Life Cycle Assessment and Winter Cropping Systems

Sabrina Spatari, Drexel University

Penn State University Cover Crop Meeting

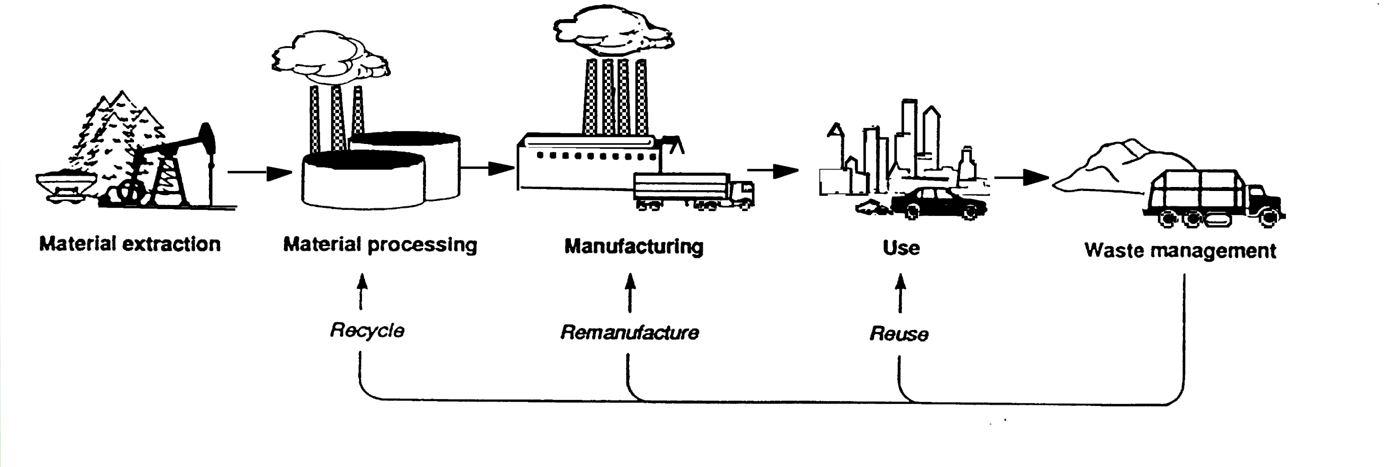
March 29, 2011

Overview

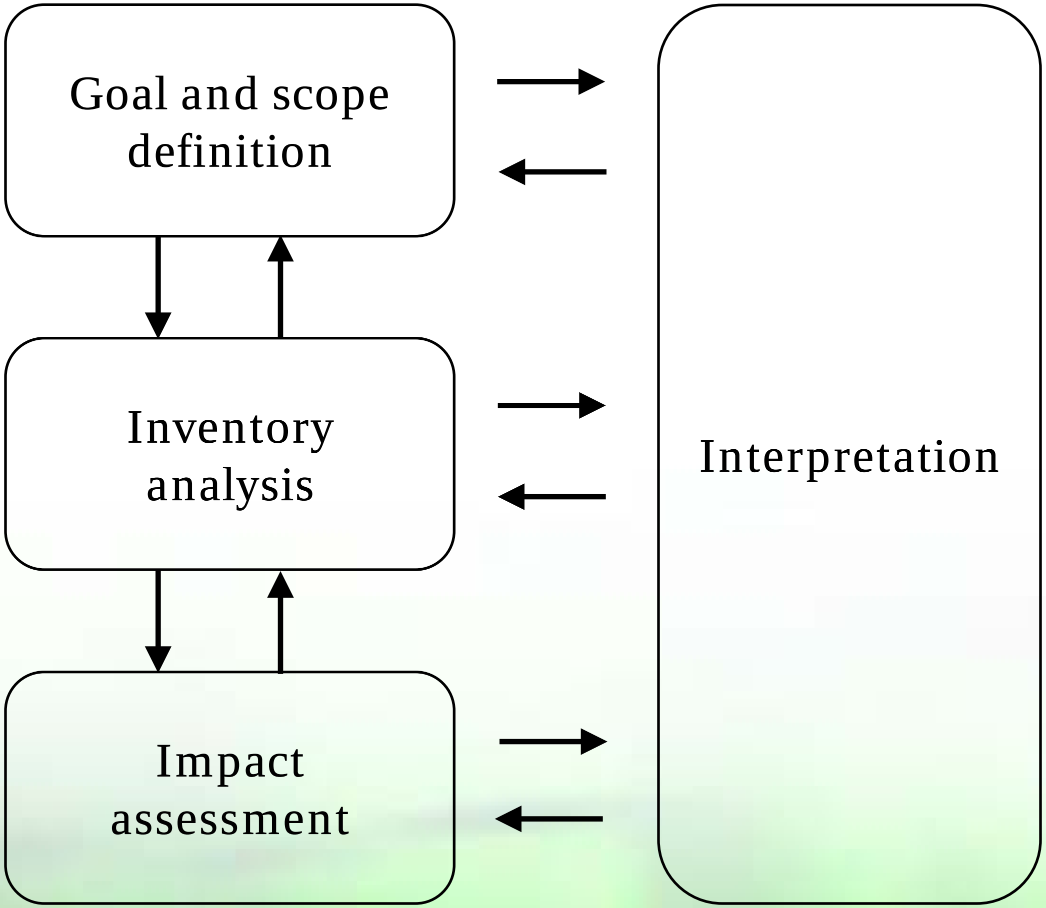
- What is life cycle Assessment?
- Why and how we use LCA to estimate the C-intensity of biofuels: background on crop and fuel pathway:
  - GHG intensity/C “footprint” of fuel pathway
  - Renewable Fuel Standard (RFS2)
- Why this is relevant for winter crops
- LCA model development
- LCA software tools (SimaPro, GaBi, GREET, GHGenius)
- Case study: Winter barley-to-ethanol, Osage Bioenergy

What is Life Cycle Assessment?

Life cycle assessment (LCA) is a decision making tool to identify environmental burdens and evaluate the environmental consequences of a product, process or service over its life cycle from cradle to grave (i.e. from extraction of resources through to the disposal of unwanted residuals).



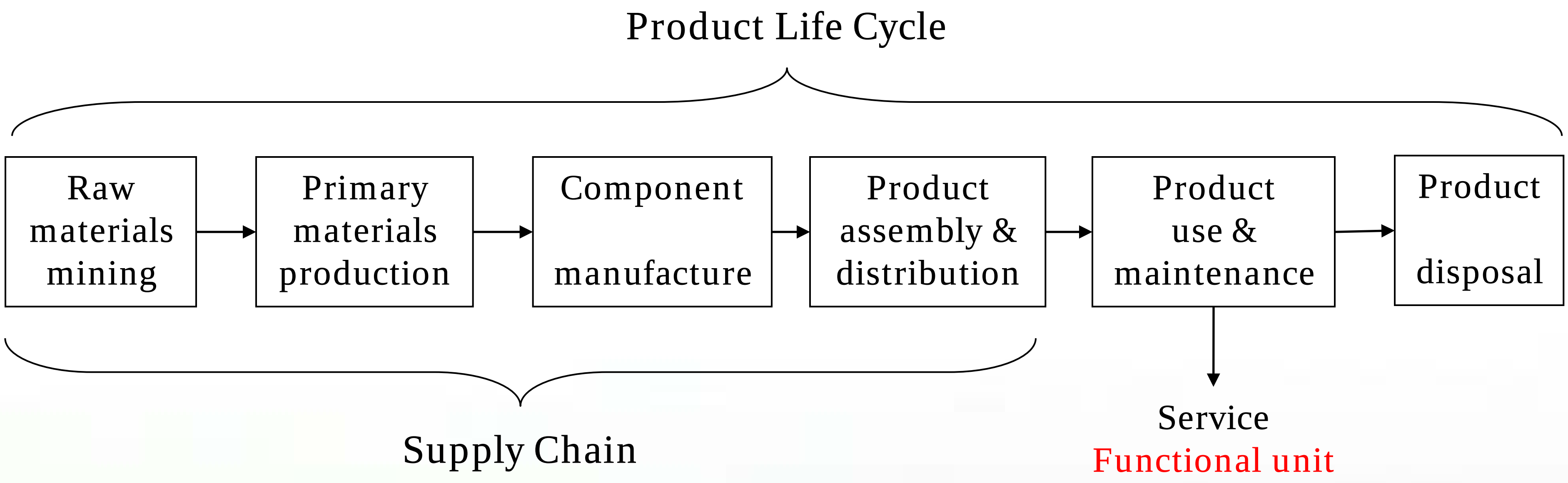
Life Cycle Assessment Framework



Definition of LCA according to ISO 14040:
LCA is a technique [...] compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study.

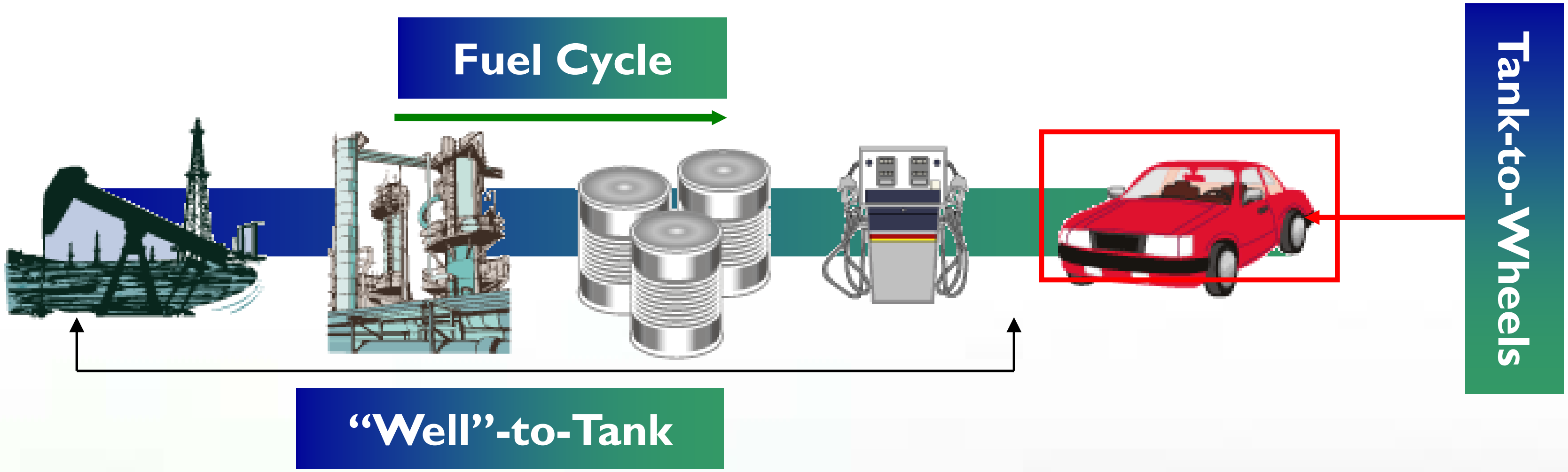
Source: ISO 14040

What is a Product Life Cycle?



The boxes are process groups called life cycle stages (system components).
The arrows are economic material flows (relationships between system components)

Well-to-wheel (WTW) analysis



Adapted from Wang (2004)

Impact Assessment

Impact categories proposed by UNEP/SETAC Life Cycle Initiative in 2003

Midpoint categories (environmental problems)

LCI results →

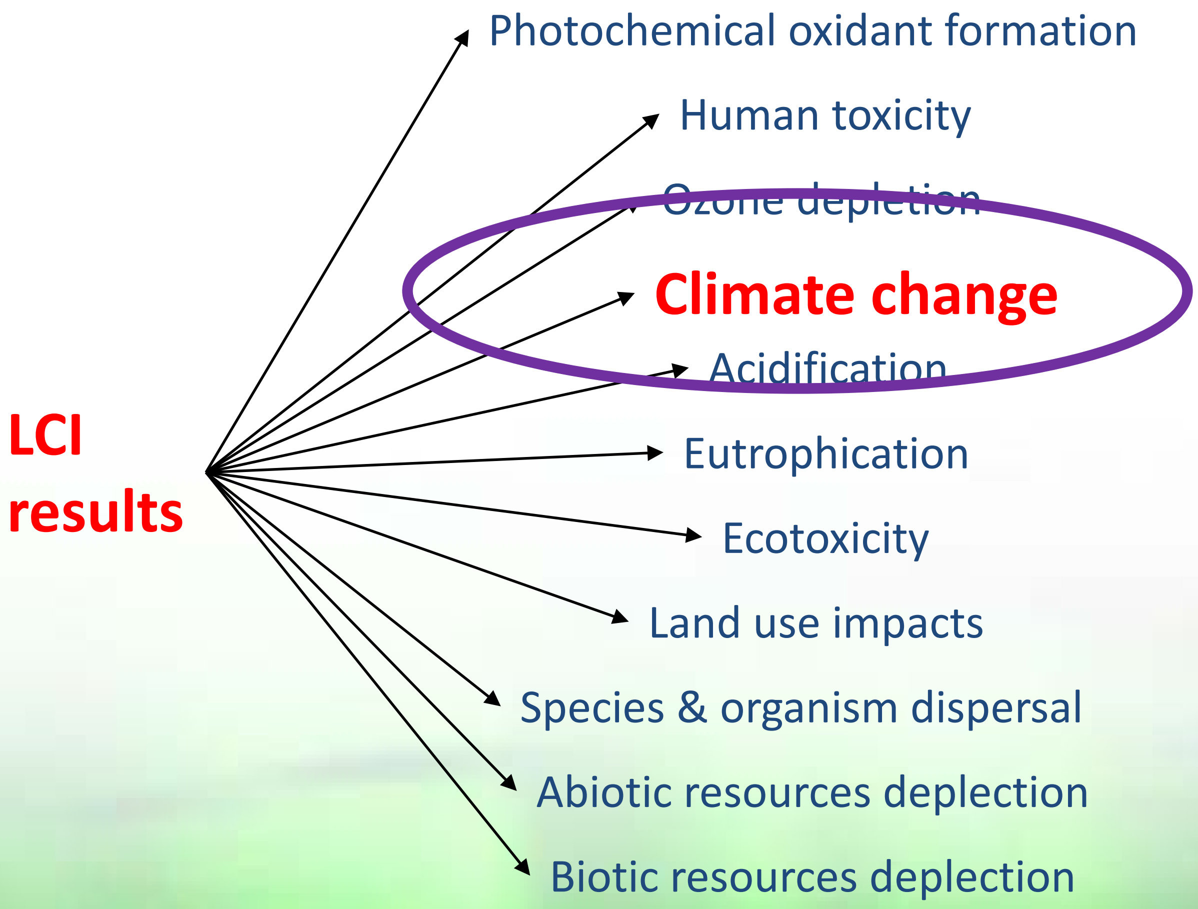
- Photochemical oxidant formation
- Human toxicity
- Ozone depletion
- **Climate change**
- Acidification
- Eutrophication
- Ecotoxicity
- Land use impacts
- Species & organism dispersal
- Abiotic resources deplection
- Biotic resources deplection

Source: Int J of LCA 9(6) 2004

Impact Assessment

Impact categories proposed by UNEP/SETAC Life Cycle Initiative in 2003

Midpoint categories (environmental problems)



Source: Int J of LCA 9(6) 2004

Tools: Simapro LCA Software

- Tool that operates as database and computational tool:
  - Like MS Access and Excel in 1 tool
- Data sets contain “cradle-to-gate” modules for specific end products, e.g., ingot steel
  - Traces inputs/outputs “back to earth”
- Visual tool for constructing material flow diagrams for LCA and calculating life cycle environmental impacts, e.g., C-footprint
- Other tools: GaBi (private); GREET, GHGenius (public)

Pré Consultants

How LCA is Used for Policy Decisions on Biofuels: What are RFS2 Requirements?

- The standard requires a certain volumetric production schedule between 2008-2022
- There are 3 categories of biofuels:
  - Renewable: corn feedstocks allowed; ↓GHGs by 20%
  - Advanced: non-corn feedstocks that ↓GHGs by 50%
  - Cellulosic: biomass-based feedstocks that ↓ GHGs by 60%
- LCA models are used to construct comprehensive accounts of biofuel C-footprint

Example: Winter barley, an advanced fuel?

- Winter barley is a starch-based feedstock;
- Produced in winter when certain agricultural fields are normally left fallow (subject to ag. Sector economics)
- Therefore, can winter barley converted to ethanol reduce life cycle GHG emissions relative to gasoline by 50%?
- How do we measure this?
- What are the variables to consider?

Basis of comparison

- In LCA, this is known as the functional unit (FU)
- Define FU for fuels: 1 MJ (energy unit)
  - Assumption: 1 MJ of gasoline can provide propulsion at the same efficiency as 1 MJ of ethanol
- Adjust inputs/outputs based on lower heating value (LHV) of ethanol
  - LHV gasoline: 33 MJ/L
  - LHV ethanol: 21 MJ/L
- Construct LCA model for barley-to-ethanol

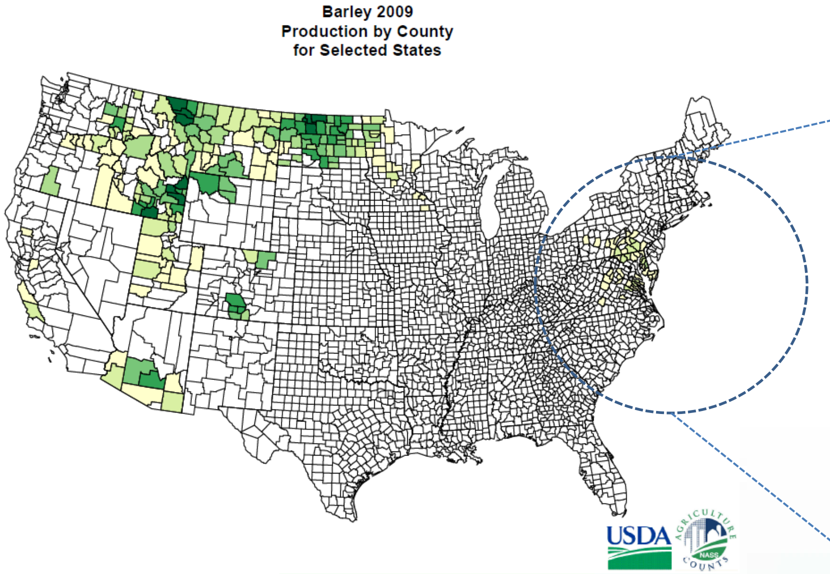
Case study: Winter Barley and Low Carbon fuels

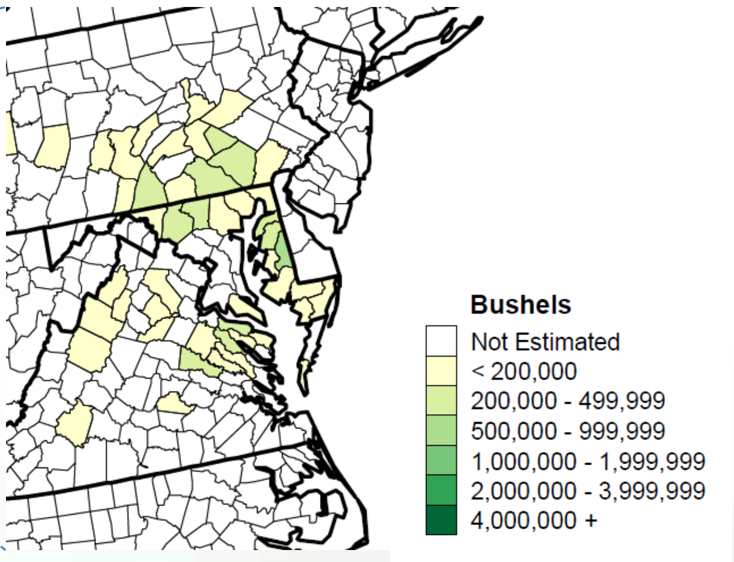
- Advanced fuel status under RFS2
  - 50% reduction in life cycle GHG emissions relative to gasoline
  - Assessment of land use change
    - Economic models employed
- Interest on the east coast U.S.
  - Winter crops and water quality
  - Maintaining agricultural lands
    - Anticipated positive impacts on land use
    - Not interfering with soybean crops
- Develop a LCA model to evaluate the life cycle GHG emissions of:
  - w. barley-to-ethanol

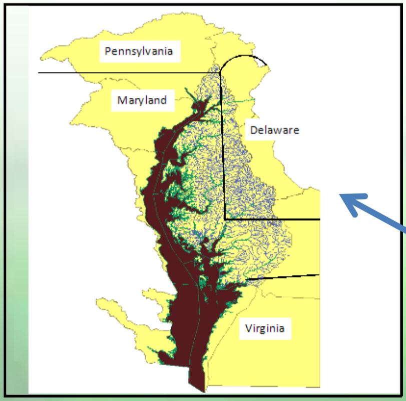
Why Winter Barley?

- Low or no anticipated indirect land use implications → use existing fallow land
  → maintain soybean yields
- Reduces nutrient leaching and runoff into surface and groundwater
- Erosion protection
- Economic benefits to participating farmers
- The growth of winter barley is promoted by the Chesapeake Bay Commission as a means of reducing nutrient and sediment runoff from farm fields

W. Barley – Spatial/temporal system boundaries







Counties in the DelMarVa region within 100-mi radius of Osage facility where WB can grow;

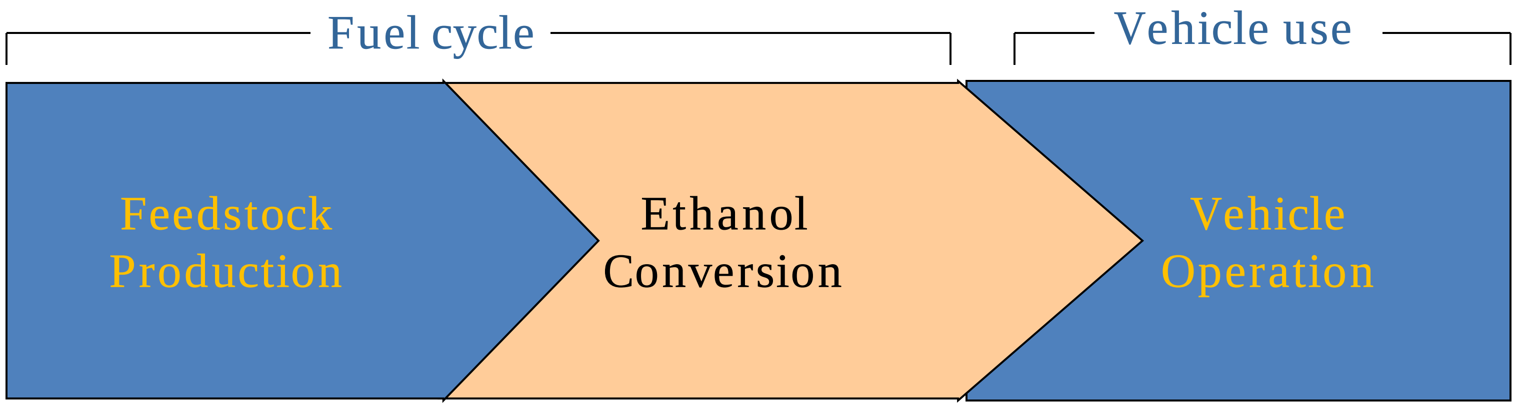
Significant Chesapeake Bay watersheds

Data sources: USDA (2010)

Biogeochemical Models

- Examination of N_2O fluxes from 10 sites in 6 states (NC, VA, KY, MD, DE, and PA)using the DAYCENT model
- Potential GHG variability/credits due to:
  - N application and timing
  - Land use history
  - Straw harvest and sale as co-product
- Allocation of N_2O fluxes in corn-winter barley-soybean 2-year rotation

Life Cycle Model



- Fertilizer
- Herbicides
- Harvesting operations
-CO2/N2O flux

Feedstocks:
- Winter barley

- Chemicals, Enzymes,
-Nutrients
-Co-products
-Denaturant (2% gasoline)

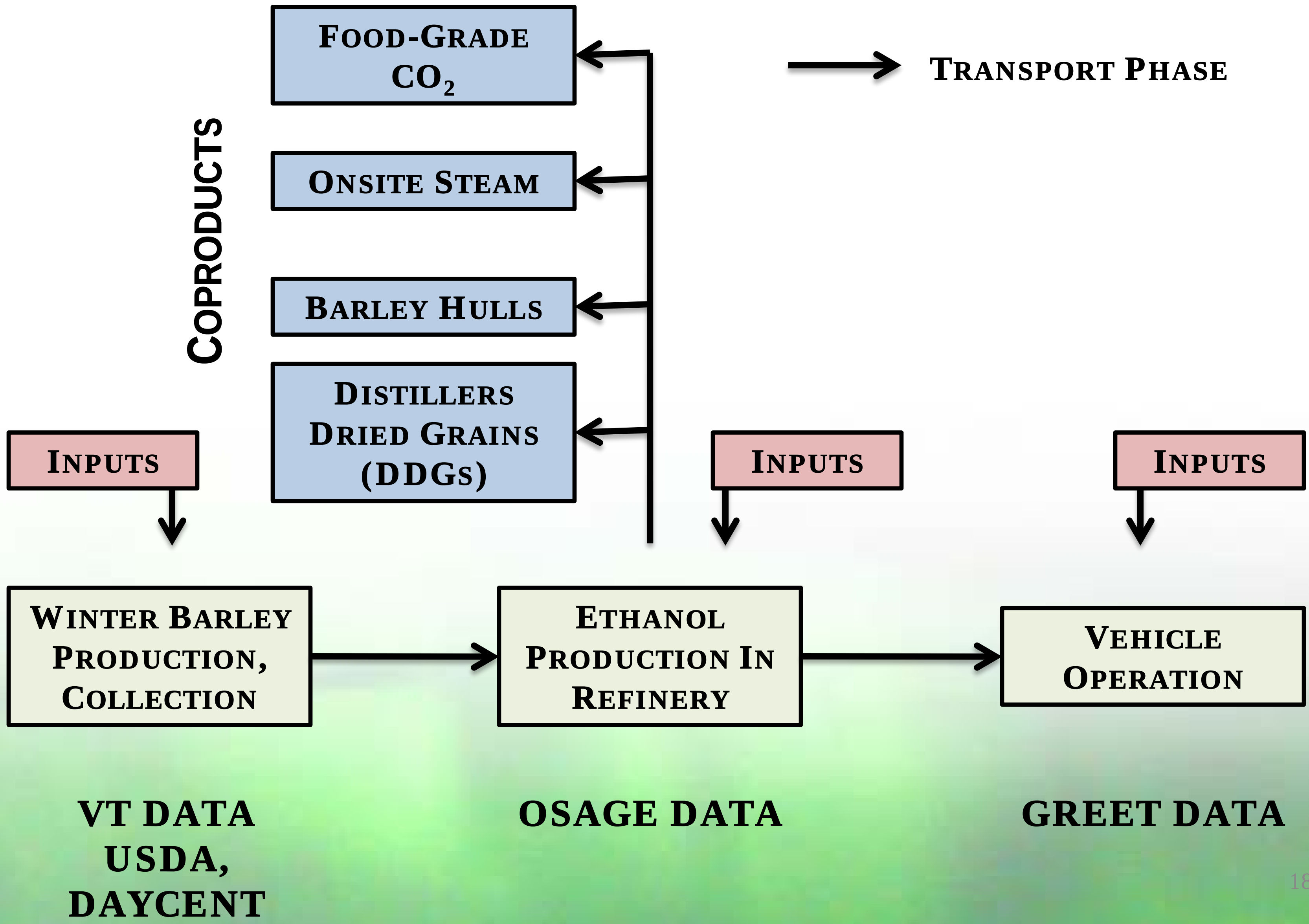
Technologies:
-Dry grind process
-Sugar generation
-Fermentation
-co-product crediting

- Blending with gasoline
- Vehicle operation

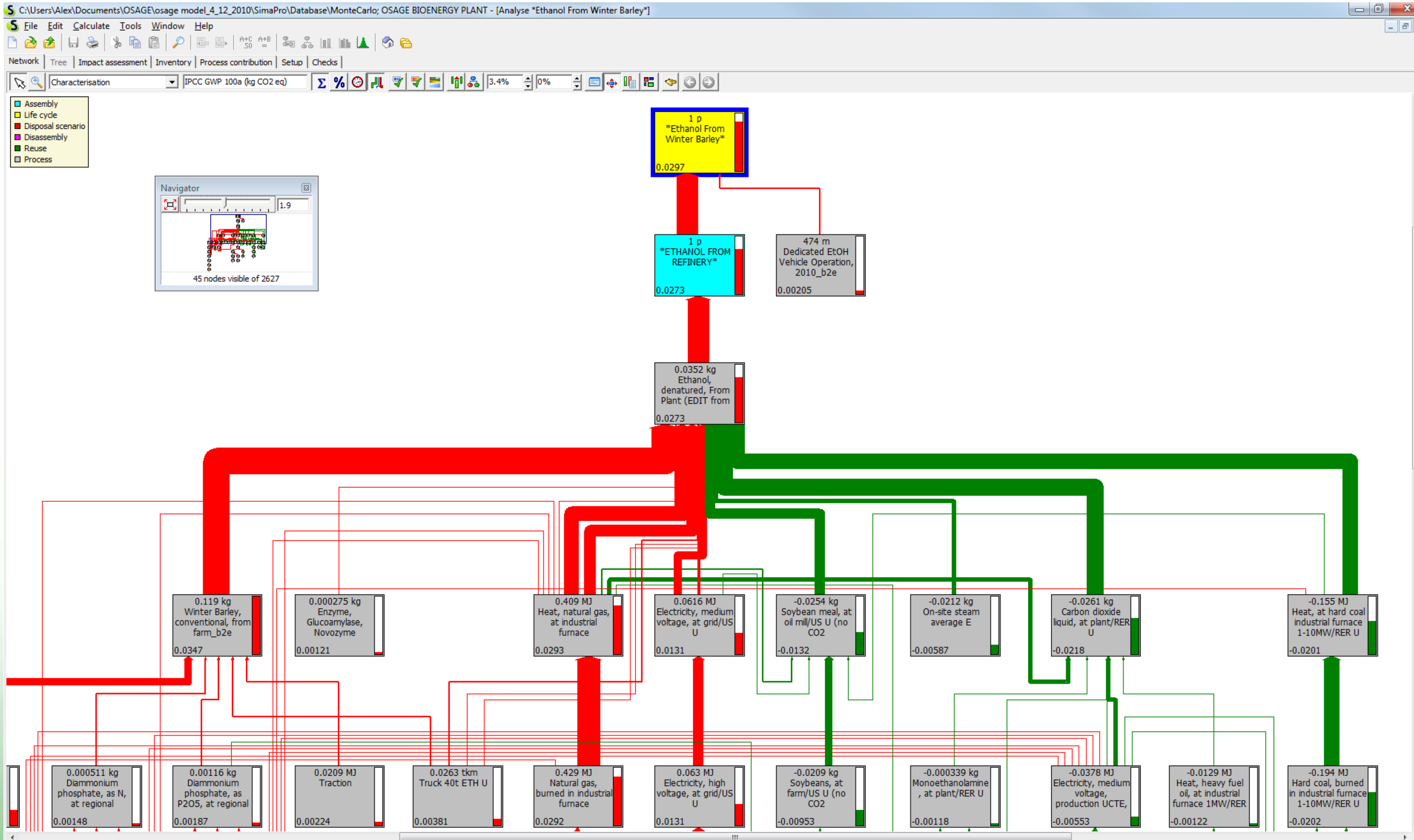
Vehicle:
-Ethanol-fueled vehicle (E92)

-Compare with baseline
-gasoline vehicle
(96 g CO2e/MJ)

Winter Barley to Ethanol



LCA Model



C:\Users\Alex\Documents\OSAGE\osage model_4_12_2010\SimaPro\Database\MonteCarlo; OSAGE BIOENERGY PLANT - [Analyse *Ethanol From Winter Barley*]
File Edit Calculate Tools Window Help
Network Tree Impact assessment Inventory Process contribution Setup Checks
Characterisation
IPCC GWP 100a (kg CO2 eq)
3.4%
0%
Assembly
Life cycle
Disposal scenario
Disassembly
Reuse
Process
Navigator
1.9
45 nodes visible of 2627
1 p *Ethanol From Winter Barley* 0.0297
1 p *ETHANOL FROM REFINERY* 0.0273
474 m Dedicated EtOH Vehicle Operation, 2010_b2e 0.00205
0.0352 kg Ethanol, denatured, From Plant (EDIT from 0.0273
0.119 kg Winter Barley, conventional, from farm_b2e 0.0347
0.000275 kg Enzyme, Glucoamylase, Novozyme 0.00121
0.409 MJ Heat, natural gas, at industrial furnace 0.0293
0.0616 MJ Electricity, medium voltage, at grid/US U 0.0131
-0.0254 kg Soybean meal, at oil mill/US U (no CO2 -0.0132
-0.0212 kg On-site steam average E -0.00587
-0.0261 kg Carbon dioxide liquid, at plant/RER U -0.0218
-0.155 MJ Heat, at hard coal industrial furnace 1-10MW/RER U -0.0201
0.000511 kg Diammonium phosphate, as N, at regional 0.00148
0.00116 kg Diammonium phosphate, as P2O5, at regional 0.00187
0.0209 MJ Traction 0.00224
0.0263 tkm Truck 40t ETH U 0.00381
0.429 MJ Natural gas, burned in industrial furnace 0.0292
0.063 MJ Electricity, high voltage, at grid/US U 0.0131
-0.0209 kg Soybeans, at farm/US U (no CO2 -0.00953
-0.000339 kg Monoethanolamine, at plant/RER U -0.00118
-0.0378 MJ Electricity, medium voltage, production UCTE, -0.00553
-0.0129 MJ Heat, heavy fuel oil, at industrial furnace 1MW/RER -0.00122
-0.194 MJ Hard coal, burned in industrial furnace 1-10MW/RER U -0.0202

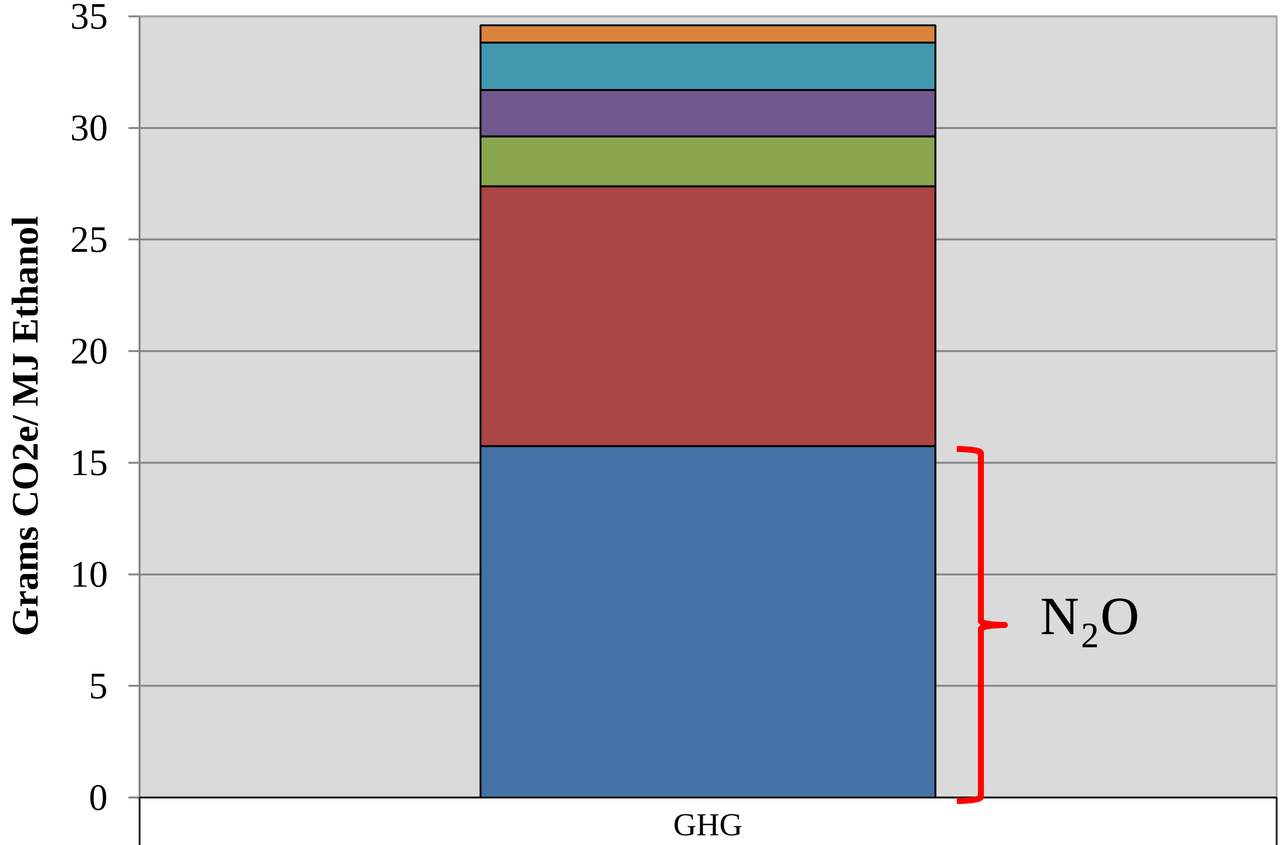
Avoided Products

- Steam co-generated and recycle:
  - displacing electricity from the local grid and natural gas heat needed for steam generation.
- Fermentative CO_2 is captured, liquefied, and sold as a food grade CO_2 co-product.
- Distiller's dried grains (DDGs)/"barley protein meal," co-produced and assumed to displace soybean meal.
- Barley hull biowaste is sold as fuel to a neighboring coal powered utility.

Emissions Calculation

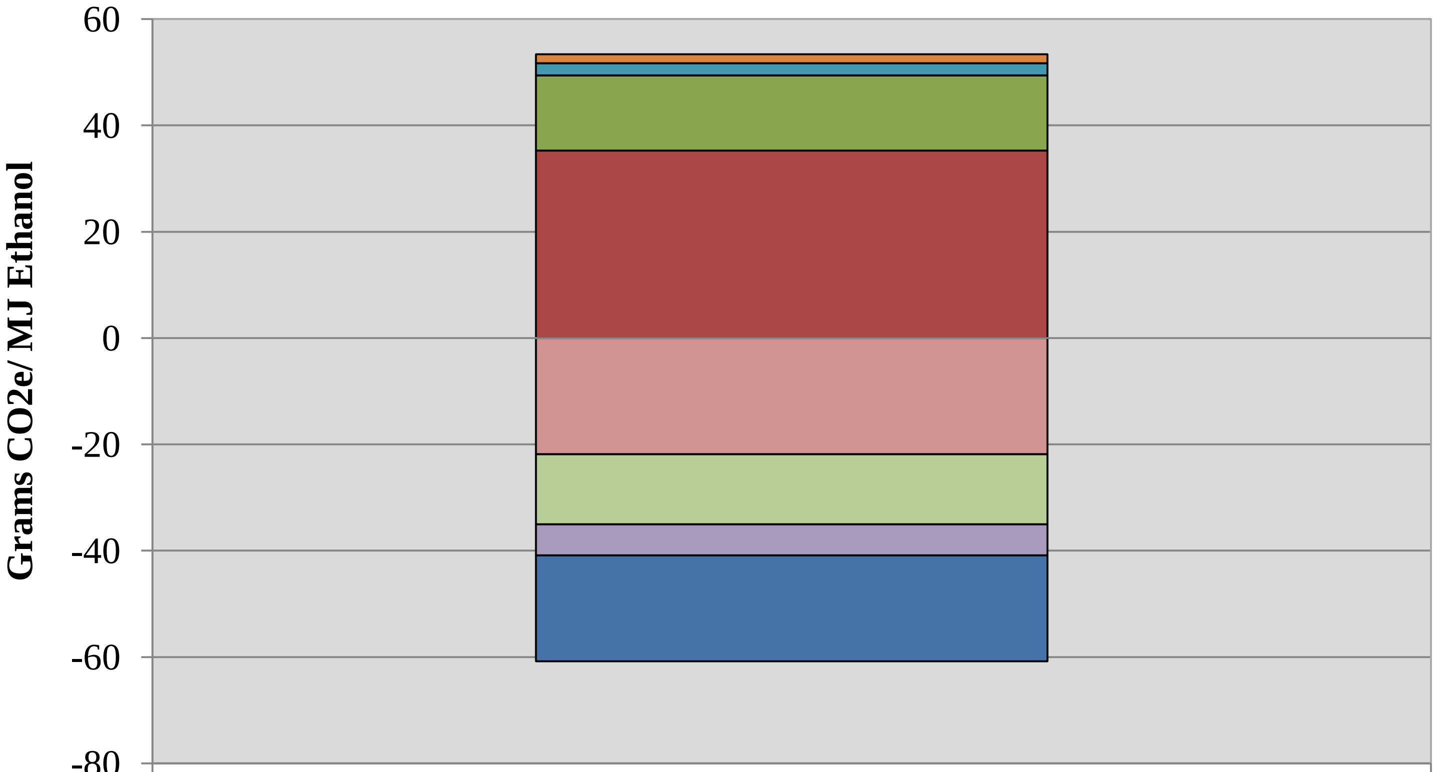
- Results document the expected GHG emissions for each phase of ethanol production.
- Emissions converted into grams CO_2 equivalents per MJ of fuel using the global warming potential coefficients relative to CO_2.
  - (CO_2=1, CH_4 = 25, N_2O = 298)
- Avoided Products (Credits)

Feedstock Process Emissions



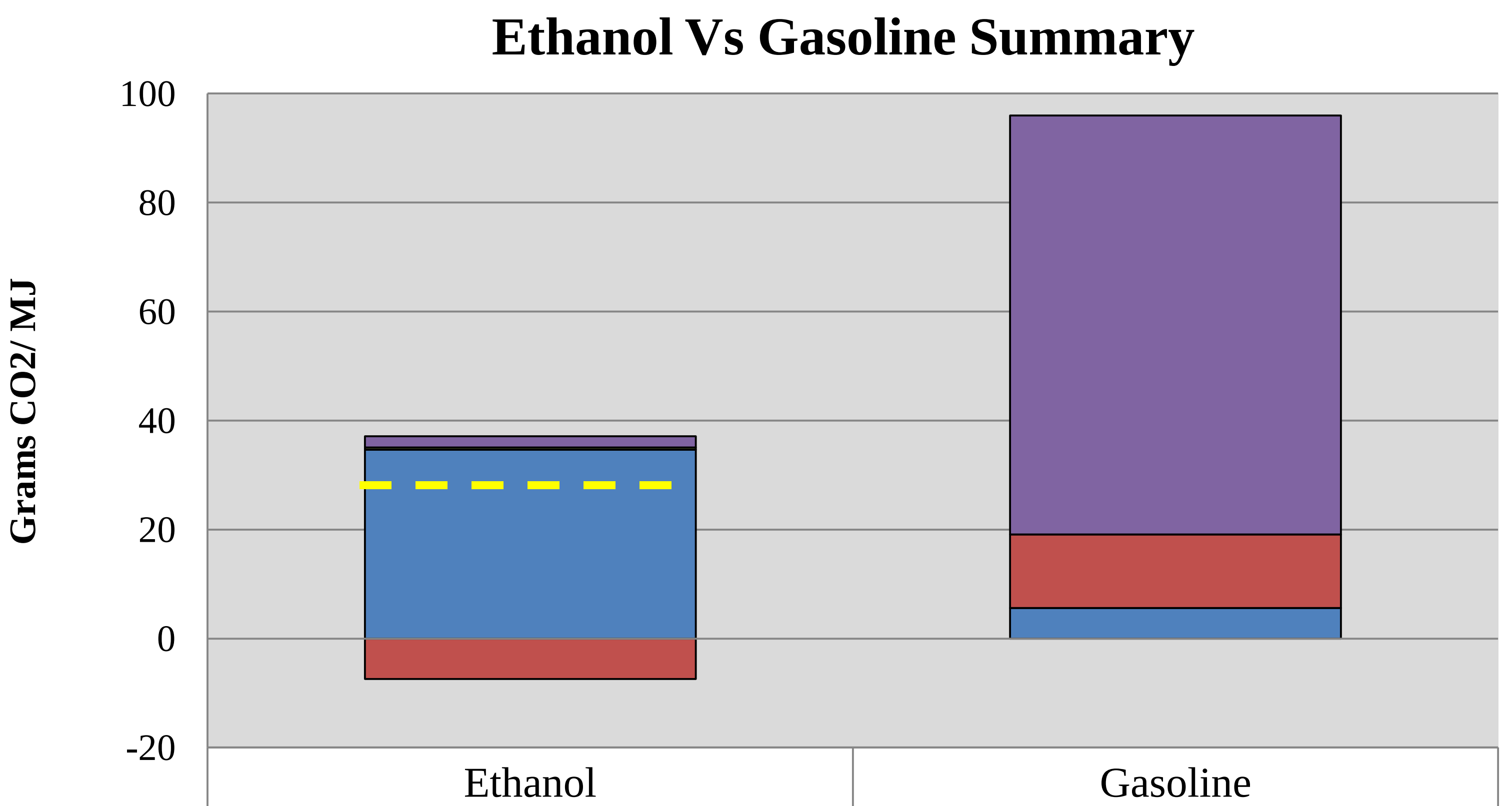
	GHG
Fertilizer (K20)	0.8
Transport	2.1
Fertilizer (P)	2.1
Traction	2.2
Fertilizer (N)	11.6
Process Emissions to Air	15.8

Refinery Process Emissions



Heat, Coal, Avoided	-19.9
On Site Steam, Avoided	-5.9
Soy Meal, Avoided	-13.2
CO2, Liquid, Avoided	-21.8
Transport	1.7
Chemicals, Etc.	2.3
Electricity, Med Voltage	14.1
Heat, Natural Gas	35.3

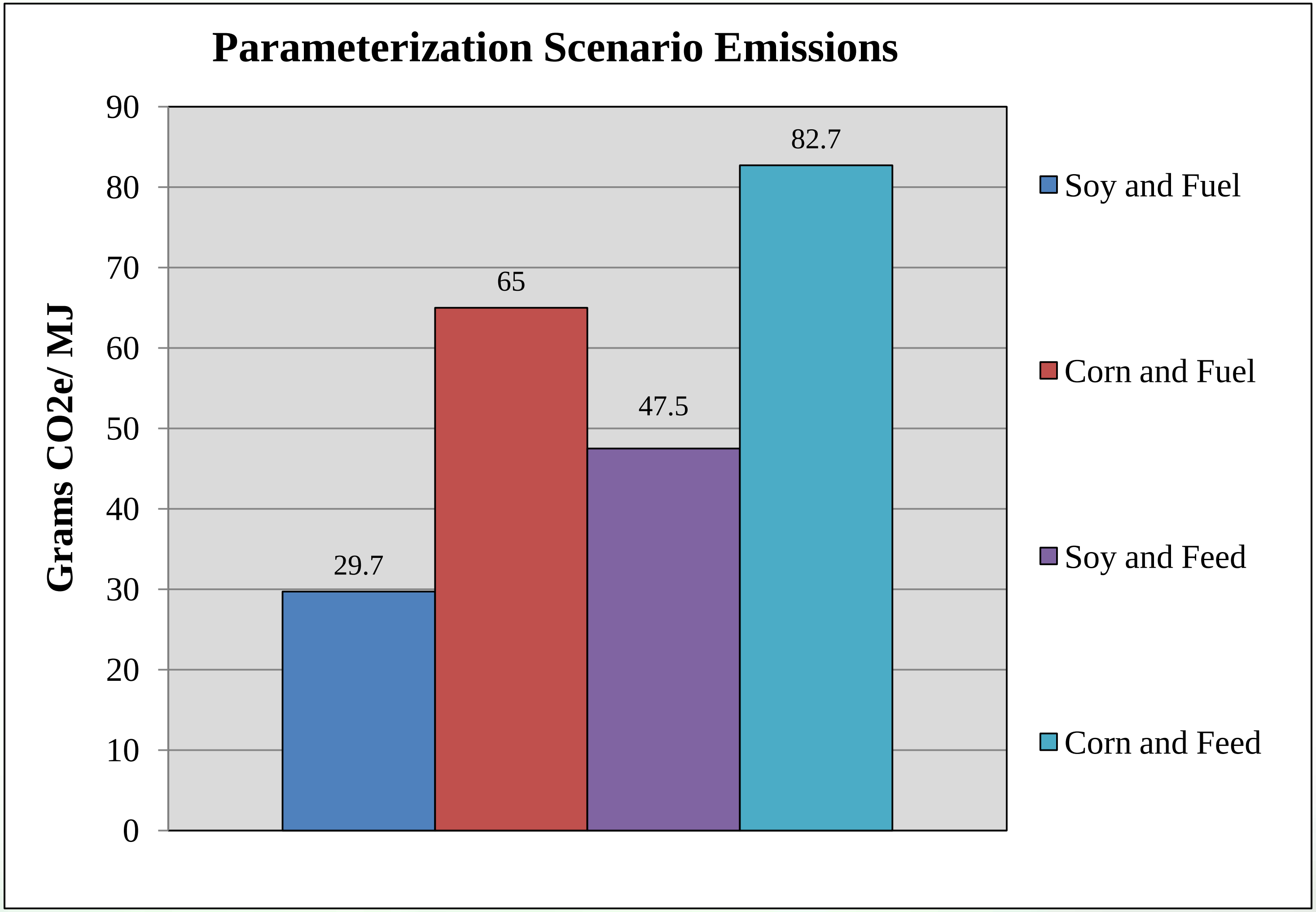
Net GHG Emissions Relative to Gasoline



	Ethanol	Gasoline
Vehicle Operation	2.1	77
Fuel Transport	0.4	
Ethanol Production and Distribution	-7.4	14
Feedstock Production, Collection and Transport	34.7	6

Parameterization

- Examination of protein co-product scenario alternatives
  - Barley hulls as fuel vs. feed
  - DDGs replaces Soybean Meal vs. Corn Meal
- Shows best scenario:
  - Hulls as fuel; DDGs replace soybean meal
- Future parameterization of:
  - Transport types/ Distances
  - Incorporate DAYCENT C/N fluxes and consideration of allocation among rotation



- ***Soybean/Corn*** *= DDGS replaces either soybean or corn meal*
- ***Fuel/ Feed*** *= Hulls utilized as either a fuel or a filler in agricultural feed*

Findings

- Life cycle GHG intensity of ethanol from winter barley is *30 grams CO_2e/MJ* ethanol
  - Compared to gasoline, which emits 96 grams CO_2e/MJ
  - A GHG emission reduction (**~69%** compared to gasoline) that would meet advanced status under RFS2
  - Important caveat: if the systems performs as modeled using single-point estimates
  - Monte Carlo Uncertainty Analysis needed:
    - Variability in N application and consequent N2O emissions
    - Changes in co-products (e.g., CO2 bottling plant)
- On-going work is evaluating variability in the GHG intensity, especially associated with the cropping system

Acknowledgements

- Alexander Stadel, Drexel University
- Osage Bio Energy
- USDA-ARS: Paul R. Adler, Kevin Hicks, Andrew McAloon
- Gregory W. Roth, Penn State University
- Wade Thomason, Virginia Tech