Argonne NATIONAL LABORATORY

Fuel Life Cycle Assessment of Bioethanol Produced from Corn Stover

May Wu, Michael Wang, and Hong Huo

Center for Transportation Research

Argonne National Laboratory

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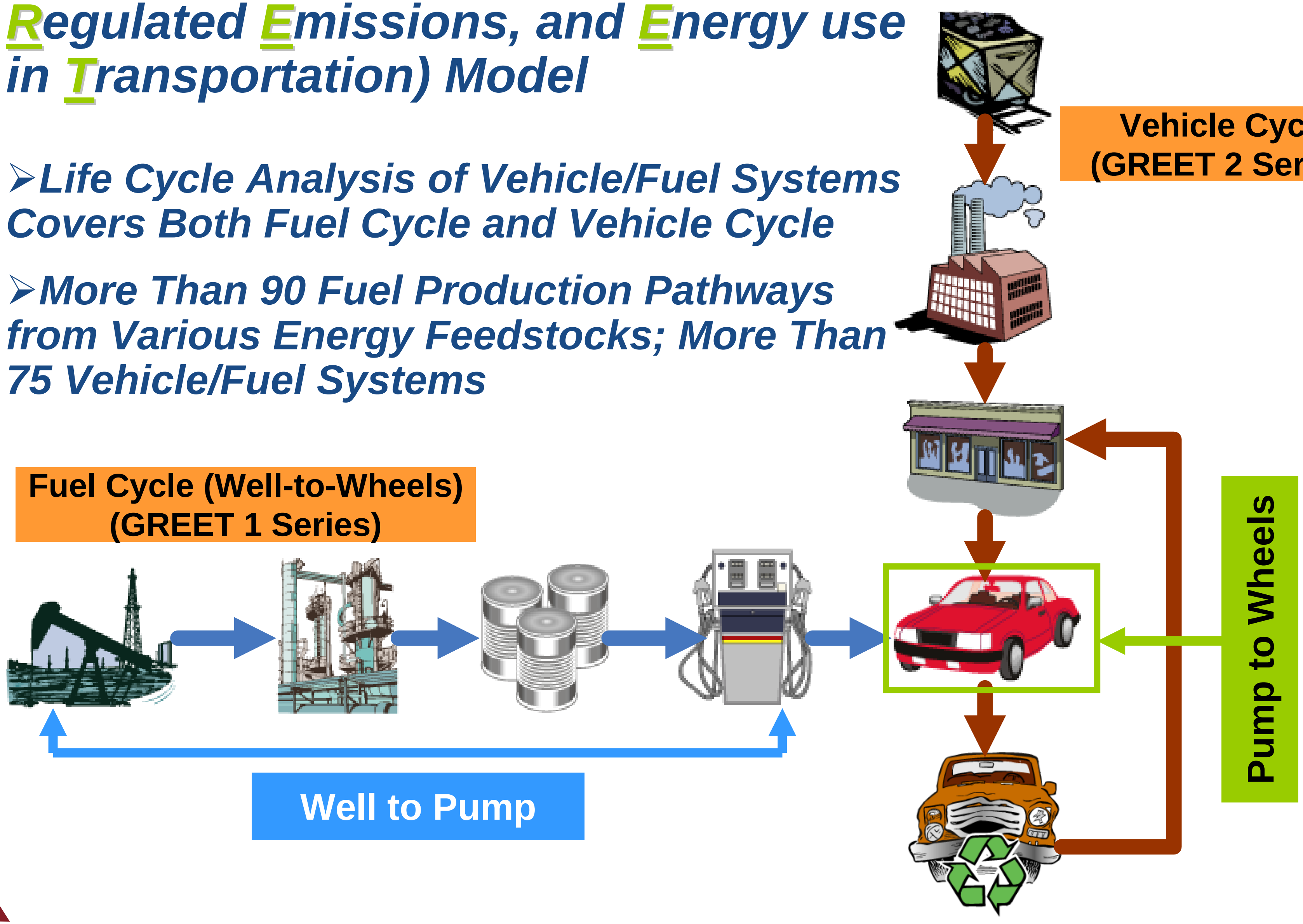
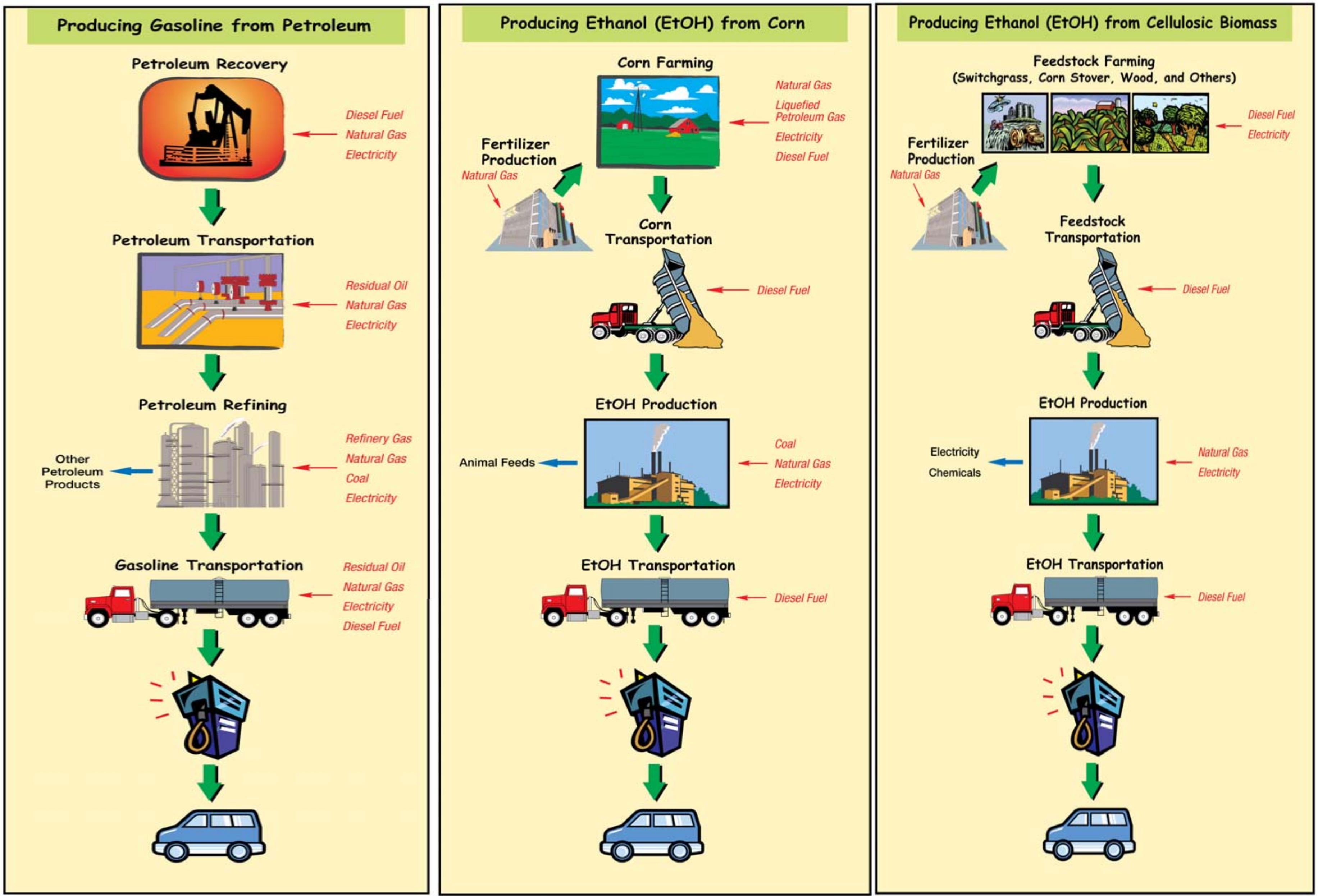
The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model

- *Life Cycle Analysis of Vehicle/Fuel Systems Covers Both Fuel Cycle and Vehicle Cycle*
- *More Than 90 Fuel Production Pathways from Various Energy Feedstocks; More Than 75 Vehicle/Fuel Systems*



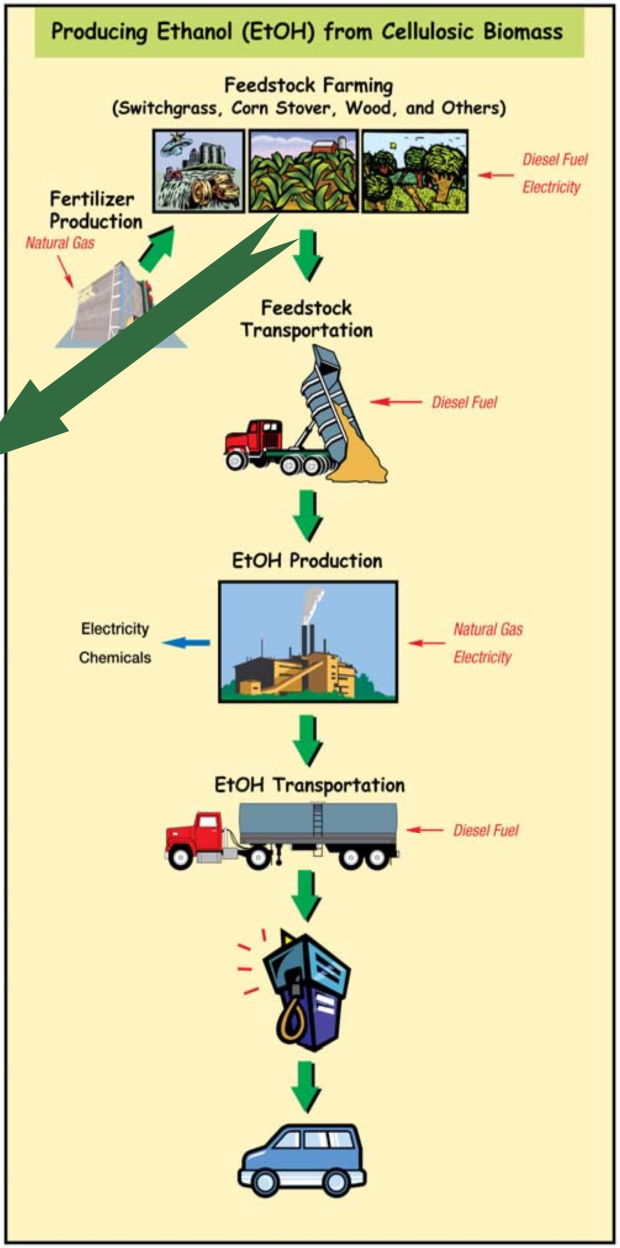
A Complete, Robust Way Of Evaluating A Fuel's Effects Is To Compare the Fuel With Those To Be Displaced



Corn Stover Facts: US

- 76 million acre currently used to grow corn
- 376 million dry tons/year
- 256 million dry tons/year could be sustainably removable

Source: USDA, 2005



Scenarios Examined in This Analysis

Near Term: 2012

1. Conventional crude to gasoline
2. Corn to ethanol through conventional bioconversion
3. Corn stover to ethanol through BC conversion, 2000dt/d plant capacity

Long Term: 2030

4. Conventional crude and oil sands to gasoline
5. Corn to ethanol through conventional bioconversion
6. Corn stover to ethanol through a biorefinery with consolidated bioprocessing (CBP) and gasification turbine combined cycle (GTCC), 5000dt/d
7. Forest residues to mixed alcohols through a BC/TC biorefinery, 5000dt/d

Major Assumptions: Corn Stover Harvesting and Transportation

- Corn stover yield (with 50% collection)
  - 1.67 dt/acre (2012)
  - 1.95 dt/acre (2030)
- The ethanol plant is surrounded by the corn farm
- Acreage use by corn farm in an area: 75%
- Harvest equipments dedicated to corn stover
- Stover bale transported to ethanol plant by a 48-ft flatbed trailer and heavy trucks with 20-24 tons of max. payload
- Delivery distance from the edge of field to plant gate (one-way):
  - 24 miles in 2012 for the 2000 dt/d plant
  - 35 miles in 2030 for the 5000 dt/d plant

Energy Consumption in Farming Machinery Manufacturing

i. Material Production Energy – Embodied Energy

ii. Fabrication and Assembly Energy

iii. Repair Parts Energy

- Compared Six Studies
  - Berry-Fels (1972)
  - Pimentel (1973); Doering (1980); Hill (2006)
  - WEC (1995); Fruehan (2000)

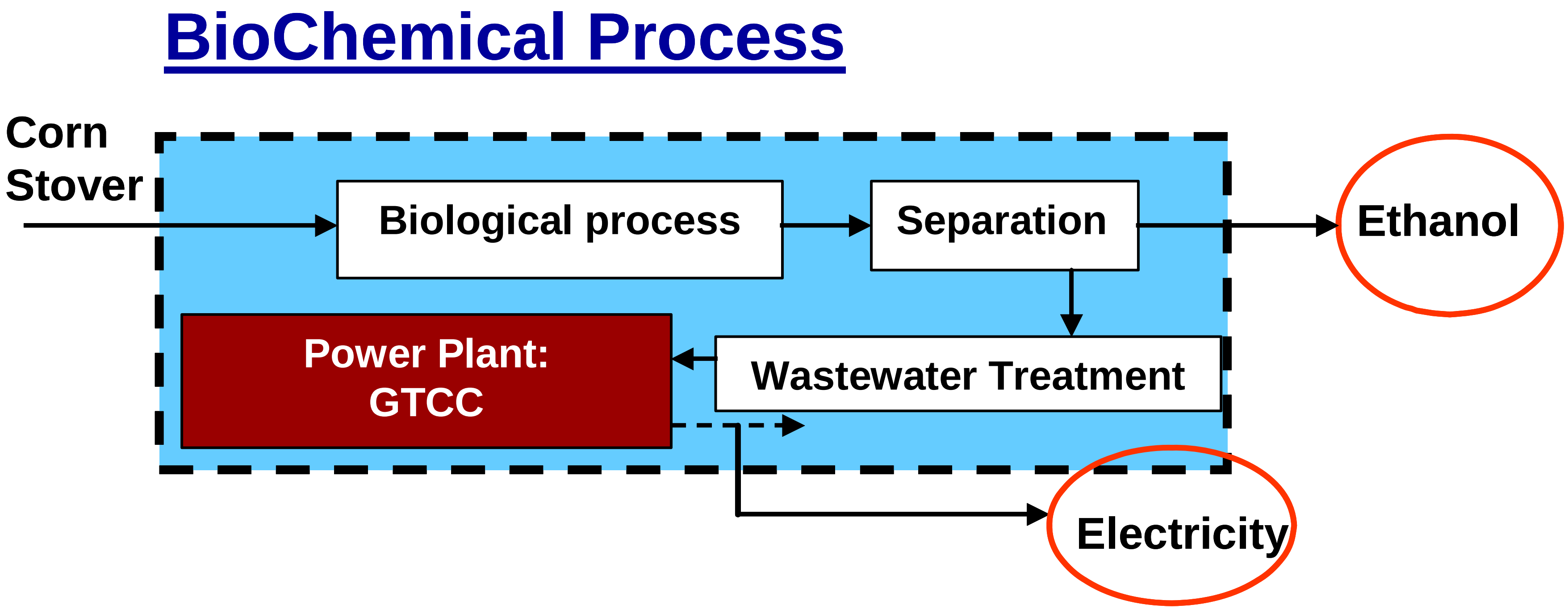
Comparison of Machinery Manufacturing Energy from Various Studies

Energy type	Pimentel (1973)	Berry-Fels (1972)	Doering (1980)	WEC (1995)	Fruehan (2000)	Hill (2006)	This study
Embodied - Steel (kcal/kg)		14,648	[15,000]	5,733	8,375	5972	11,389
Embodied - Rubber tire (kcal/kg)			[20,500]	10,340	10,340	10,340	10,340
Embodied - Tractor (kcal/kg)	18,800[1]		11814[2]				
Total energy (kcal/kg of machinery)	19,928	19,890	16,396	10,526	12,949	10,745	15,712
Changes from 1973 estimate (%)			-17.7%	-47.2%	-35.0%	-46.1%	-21.2%

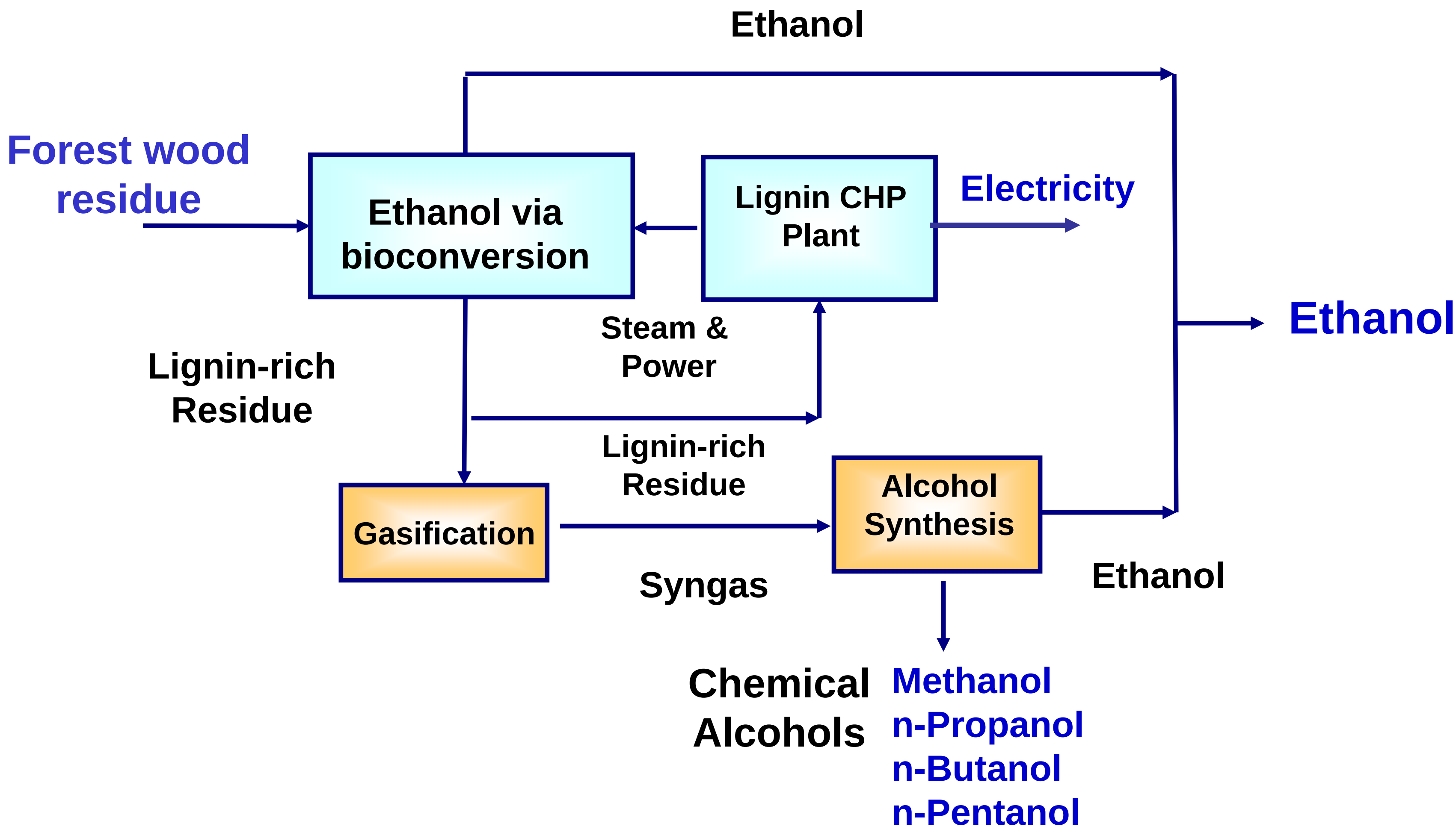
Model tractor: 6078 kg

1. **Material and assembly energy**
2. **Material energy**

Integrated Biorefinery with CBP /GTCC that Produces Ethanol, Generates Steam, and Electricity, 2030



Integrated Biochemical/Thermochemical Biorefinery Scenarios, 2030



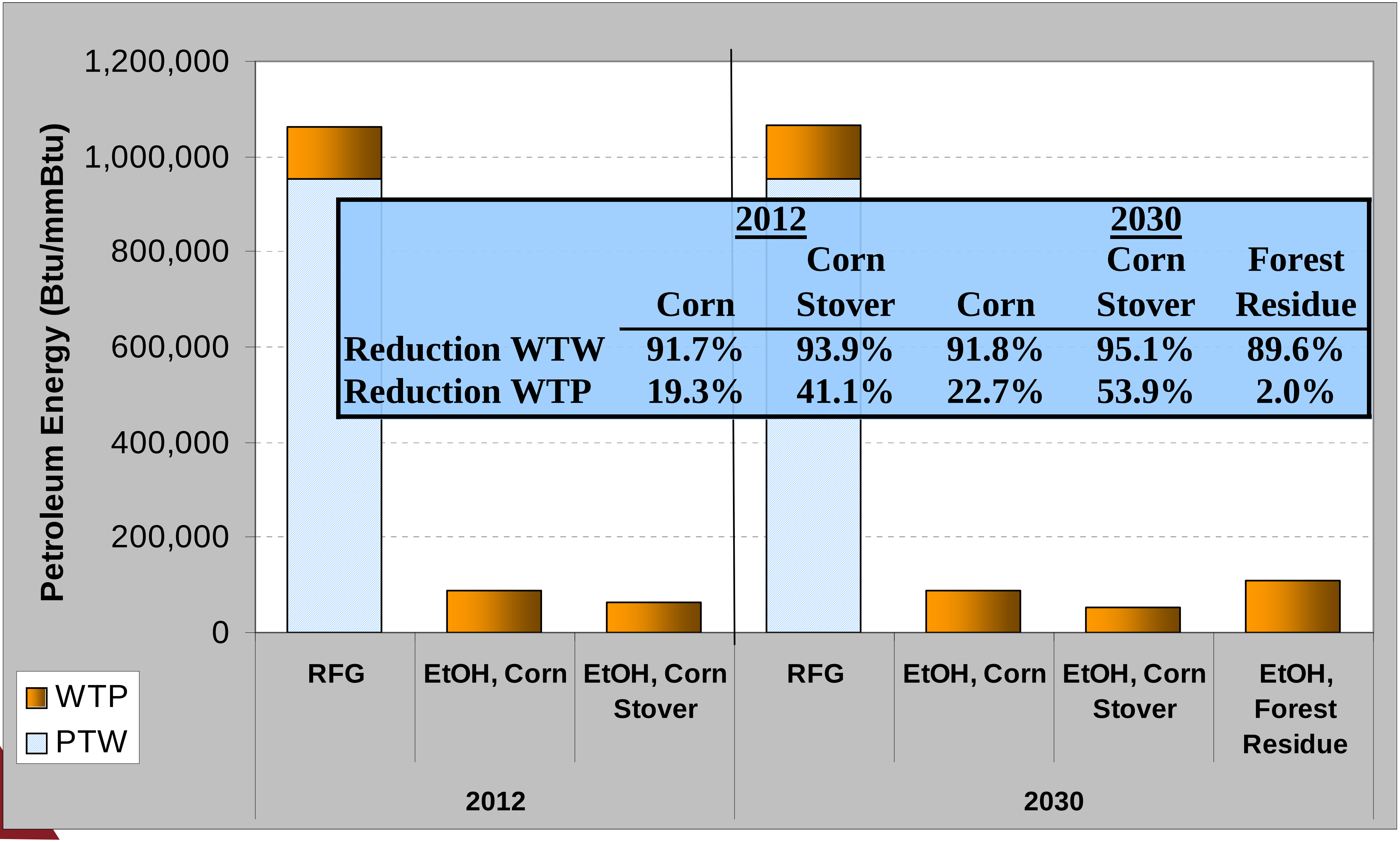
Source: J. Jechura, National Renewable Energy Laboratory

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

Production Scenarios	Transportation Fuel	Power	Chemicals
Stover/BC (2012)	91.2%	8.8%	
Stover/Biorefinery (CBP/GTCC) (2030)	79.6%	20.4%	
Wood Residue/Biorefinery (BC/TC) (2030)	91.4%	5.4%	3.1%

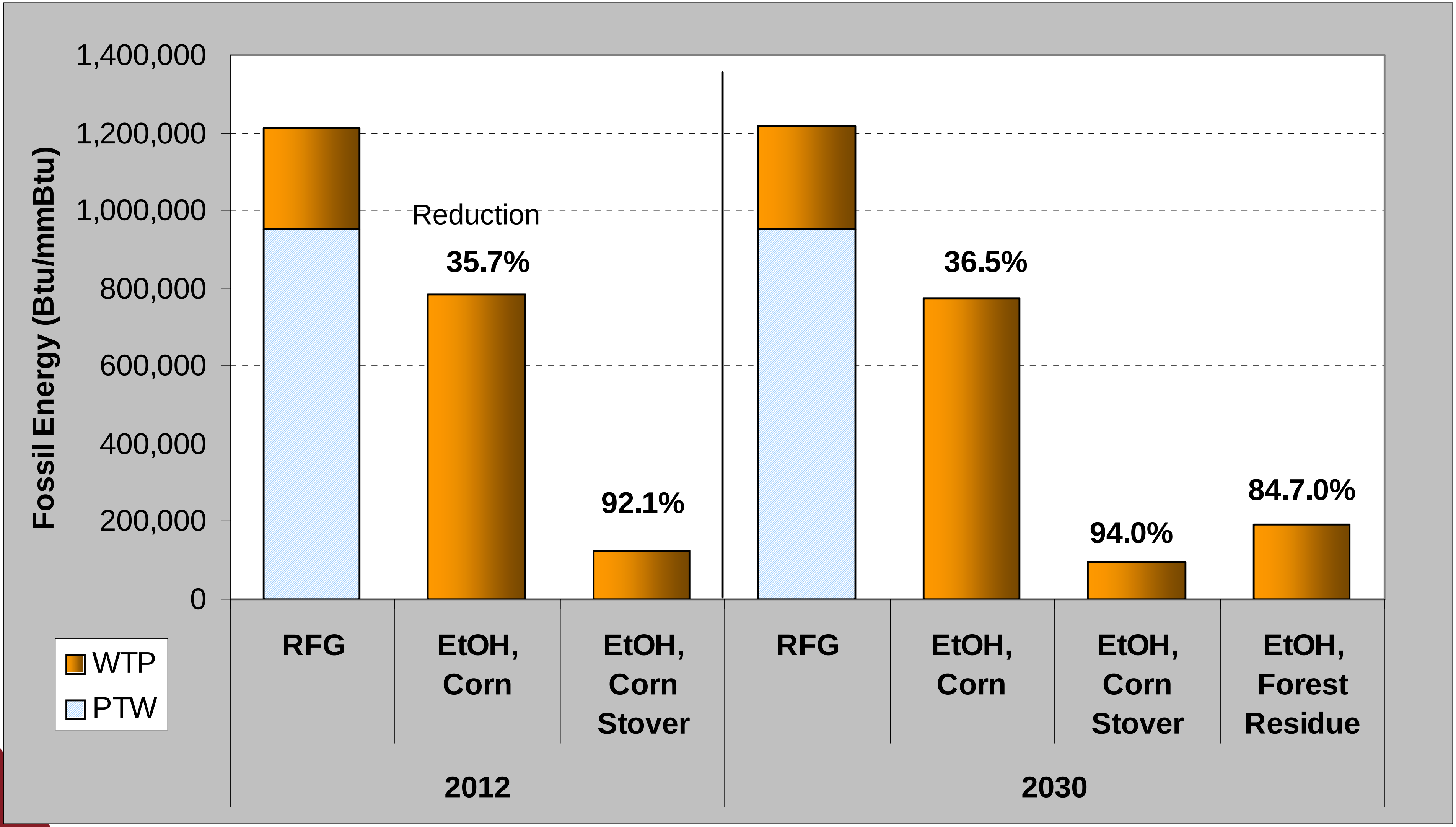
The displacement or allocation method could be used in dealing with joint products. The allocation method is used in this study; but GREET generally takes the displacement method.

Corn Stover-Derived Ethanol Offers Substantial Oil Savings (94-95%) When Displaces Gasoline

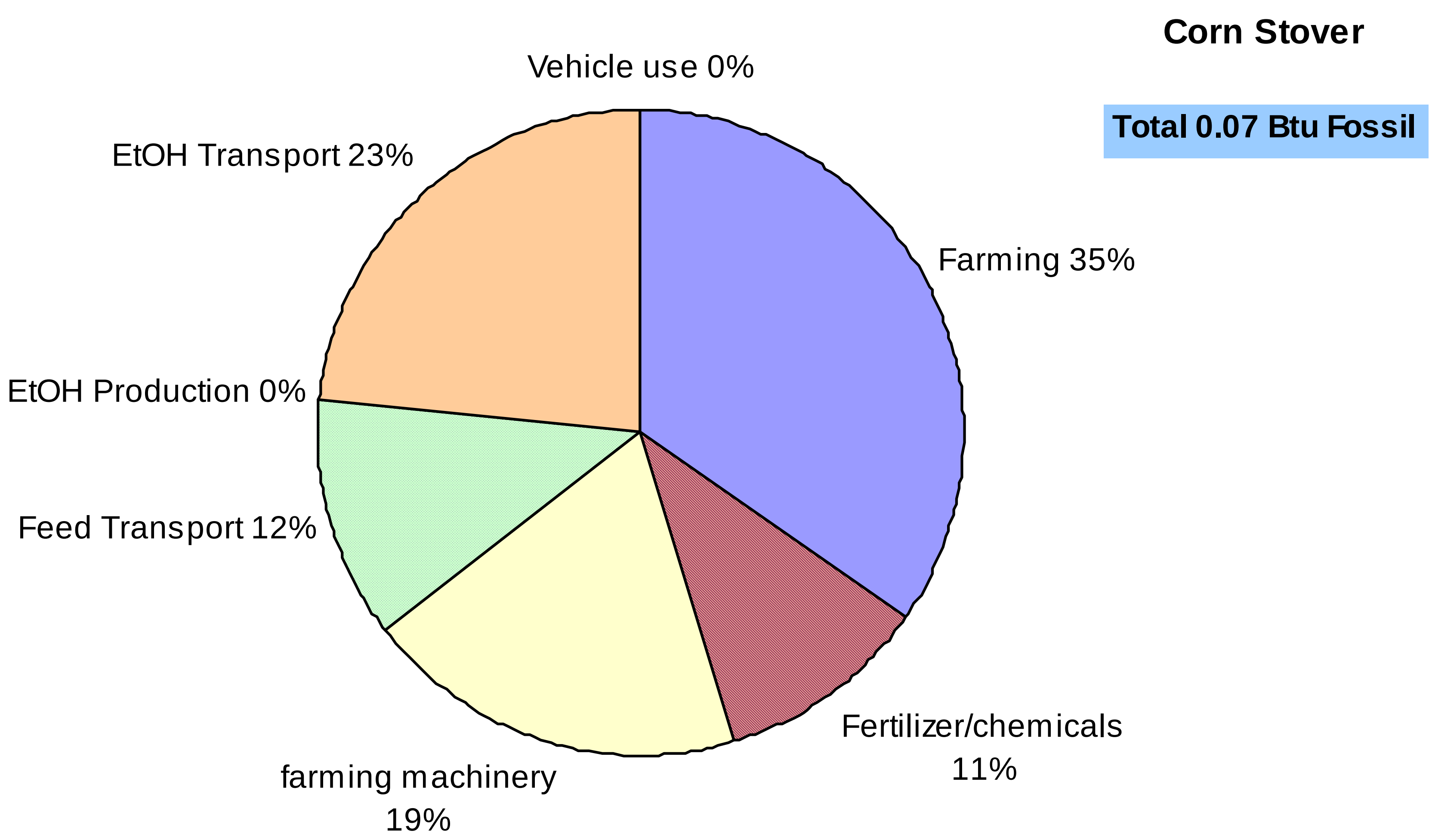


	2012		2030		
	Corn	Corn Stover	Corn	Corn Stover	Forest Residue
Reduction WTW	91.7%	93.9%	91.8%	95.1%	89.6%
Reduction WTP	19.3%	41.1%	22.7%	53.9%	2.0%

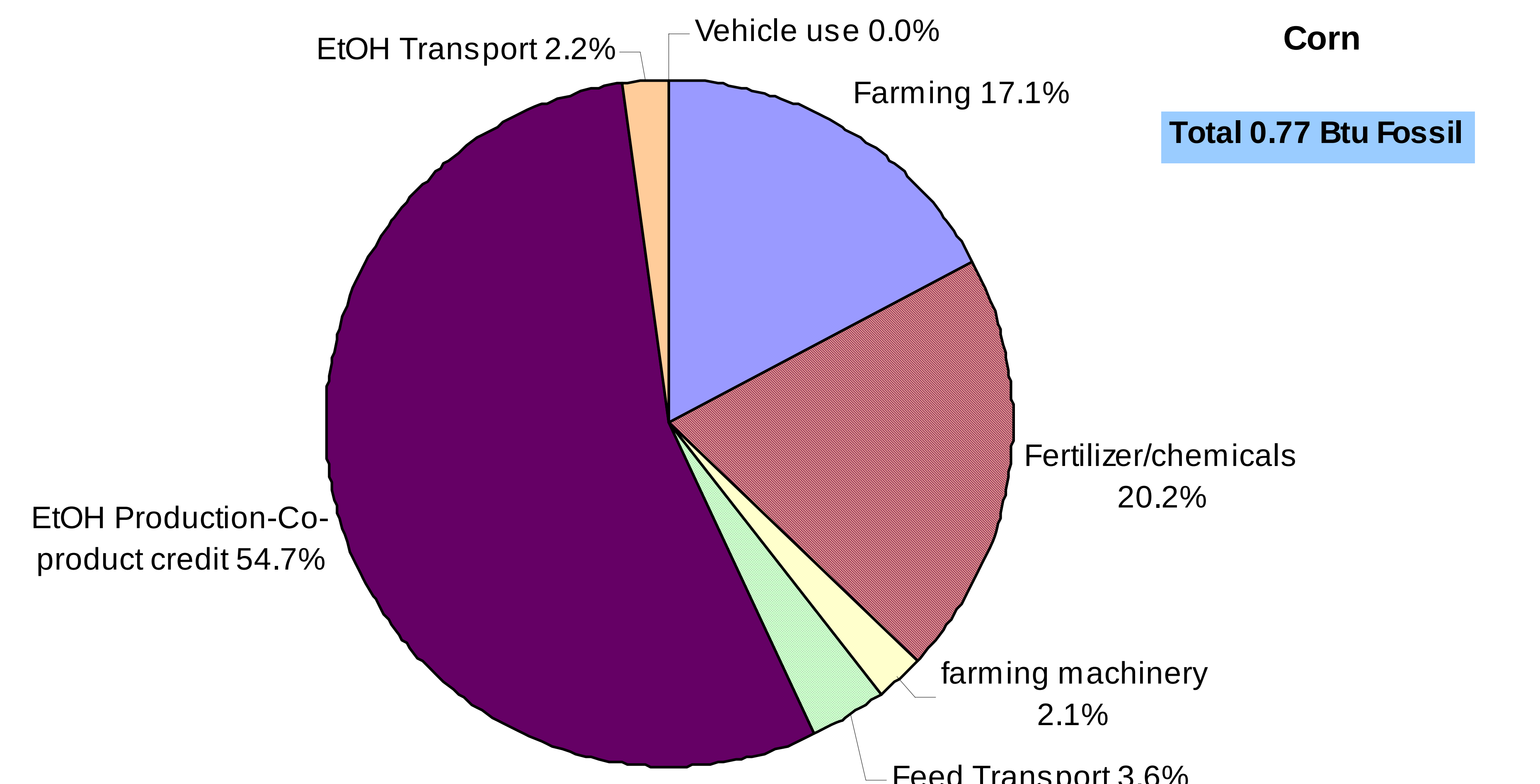
Cellulosic Ethanol Produced from Corn Stover Reduces Fossil Energy Use by 92-94%



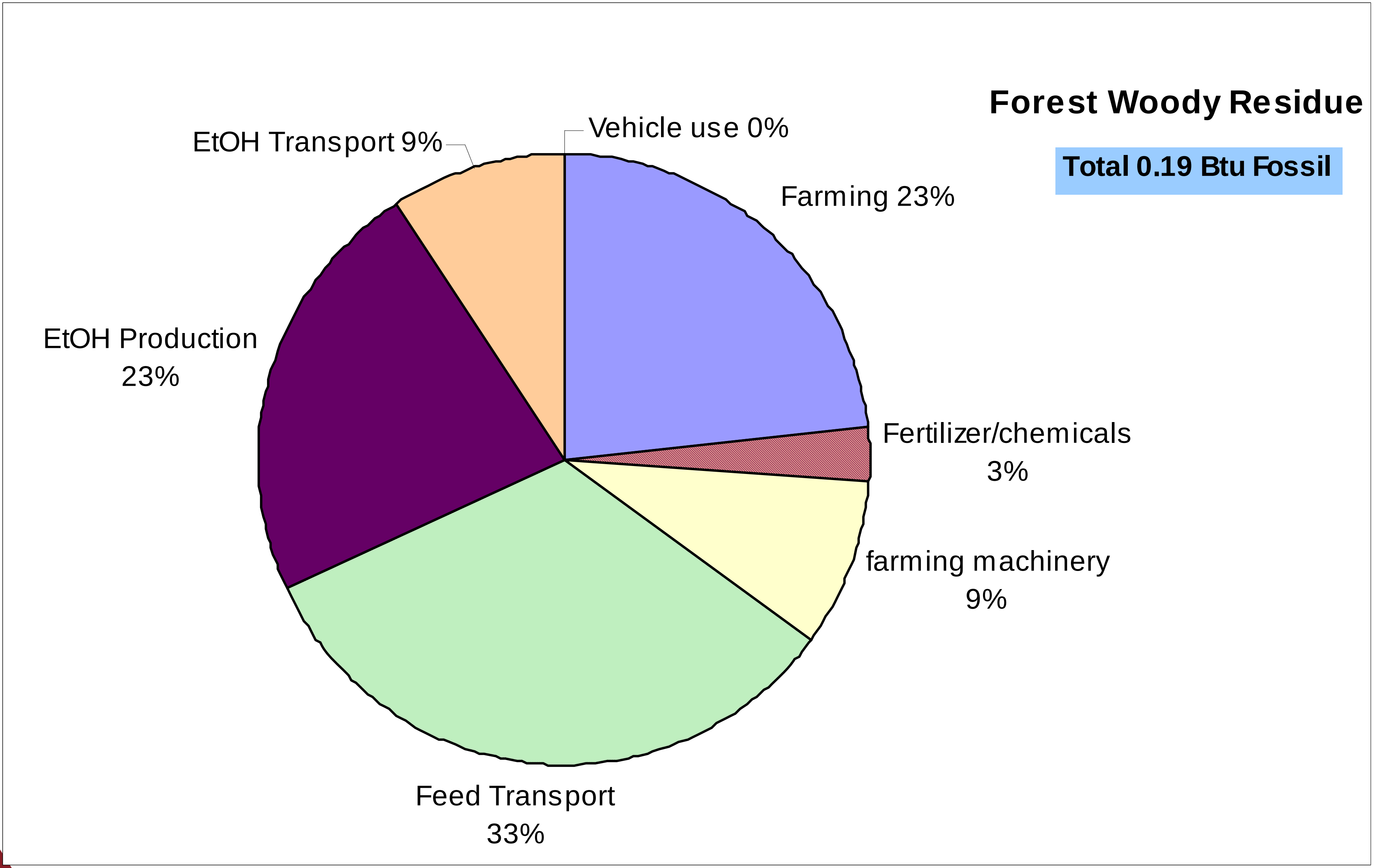
Fossil Energy Use Breakdown: Corn Stover Ethanol



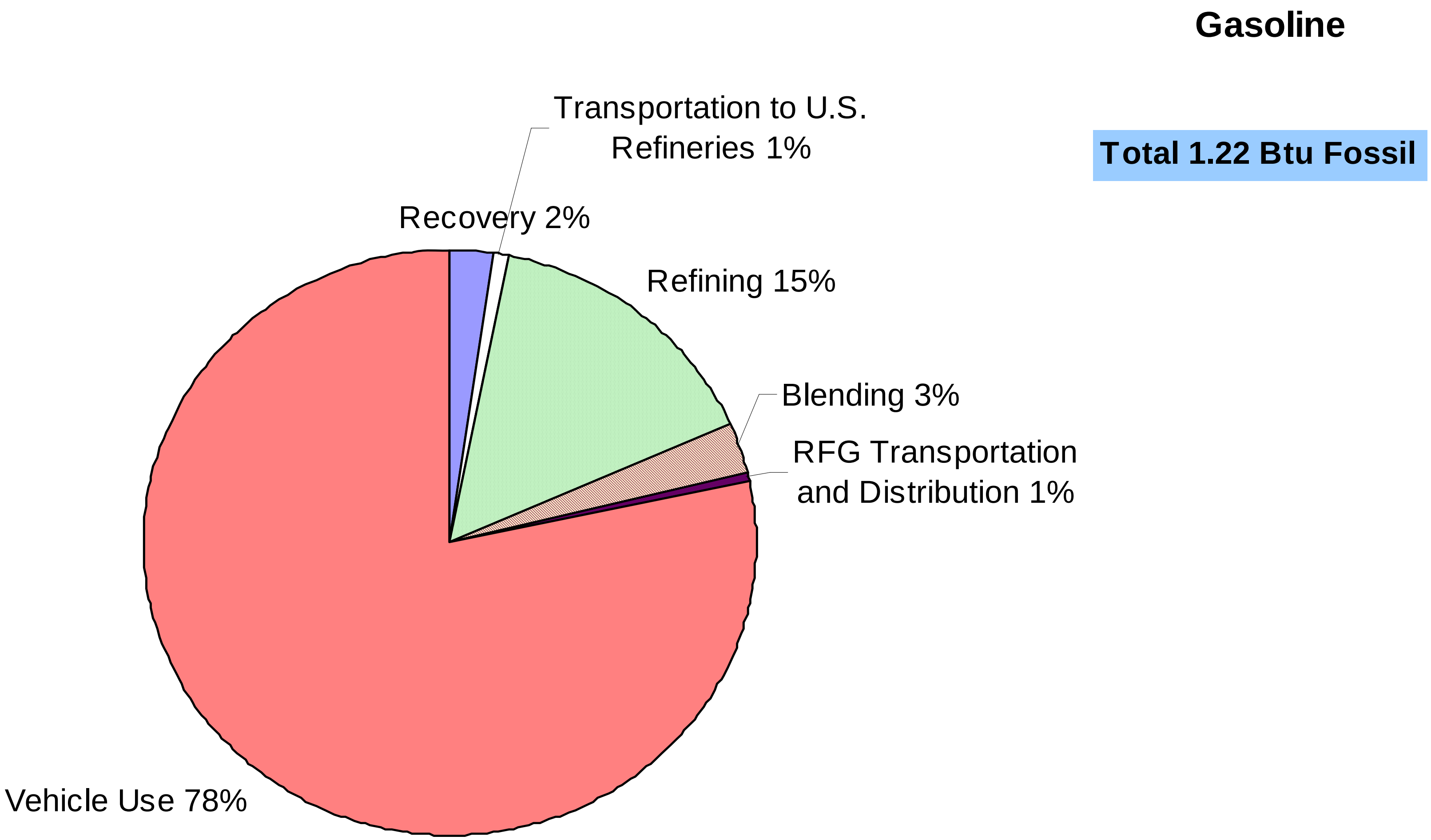
Fossil Energy Use Breakdown: Corn Grain Ethanol



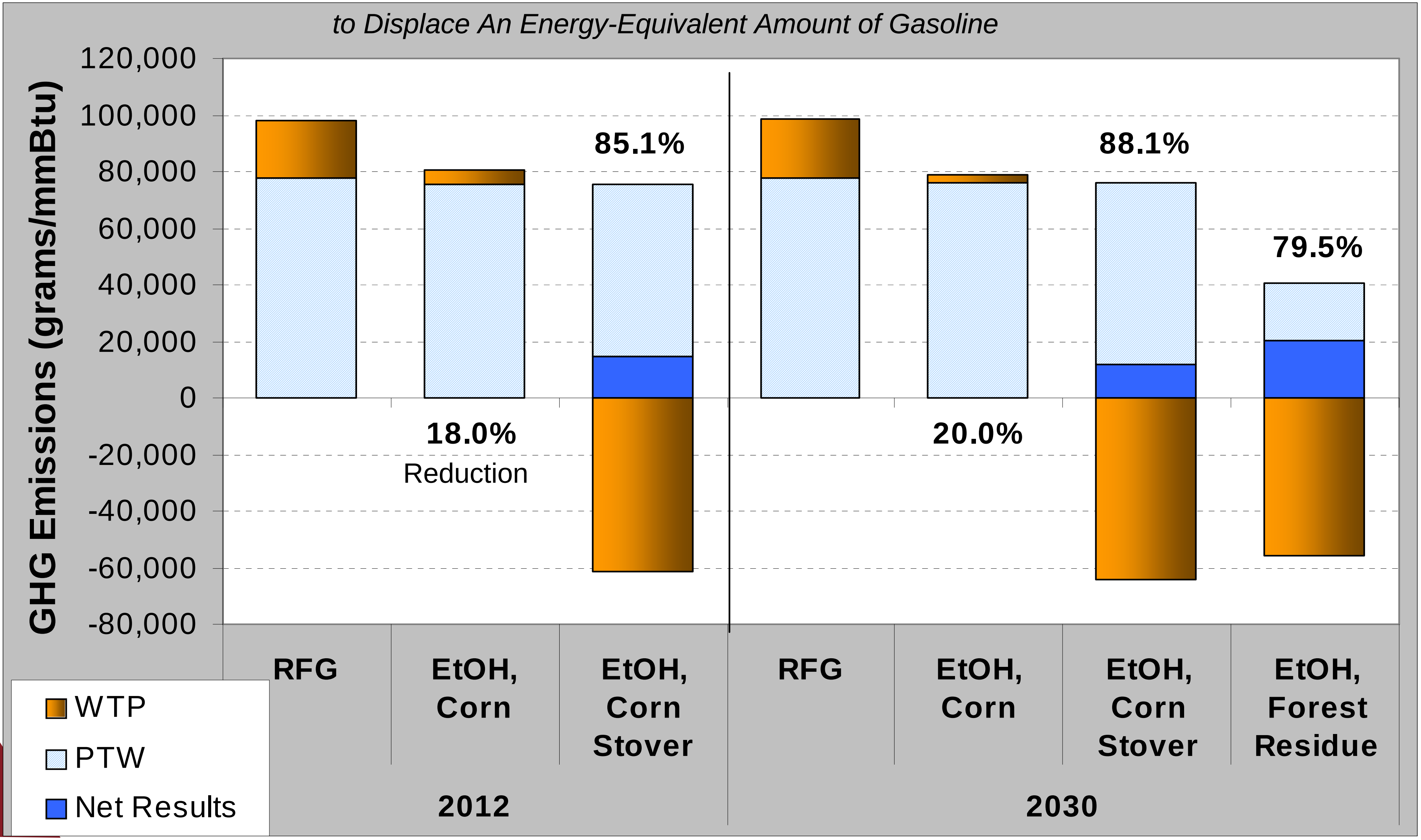
Fossil Energy Use Breakdown: Forest Woody Residue Ethanol



Fossil Energy Use Breakdown: Gasoline



Corn Stover and Forest Wood Residue Derived Ethanol Can Avoid 80-88% of GHG Emissions



Criteria Pollutants Emissions in Urban and Rural Area

- Bio-ethanol achieves cross-board reductions in urban emissions of CO, VOC, NOx, SOx and PM10 relative to gasoline in both near and long term.

- In the near term (2012), corn stover ethanol has large increase in total (urban and rural) VOC and CO emissions due to high emissions of biomass boilers.

- Net reductions of total VOC, CO, PM10 and SOx from corn stover ethanol is achievable with biorefinery design for EtOH production and GTCC power in 2030.

- Forest woody residue derived ethanol through the BC/TC refinery achieves total SOx reduction relative to gasoline but causes increases in total CO, VOC, NOx and PM10.

Conclusions and Outstanding Issues

- Corn stover-derived fuel ethanol could substantially reduce petroleum (94%) and fossil energy (92%) use when displacing gasoline at energy equivalent basis. Fossil energy reductions are enhanced by bio-power from lignin residue and by savings in nitrogen fertilizer use.
- For each btu of fuel produced and used, 0.07btu of fossil input is required for corn stover ethanol, 0.19btu for forest wood residue, 0.77btu for corn, and 1.22btu for gasoline.
- Corn stover ethanol life cycle shows low CO_2 and CH_4 burdens. More than 85% GHG emissions can be avoided relative to gasoline.
- Farming stage is a key activity for corn stover ethanol life cycle. Change of allocation of farming operation and fertilizer between corn and stover would impact energy, GHG benefits and particularly NOx emissions.
- Outstanding issues include stover harvest, transport and storage technologies, and land and water use for bioethanol life cycles need to be addressed.