

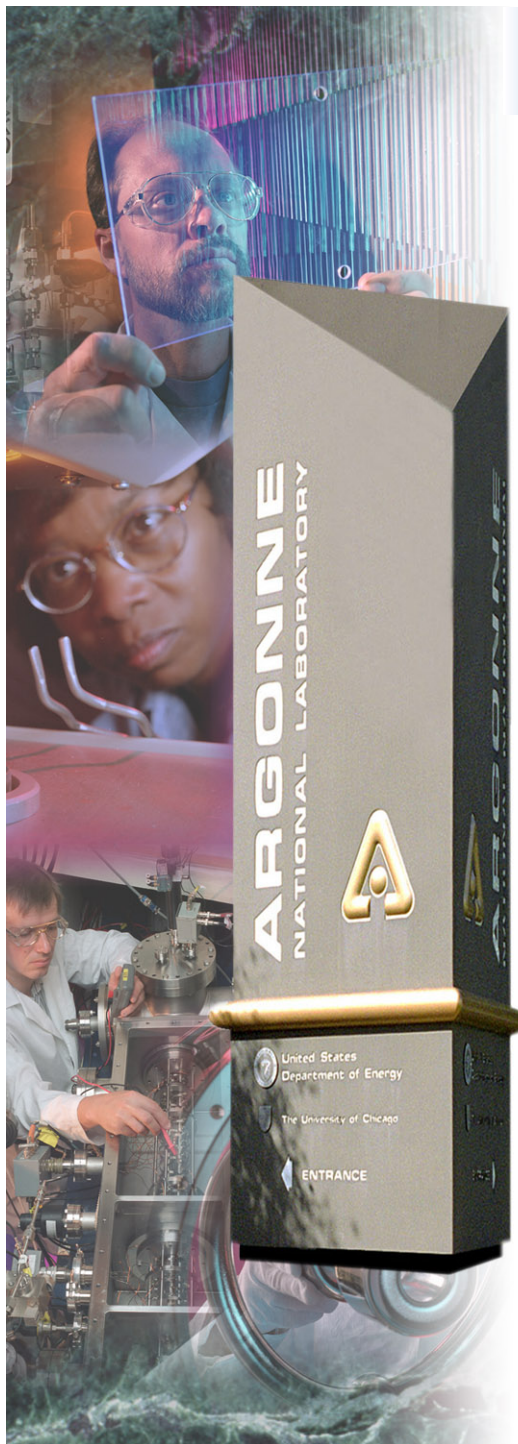
The Debate on Energy and Greenhouse Gas Emissions Impacts of Fuel Ethanol

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

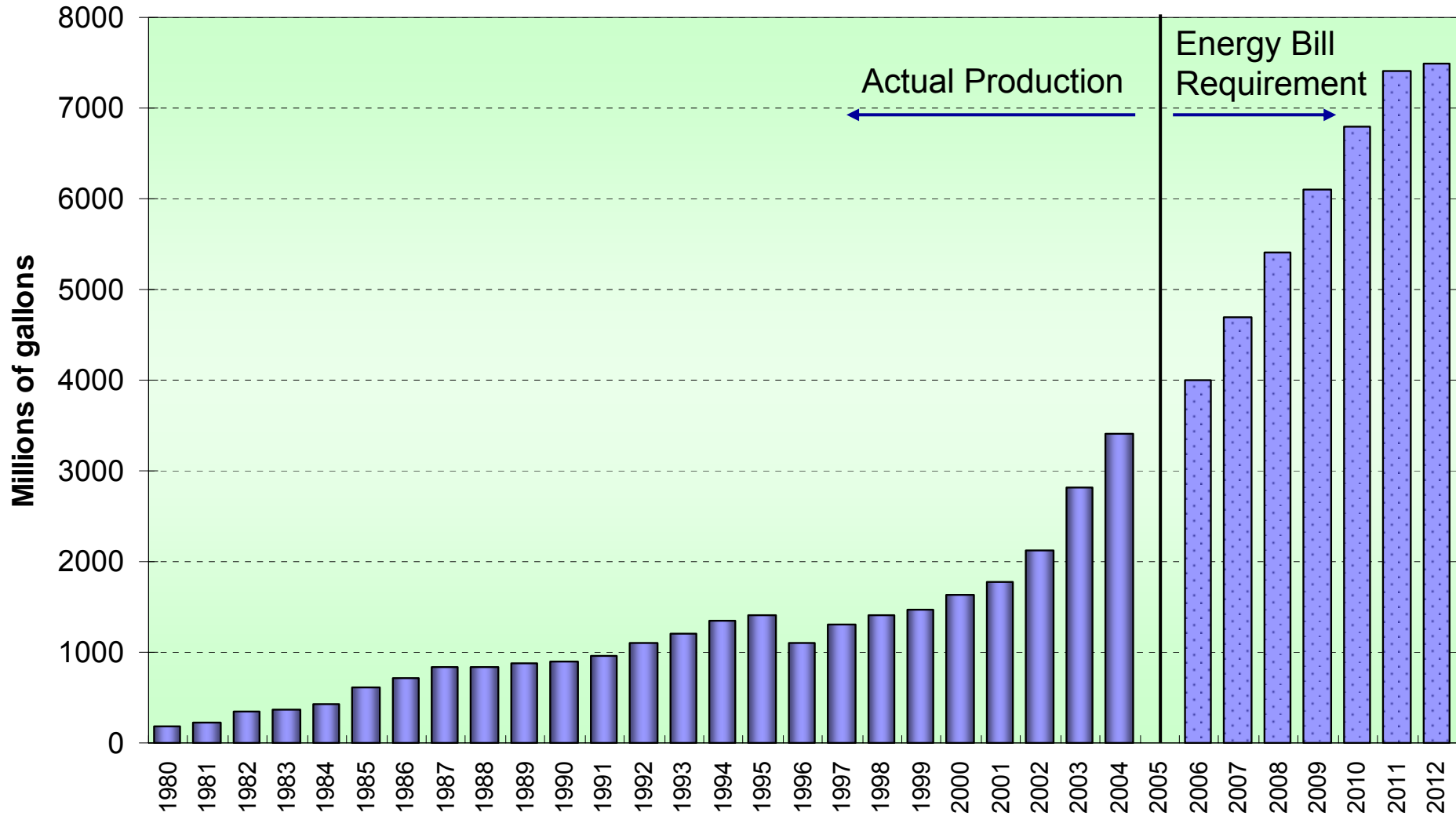
*Energy Systems Division Seminar
Argonne National Laboratory
August 3, 2005*



*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

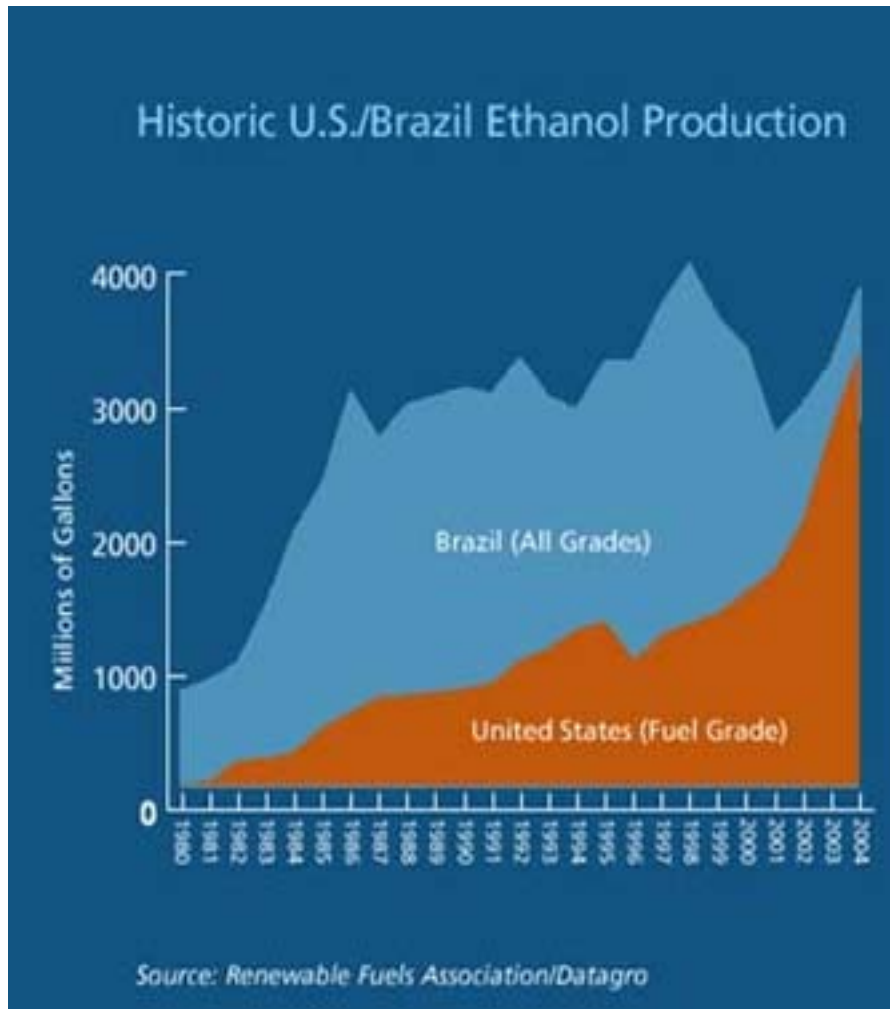


Source: Renewable Fuels Association

Almost All U.S. Ethanol Plants Are Located in U.S. Midwest



Brazil and The U.S. Lead Fuel Ethanol Use



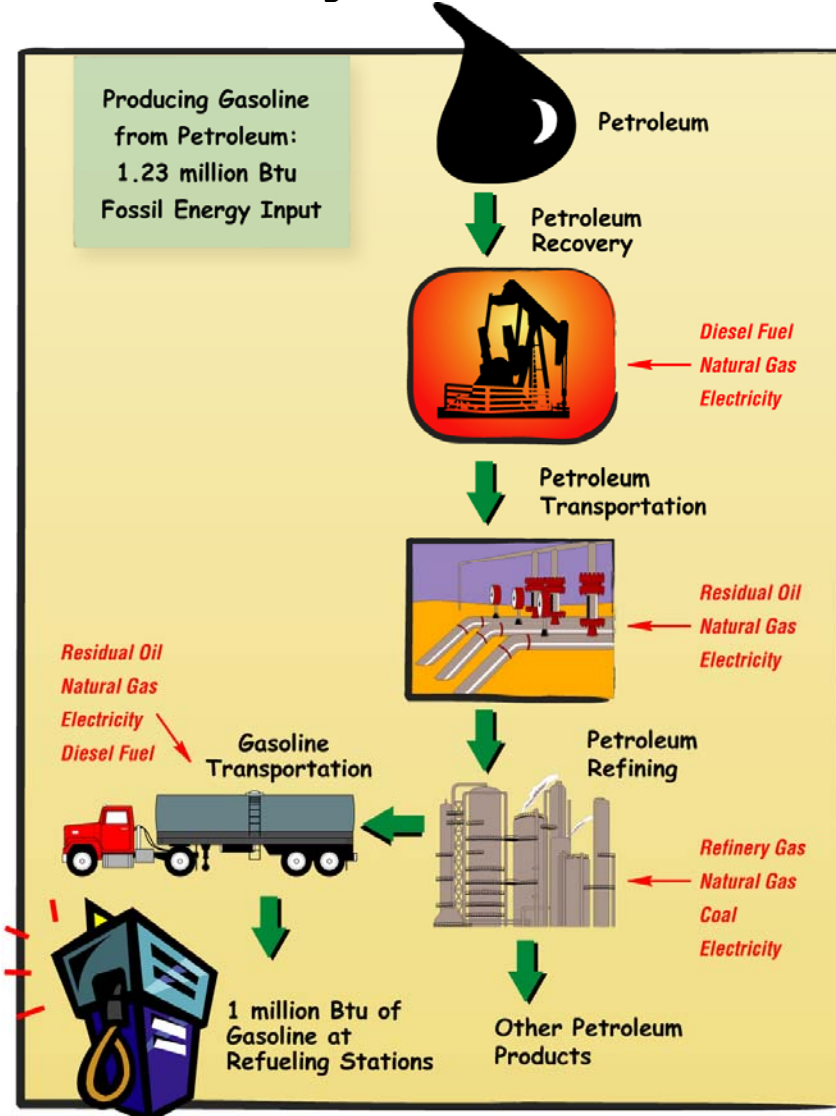
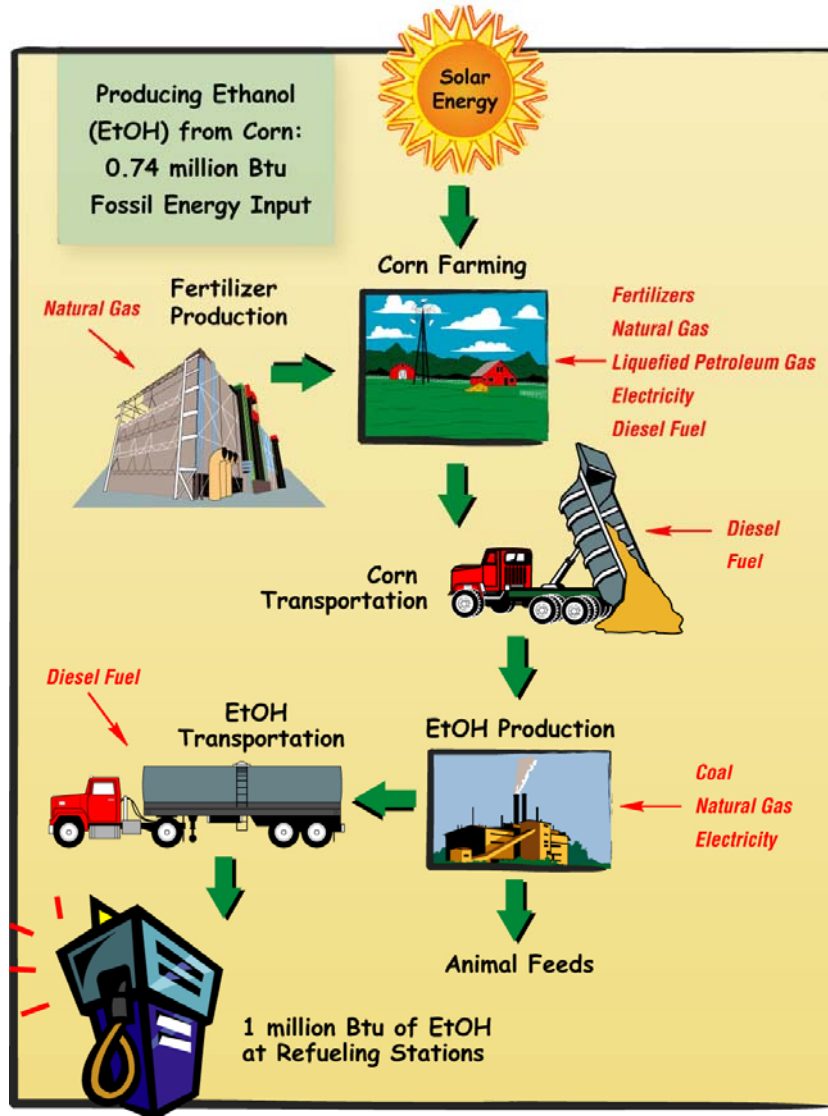
2004 World Ethanol Production
(All grades, million gallons, from F.O. Licht)

Brazil	3,989	Italy	40
U.S.	3,535	Australia	33
China	964	Japan	31
India	462	Pakistan	26
France	219	Sweden	26
Russia	198	Philippines	22
South Africa	110	South Korea	22
U.K.	106	Guatemala	17
Saudi Arabia	79	Cuba	16
Spain	79	Ecuador	12
Thailand	74	Mexico	9
Germany	71	Nicaragua	8
Ukraine	66	Mauritius	6
Canada	61	Zimbabwe	6
Poland	53	Kenya	3
Indonesia	44	Swaziland	3
Argentina	42	Others	338

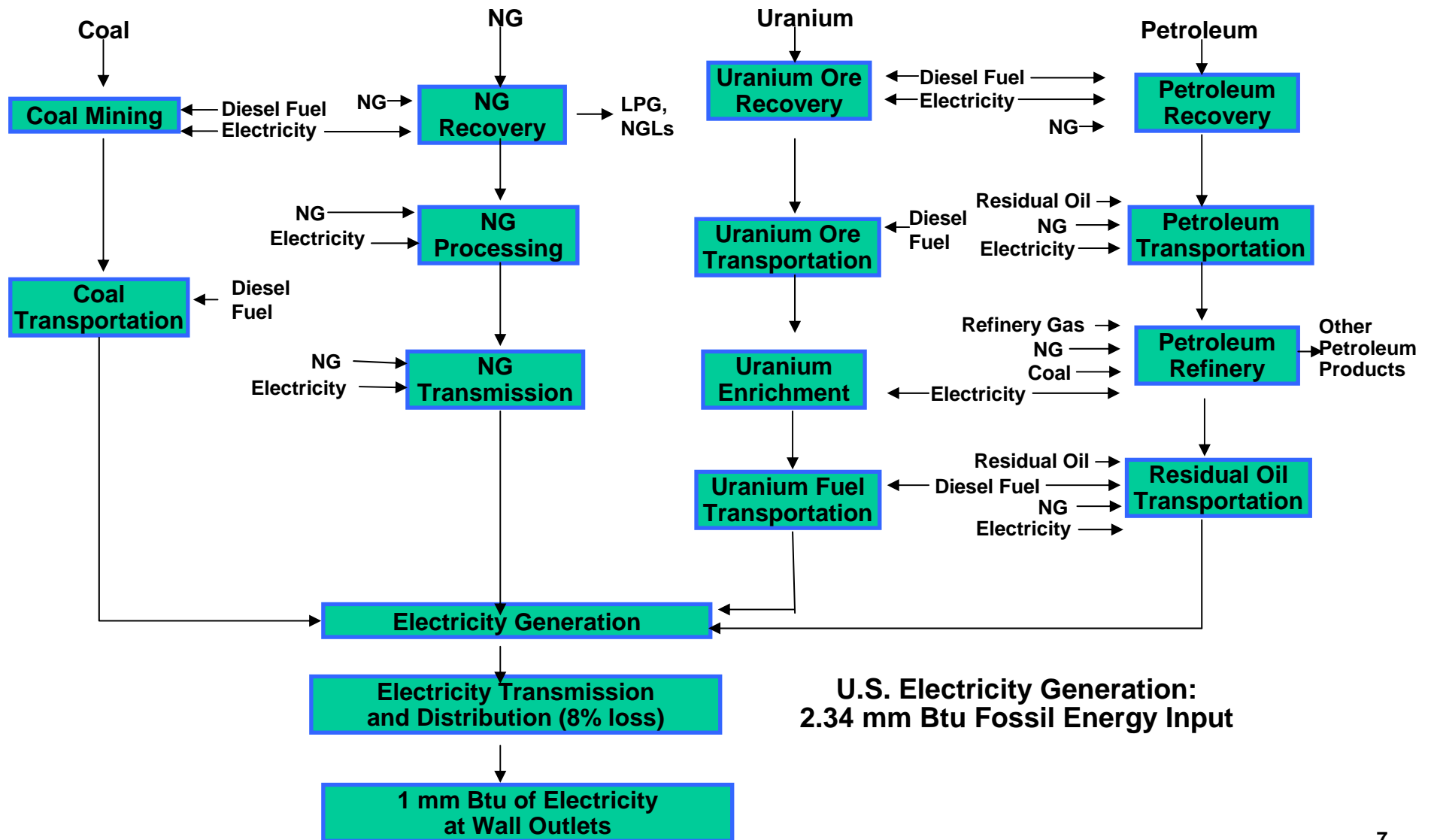
A Recent Study by Pimentel&Patzek Conclude Increases in Fossil Energy Use by Biofuels

- ❑ **Pimentel&Patzek conclude that**
 - **Corn ethanol increases fossil energy use by 29%**
 - **Cellulosic biomass-based ethanol by 50-57%**
 - **Biodiesel by 27-118%**
- ❑ **Other studies have very different conclusions**
 - **Argonne has shown**
 - **Corn ethanol reduces fossil energy use by 26%**
 - **Cellulosic biomass-based ethanol reduces by 90%**
 - **National Renewable Energy Laboratory has shown that biodiesel reduces fossil energy use by 69%**
- ❑ **Differences between Pimentel&Patzek and others lie in**
 - **Corn farming energy use**
 - **Energy use for producing nitrogen fertilizer**
 - **Ethanol plant energy use**
 - **Credits for co-products from biofuel plants**

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

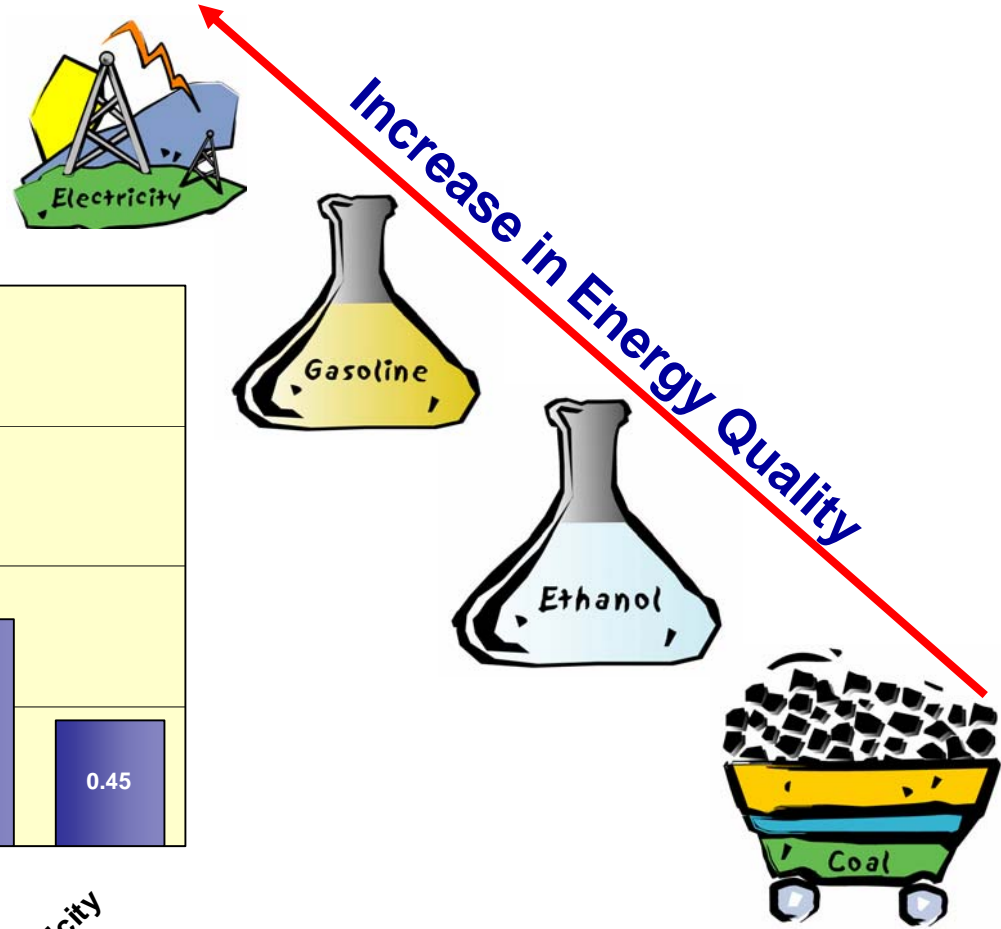
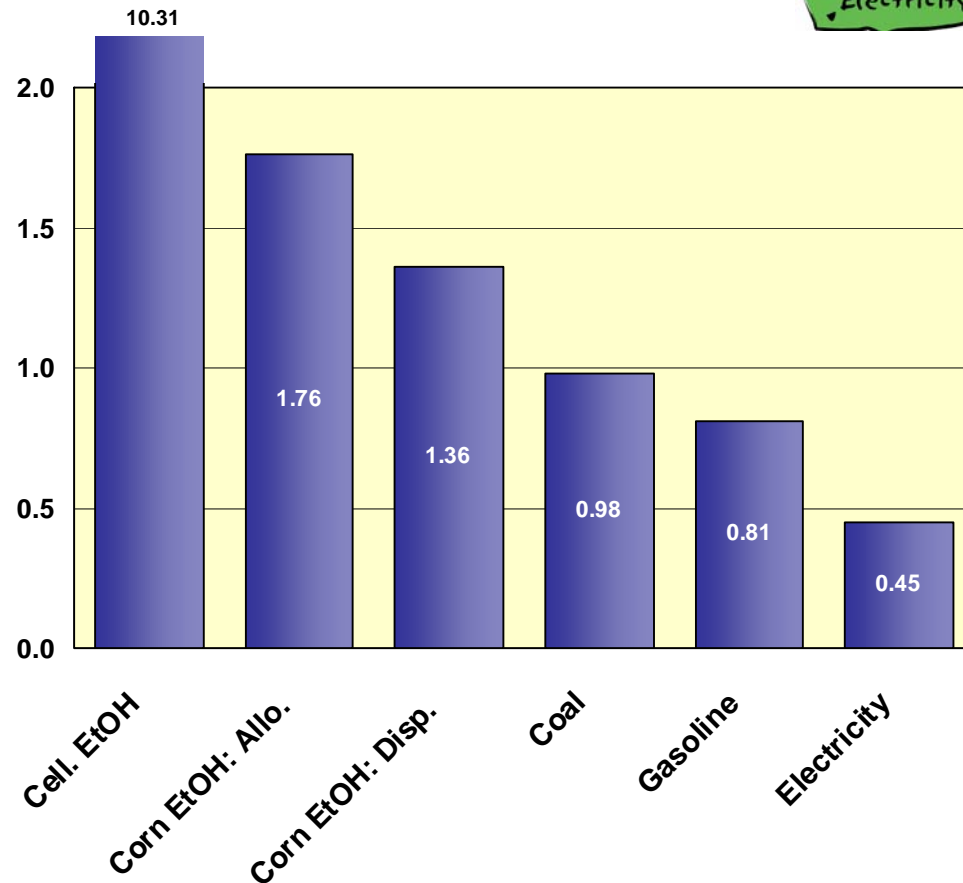


Though Electricity Requires a Large Amount of Fossil Energy Input, There Is No Substitute

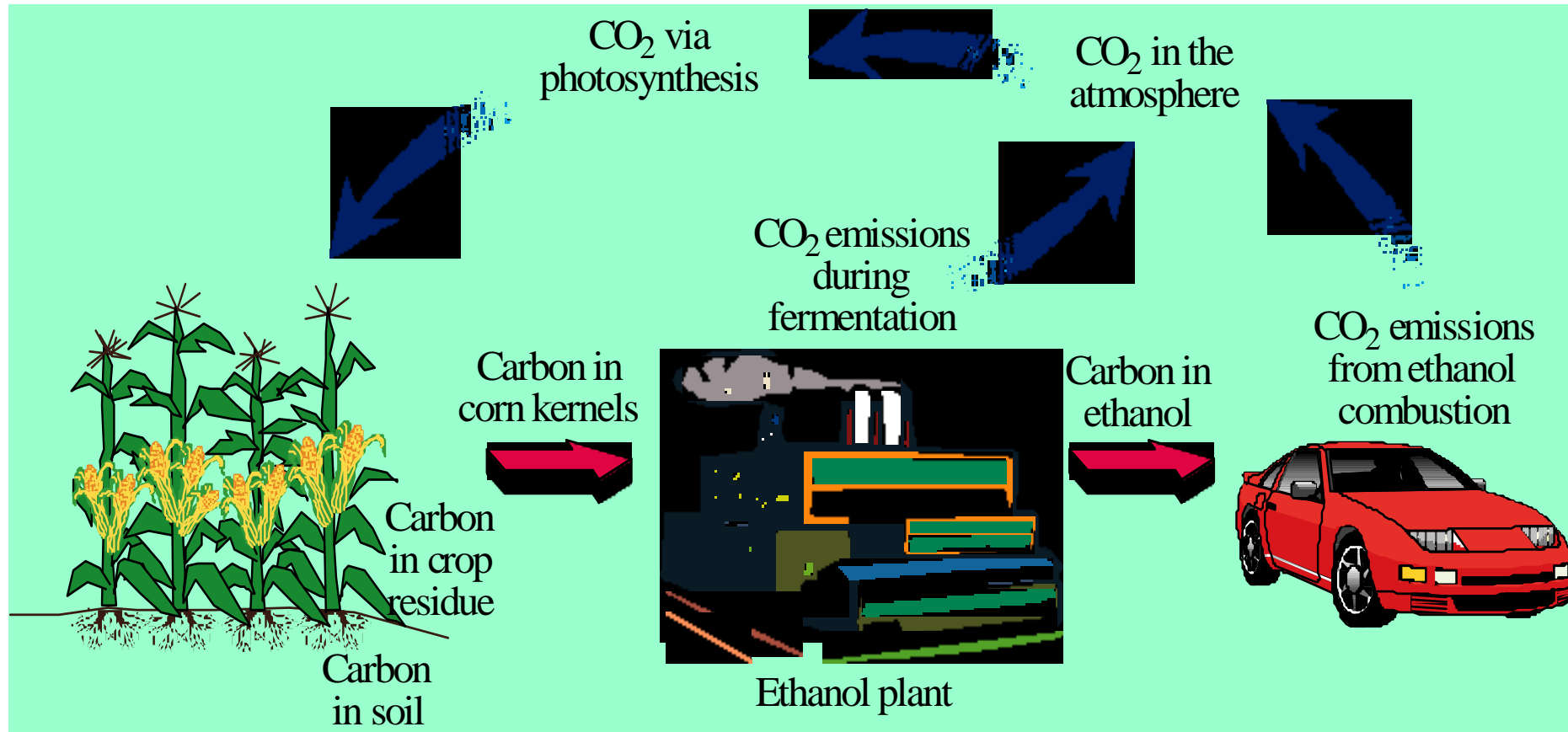


Energy in Different Fuels Can Have Very Different Qualities

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

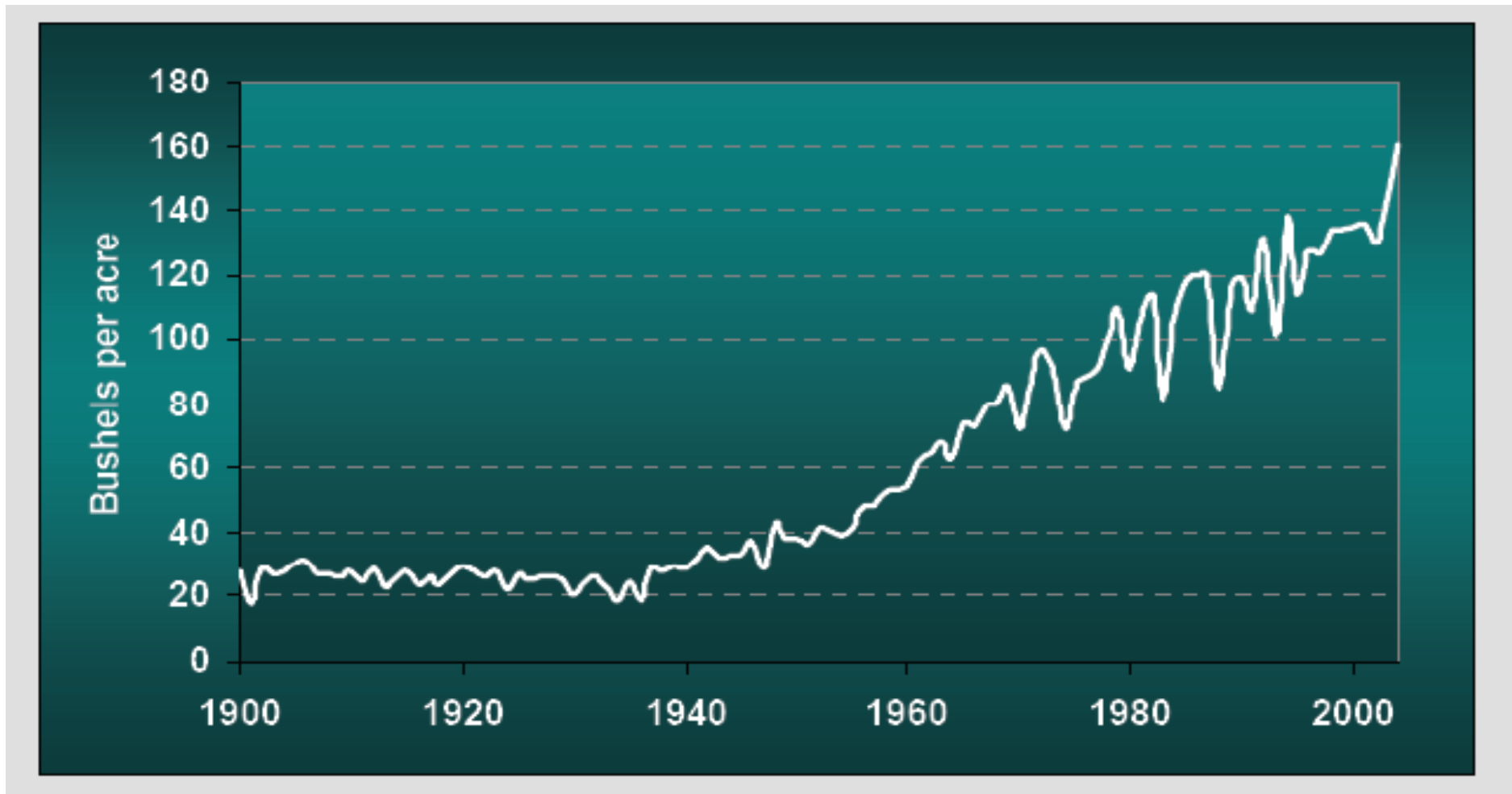


Recycling of Carbon by Ethanol Results in CO₂ Benefits for It



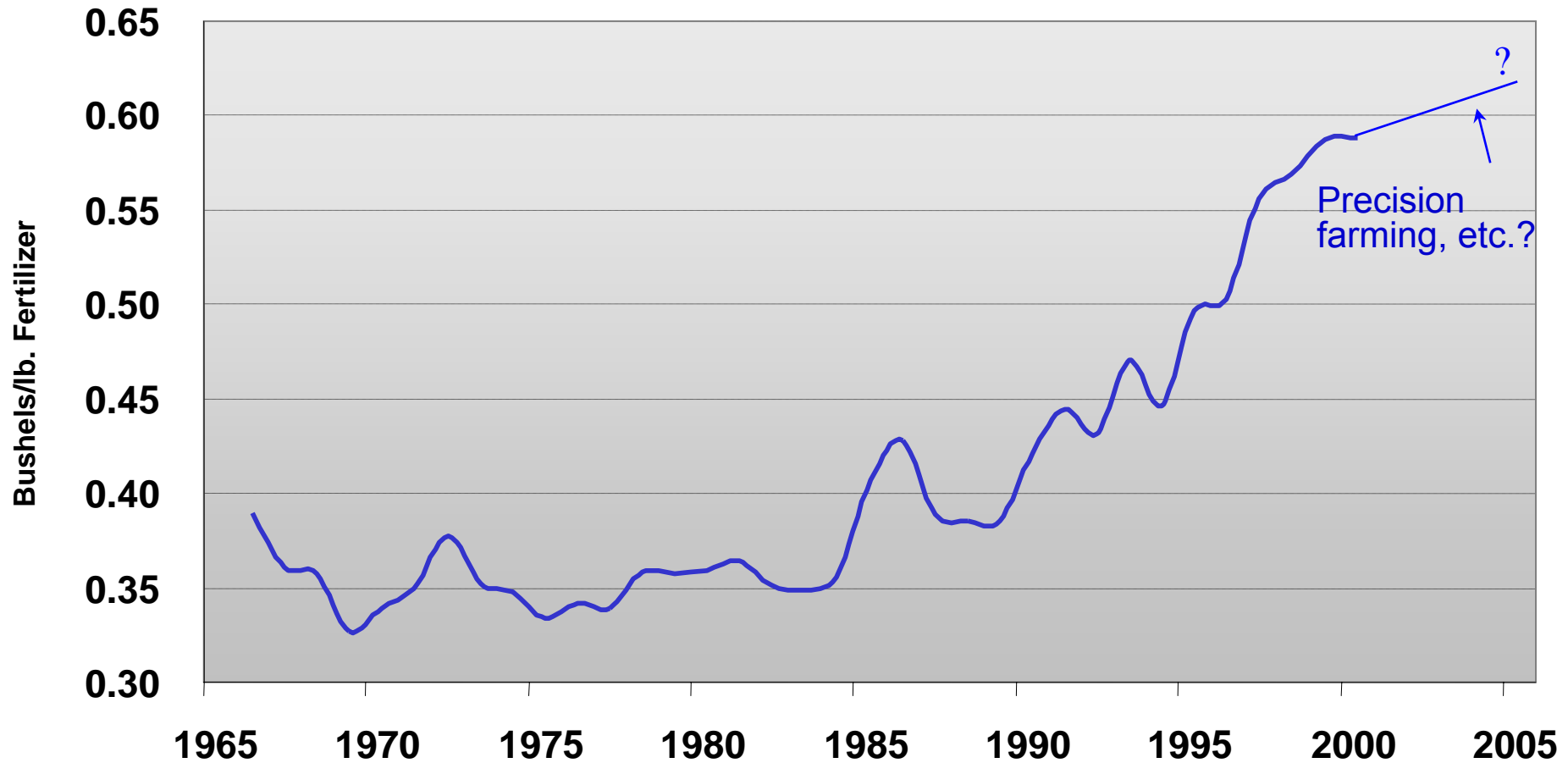
Carbon capture in ethanol plants for beverage use is not considered in ANL analysis. Additional GHG benefits could be achieved by considering carbon capture.

U.S. Corn Yield Per Acre Has Increased by Nearly 8 Times in The Past 100 years



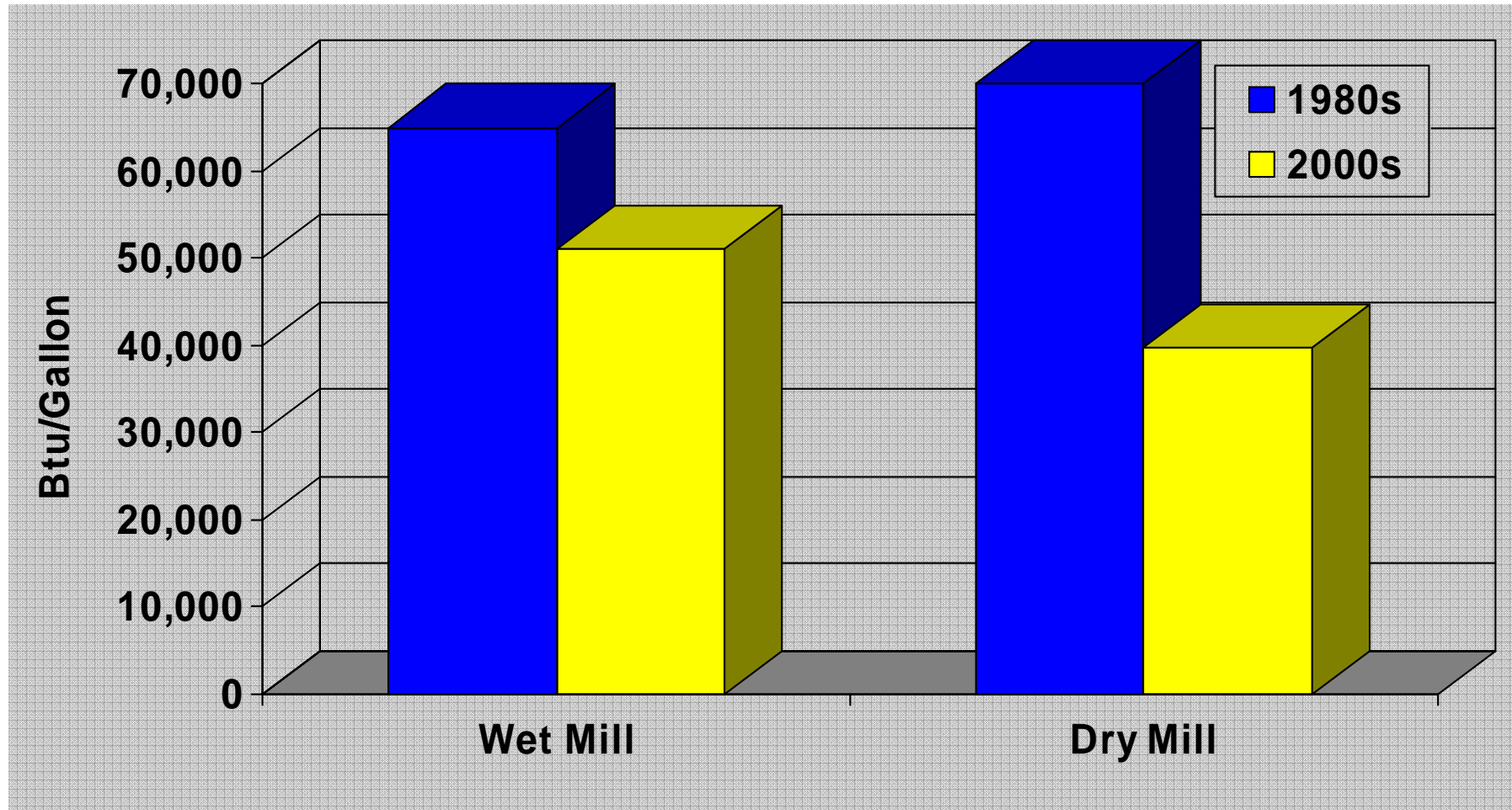
Source: Oak Ridge National Laboratory (2005)

U.S. Corn Output Per Pound of Fertilizer Has Risen by 70% in The Past 35 Years



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

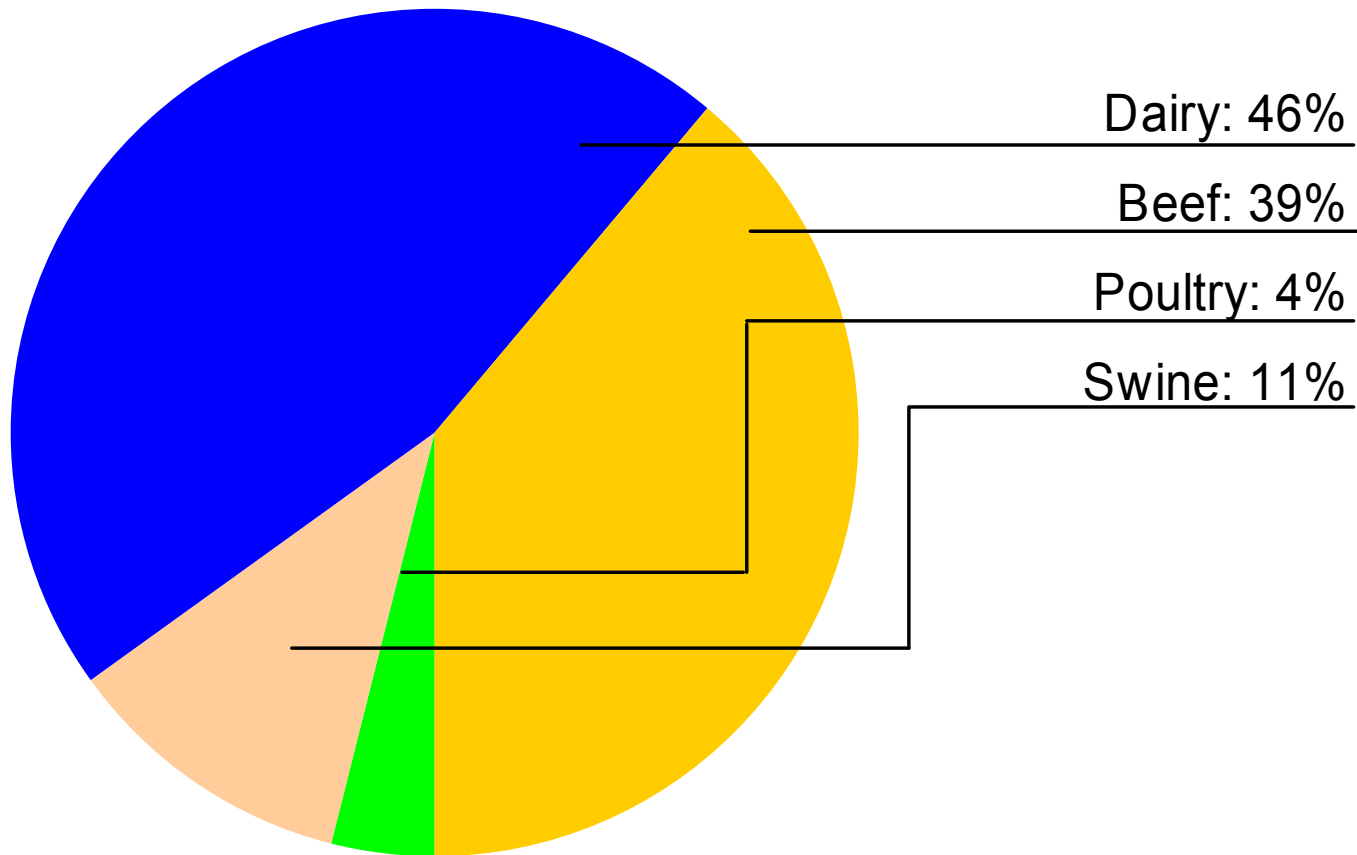
Technology and Desire for Reducing Operation Costs Have Resulted in Reduced Energy Use in Corn Ethanol Plants



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

One-Third of Corn Kernel Mass Ends in Distillers Dry Grains and Solubles (DDGS) in Ethanol Plants

2003 North American DDGS Consumption



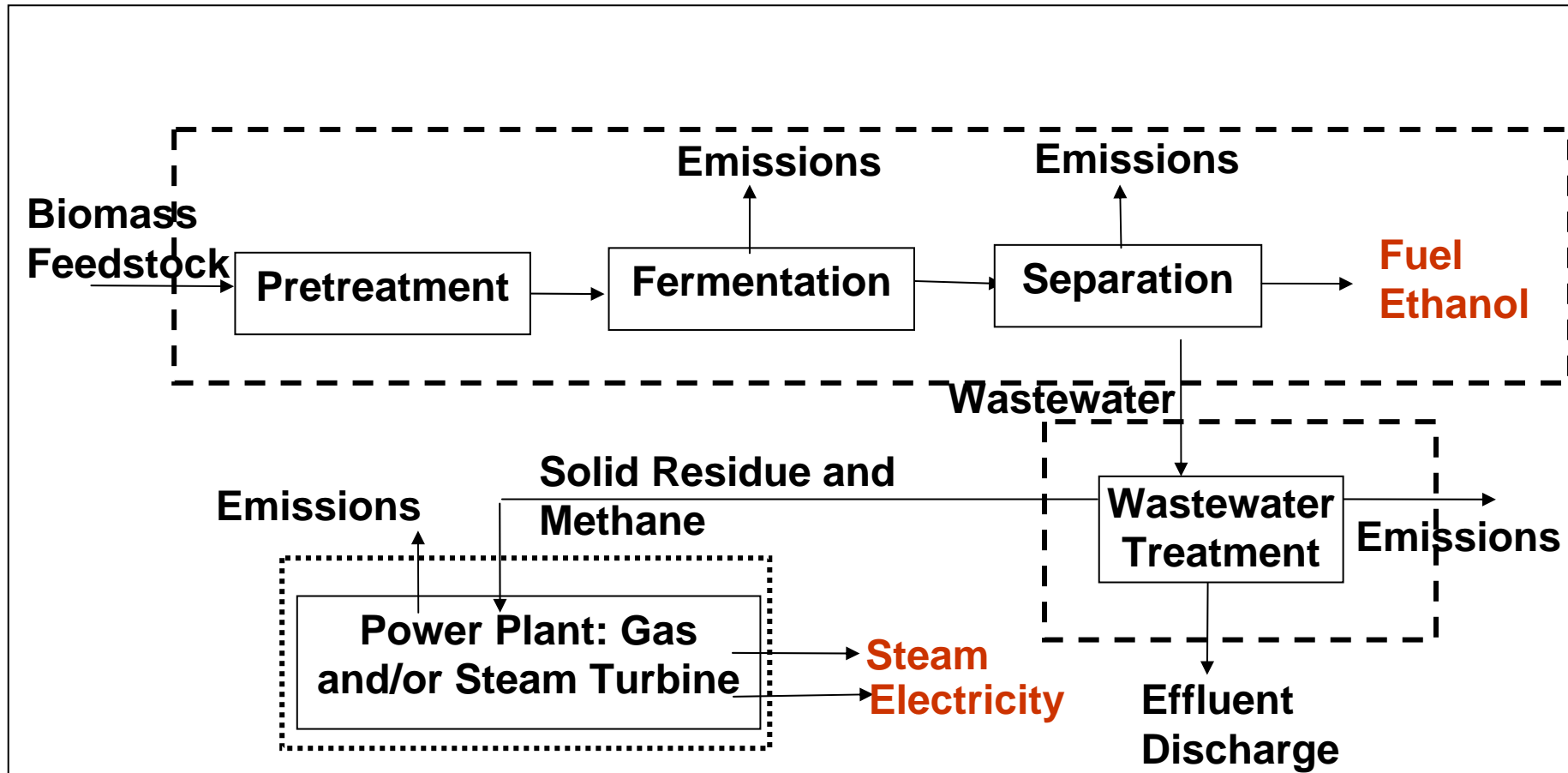
Source: Commodity Specialist Co. (in RFA, 2005)

Allocation Method for Animal Feed Is a Critical Factor in Determining Ethanol's Energy and Emission Results

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

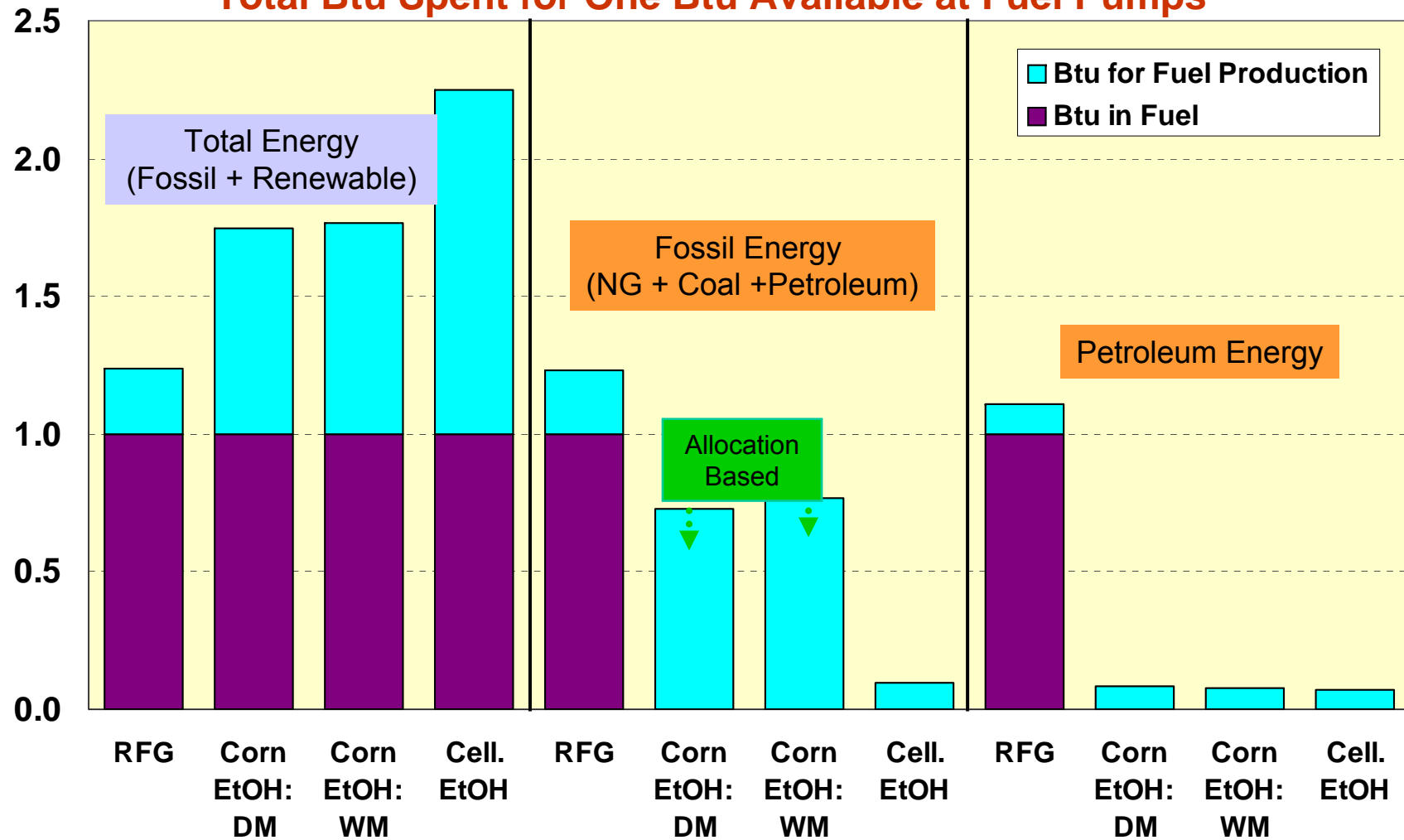
- Weight and energy methods no longer used
- Process energy allocation values are from USDA 2004
- Some studies did not consider co-products at all

Cellulosic Ethanol Plant Designs Under Consideration Use the Unfermentable Portion of Biomass to Generate Steam and Electricity

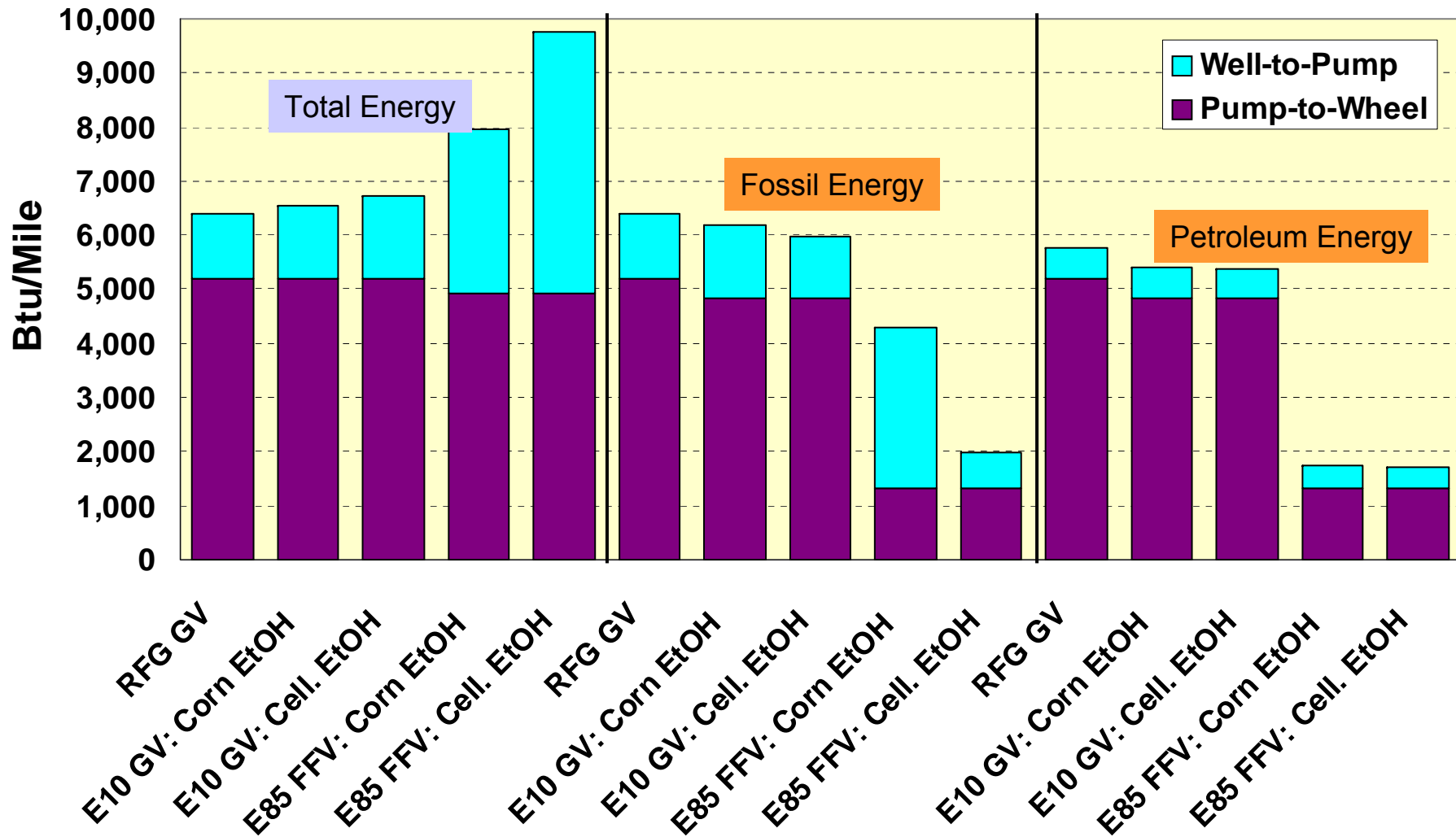


Energy Benefits of Fuel Ethanol Lie in Reductions in Fossil Energy and Petroleum Use

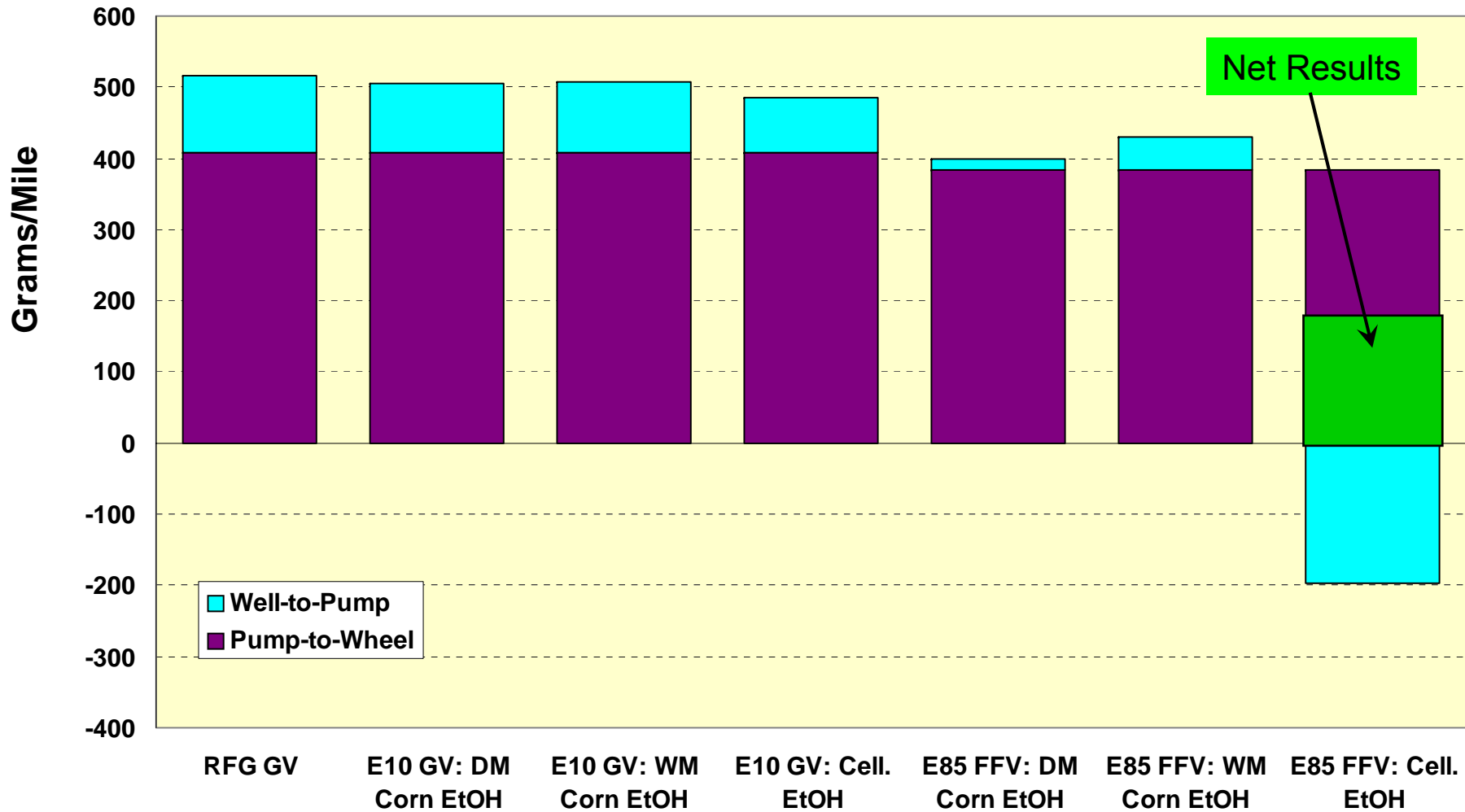
Total Btu Spent for One Btu Available at Fuel Pumps



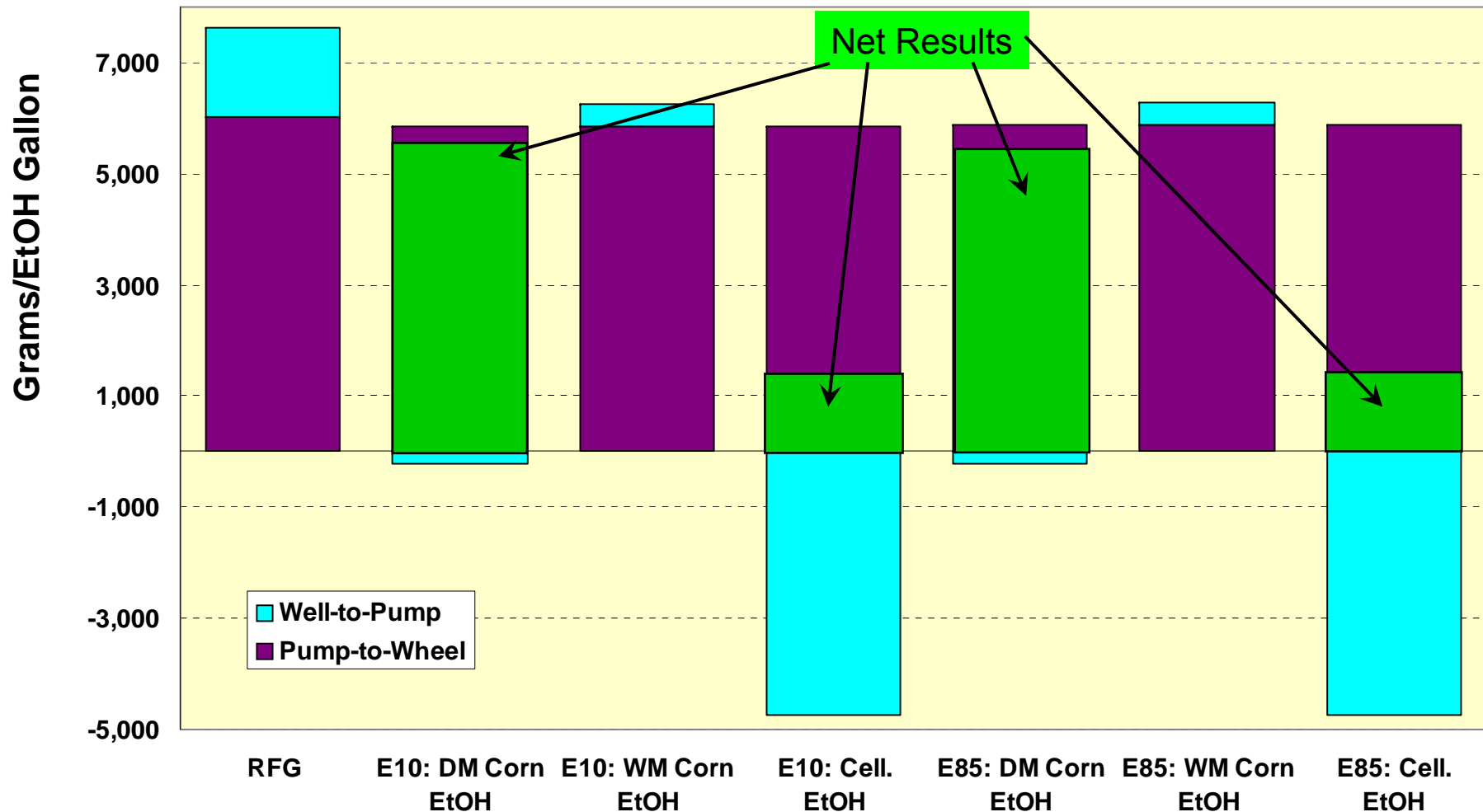
Use of Ethanol to Replace Gasoline Results in WTW Fossil Energy and Petroleum Benefits



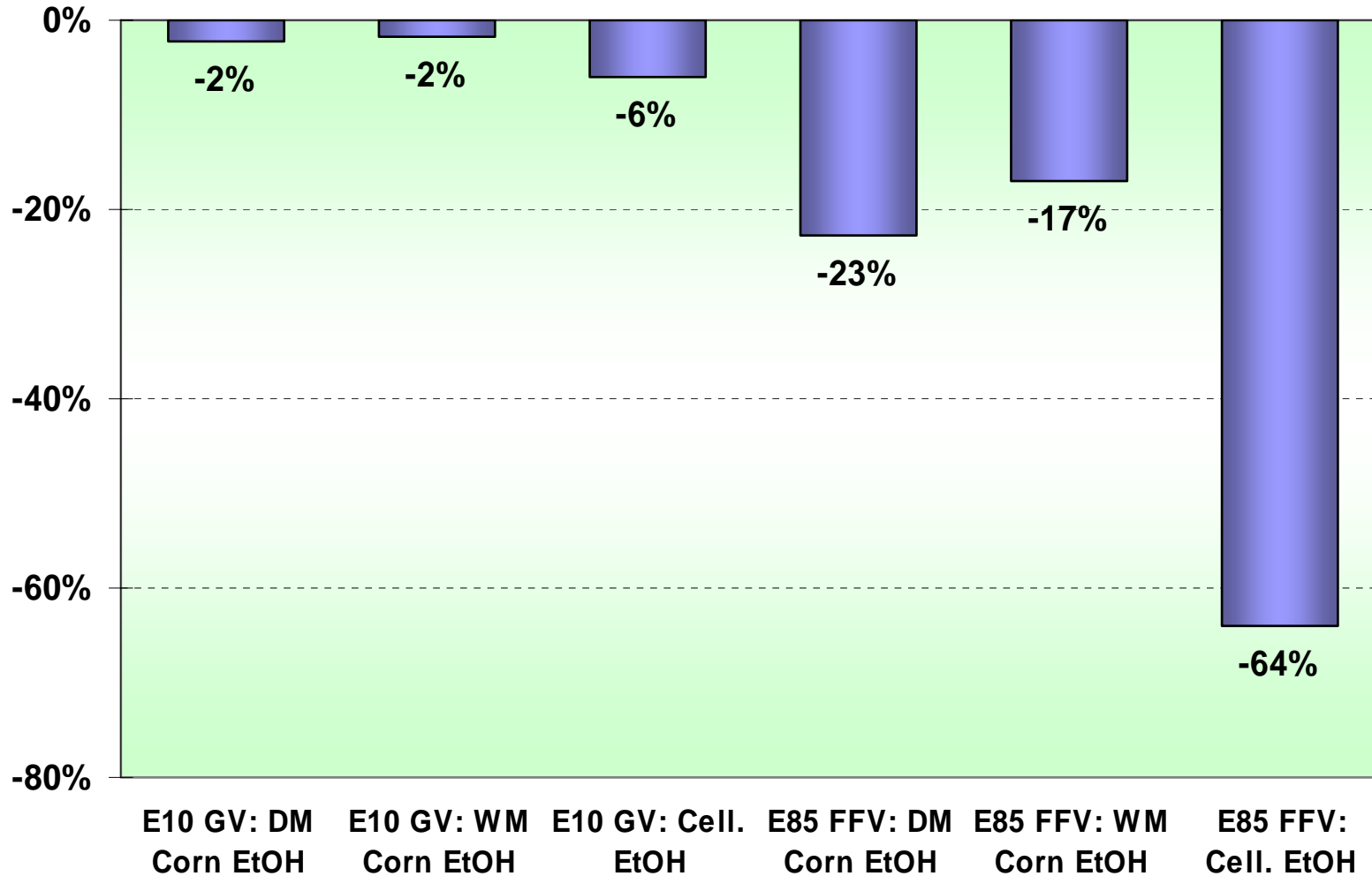
Per-Mile GHG Emission Results Show Larger Benefits of E85 Blend and Cellulosic Ethanol



Per Gallon of EtOH Used, E85 Achieves Incremental Benefits in GHG Reduction Over E10

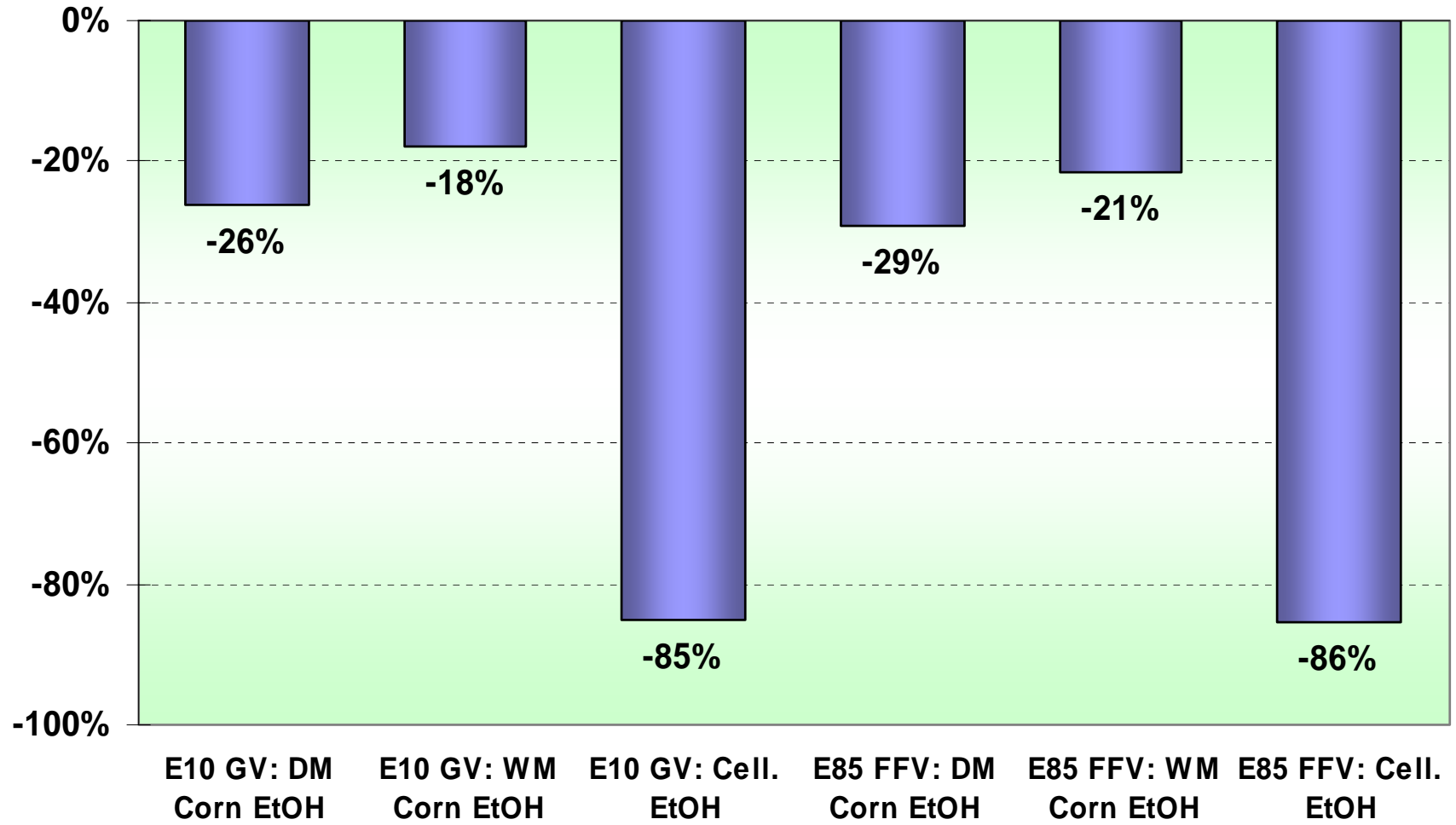


Per Mile Driven with EtOH Blends, E85 (Especially with Cellulosic EtOH) Reduces Far Greater GHG Emissions



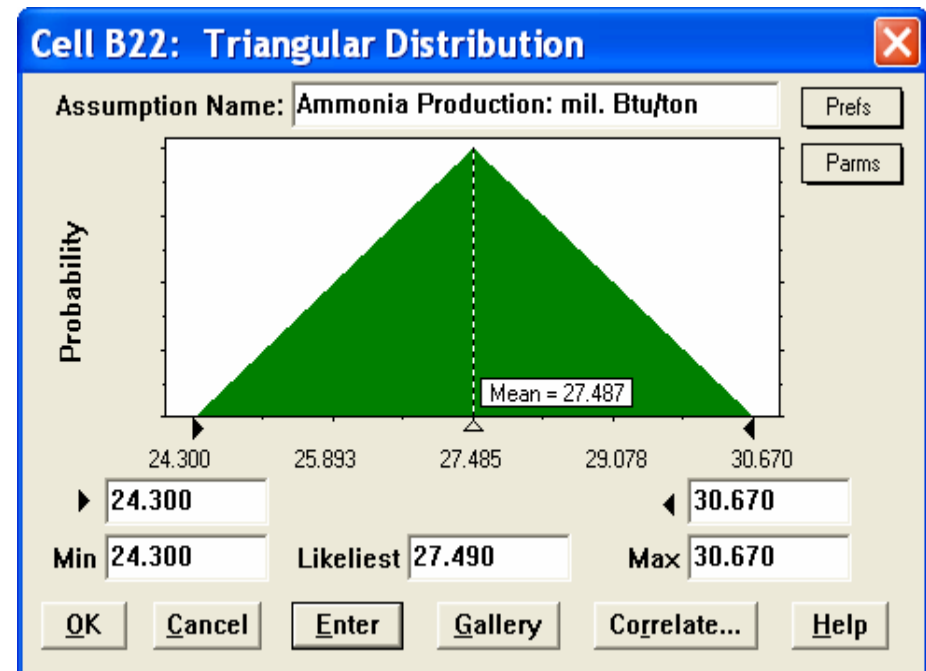
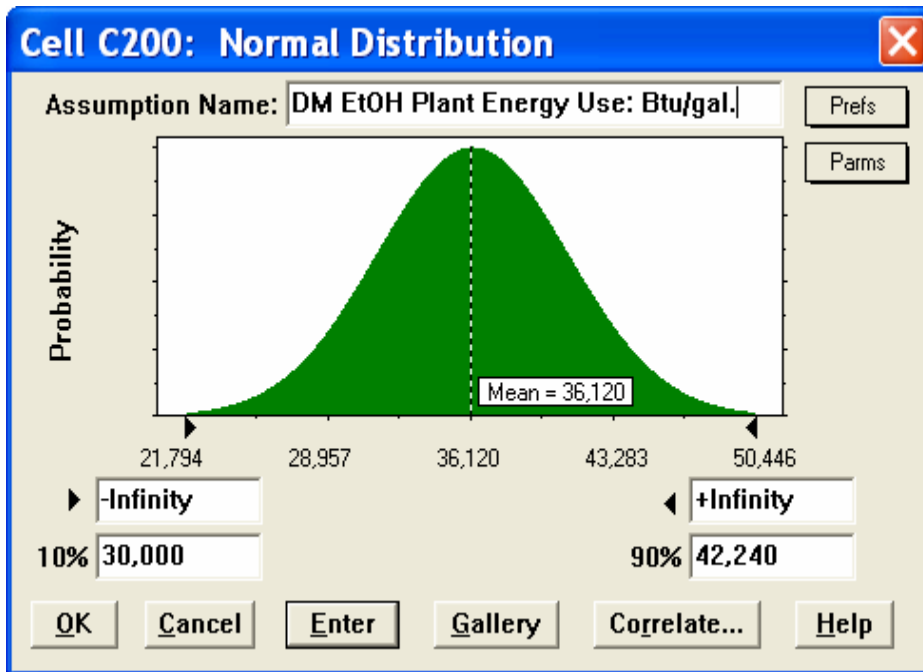
Per-Mile GHG Emission Reductions by Ethanol Blends to Displace Gasoline

Per Gallon of EtOH Used, Corn EtOH Yields 18-29% Reduction in GHGs and Cellulosic EtOH Yields 85-86% Reduction

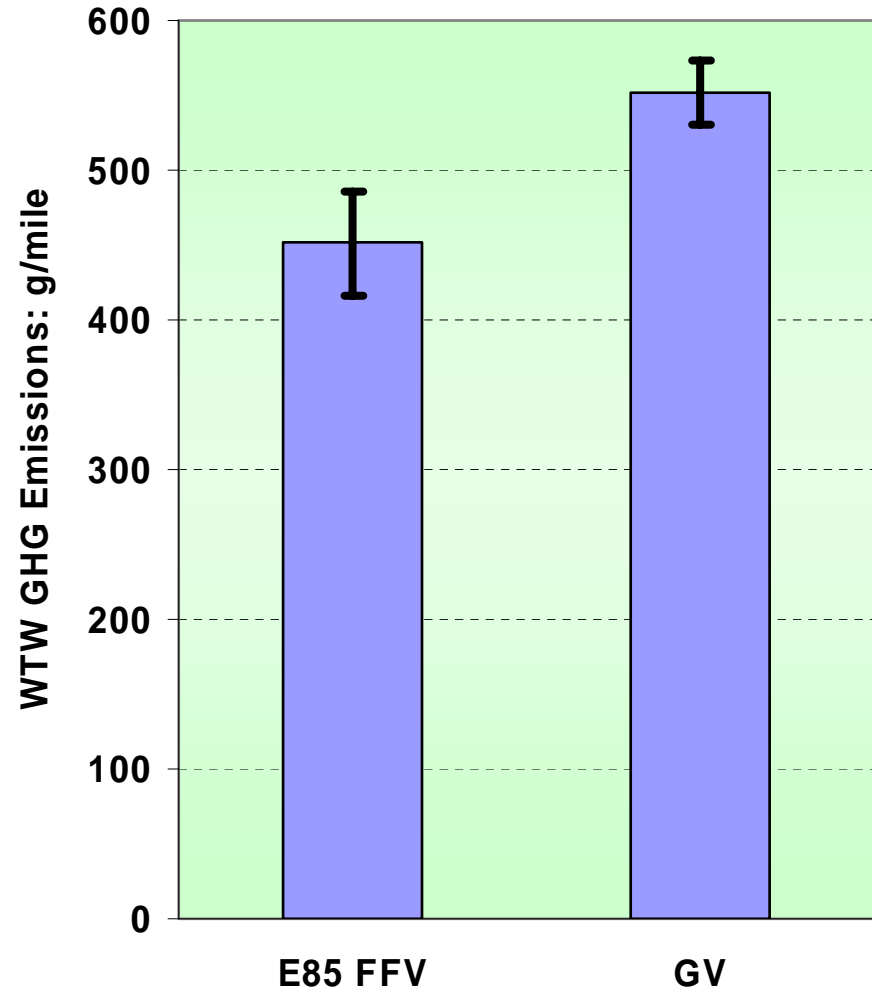
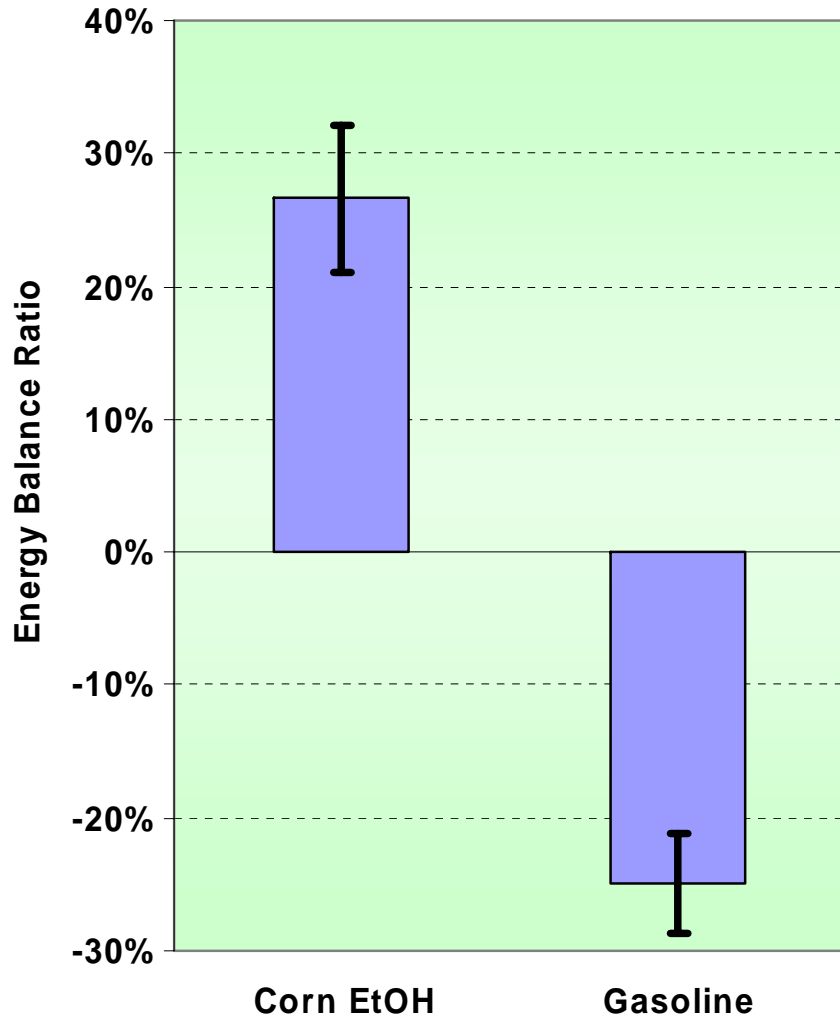


GHG Emission Reductions Per Gallon of Ethanol to Displace An Energy-Equivalent Amount of Gasoline

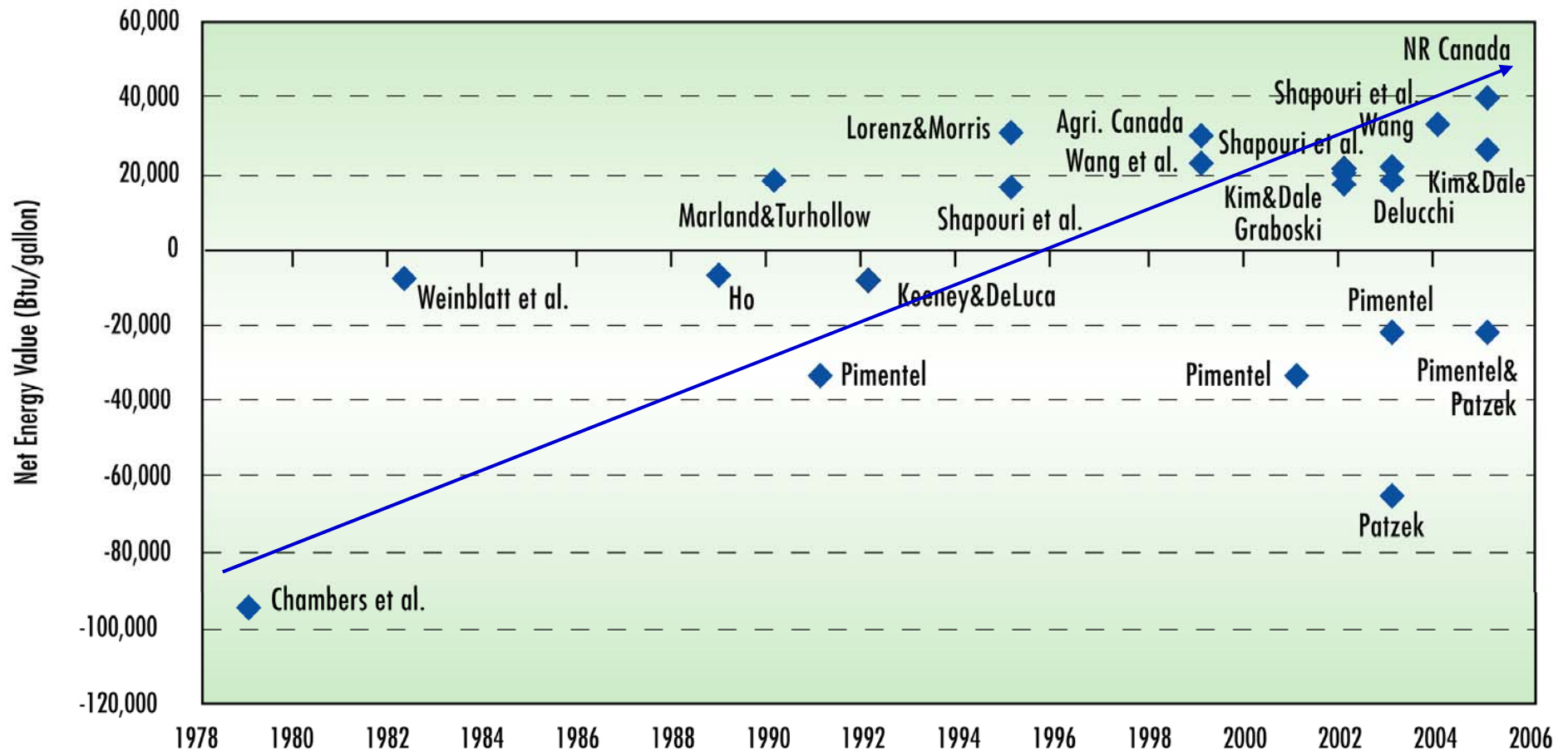
GREET Is Designed to Conduct Stochastic Simulations to Address Uncertainties for Key Parameters



With Stochastic Simulations, GREET Generates Results Showing The Range of Outcomes

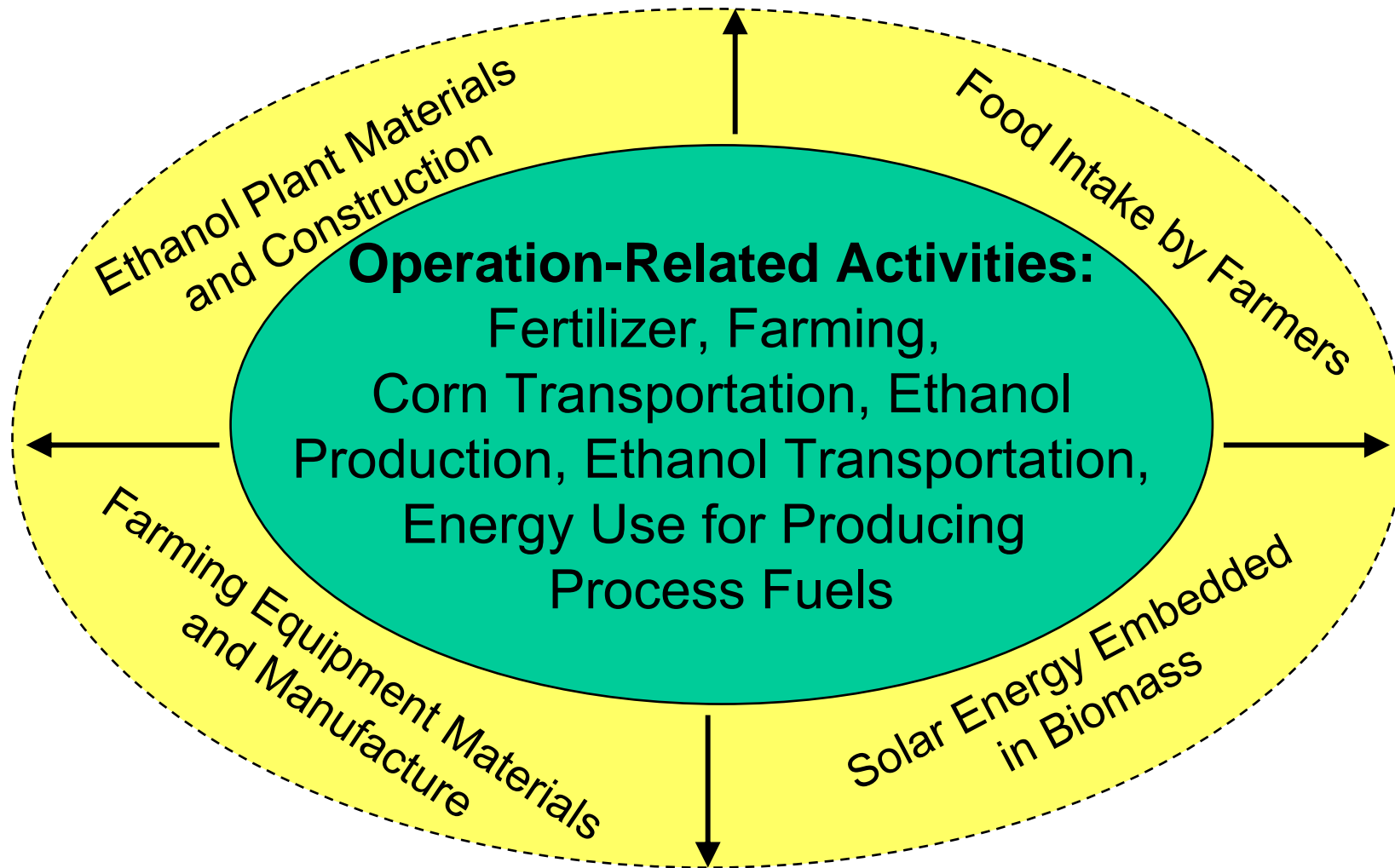


Corn EtOH Energy Balance Results Among Completed Studies Show an Uptrend



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

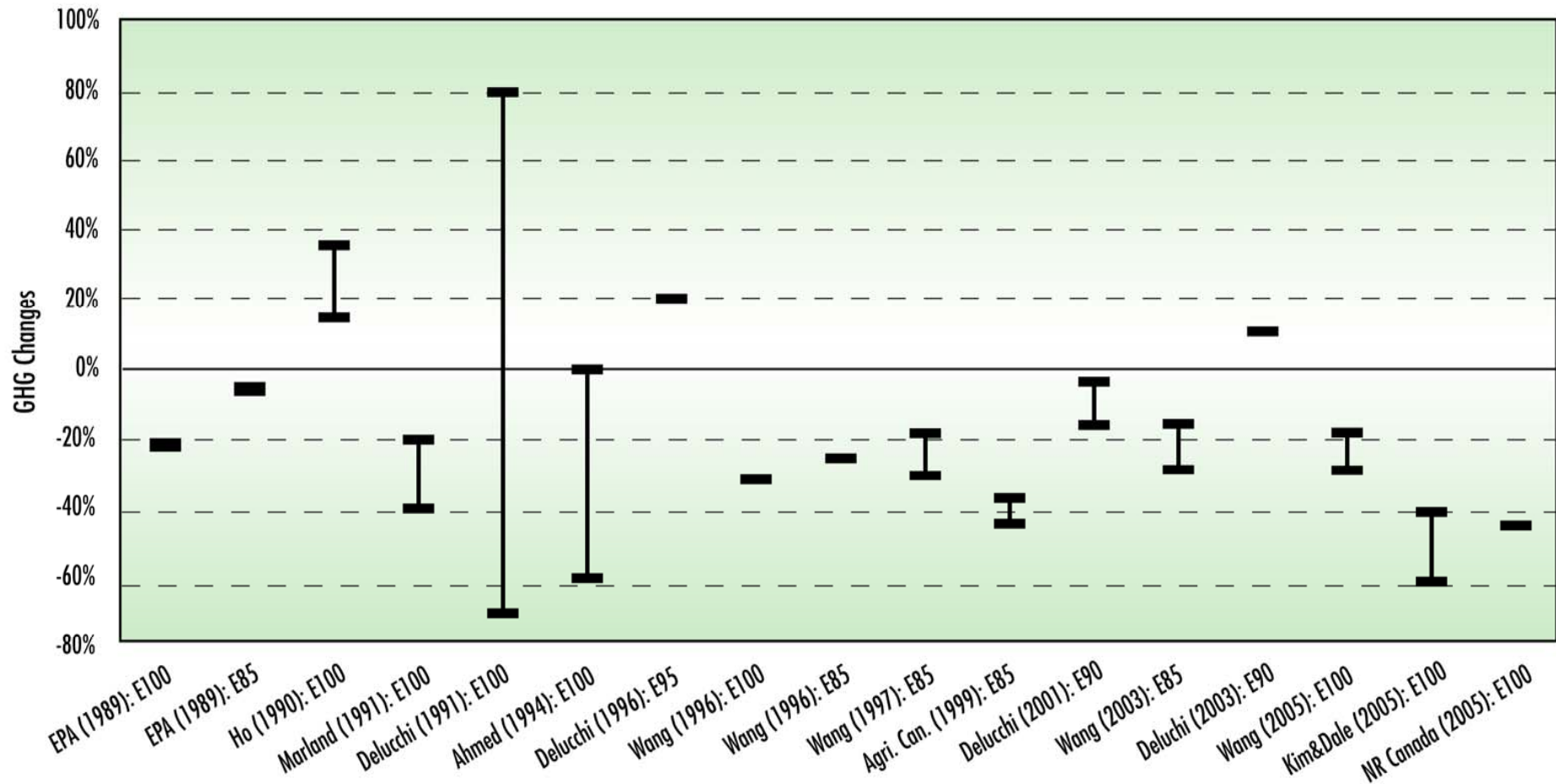
Energy Balance Results of Ethanol Depend Heavily on System Boundary Choices



Debate on Energy Balance Itself May Have Little Practical Meaning

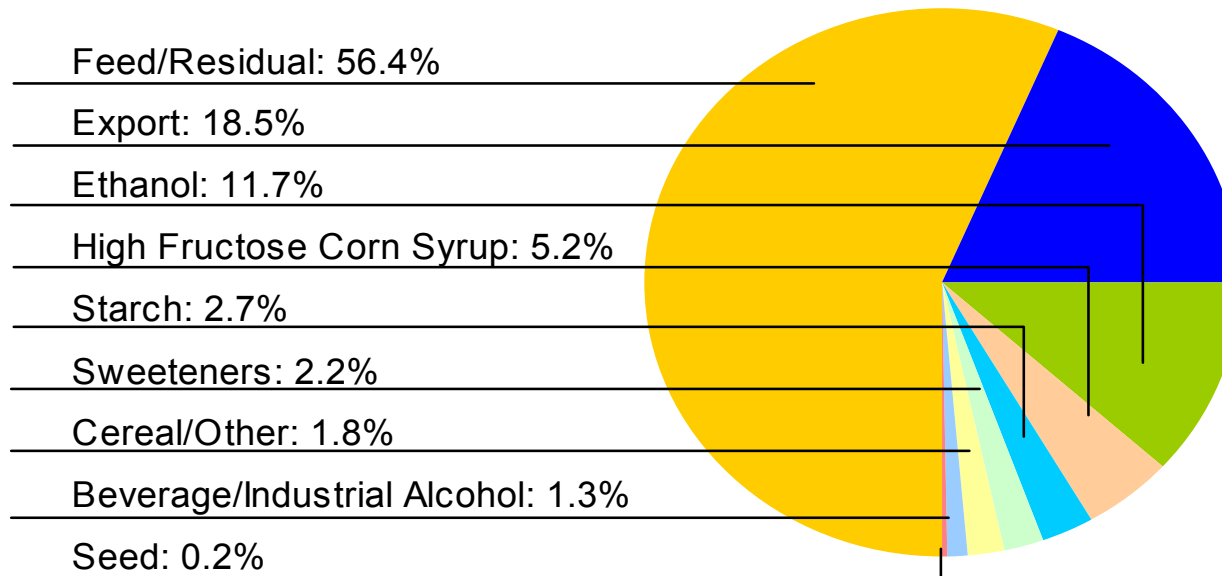
- ❑ Though self evaluation of a fuel's energy balance is easy to understand, to do so for a fuel in isolation could be arbitrary
- ❑ All Btus are not created equal. The energy sector has been converting low-value Btus into high-value Btus, with energy losses
- ❑ Society has not made energy choice decisions 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 fuels
- ❑ 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 Completed Studies on GHG Emissions Show GHG Emission Reduction by Corn EtOH vs. Gasoline



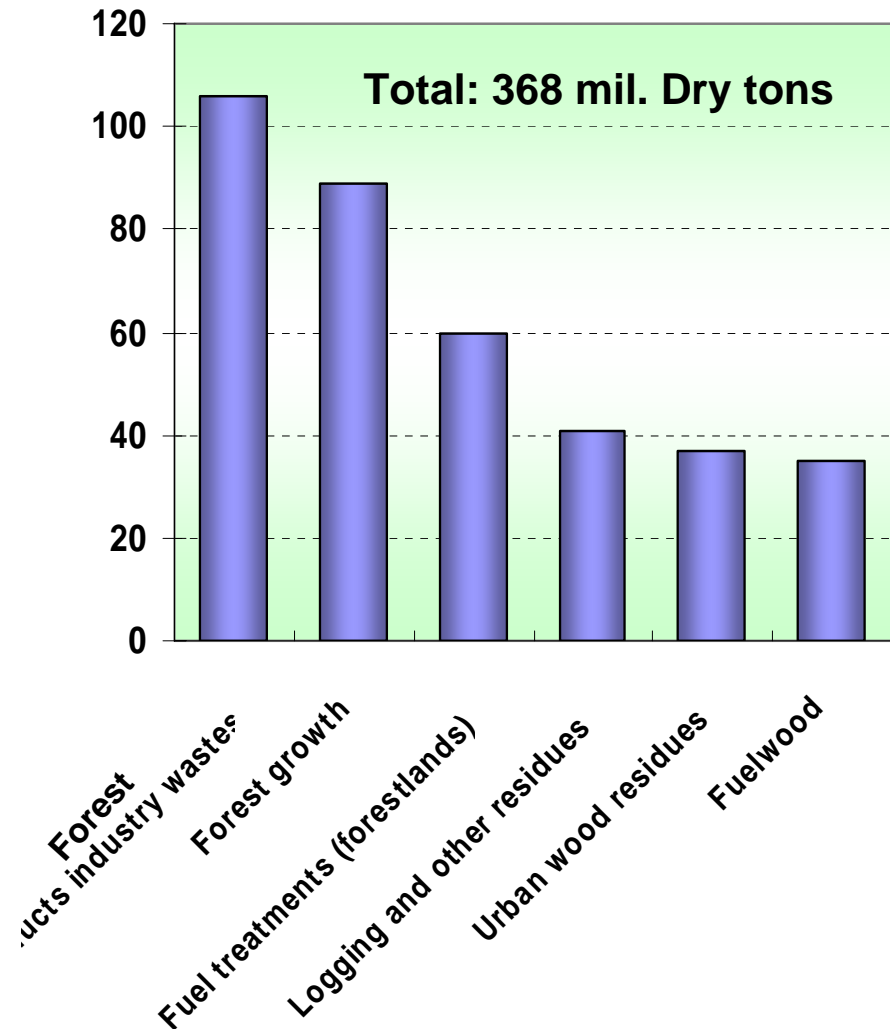
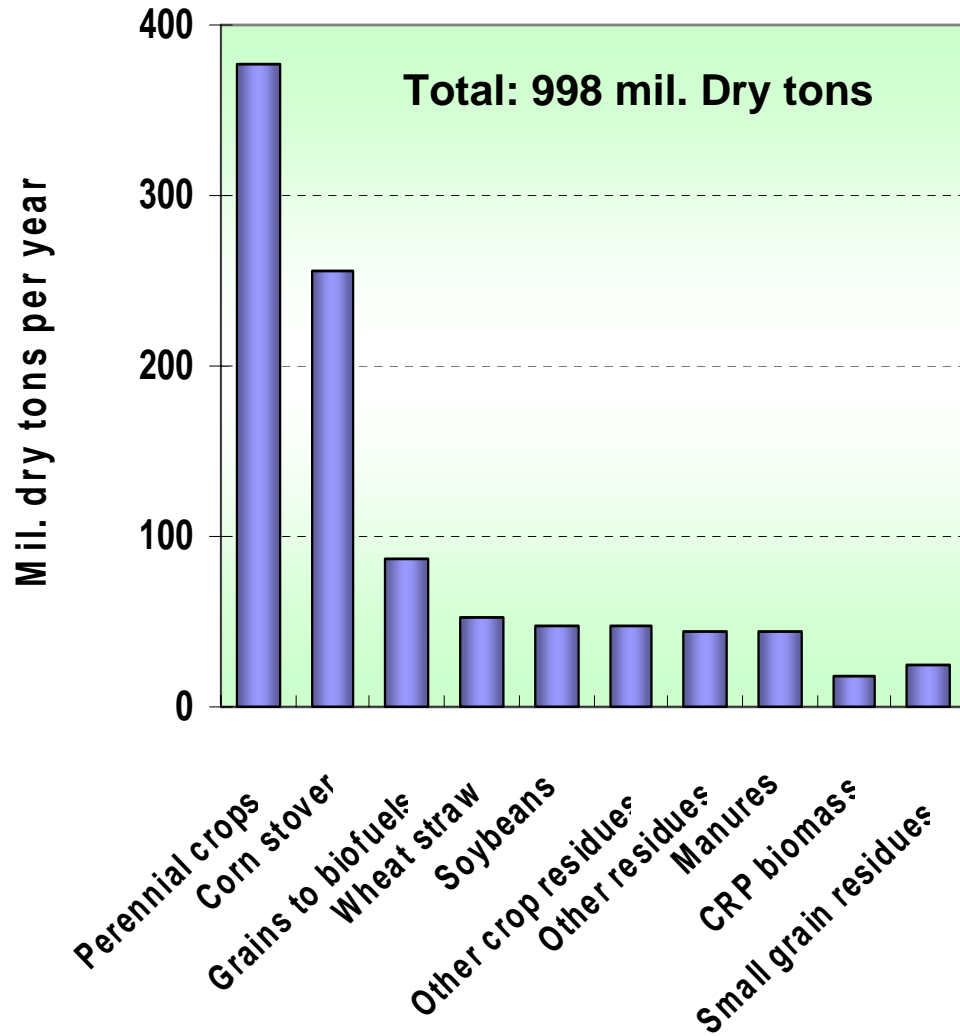
Of the 11.8 Billion Bushels of Corn Produced in U.S. in 2004, About 12% Was Used for Ethanol Production

U.S. Corn Usage by Segment 2004



- ❑ 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

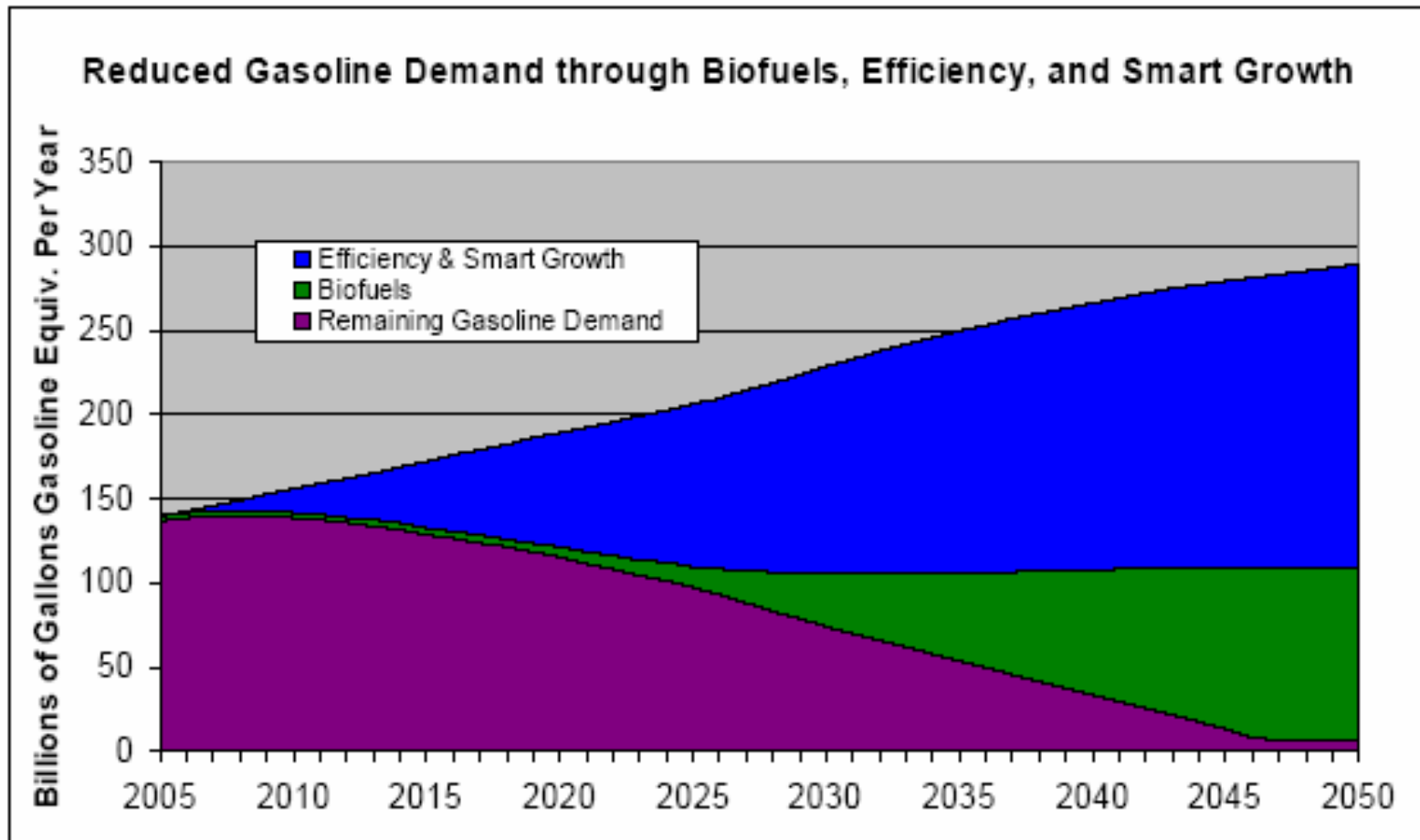
A Recent Study by Oak Ridge National Laboratory Concludes 1.3 Billion Tons of Biomass Available in U.S. Per Year



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

A Recent Study by NRDC Concludes That Efficiency and Renewable Fuels Together Could Eliminate U.S. Gasoline Need



Source: Natural Resources Defense Council, 2005

Argonne Analyzed Bio-Fuels, Power, and Chemicals Production from Cellulosic Biomass for a Comprehensive Study of Bio-Fuels

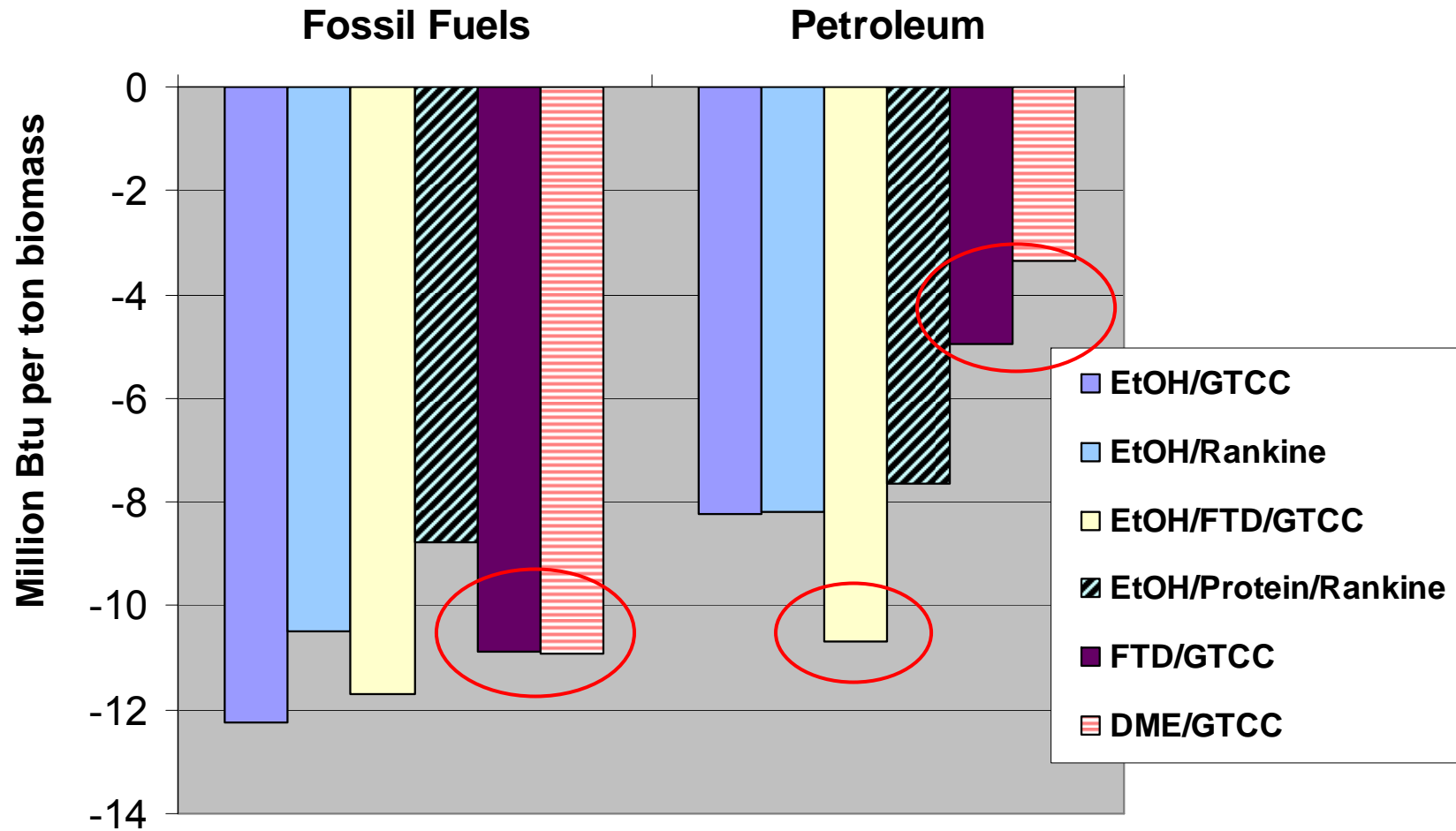
Production Scenarios	Transportation Fuel	Power	Others
EtOH/GTCC	Ethanol	√	
EtOH/Rankine	Ethanol	√	
Multi-fuel	Ethanol, FTDiesel	√	FTgasoline, FTnaphtha
EtOH/Protein/Rankine	Ethanol	√	Protein
FTD/GTCC	FTDiesel	√	FTgasoline, FTnaphtha
DME/GTCC	DMEther	√	

Shares of Biofuels and Co-Products (Based on Energy Content) Vary for the Scenarios Evaluated

Production Scenarios	Transportation Fuel	Power	Others
EtOH / GTCC	79.6%	20.4%	
EtOH / Rankine	88.2%	11.9%	
Multi-fuel	89.9%	1.8%	8.3%
EtOH / Protein / Rankine	83.2%	3.5%	13.3%
DME / GTCC	44.7%	55.3%	
FTD / GTCC	36.8%	40.4%	22.9%

- ❑ Bio-EtOH has the largest amount of energy share in fuel products.
- ❑ Thermochemical process generates similar amount of energy between fuel and power.

Energy Benefits of Biofuels Vary Among Different Production Scenarios



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 transportation's 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

(For more information, please visit the GREET model website at <http://greet.anl.gov>)