Key Issues for GREET Transportation Fuel LCA

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CRC Workshop on Life Cycle Analysis of Transportation Fuels
Argonne, IL
Oct. 16-17, 2013

*GREET™ and its documents are available at argonne's GREET website (*greet.es.anl.gov)

- DOE EERE has been sponsoring GREET development and applications since 1995
- A new GREET version (GREET1_2013) was completed on Oct. 11 2013
  - Petroleum refinery efficiency as a function of crude quality and refinery complexity
  - Updated efficiencies and emission factors of power plants
  - Methane leakage update for natural gas pathways
  - Marine fuel pathways and commercial vessel operations
  - Land use change (LUC) updates with updated GTAP LUC results and detailed soil carbon modeling results
  - Light-duty vehicle tailpipe emission factors updates with EPA MOVES modeling
- First full release of GREET in the .net platform

GREET includes more than 85 on-road vehicle/fuel systems

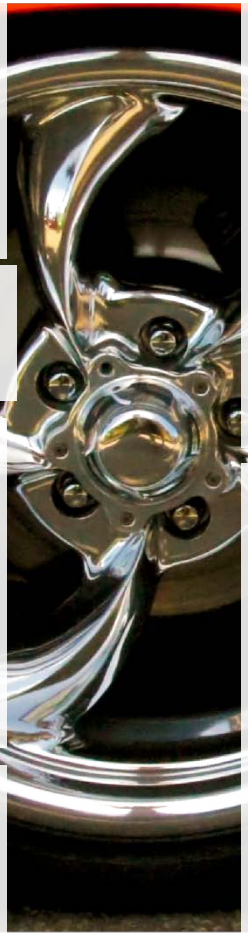
Conventional Spark-Ignition Engine Vehicles
- Gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol
- Renewable gasoline
- Pyrolysis-based gasoline

Spark-Ignition, Direct-Injection Engine Vehicles
- Gasoline
- Methanol and ethanol

Compression-Ignition, Direct-Injection Engine Vehicles
- Diesel
- Fischer-Tropsch diesel
- Dimethyl ether
- Biodiesel
- Renewable diesel
- Pyrolysis-based diesel

Fuel Cell Vehicles
- On-board hydrogen storage
  - Gaseous and liquid hydrogen
- On-board hydrocarbon reforming to hydrogen

Battery-Powered Electric Vehicles
- Various electricity generation sources



Hybrid Electric Vehicles (HEVs)
- Spark-ignition engines:
  - Petroleum and renewable gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Petroleum and renewable diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel

Plug-in Hybrid Electric Vehicles (PHEVs)
- Spark-ignition engines:
  - Petroleum and renewable gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Petroleum and renewable diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel
- Fuel cell
  - Gaseous and liquid hydrogen from various sources

GREET covers LCA for aviation fuels

Fuels and Feedstocks

- **Petroleum Jet Fuel**
  - Conventional Crude
  - Oil Sand
- **Pyrolysis Oil Jet Fuel**
  - Crop Residues
  - Forest Residues
  - Dedicated Energy Crops
- **Hydrotreated Renewable Jet Fuel**
  - Soybeans
  - Palm Oil
  - Rapeseeds
  - Jatropha
  - Camelina
  - Algae
- **Fischer-Tropsch Jet Fuel**
  - Conventional Natural Gas
  - Shale Gas
  - Renewable Natural Gas
  - Biomass Gasification
  - Coal Gasification
  - Coal/Biomass Gasification

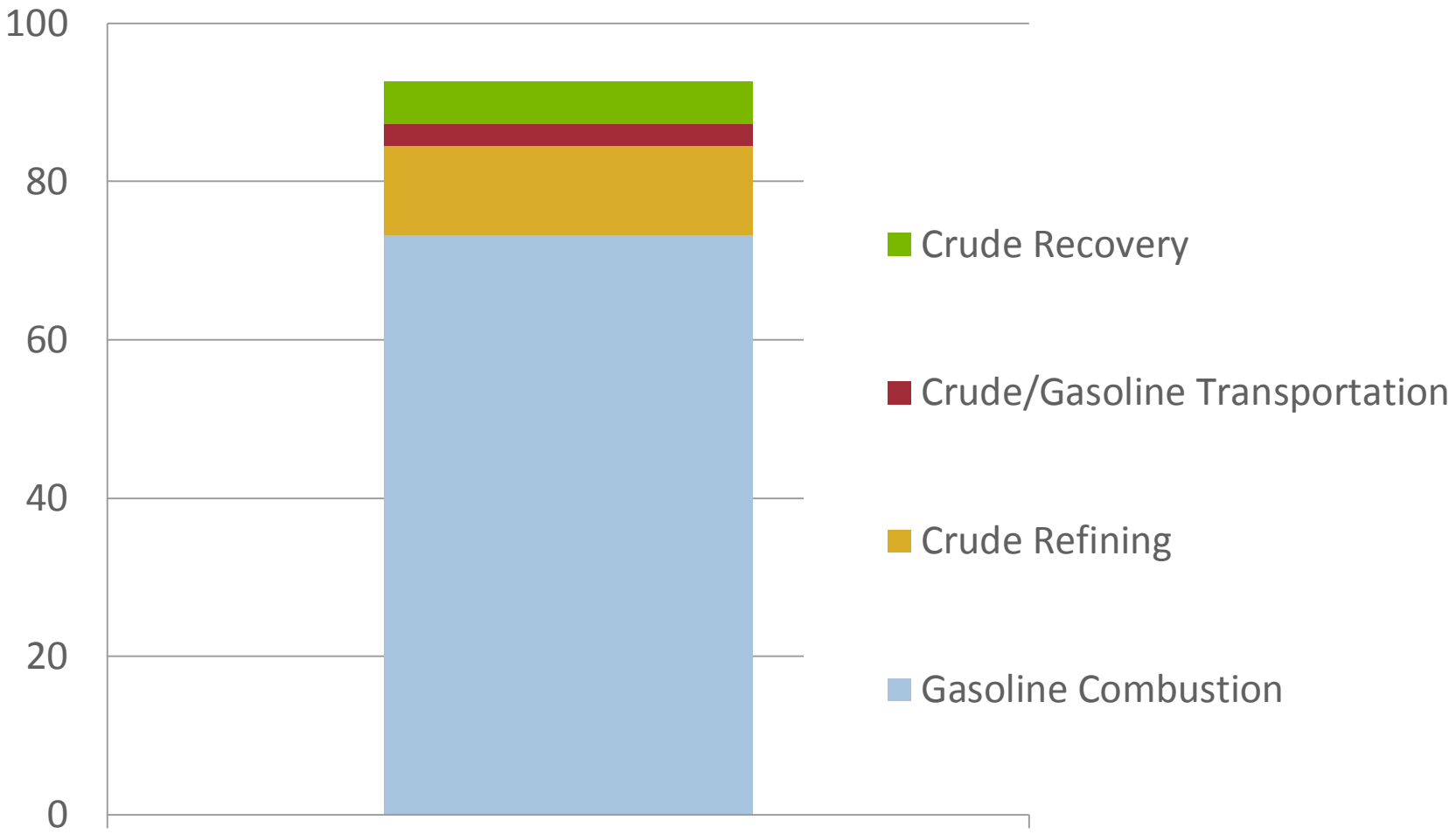
Aircraft Types

- **Passenger Aircraft**
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad
  - Regional Jet
  - Business Jet
- **Freight Aircraft**
  - Single Aisle
  - Small Twin Aisle
  - Large Twin Aisle
  - Large Quad
- **LCA Functional Units**
  - Per MJ of fuel
  - Per kg-km
  - Per passenger-km

GREET1.2013 includes LCA of marine fuels

- **Petroleum-based Fuel**
  - Heavy Fuel Oil
  - Marine Distillate
  - Low Sulfur Distillate
- **Biodiesel Fuel**
  - Soybeans
  - Palm Oil
  - Rapeseeds
  - Jatropha
  - Camelina
- **Hydrotreated Renewable Diesel Fuel**
  - Soybeans
  - Palm Oil
  - Rapeseeds
  - Jatropha
  - Camelina
  - Algae
- **Pyrolysis Diesel Fuel**
  - Crop Residues
  - Forest Residues
- **Liquid Natural Gas**
  - Conventional Natural Gas
- **Fischer-Tropsch Diesel Fuel**
  - Conventional Natural Gas
  - Renewable Natural Gas
  - Biomass Gasification
  - Coal Gasification
  - Coal/Biomass Gasification

Gasoline GHG emissions: grams/MJ

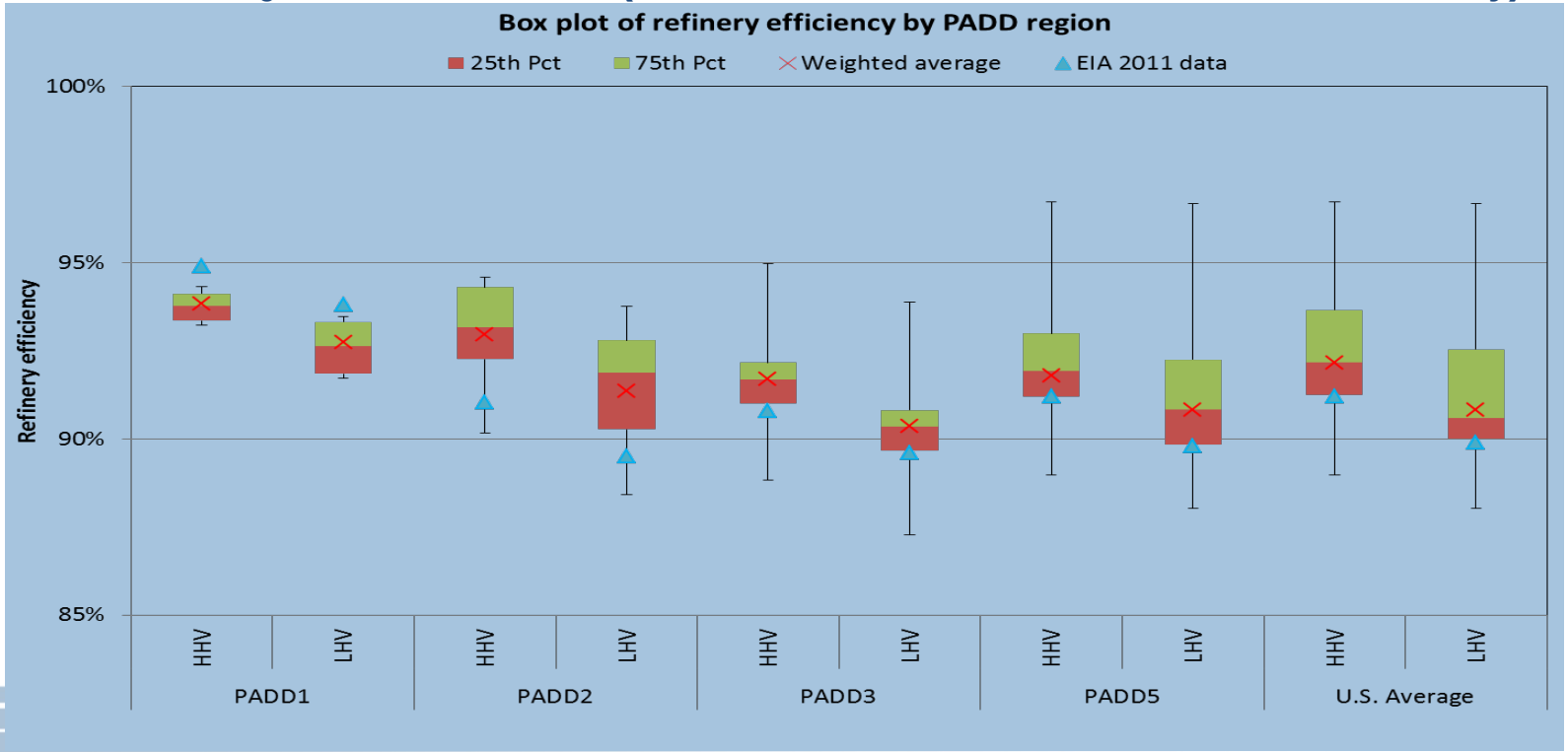


Petroleum refining is a major WTP emission source for petroleum fuels

US refinery overall efficiency based EIA annual survey data

	PAD Districts					US average HHV		LHV	
	I	II	III	IV	V	w/ asphalt	w/o asphalt	w/ asphalt	w/o asphalt
2008	93.1%	90.8%	90.2%	88.9%	90.8%	**90.7%**	**87.9%**	**89.1%**	**86.5%**
2010	94.8%	91.2%	91.2%	89.5%	91.5%	**91.5%**	**89.0%**	**90.2%**	**87.8%**
2011	**94.9%**	**91.0%**	**90.8%**	**89.3%**	**91.2%**	**91.2%**	**88.9%**	**89.9%**	**87.6%**

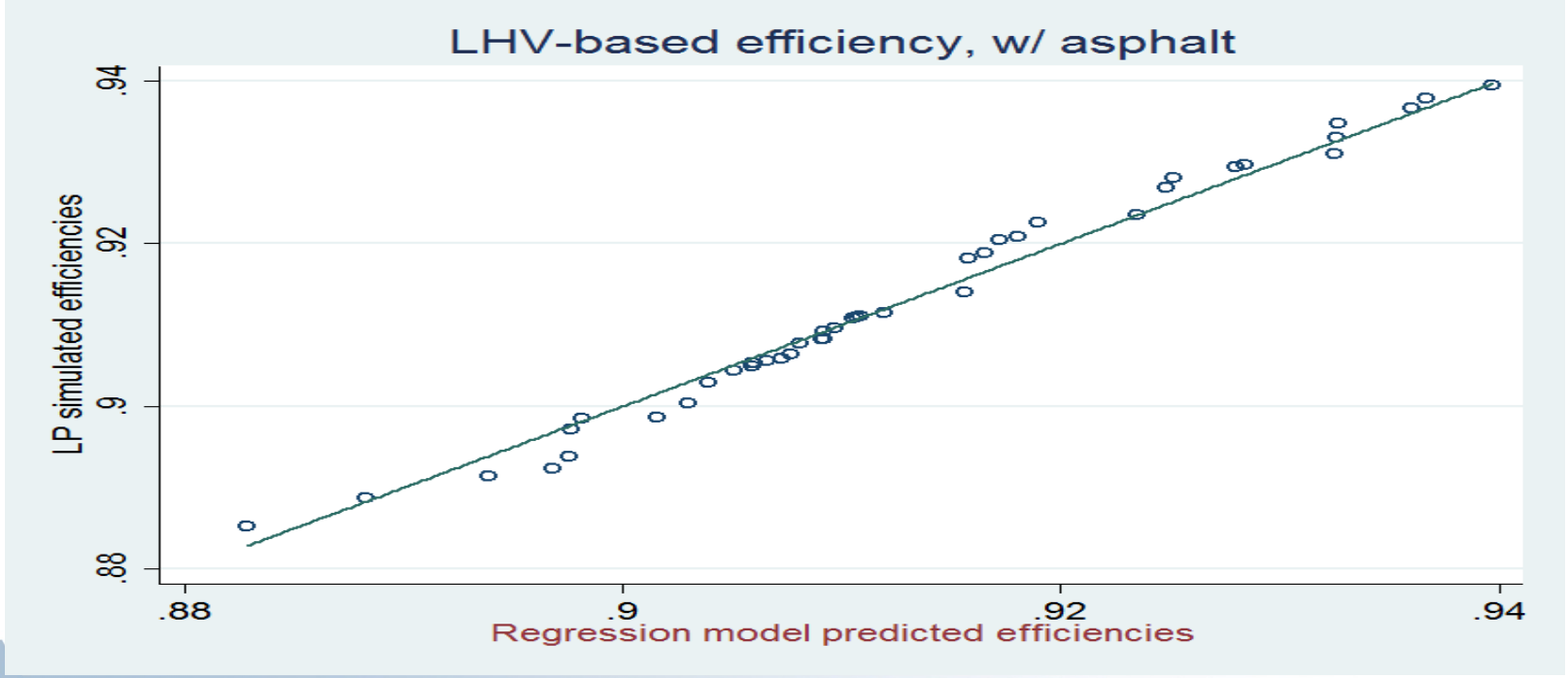
LP Modeling of 48 US refineries (in collaboration with Sasol and Jacobs Consultancy)



Regression model to predict refinery overall efficiency:
LHV-based efficiency with asphalt included
(in collaboration with Sasol and Jacobs Consultancy)

Eff = 0.9181 + 0.001144 x API – 0.00675 x S + 0.0462 X HS - 0.002645 X CI

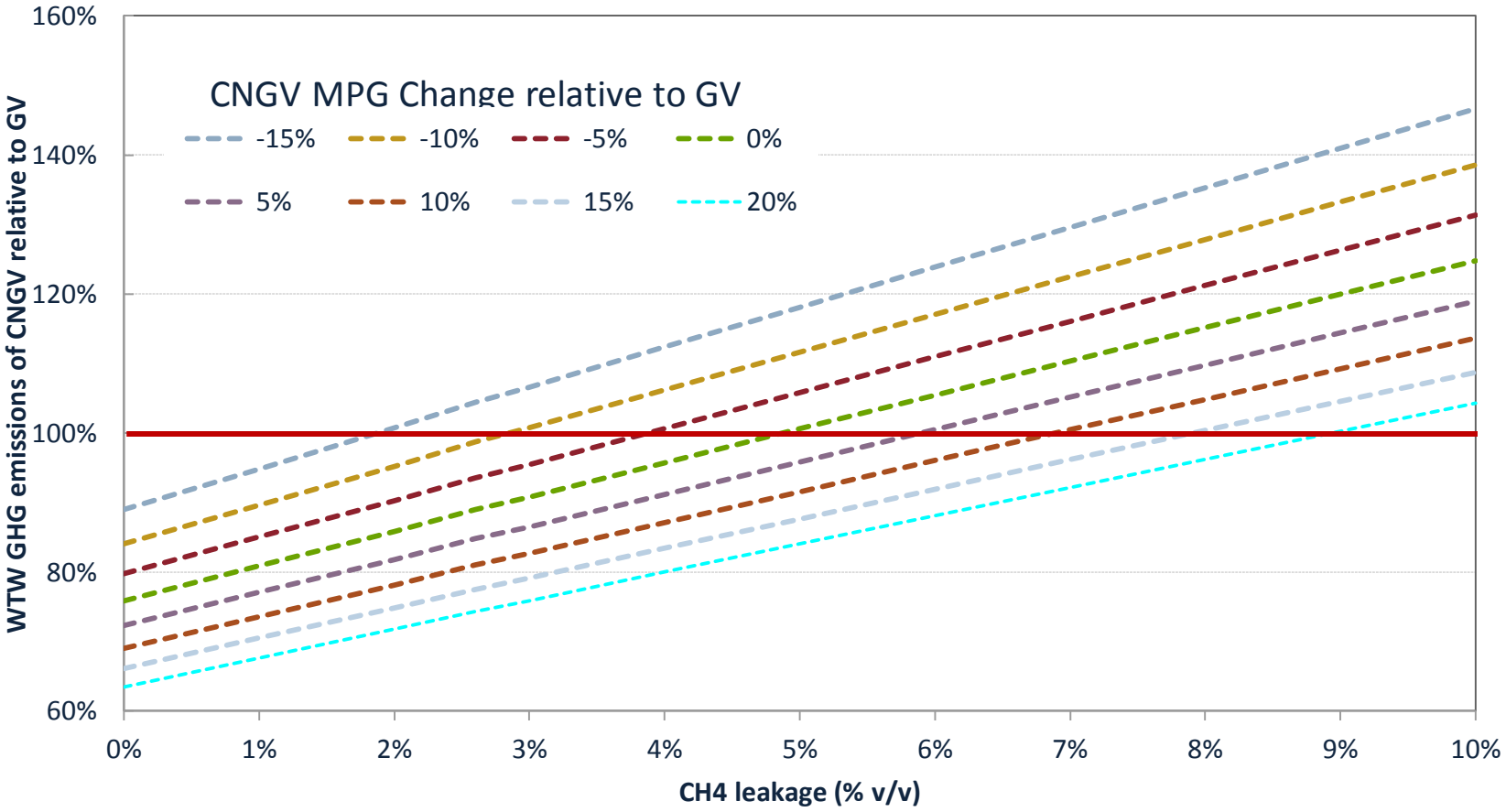
Eff – refinery efficiency (%)
API – crude API index
S – crude sulfur content (%)
CI – refinery complex index
HS – heavy product share in refinery products (%, including residual oil and asphalt)



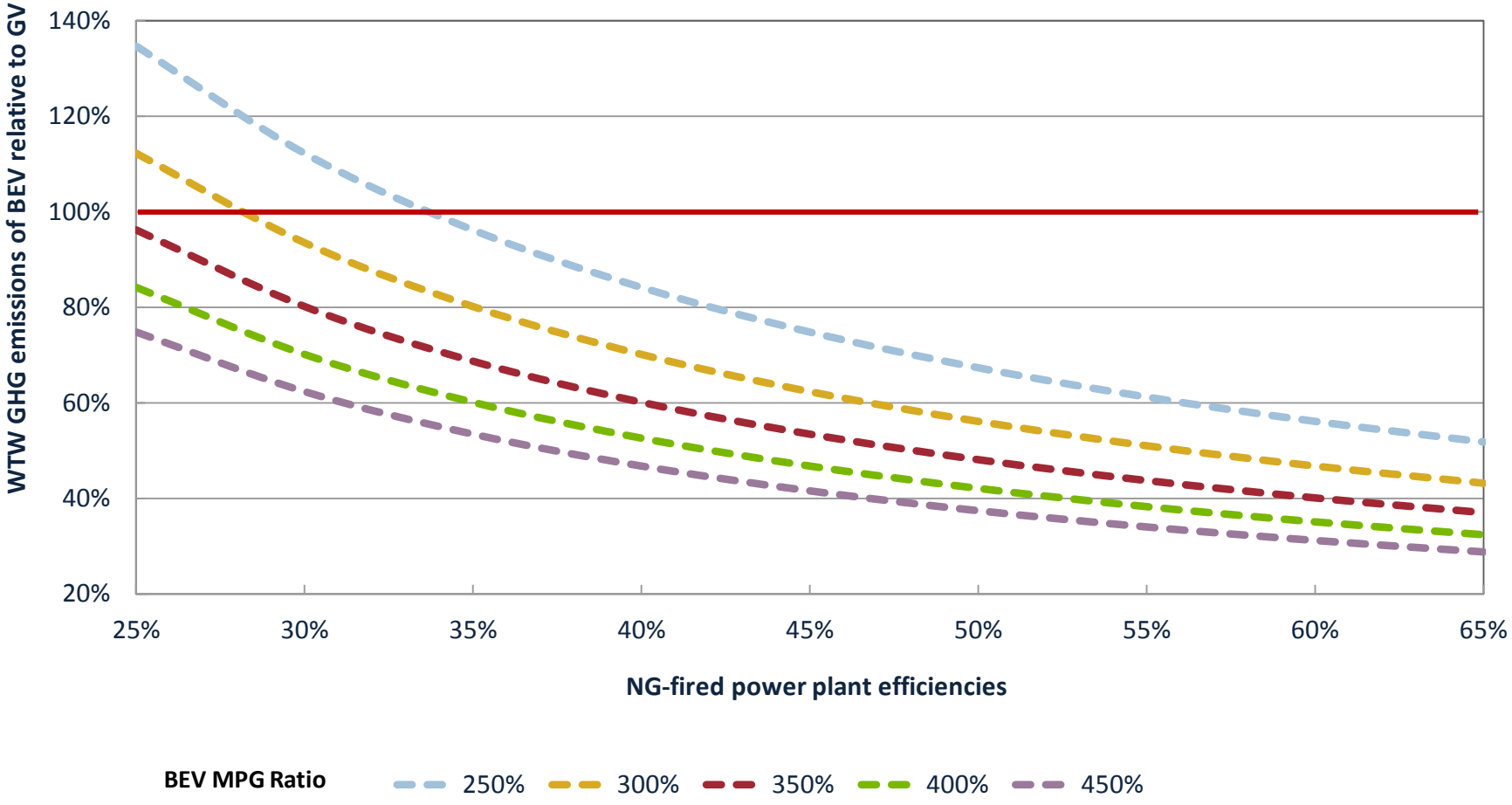
Methane Leakage of Natural Gas Production, Transmission, and Distribution Is A Major Concern

Sector	CH_4 Emissions: Percent of Volumetric NG Produced (Gross)									
	EPA - Inventory 5 yr avg (2011)	CMU - Marcellus Shale (2011)	NREL - Barnett Shale (2012)	API/ ANGA Survey (2012)	NOAA - DJ Basin (2012)	NOAA - Uintah Basin (2013)	Exxon Mobil (2013)	EPA - Inventory 5 yr avg (2013)	EPA - Inventory 2011 data (2013)	Univ. Texas (2013)
Gas Field	1.18		0.9	0.75	2.3-7.7	6.2-11.7	0.6	0.59	0.44	0.42
Completion/ Workover			0.7					0.22	0.17	0.03
Unloading			0					0.08	0.04	0.05
Other Sources			0.2					0.29	0.23	0.34
Processing	0.16		0				0.17	0.15	0.16	
Transmission	0.38		0.4				0.42	0.36	0.34	
Distribution	0.26							0.26	0.23	
Total	1.98	2.2						1.36	1.17	

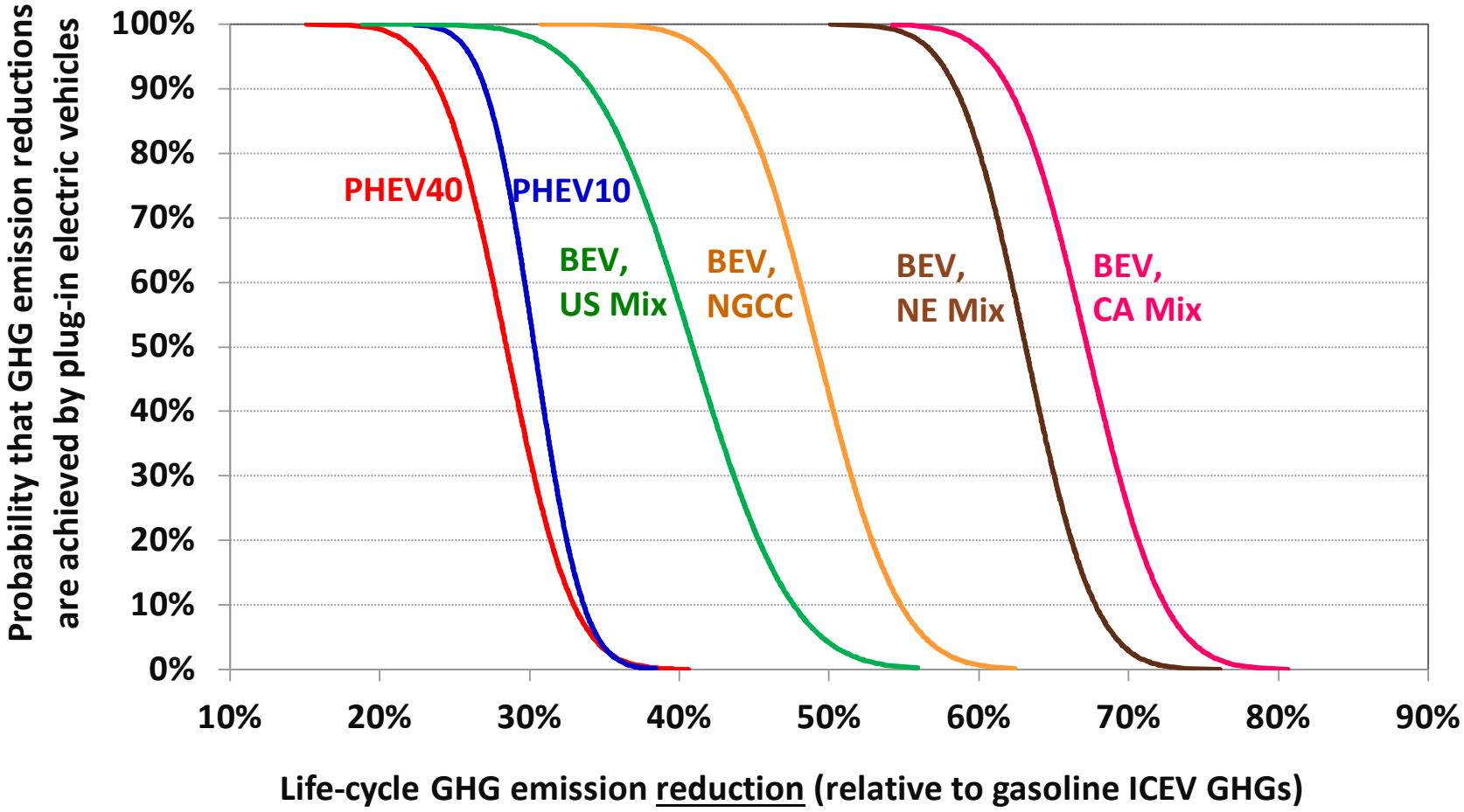
WTW GHG emissions of CNG vehicles vs. gasoline vehicles – methane leakage and CNGV efficiency are two key factors



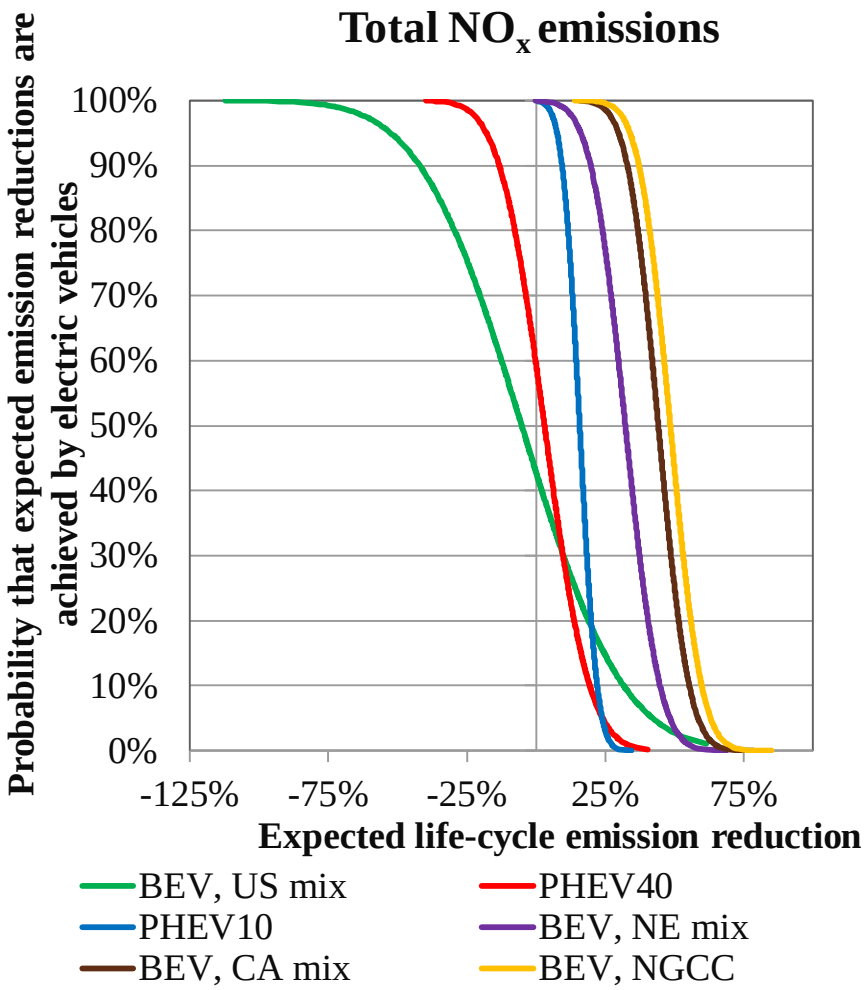
WTW GHG emissions of battery EVs with NG electricity vs. gasoline vehicles – NG plant efficiency and EV efficiency are two key factors

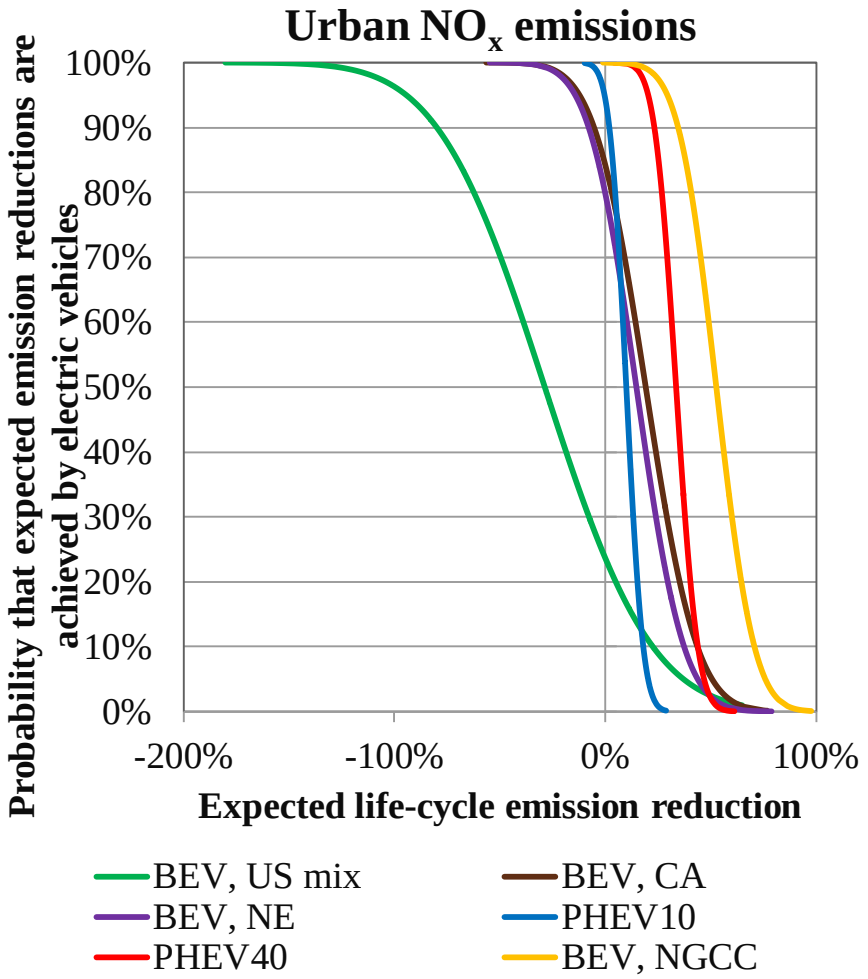


Plug-in vehicles with various configurations provide varying GHG emissions reduction potentials



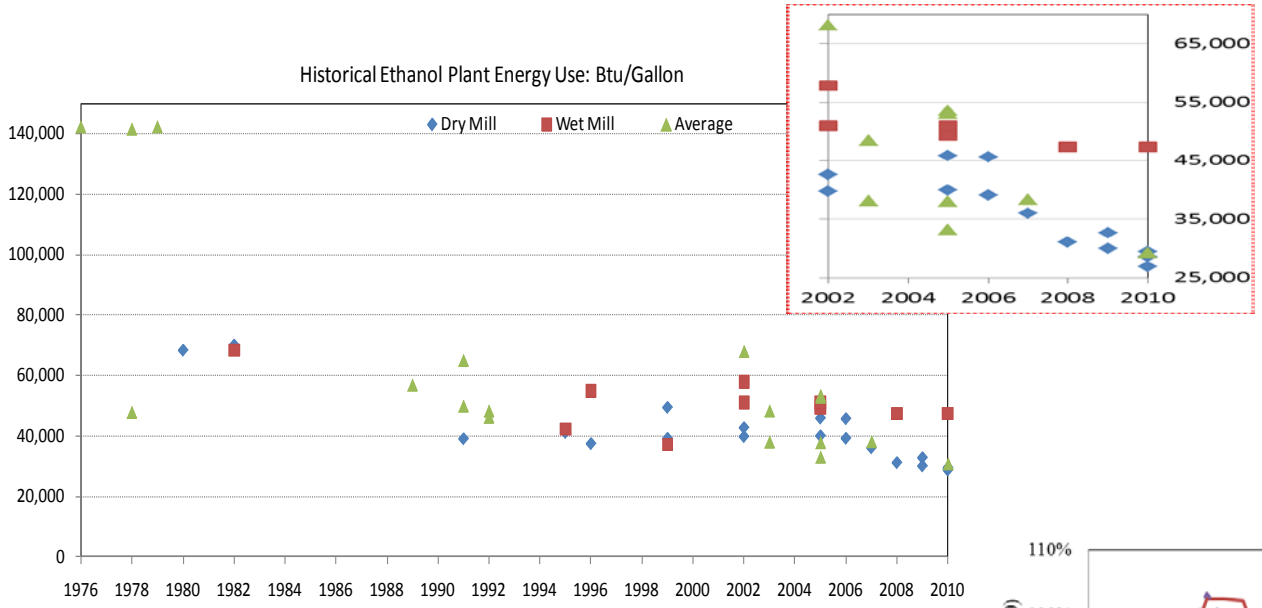
Plug-in vehicles with various configurations have varying air emissions

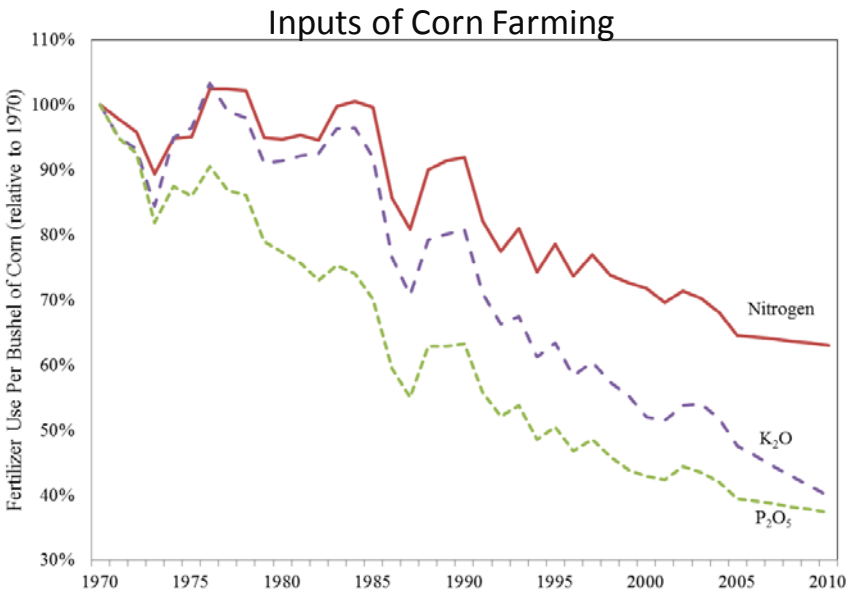




Technology improvement is a key issue in LCA

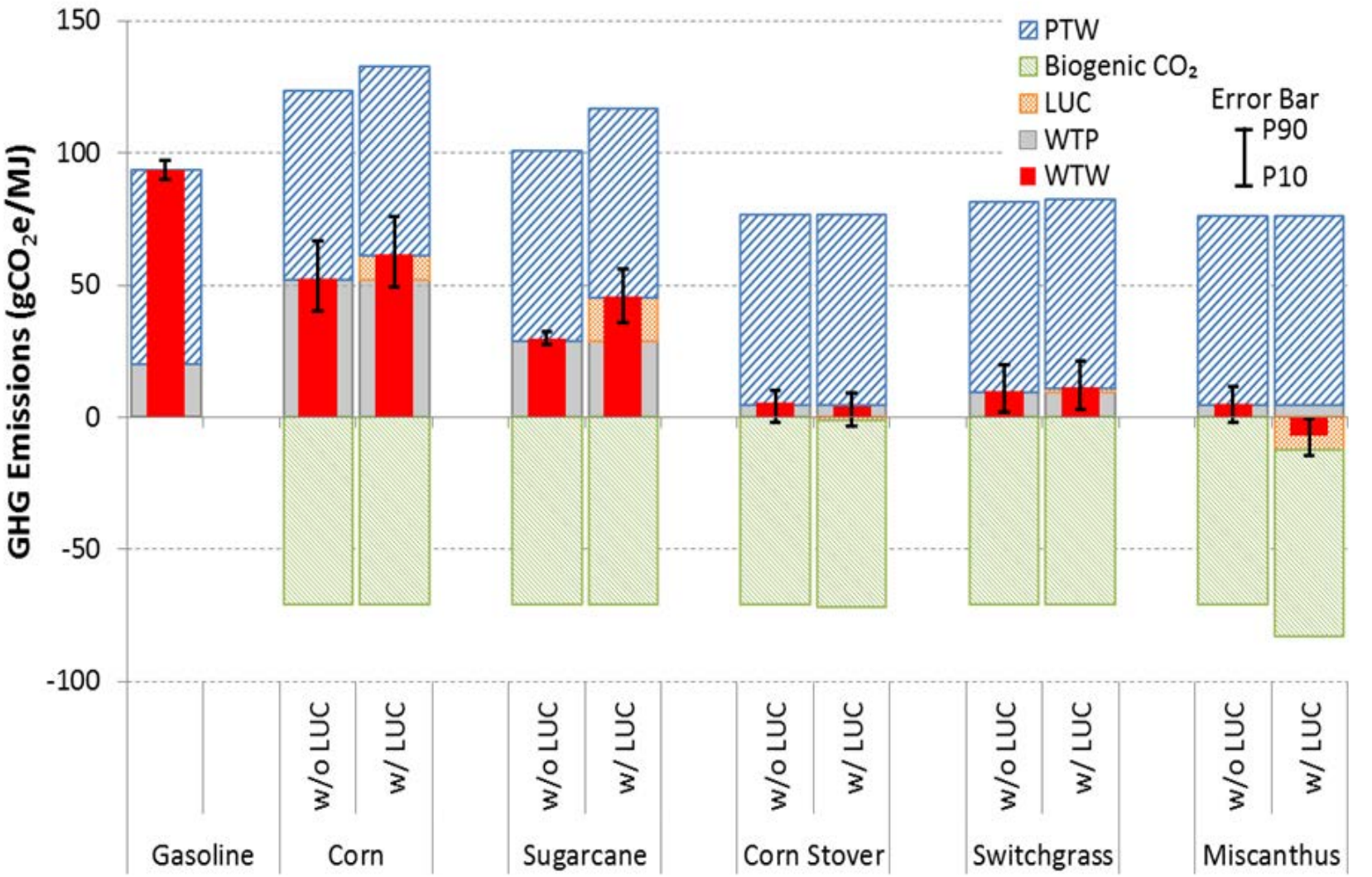
Examples of corn ethanol plants and corn farming





Wang M. et al., 2011, *Biomass and Bioenergy*

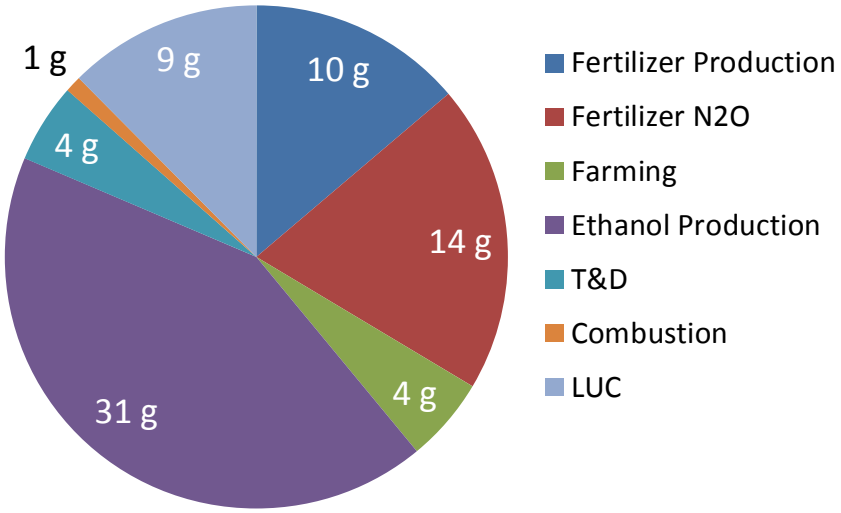
LCA GHG emissions of gasoline and bioethanol pathways



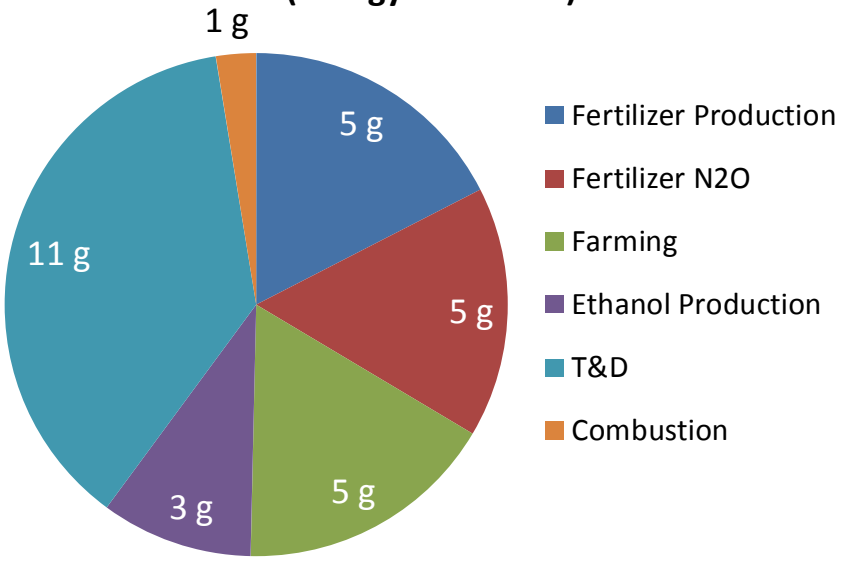
Wang M., et al., 2012, *Environ. Research Letters*

GHG emission sources for corn and sugarcane ethanol

Corn Ethanol: 60 g CO2e/MJ
(DGS Credit: -13)



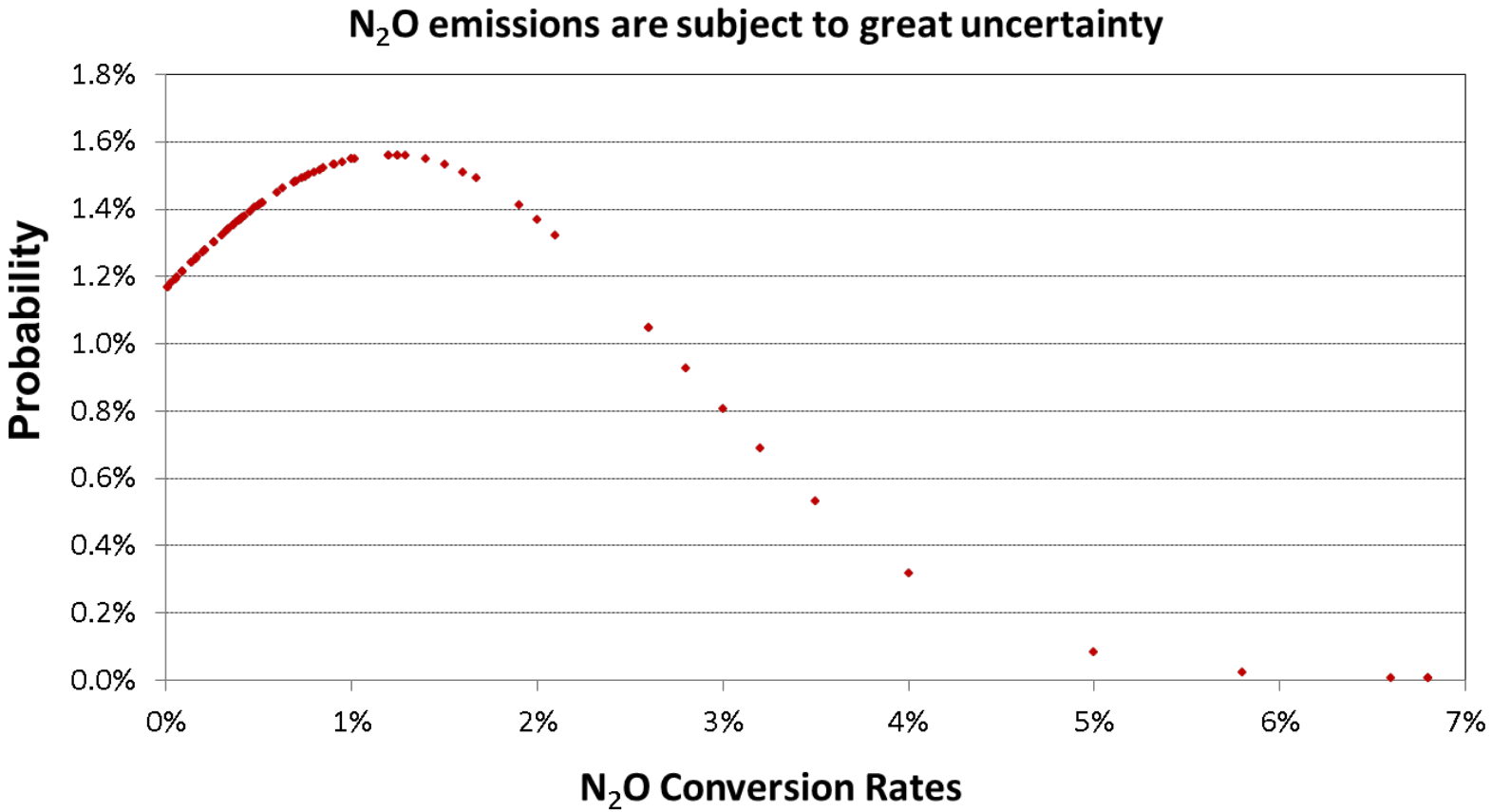
Sugarcane Ethanol: 30 g CO2e/MJ
(Energy allocation)



From Wang et al. (2012)

N_2O emissions in fields are a significant, uncertain factor affecting biofuel LCA GHG results

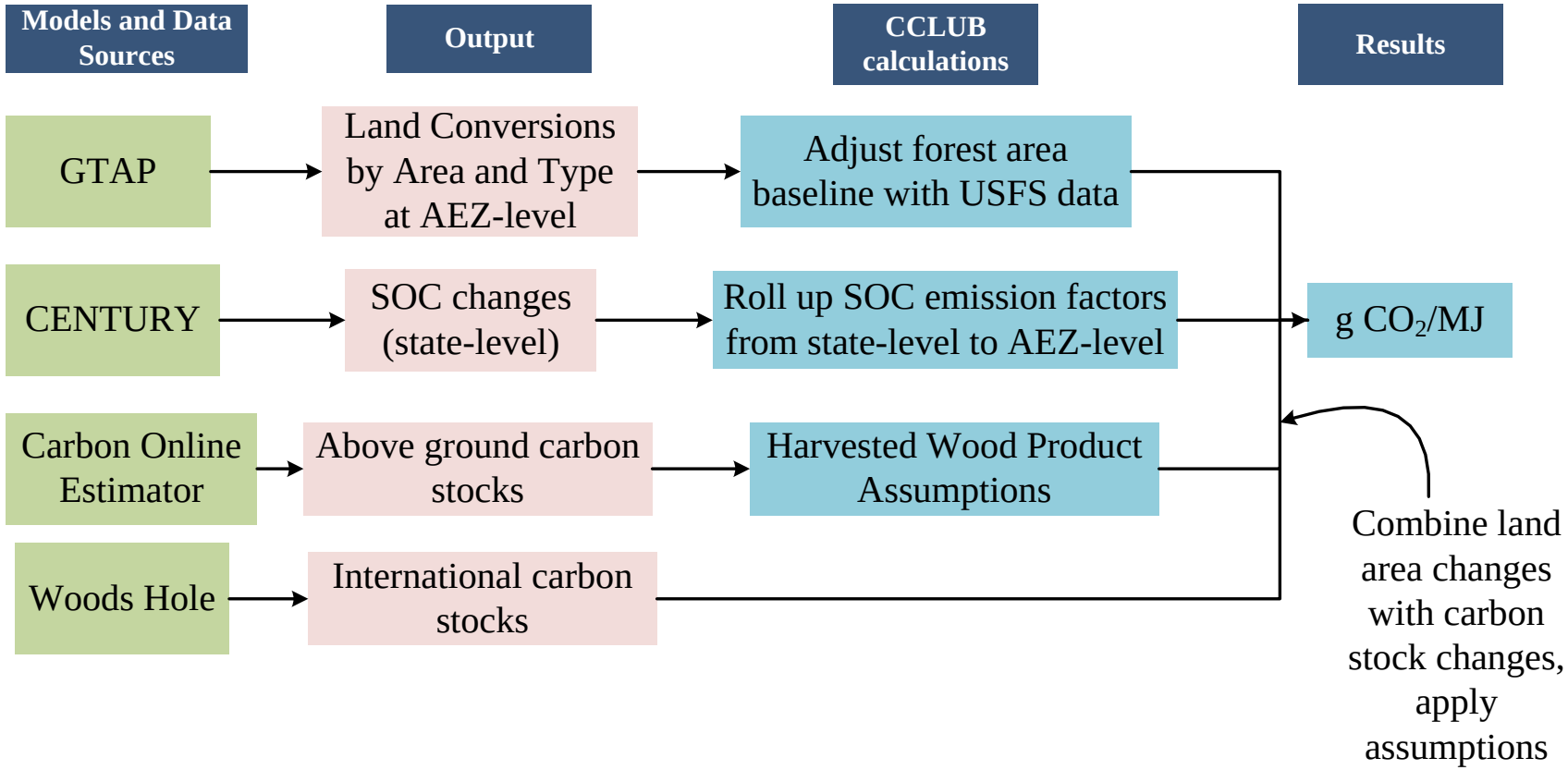
- N_2O emissions can account for up to ¼ of GHG emissions for corn ethanol
- N inputs to farming fields include synthetic fertilizer, manure, crop residues, etc.
- N_2O emissions from these sources are affected by soil type, N sources, climate, and crop types



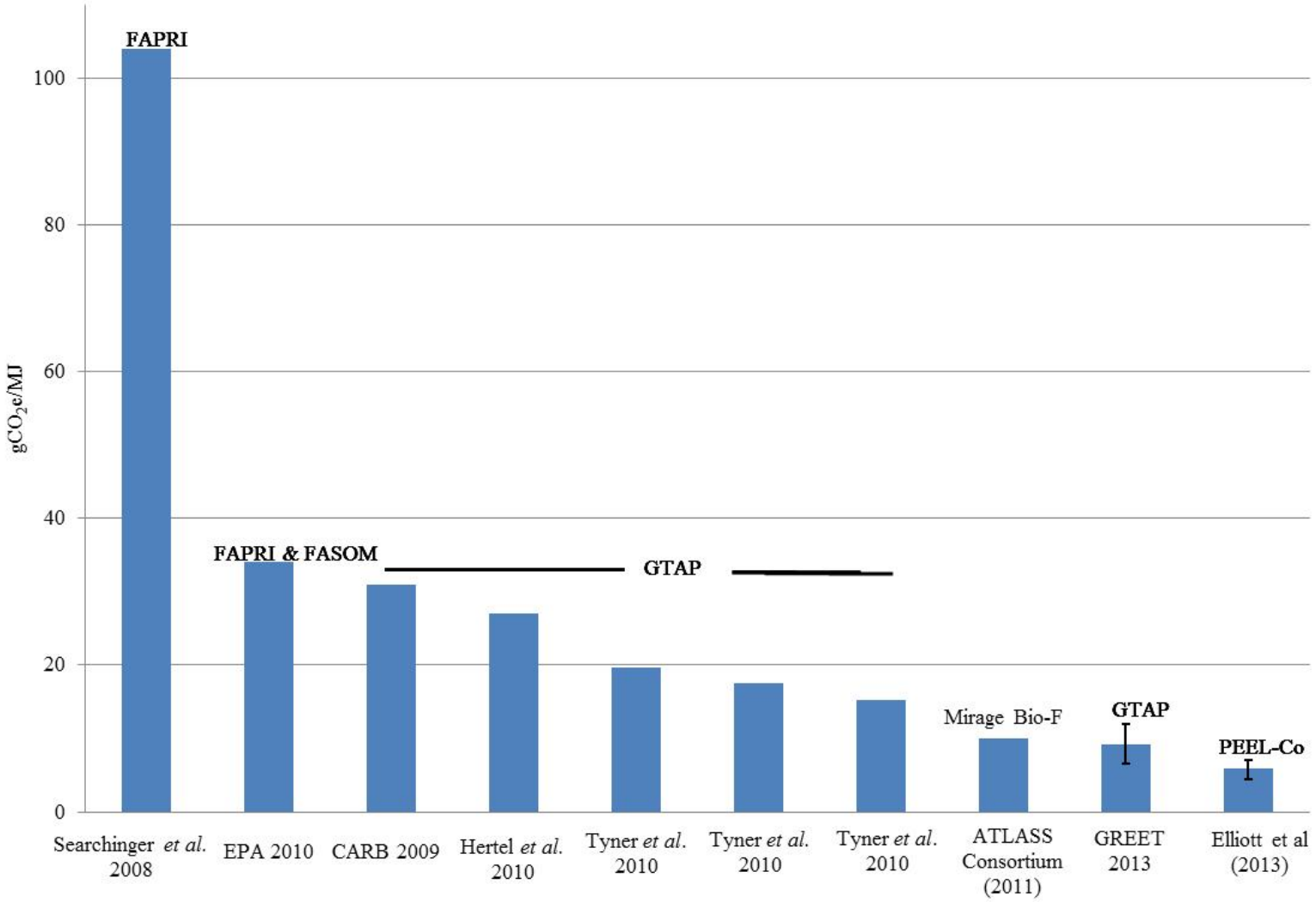
Wang M., et al., 2012, *Environ. Research Letters*

Estimating land-use change GHG emissions incorporates results from several models and data sets

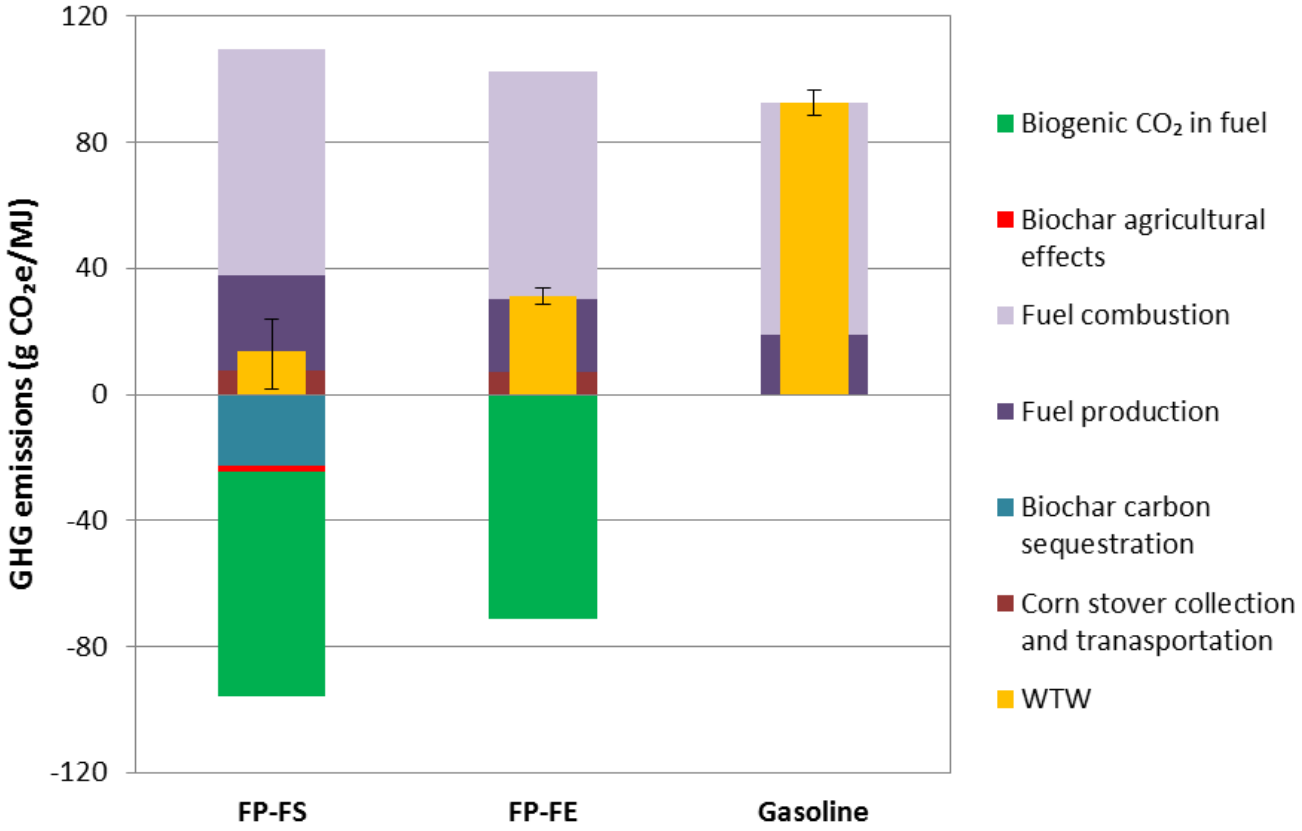
Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) in GREET



Estimates of LUC GHG emissions for the corn ethanol pathway



Fate of by-products affects main product GHG results: biochar from pyrolysis

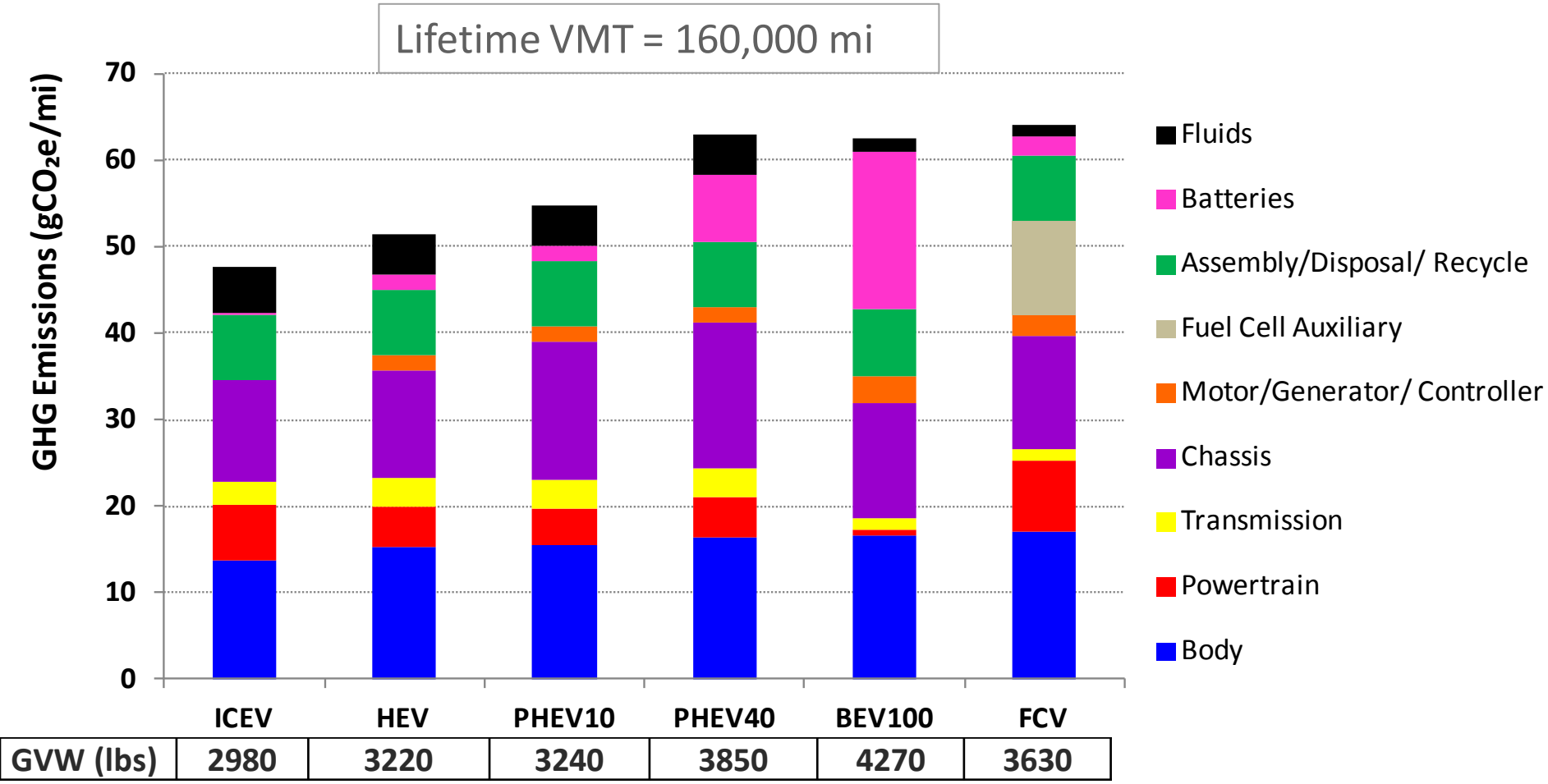


WTW GHG emissions for pyrolysis fuels compared to petroleum gasoline

FP-FS: Fast pyrolysis, pyrolysis oil upgraded for fuel, biochar applied to soil

FP-FE: Fast pyrolysis, pyrolysis oil upgraded for fuel, biochar combusted for electricity

Vehicle-cycle GHG emissions vary among vehicle propulsion technologies



	ICEV	HEV	PHEV10	PHEV40	BEV100	FCV
GVW (lbs)	2980	3220	3240	3850	4270	3630

For GREET model and technical reports, please visit

http://greet.es.anl.gov