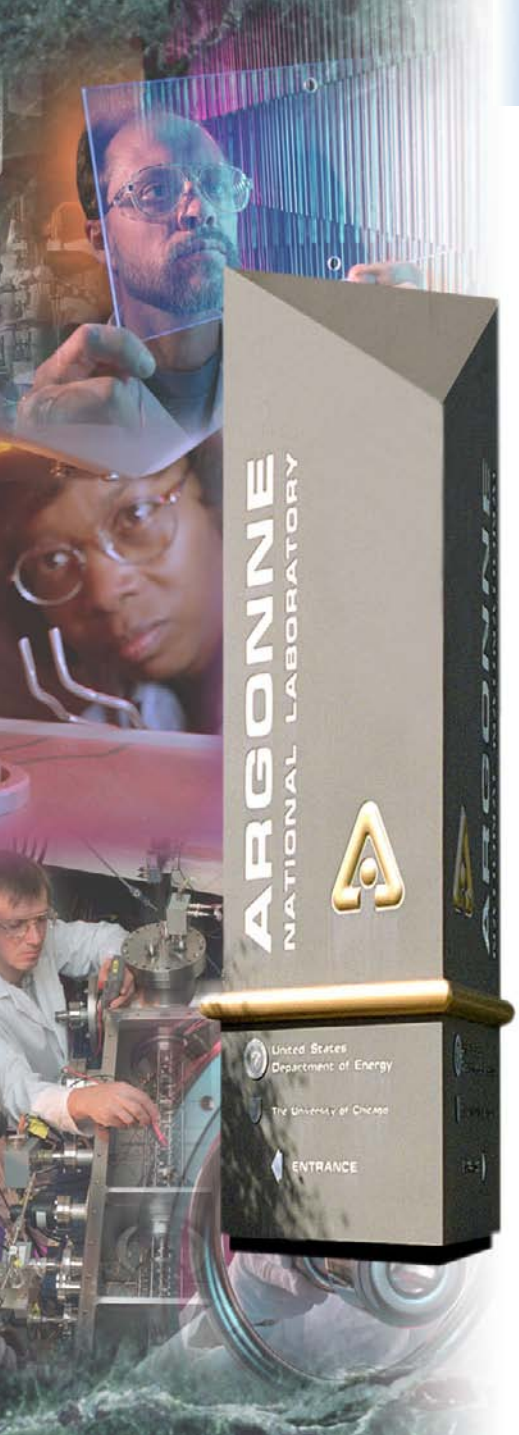


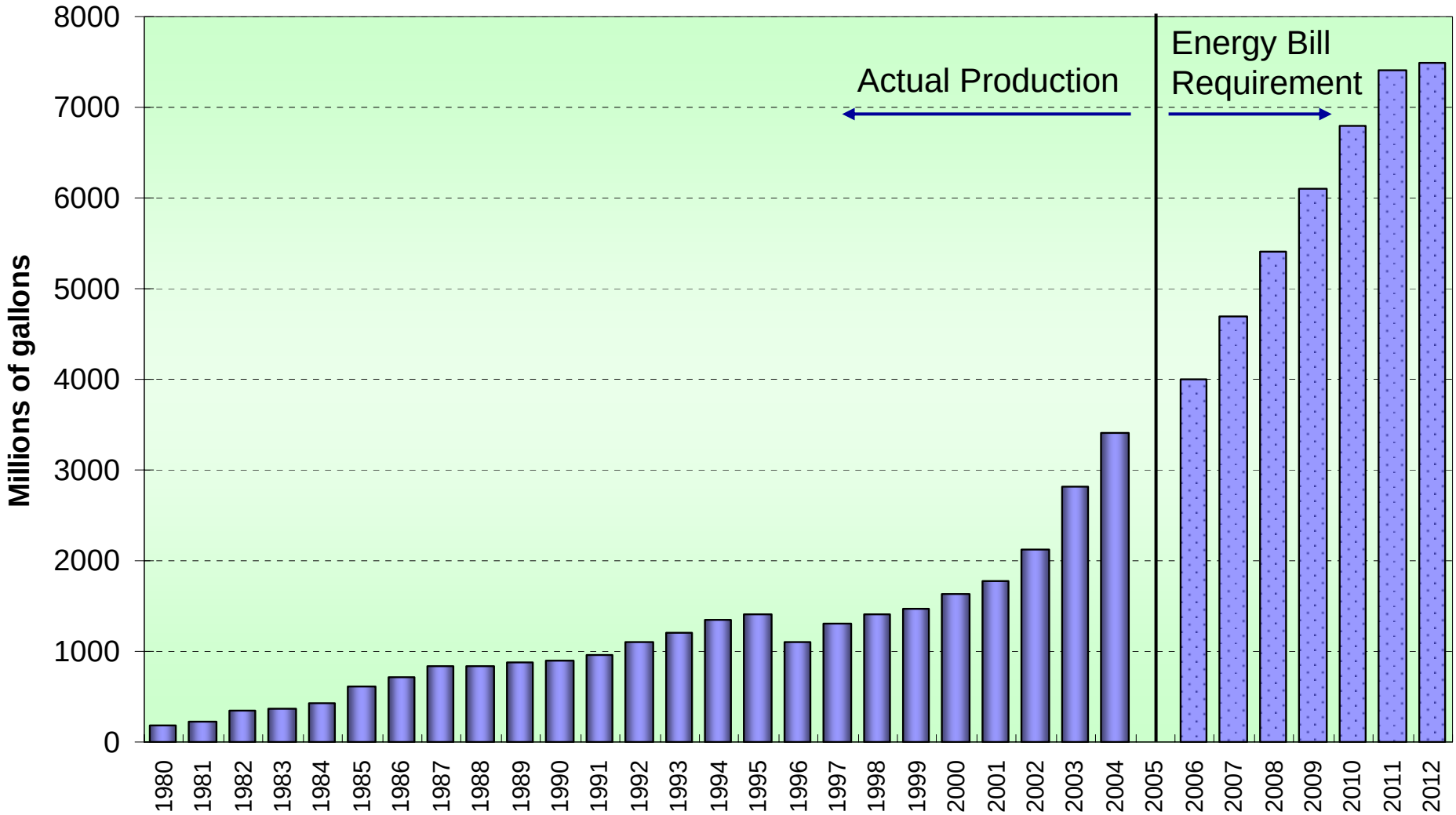
Updated Energy and Greenhouse Gas Emissions Results of Fuel Ethanol

Michael Wang
Center for Transportation Research
Energy Systems Division
Argonne National Laboratory

The 15th International Symposium on Alcohol Fuels
San Diego, CA
September 26-28, 2005

Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

U.S. Fuel Ethanol Production Has Experienced Large Increases, and the Trend Will Continue

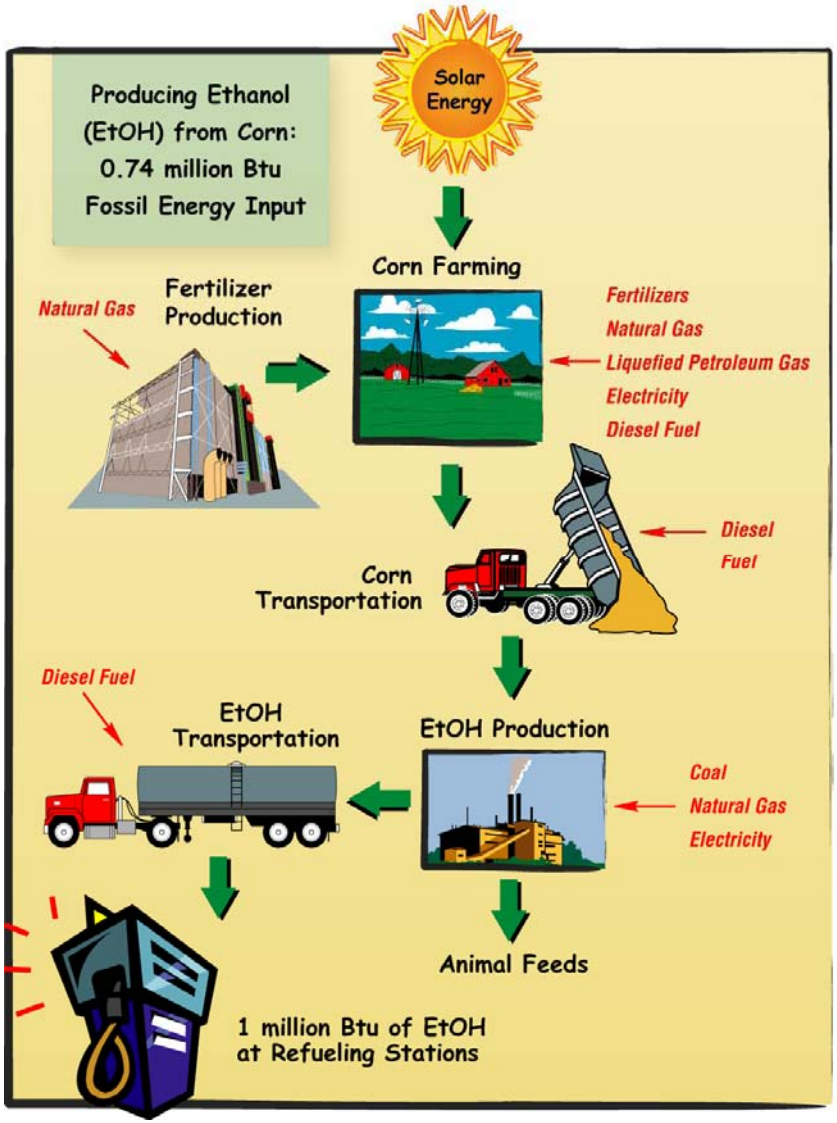


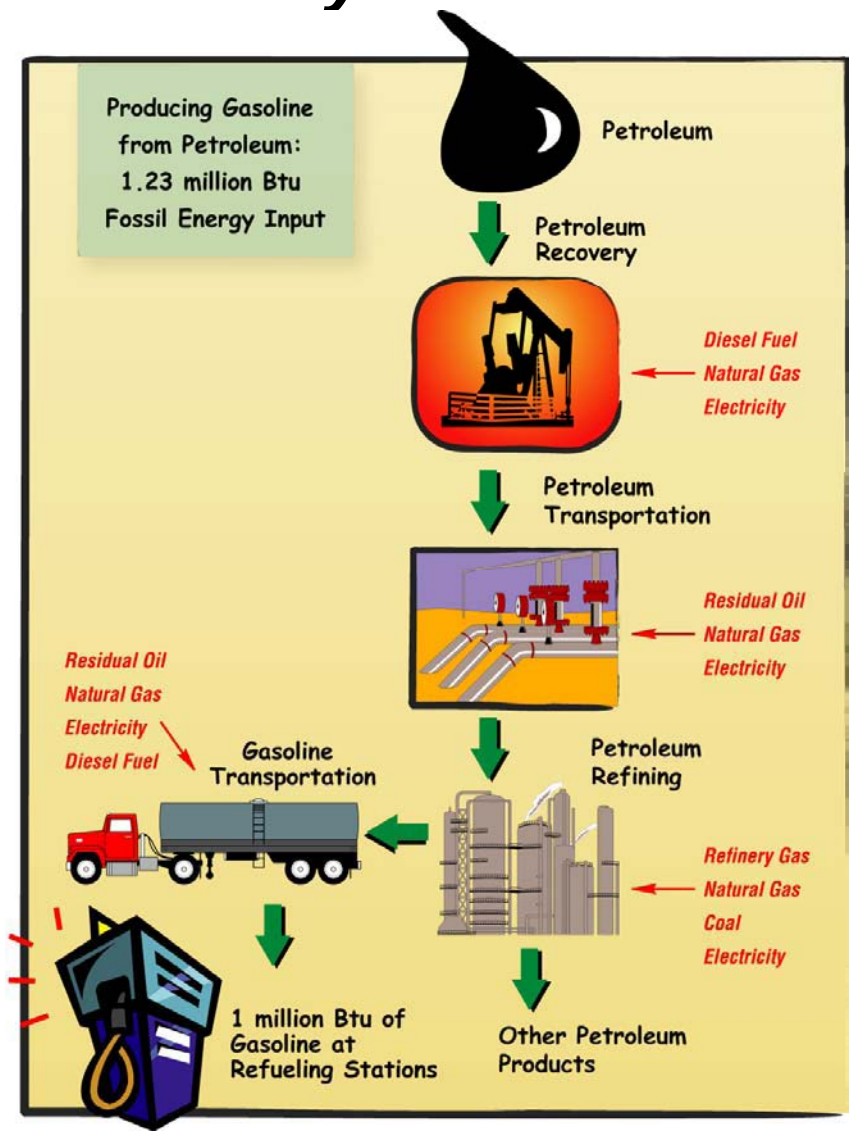
Source: Renewable Fuels Association

Argonne Has Conducted Life Cycle Analyses of Transportation Fuels for More Than 25 Years

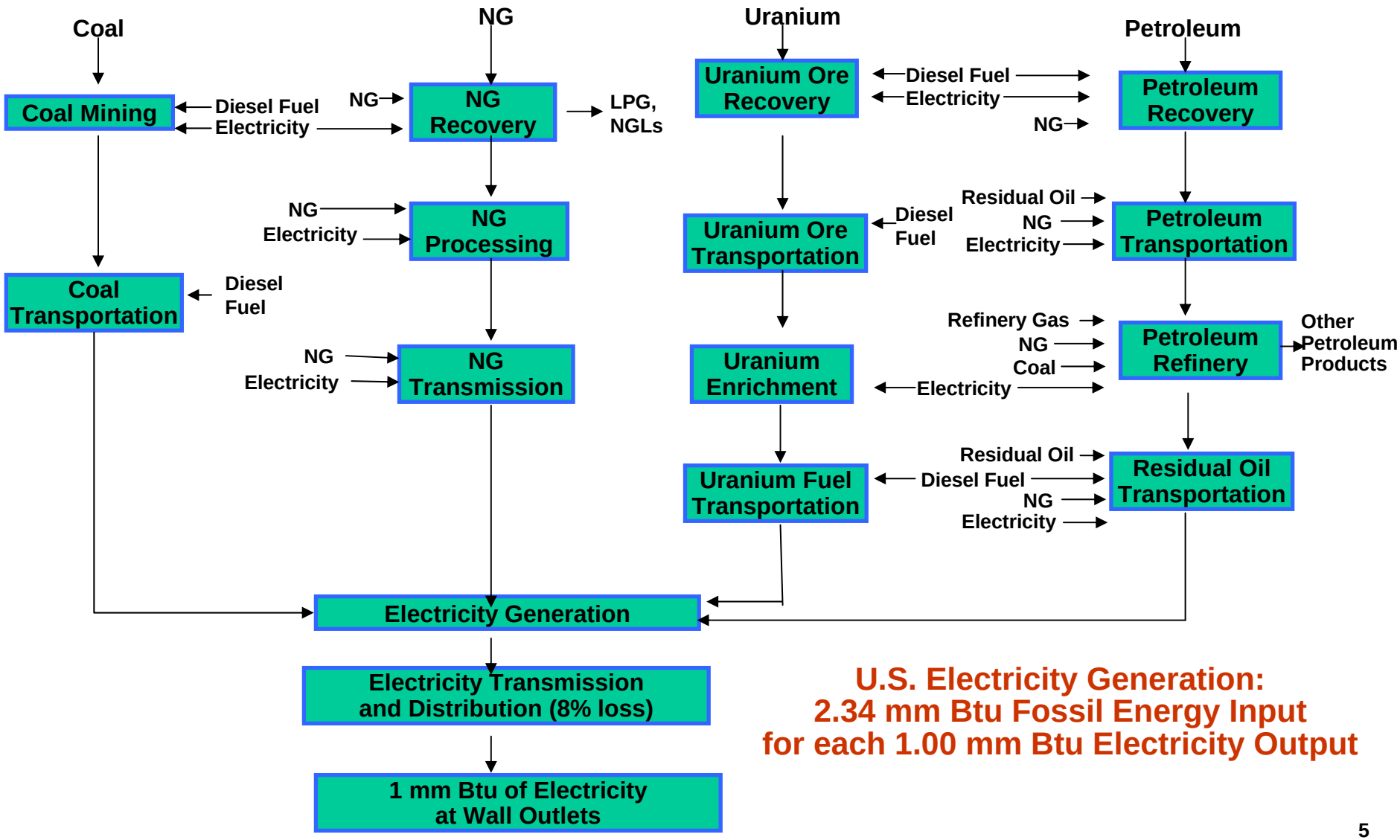
- Its Center for Transportation Research has analyzed energy and emission effects of transportation fuels for DOE since 1980s
- With DOE support, Argonne began to develop the GREET model in 1995
  - GREET is a life cycle model for transportation fuels and vehicle technologies
  - It contains more than 85 transportation fuel pathways including four fuel ethanol pathways
  - GREET is in the public domain; there are more than 2,000 registered users worldwide
- Since 1997, Argonne has used GREET to evaluate fuel ethanol's energy and emission effects; this presentation summarizes updated GREET results for fuel ethanol

Comparative Results Between Ethanol and Gasoline Are More Relevant to Policy Debate





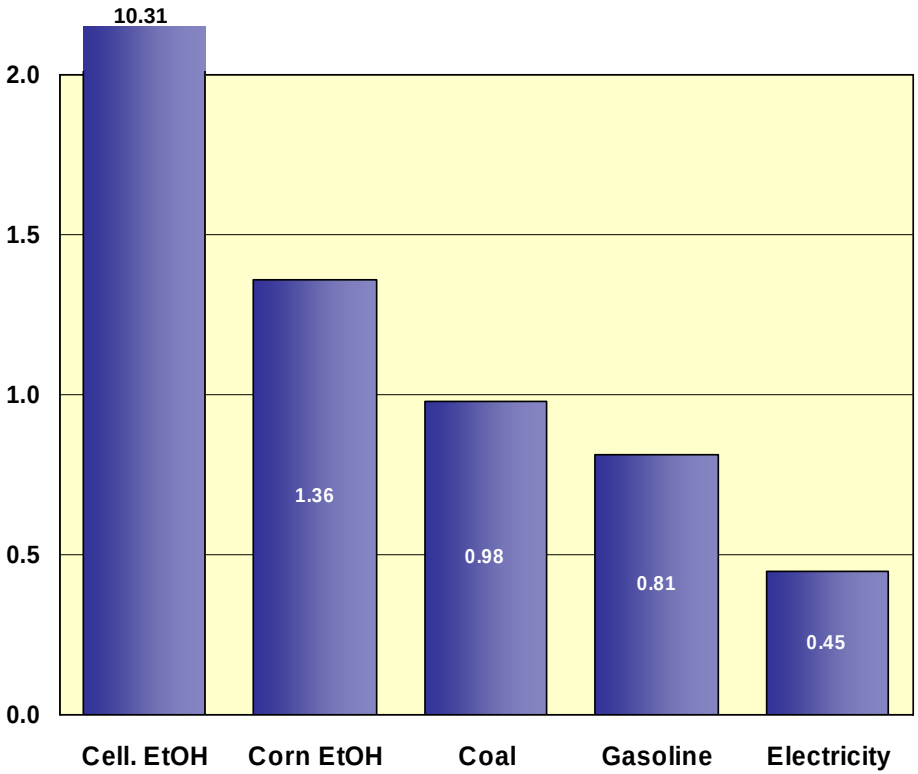
Even Though Electricity Has a Large Negative Net Energy Balance, There Is No Substitute for Its Main Uses

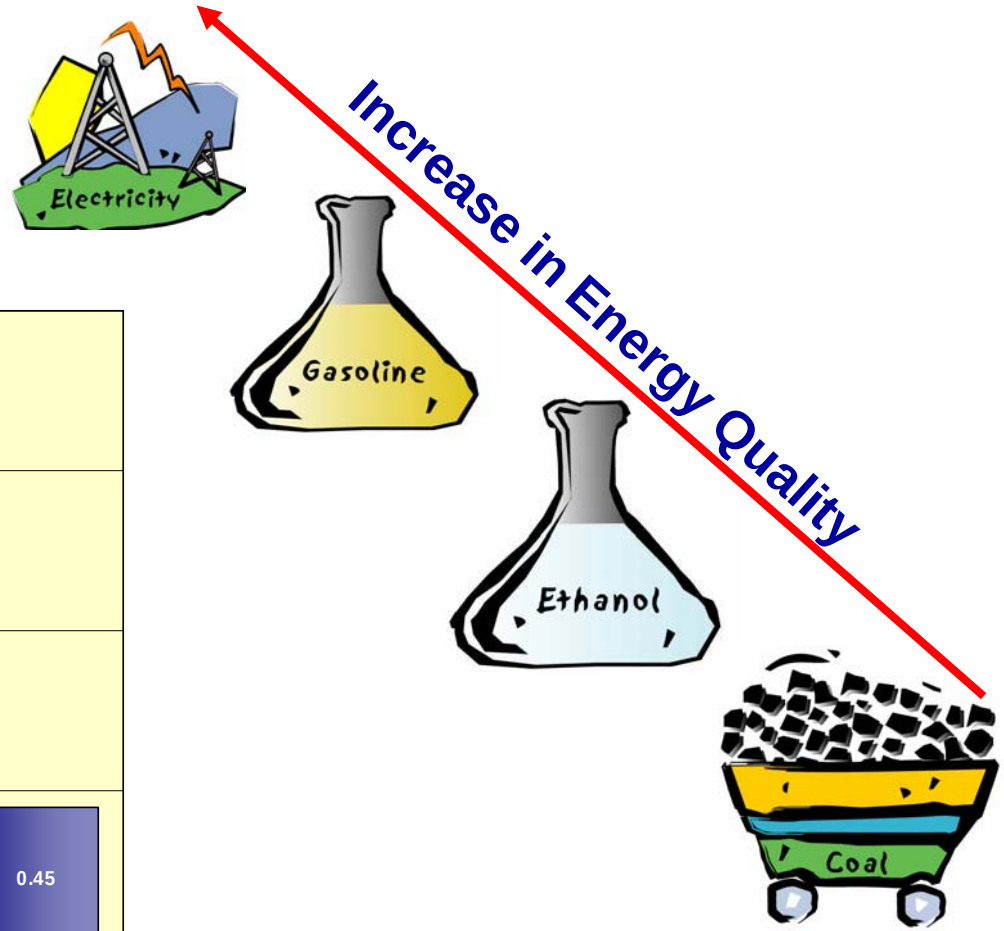


U.S. Electricity Generation:
2.34 mm Btu Fossil Energy Input
for each 1.00 mm Btu Electricity Output

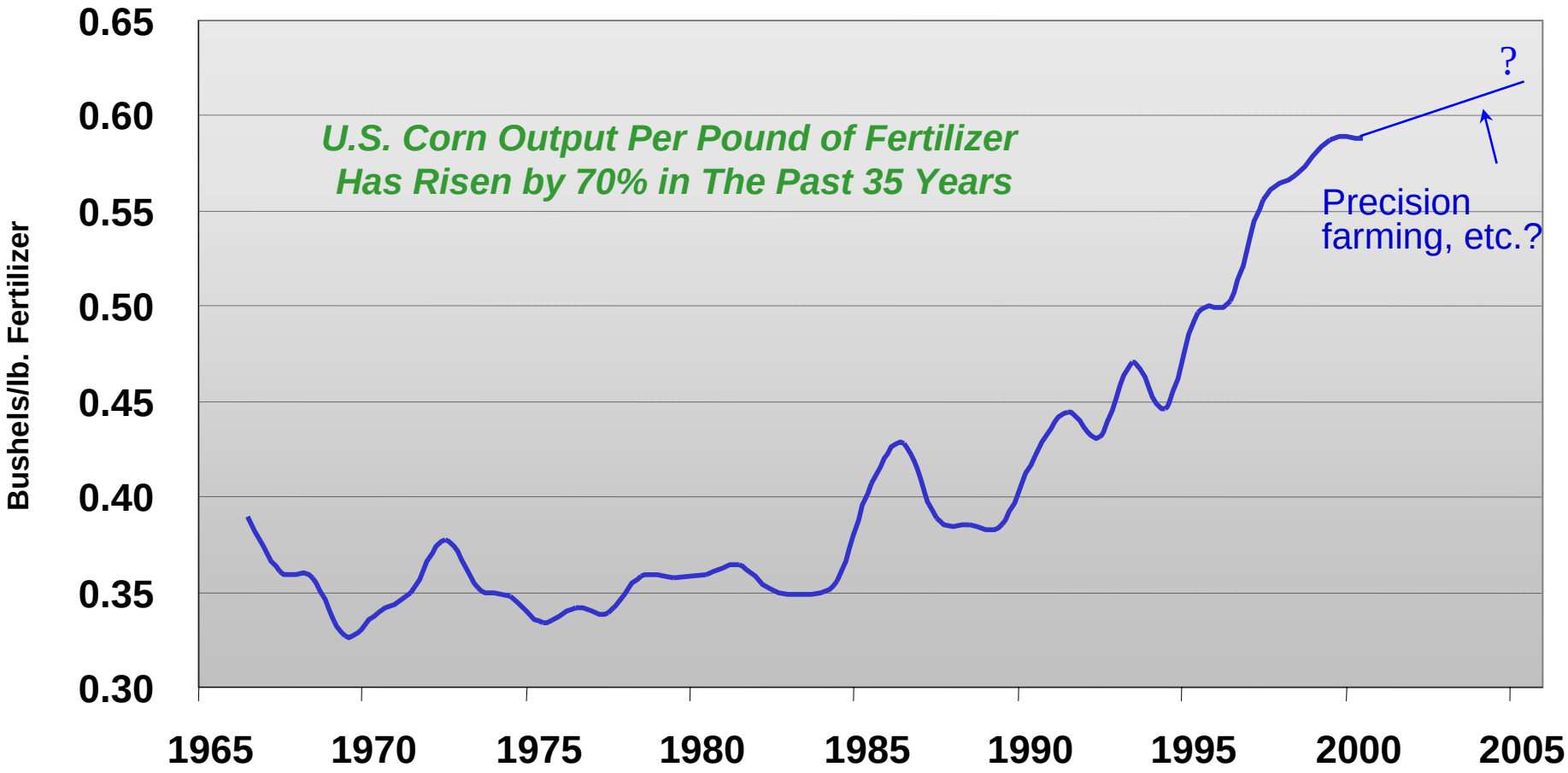
Energy in Different Fuels Can Have Very Different Qualities

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



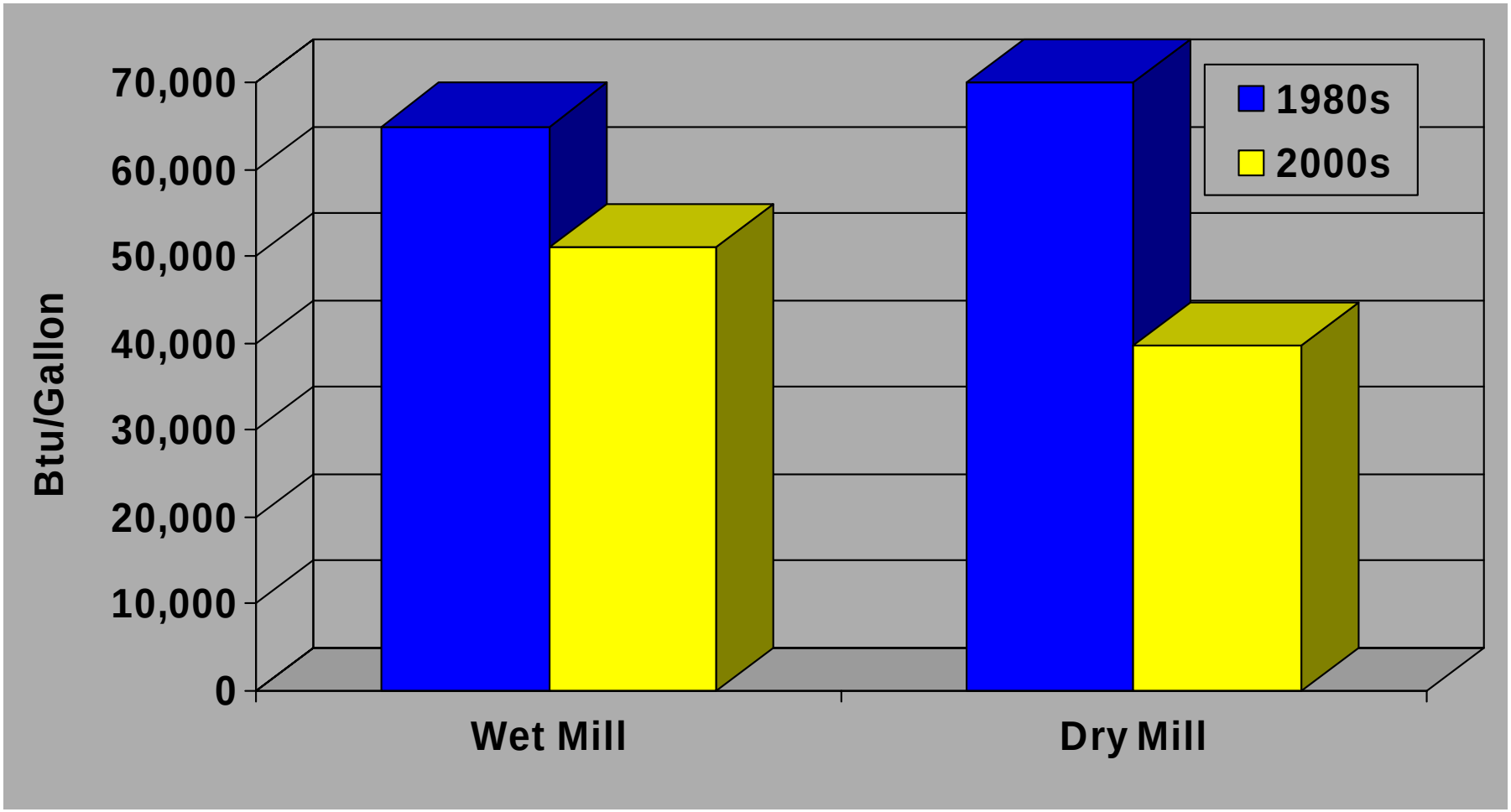


Accurate Ethanol Energy Analysis Must Account for Increased Productivity in Farming Over Time



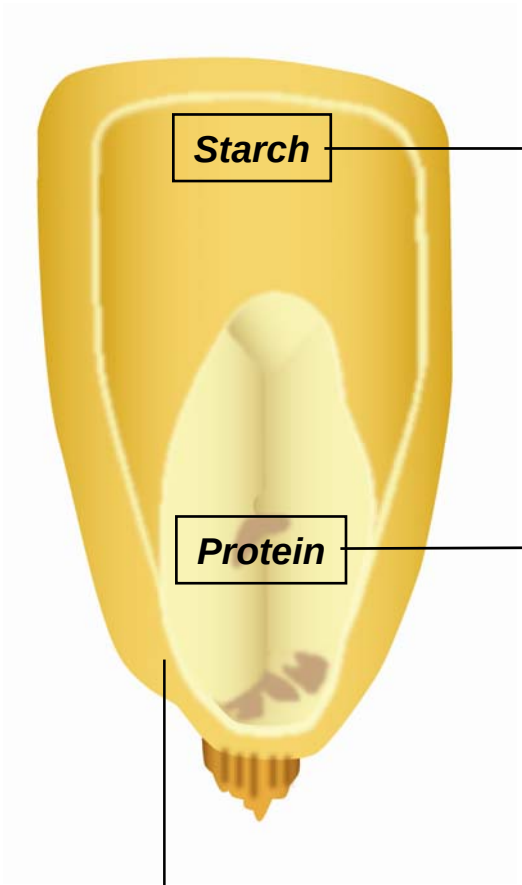
Based on historical USDA data; results are 3-year moving averages

Improved Technology Has Reduced Energy Use and Operating Costs in Corn Ethanol Plants



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

One-Third of Corn Kernel Mass Ends as Animal Feed (a Co-Product) in Ethanol Plants

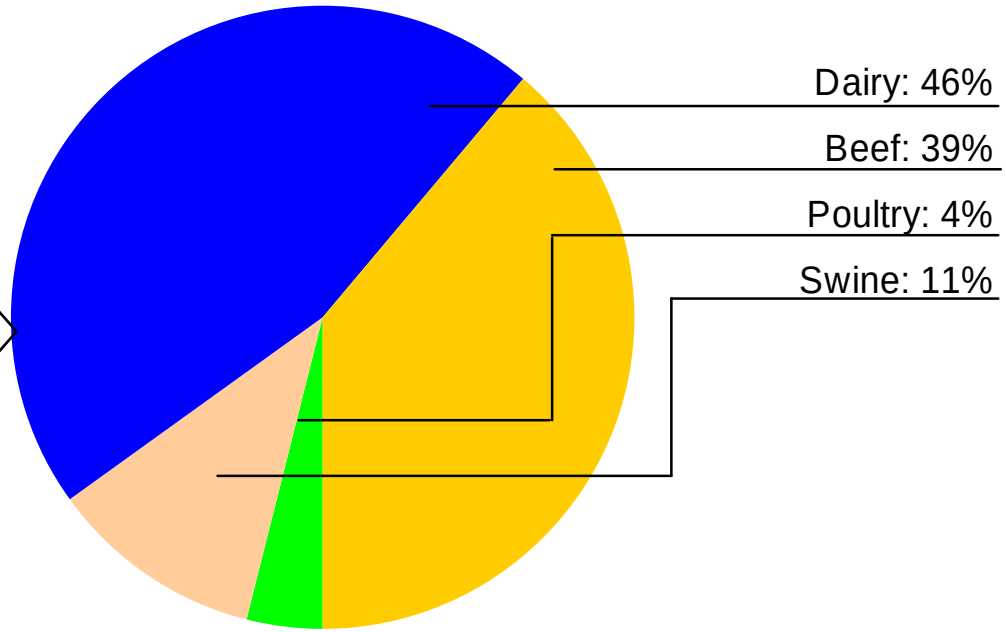


Starch → Ethanol

Protein → Distillers Dry Grains and Solubles (DDGS)

Carbon Dioxide

2003 North American DDGS Consumption



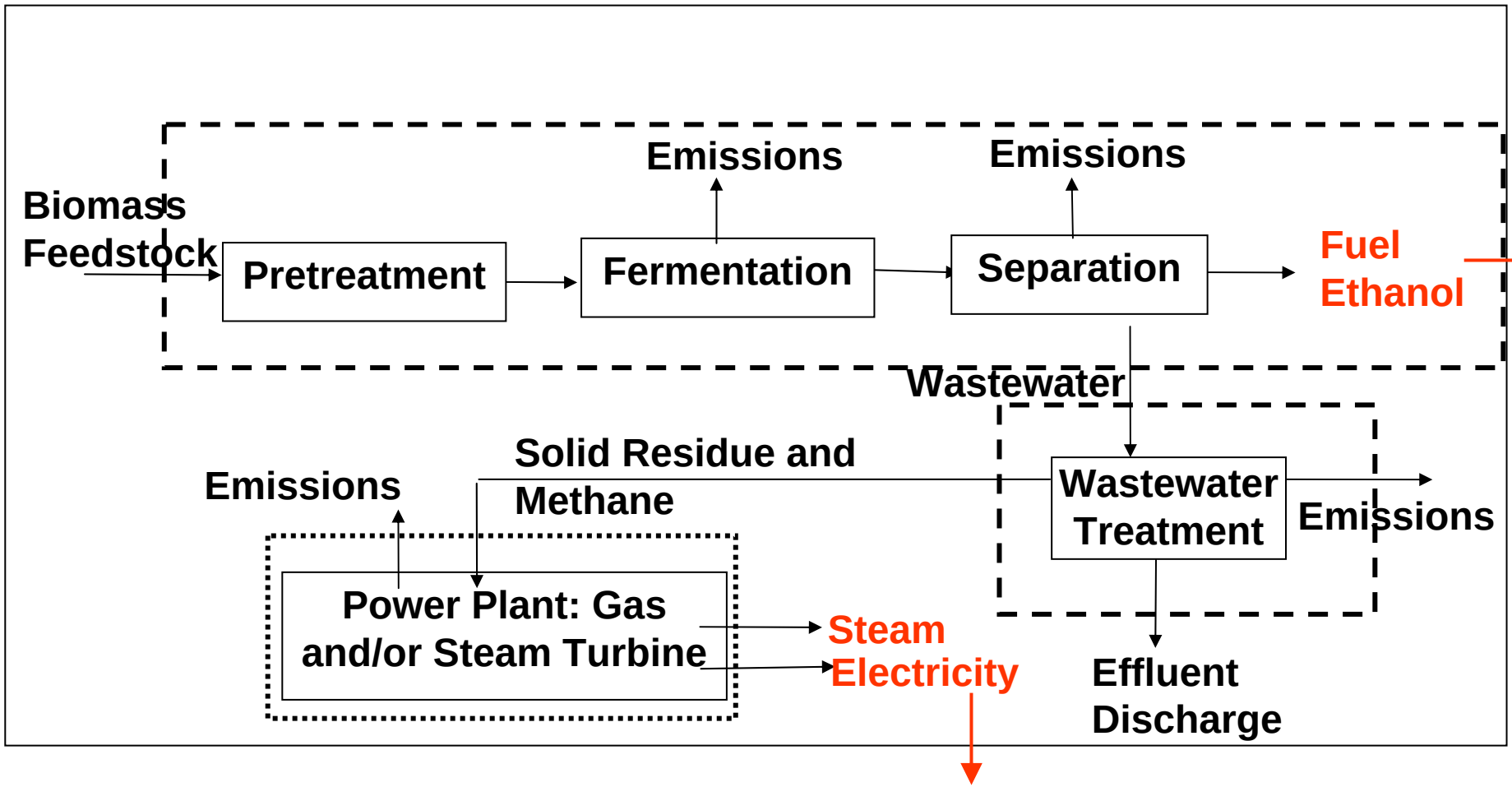
Source: Commodity Specialist Co. (in RFA, 2005)

Accounting for Animal Feed Is a Critical Factor in Ethanol's Lifecycle Analysis

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

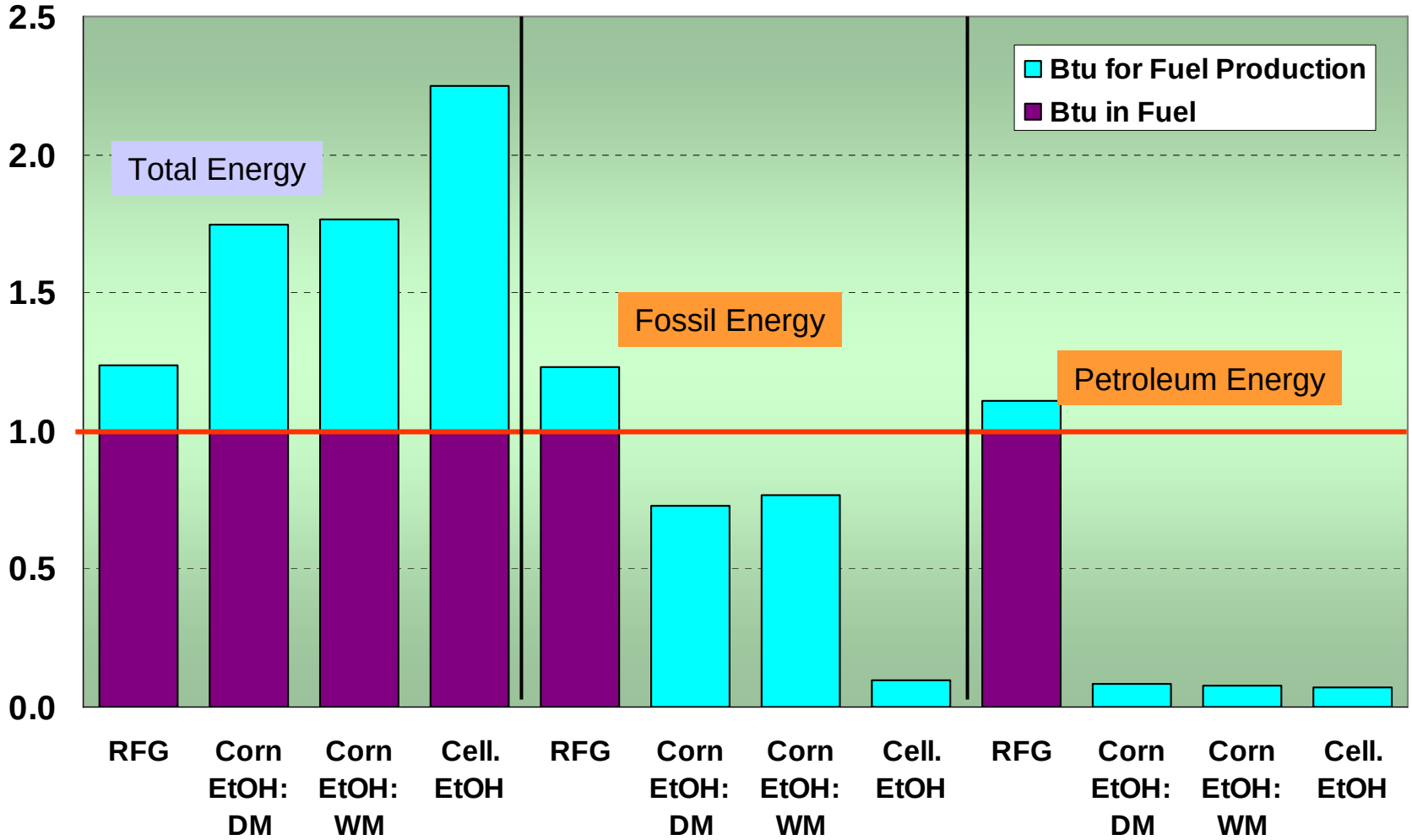
- Weight and energy methods are no longer used
- Argonne uses the displacement method, the most conservative approach
- Some studies do not consider co-products at all

Cellulosic Ethanol Plants Will Be Significantly More Efficient than Corn Ethanol Plants



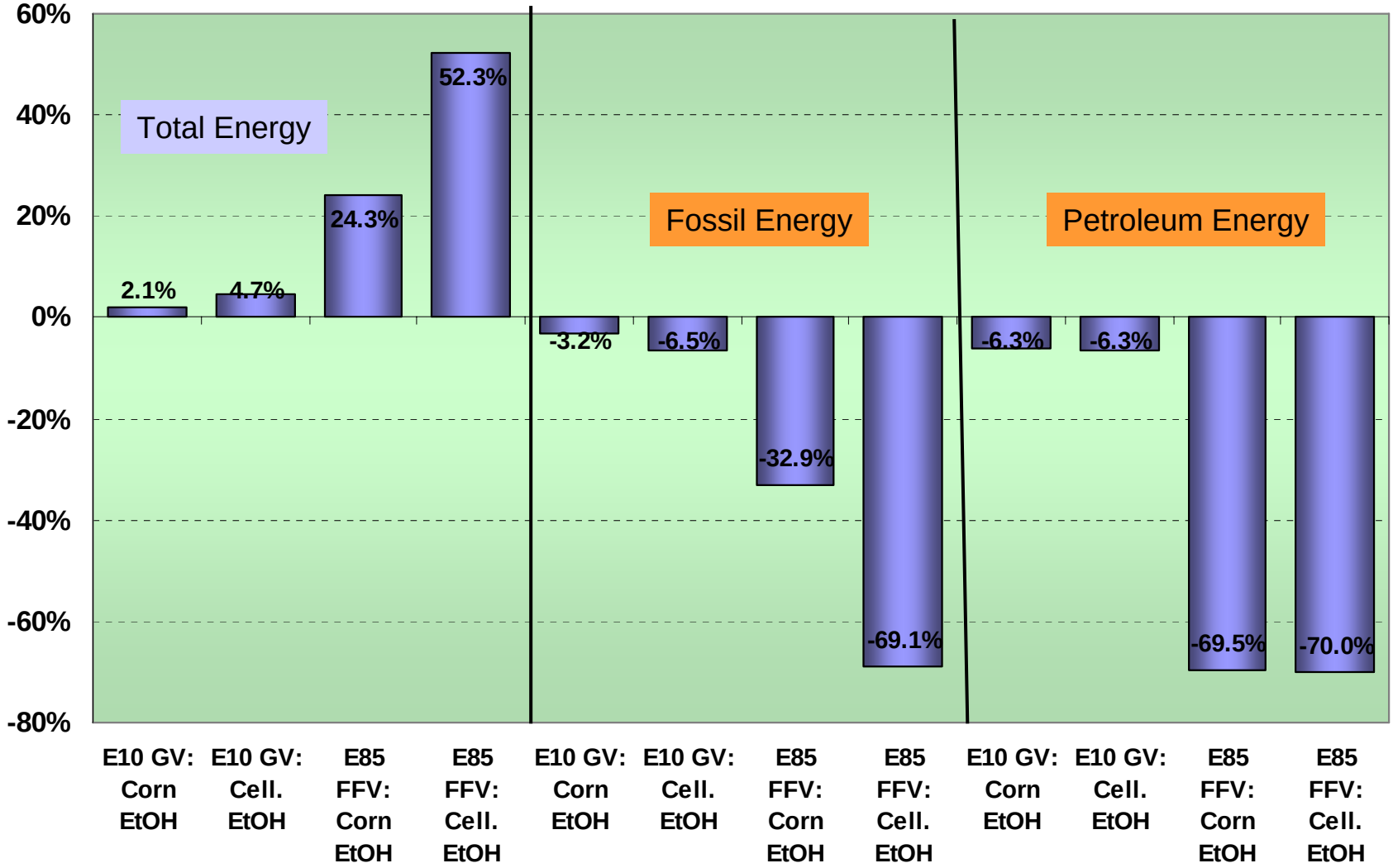
Plants under intensive R&D efforts are designed to use the unfermentable portion of biomass to generate steam and electricity.

Energy Effects of Fuel Ethanol Depend on the Type of Energy Being Analyzed



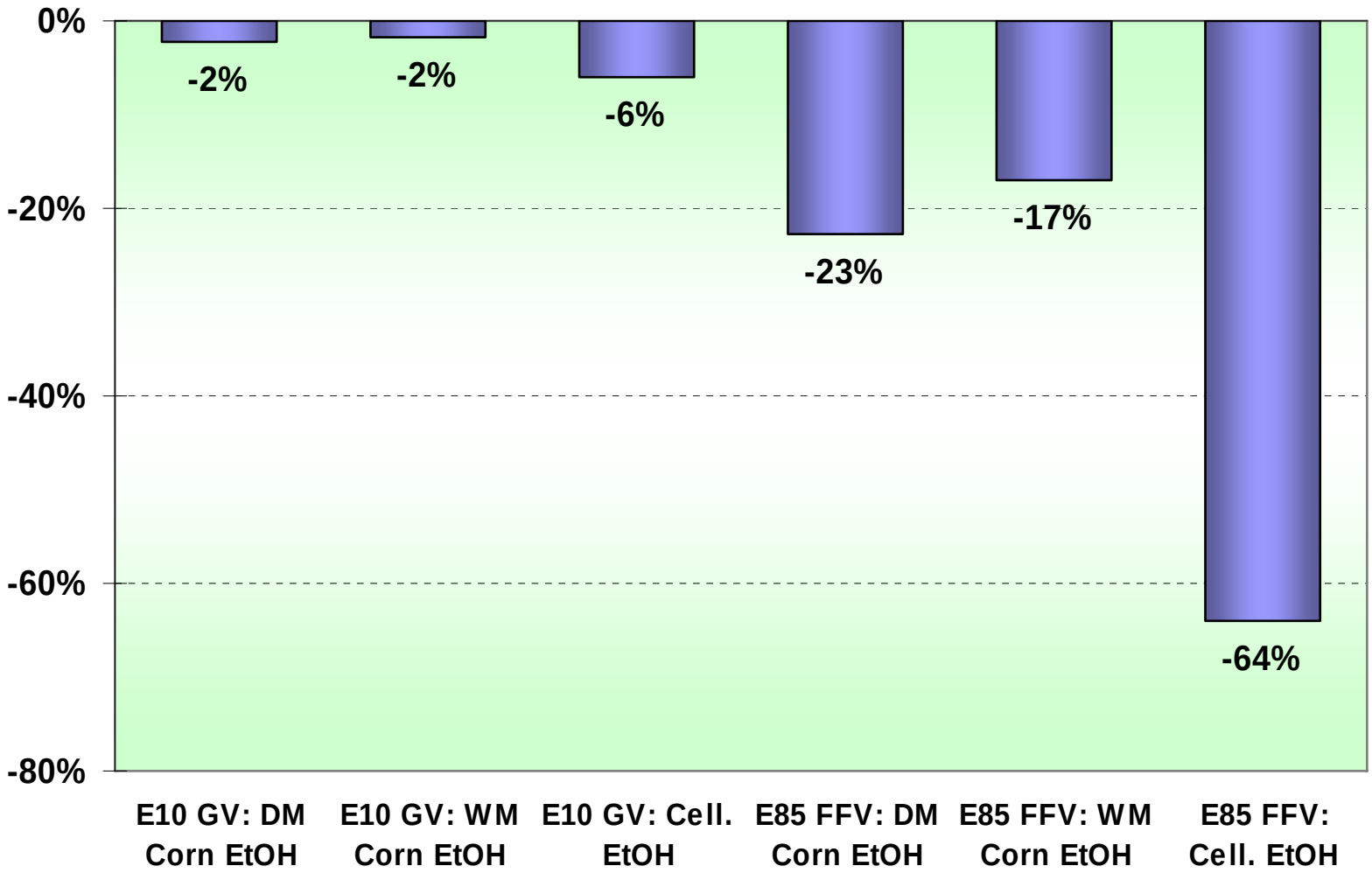
Total Btu Spent for One Btu of Gasoline and Ethanol Available at Fuel Pumps

Use of Ethanol to Replace Gasoline Results in Fossil Energy and Petroleum Reduction Benefits



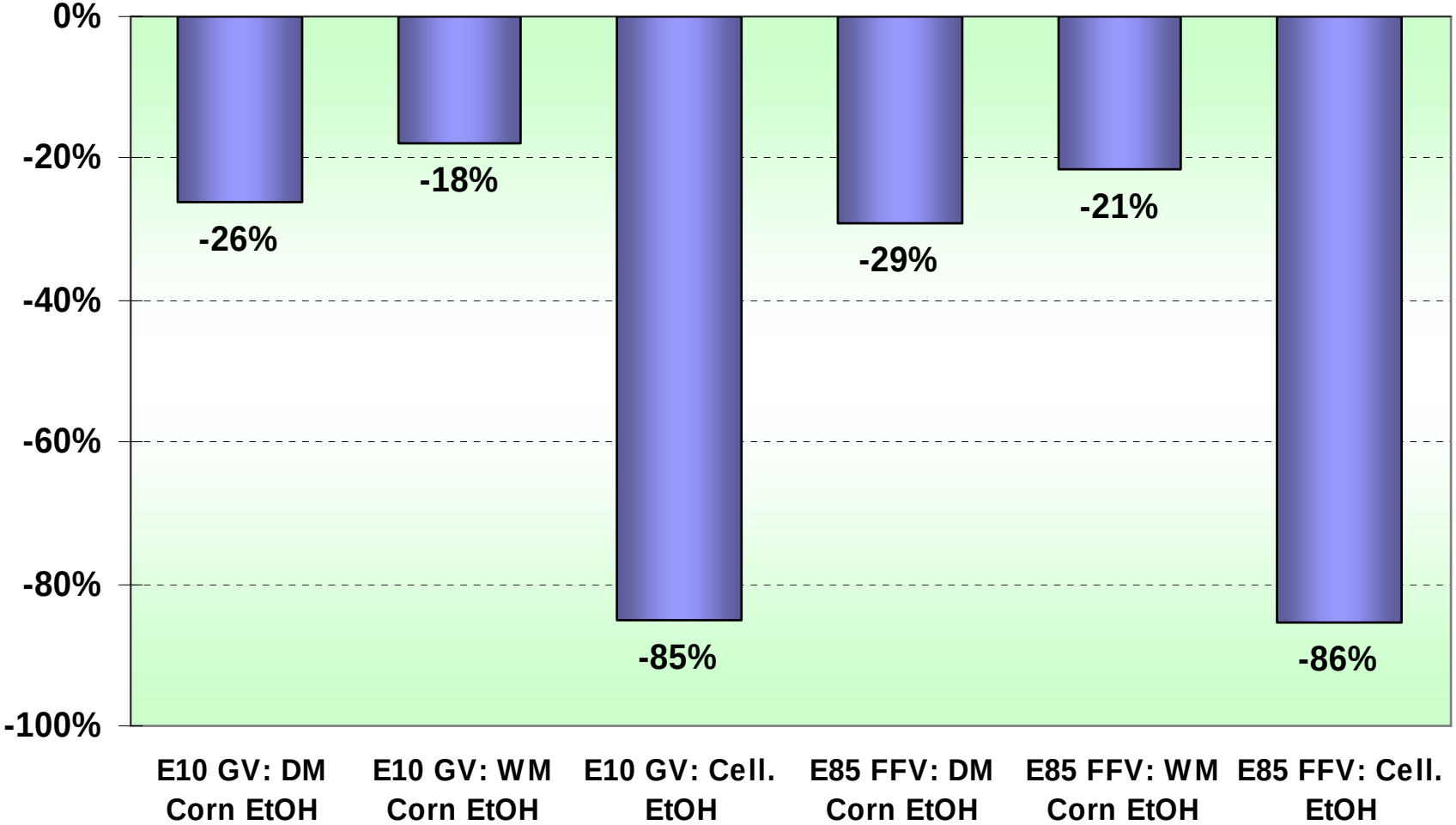
Change in Per-Mile Energy Use by Ethanol Blend to Displace Gasoline

Ethanol Blends, Especially E85 Made from Cellulosic Ethanol, Can Significantly Reduce GHG Emissions



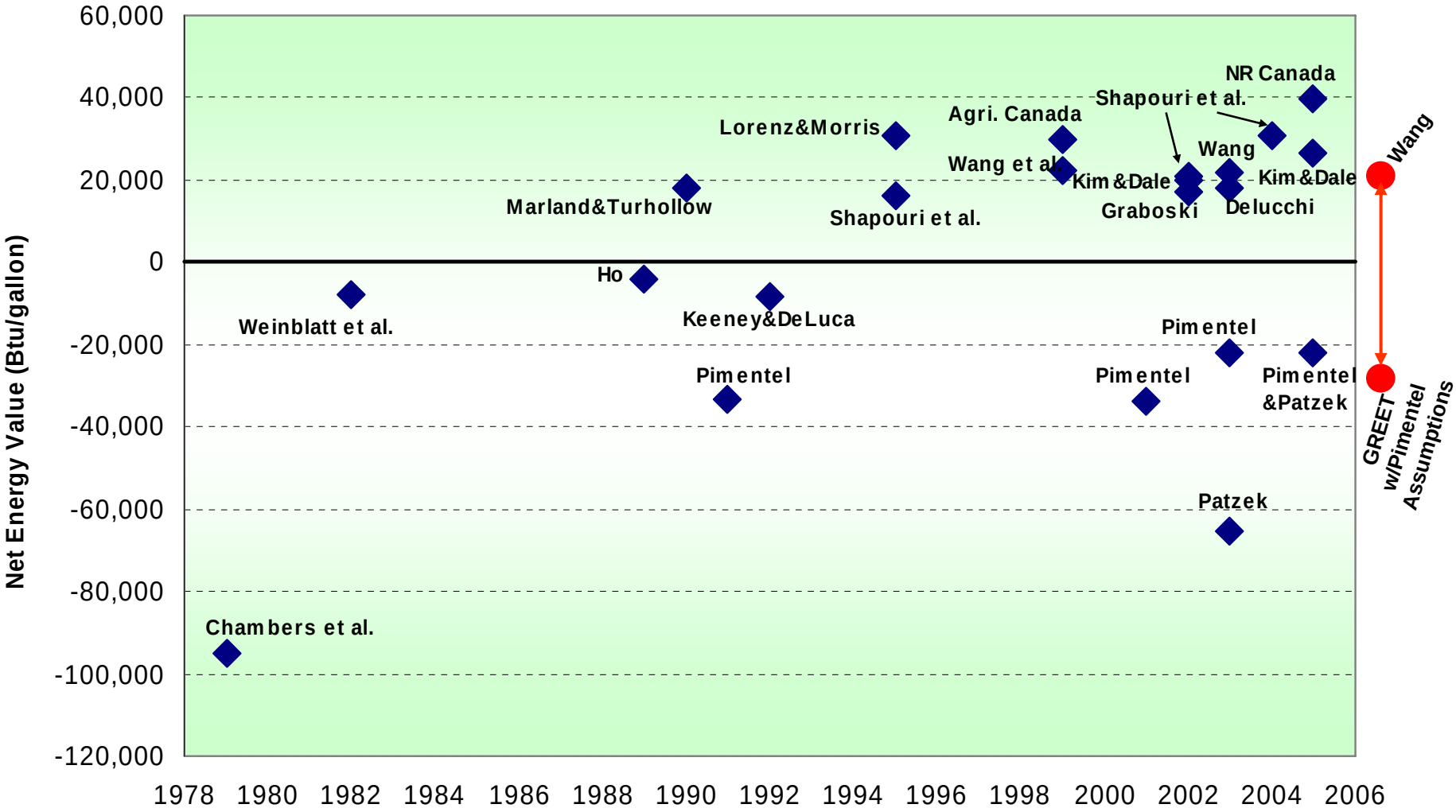
Reductions in Per-Mile GHG Emissions by Ethanol Blend to Displace Gasoline

Corn EtOH Reduces GHGs by 18-29% While Cellulosic EtOH Yields 85-86% Reduction. on Per Gallon Basis of EtOH Used



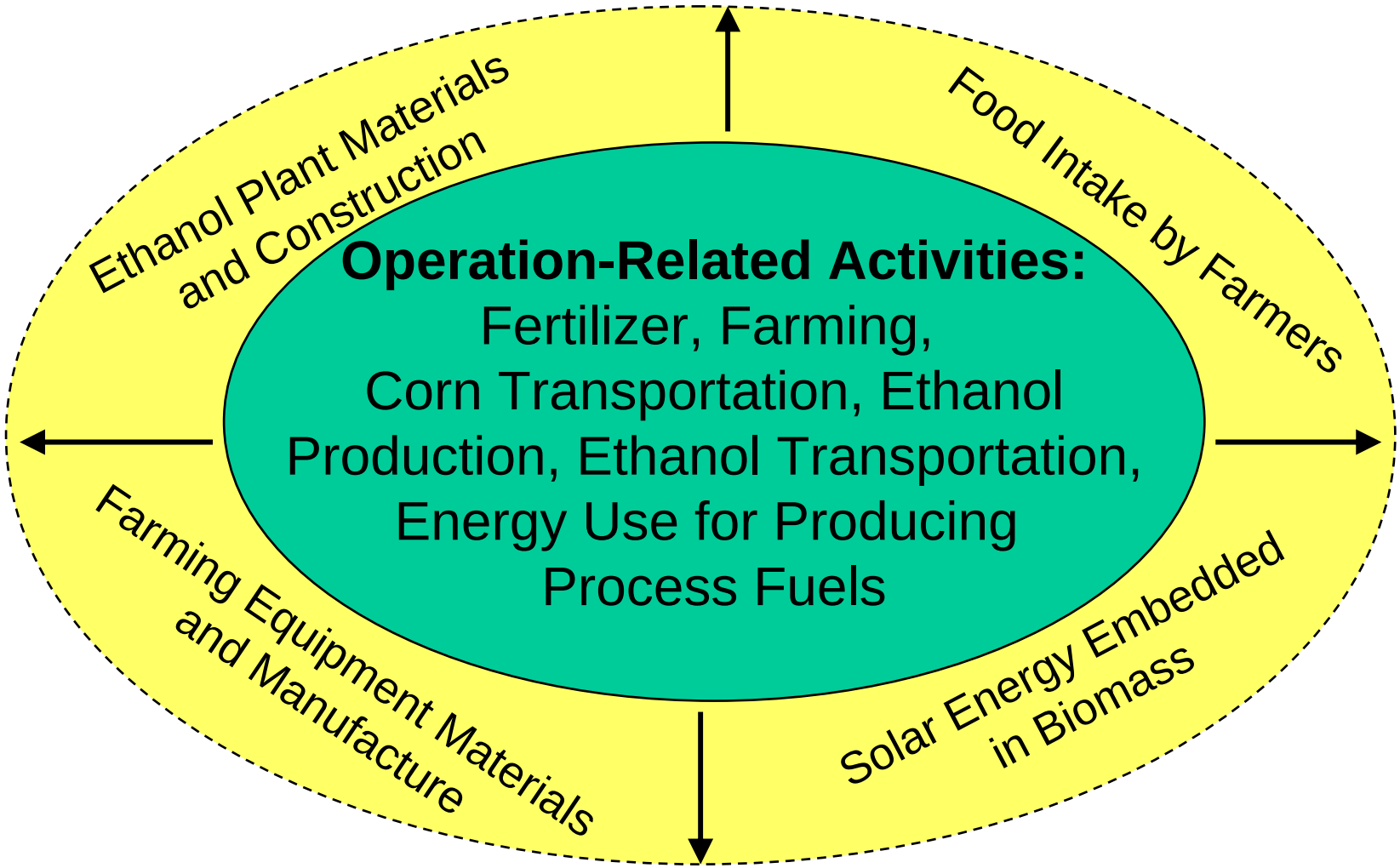
GHG Emission Reductions Per Gallon of Ethanol to Displace An Energy-Equivalent Amount of Gasoline

Most of the Recent Corn EtOH Studies Show a Positive Net Energy Balance



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

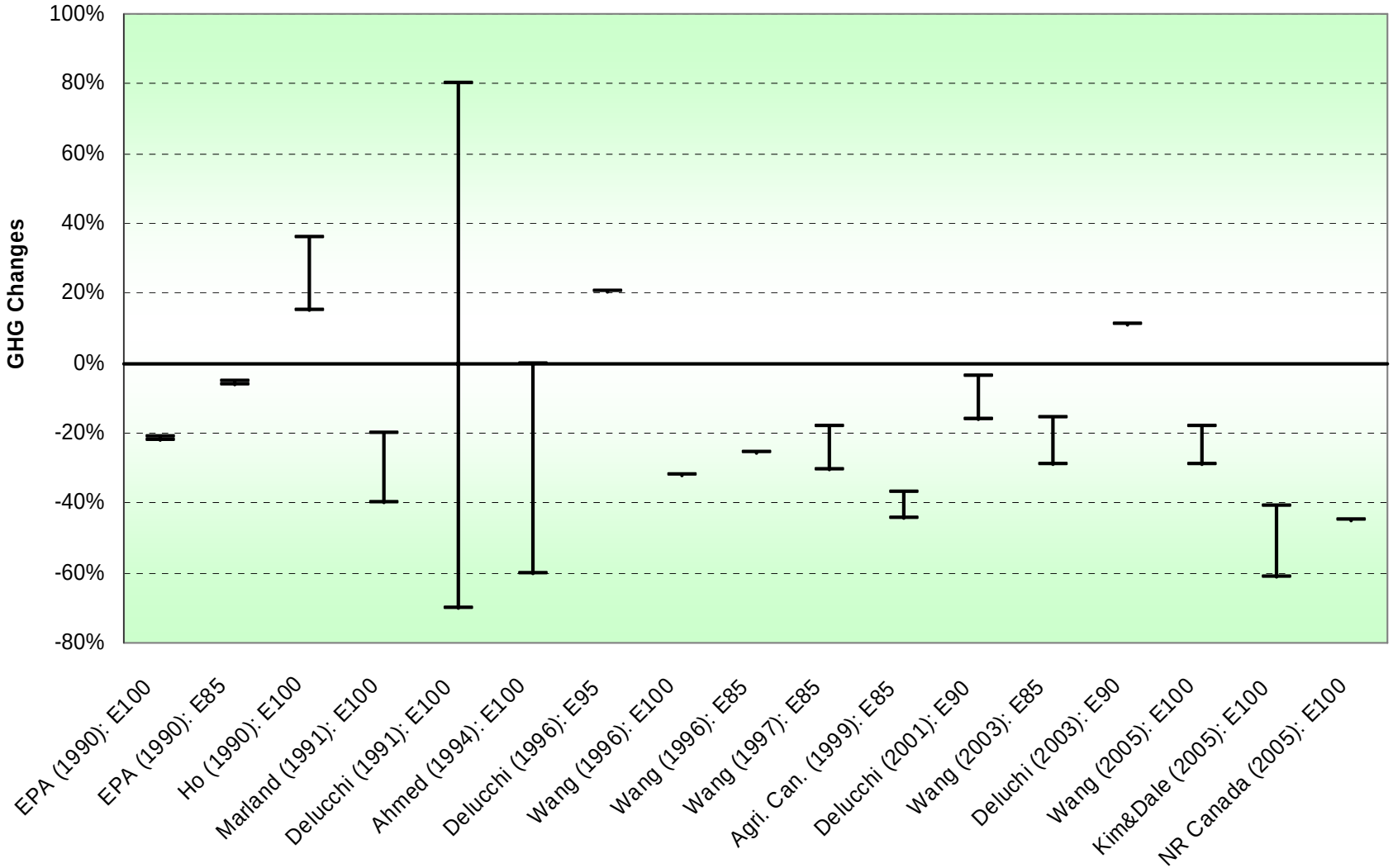
Energy Balance Results of Ethanol Depend Heavily on System Boundary Choices



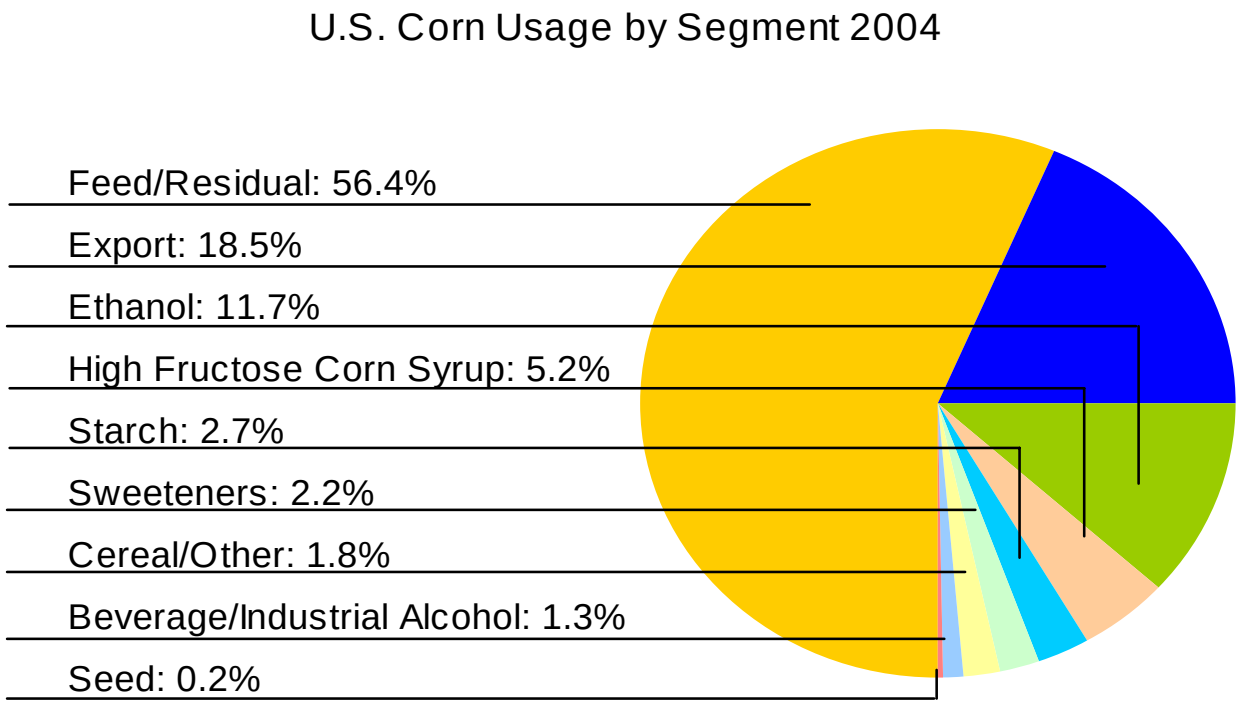
The Debate on Energy Balance Itself May Have Little Practical Meaning

- Though self evaluation of a fuel's energy balance is easy to understand, to do so for a fuel in isolation could be arbitrary
- All Btus are not created equal. The energy sector has been converting low-value Btus into high-value Btus, *with energy losses*
- Society has not made energy choice decisions on the basis of energy balance values of individual energy products
- Issues of concern, such as petroleum consumption and GHG emissions, should be analyzed directly for fuel alternatives
- A complete, robust way of evaluating a fuel's effects is to compare the fuel (e.g., ethanol) with those to be displaced (e.g., gasoline)

Most Studies on GHG Emissions Show GHG Emission Reduction by Corn EtOH as Compared to Gasoline



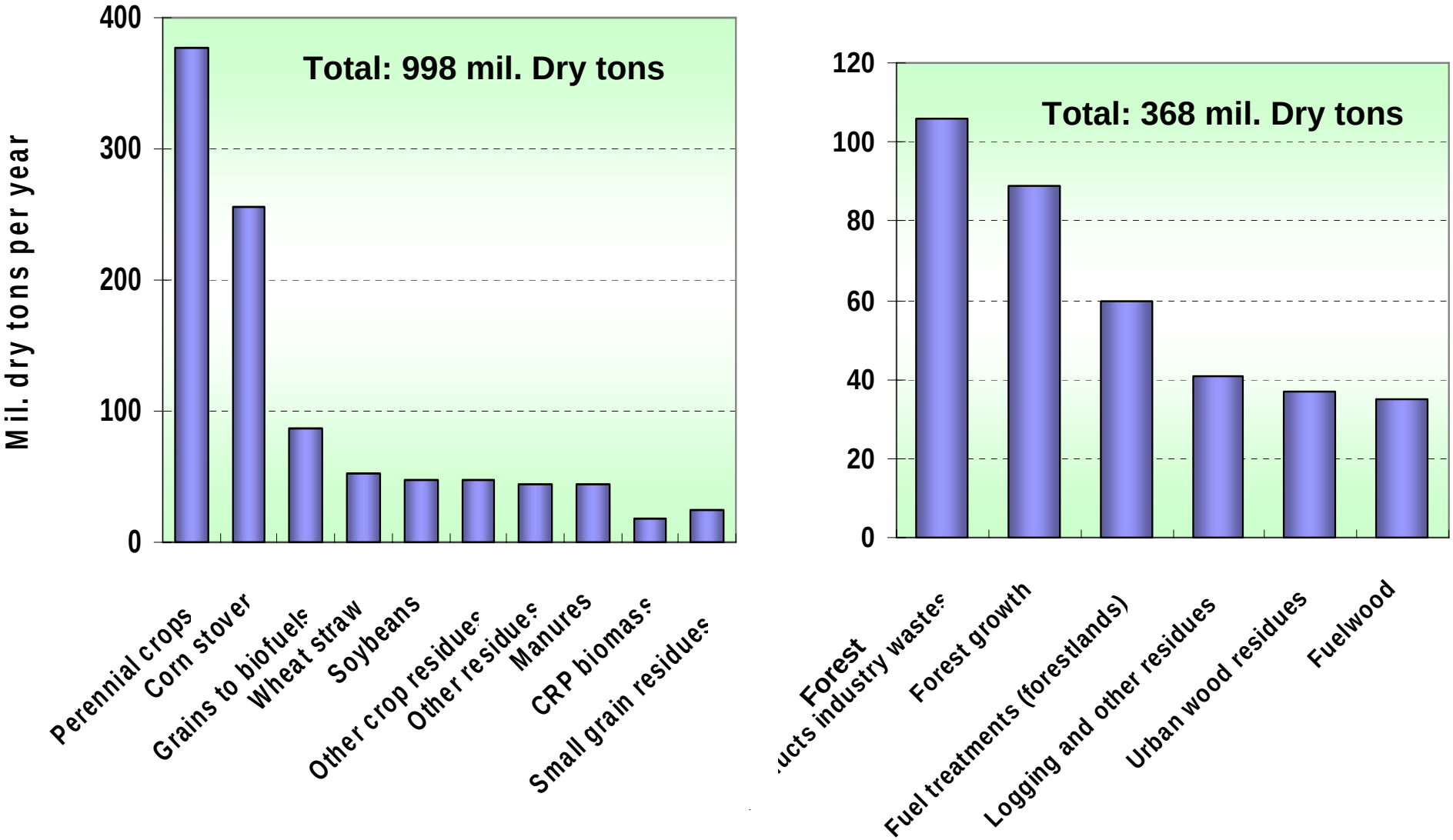
Of the 11.8 Billion Bushels of Corn Produced in U.S. in 2004, About 12% Was Used for Ethanol Production



- The U.S. produced 3.41 billion gallons of fuel ethanol in 2004, equivalent to 2.28 billion gallons of gasoline
- In 2003, the U.S. consumed 134 billion gallons of gasoline and 39 billion gallons of on-road diesel fuels

Source: ERS/USDA, 2004, Feed Outlook (in RFA, 2005); EIA

A Recent Study by Oak Ridge National Laboratory Concludes 1.3 Billion Tons of Biomass Available in U.S. Per Year



The Energy Bill Encourages Production of Cellulosic Ethanol

- Creates a credit-trading program where 1 gallon of cellulosic ethanol is equal to 2.5 gallons of renewable fuel
- Creates a program for production of 250 million gallons of cellulosic ethanol in 2013
- Creates a Loan Guarantee Program of $250 million per facility
- Creates a $650 million Grant Program for cellulosic ethanol
- Creates an Advanced Biofuels Technologies Program of $550 million

Information is courtesy of the Renewable Fuels Association

Conclusions

- Energy balance value for a given energy product alone is not meaningful in evaluating its benefit
- Any type of fuel ethanol helps substantially reduce fossil energy and petroleum use, relative to petroleum gasoline
- Corn-based fuel ethanol achieves moderate reductions in GHG emissions
- Cellulosic ethanol can achieve much greater energy and GHG benefits