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# ***Energy and Greenhouse Gas Impacts of Fuel Ethanol***

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***2007 Biobased Industry Outlook Conference***

***Iowa State University, Ames, Iowa***

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U.S. Department  
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UChicago ►  
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# ***U.S., Brazil and China Are Major Fuel Ethanol Producing Countries***

## **□ U.S.**

- *Corn ethanol***
- *No.1 producing country with 4.9 billion gallons in 2006***

## **□ Brazil**

- *Sugarcane ethanol***
- *No.2 producing country with 4.5 billion gallons in 2006***

## **□ China**

- *Corn ethanol***
- *No.3 producing country with 440 million gallons in 2006***

# ***President's State of Union Address Set an Aggressive Goal to Displace 20% of Gasoline Consumption in 10 Years (20 in 10)***

- ❑ Energy use in the transportation sector consists almost exclusively (98%) of petroleum fuels; in 2006, motor vehicles consumed
  - 140 billion gallons of gasoline
  - 50 billion gallons of diesel
- ❑ EIA projects that the gasoline demand will reach 175 billion gallons by 2017
- ❑ The president's goal is to displace 35 billion gallons of gasoline by biofuels and alternative fuels, 20% of the gasoline market then
- ❑ In 2006, fuel ethanol use was about 3% of gasoline demand volumetrically

# ***Biofuels Can Be Used in Vehicles at Low- Or High-Level Blends***

- ❑ Low-level blends of ethanol/gasoline in gasoline vehicles
  - E5 in Canada (now), Australia, and Sweden
  - ETBE in France, Spain, and Germany
  - E3 in Japan
  - E6-E10 in U.S.
  - E10 in China, Thailand, and Canada (future)
  - E20-E25 in Brazil
- ❑ High-level ethanol blends in flexible fuel vehicles (FFVs)
  - E85 in the U.S.
  - Up to E100 in Brazil
  - E85 in Sweden
- ❑ Varied levels of biodiesel/diesel blends in diesel vehicles
  - B2-B20 in different countries

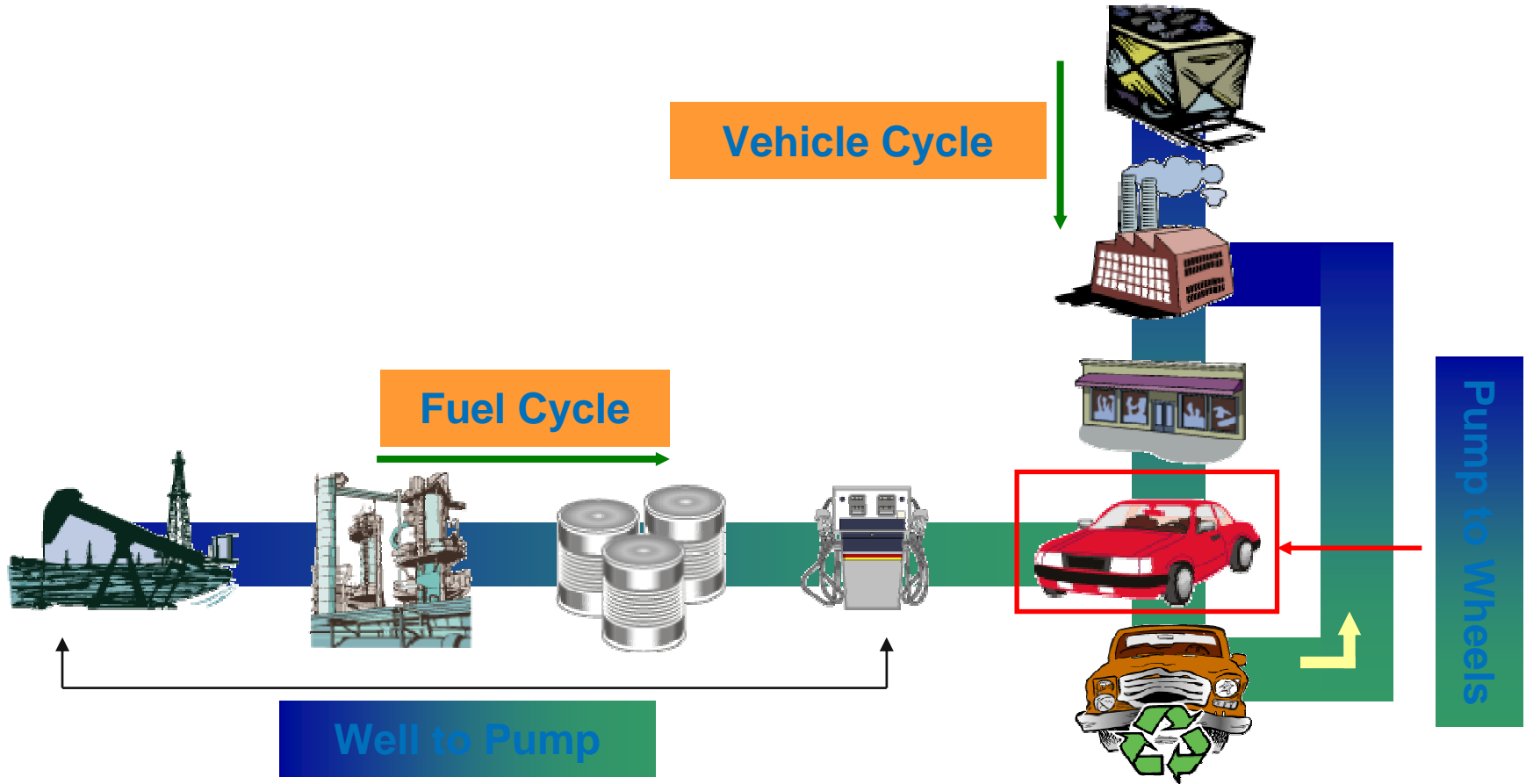
# *Requirements Are in Place or Proposed to Promote Biofuel Use Further*

- ❑ EU biofuel requirements
  - 5.75% until 2010 (only 1.4% achieved in 2005)
  - 10% between 2010 and 2020
- ❑ Japan: target of 500 million liters of ethanol by 2010
- ❑ China
  - Goal of doubling ethanol use in the next few years
  - New ethanol production will be non-grain based
- ❑ Canada: proposed E10 nationwide
- ❑ Low-carbon fuel standard (LCFS) in California, the European Union, and some other U.S. states
- ❑ GHG emission standards for vehicles/fuels to be proposed by the U.S. EPA

# The Role of Biofuels May Be Affected by Land Availability and Oil Use in Individual Countries

Country	Land Area, 10 <sup>3</sup> km <sup>2</sup>	Population, Million	Arable Land, 10 <sup>3</sup> km <sup>2</sup>	Arable Land km <sup>2</sup> per 10 <sup>3</sup> people	Oil Use, mil. barrels a day
USA	9,161	296	1,752	5.92	20.0
China	9,326	1,306	1,436	1.10	6.3
Japan	374	127	46	0.36	5.6
Germany	349	82	118	1.44	2.7
India	2,973	1,080	1,617	1.50	2.3
Canada	9,093	32	451	14.09	2.2
Brazil	8,457	186	588	3.16	2.1
France	545	60	183	3.05	2.1
The U.K.	241	60	57	0.95	1.7
Spain	499	40	130	3.25	1.5
Thailand	511	65	150	2.31	0.9
Australia	7,617	20	499	24.95	0.8
Pakistan	778	162	216	1.33	0.4
Sweden	410	9	27	3.00	0.4

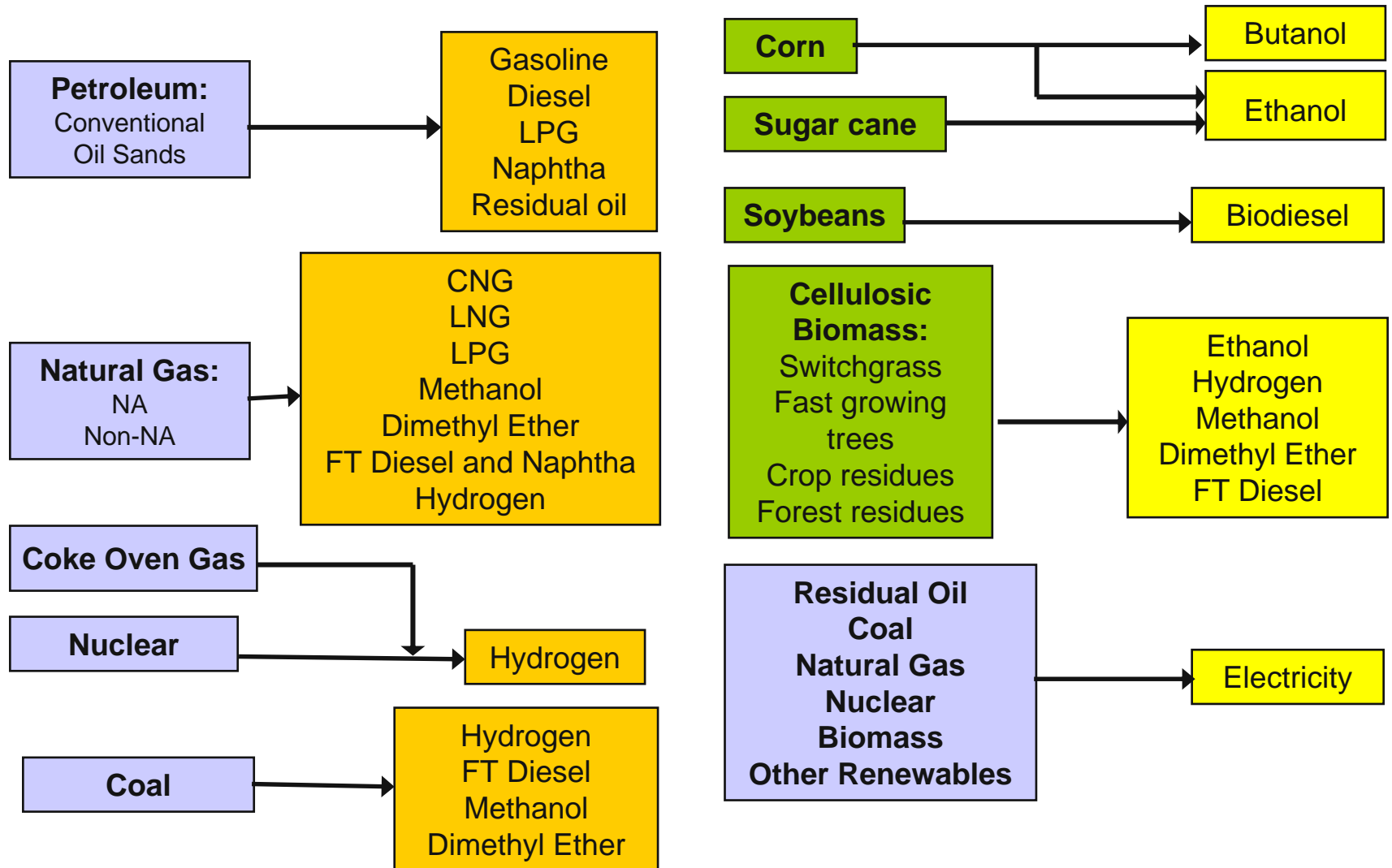
# Well-to-Wheels Analysis of Vehicle/Fuel Systems Covers Activities for Fuel Production and Vehicle Use



# ***The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model***

- ❑ **Argonne began GREET development in 1995 with DOE support**
- ❑ **Includes emissions of greenhouse gases**
  - CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O (and optional GHGs such as VOC, CO, and NO<sub>x</sub>)
- ❑ **Estimates emissions of six criteria pollutants**
  - VOC, CO, NO<sub>x</sub>, SO<sub>x</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub>
  - Total and urban separately
- ❑ **Separates energy use into**
  - All energy sources (fossil and non-fossil)
  - Fossil fuels (petroleum, natural gas, and coal combined)
  - Petroleum
  - Coal
  - Natural gas
- ❑ **GREET is in public domain**
  - Available at *<http://www.transportation.anl.gov/software/GREET/>* (or simply *Google GREET on the Web*)
  - At present, there are more than 3,500 registered GREET users worldwide
  - The most recent GREET version was released in August 2007

# Fuel Production Pathways from Various Energy Feedstocks (Well-to-Pump) in GREET



# GREET Includes More Than 75 Vehicle/Fuel Systems

## Conventional Spark-Ignition Vehicles

- Conventional gasoline, federal reformulated gasoline, California reformulated gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol

## Compression-Ignition Direct-Injection Hybrid Electric Vehicles: Grid-Independent and Connected

- Conventional diesel, low sulfur diesel, dimethyl ether, Fischer-Tropsch diesel, E-diesel, and biodiesel

## Spark-Ignition Hybrid Electric Vehicles: Grid-Independent and Connected

- Conventional gasoline, federal reformulated gasoline, California reformulated gasoline
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## Battery-Powered Electric Vehicles

- U.S. generation mix
- California generation mix
- Northeast U.S. generation mix
- User-selected generation mix

## Fuel Cell Vehicles

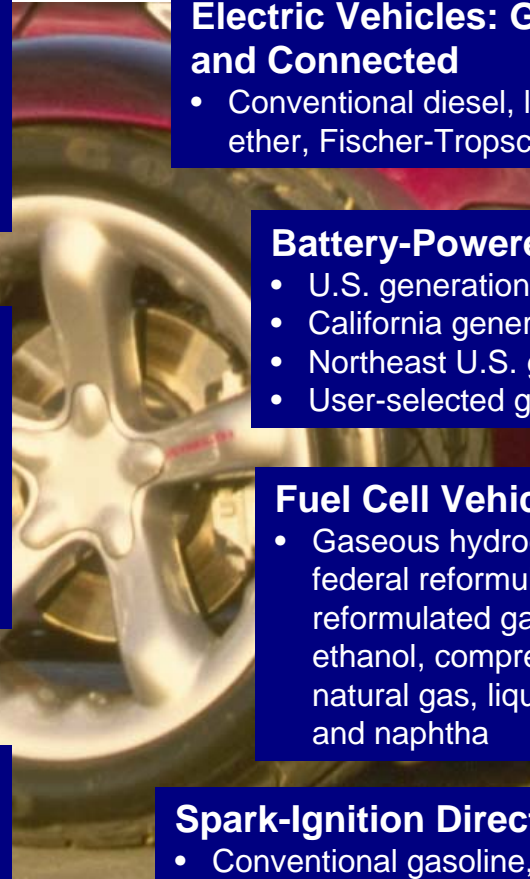
- Gaseous hydrogen, liquid hydrogen, methanol, federal reformulated gasoline, California reformulated gasoline, low sulfur diesel, ethanol, compressed natural gas, liquefied natural gas, liquefied petroleum gas, and naphtha

## Compression-Ignition Direct-Injection Vehicles

- Conventional diesel, low sulfur diesel, dimethyl ether, Fischer-Tropsch diesel, E-diesel, and biodiesel

## Spark-Ignition Direct-Injection Vehicles

- Conventional gasoline, federal reformulated gasoline, and California reformulated gasoline
- Methanol and ethanol



# Among Various Biofuel Production Pathways, GREET Includes Only Some

## ☐ 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

- Fischer-Tropsch diesel
- Hydrogen
- Methanol

## ☐ Oils for Biodiesel/Renewable Diesel

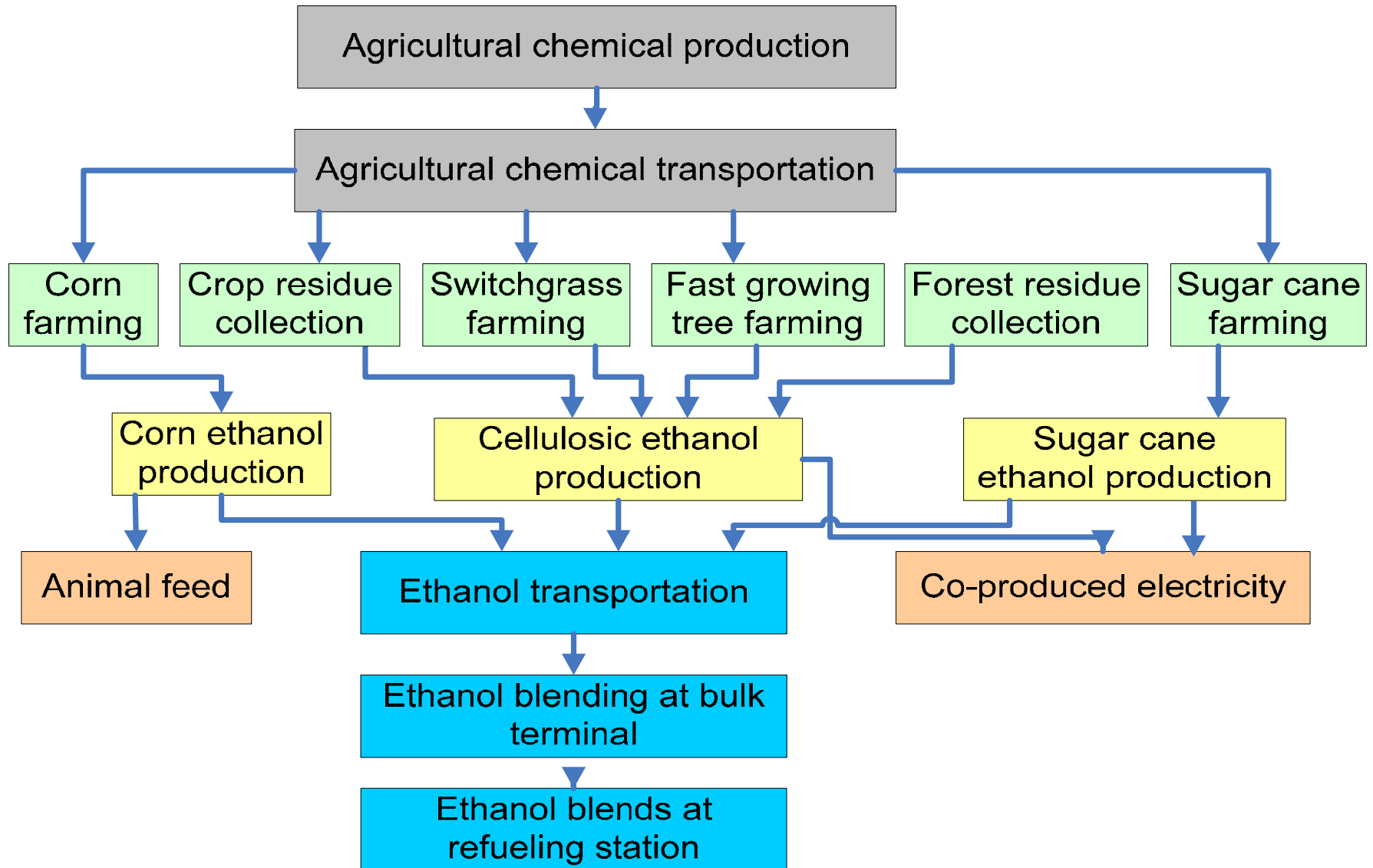
- Soybeans
- Rapeseed
- Palm oil
- Jatropha
- Waste cooking oil
- Animal fat

## ☐ 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 included in the GREET model.

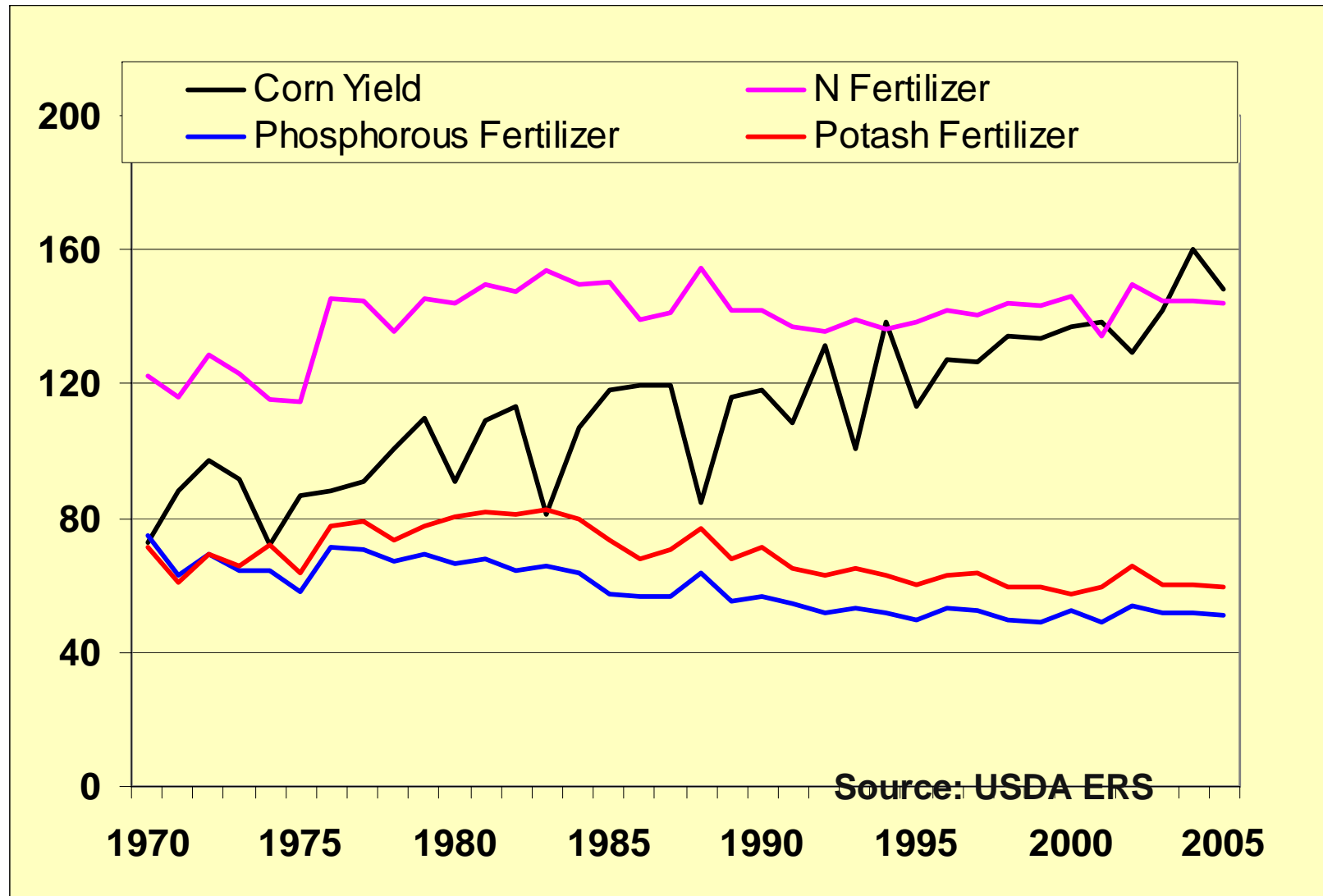
# ***REET Ethanol Life-Cycle Analysis Includes Activities from Fertilizer to Ethanol at Refueling Stations***



# Key Issues for Biofuel Life-Cycle Analysis

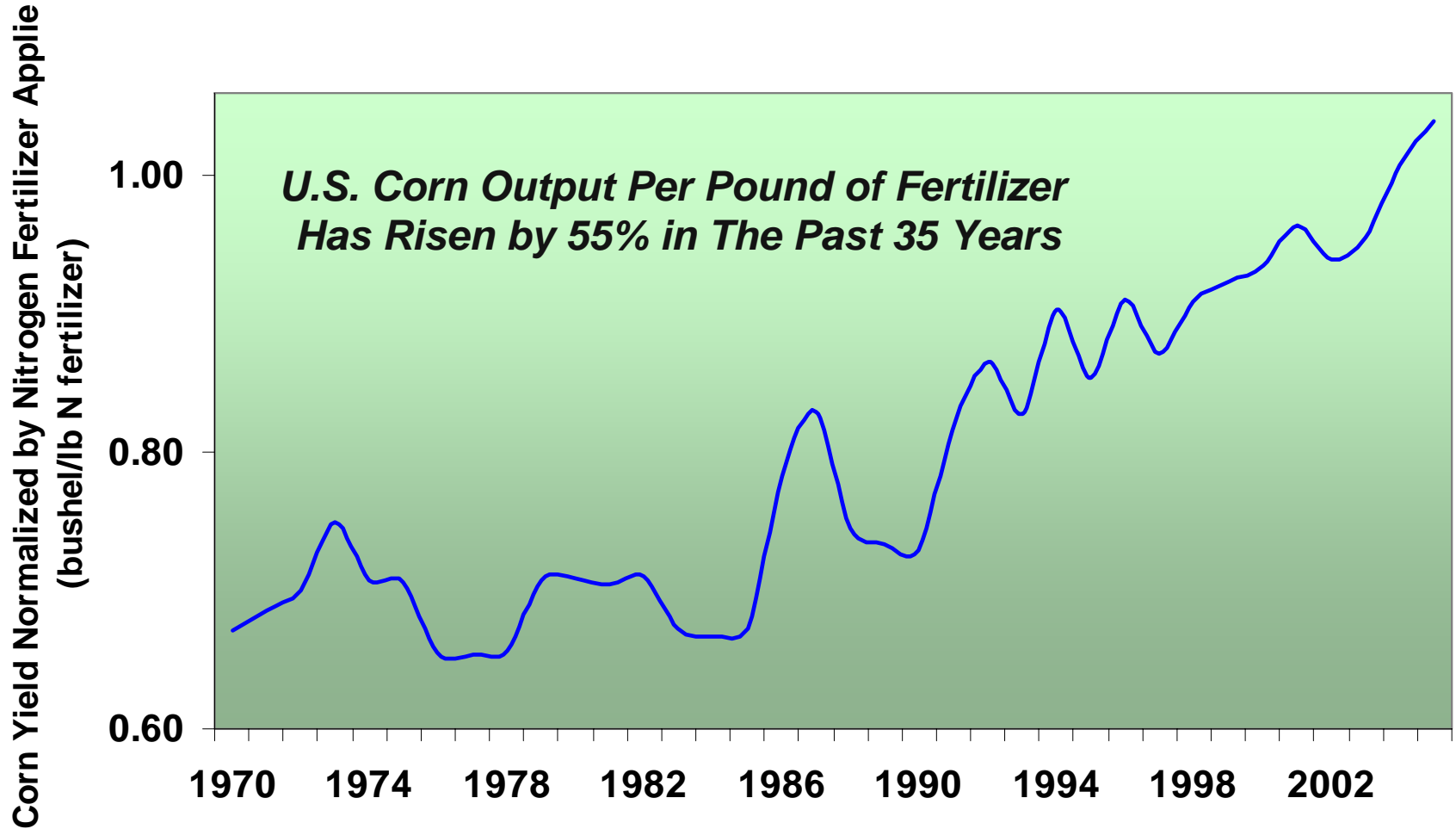
- ❑ Nitrogen fertilizer production: primarily from natural gas and a small amount from coal
- ❑ Use of fertilizer in farms
  - Nitrogen fertilizer: energy in fertilizer and N<sub>2</sub>O emissions from N nitrification and denitrification
  - Lime: CO<sub>2</sub> emissions from lime stone (CaCO<sub>3</sub>) to lime (CaO) in fields for stabilizing soil acidity
- ❑ Energy use for farming
- ❑ Open field burning in sugarcane plantations
- ❑ Nitrogen cycle and resultant N<sub>2</sub>O emissions
- ❑ Energy use in biofuel plants
  - The amount of process fuels for steam production
  - The type of process fuels
- ❑ Co-products
- ❑ Land use change and resulted CO<sub>2</sub> emissions

# U.S. Fertilizer Use for Corn Farming Has Stabilized or Declined, While Corn Yield Continues to Increase



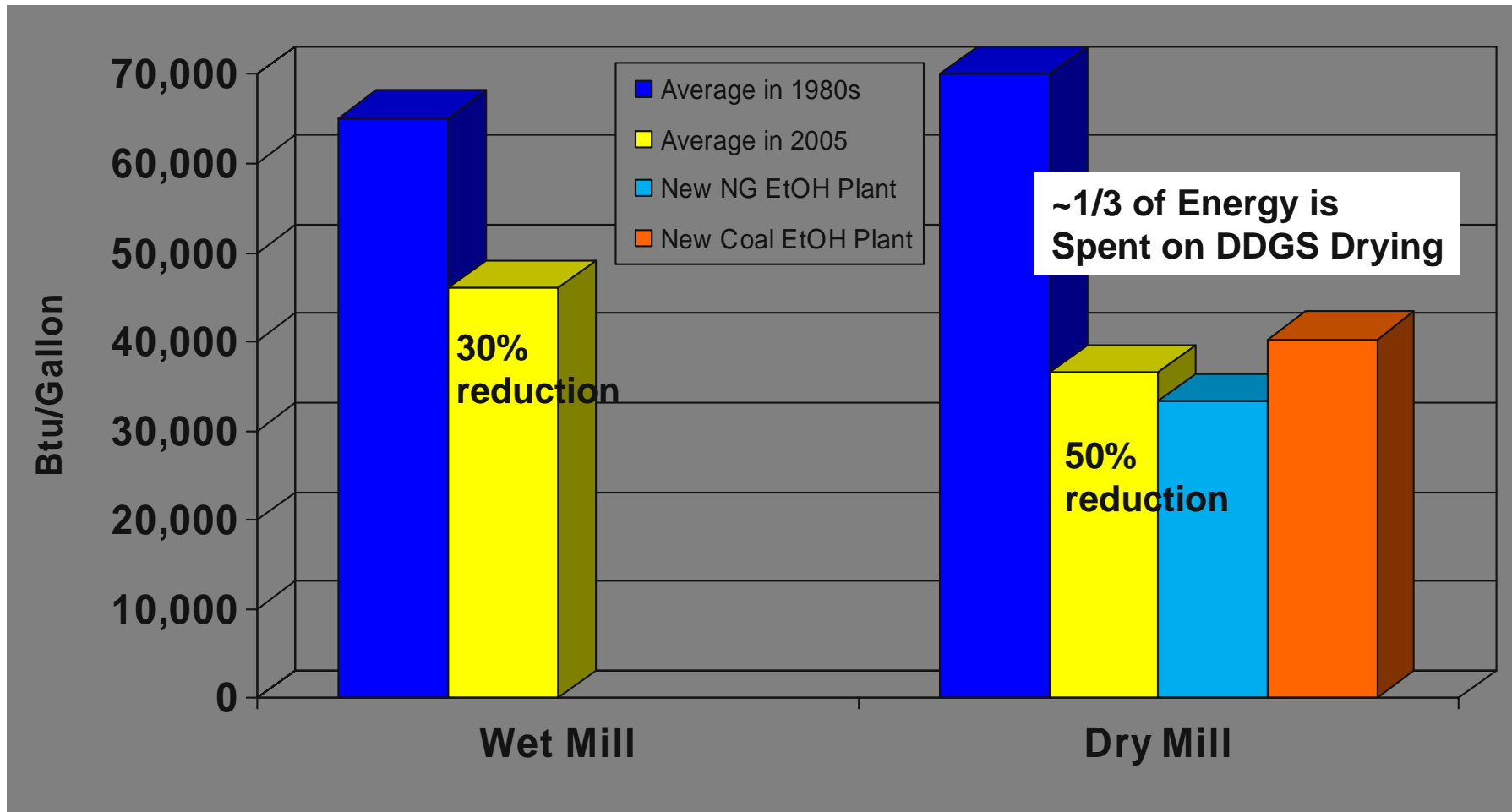
Corn yield is in bushels/acre; Fertilizer use is in lbs/acre.

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



Based on harvested acreage. Source: USDA ERS

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



Data for new ethanol plants is from Mueller and Cuttica (2006)

# Co-Products with Biofuels

- ❑ Types of co-products
  - Corn ethanol: animal feeds (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*
  - Plant process purpose based
- ❑ Scale of biofuel production and co-product production will affect the choice of methods

# Accounting for Animal Feed Is a Critical Factor in Corn 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%

Argonne uses the displacement method, the most conservative approach.

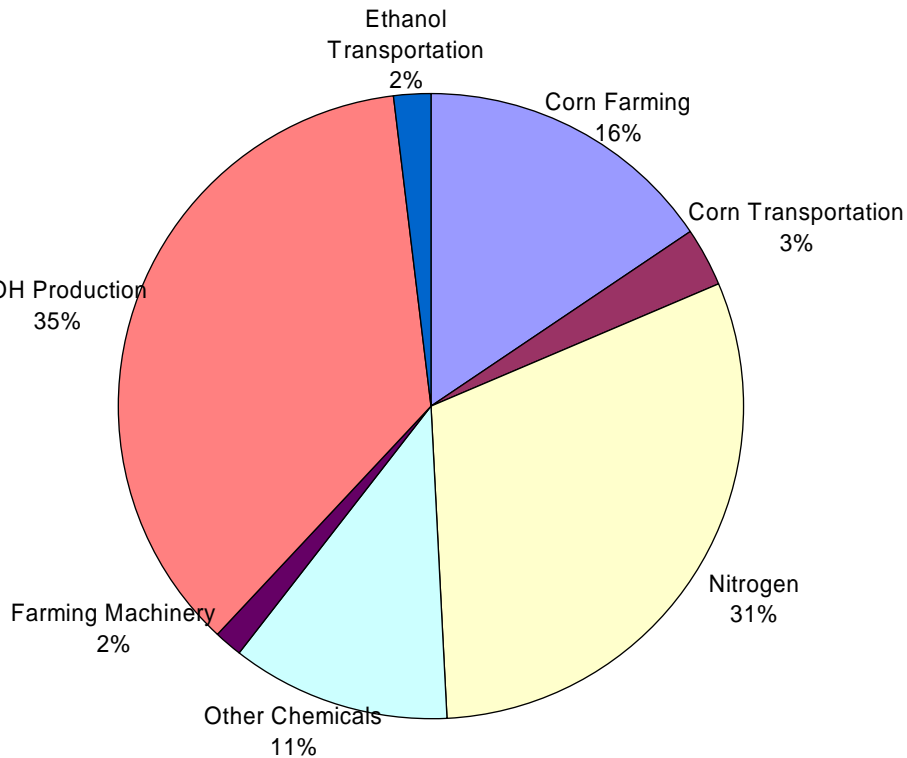
# ***GREET Analysis Concluded That Energy Embedded in Farming Equipment Is Not a Significant Contributor to Ethanol's Life-Cycle Energy Use***

- Size of farm
- Life time of equipment
- Energy for producing equipment materials (the majority of equipment materials is steel and rubber)
- Argonne has found that farming equipment may contribute to <2% of energy and ~1% GHG emissions for corn ethanol

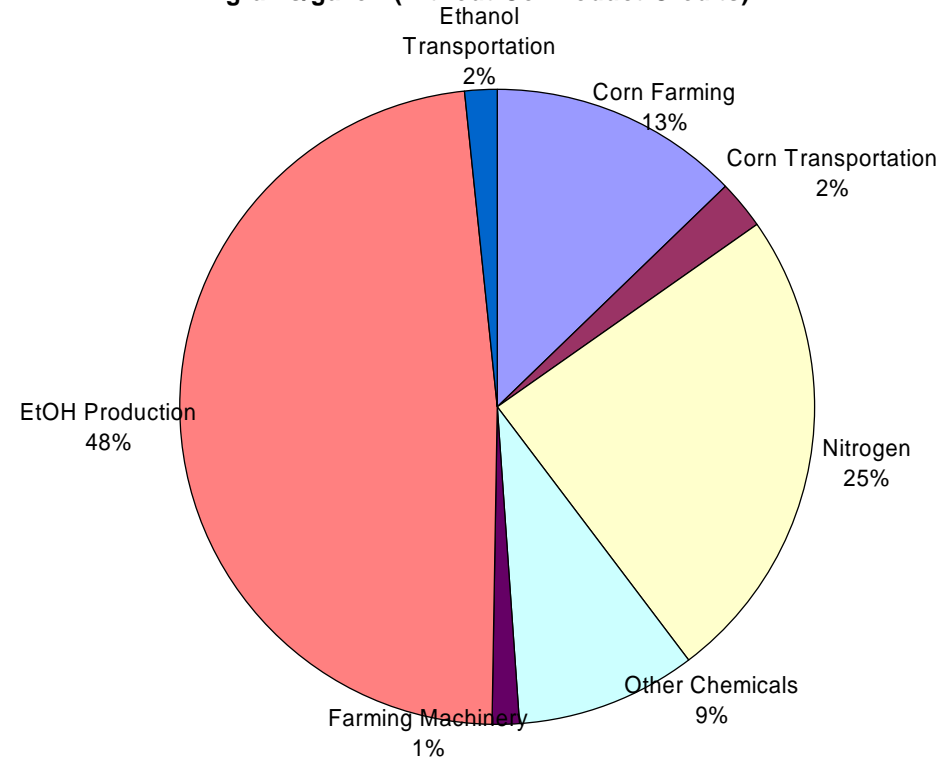
Equipment	Weight (tons)	Lifetime (yr)
Large tractor	10	15
Small tractor	5.7	15
Field cultivator	2.6	10
Chisel plow/ripper	4.0	10
Planter	3.7	10
Combine	13.7	15
Corn combine head	4.0	10
Gravity box (4)	7.3	15
Auger	0.9	10
Grain bin (3)	10.5	15
Irrigation	5.3	12
Sprayer	0.6	10

# Fuel-Cycle GHG Emission Shares: Corn-Based Ethanol

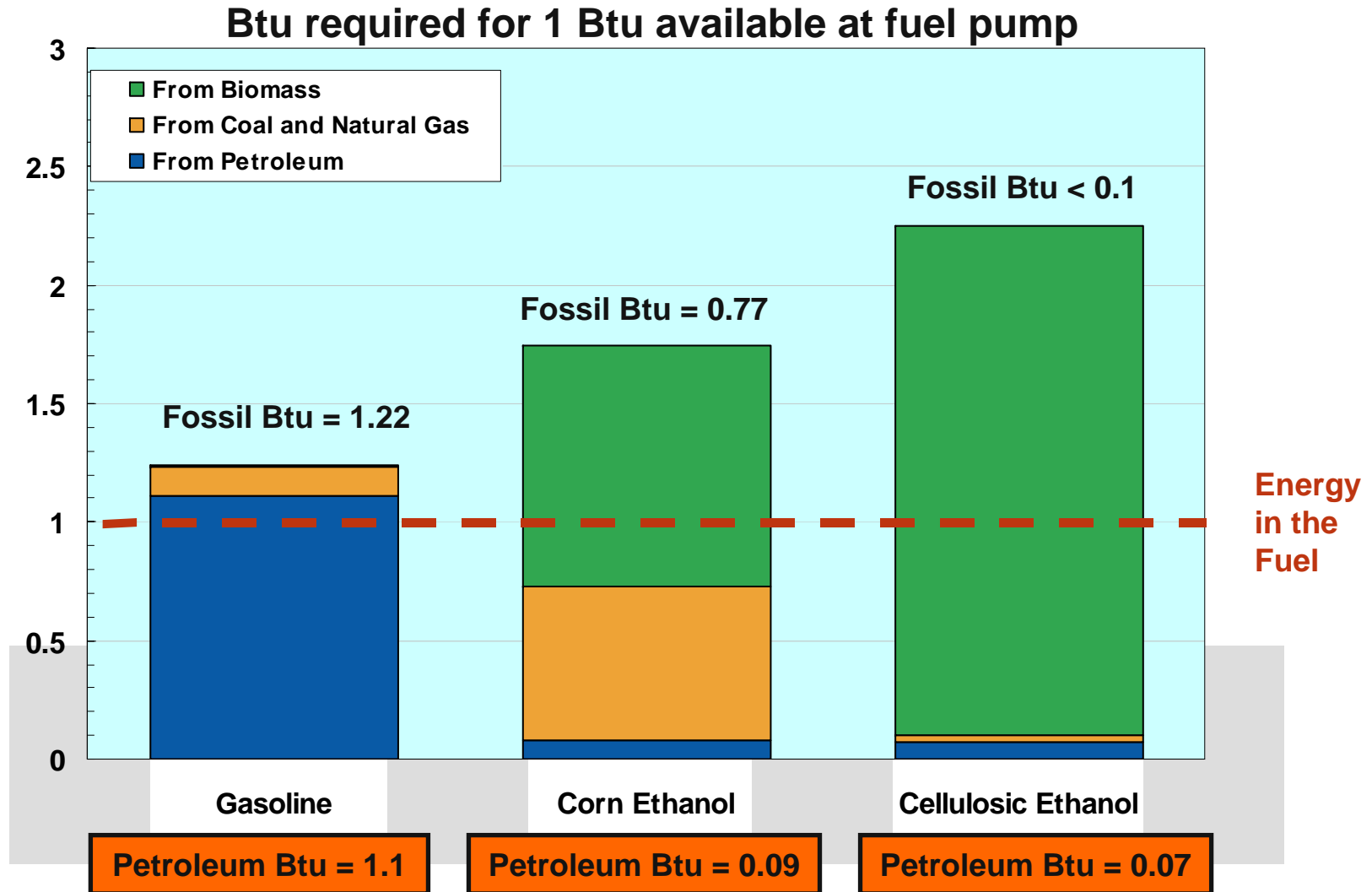
Shares of GHG Emissions for Corn Ethanol: Total of 5,795 grams/gallon (with Co-Product Credits)



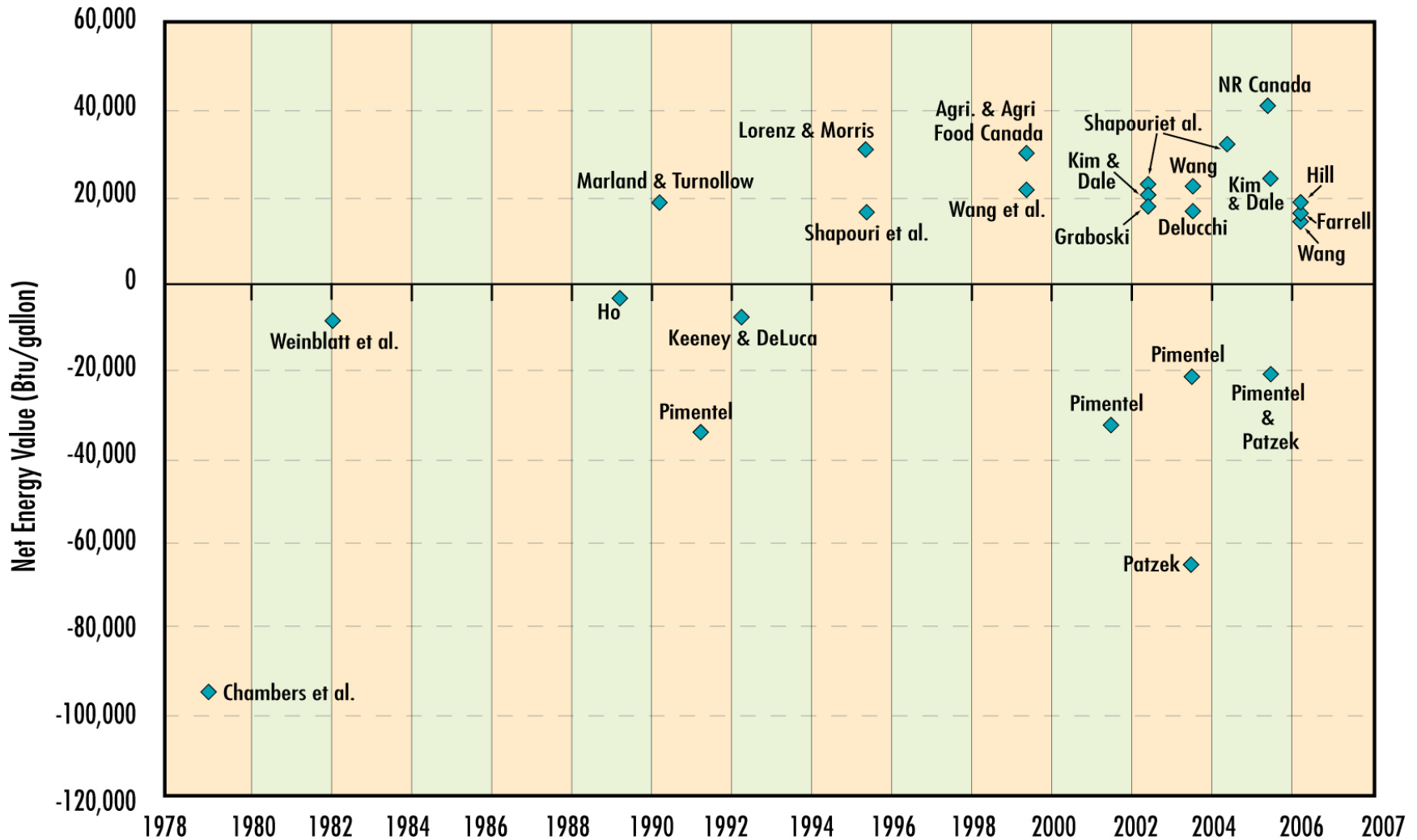
Shares of GHG Emissions for Corn Ethanol: Total of 7,171 grams/gallon (without Co-Product Credits)



# The Type of Energy, As Well As the Amount of Energy, Is Important When Addressing Energy Effects



# Most Recent Studies Show Positive Net Energy Balance for Corn Ethanol



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

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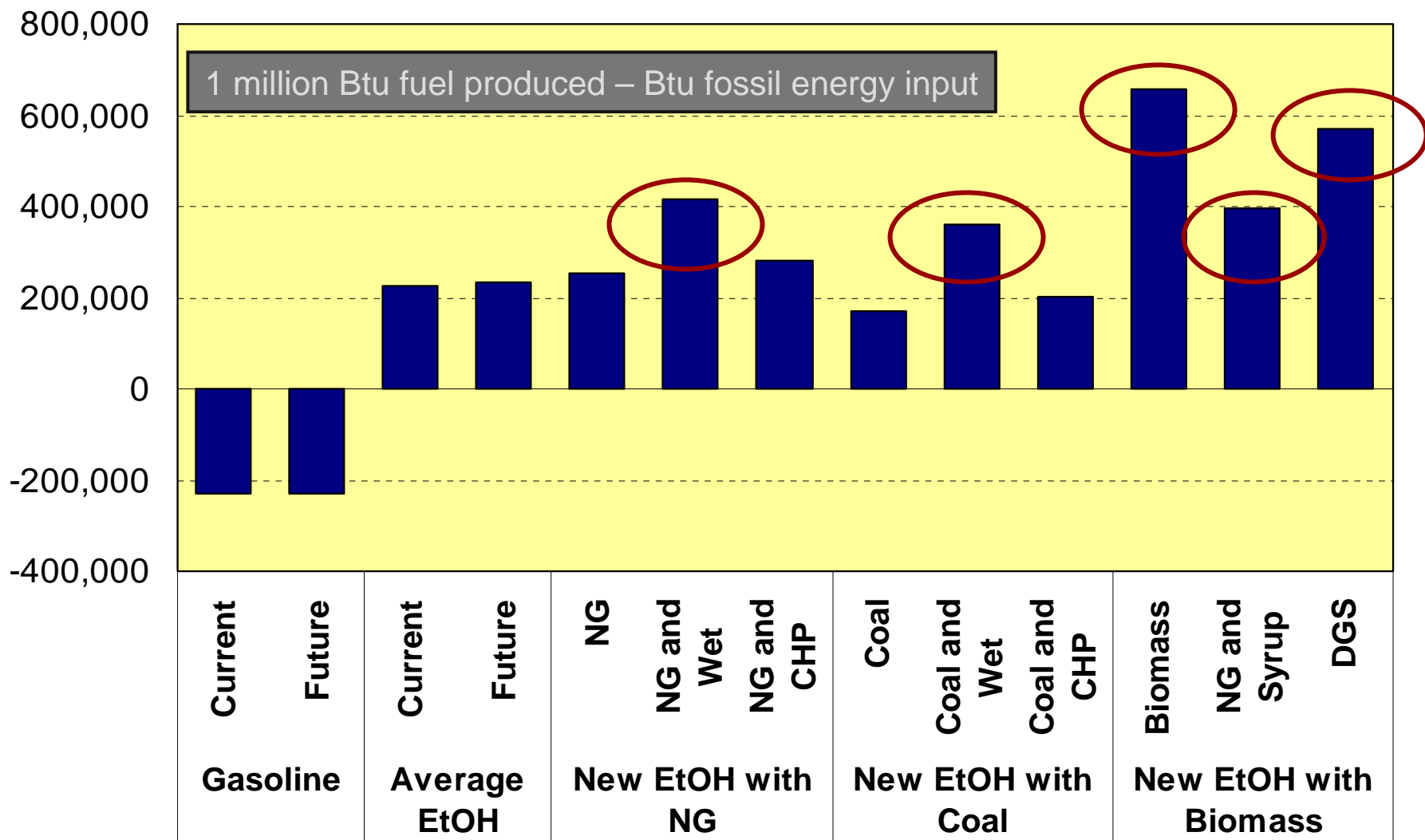
# Argonne Recently Examined Life-Cycle Impacts of Process Fuels in Different Types of Corn Ethanol Plants

	NG	Coal	Biomass	DGS
Base Design	✓	✓	✓	✓
CHP	✓	✓		
Syrup	✓			
Wet DGS (No drying)	✓	✓		

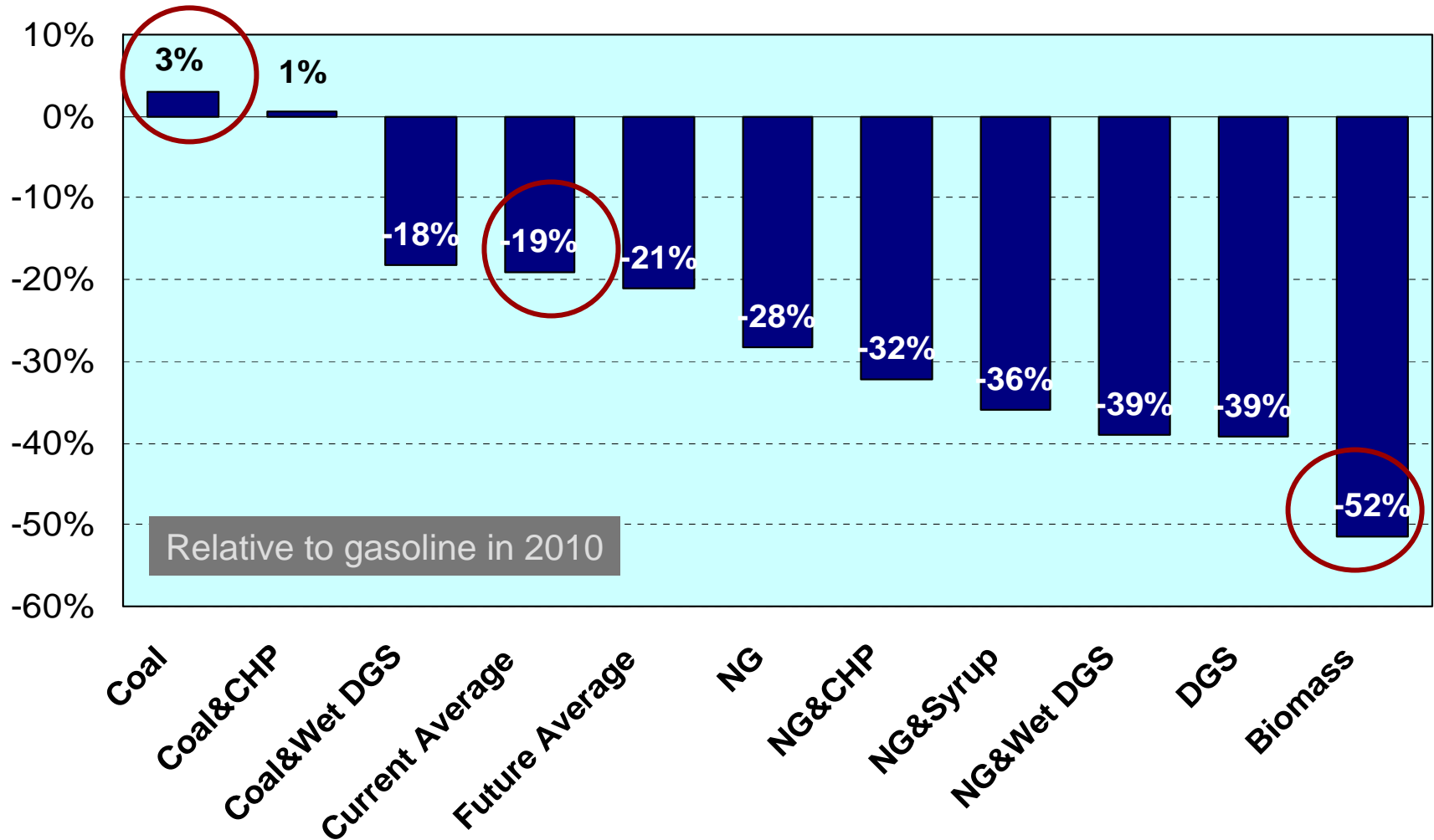
# *Energy Consumption Per Gallon of Ethanol Produced in Different Ethanol Plant Types*

<b>Ethanol Plant Type</b>	<b>Natural Gas: Btu</b>	<b>Coal: Btu</b>	<b>Renewable Process Fuel: Btu</b>	<b>Electricity: kWh</b>
<b>Current Average EtOH</b>	<b>26,420</b>	<b>8,900</b>	<b>-</b>	<b>0.88</b>
<b>2010 Average EtOH</b>	<b>26,050</b>	<b>7,950</b>	<b>-</b>	<b>0.95</b>
<b>1. NG</b>	<b>33,330</b>	<b>-</b>	<b>-</b>	<b>0.75</b>
<b>2. NG and Wet DGS</b>	<b>21,830</b>	<b>-</b>	<b>-</b>	<b>0.75</b>
<b>3. NG and CHP</b>	<b>34,600</b>	<b>-</b>	<b>-</b>	<b>0.17</b>
<b>4. Coal</b>	<b>-</b>	<b>40,260</b>	<b>-</b>	<b>0.90</b>
<b>5. Coal and Wet DGS</b>	<b>-</b>	<b>26,060</b>	<b>-</b>	<b>0.90</b>
<b>6. Coal and CHP</b>	<b>-</b>	<b>44,310</b>	<b>-</b>	<b>0.06</b>
<b>7. Wood Chips</b>	<b>-</b>	<b>-</b>	<b>40,260</b>	<b>0.90</b>
<b>8. NG and Syrup</b>	<b>21,000</b>	<b>-</b>	<b>14,000</b>	<b>0.75</b>
<b>9. DGS Combustion</b>	<b>-</b>	<b>-</b>	<b>40,260</b>	<b>0.75</b>

# Use of Renewable Process Fuels Improves Net Energy Balance Significantly for Corn Ethanol



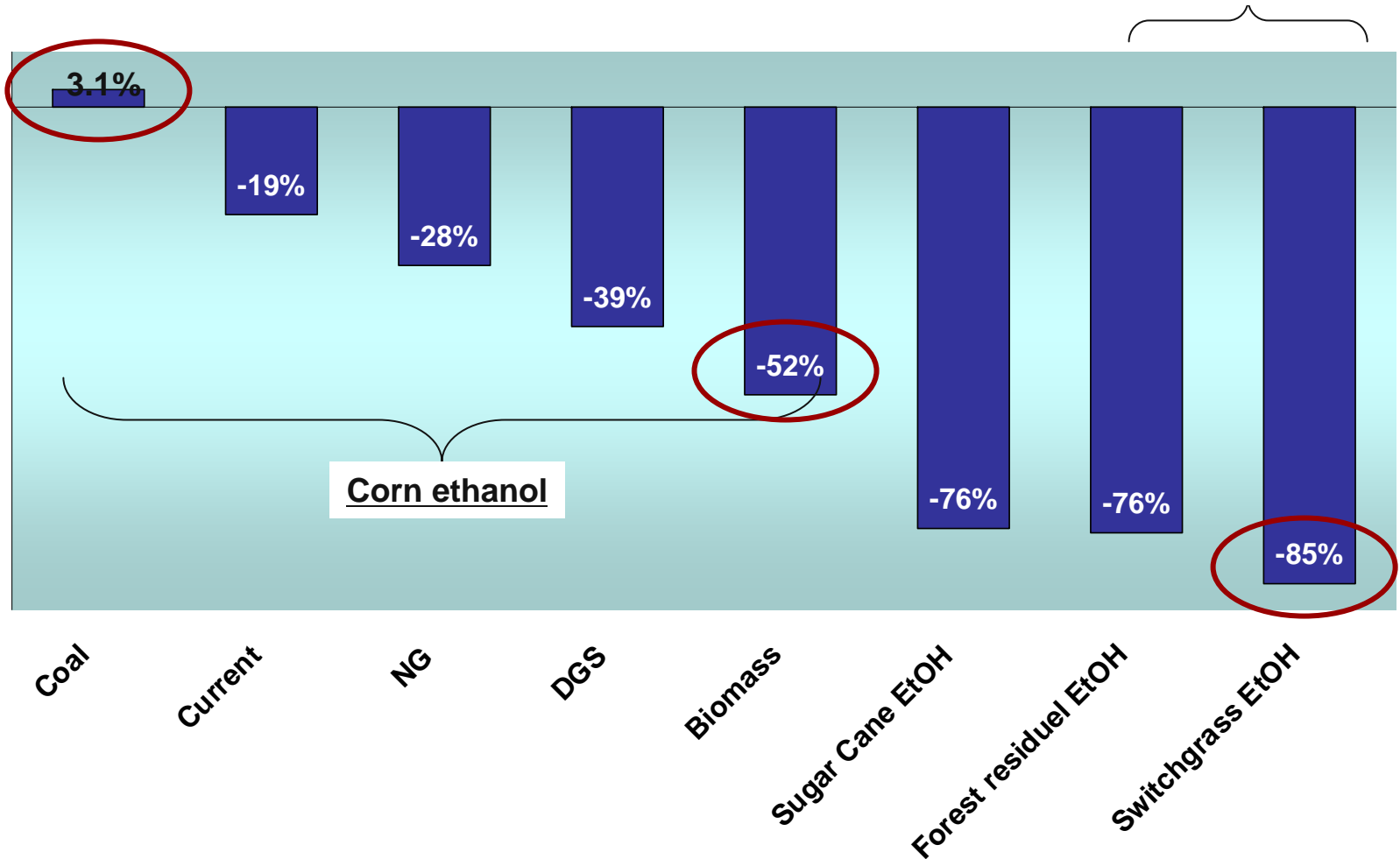
# Large Avoidance of GHG Emissions by Corn Ethanol With Use of Renewable Process Fuels



# From Corn to Sugar Cane to Cellulosic Biomass, GHG Emissions Avoidance Are Increased

GHG Emission Reductions by Ethanol Relative to Gasoline (per Energy Unit Basis)

Sugar cane cellulosic ethanol



# Potential Land Use Change by Large-Scale Biofuel Production Needs to Be Examined

- ❑ **Primary land use change and secondary land use change**: the latter is much more difficult to assess
- ❑ No comprehensive simulations of land use change at the national and global level have been done yet, especially for a biofuel future; agricultural community needs to be engaged in land use change modeling
- ❑ Soil carbon content and vegetation carbon content in different land use patterns
- ❑ U.S. annual corn ethanol production from 6 to 15 billion gallons in ten years by 2015
  - Besides increases in per-acre corn yield, where will additional amount of corn for ethanol production be from?
  - In 2007, U.S. corn farming acres have increased by 12 million through switch from soybean to corn farming
  - U.S. has been exporting 20% of its total annual corn production; reduction in U.S. corn export will impact global corn/grain market
- ❑ Brazil has 12.4 million acres of sugar cane plantations. It can increase sugar cane plantations to 25 million acres in the near future
  - While sugar cane farming is in South Central Brazil, what is the current farming practice and vegetation for the additional sugar cane acres?
  - Will the increase in sugar cane farming acres push farming of corn, soybean, and cattle to the Amazon rainforest region?
- ❑ Palm oil production in Malaysia has caused conversion of some tropical forest and pit soil into palm tree farming; what is the environmental and GHG consequences?

# Concluding Remarks

- ❑ With a moderate production level,
  - corn ethanol life cycle fossil energy consumption can be reduced further by targeting the key step of ethanol production
  - The largest reduction can be achieved via use of renewable process fuels in corn ethanol plants; Implementing CHP achieves somewhat smaller improvements in the ethanol plant options investigated
  - Employing DGS and biomass as process fuels in corn ethanol plant can result in significant life cycle GHG emission benefits
- ❑ If corn ethanol production is tripled in ten years, GHG and fossil energy results of corn ethanol need thorough re-examination
- ❑ Of all the feedstocks and ethanol plant process fuel types examined, cellulosic ethanol gives the largest reduction in fossil energy use and GHG emissions relative to gasoline