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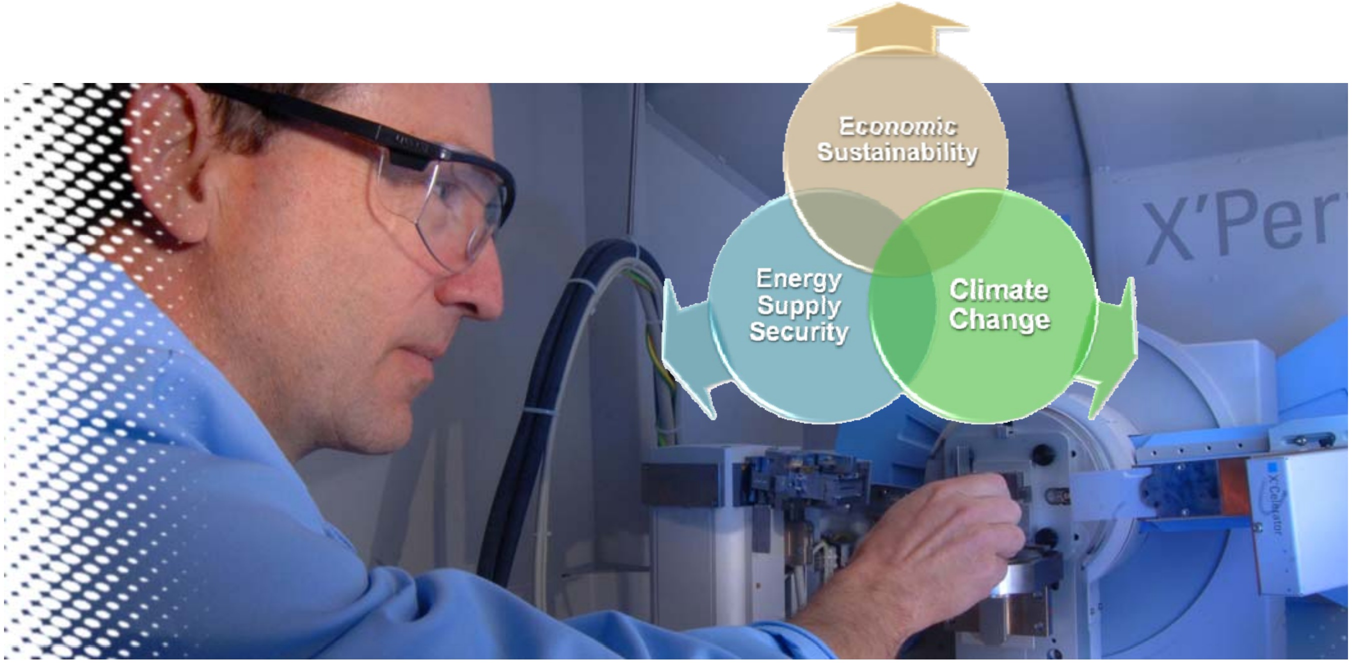

Life Cycle Analysis: Ethanol from Biomass

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U.S. DEPARTMENT OF ENERGY

Agenda

- Background
- LCA&C Design Basis
- Life Cycle Assessment (LCA) Environmental Results
- Life Cycle Cost (LCC) Results
- Life Cycle Land and Water Results
- Conclusion - Lessons Learned

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Background

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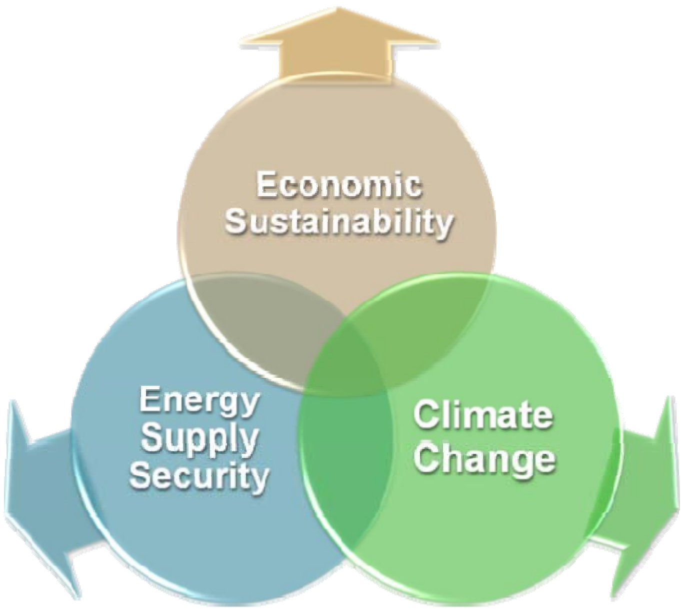
Background

The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has been evaluating the production of energy in both the renewable and non-renewable sectors for use in energy (heat and power) and liquid transportation fuels.

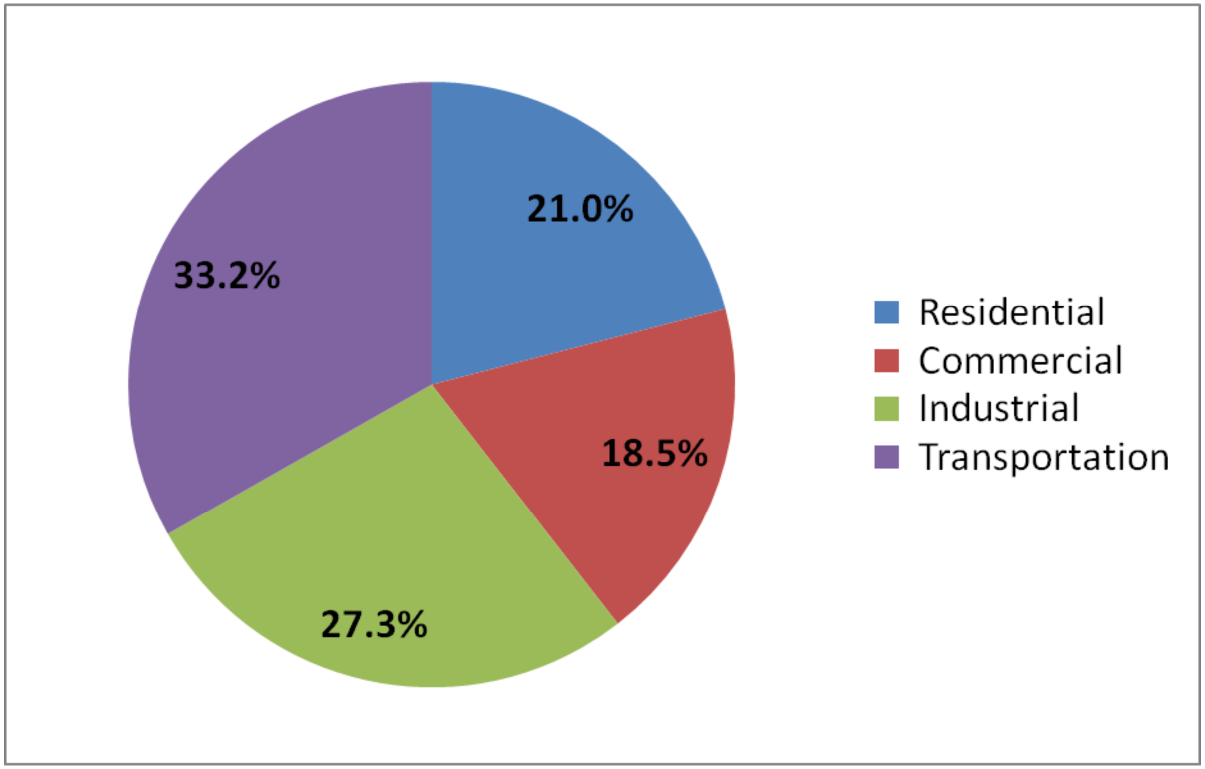


In order to better inform stakeholders of the consequences of energy pathways, NETL is developing a standard method to perform environmental Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) analysis.

Background

Fossil-based transportation fuel is responsible for more carbon dioxide (CO_2) emissions than any other sector of the U.S. economy, accounting for 1/3 of total annual CO_2 emissions.

What effect will ethanol blends of 10% and 85% have on emissions in ICE vehicles?



Source: EIA; Emissions of Greenhouse Gases Report
http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html

Background

NETL is performing an independent life cycle assessment (LCA) and life cycle cost (LCC) analysis on a variety of ethanol production and end use pathways.

NETL modeled an expanded life cycle (LC) to include not only CO_2 emissions, but also to provide a balanced environmental LC perspective that includes:

- Greenhouse gas (GHG) emissions
- Resource energy consumption
- The release of criteria air pollutants (CAPs) and other air pollutants to the atmosphere
- The release of water pollutants
- The withdrawal and consumption of water from both surface and groundwater supplies
- The type and acreage of the land used

Background

For this study, four separate basis documents were used:

- EPA (2009a). *Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program*. U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division. http://www.epa.gov/otaq/renewablefuels/420d09001.pdf. EPA-420-D-09-001.

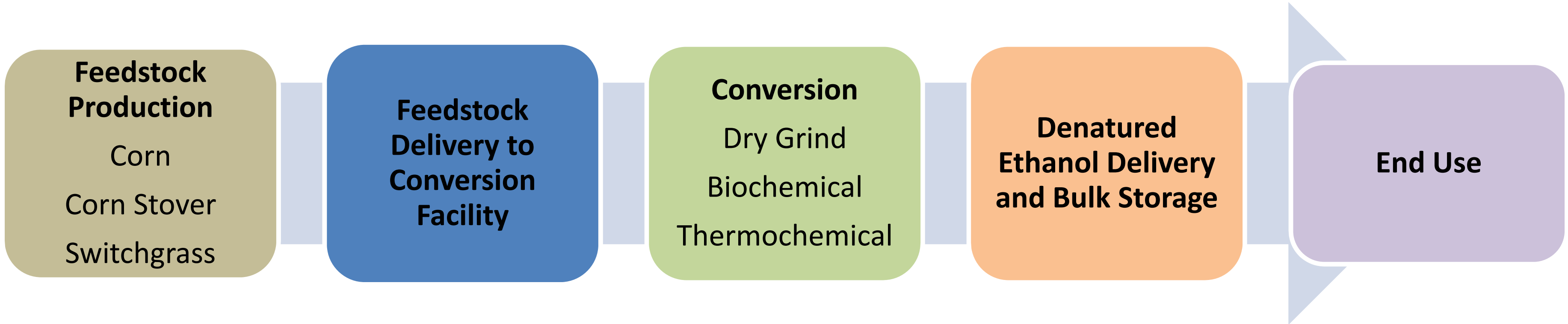
- EPA. (2009b). *Federal Register: Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program; Proposed Rule*. U.S. Environmental Protection Agency. http://www.epa.gov/otaq/renewablefuels/rfs2_1-5.pdf. 40 CFR Part 80.

- Aden, Andy, Ruth, M., Ibsen, K., *et al.*, (2002). *Lignocellulosic Biomass to Ethanol Process Design and Economic Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*. National Renewable Energy Laboratory. NREL/TP-510-32438.

- Phillips, S. D., Aden, Andy, Jechura, J., *et al.* (2007). *Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass*. National Renewable Energy Laboratory, Golden, CO. NREL/TP-501-41168.

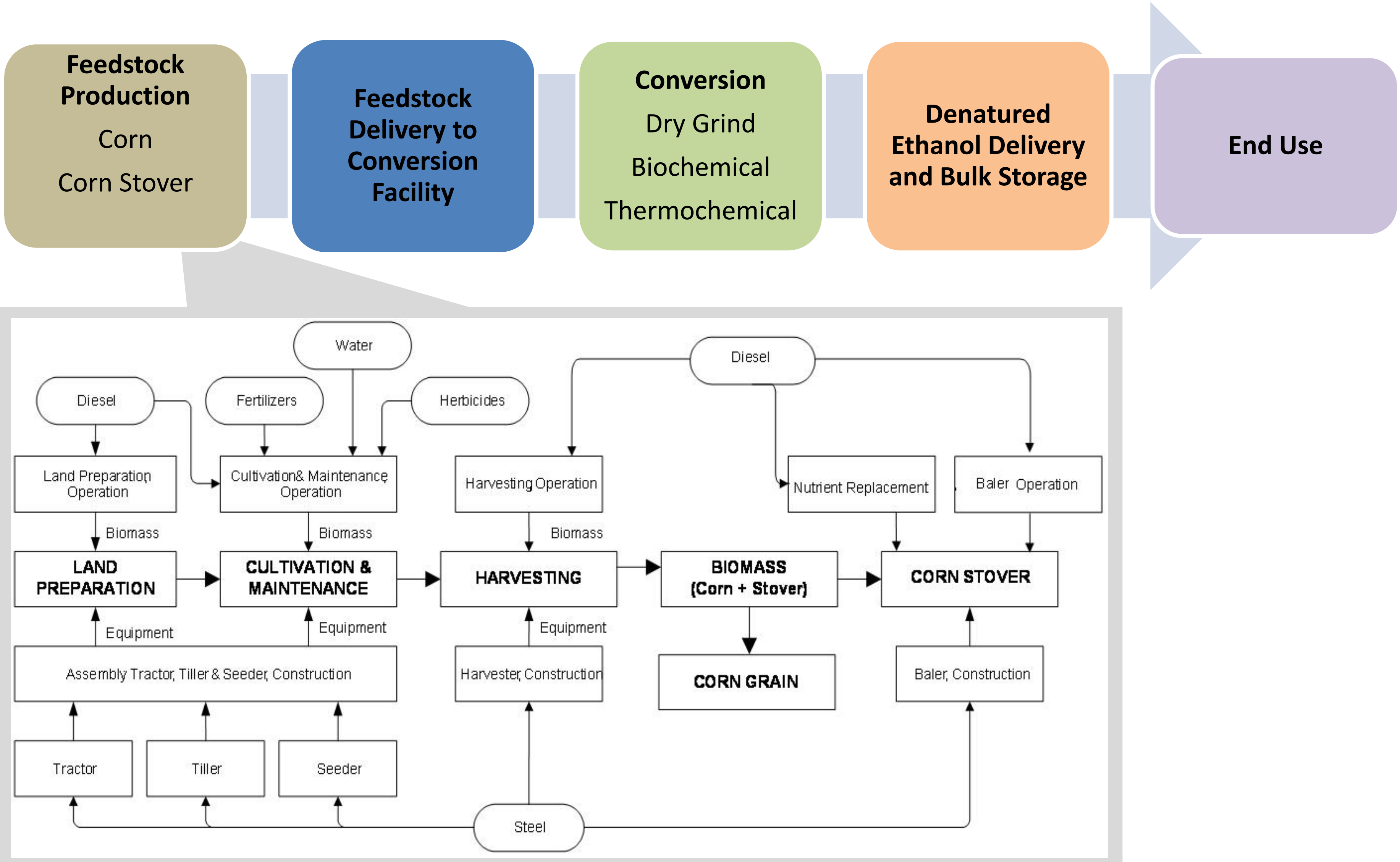
LCA & C Design Basis

Environmental System Boundary

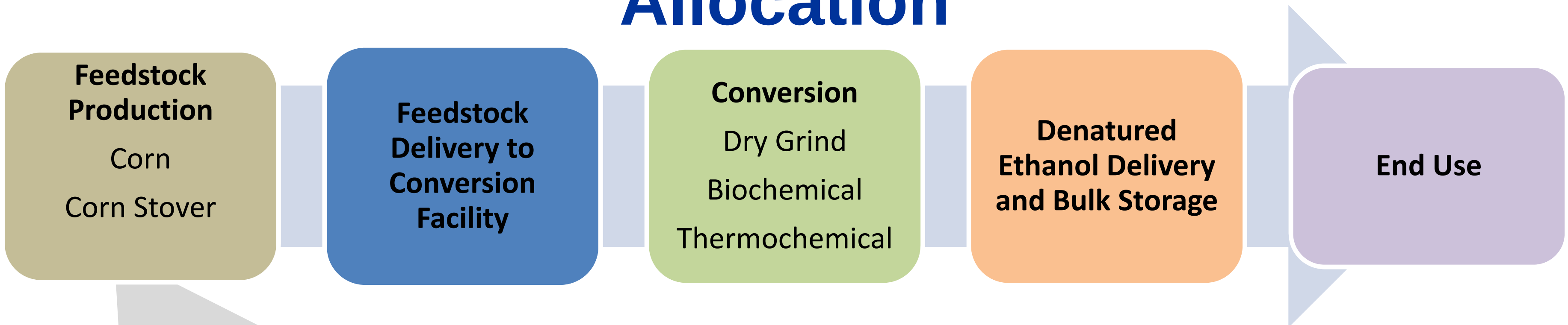


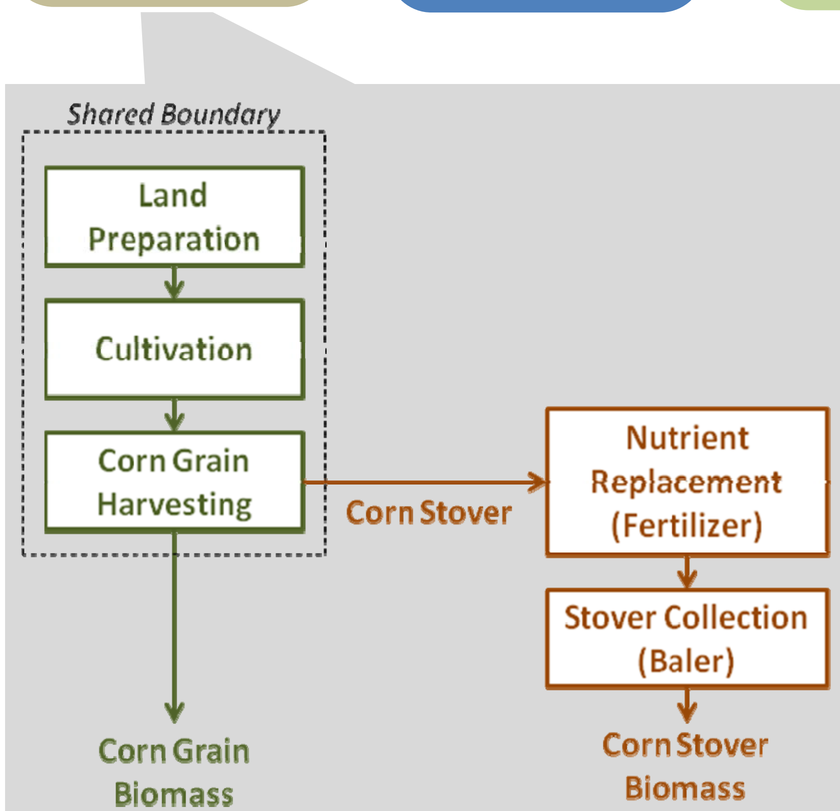
The functional unit of this study is the quantity of fuel that is necessary to produce one megajoule (MJ) lower heating value (LHV) of combustion energy to move a 2012 model passenger car with a conventional internal combustion engine (EPA, 2008). All results of this analysis are expressed on this basis.

Corn Grain and Stover Production Processes



Stover and Corn Grain Shared Boundary and Allocation





Co-product allocation

Scenarios that include the production of ethanol from corn stover assume that both corn grain and corn stover are viable fuel feedstocks, which makes co-product allocation necessary.

Co-product allocation is based on the relative yields and calorific values of corn grain and corn stover.

Corn Grain	Corn Stover
41%	59%

Switchgrass Production Processes

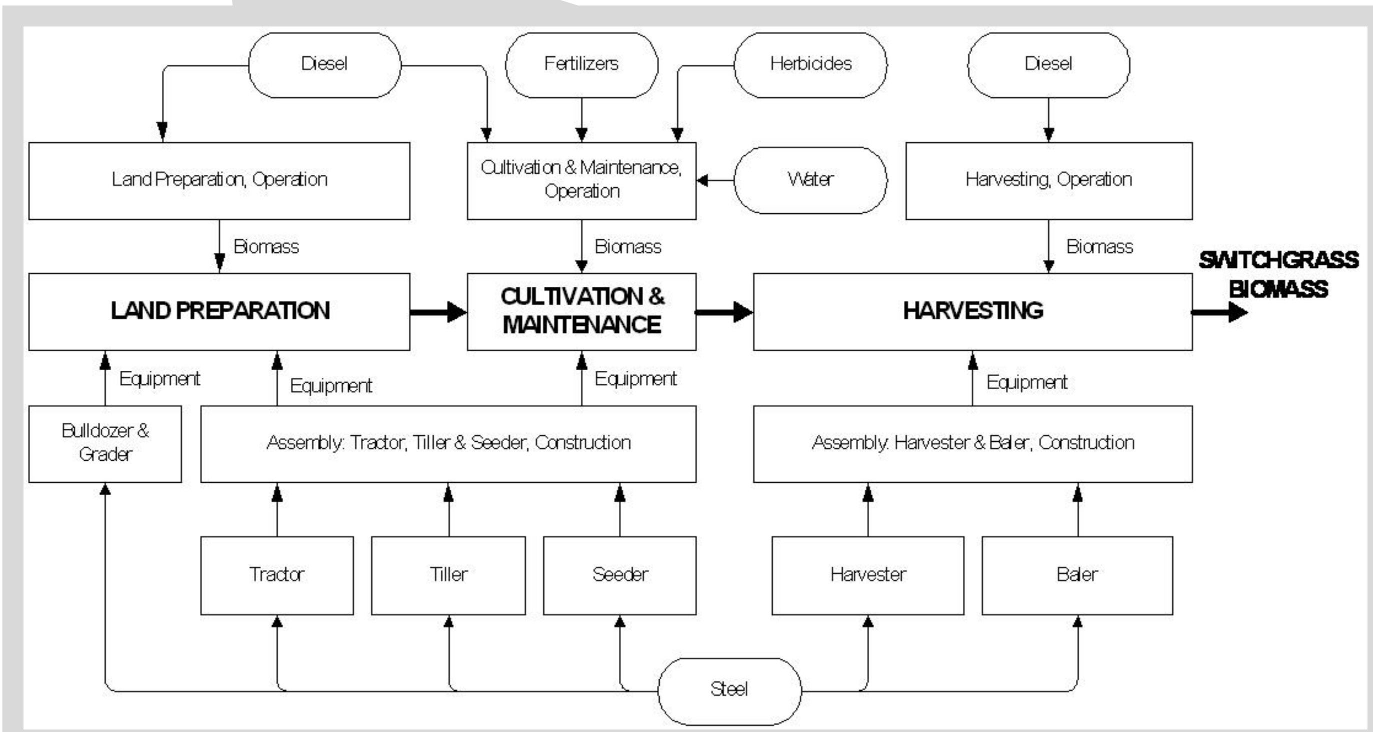
Feedstock Production
Switchgrass

Feedstock Delivery to Conversion Facility

Conversion
Biochemical
Thermochemical

Denatured Ethanol Delivery and Bulk Storage

End Use



Dry Grind Pathways to E10 and E85 Production

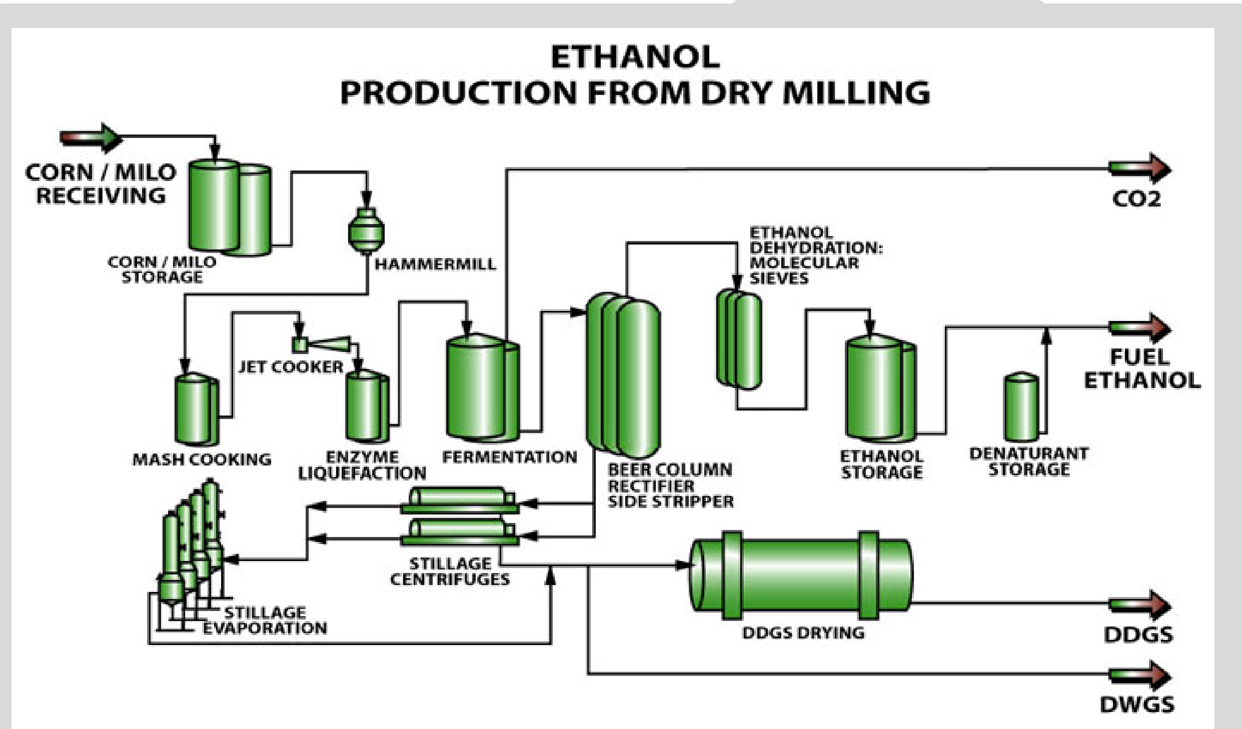
Feedstock Production
Corn
Corn Stover
Switchgrass

Feedstock Delivery to Conversion Facility

Conversion
Dry Grind

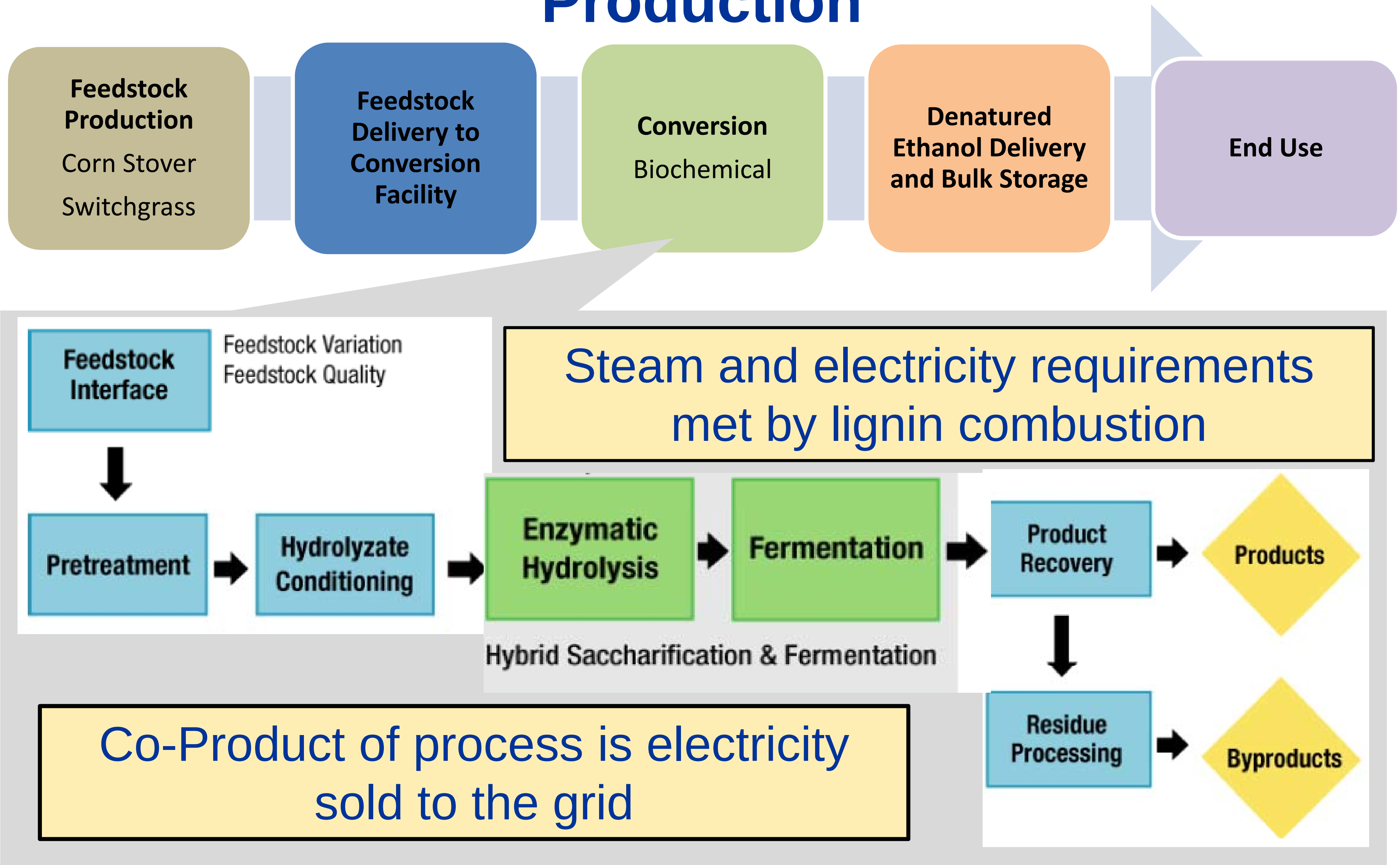
Denatured Ethanol Delivery and Bulk Storage

End Use

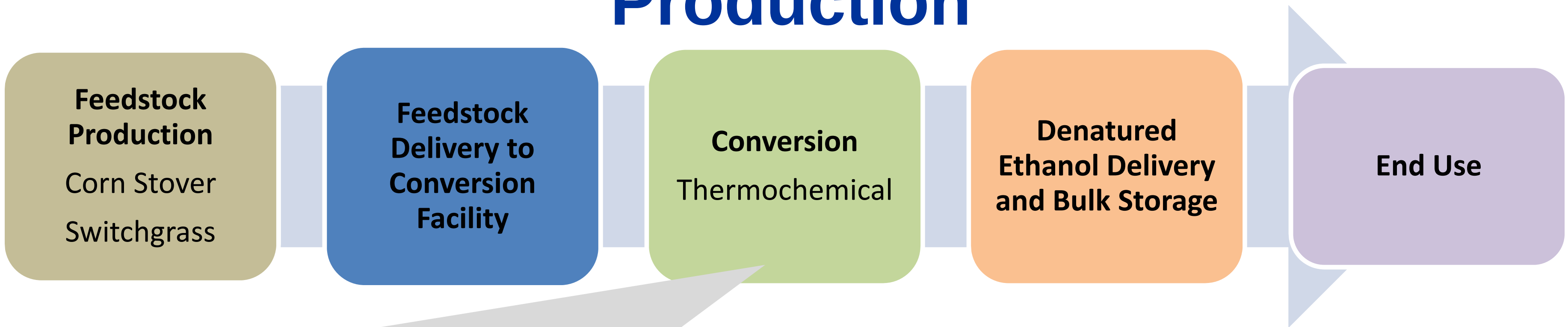


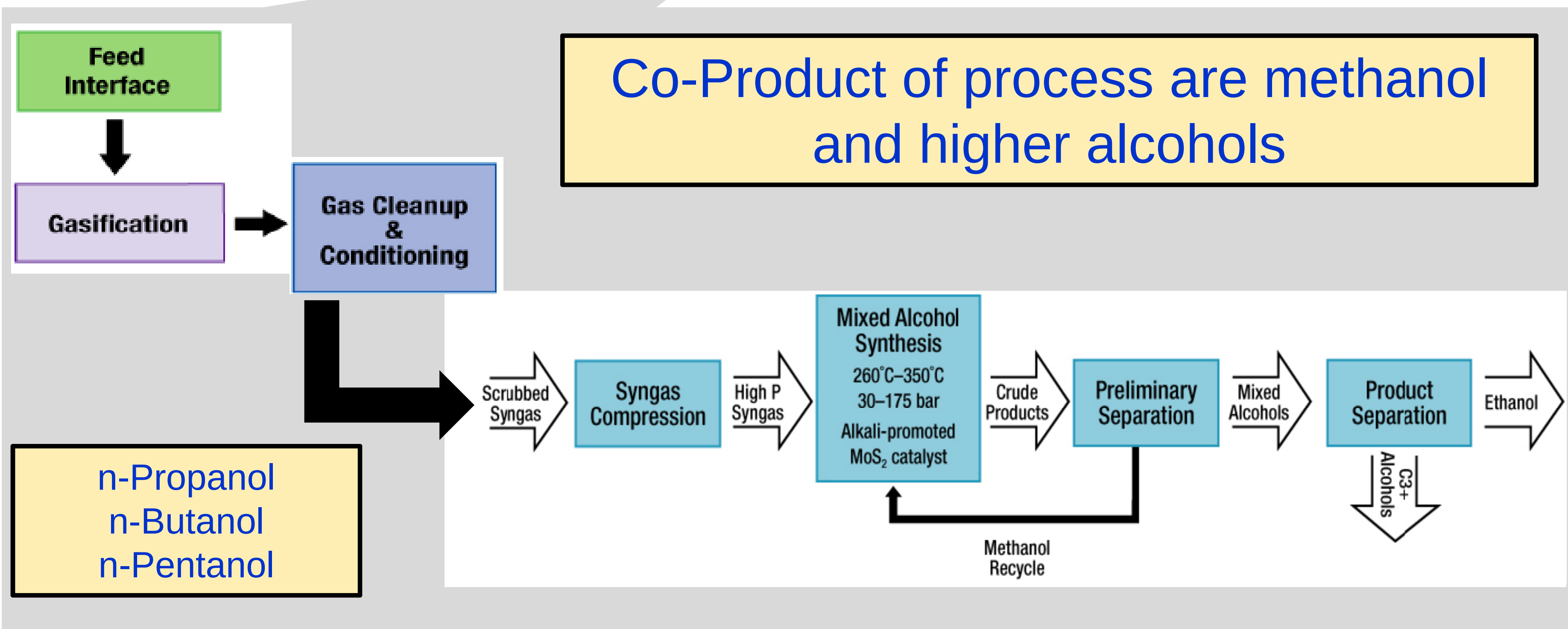
- *90% of Ethanol in U.S. is made from using dry grind process*
- *DDGS - High value animal feed*
- *Corn oil is a possible co-product*
- *CCS option modeled*

Biochemical Pathways to E10 and E85 Production

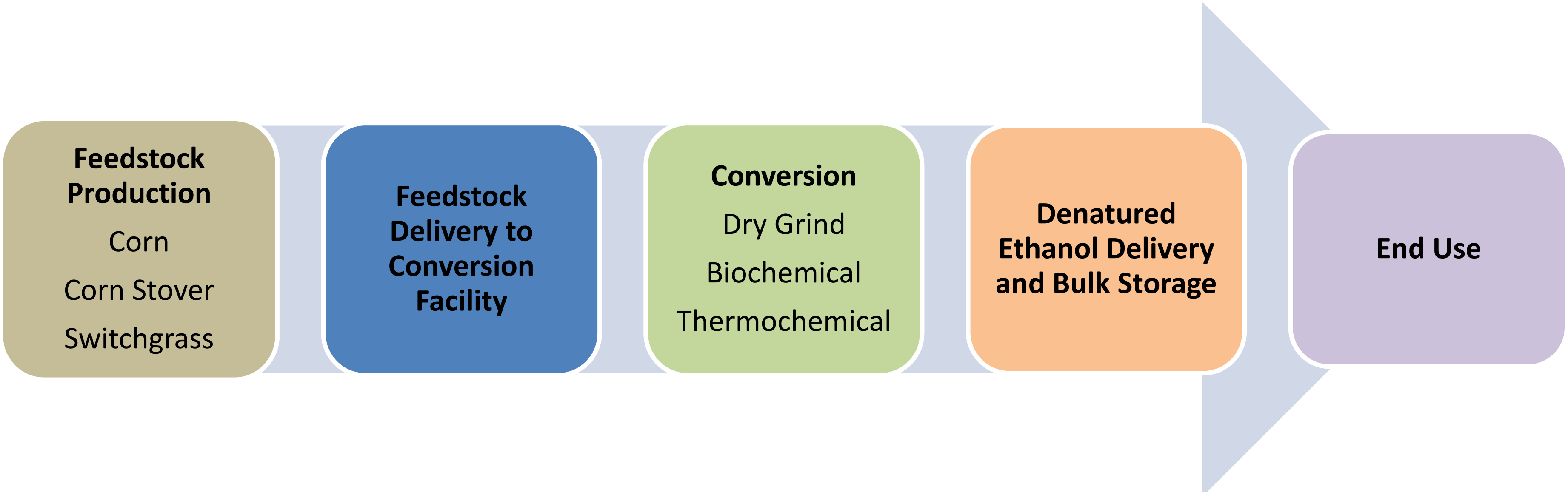


Thermochemical Pathways to E10 and E85 Production

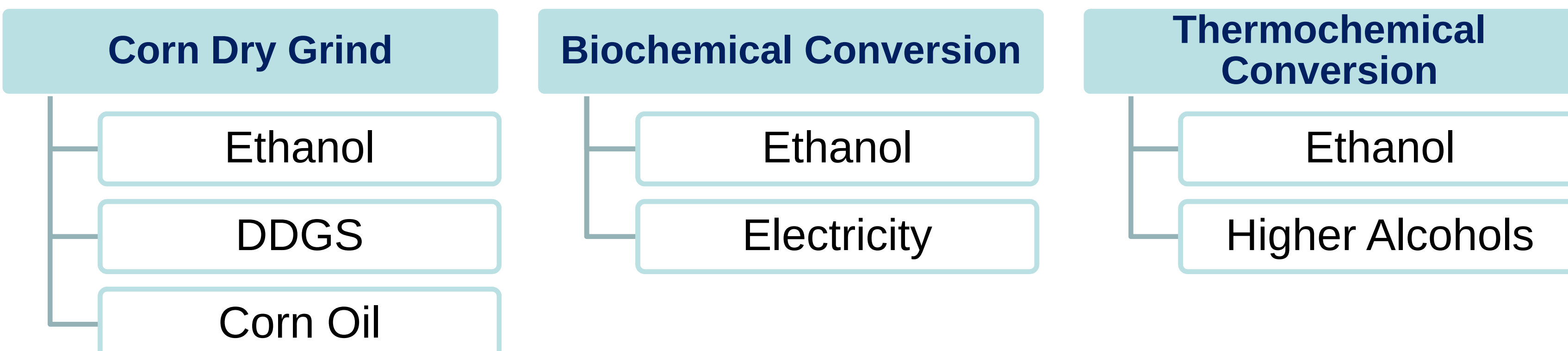




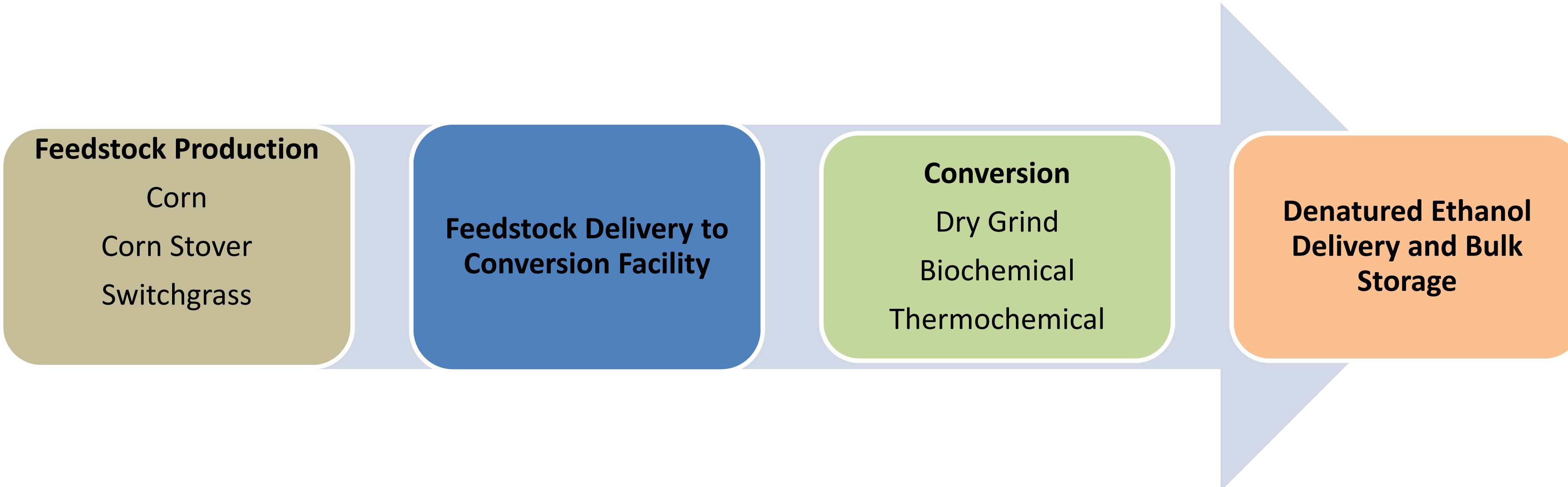
Environmental System Boundary



System Expansion is used to manage the co-products of ethanol plants



Economic System Boundary



- **Capital and operating costs are calculated for each scenario at each LC stage**
- **Neither ethanol end use, i.e., combustion in an ICE, nor the final use of the co-products are included in the LCC**

Key Capital and Operating Costs

Technology	Total Capital Cost ($2008)	Data Source
Dry Grind Ethanol Plant w/ Corn Oil Extraction	$94,600,000	USDA, 2008
Dry Grind Ethanol Plant w/ Corn Oil Extraction and CO_2 Recovery	$99,100,000	USDA, 2008
Biochemical Ethanol Plant	$133,000,000	Aden *et al.*, 2002
Thermochemical Ethanol Plant	$146,000,000	Phillips *et al.*, 2007

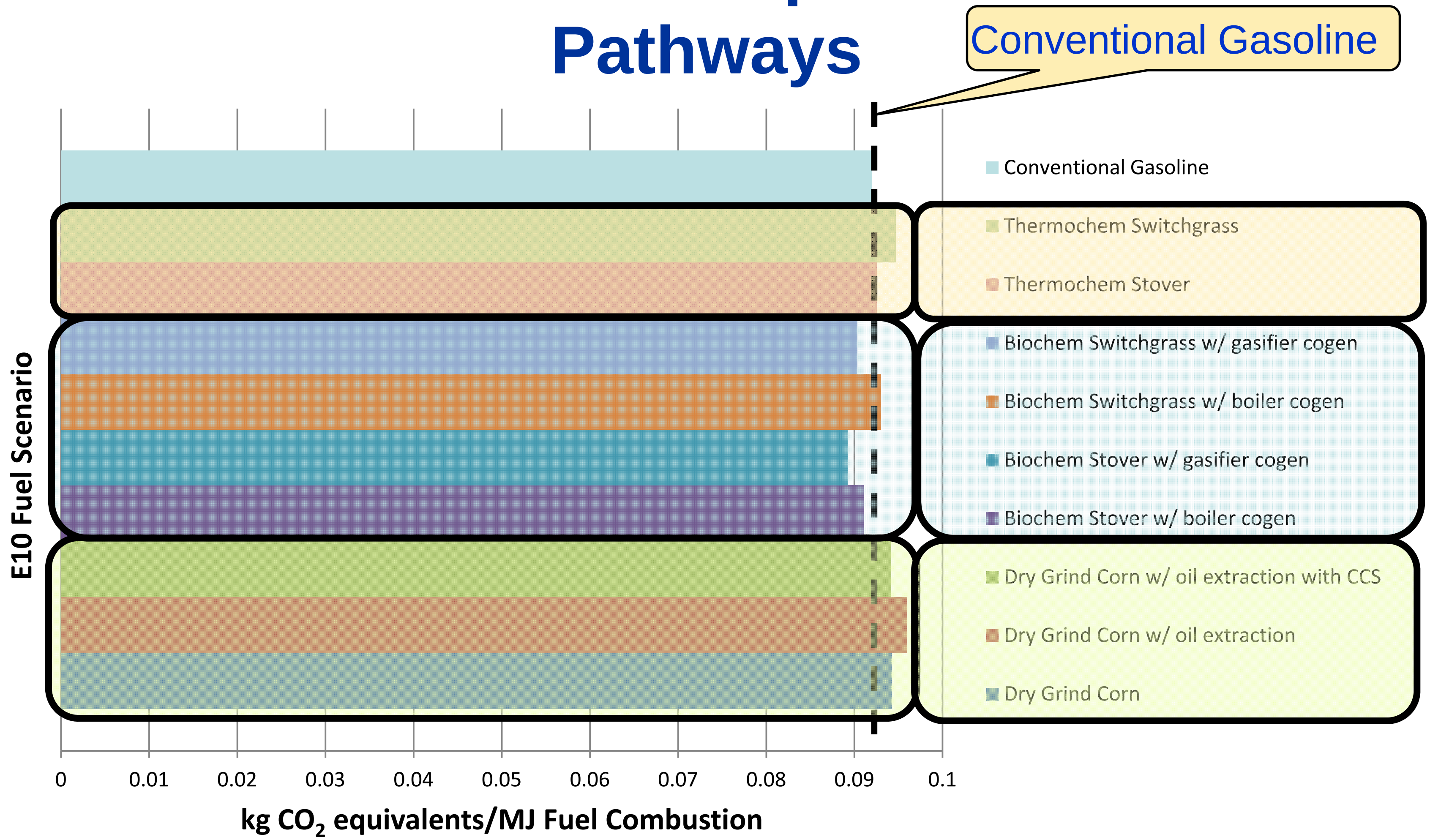
Utilities	**Unit Cost**	**Data Source**
Natural gas	$7.71/MMBtu (2007 dollars)	EIA, 2009
Electricity	$0.065/kWh (2007 dollars)	EIA, 2009
Coproducts	**Unit Cost**	**Data Source**
DDGS	$0.137/kg (2008 dollars)	USDA, 2008
Corn oil	$0.353/kg	Present Study
Electricity	$0.065/kWh (2007 dollars)	EIA, 2009
Higher alcohols	$1.15/gal (2005 dollars)	Phillips, 2007

Financial Parameters Used in LCC

Property	Value	Units
Reference Year Dollars	2008	Year
Assumed Start-Up Year	2012	Year
Real After-Tax Discount Rate	10.0	Percent
After-Tax Nominal Discount Rate	12.1	Percent
Assumed Study Period	30	Years
MACRS Depreciation Schedule Length	Variable	Years
Inflation Rate	1.9	Percent
State Taxes	6.0	Percent
Federal Taxes	34.0	Percent
Total Tax Rate	38.0	Percent

LCA Environmental Results

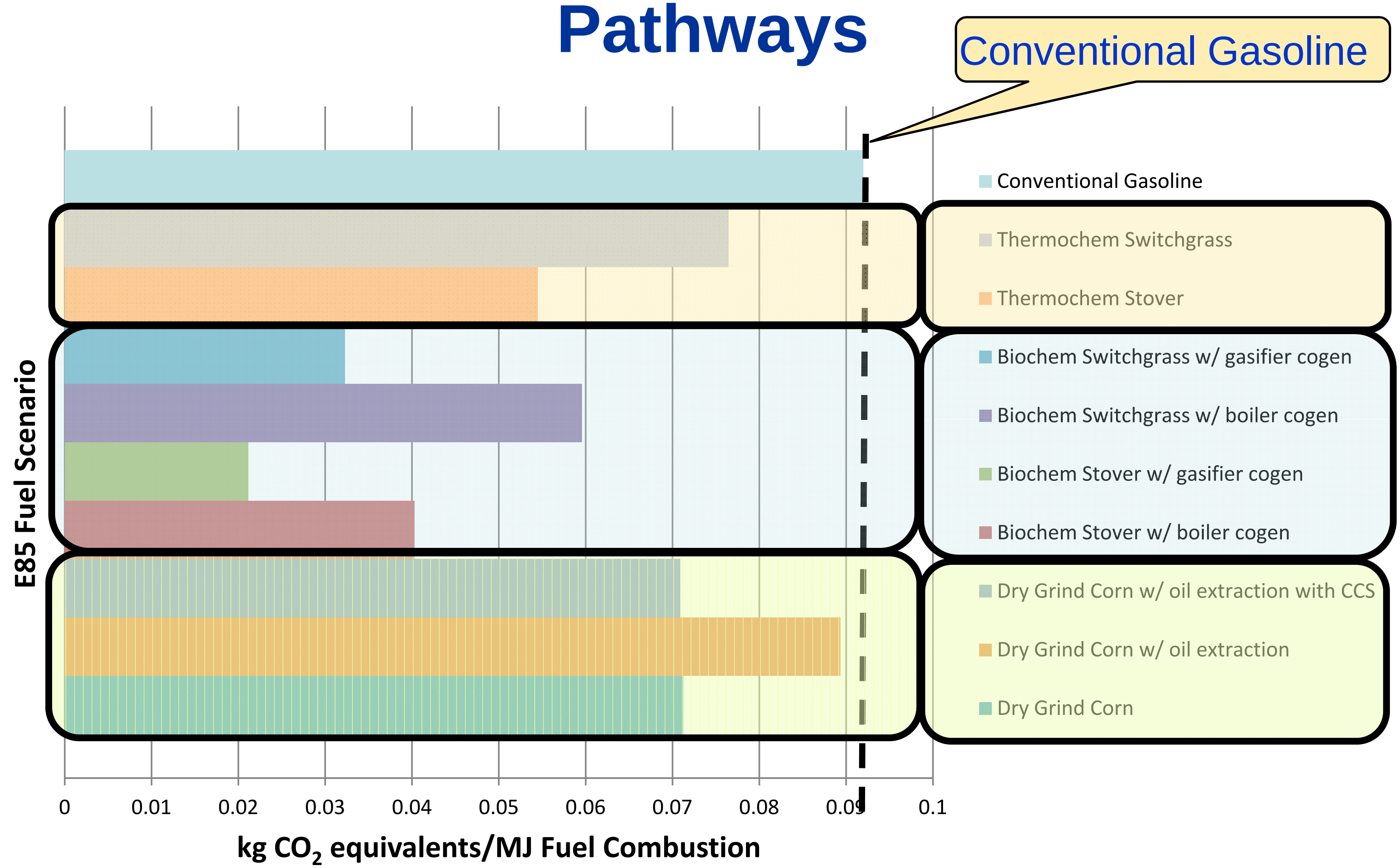
Net Carbon Dioxide Equivalents for E10 Pathways



The biochemical pathways are the only E10 scenarios that show improvement over conventional gasoline.

Thermochemical | Biochemical | Corn Dry Grind

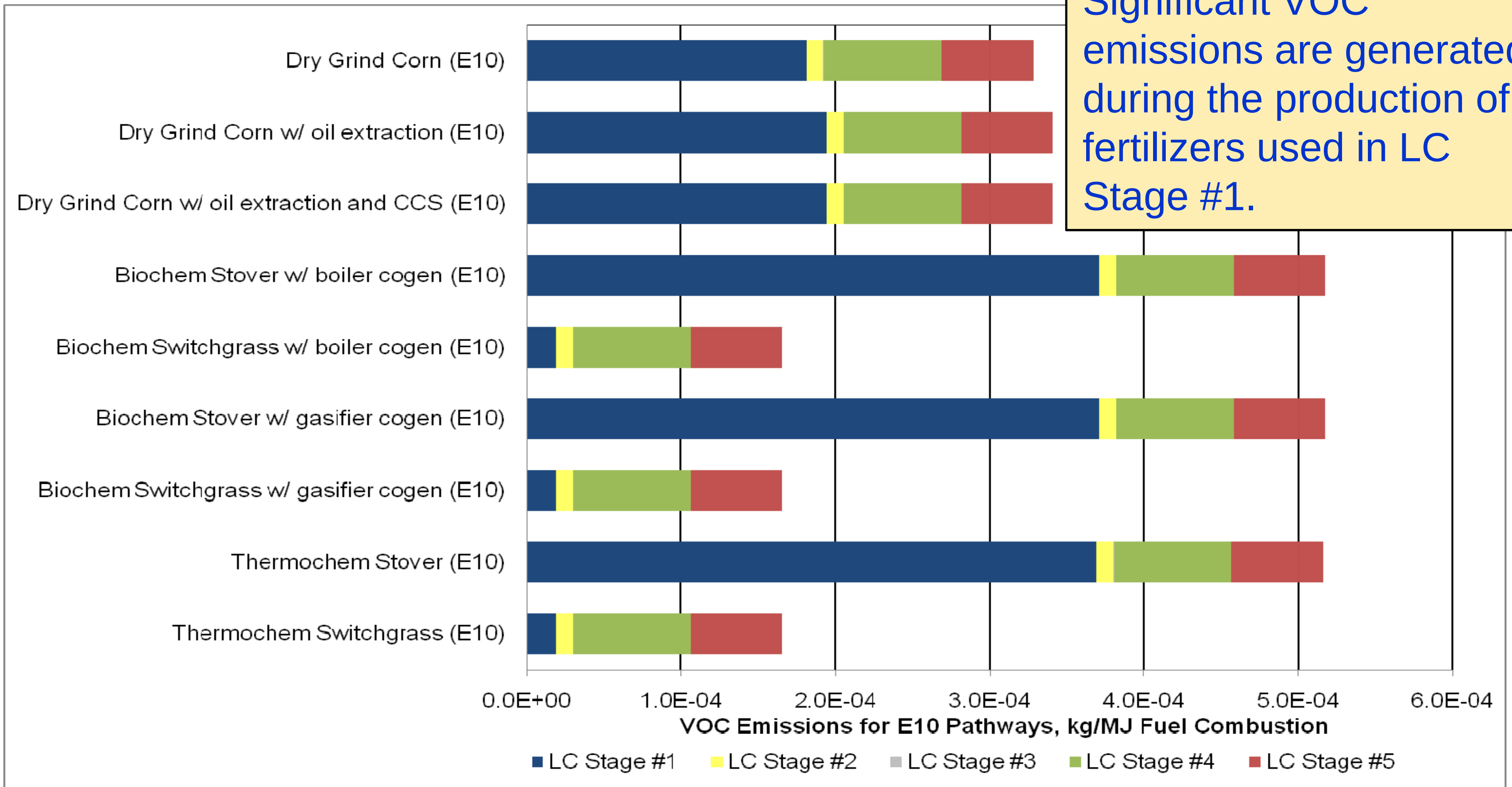
Net Carbon Dioxide Equivalents for E85 Pathways



All E85 pathways show improvement over conventional gasoline.

Thermochemical | **Biochemical** | **Corn Dry Grind**

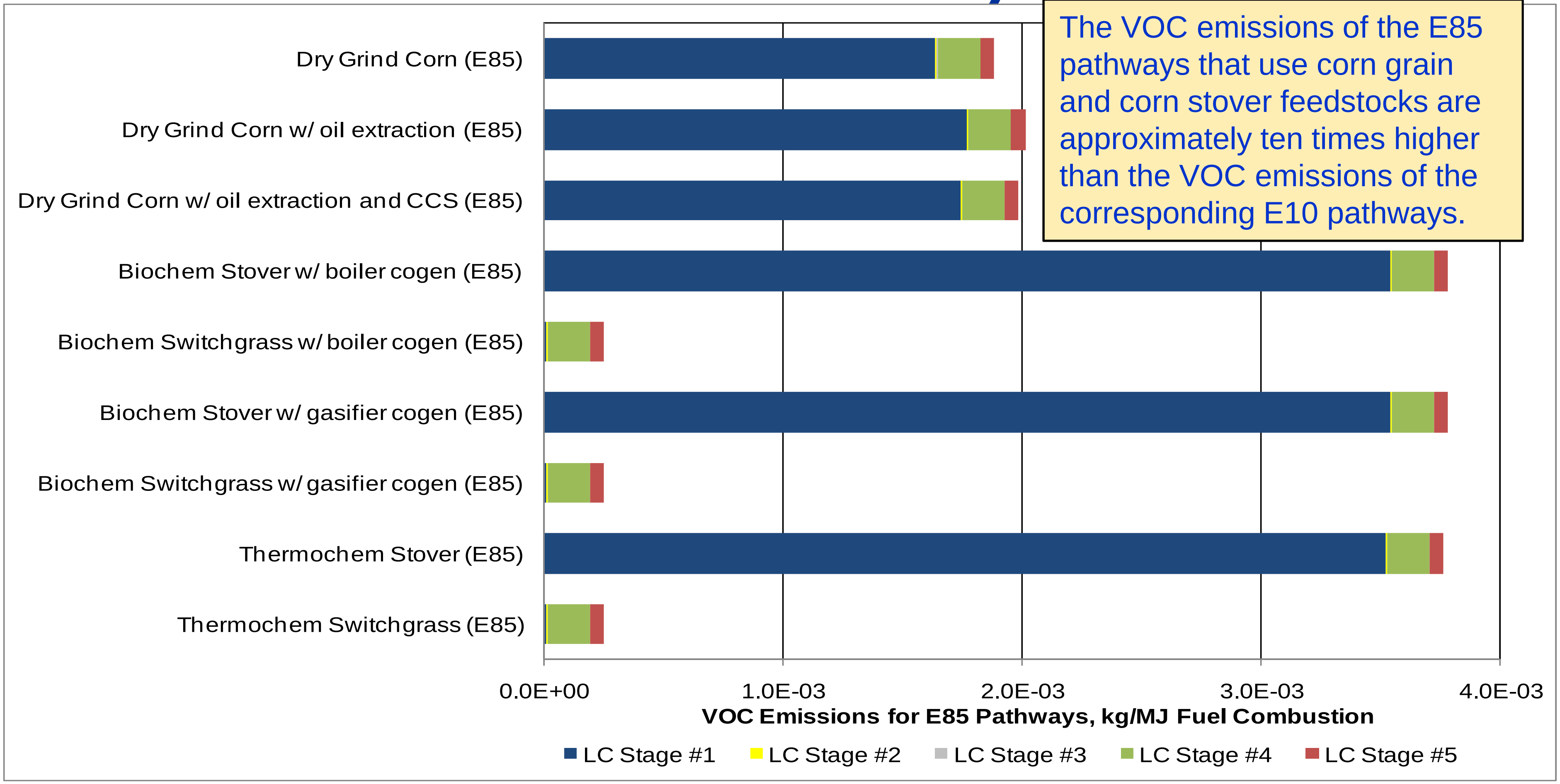
VOC Emissions from E10 Pathways (Cradle-to-Combustion)



Significant VOC emissions are generated during the production of fertilizers used in LC Stage #1.

Switchgrass production requires less fertilizer than corn products production, and thus the switchgrass pathways have the lowest VOC emissions.

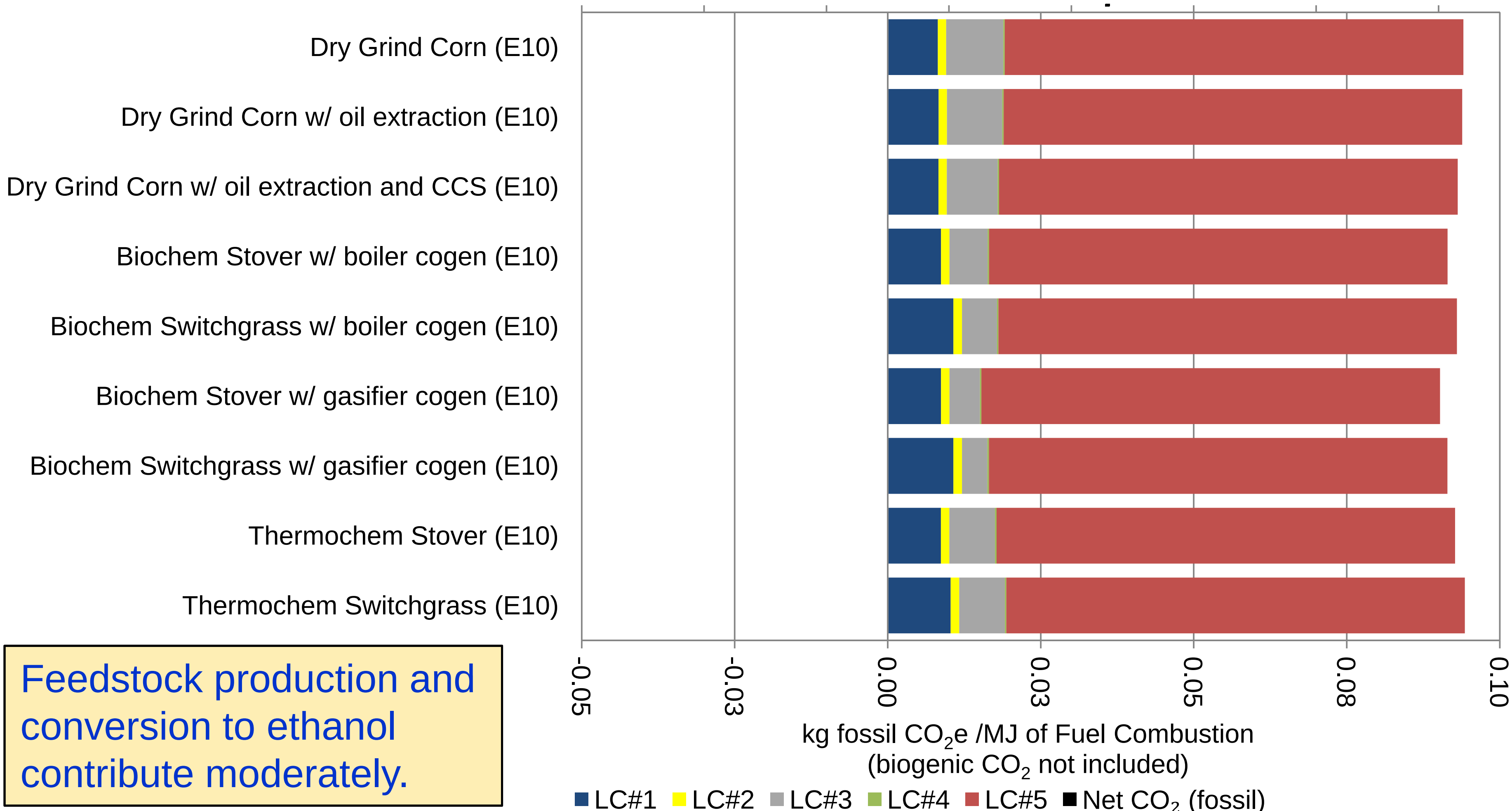
VOC Emissions from E85 Pathways (Cradle-to-Combustion)



The VOC emissions of the E85 pathways that use corn grain and corn stover feedstocks are approximately ten times higher than the VOC emissions of the corresponding E10 pathways.

The VOC emissions of the E85 pathways that use switchgrass are approximately two times higher than the VOC emissions of the corresponding E10 pathways.

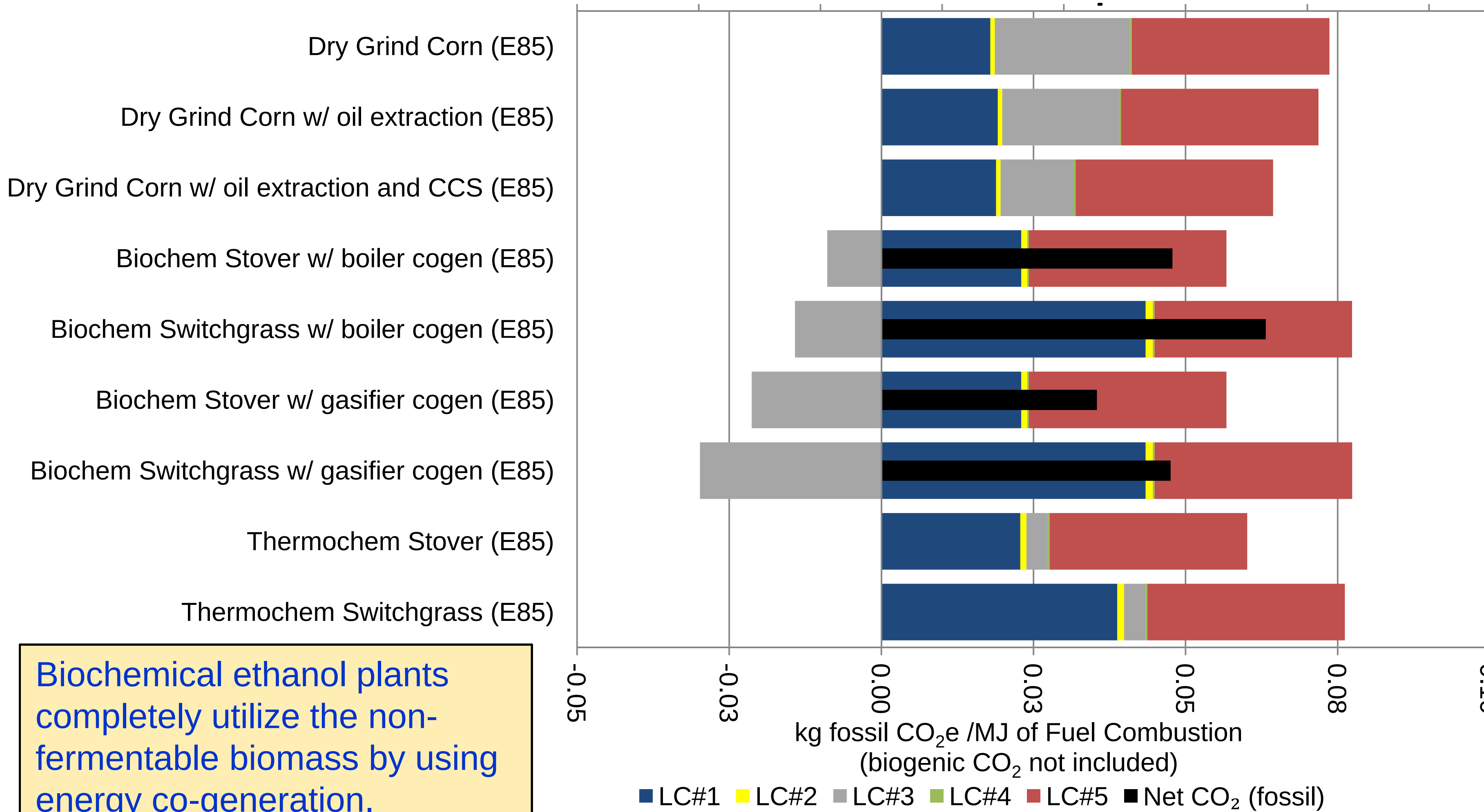
Fossil Carbon Dioxide Equivalents for each LC Stage of E10 Pathways



Feedstock production and conversion to ethanol contribute moderately.

Vehicle fuel combustion (LC stage #5) is responsible for the majority of fossil carbon emissions from the E10 pathways.

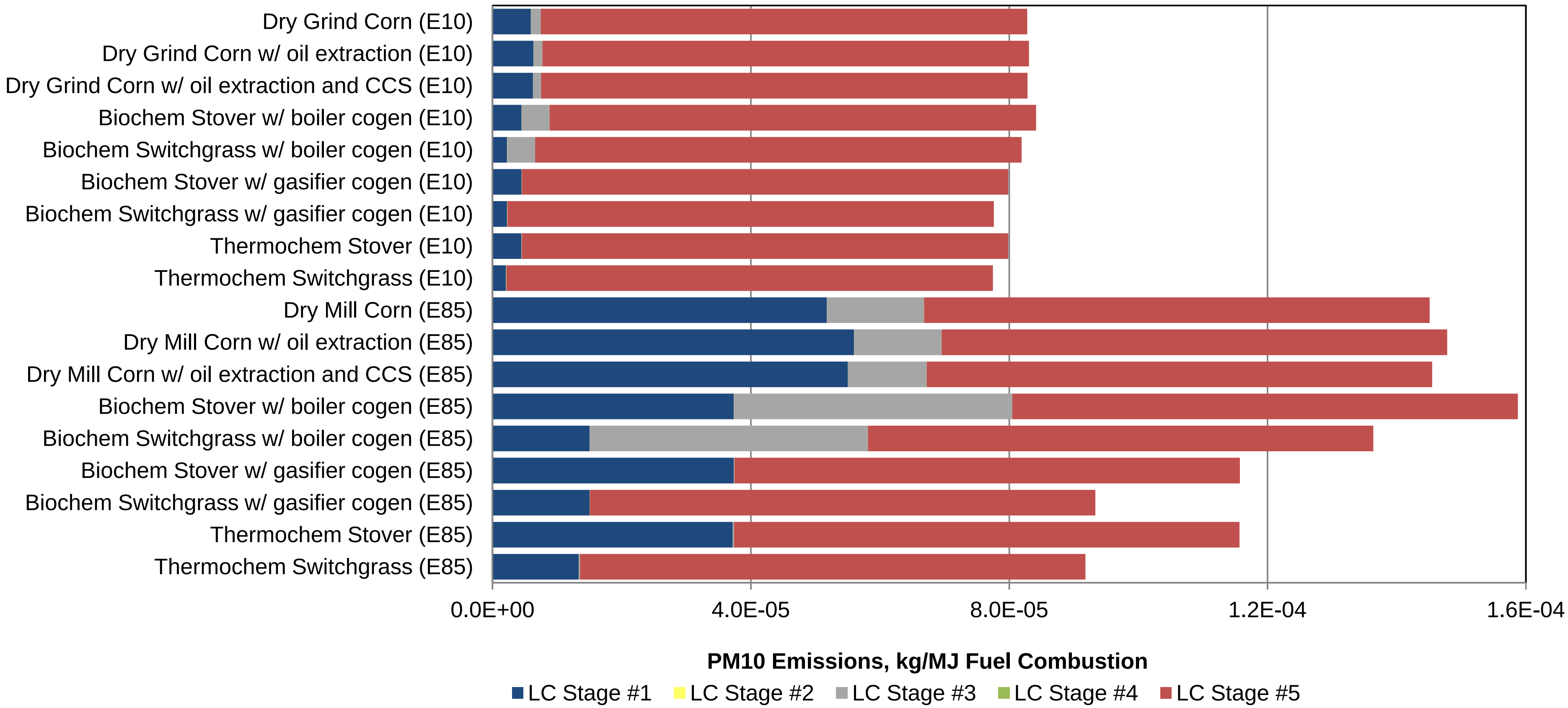
Fossil Carbon Dioxide Equivalents for each LC Stage of E85 Pathways



Biochemical ethanol plants completely utilize the non-fermentable biomass by using energy co-generation.

Fossil CO_2 from E85 combustion (LC Stage #5) is significantly lower in comparison to E10.

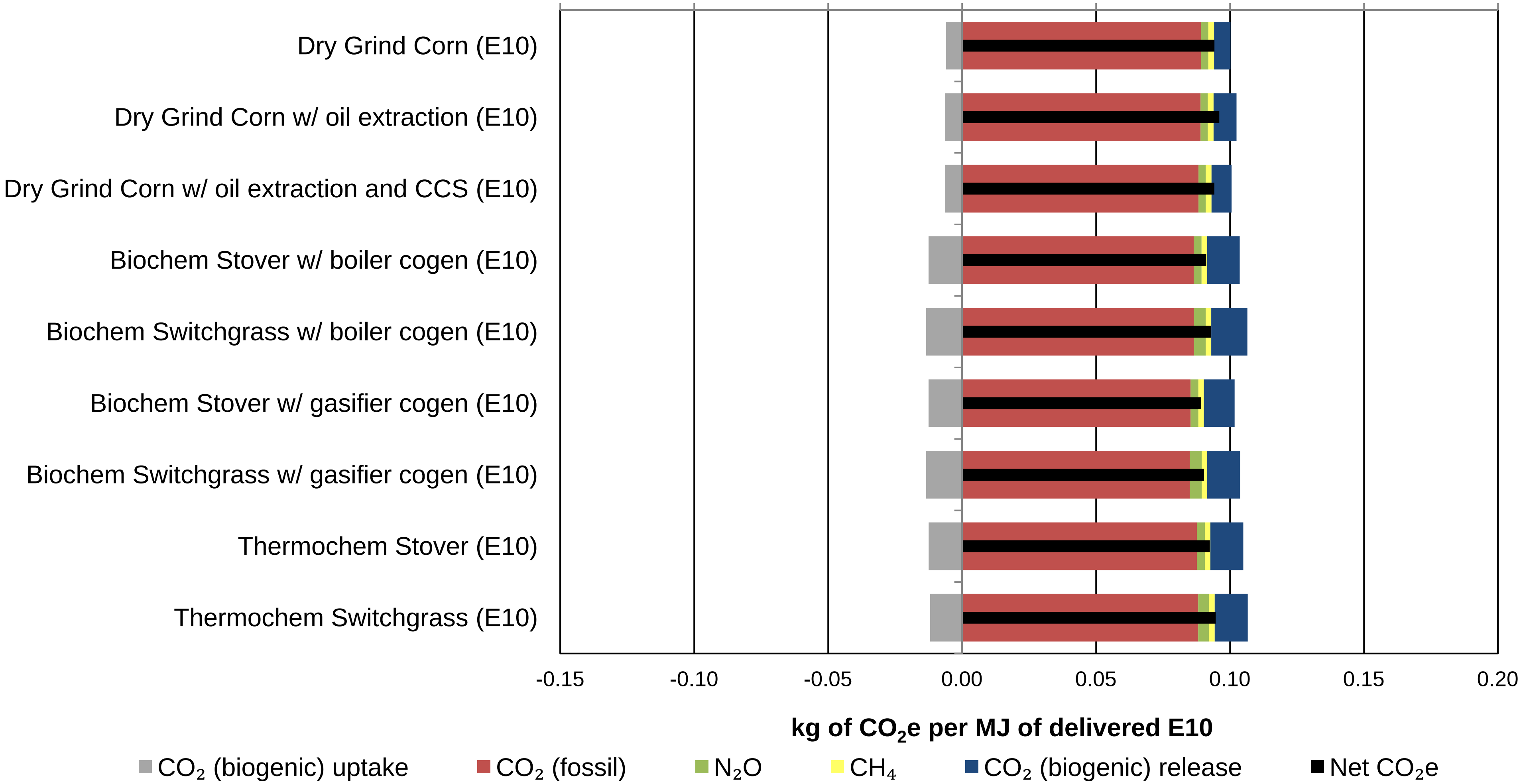
PM Emissions from E10 and E85 Pathways (Cradle-to-Combustion)



The majority of PM emissions occur during LC Stage #5.

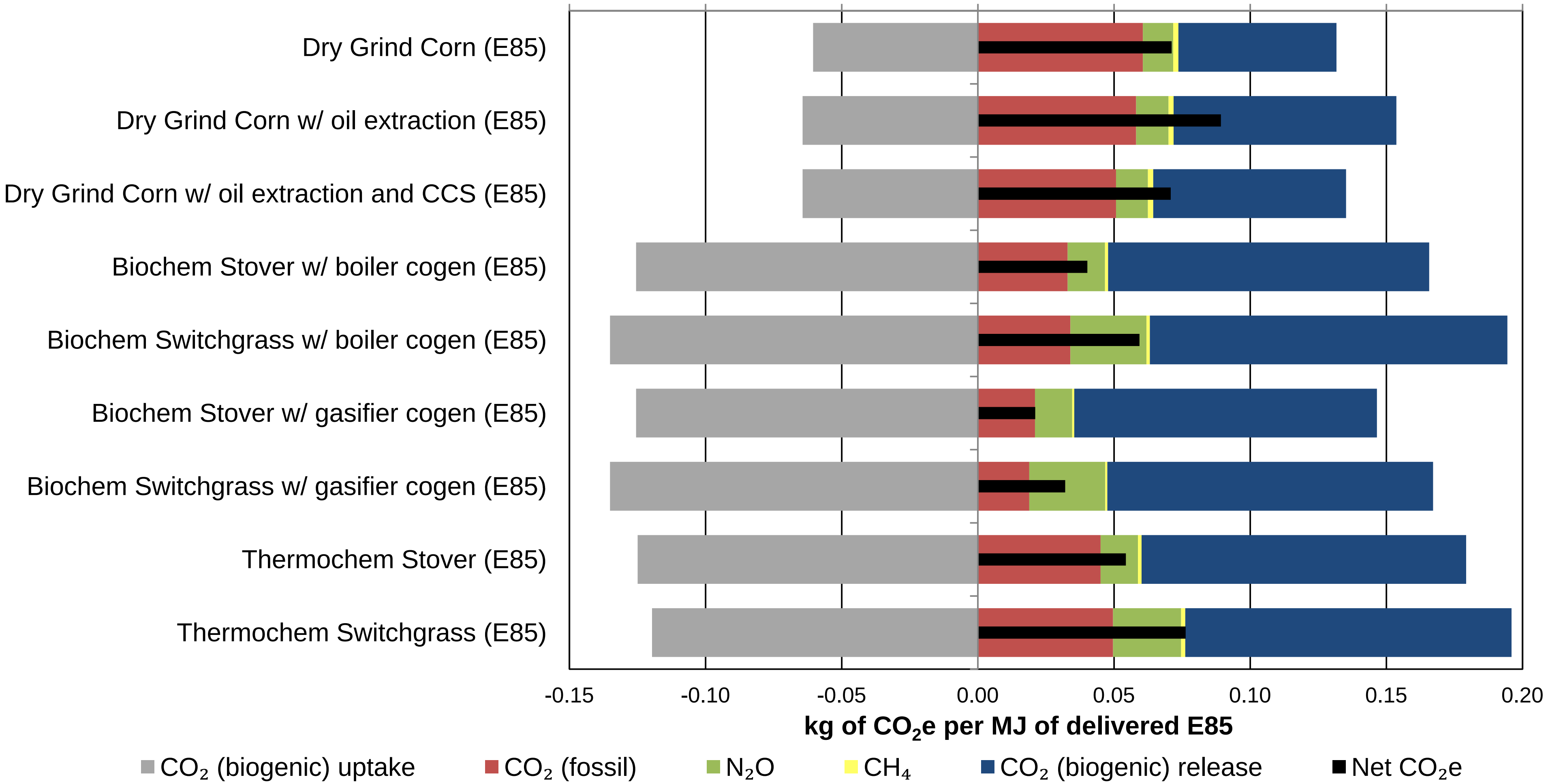
The elevated PM emissions of the dry grind and biochemical pathways are from the combustion of diesel during the land preparation, cultivation, and harvesting of corn products.

Biogenic and Fossil Carbon Dioxide Equivalents for E10 Pathways



For E10 pathways, the net CO_2e is comparable to the fossil CO_2 plus the global warming potentials (GWP) of CH_4 and N_2O.

Biogenic and Fossil Carbon Dioxide Equivalents for E85 Pathways



- In general, the net CO_2e of E85 is lower than the net CO2e of E10.
- Biochemical pathways have the lowest net CO_2e within the E85 pathways.

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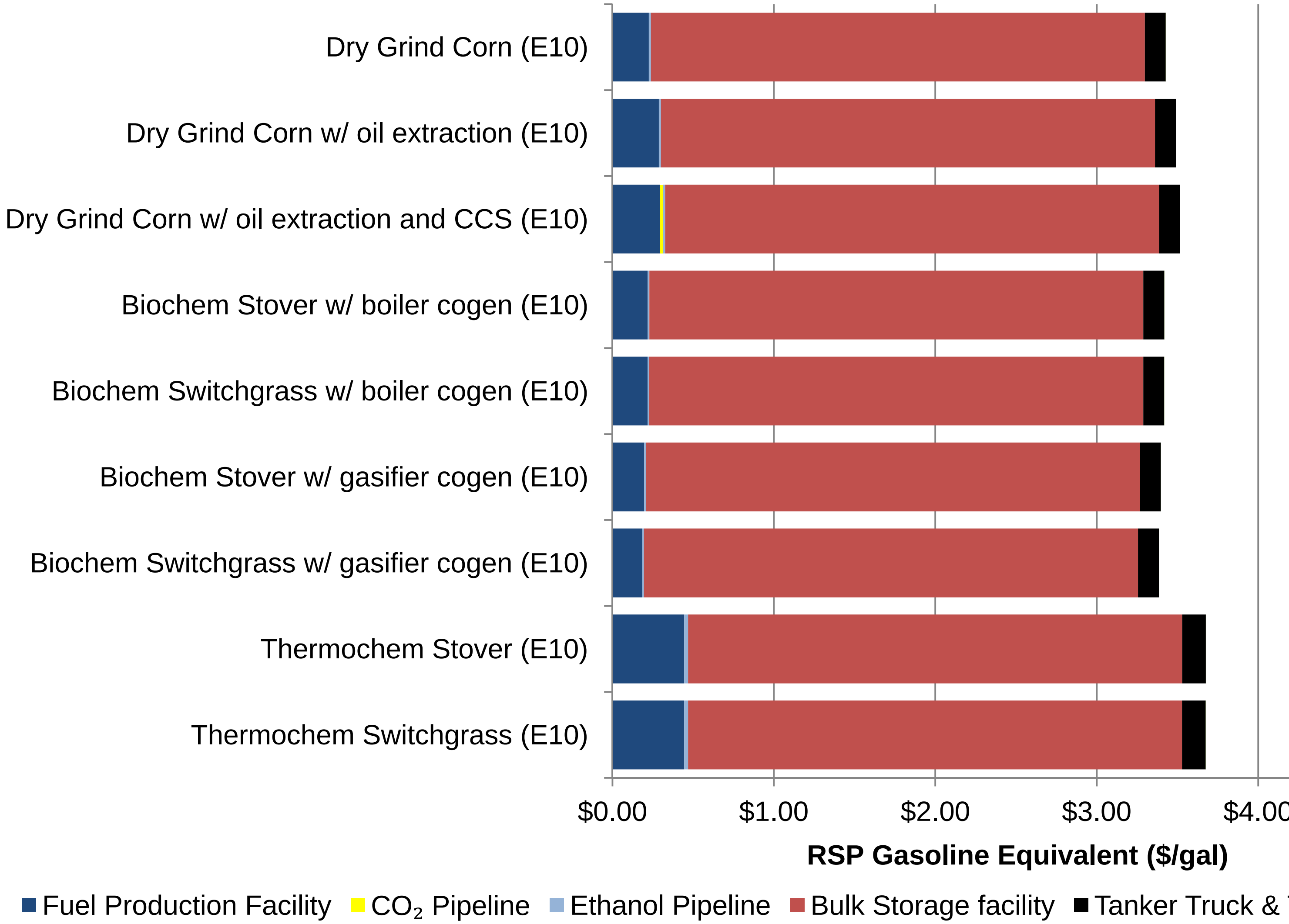
LCC Results

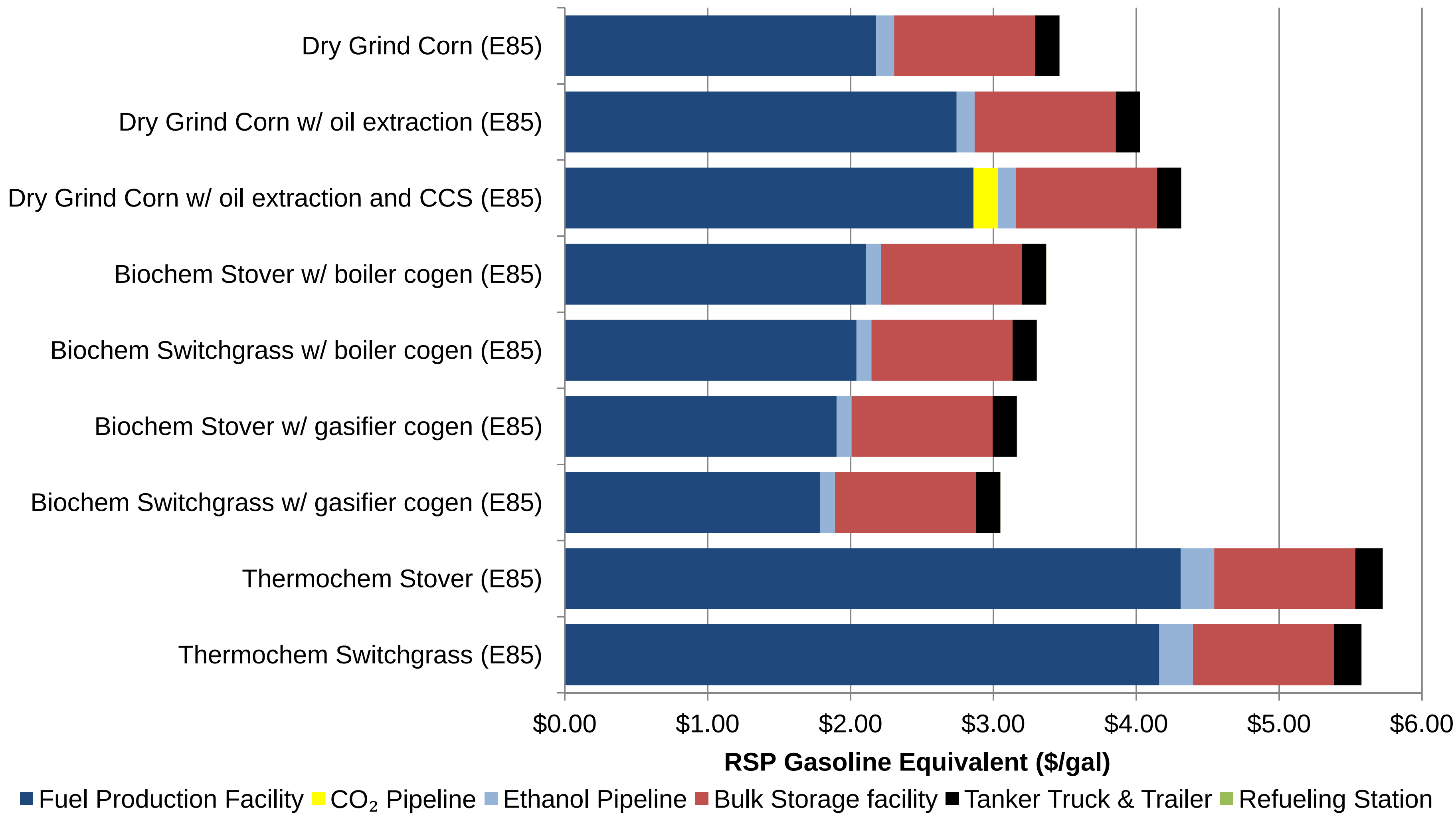
LCC Results for E10 Pathways



- Cost boundaries of this analysis do not include vehicle end use
- Required selling price (RSP) is normalized to the heating value of gasoline
- Allows comparison of E10 and E85 on an equivalent energy basis
- Allows fairer comparison between ethanol blends and conventional gasoline.

The majority of costs for the E10 pathways occur at the bulk loading terminal since E10 has a higher proportion of gasoline than ethanol.

LCC Results for E85 Pathways



The majority of costs for the E85 pathways occur at the ethanol plants.

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Land and Water Results

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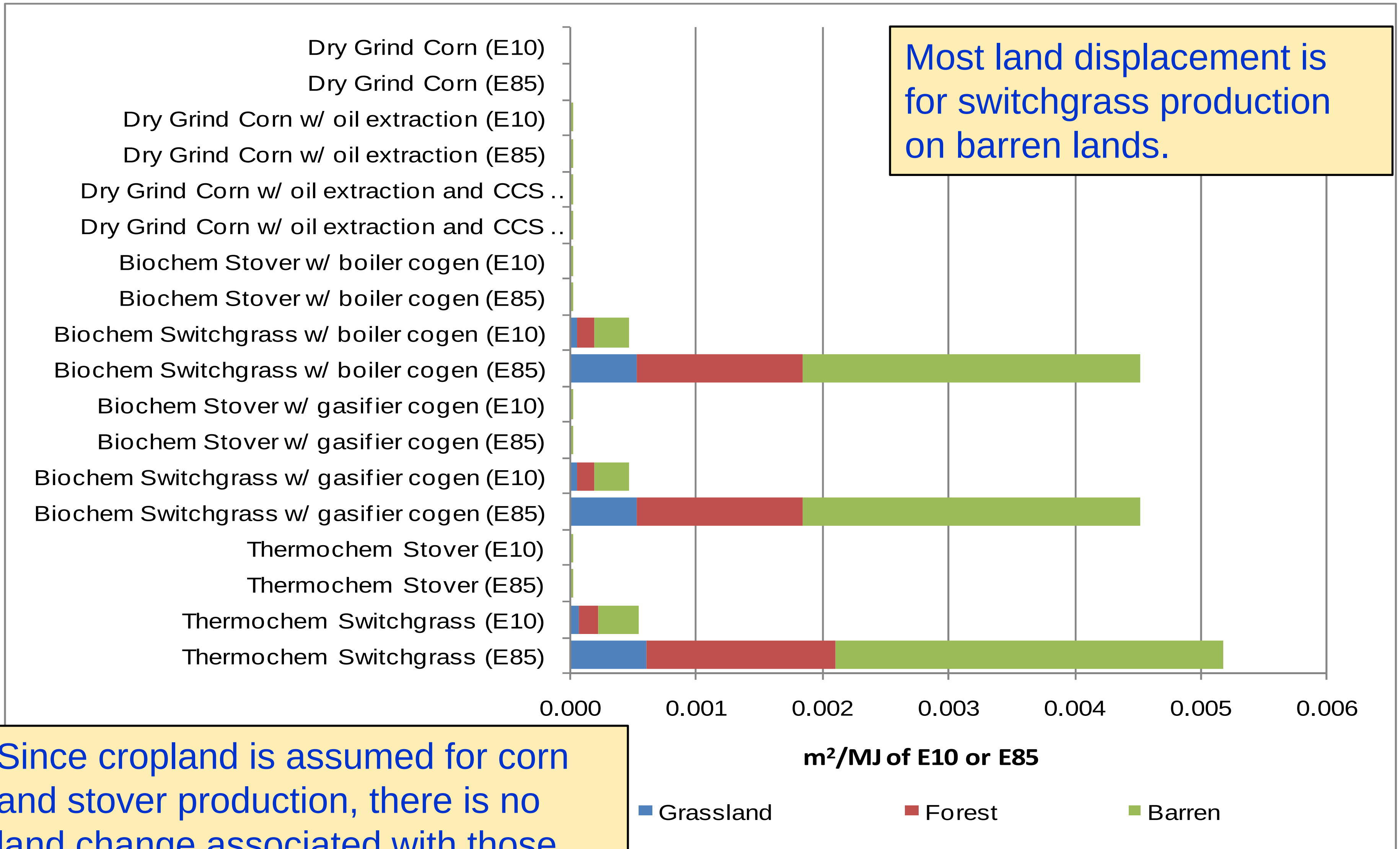
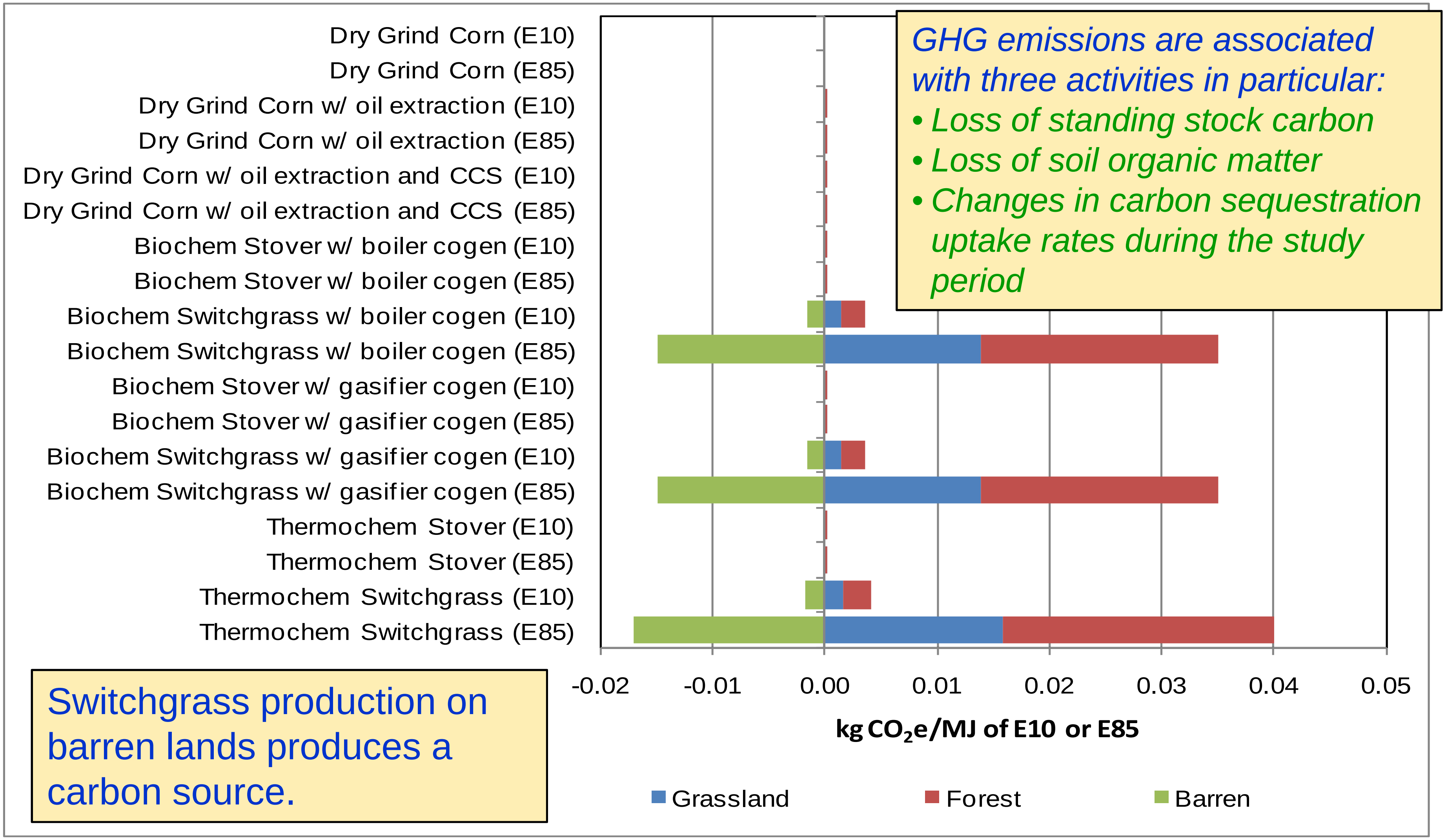
Total Transformed Land Area (m^2/MJ)



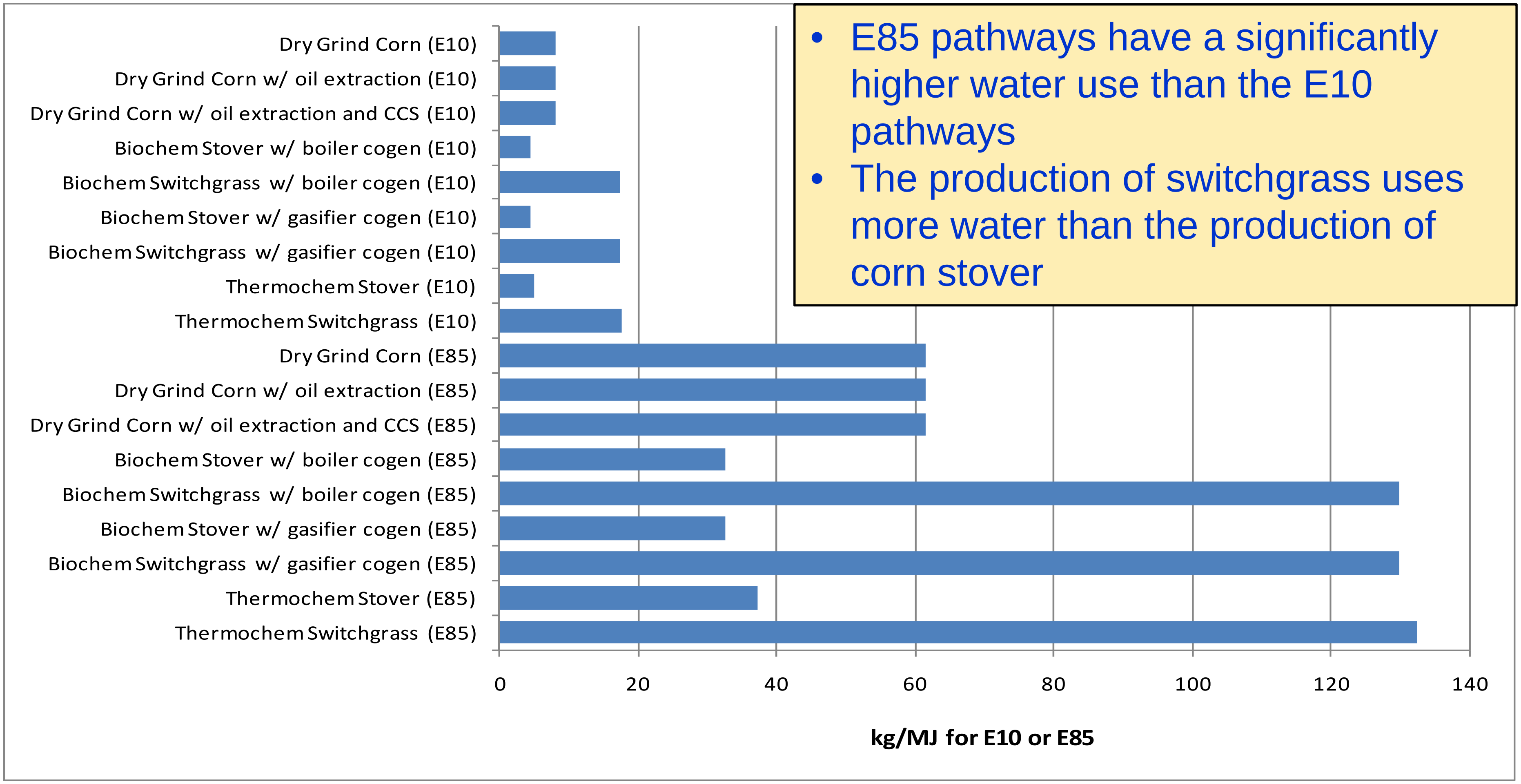
Most land displacement is for switchgrass production on barren lands.

Since cropland is assumed for corn and stover production, there is no land change associated with those pathways.

Total GHG Emissions (kg CO_2/MJ) in Transformed Land



Net Water Consumption for E10 and E85 Pathways (Cradle-to-Combustion)

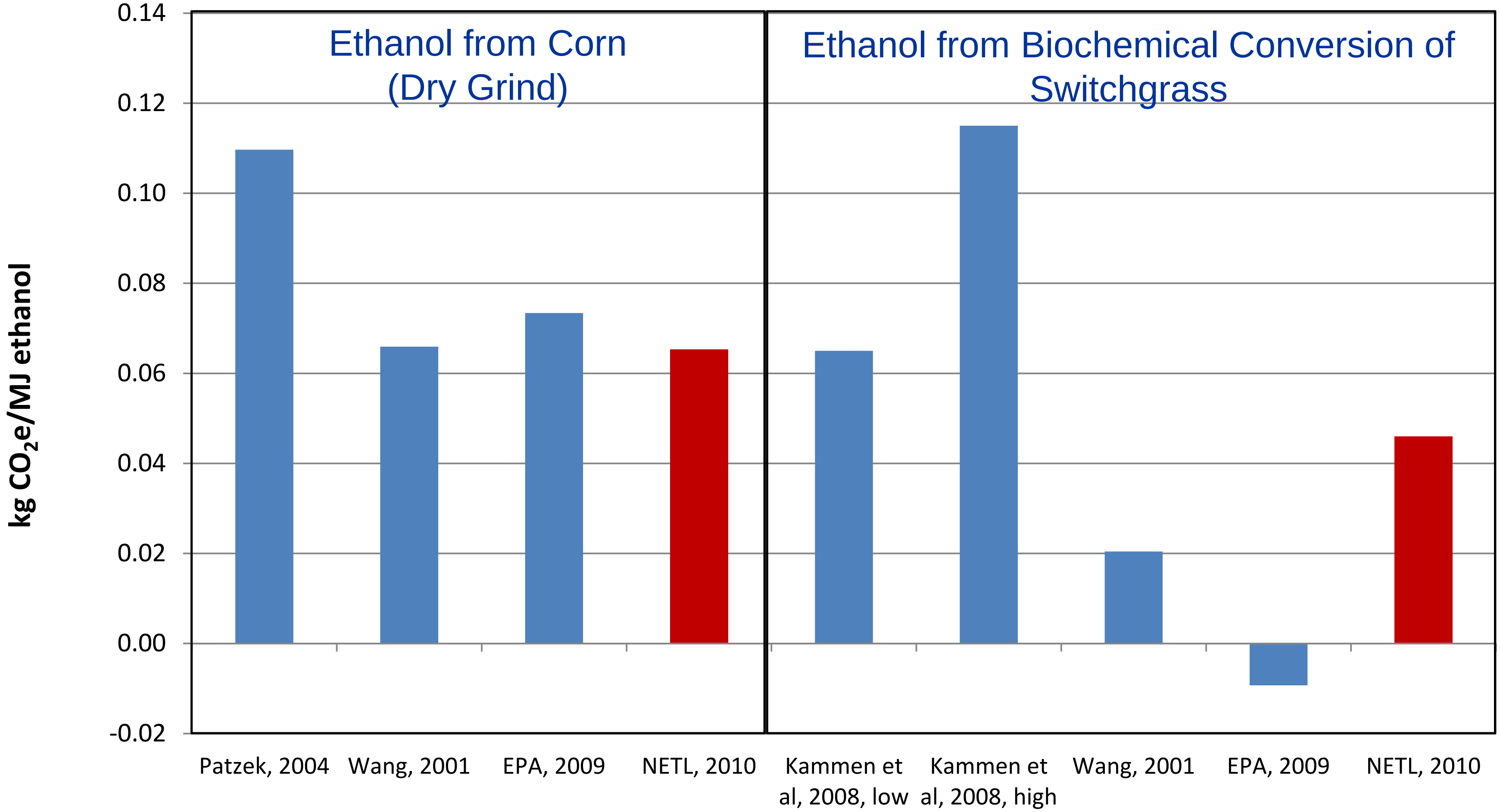


- E85 pathways have a significantly higher water use than the E10 pathways
- The production of switchgrass uses more water than the production of corn stover

Nearly all water consumption is in LC Stage #1

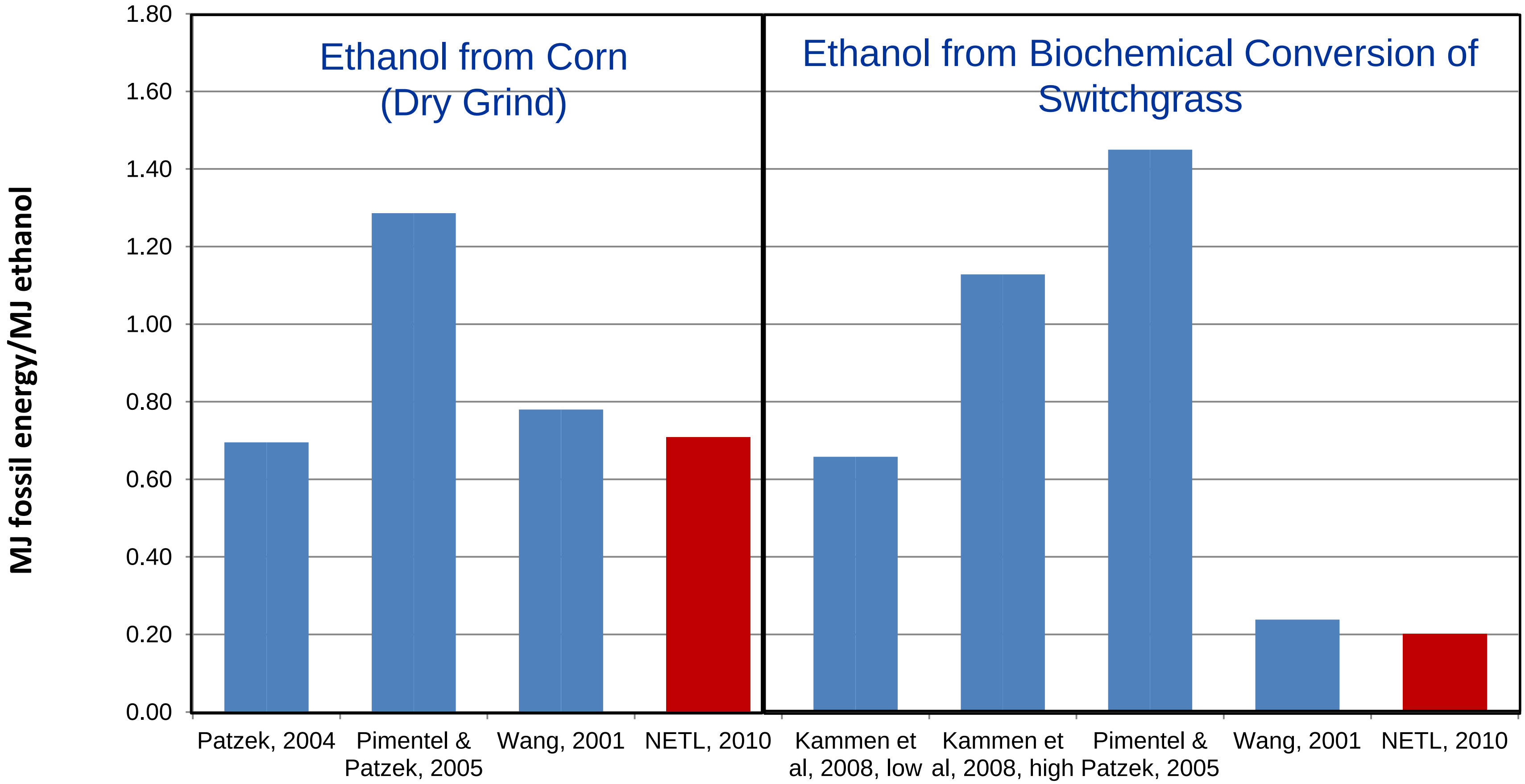
Conclusion - Lessons Learned

Comparison of LC Ethanol GHG Results



Life Cycle GHG results from NETL study compare well with many other peer reviewed reports.

Life Cycle Non-Renewable Energy for Ethanol



NETL Life Cycle results from the use of non-renewable energy also compare well with literature.

Conclusions

This analysis includes two models:

- Environmental LCA Model: A cradle-to-grave inventory of GHGs, CAPs, other air pollutants of interest (e.g., mercury), solid waste, resource energy, water emissions, and water withdrawal.
- LCC analysis: A discounted cash flow model that assumes a 30-year study period and accounts for key capital costs and O&M costs from acquisition of raw materials to the delivery of fuel to the consumer.

Conclusions

This analysis provides a life cycle comparison of three tiers of technology, three types of biomass feedstocks, and two fuel-blending compositions for a total of 18 distinct pathways.

- The three tiers of technology are the production of ethanol using dry grind technology, biochemical conversion, and thermochemical conversion.
- The three biomass feedstocks are corn grain, corn stover, and switchgrass.
- The two fuel-blending compositions are E10 and E85.

Conclusions

CCS does not result in significant reductions in life cycle CO_2 emissions.

- The electricity requirements of CO_2 capture at the ethanol plant offset the CO_2 reductions from carbon capture.
- The CO_2 emissions from the ethanol plant are small in comparison to CO_2 emissions from the combustion of fuel in a passenger vehicle)

Conclusions

- The results of the LCC analysis demonstrate that the operating costs incurred during the 30-year period of ethanol production overshadow the capital costs for the construction of ethanol plants and fuel distribution infrastructure (pipelines, fuel terminals, and tanker trucks).
- The majority of costs for the E10 pathways are tracked at the bulk loading terminal (LC Stage #4)
  - Gasoline enters the boundaries of the LCC model at the bulk loading terminal; since E10 has a high proportion of gasoline, the majority of E10 costs are accounted for at the bulk loading terminal.
- The majority of costs for the E85 pathways are tracked at the ethanol plants (LC Stage #3).
  - Since E85 has a high proportion of ethanol, the majority of E85 costs are attributed to the activities at ethanol plants.

Conclusions

- The majority of NO_x and CO emissions occur in the final life cycle stage – the combustion of fuel in a passenger vehicle.
- VOCs are significantly higher for the pathways that use corn stover due to the methanol emissions associated with the production of potassium fertilizer that is used to replenish nutrients after corn stover is removed from the field.
- PM10 is 58 percent higher for the E85 pathways than for E10 pathways due to the emissions from farm equipment used for biomass production.
- There is a 20 percent difference between the highest and lowest lead emissions of this analysis. The thermochemical pathways have the highest lead emissions because they do not have any co-products that cause the displacement of lead emissions from substitute products.
- Mercury emissions are higher for the E10 pathways than for the E85 pathways because of the relatively higher mercury emissions of the petroleum supply chain in comparison to biomass production.