Biofuels: The Land Use and Environmental Implications of Addressing Transportation and Energy Problems

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October 17, 2011
UCLA Conference, Lake Arrowhead

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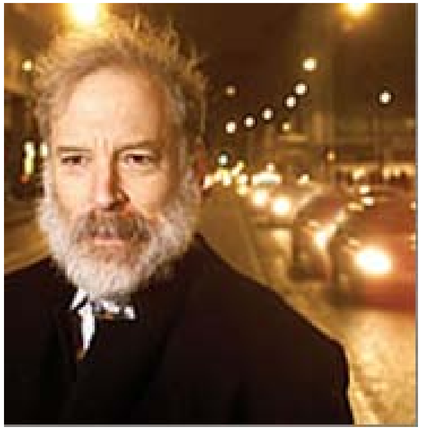
Dedication to Lee Schipper



October 17, 2011
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Outline:

- Biofuels and policy context for decarbonizing transportation
- Global consequences of biofuels → LUC, ILUC
- Life Cycle Assessment (LCA) of lignocellulosic biofuel conversion technologies
  - Models; uncertainty
  - Focus: GHG environmental impacts
- Better biomass and biofuels:
  - perennial grasses, ag. residues, winter crops,
  - pyrolysis bio-oil, higher alcohols, algae bio-oils

Introduction and Background

- A 2004 paper outlined a strategy for reducing GHG emissions from different economic sectors by 1 gigaton each, a "wedge analysis"
  Pacala and Socolow, *Science*, 2004. 305: 968-972
- The Gigaton Throwdown Project
  - Launched by venture capitalists in clean tech industry
  - What is the capital cost of investment to achieve a 1 gigaton reduction in GHG emissions by 2020?
- Biofuels are one avenue for achieving this "wedge" in the transportation sector

Policy Context:

- Since 2004, low carbon and renewable fuel policies in development around the world
  - LCFS (California, North-east states, Ontario), RFS (US)
  - Reduce GHGs relative to baseline gasoline ~93 gCO_2e/MJ
- Biofuels compatible, attractive strategy for reducing transportation's carbon intensity
  - Feedstocks today: corn (ethanol), soybean (diesel)
    - Mingles energy with food markets
- Recent research on adverse "land-based" impacts of biofuels:
  - Direct and indirect CO_2 from land use change (LUC)
  - Other sustainability risks: water, biodiversity, food security
- Need a robust life cycle assessment tool to estimate complete fuel cycle GHG emissions + consequences

Land use change (LUC) may cause large GHG emissions

U.S. corn/soybean farmers sell land to developers, land is now developed

U.S. soybean exports go down and world soybean prices rise

Additional land in Brazil (for instance) is put into soy production

Soy farmers everywhere use more inputs to increase yields

Unobservable variables!

Indirect LUC emissions

Indirect process emissions

Potentially large global land carbon debt!

Direct process emissions: Change in CO_2 flux on land

From M. O’Hare, UC Berkeley; Searchinger et al., 2008, 10.1126/science.1151861

Sustainability issues:

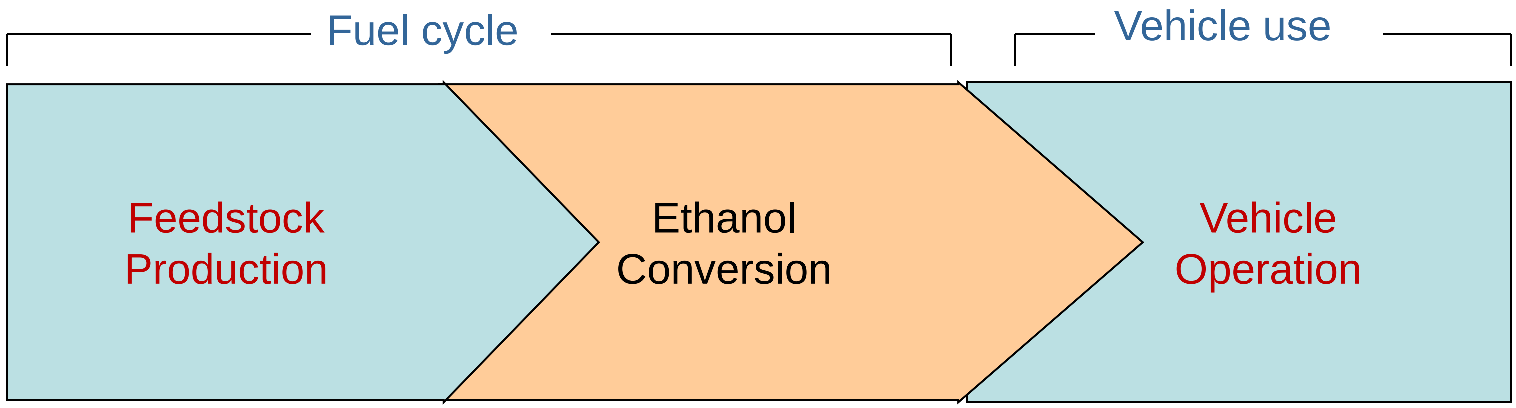
Sustainability criteria[1]	
Ecological	**Socio-economic**
Water use	Food and energy security
Water pollution	Land tenure
Organic pollutants	Net Employment
Agro-chemicals	Income distribution
Biodiversity	Wages
Soil erosion	Working conditions
Fertilizer use	Child labor
GMOs	Social responsibility
GHGs/energy input	Competitiveness
Harvesting practices	Culture - Traditional way of life

[1]Direct + Indirect

Scale: Regional, national, global

Spatari, O'Hare et al. 2008

LCFS/RFS: Fuel Cycle Model



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

Feedstocks:
- Winter barley

- Chemicals, Enzymes,
-Nutrients
-Co-products: CO2, protein meal, hulls (energy recovery)
-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)

+ Indirect consequences

Policy Context:

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- Biofuels compatible, attractive strategy for reducing transportation's carbon intensity
- New research on adverse "land-based" impacts of biofuels:
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  - Other sustainability risks: water, biodiversity, food security
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Methods

- LCA methods used to estimate C-intensity of biofuels
- Established process-based and EIO-LCA methods not equipped to estimate “market-mediated” LUC effects
  - Need new tools: Consequential LCA (CLCA)
  - Example: Price response via CGE or PE models
- Circumvent iLUC effects by selecting lignocellulosic feedstocks that do not compete for arable land and use “sustainable” fractions:
  - Ag. Residue, MSW, forest/mill waste, novel technologies (e.g., algae)

Key challenges with CLCA (1)

- Completeness: what are the "full" consequences of a decision (e.g., implementing the Renewable Fuel Standard) in the uncertain future with all its dynamics?
  - 1st order consequences: directly associated with the physical flows
  - 2rd order consequences: caused by equilibrium shifts controlled by price mechanisms
  - Other rebound effects

- Data availability and uncertainties
  - E.g., what will be the marginal electricity mix for future biorefineries? (varies by time horizon, available resources, cost, technologies, capacities, etc.)

References:
Zhang, Spatari, Heath, 2010; Ekvall T. 2002; Sandén and Karlström, 2007.

Key challenges with CLCA (2)

- Modeling tools
  - Commonly used tools:
    - ➢ Macro-economic and/or econometrical models, e.g.,
      1) Partial equilibrium (PE) models
      2) Computable general equilibrium (CGE) models
    - ➢ Agent-based models
    - ➢ System Dynamics models
    - ➢ Scenarios

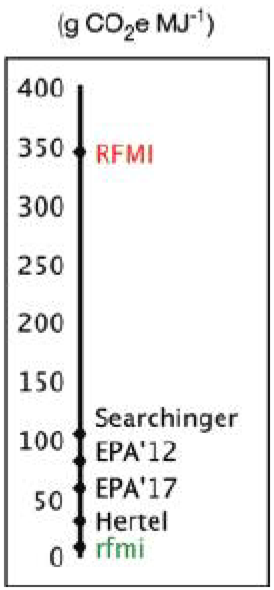
From: Zhang, Y. National Renewable Energy Laboratory (NREL)

Reference: Davis, et al. 2009.

Ethanol: Energy and Environment

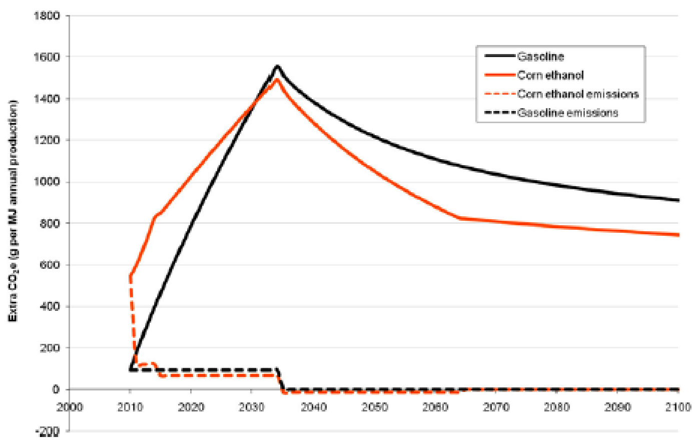
- Energy security: compared to gasoline, corn ethanol:
  - Significantly reduces petroleum use (~95%), moderately lowers (13%) fossil energy use (Farrell et al. 2006);
- *M*any increased risks related to LUC

iLUC



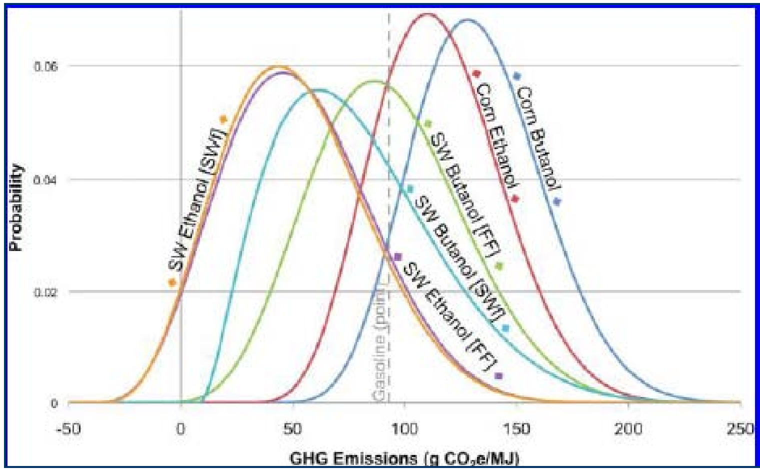
Plevin et al 2010

Time Effects



O'Hare et al 2009

Uncertainty



Mullins et al 2010

Direct GHG Emissions – biofuels versus conventional & unconventional oil

energy source	energy yield (PJ/ha)	GHG emissions per disturbed area (t CO_2e/ha)	GHG emissions per energy output (g CO_2e/MJ)
Fossil Fuel			
California oil	0.79 (0.48–2.6)	73 (59–117)	0.09 (0.02–0.25)
	0.55 (0.33–1.8)		0.13 (0.03–0.35)
Alberta oil	0.33 (0.16–0.69)	157 (74–313)	0.47 (0.12–1.98)
	0.20 (0.092–0.40)		0.78 (0.20–3.39)
oil sands - surface mining	0.92 (0.61–1.2)	3596 (953–6201)	3.9 (0.83–10.24)
oil sands - in situ	3.3 (2.2–5.1)	205 (23–495)	0.04 (0.0–0.23)
Biofuel			
palm biodiesel (Indonesia/Malaysia)[a]	0.0062	702 ± 183	113 ± 30
palm biodiesel (Indonesia/Malaysia)[a]	0.0062	3452 ± 1294	557 ± 209
soybean biodiesel (Brazil)[a]	0.0009	737 ± 75	819 ± 83
sugar cane (Brazil)[a]	0.0059	165 ± 58	28 ± 10
soybean biodiesel (Brazil)[a]	0.0009	85 ± 42	94 ± 47
corn ethanol (US)[a]	0.0038	134 ± 33	35 ± 9
corn ethanol (US)[a]	0.0038	69 ± 24	18 ± 6

→ Peatland conversion

Yeh et al. 2010, Environ. Sci. Tech. 44: 8766-8772

Better Biomass & Biofuels

- LCA methods used to estimate C-intensity of biofuels
- Established process-based and EIO-LCA methods not equipped to estimate “market-mediated” LUC effects
  - Example: Price response via CGE or PE models
- Minimize iLUC effects by selecting lignocellulosic feedstocks that do not compete for arable land and use “sustainable” fractions:
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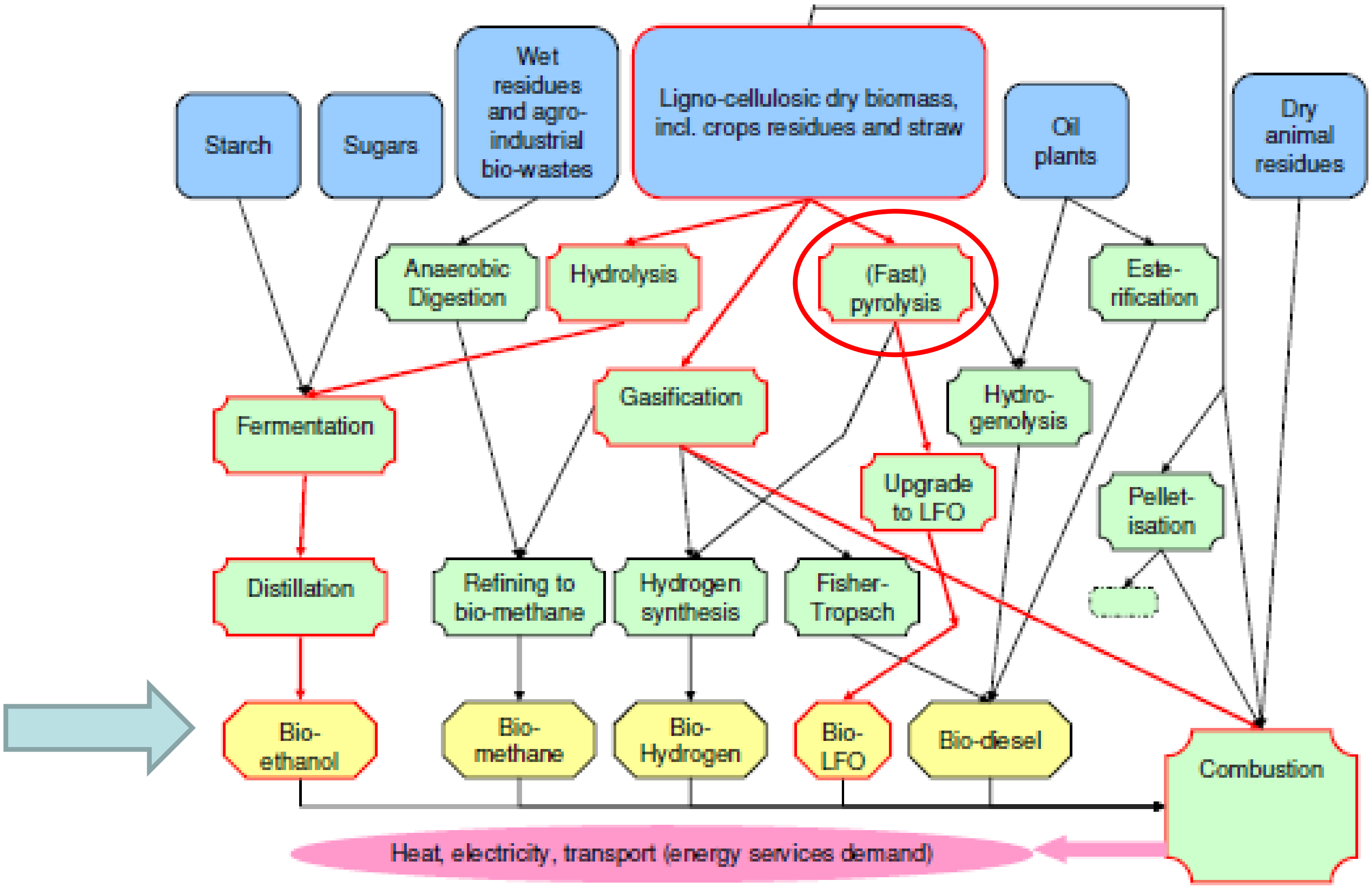
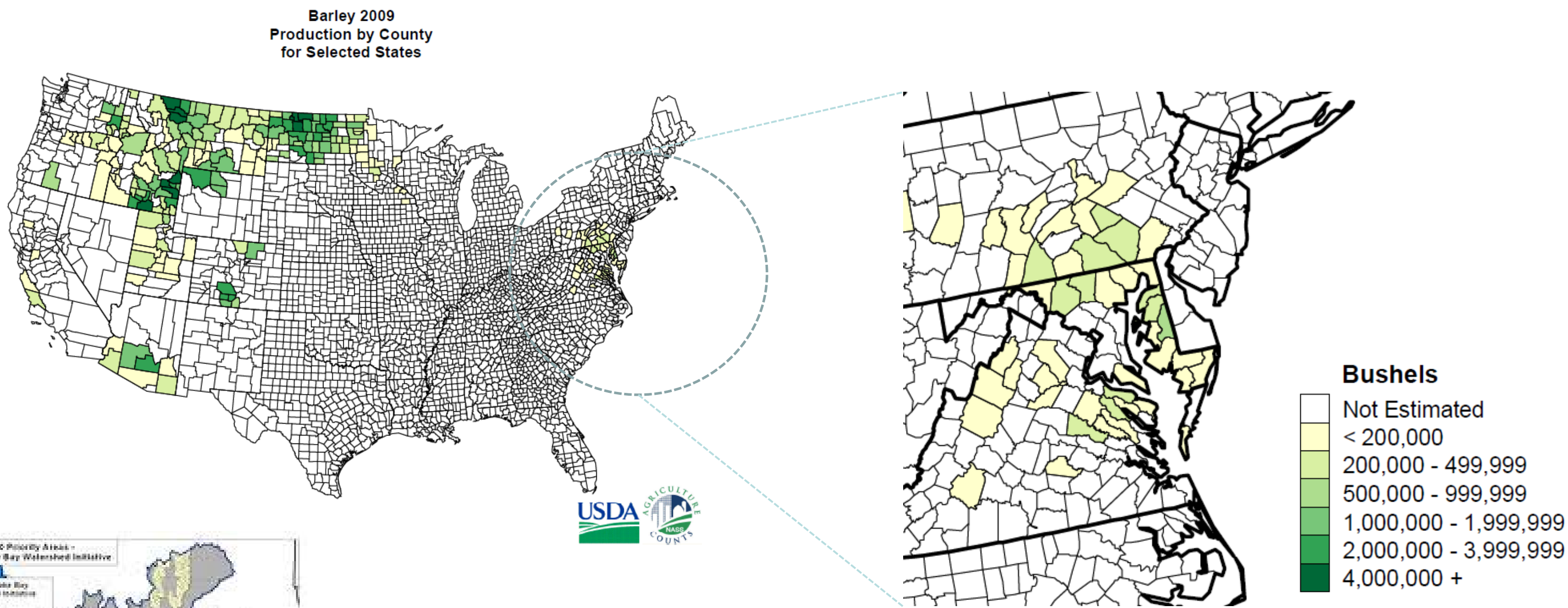
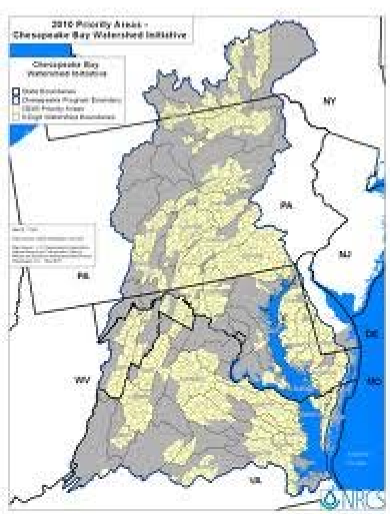
Bioenergy Production Pathways



Clarke et al., 2009

W. Barley – Spatial/temporal system boundaries



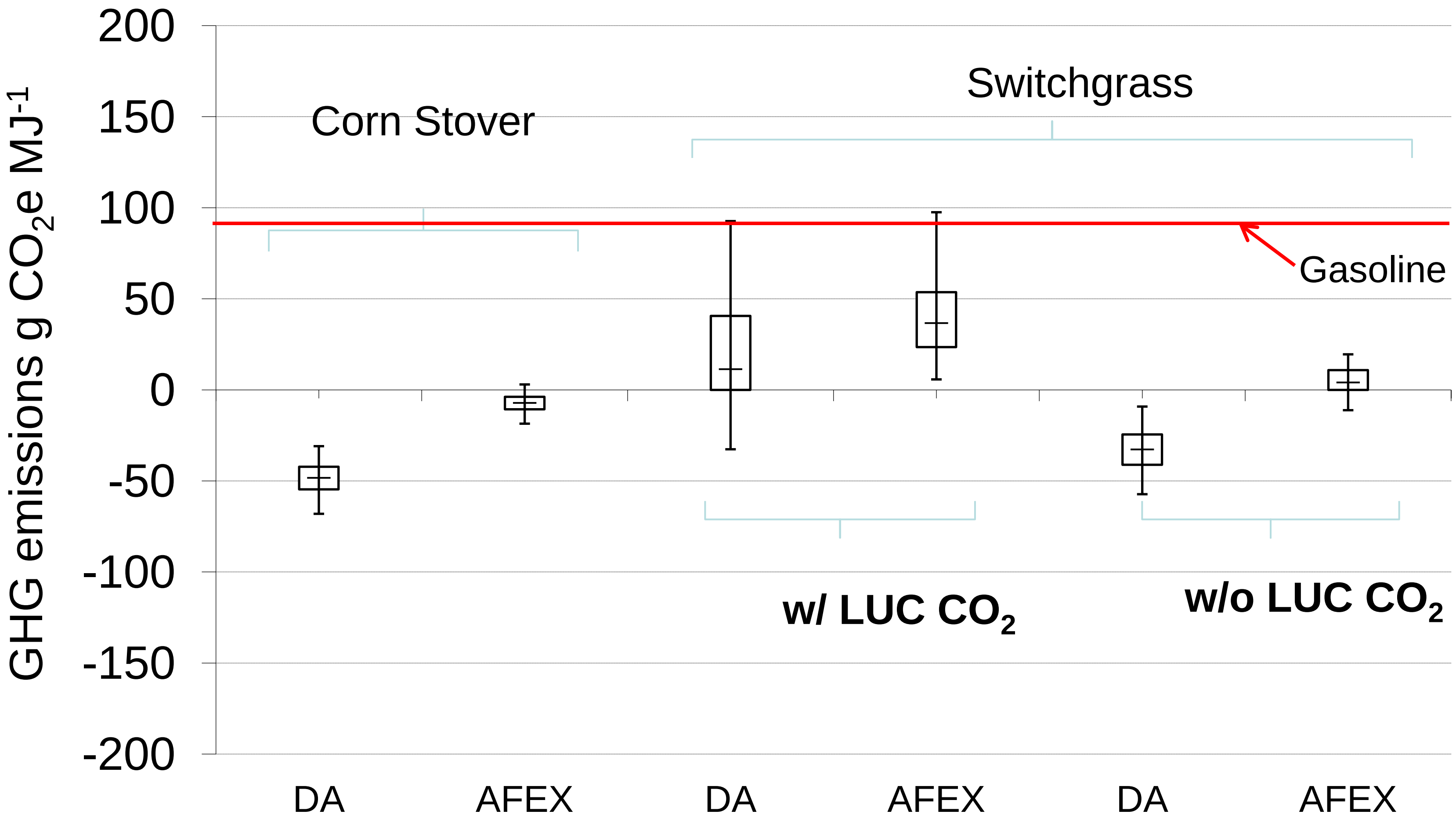


Counties in the DelMarVa region within 100-mi radius of Osage biorefinery; conversion to E98: ~38 g CO_2e/MJ

Significant Chesapeake Bay watersheds

Data sources: USDA (2010); NRCS (2011)

Uncertainty in LC GHG emissions (with LUC vs. without LUC)



DA = dilute acid pretreatment followed by simultaneous saccharification and cofermentation (SSCF)
AFEX = ammonia fiber explosion pretreatment followed by SSCF

Spatari and MacLean (2010), Environ. Sci. Technol. 44: 8773-8780

Better Biofuels? Lignocellulosic biomass

- LCA models show reduction in GHG intensity of ag. residue and energy crops on marginal lands
  Spatari et al., 2010. *Bioresource Technology*, doi:10.1016/j.biortech.2009.08.067
- Lignocellulosic ethanol is still under development!
  - No competitive technologies at commerical-scale
  - Key technological challenge for R&D is enhancing individual processes AND overall **integration**
  - Demonstration scale projects
- Development of other infrastructure compatible fuels show promise but need further research
  - Upgraded pyrolysis bio-oil + biochar
  - Higher alcohols

Acknowledgements

- Osage Bio Energy
- USDA-ARS: Paul R. Adler, Kevin Hicks, Andrew McAloon, Akwasi Boateng
- Gregory W. Roth, Penn State University
- Wade Thomason, Virginia Tech
- Yimin Zhang, NREL

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