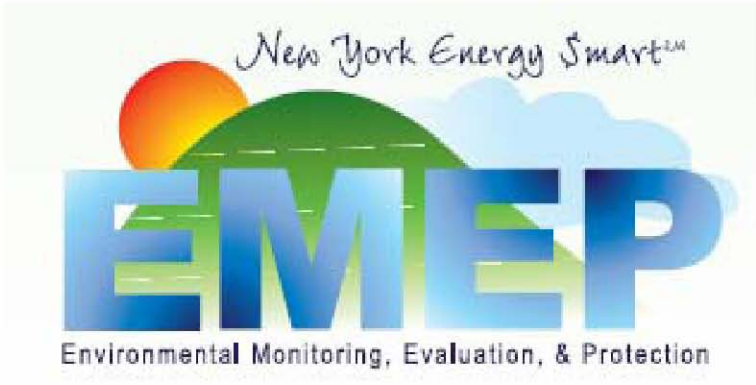

Ethanol/Biodiesel - Challenges and Opportunities

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Rochester Institute of Technology

November 16, 2007

Motivation and Approach

- Development of New York State energy policy requires understanding of the environmental impacts associated with the use of ethanol and biodiesel
  - Analyze the range of current understanding
  - Highlight sources of uncertainty and areas that need further research
  - Develop tools to help evaluate impacts in a policy context

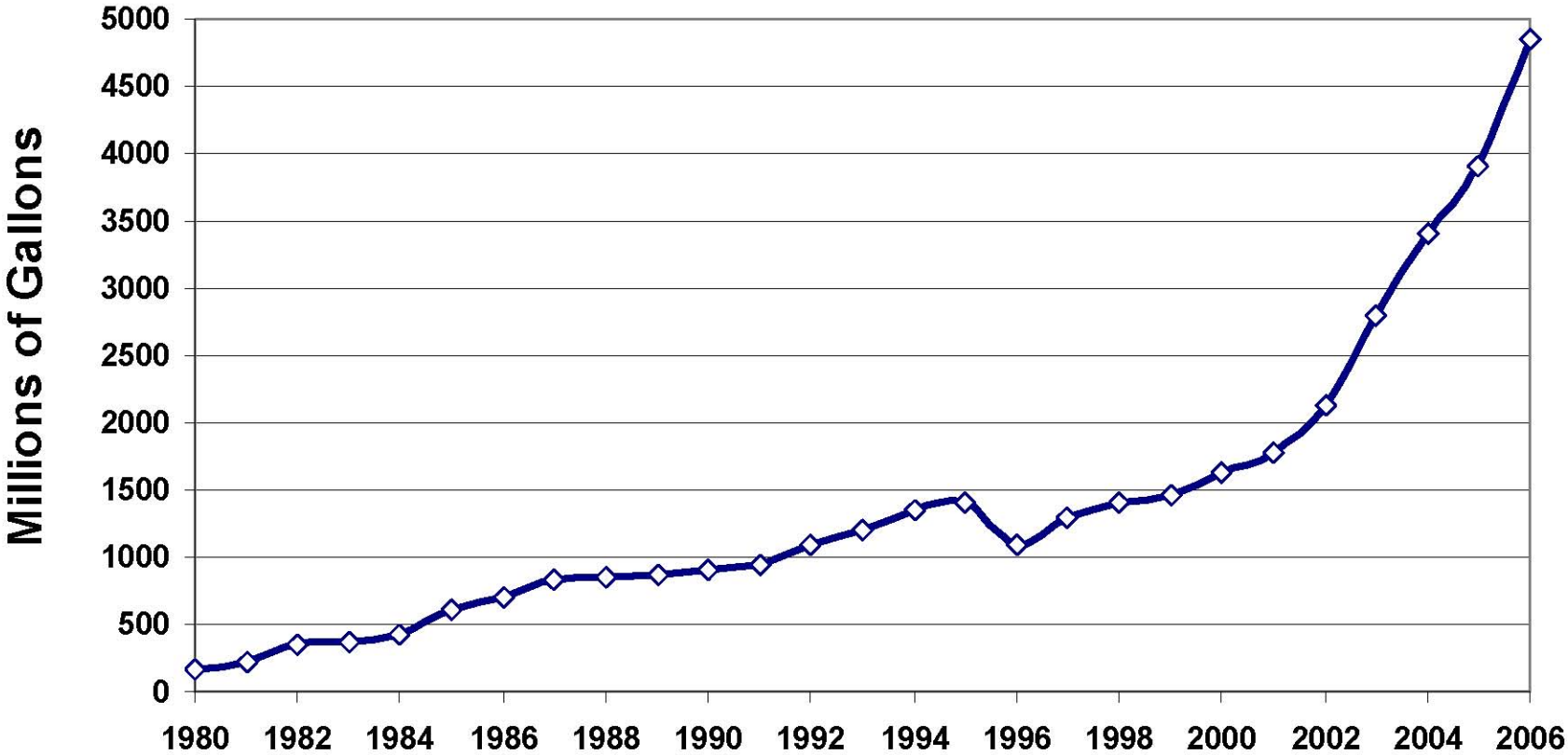
- Important issues to consider for ethanol and biodiesel
  - Net-Energy Ratio (NER)
  - Greenhouse Gas (GHG) Emissions
  - Regional and Local Air Pollutants
  - Land-use Impacts

- Approaches
  - Comprehensive literature review (being conducted by Pace Energy Project)
  - NY-GREET total fuel cycle analysis model (developed by Energy and Environmental Research Associates, LLC)

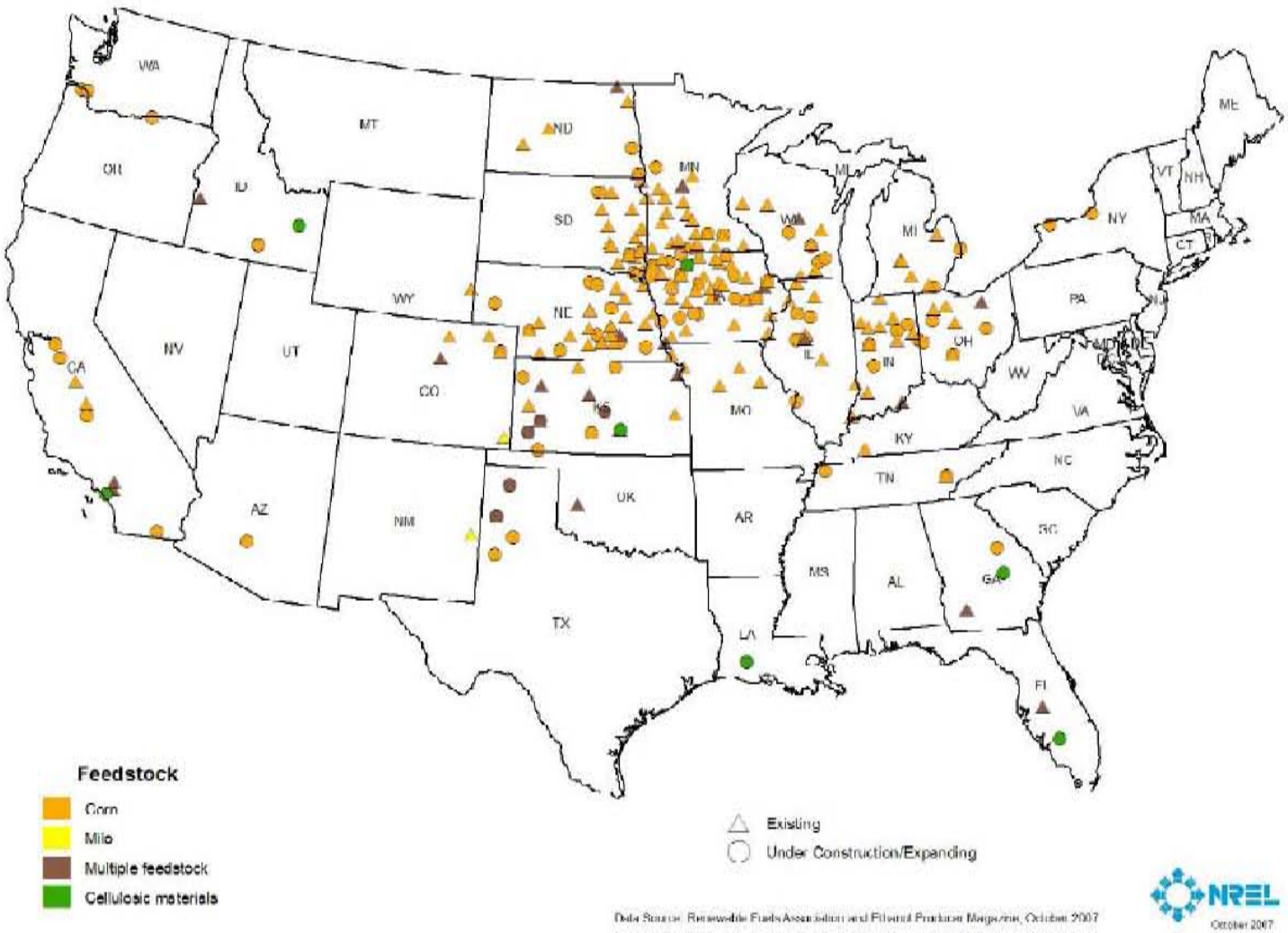
Agenda

1. U.S. Biofuels Markets
2. Scope of Existing Work
3. Energy and Environmental Metrics
4. Analysis Tool Development: NY-GREET
5. Modeling, Land-Use, and Other Issues
6. Summary and Next Steps

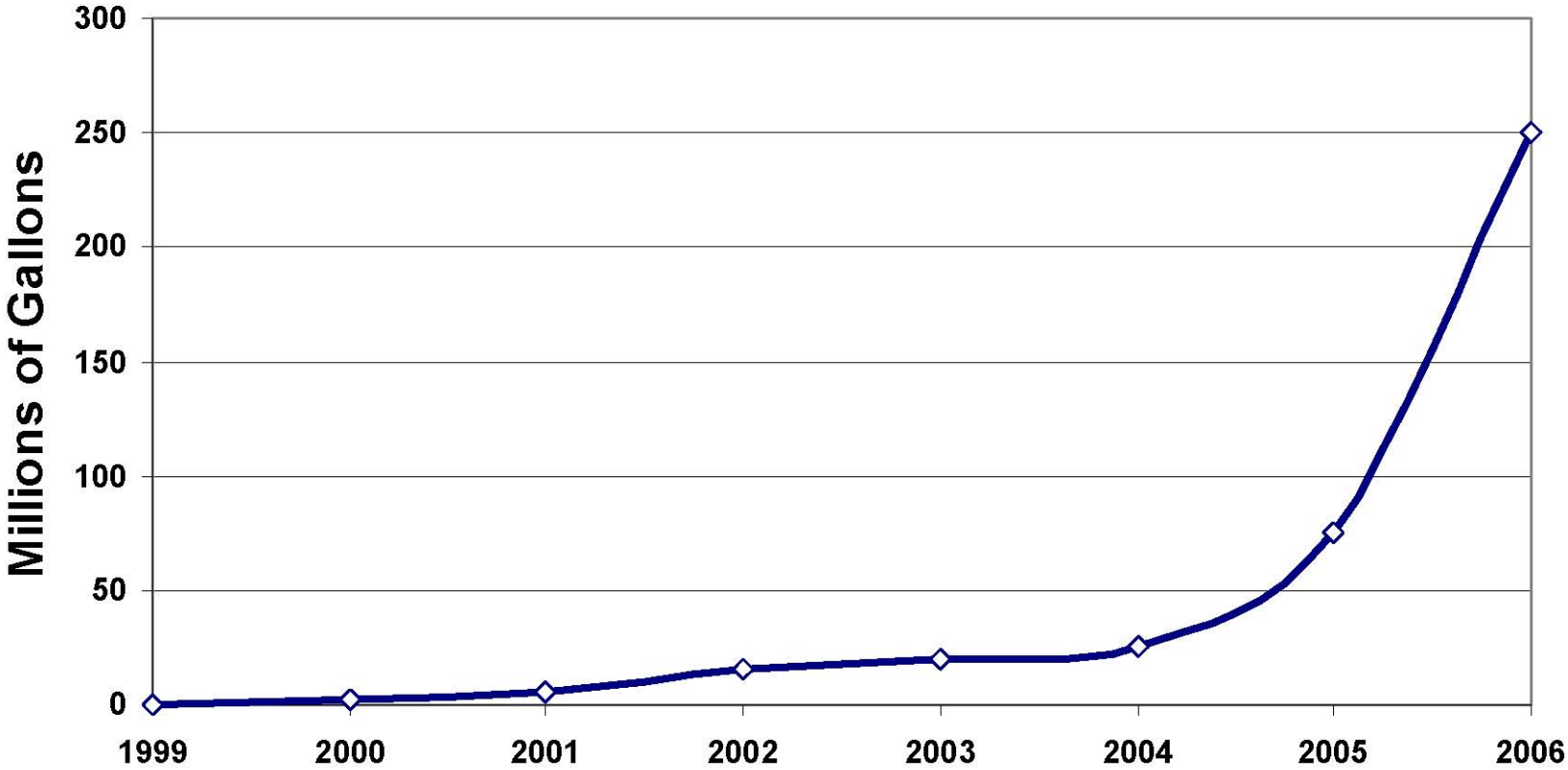
U.S. Ethanol Production



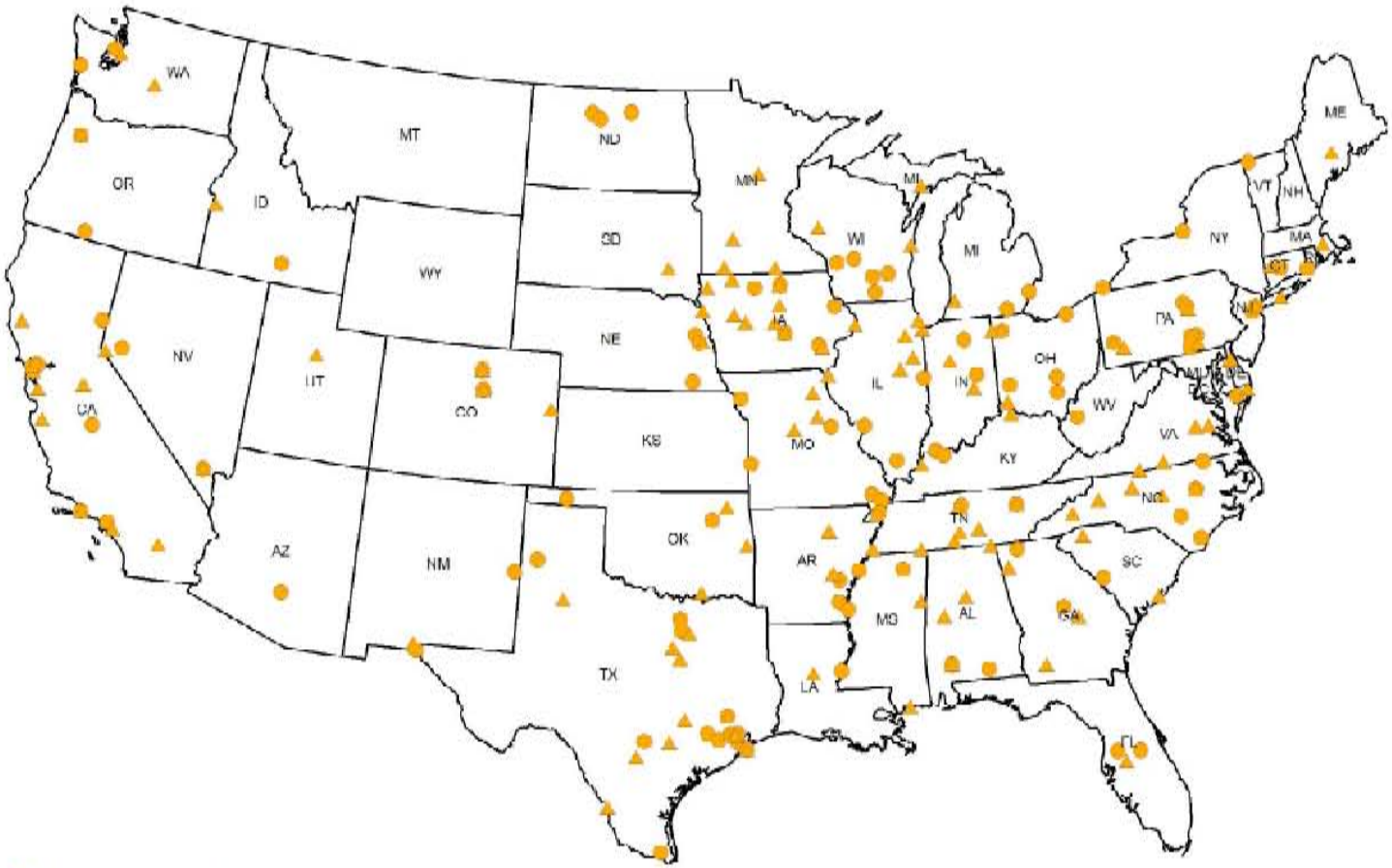
U.S. Ethanol Biorefineries



U.S. Biodiesel Production



U.S. Biodiesel Production Facilities



▲ Biodiesel Plant Existing

● Biodiesel Plant - Expanding/Under Construction

Data Source: National Biodiesel Board and Biodiesel Magazine, March 2007

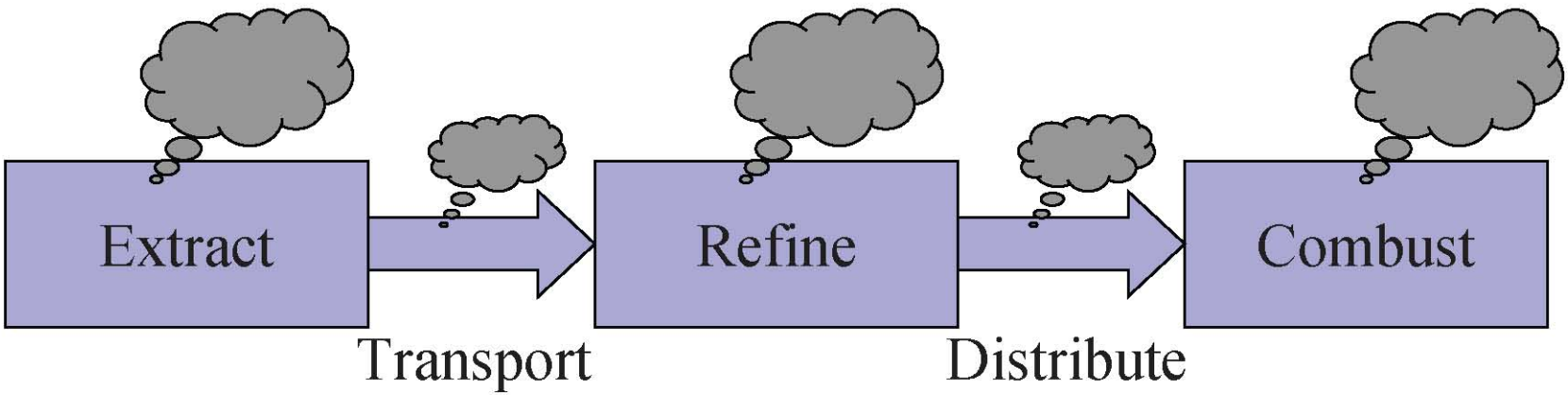
NREL

May 2007

Scope of Existing Work

- **Work focuses on understanding Total Fuel Cycle (TFC) impacts:**
  1. **Feedstock Production (farming, harvesting)**
  2. **Feedstock Transportation**
  3. **Fuel Production (Biorefinery)**
  4. **Fuel Transportation and Distribution**
  5. **Fuel Consumption**

A total-fuel cycle (TFC) analysis (also known as "well-to-wheels") accounts for energy consumption and emissions along the entire fuel cycle of a given fuel



Key Issues Under Review

- TFC Net-Energy-Ratio (NER)
  - Energy content of a fuel divided by the nonrenewable energy required to produce and deliver the fuel
  - Also called "energy return-on-investment“
  - Does not equal petroleum savings
  - NER is an overemphasized proxy metric
- TFC Greenhouse Gases (GHG)
  - Carbon dioxide (CO_2)
  - Nitrous oxide (N_2O)
  - Methane (CH_4)
  - Others
- TFC Air Pollutants
  - Criteria pollutants: particulate matter (PM) hydrocarbons (HC), carbon monoxide (CO), sulfur oxides (SOx), and nitrogen oxides (NOx), as well as an assessment of the species of HC present
  - Toxic products

Key Issues (cont'd)

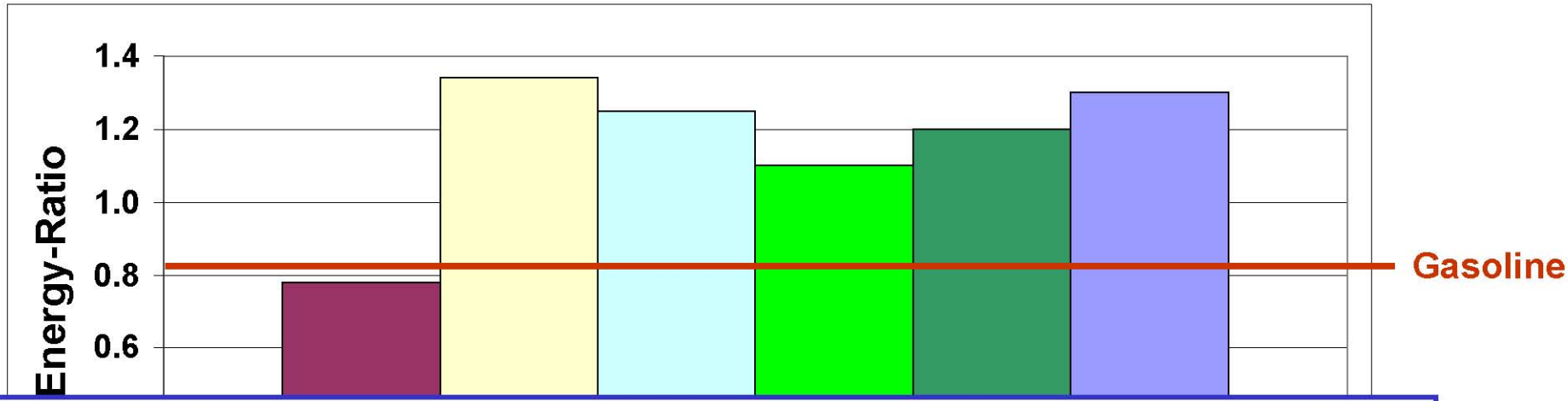
- Land-use
  - Habitat changes
  - Soil erosion / soil contamination
  - Fertilizer use and runoff
  - Water consumption and quality impacts
  - Pesticide use
- Socioeconomic Impacts
  - Impact on other agricultural sectors
  - Realities behind the Food vs. Fuel discourse

Ethanol Net-Energy Ratio

- **Perhaps the most contentious metric in the biofuels literature**

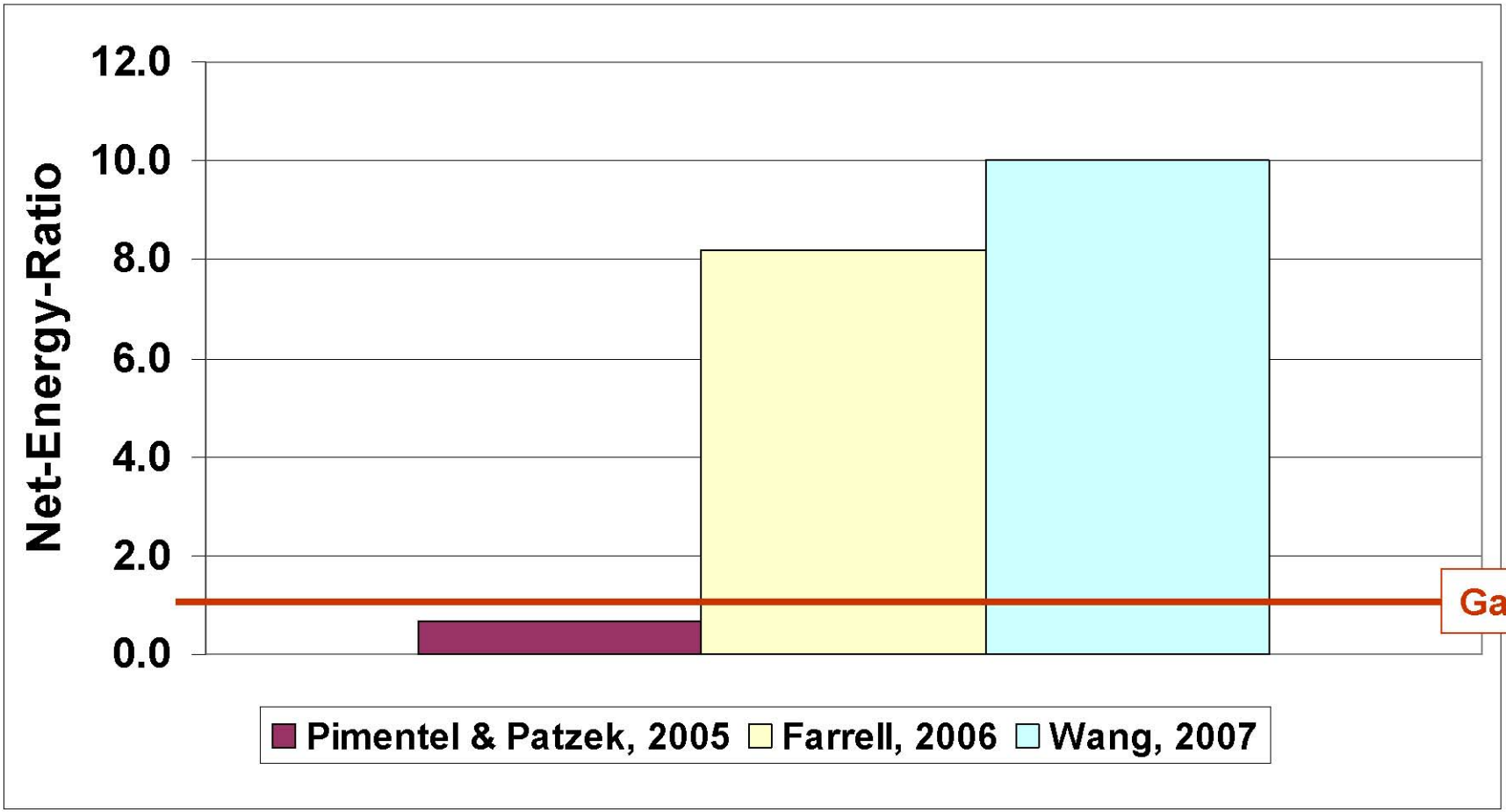
Feedstock	Net-Energy-Ratio
Corn (Coal)	0.78 - 1.3
Corn (Natural Gas)	
Corn (Biomass)	
Cellulosic - Mixed Grasses	0.68 - 10
Cellulosic - Wood Crops	
Cellulosic - Wood Wastes	
Cellulosic - Stover	

Corn-Ethanol Net-Energy Ratio



- All studies have different assumptions
  - Primary difference is process energy assumption
- Pimentel differs for several reasons:
  - Does not include co-products (US EPA recommends *displacement method*)
  - Fertilizer usage is significantly higher than other studies
  - Accounts for energy embodied in farm labor food consumption

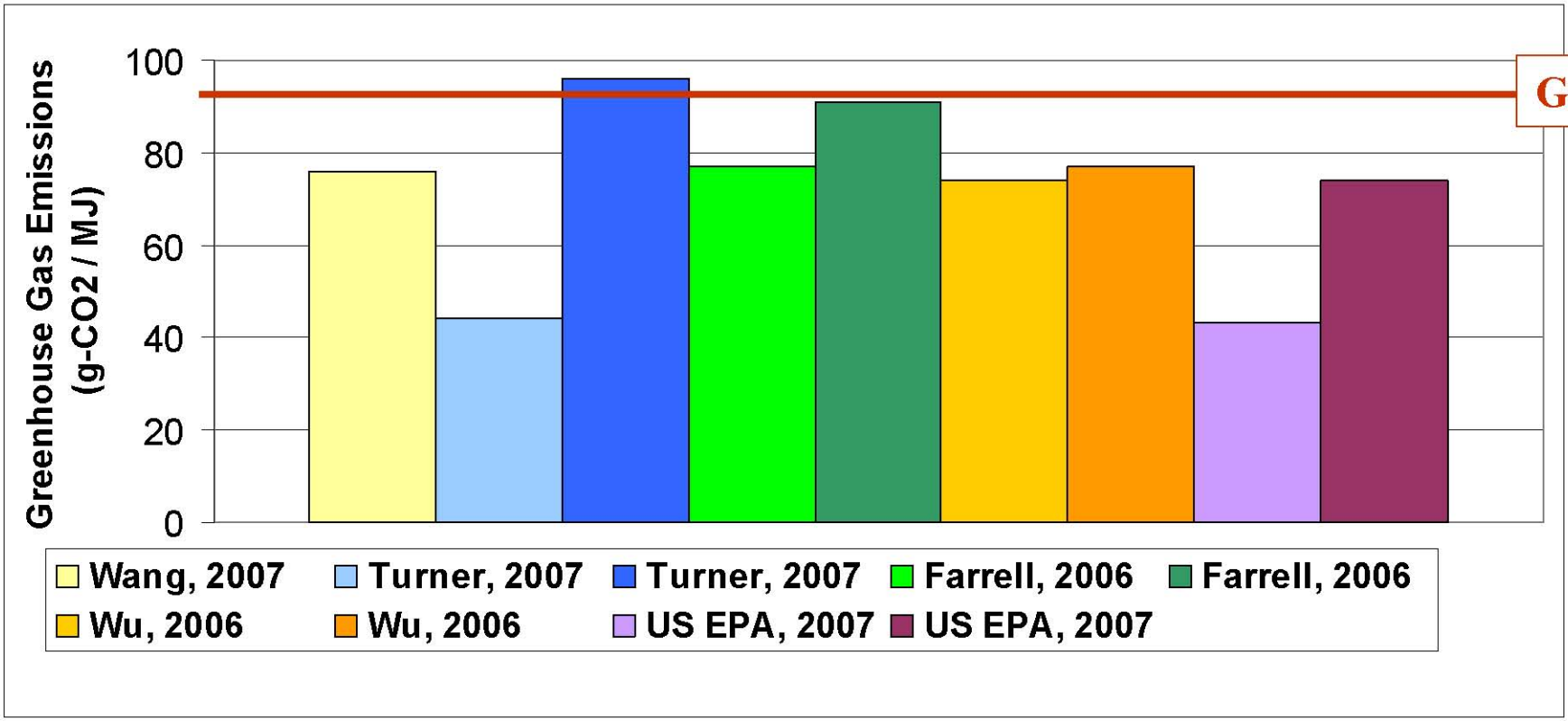
Cellulosic-Ethanol Net-Energy Ratio



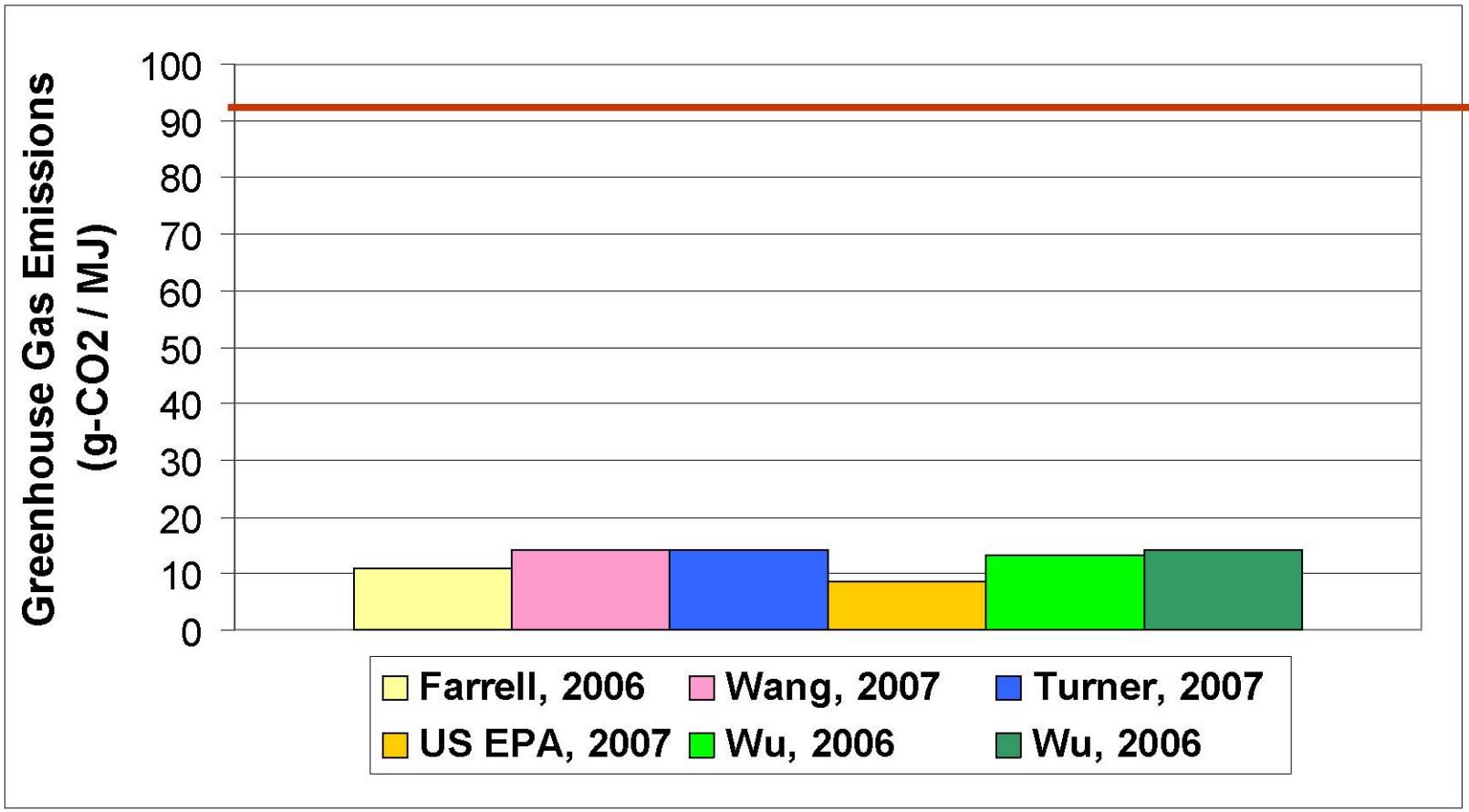
Ethanol Greenhouse Gases

Feedstock	Greenhouse Gas Emissions (g CO2eq/MJ)
Corn (Coal)	43 - 96
Corn (Natural Gas)	
Corn (Biomass)	
Cellulosic - Mixed Grasses	8.6 - 14
Cellulosic - Wood Crops	
Cellulosic - Wood Wastes	
Cellulosic - Stover	

Corn-Ethanol Greenhouse Gases



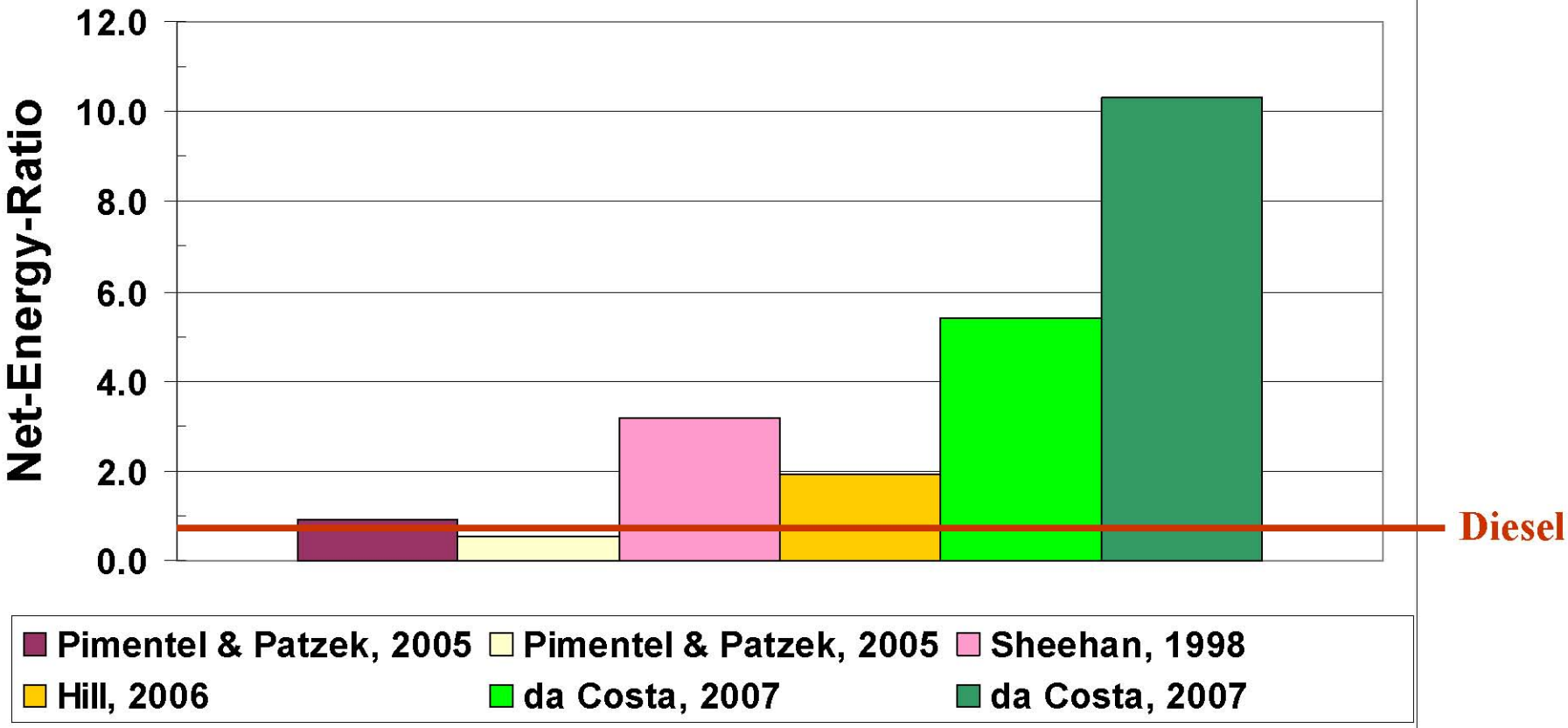
Cellulosic-Ethanol Greenhouse Gases



Biodiesel Net-Energy Ratio

Feedstock	Net-Energy-Ratio
Animal Fats / Used Cooking Grease	–
Canola/Soy/Sunflower	0.52 - 3.2
Palm Oil (Tropical)	5.4 - 10

Biodiesel Net-Energy Ratio



Biodiesel Greenhouse Gases

Feedstock	Greenhouse Gas Emissions (g CO2eq/MJ)
Animal Fats / Used Cooking Grease	30, 33
Canola/Soy/Sunflower	
Palm Oil (Tropical)	

Petroleum Diesel Greenhouse Gas Emissions: 92 g CO2eq/MJ

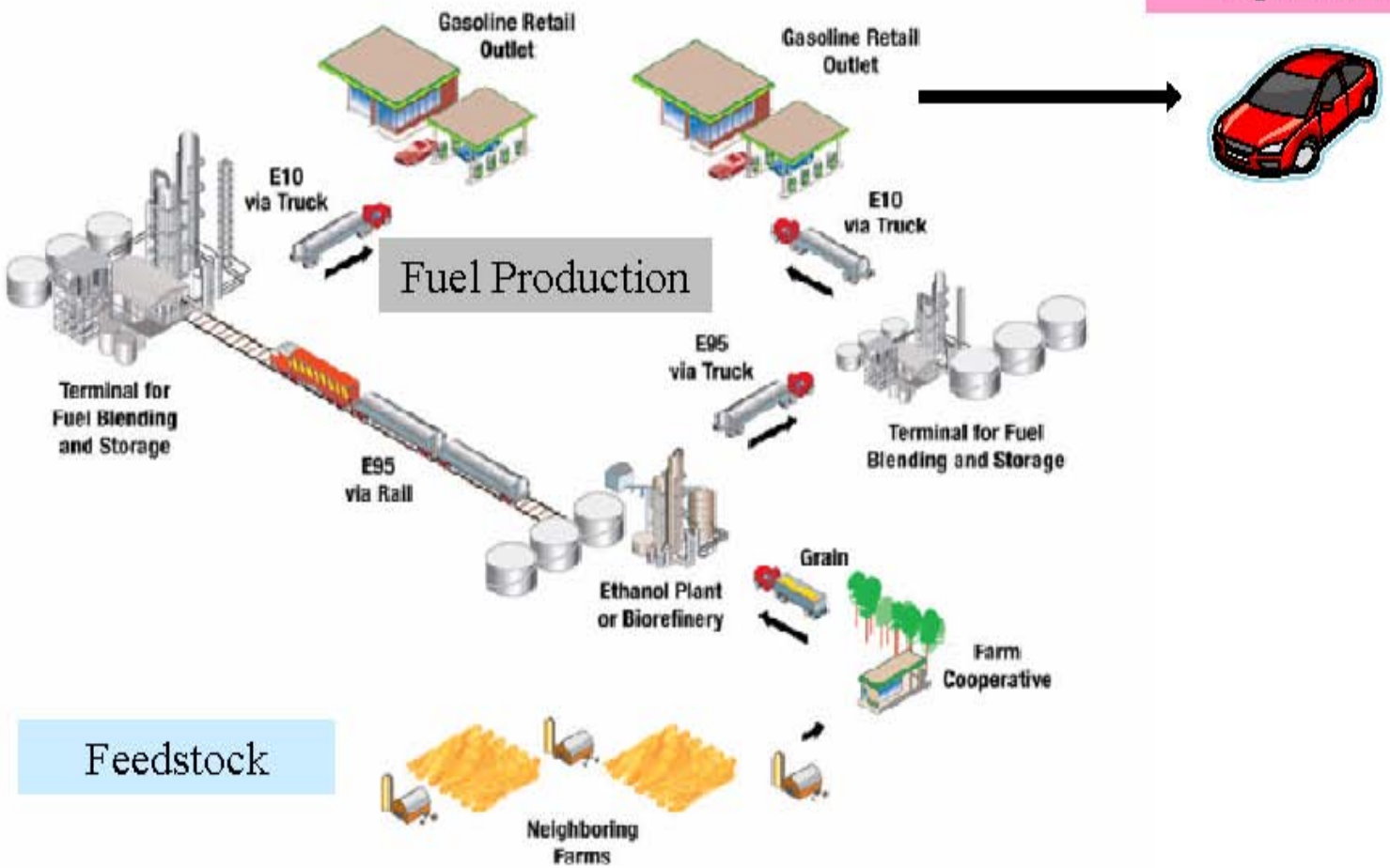
NY-GREET Model: Background

- *N*ew *Y*ork *G*reenhouse Gas, *R*egulated *E*missions, and *E*nergy Use in *T*ransportation Model
- Based on GREET model developed at ANL
- W2W for near-term and long-term technologies
- EXCEL-based model
- Output: per-mile energy, petroleum, and emissions
- GHGs and criteria pollutants included
- Developed by Energy and Environmental Research Associates, LLC

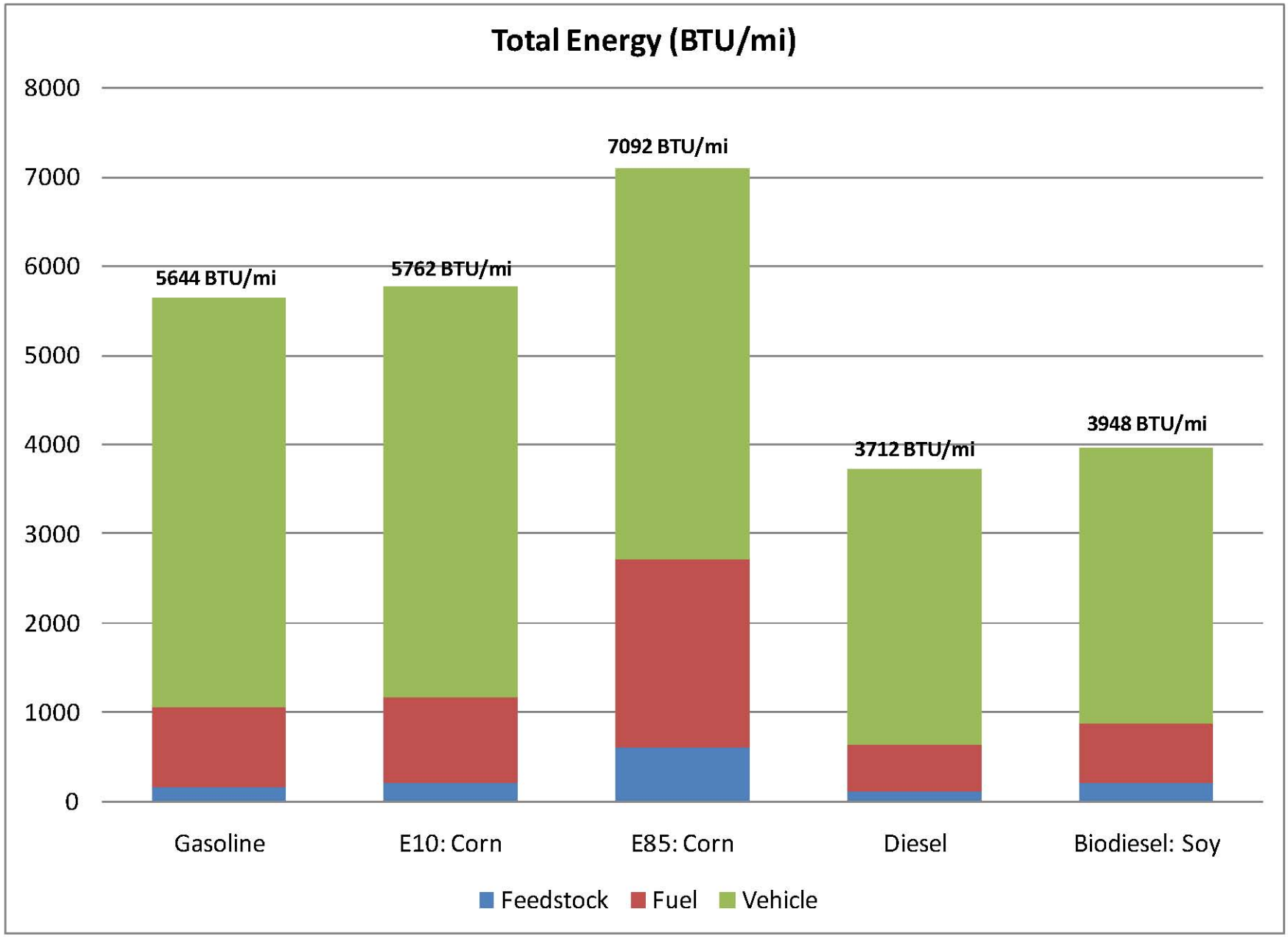
NY-GREET Model (cont'd)

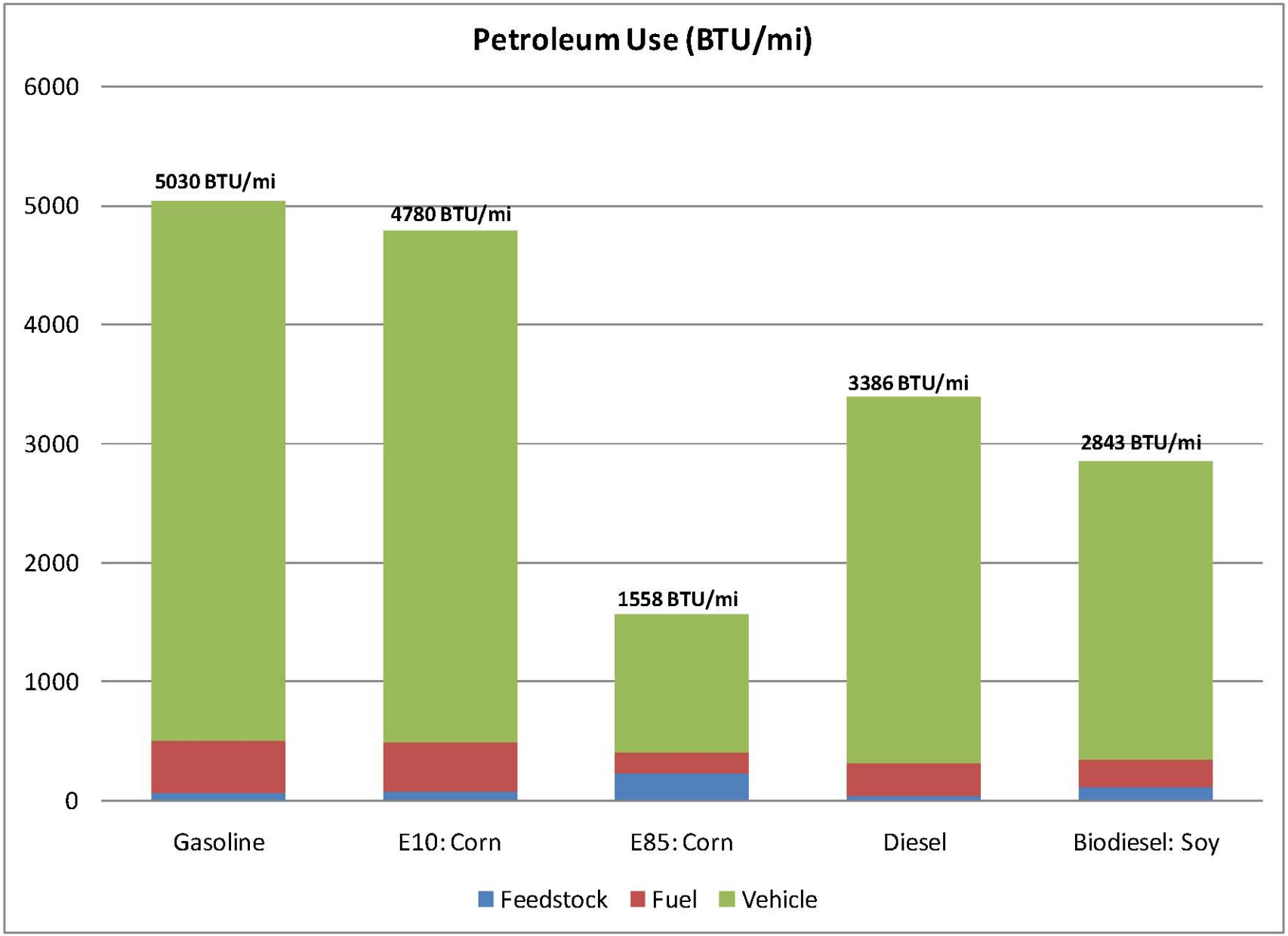
- Only analyzes light-duty vehicles
- Uses national and state assumptions (as appropriate)
  - Combustion processes
  - Origination of feedstock
  - Transportation of feedstock and fuel
  - Other state data as available
- Methodology is the recognized "gold standard"
- NY is only the second state (after CA) to have its own GREET model (original GREET has *some* CA values, but NY-GREET is more comprehensive and state-specific)

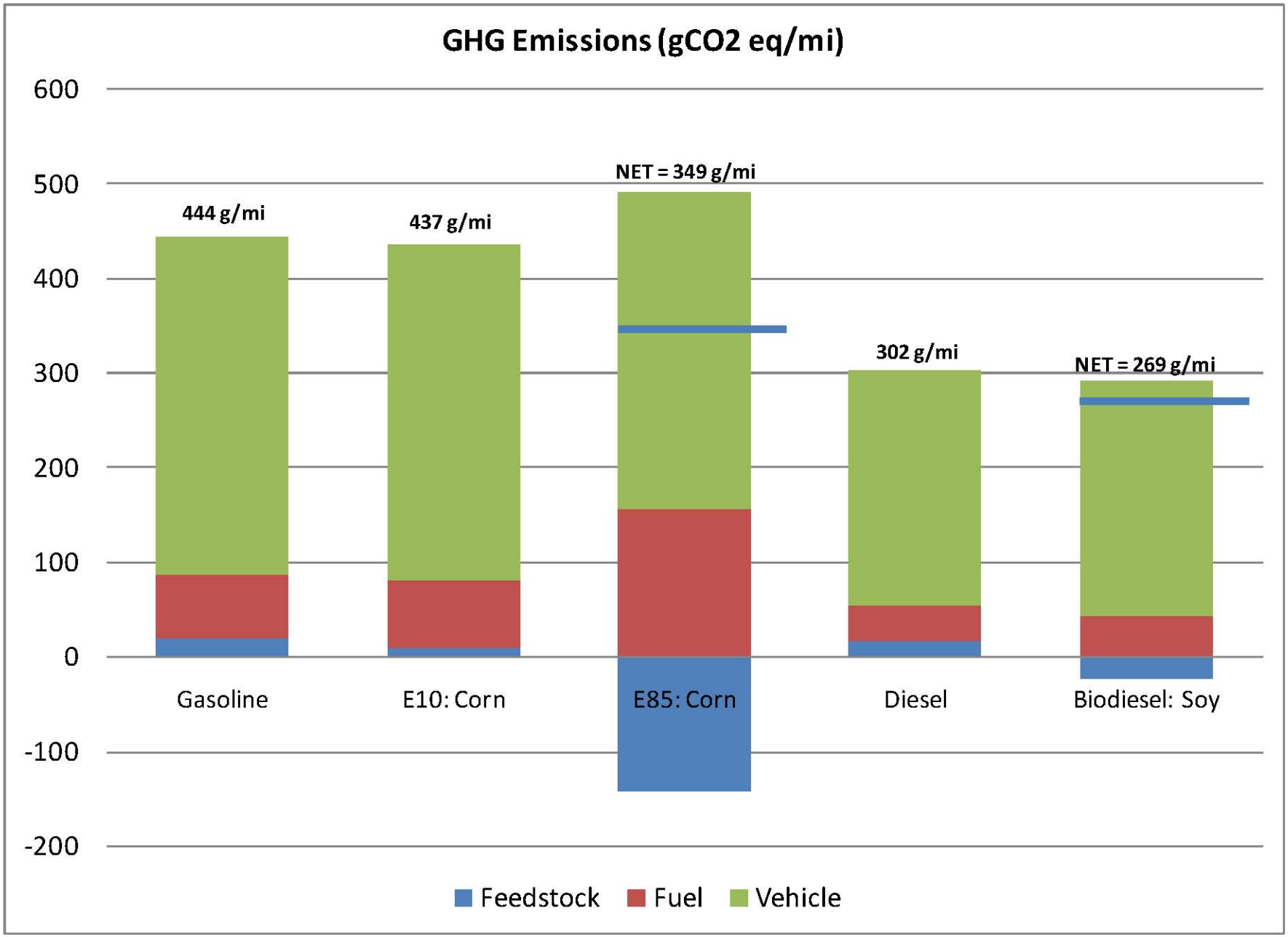
1. Rail and Truck Ethanol Distribution System



Source: National Bioenergy Center, National Renewable Energy Laboratory; E95 is Fuel Ethanol (200-proof alcohol denatured with 5 percent natural gasoline.)


Total Energy (BTU/mi)
8000
7000
6000
5000
4000
3000
2000
1000
0
5644 BTU/mi
5762 BTU/mi
7092 BTU/mi
3712 BTU/mi
3948 BTU/mi
Gasoline
E10: Corn
E85: Corn
Diesel
Biodiesel: Soy
Feedstock
Fuel
Vehicle


Petroleum Use (BTU/mi)
6000
5000
4000
3000
2000
1000
0
5030 BTU/mi
4780 BTU/mi
1558 BTU/mi
3386 BTU/mi
2843 BTU/mi
Gasoline
E10: Corn
E85: Corn
Diesel
Biodiesel: Soy
Feedstock
Fuel
Vehicle


GHG Emissions (gCO2 eq/mi)
600
500
400
300
200
100
0
-100
-200
444 g/mi
437 g/mi
NET = 349 g/mi
302 g/mi
NET = 269 g/mi
Gasoline
E10: Corn
E85: Corn
Diesel
Biodiesel: Soy
Feedstock
Fuel
Vehicle

Ethanol Air Pollutants

	E85 RELATIVE TO CONVENTIONAL GASOLINE	E85 RELATIVE TO REFORMULATED GASOLINE	E10 RELATIVE TO CONVENTIONAL GASOLINE
EMISSIONS	% DIFFERENCE	% DIFFERENCE	% DIFFERENCE
PM	-20	-	-81 to -4
CO	-40 to +31	-	-50 to -1
HC	-30 to -15	-15 to +18	-38 to -2
NOx	-20 to -10	-40 to -34	-35 to +11
TOXICS:			
benzene (C6H6)	-87 to -50	-65 to -62	-27
1,3-butadiene (C4H6)	-79 to -13	-68 to 0	-19
peroxyacetyl nitrate (PAN)	-	-	-
acetaldehyde	+1430 to +2149	+2030 to +4340	+89 to +180
formaldehyde (HCHO)	+240 to +254	+41 to +92	+6 to +28

Biodiesel Air Pollutants

B20 RELATIVE TO NO. 2 DIESEL - TRANSPORTATION	
EMISSIONS	% DIFFERENCE
PM	-36 to 0
CO	-38 to 0
HC	-36 to 0
NOx	-10 to +14
TOXICS:	
"Air Toxics"	-20 to -3
Mutagenicity	-20
benzene (C6H6)	
1,3-butadiene (C4H6)	
peroxyacetyl nitrate (PAN)	
acetaldehyde (CH3CHO)	
formaldehyde (HCHO)	
Acrolein	
Ethylbenzene	-44.9
n-Hexane	-48.7
Naphthalene	-13.8
Styrene	-3.7
Toluene	-
Xylene	-12.3

B20 RELATIVE TO NO. 2 DIESEL - HEATING	
EMISSIONS	% DIFFERENCE
PM	-13
CO	-10 to 0
NOx	-20 to -10

Modeling Issues

- Causes of model uncertainty
  - Feedstock type
  - Vehicle model and year
  - Emissions control equipment
  - Test driving cycles (speed, acceleration rates, time at idle, distance, etc.)
  - Variations in driving conditions (such as temperature and humidity)
  - Feedstock production efficiency
  - Fuel processing efficiency
- Land-use issues
  - Significant uncertainty surrounding land-use conversion assumptions for energy crops
  - EPA: accounts for 1% of total corn-ethanol GHG emissions
  - Highly debated issue
- Geospatial analysis
  - Upstream v. downstream locations
- Pollutant speciation
  - Toxicity of emissions

Land-Use Issues

- **Feedstock Production**
  - Habitat changes affect local biodiversity
  - Difficult to generalize impacts (such as soil erosion and soil/water contamination) as cultivation practices vary (monoculture, rotation, soil tilling, irrigation, fertilizer/pesticide use)
- **Fuel Processing**
  - Can require significant water resources (3-6 L water for 1 L EtOH)
  - Effluent must be processed
- **Biofuel Transportation and Storage**
  - Leaks and spills risk to soil as well as ground and surface water

Land-Use Issues

Fuel	Feedstock	Yield (liters/ha)	Nitrogen Application (kg/ha/yr)	Nitrogen Runoff (kg/ha/yr)	Soil Erosion (tons/ha/yr)
Corn-ethanol	Corn (starch)	2,500 - 4,800	140 -150	79	22
Cellulosic Ethanol	Switch grass	2,200 - 2,300	50	10	0.2 - 2
	Wood crops	-	-		2 - 4
Biodiesel	Soy	350 - 540	5.7 - 20	16	-
	Canola (Rapeseed)	1,000-1,300	-	-	-
	Sugar cane				
	Palm Oil				

Type of cultivation	Nitrogen Application (kg/ha/yr)
Continuous corn	150
Corn-Corn-Soybeans	104
Corn-Sobeans-Wheat	82
Corn-Soybeans	76
Corn-Soybeans-Soybeans	55

Summary and Next Steps

- Literature review process will continue, including interviews with researchers
- Currently evaluating how NY-GREET can be used for "NY-based" studies
  - Alternative fuel analysis
  - Sensitivity of output to data inputs
  - Improve data quality
  - Incorporate stochastic elements
  - Expand to other vehicle types (e.g., heavy-duty vehicles)
  - Expand to other modes, including goods movement (rail? marine? air?)
- Need for more studies to fill data gaps – characterize emissions (tailpipe and evaporative) associated with the use of biofuels in the full range of applications
- Explore future standards for feedstock cultivation and processing to ensure biofuel production is carried out on a sustainable basis
- Biodiesel offers multiple benefits, with 'bioheat' a winner
- Ethanol from some production pathways has positive attributes and these should be evaluated and optimized. Formation of aldehydes presents regulatory not technological challenge.

Questions and Contact Information

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