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Updated Well-to-Wheels Results of Fuel Ethanol With The GREET Model

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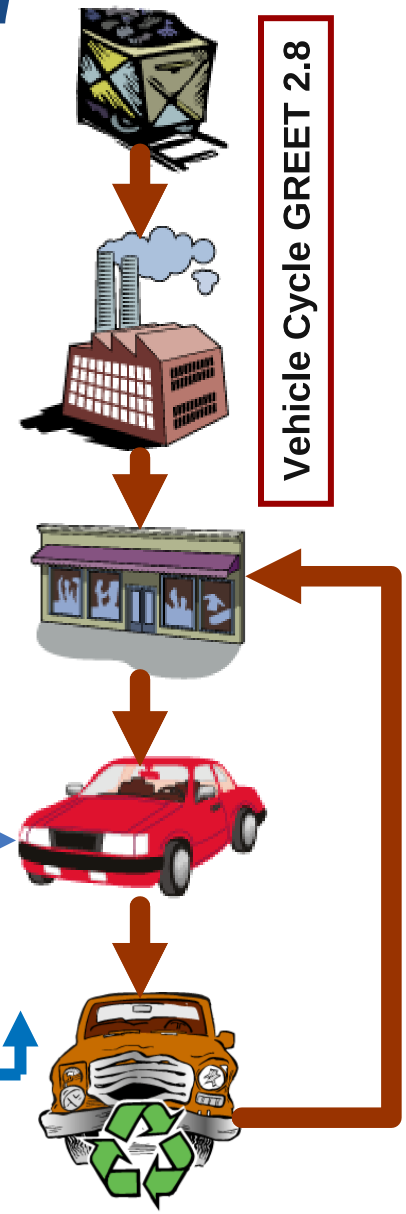
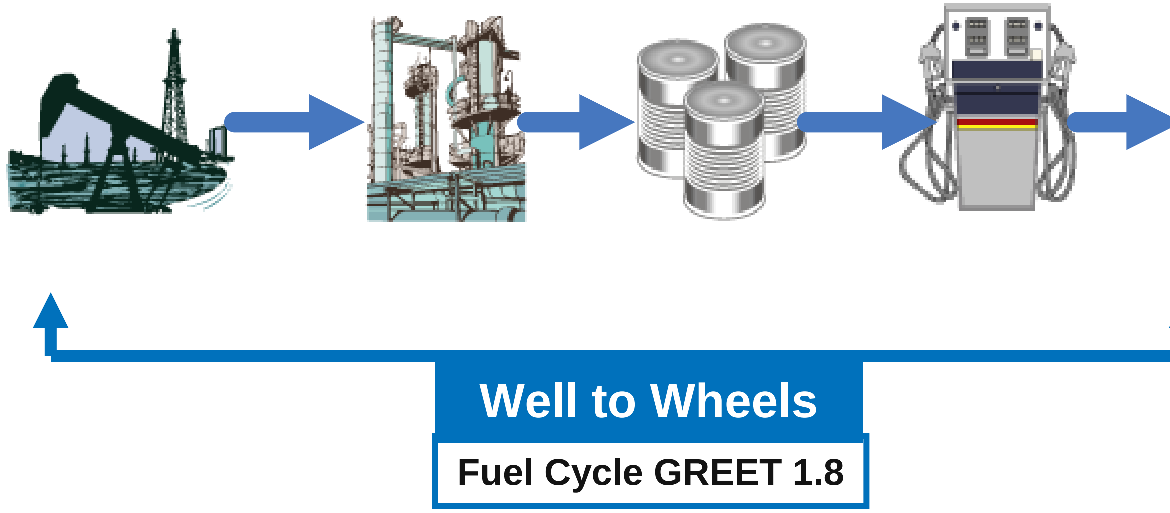
The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

- Developed at Argonne since 199
- More than 100 fuel production pathways from various feedstocks
- 75 vehicle/fuel systems





Energy and Emission Outputs with GREET

- **Emissions of greenhouse gases**
  - CO_2, CH_4, and N_2O (and other optional GHGs)
- **Emissions of six criteria pollutants**
  - VOC, CO, NO_x, SO_x, PM_{10}, and $PM_{2.5}$
  - Total and urban separately
- **Energy use by type**
  - All energy sources (fossil and non-fossil)
  - Fossil fuels (petroleum, natural gas, and coal combined)
  - Petroleum
  - Coal
  - Natural gas

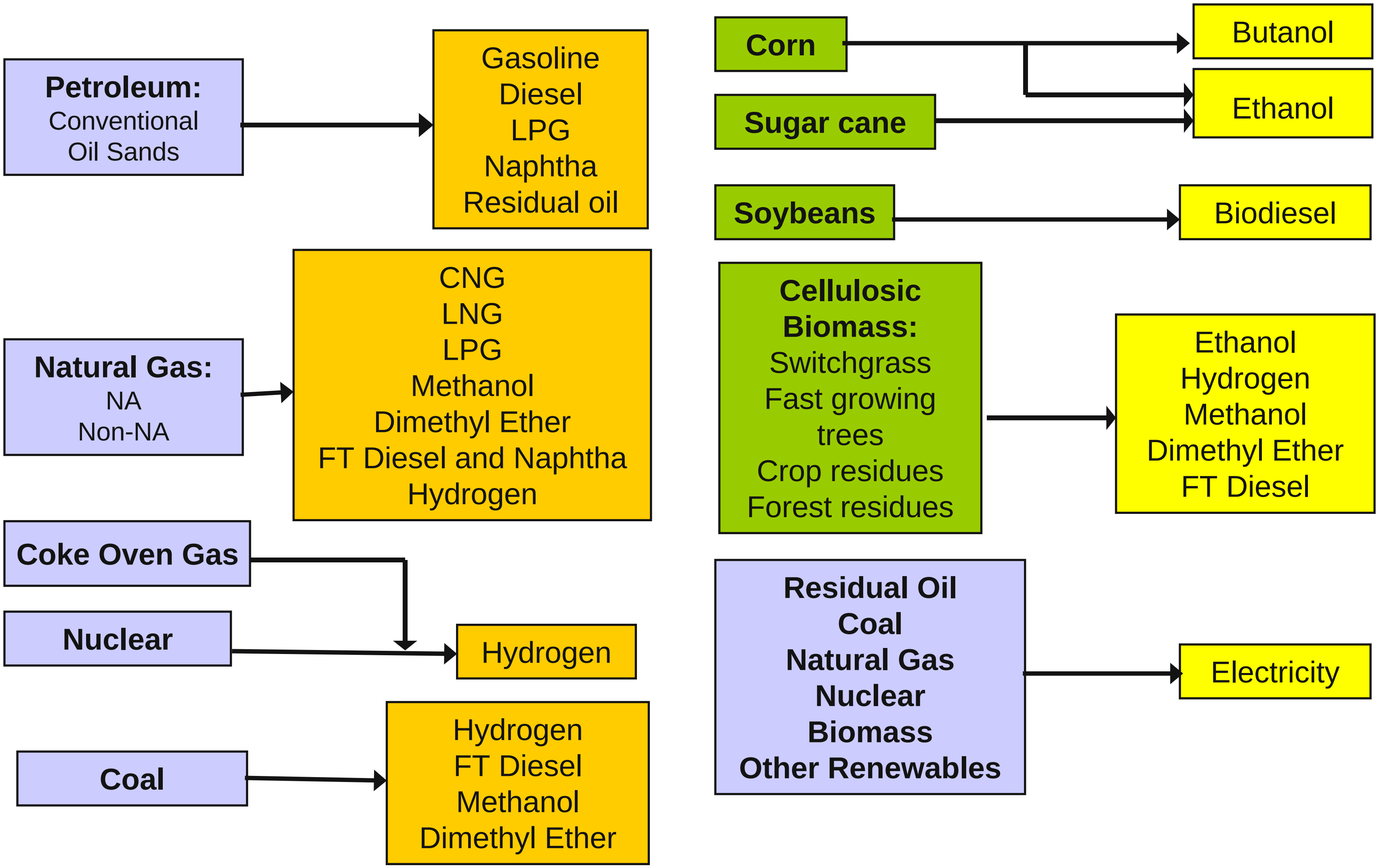
GREET is in public domain

Available at ***www.transportation.anl.gov/software/GREET/index.html***

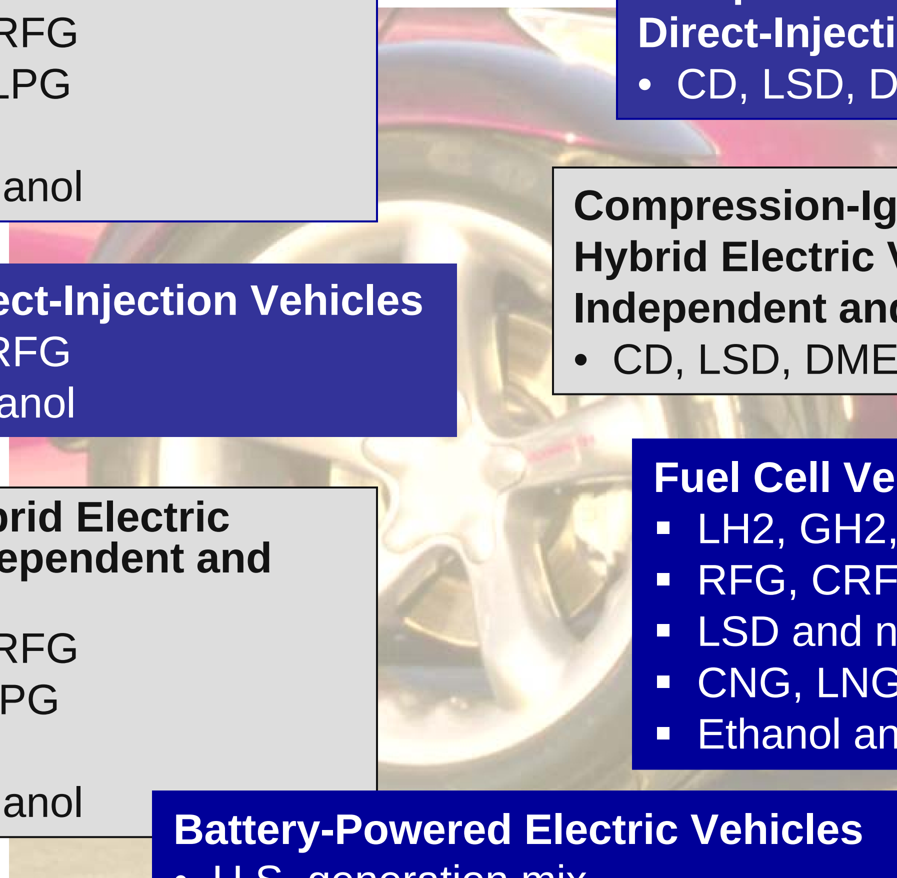
At present, there are more than 3,500 registered GREET users worldwide

The most recent GREET version was released in August 2007

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



Fuel Combustion in Vehicle/Fuel Systems (Pump-to-Wheels)



Spark-Ignition Vehicles
- CG, RFG, and CRFG
- CNG, LNG, and LPG
- LH2 and GH2
- Methanol and ethanol

Compression-Ignition Direct-Injection Vehicles
- CD, LSD, DME, FTD, ED, and BD

Spark-Ignition Direct-Injection Vehicles
- CG, RFG, and CRFG
- Methanol and ethanol

Compression-Ignition Direct-Injection Hybrid Electric Vehicles: Grid-Independent and Connected
- CD, LSD, DME, FTD, ED, and BD

Spark-Ignition Hybrid Electric Vehicles: Grid-Independent and Connected
- CG, RFG, and CRFG
- CNG, LNG and LPG
- LH2 and GH2
- Methanol and ethanol

Fuel Cell Vehicles
- LH2, GH2,,
- RFG, CRFG,
- LSD and naphtha
- CNG, LNG, LPG,
- Ethanol and methanol

Battery-Powered Electric Vehicles
- U.S. generation mix
- California generation mix
- Northeast U.S. generation mix
- User-selected generation mix

Major Assumptions Affect Life-Cycle Analysis

- WTP
  - Energy efficiencies of fuel production activities
  - GHG emissions of fuel production activities
  - Emission factors of fuel combustion technologies
- PTW
  - Fuel economy of vehicle technologies
  - Tailpipe emissions of vehicle technologies
- Approach to modeling uncertainties in GREET
  - GREET is designed to conduct stochastic simulations
  - Distribution functions are developed for key assumptions in GREET

Feedstocks for Biofuel Production Are Diversified and Vary Across Regions

- Sugar Crops
  - Sugar cane
  - Sugar beet

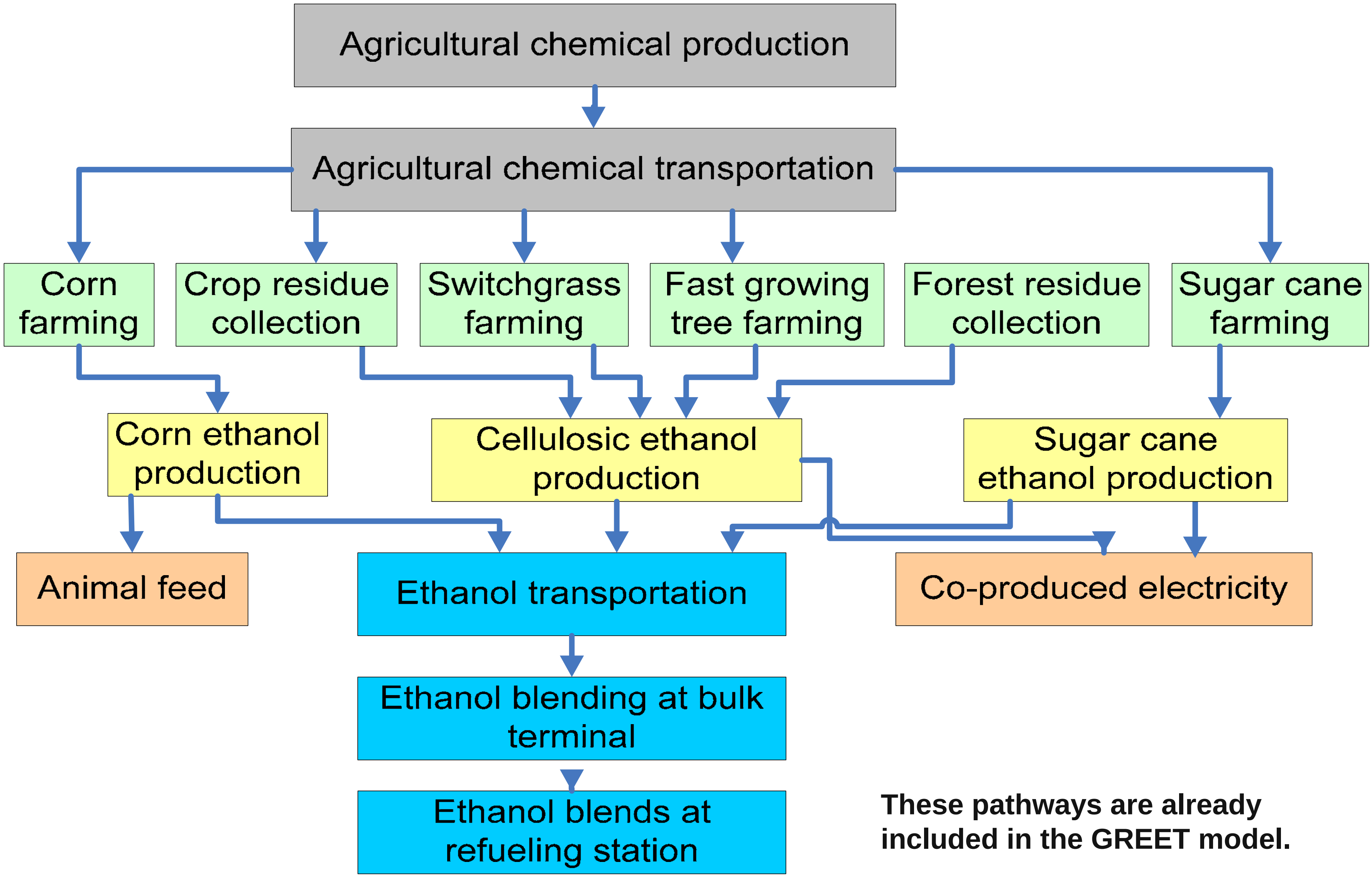
- Grain Starch
  - Corn
  - Wheat
  - Barley
  - Sorghum

- Oil Seed Crops
  - Soybean
  - Rapeseed
  - Palm
- **Others**
  - Waste cooking oil
  - Animal fat

- Cellulosic Biomass
  - Corn stover, rice straw, wheat straw
  - Forest wood residue
  - Municipal solid waste
  - Energy crops
  - Black liquor
  - Fast growing trees

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

GREET Ethanol Life-Cycle Analysis Includes Activities from Fertilizer to Ethanol at Refueling Stations

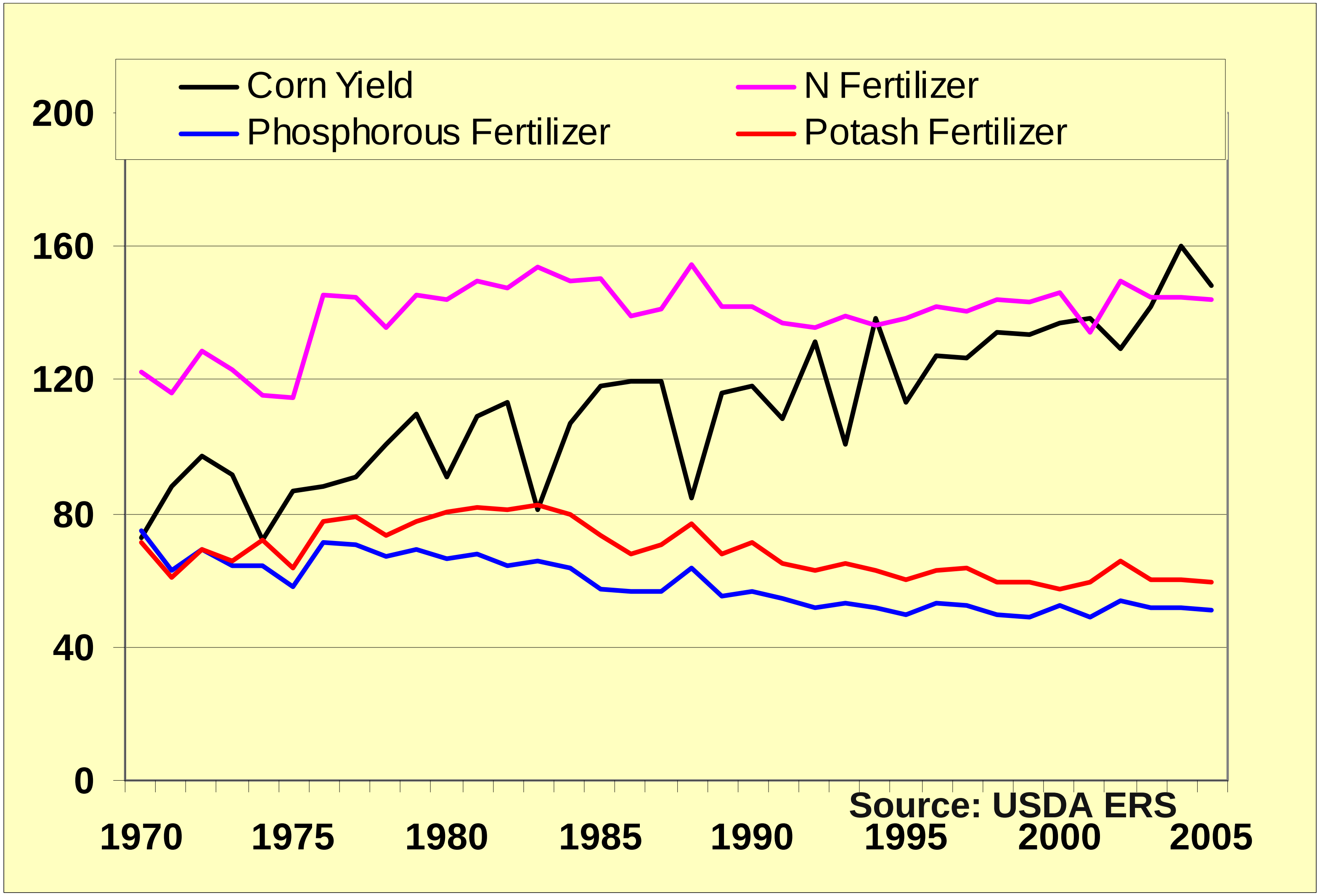


These pathways are already included in the GREET model.

Key Issues for Bio-Ethanol Life-Cycle Analysis

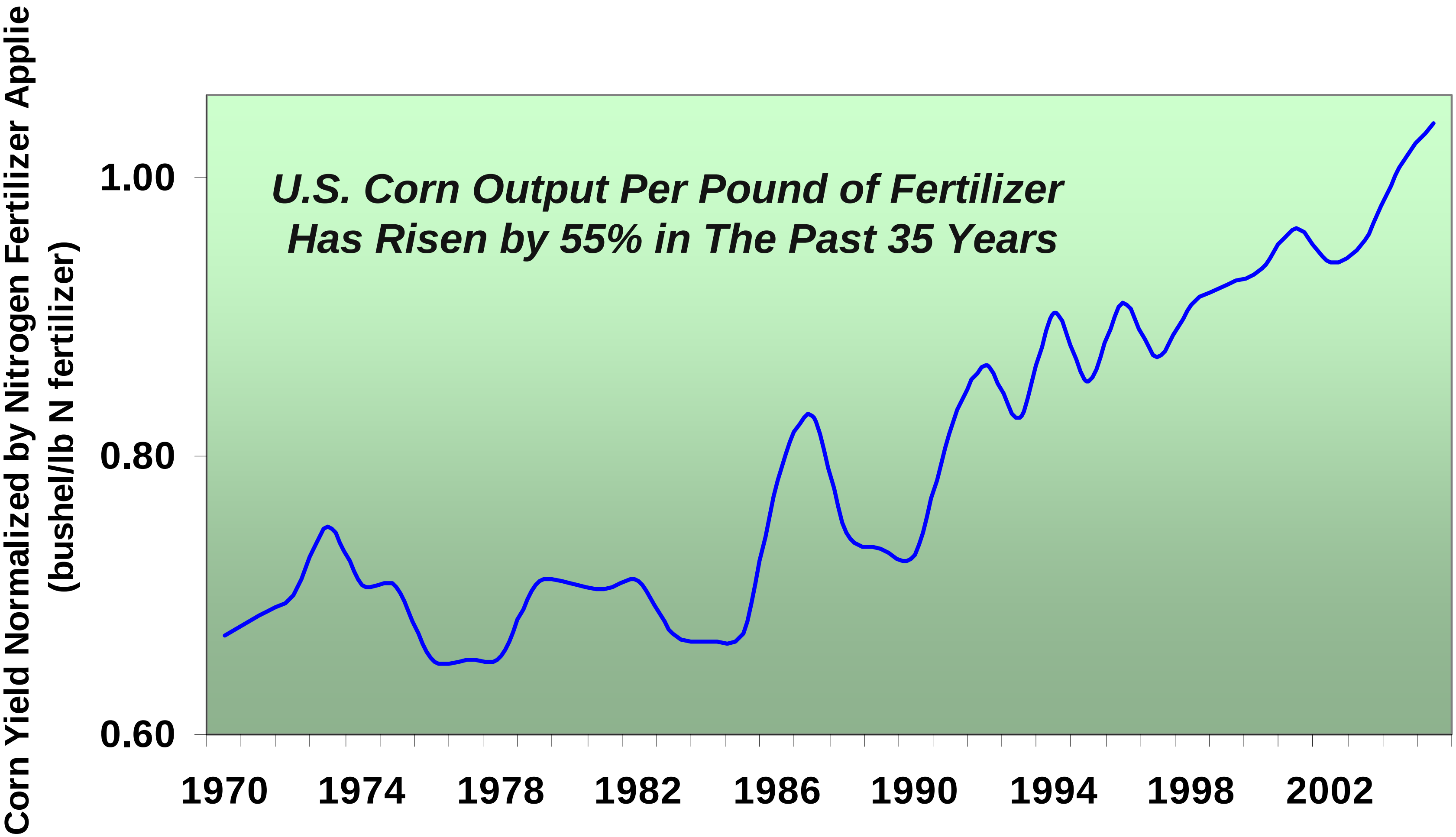
- Nitrogen fertilizer production
  - Nitrogen fertilizer is produced primarily from natural gas. About 40% of total US ammonia demand is met by imports (2005)
- Use of fertilizer and chemicals in farms
  - N2O emissions from N-fertilizer application
  - Lime application: CO2 emissions
- Farming is a key activity for cellulosic biofuel life cycle
- Open field burning in sugar cane plantations causes significant emissions (80% of can is harvested by burning in Brazil)
- Energy use in corn ethanol plants
  - The amount of process fuels for steam production
  - The type of process fuels
- Co-products
  - Animal feeds for corn ethanol
  - Electricity for cellulosic and sugar cane ethanol
- Potential land use change and resulted CO2 emissions

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



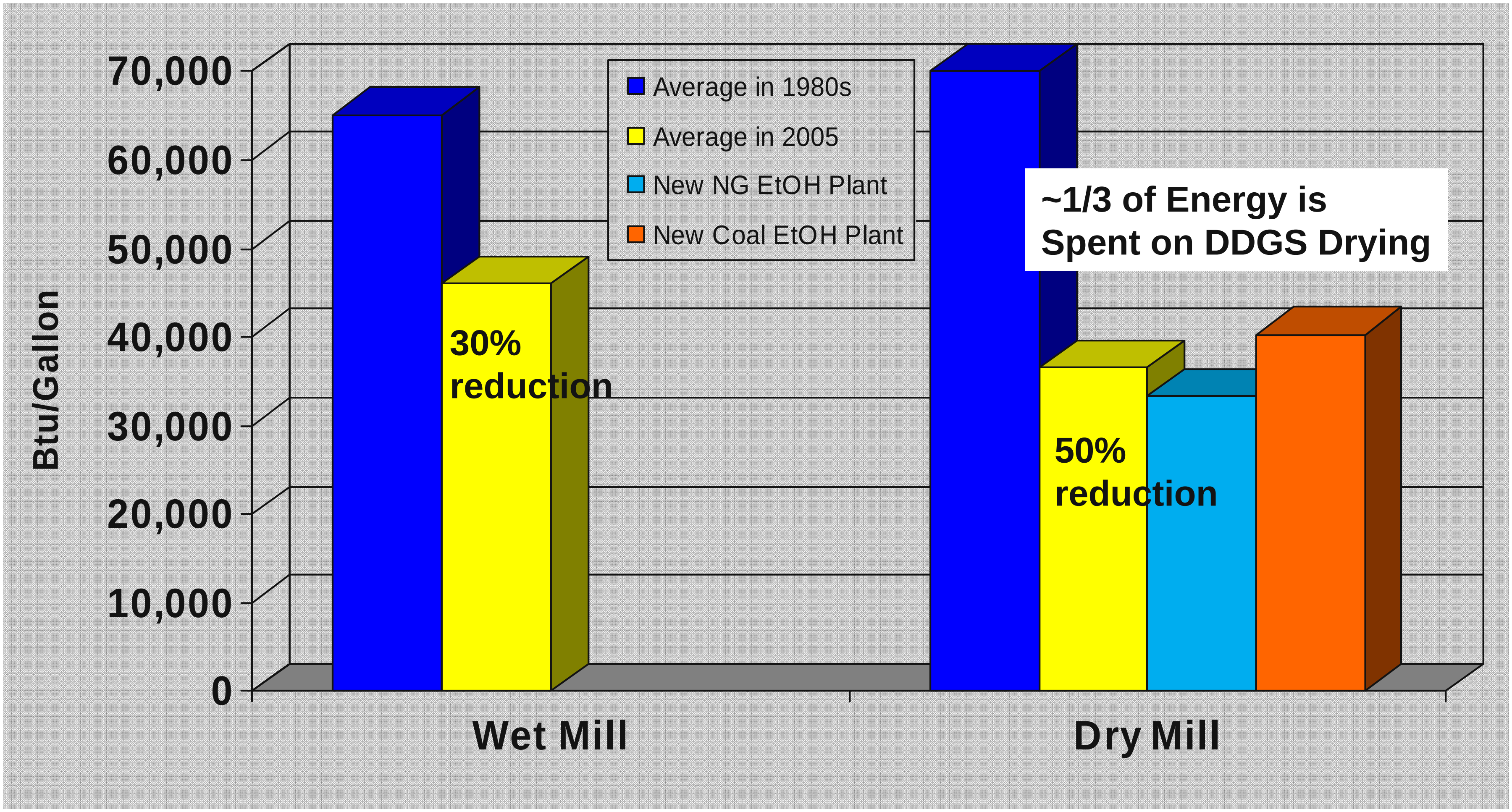
Corn yield is in bushels/acre; Fertilizer use is in lbs/acre.

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)

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%

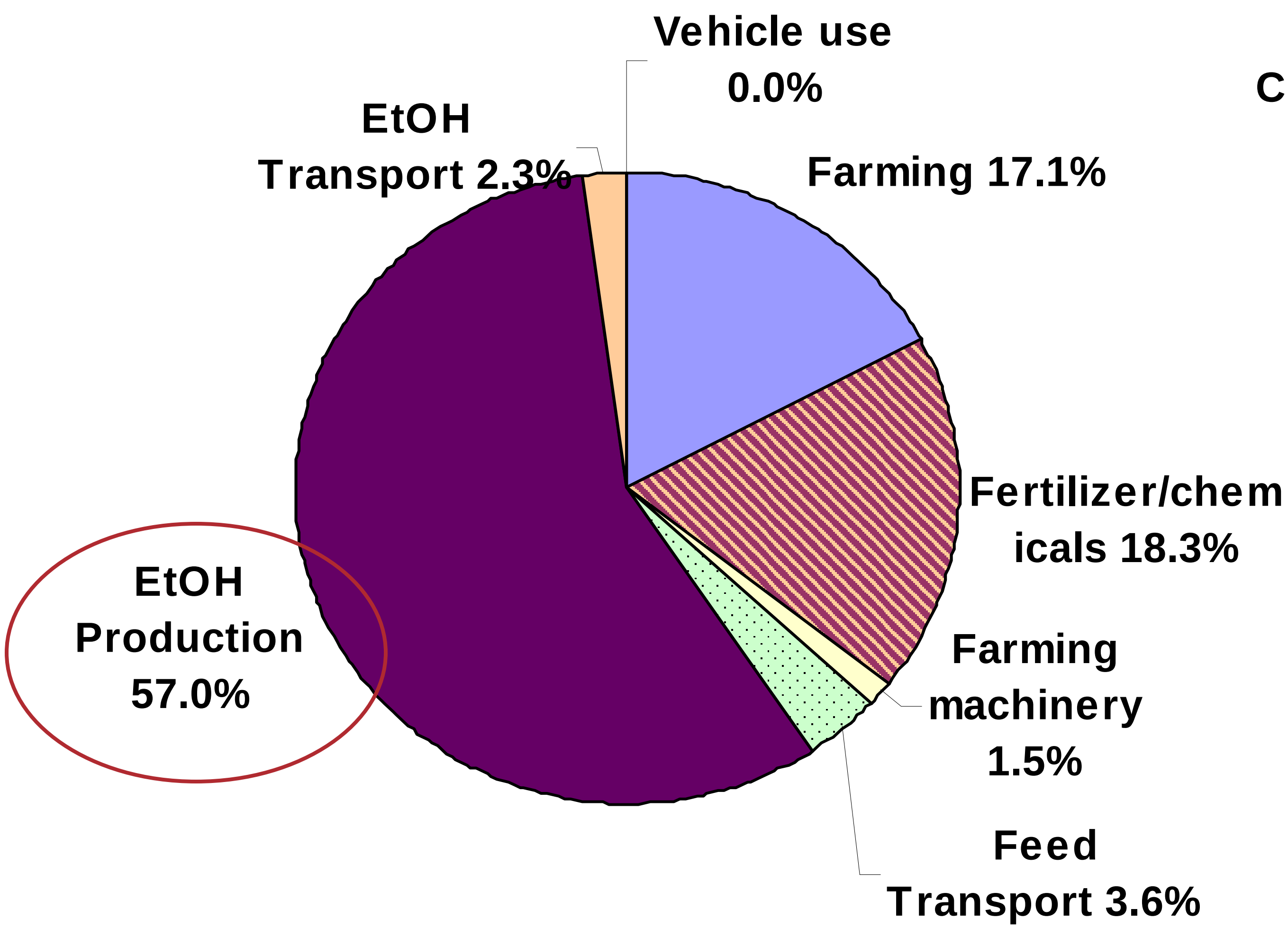
Argonne uses the displacement method, the most conservative approach.

Energy Embedded in Farming Equipment Is Not a Significant Contributor to Ethanol's Life-Cycle Energy Use

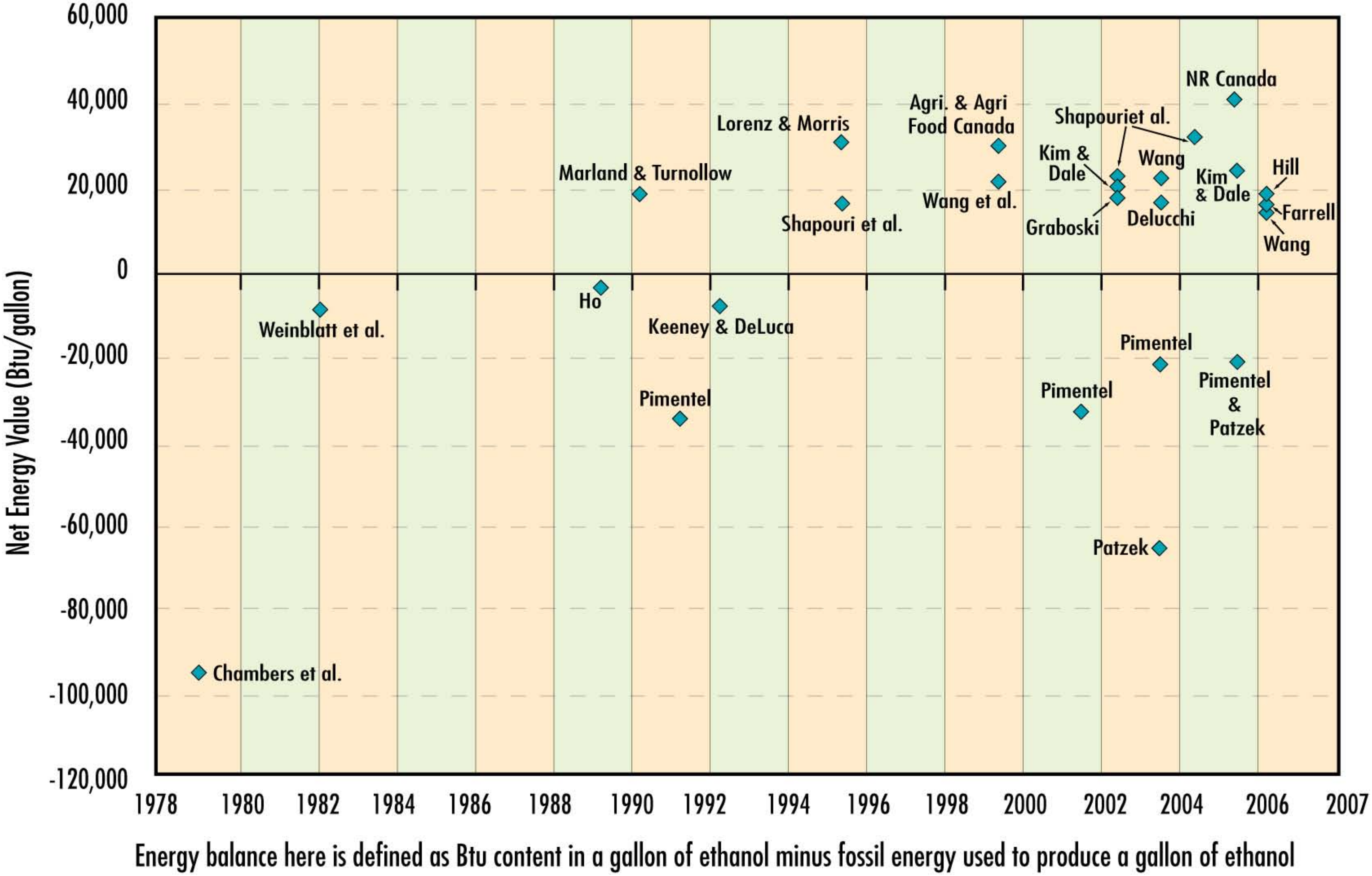
- Size of farm (550 acres assumed in this study)
- Life time of equipment
- Energy for producing equipment materials (the majority of equipment materials is steel and rubber)
- Argonne has found that farming equipment may contribute to <2% of energy and ~1% GHG emissions for corn ethanol

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

Life-Cycle Fossil Energy Use: Corn Grain Ethanol



Most Recent Studies Show Positive Net Energy Balance for Corn Ethanol

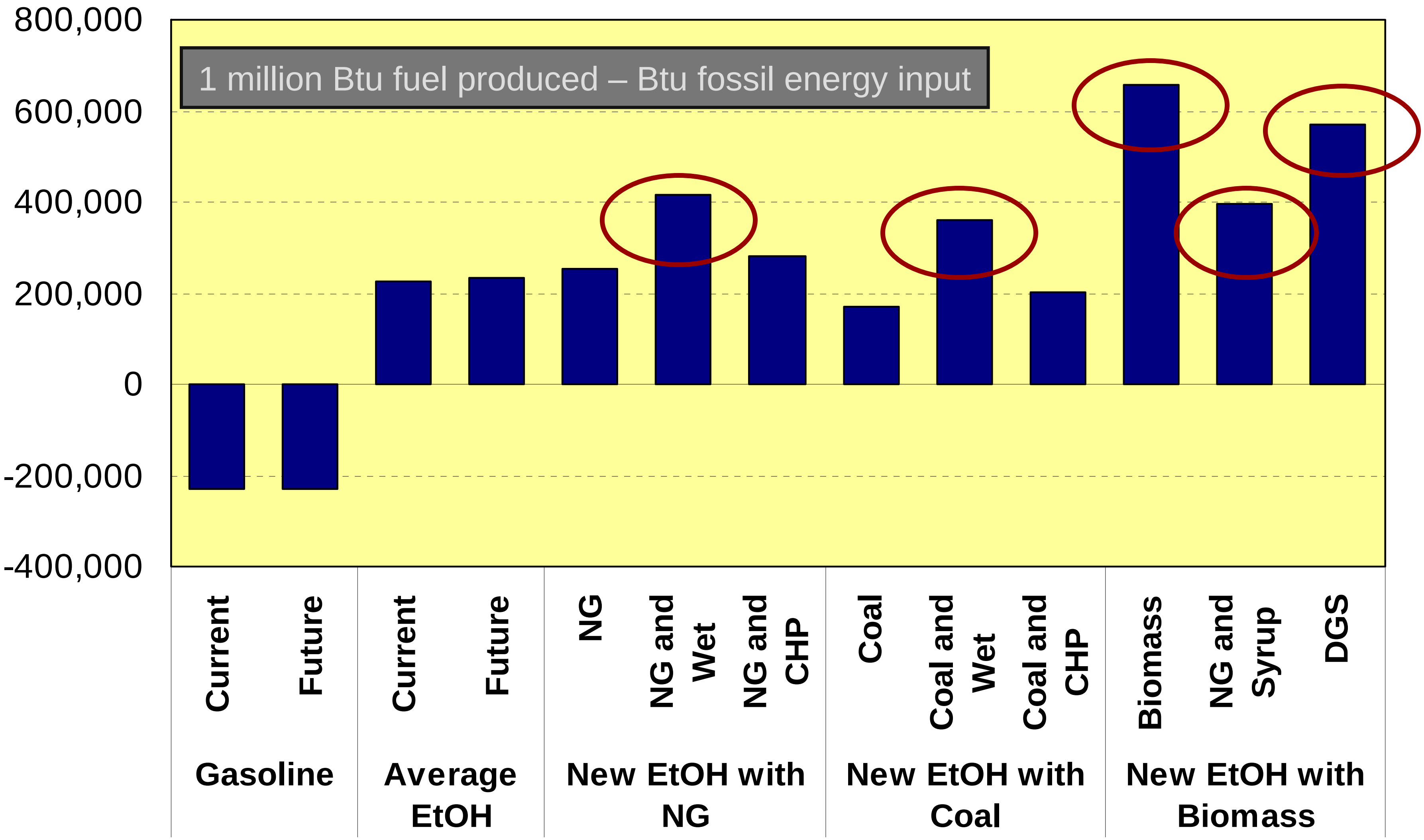


Energy balance here is defined as Btu content a gallon of ethanol minus fossil energy used to produce a gallon of ethanol

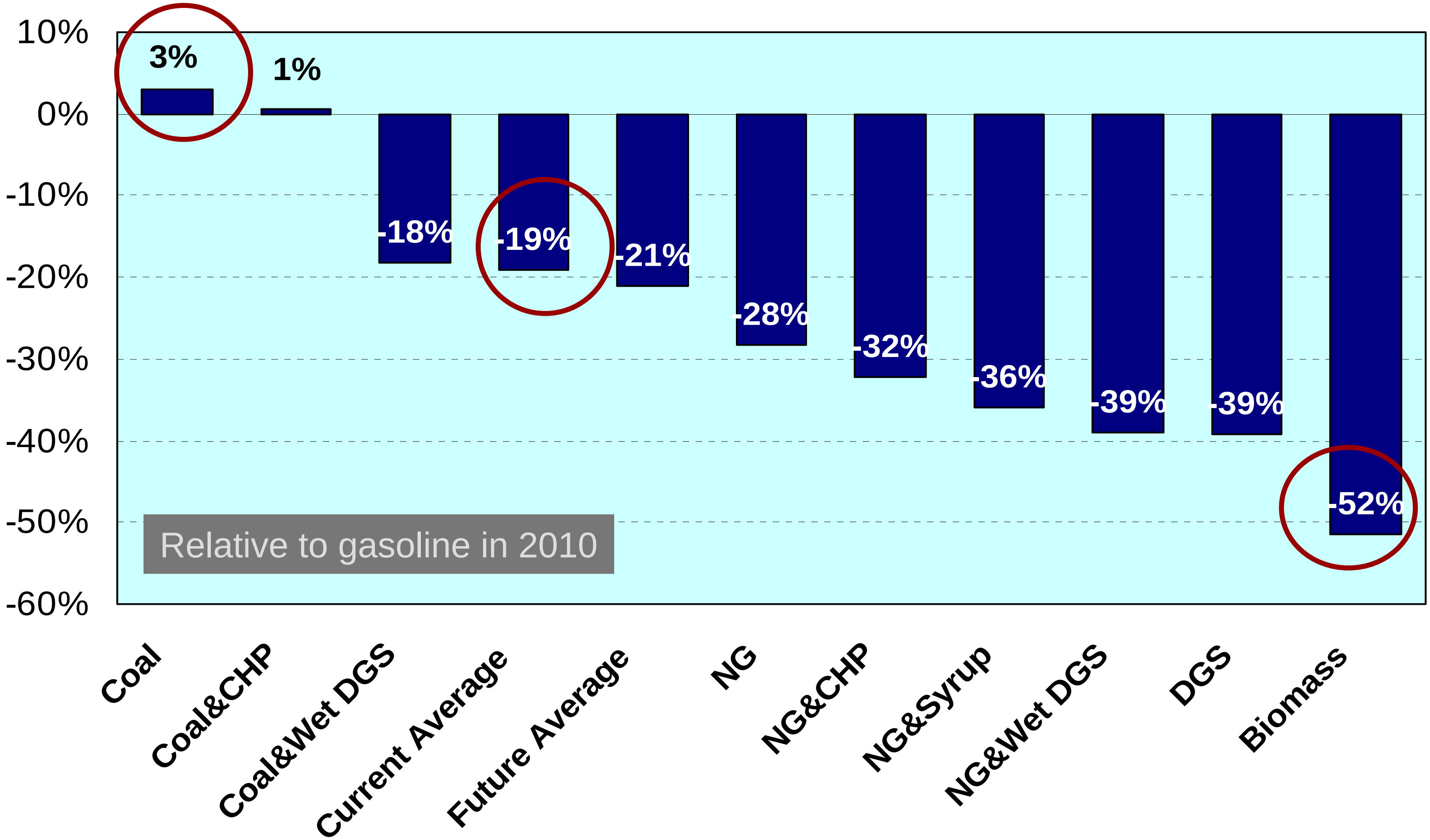
Argonne Recently Examined Life-Cycle Impacts of Process Fuels in Different Types of Corn Ethanol Plants

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

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

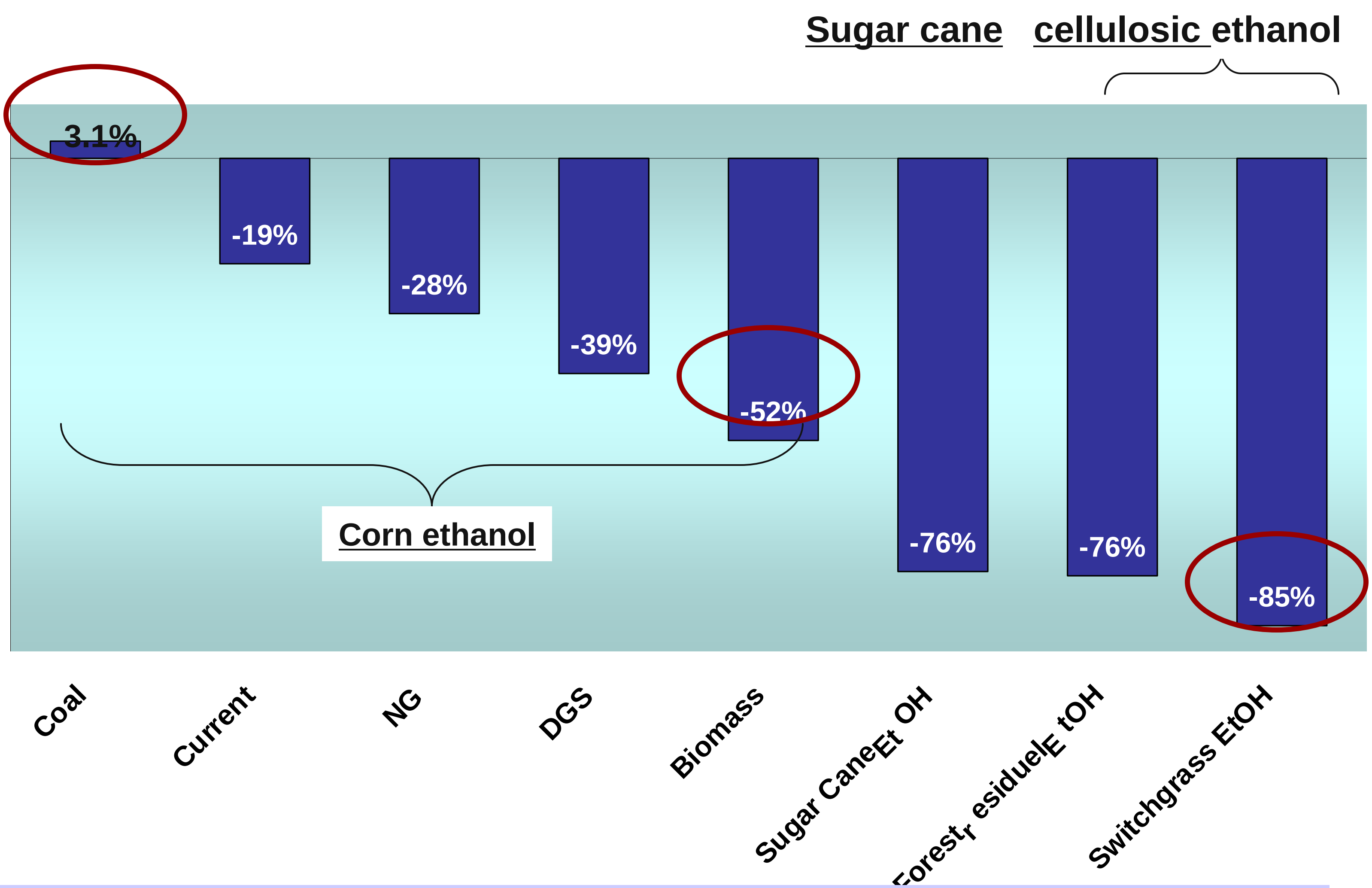


Sugarcane Farming and Ethanol Production Concentrate in the South and South Central Brazil

Reflections of Brazilian Ethanol Program

- Key players have become integral parts of the Brazilian ethanol program
  - Sugar cane growers and sugar mill operators are often the same people
  - Oil companies (e.g., PetroBras) have developed transportation and refueling infrastructure
  - Auto companies have changed the production of dedicated ethanol vehicles to flex fuel vehicles
- The flexibility of the Brazilian ethanol program
  - Sugar cane mill operators are flexible between sugar and ethanol production
  - Flex fuel vehicle owners are flexible of using gasoline and ethanol
- Environmental concerns
  - Open burning for manual harvesting creates air pollution problems
  - Manual harvesting is being displaced with mechanical harvesting
  - Ethanol plants, and stationary sources in general, lack stringent NOx emission regulations

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)

Butanol Can Be Produced from Starch/Cellulosic Feedstocks As a Potential Transportation Fuels

- Butanol poses the following advantages
  - Butanol has a low heating value of 99,840 Btu/gal
    - *86% that of gasoline*
    - *30% higher than ethanol*
  - Low co-solvency with water, low risk for corrosion in fuel storage and transport facilities
  - Butanol might be used as a fuel blend with gasoline
- Limitations of butanol include
  - No commercial scale renewable butanol production facilities
  - Lack of vehicle/engine performance data with butanol
  - Large amount of acetone co-produced from ABE process

A Large Amount of Acetone Is Produced from the ABE Process for Butanol Production

Product Yields of the ABE Process and Ethanol Plants

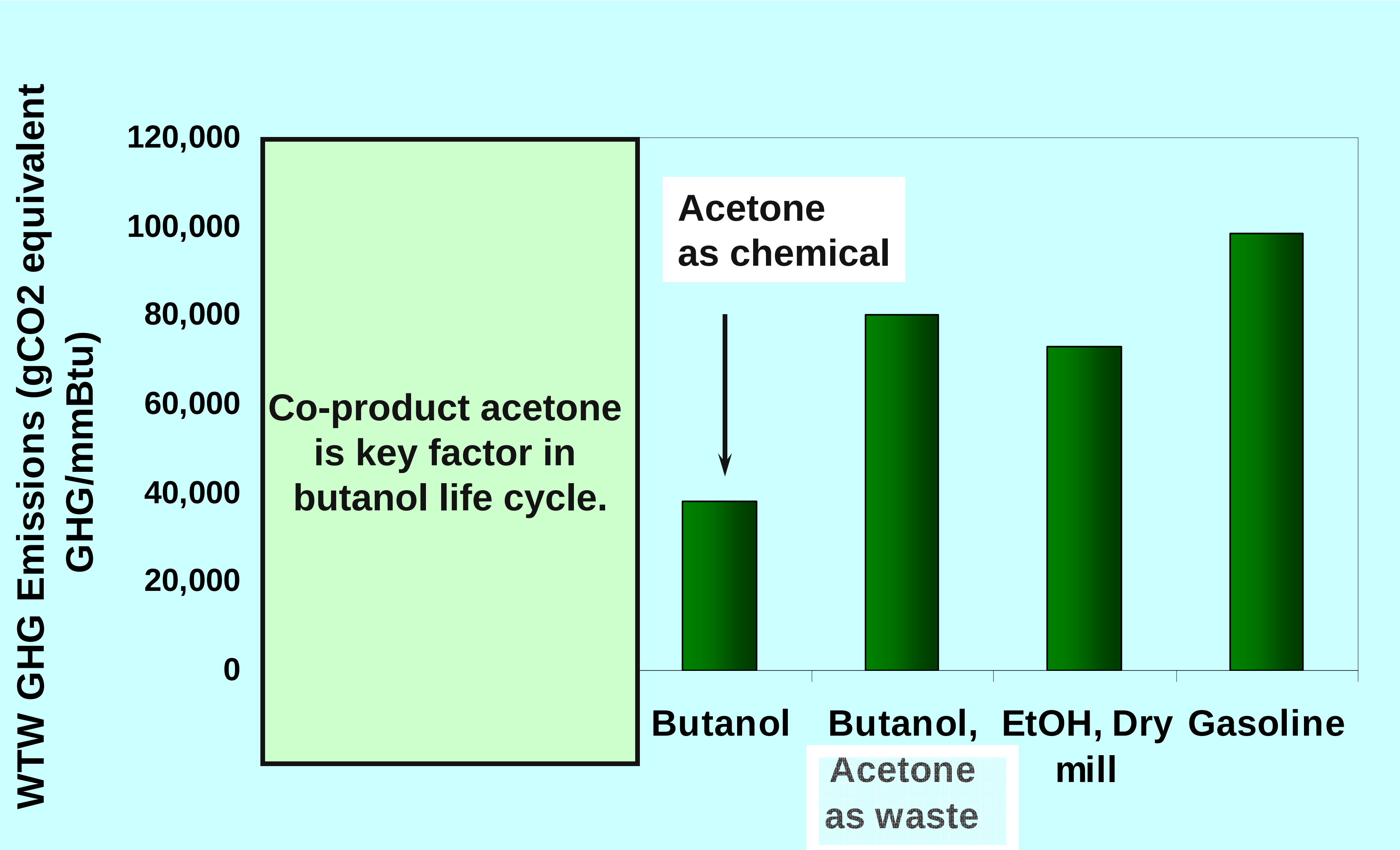
	Corn Butanol Plant				Corn EtOH Dry Mills
	Acetone	Butanol	Ethanol	Total	Ethanol
Btu/bu. Corn	69,525	149,267	2,828	221,620	198,458
Gal/bu. Corn	0.87	1.50	0.04	2.41	2.60

These are based on 15% moisture content of corn and un-denatured fuel.

Product Shares of the ABE Process

	Acetone	Butanol	Ethanol
Energy basis	31.4%	67.4%	1.3%
Volume basis	36.1%	62.2%	1.7%
Mass basis	35.4%	63.1%	1.5%

GHG Effects of Corn-Based Butanol Depend on How to Treat By-Product Acetone



Fuel Cycle: On-Going and Planned Activities for Petroleum and BioFuel Production Pathways

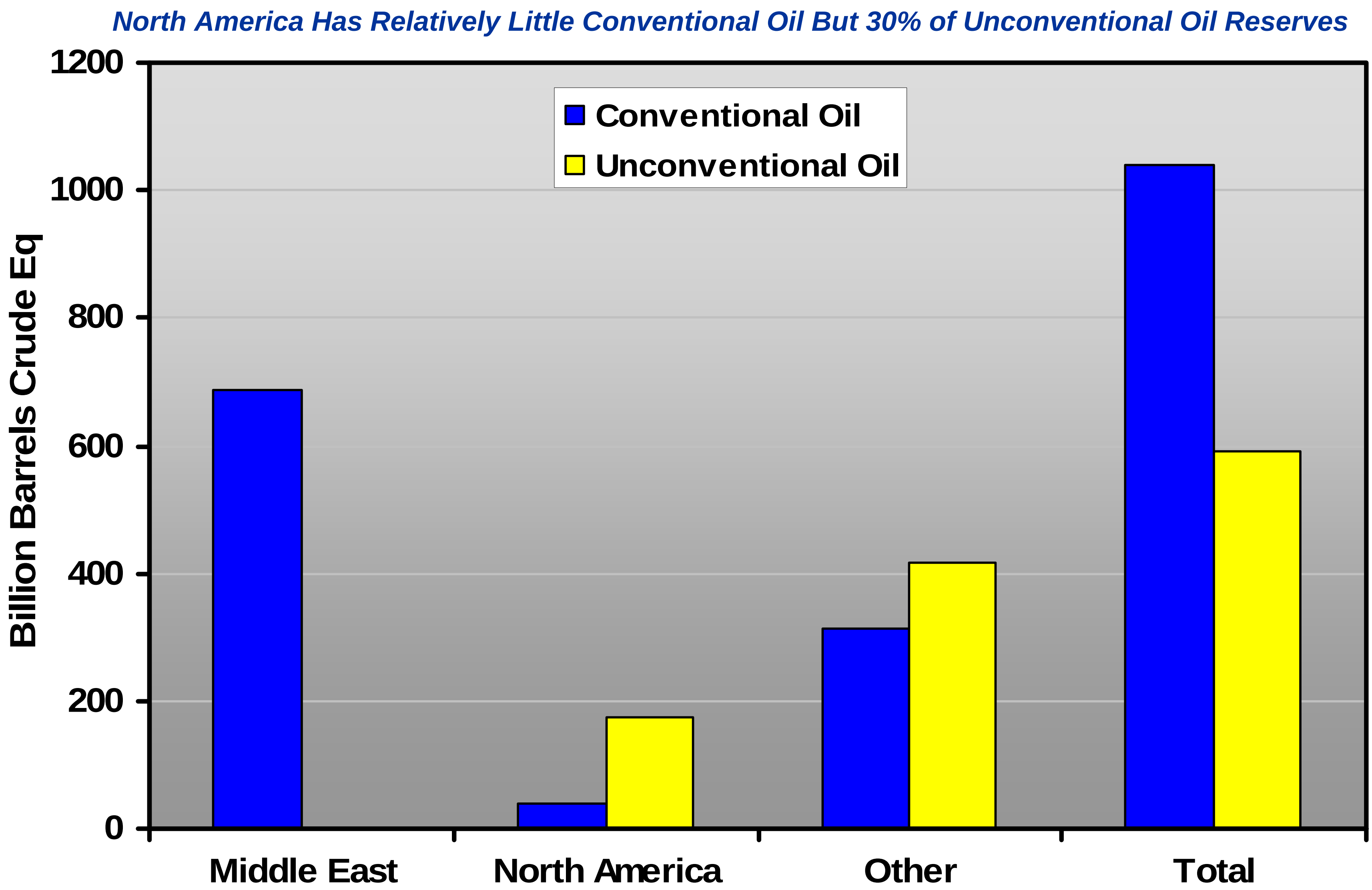
Petroleum Fuels

- Current GREET activities
  - Updating petroleum refining efficiencies with EIA survey data
- New options of interest
  - Venezuelan heavy and sour crude
  - US oil shale?
- Water requirement for petroleum fuel production

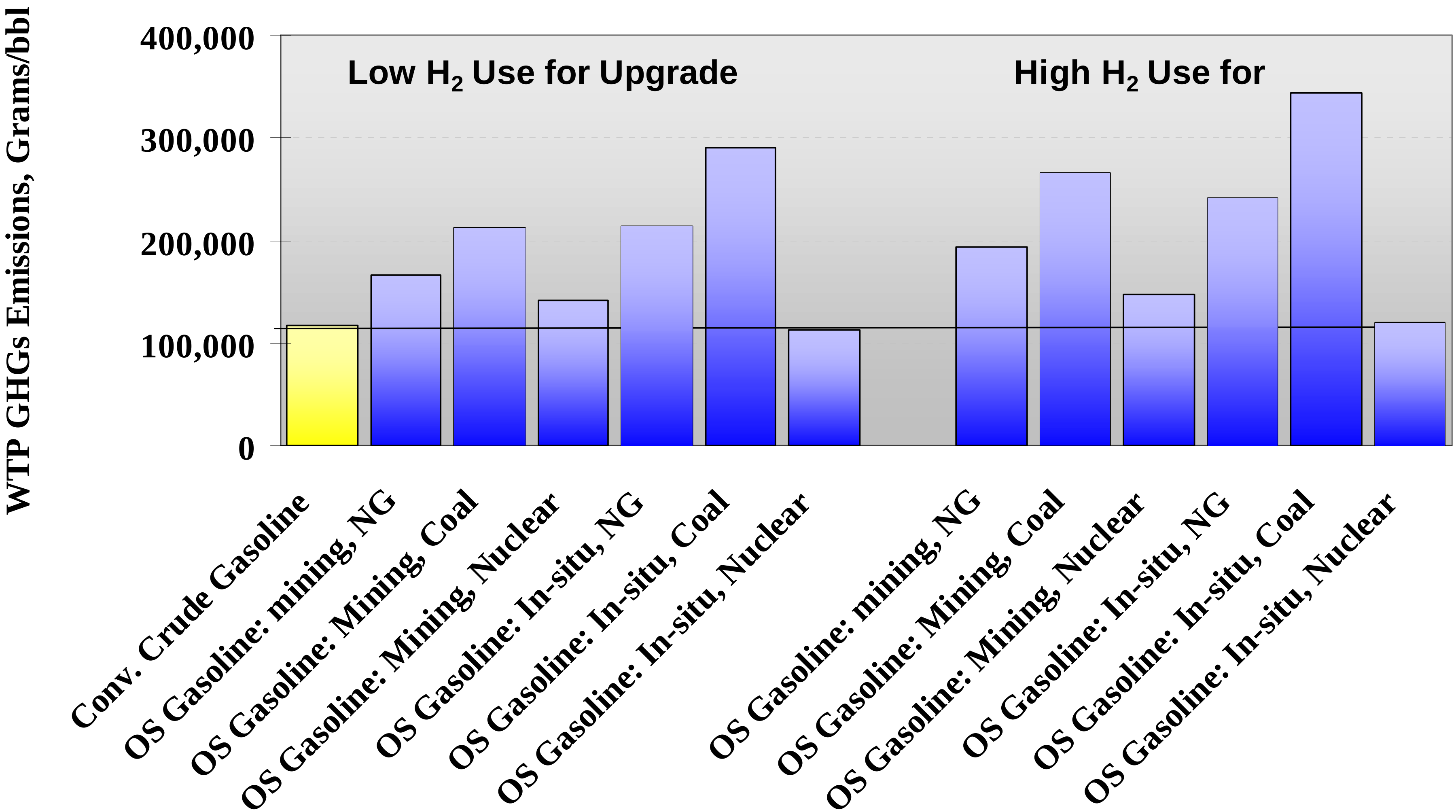
Bio-fuels

- GREET biofuel pathway additions in the near future
  - Renewable diesel from soybeans via hydrogenation
  - Ethanol from sugar beets
- Water requirement for biofuel production
- Other biofuel pathways of interest
  - Biodiesel and renewable diesel from
    - *Rapeseeds*
    - *Animal fats*
    - *Palm oil*

ANL Analyzed Energy and GHG Emissions of Oil Sands Recovery and Upgrade



WTP GHG Results Show That Oil Sands Operations Are Carbon-Intensive



Potential Land Use Change by Large-Scale Biofuel Production Is Being Debated

- 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 (additional 1.5 billion bushels of corn for additional 4 billion gallons of corn ethanol)
  - 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?
- No quantitative simulations of land use change at the national and global level have been done yet, and results may not be available anytime soon