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Life Cycle Greenhouse Gas Emissions from Biofuels: Variability, Uncertainty, and Steps Toward Accurate Regulation

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Life Cycle Greenhouse Gas Emissions from Biofuels: Variability, Uncertainty, and Steps Toward Accurate Regulation

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Today's Presentation

a) Variability in life cycle greenhouse gas (GHG) emissions from corn-ethanol:

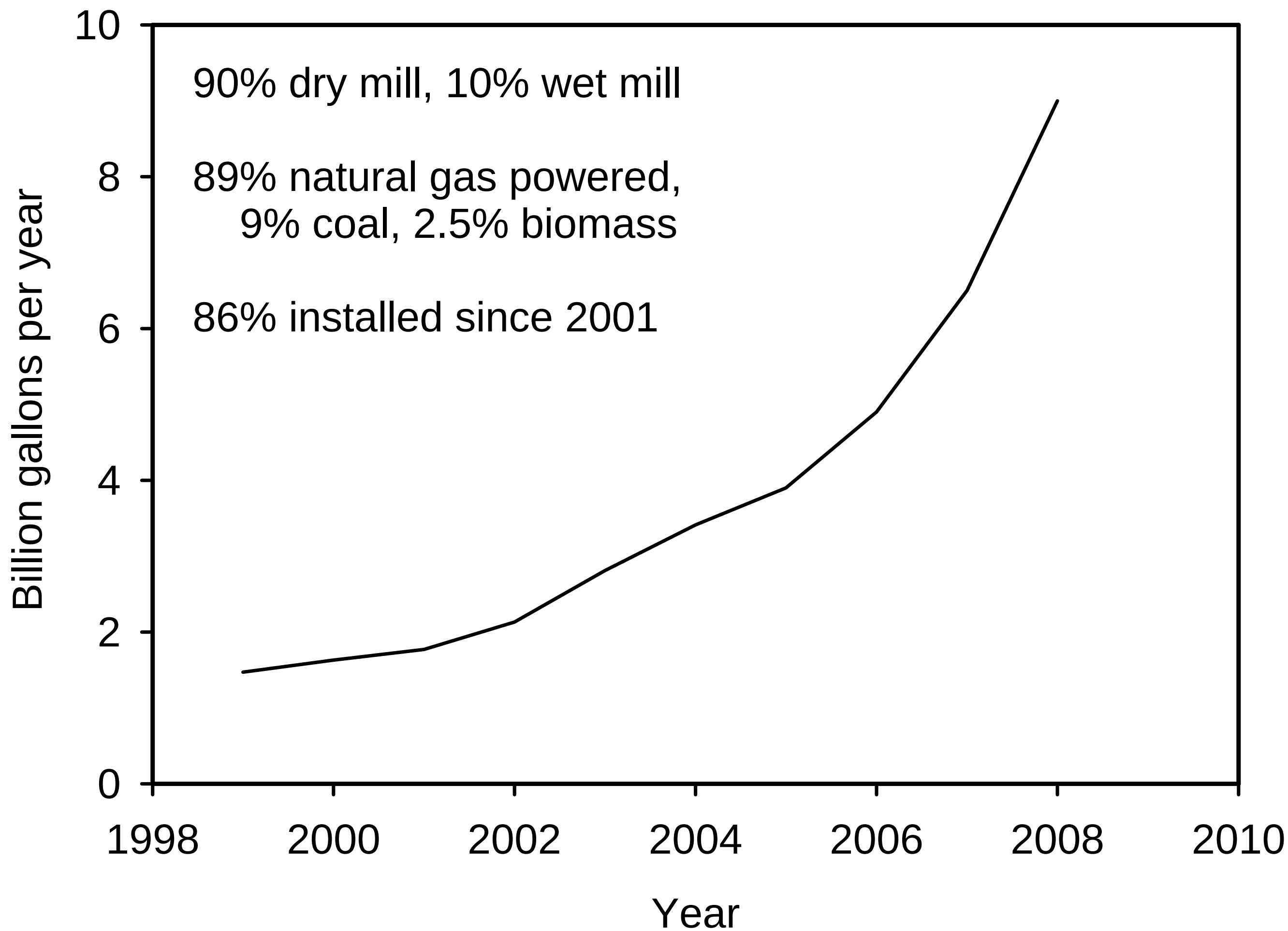
- biorefineries
- cropping systems
- co-product feeding to livestock

b) EPA regulation of life cycle GHG emissions from biofuels & use of life cycle analysis (LCA):

- uncertainties & inaccuracies
- indirect effects

c) Building accurate knowledge infrastructure, theory, and research teams for accurate LCA methods for biofuels

~90% of U.S. ethanol production uses corn grain at new natural gas-powered dry mills

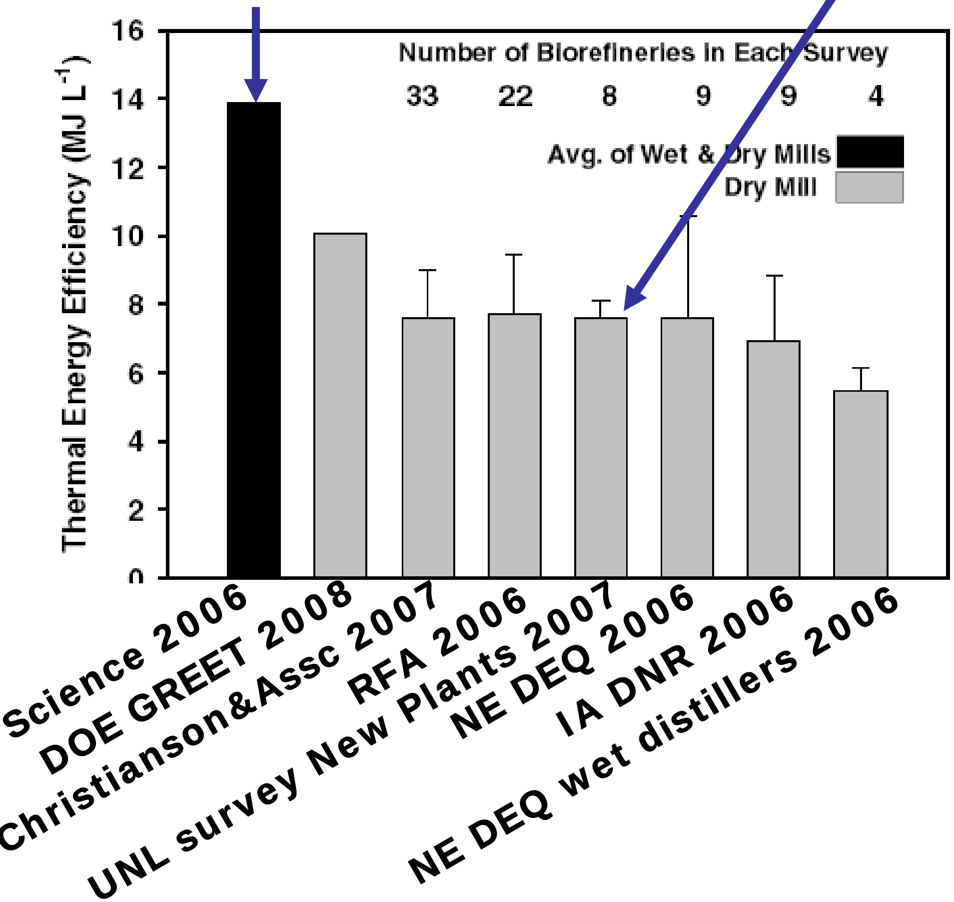


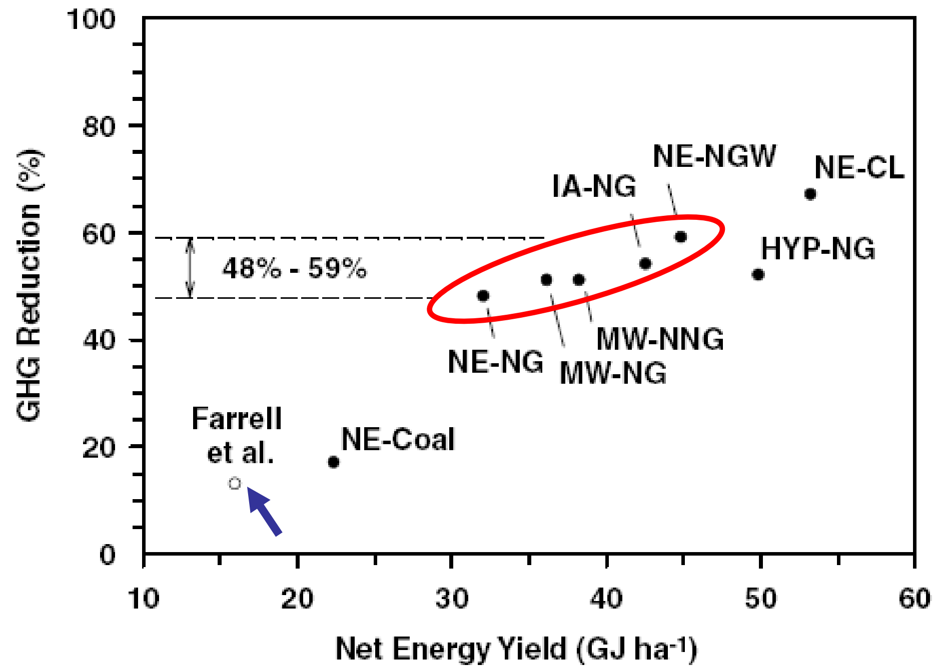
Source: Liska AJ & Perrin RK. Energy and Climate Implications for Agricultural Nutrient Use Efficiency. IN: *GIS Applications in Agriculture–Nutrient Management for Improved Energy Efficiency*. CRC Press. in press

New survey data shows improved energy efficiency at biorefineries & reduced life cycle GHG emissions

Avg. natural gas use in 2001 70% of life cycle emissions

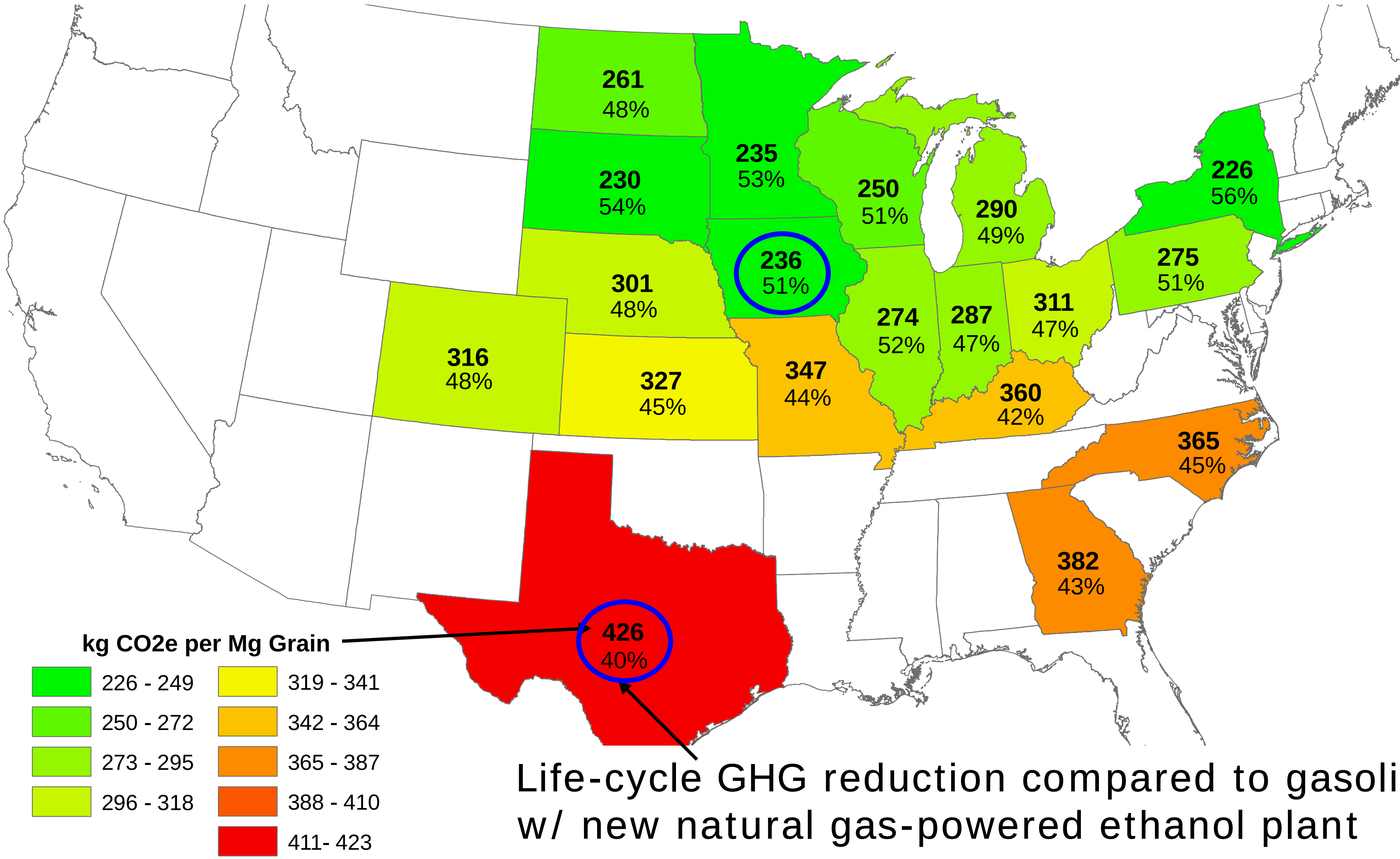
Avg. natural gas use in newer plants, less variability





Source: Liska et al, *Journal of Industrial Ecology*, 13, 58-74 (2009)

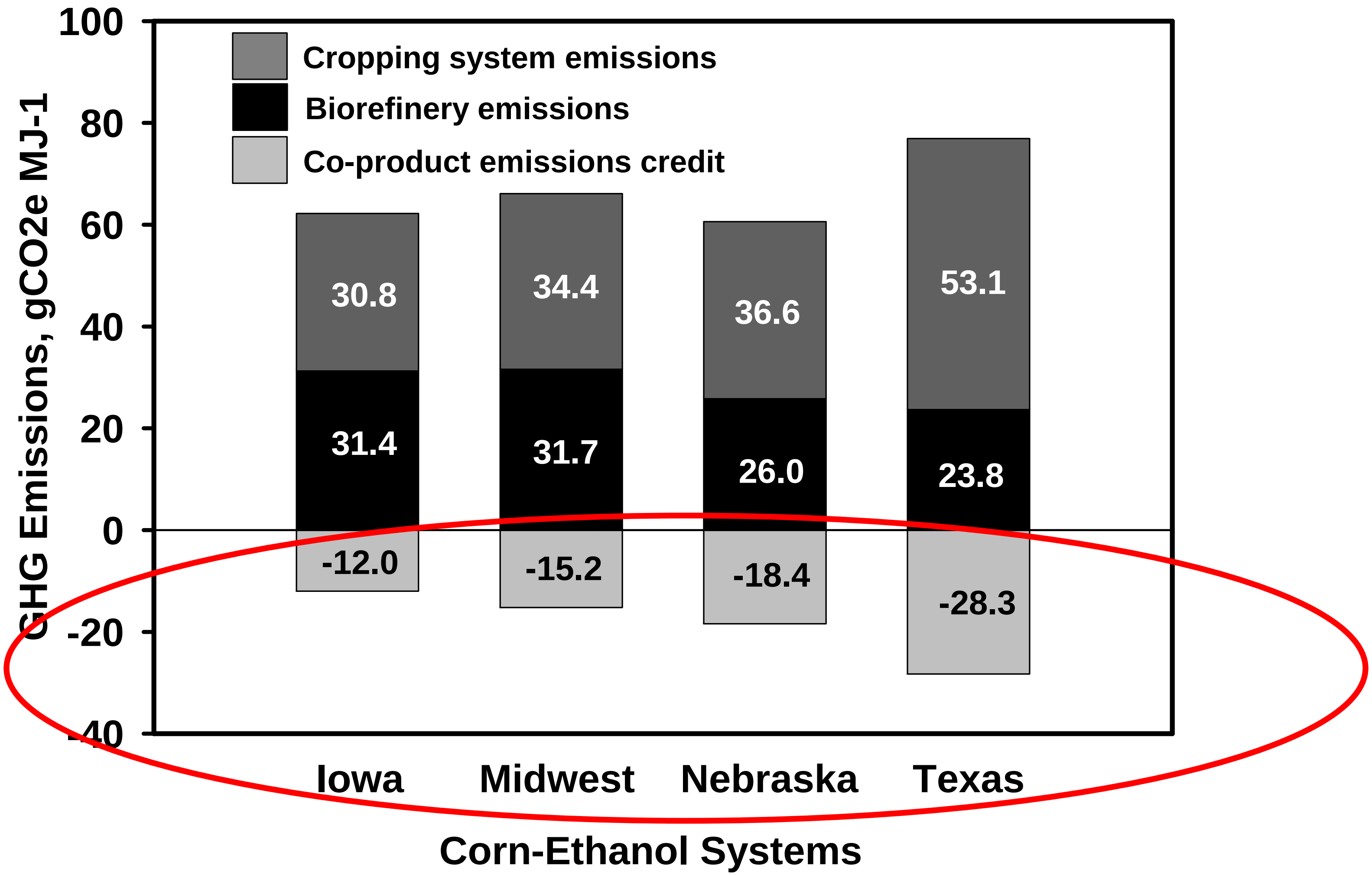
GHG emissions from corn production depend on *crop yields*, *nitrogen fertilizer rates*, and *cropping inputs*, producing variability in ethanol life cycle emissions



Source: Liska et al, *Journal of Industrial Ecology*, 13, 58-74 (2009)

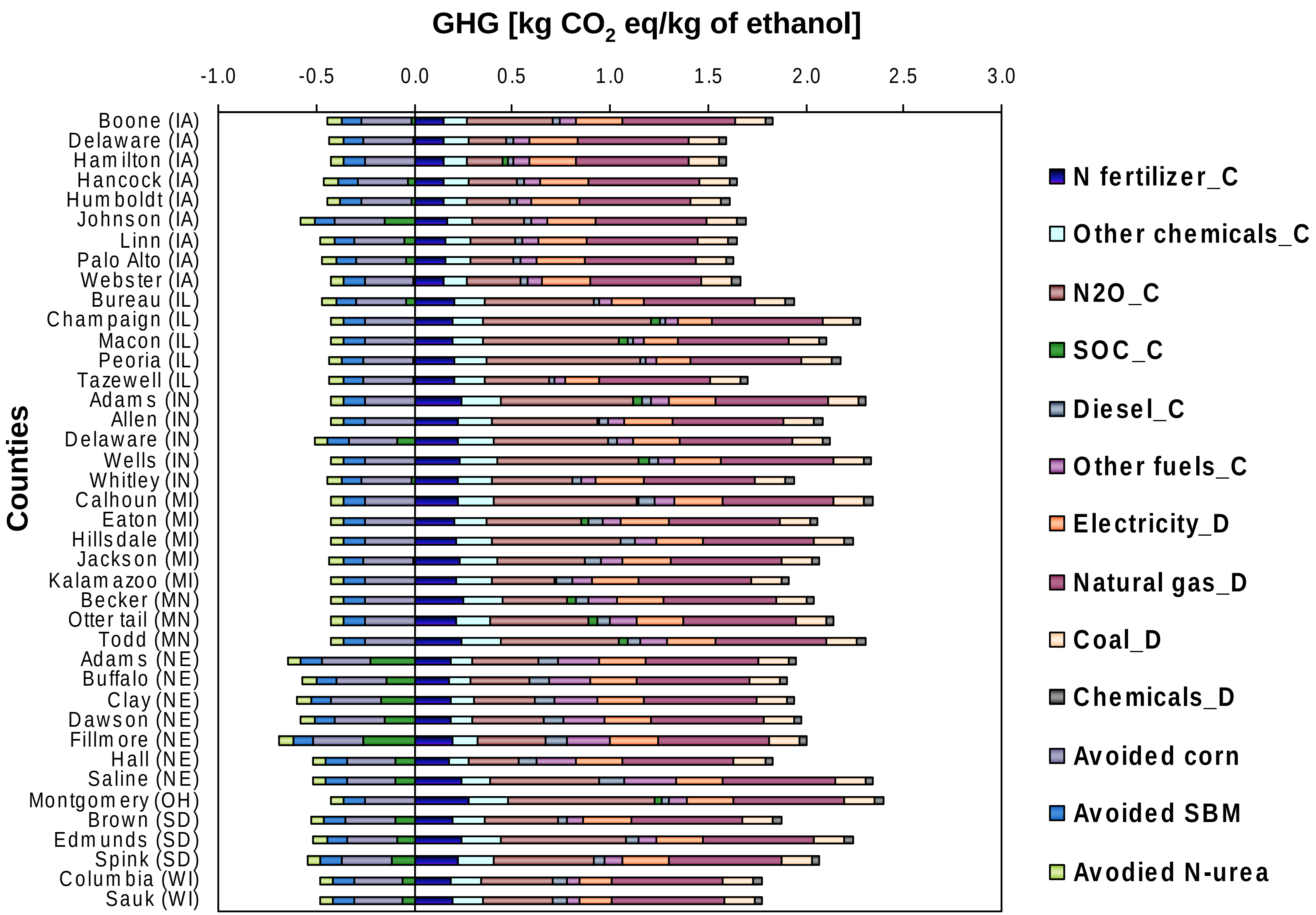
GHG emissions credits for distillers grains depend on *types produced*, *livestock fed*, and *cropping region*

(Wet vs. Dry Distillers) (Beef Cattle vs. Dairy/Swine) (State)



Source: Bremer et al. *Journal of Environmental Quality* (2010)

Soil and *climate variability* determine regional life cycle GHG-intensities of corn-ethanol



Source: Kim, S. & Dale, BE., *International Journal of Life Cycle Assessment*, 14, 540–546, 2009

Research Leads to General Principles of Biofuel LCA

- Biofuel production is a complex **system of systems,**
  crop production, biorefinery, co-products, fossil fuel inputs, etc.
- **Variability in space and time** for *cropping*, *biorefineries*, and *distillers grains feeding* leads to variability and uncertainty in LCA results
- **Small changes in the magnitude** of sensitive parameters *dramatically* change LCA results: crop and biorefinery yields, N_2O emissions, biorefinery natural gas and electricity, lime appl. rates
- **Empirical data are scarce** for key aspects of the system
- LCA results depend on the **depth and rigor of analysis**
- **“Standardized” LCA methods** are being developed for biofuels (EPA, California), but none currently exist. *The academic community vigorously discusses biofuel LCA methods, but the science is currently far from clear*

EISA 2007 and EPA Regulation

- Requires reductions in life cycle GHG emissions (CO_2, CH_4, N_2O) for corn-ethanol vs gasoline by ***20%***
- EPA RFS2 proposes to use a range of hypothetical average efficiencies to determine the GHG emissions performance for different biorefinery types for corn-ethanol
- ***Problem:***

  Significant variability is observed for many parameters & hypothetical averages do not accurately represent the GHG emissions from individual biofuel producers

- ***Therefore:***

  Frequent surveys of data on biofuel producers, regional cropping, & livestock feeding *are necessary to accurately assess GHG emissions reductions for regulated facilities*

EPA Proposed LCA Regulations

"…it would require an extremely complex assessment and administratively difficult implementation program to track how biofuel production might continuously change from month to month or year to year [state to state]. Instead, it seems appropriate that each biofuel be assessed a level of GHG performance that is constant over the implementation of this rule, allowing fuel providers to anticipate how these GHG performance assessments should affect their production plans…"

--Proposed Rule, May 26, 2009, *Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program*. Federal Register / Vol. 74, No. 99

Assessing the Complexity of Biofuel Production: Inventory of Life Cycle GHG Emissions for Corn-Ethanol using One (1) Model

Component	GHG emission category	$gCO_2e\ MJ^{-1}$	Mg CO_2e*	% of LC
Crop Production				
	Nitrogen fertilizer, N	4.26	34,069	7.46
	Phosphorus fertilizer, P	0.953	7,618	1.67
	Potassium fertilizer, K	0.542	4,337	0.950
	Lime	2.82	22,577	4.95
	Herbicides	1.51	12,079	2.65
	Insecticides	0.018	141	0.031
	Seed	0.193	1,540	0.337
	Gasoline	0.355	2,837	0.621
	Diesel	1.73	13,848	3.03
	LPG	1.24	9,932	2.18
	Natural gas	0	0	0
	Electricity	0.348	2,785	0.610
	Depreciable capital	0.268	2,144	0.470
	N_2O emissions**	14.1	112,550	24.7
	TOTAL	28.3	226,456	49.6
Biorefinery				
	Natural gas input	19.7	157,356	34.5
	NG Input: drying DGS†	0	0	0
	Electricity input	6.53	52,201	11.4
	Depreciable capital	0.458	3,663	0.802
	Grain transportation	2.11	16,851	3.69
	TOTAL	28.8	230,071	50.4
Co-Product Credit				
	Diesel	0.216	1,731	0.379
	Urea production	-2.62	-20,956	-4.59
	Corn production	-11.4	-91,501	-20.0
	Enteric fermentation-CH_4	-2.64	-21,102	-4.62
	TOTAL	-16.5	-131,828	-28.9
Transportation of Ethanol from Biorefinery		1.40	11,196	0
LIFE-CYCLE NET GHG EMISSIONS		42.0	335,895	100
GHG-intensity of ethanol, g $CO2e\ MJ^{-1}$		42.0	335,895	
GHG-intensity of gasoline‡, g $CO2e\ MJ^{-1}$		92.0	735,715	
GHG reduction relative to gasoline, %		50.0	399,819	54.3%

Crop & Soil System

Nitrogen Fertilizer Production/Distribution System

Seed Production System

Fossil Fuel Production/Distribution System

Nutrient Cycle, N-related GHG emissions

Biorefining System

Enzyme System

Grain Transportation System

Livestock feeding System

Source: Liska et al, *Journal of Industrial Ecology*, 13, 58-74 (2009)

Gasoline System

Modeling Complexity in Biofuel Life Cycle Emissions

- ***Problem:*** Most biofuel LCA's use one (<u>1</u>) model that has 300-400 parameters, *yet lengthy controversy* exists due to inconsistent use of *<u>data sources</u>* and *<u>system boundaries</u>*
- *Highly controversial* Searchinger study of indirect land use emissions combined <u>2</u> complex models: GREET & FAPRI
- EPA RFS2 LCA methodology <u>combines 6-8 highly complex models</u> to capture *direct* & *indirect* emissions:

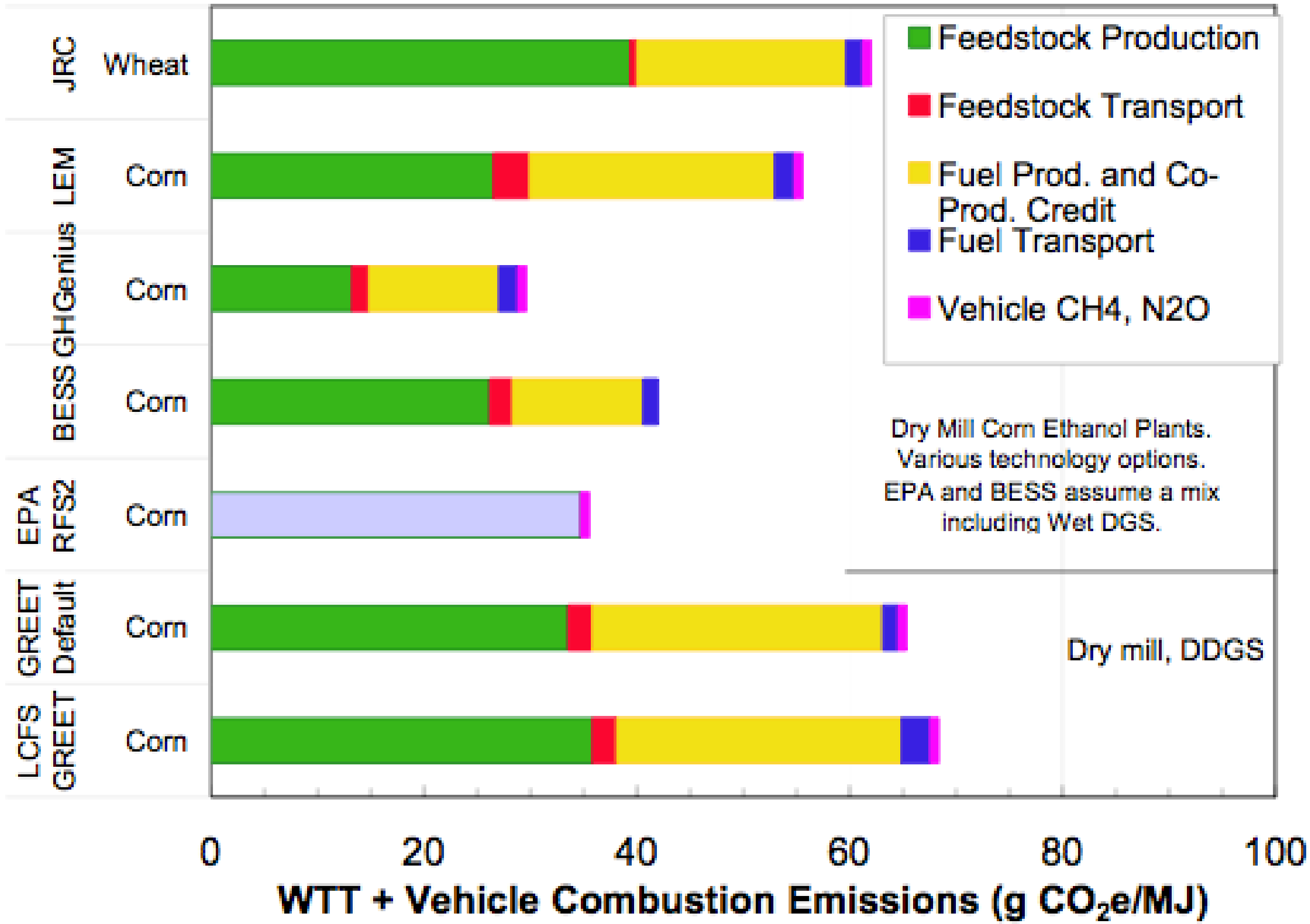
  GREET, FASOM, ASPEN, MOVES, FAPRI, NEMS, and perhaps GTAP & DAYCENT in total having *<u>tens of thousands of parameters</u>*

  No similar LCA is found in the scientific literature
- *RFS2 approach will likely still not capture <u>all significant indirect emissions</u> (Liska & Perrin 2009), and a <u>reasonable level of accuracy by this method is nearly unattainable</u> due to uncertainty in projected parameters values (Kim, Kim, Dale 2009)*

Single Models using 300-400 Parameters give Highly Variable Results

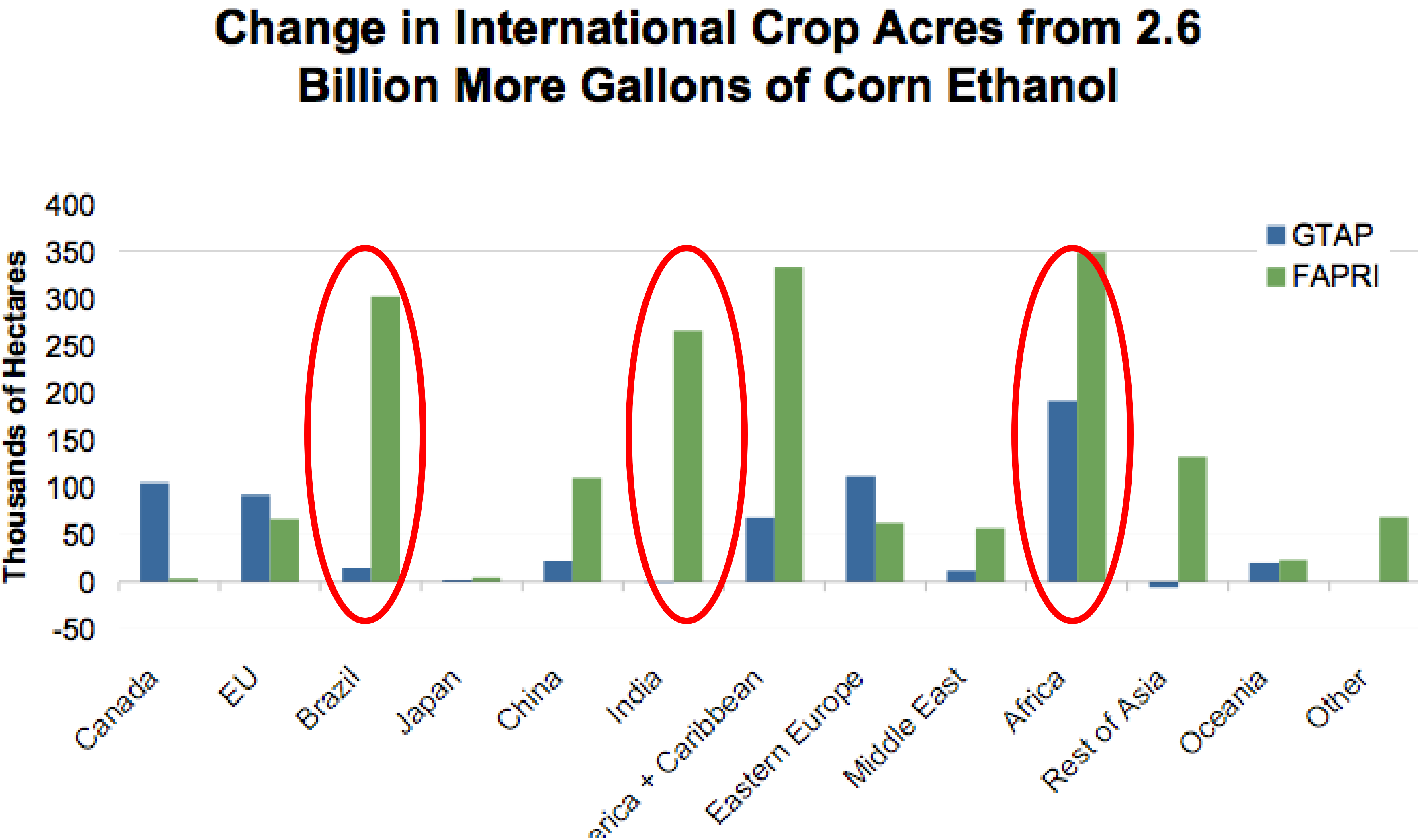
Corn/Wheat to Ethanol

UNL



Presentation: Stefan Unnasch, Review of Transportation Fuel Life Cycle Analysis and CA GREET, CRC WORKSHOP ON LIFE CYCLE ANALYSIS OF BIOFUELS, Argonne National Laboratory, October 20-21, 2009
http://www.crcao.org/workshops/LCA%20October%202009/LCAindex.html

Emissions from Indirect Land Use Change Projections Depends on Models Used & Many Implied Assumptions



Presentation: Bruce A. Babcock, *Overview of the CARD/FAPRI Modeling System*
CRC WORKSHOP ON LIFE CYCLE ANALYSIS OF BIOFUELS,
Argonne National Laboratory, October 20-21, 2009
http://www.crcao.org/workshops/LCA%20October%202009/LCAindex.html

Transparency & Complex Indirect Effects in Regulations

- ***Problem:*** *When using tens of thousands of parameters, can regulatory LCA be 100% transparent? Likely No.*
- Any regulatory LCA methodology <u>must approach complete transparency</u> of *calculations*, *parameter values*, and *references* for data used to ensure accuracy
- <u>Evaluating all indirect effects in one LCA is excessively complex</u>, particularly for contentious EPA regulation
- ***RFS2 LCA methods should only be as complex as can be practically & transparently reviewed & supported by accurate data, within acceptable uncertainty limits***
- *<u>If sufficient transparency & accuracy are not achieved, indirect effects should be excluded from RFS2</u>*

Proposed **Land Grant Biofuel LCA Working Group**

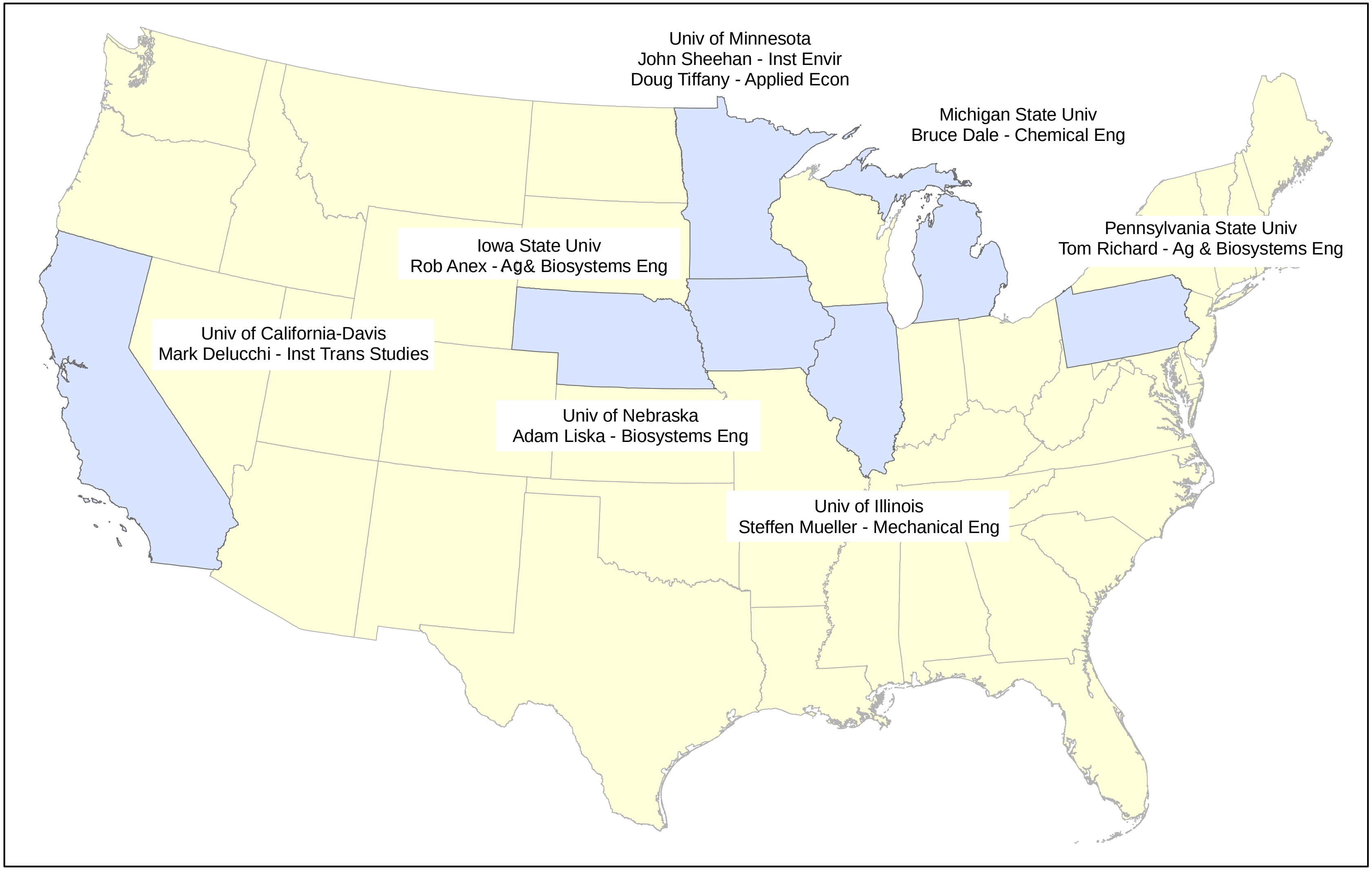
- Provide integrated scientific leadership & assistance in regulatory LCA to help *ensure accuracy*, *rigor* and *fairness* by building consensus in modeling approaches & integrating information from stakeholders & parallel working groups
- Proposed requirements for <u>researchers in working group</u>:
  - *Faculty from Land Grant universities*

    (non-industry perspective with access to broad research resources)
  - *Published scientific articles on biofuel LCA & related issues*

    (experience in nuances of LCA research)
  - *Involved in agricultural research & closely related disciplines*

    (experience directly in bioenergy systems—as *corn-ethanol is the dominant fuel under scrutiny*, those with direct experience in these systems will have best insight)

Proposed **Land Grant Biofuel LCA Working Group**



In total, these Land Grant faculty have published 80+ scientific articles directly on LCA of biofuels and closely related agricultural & engineering issues

Proposed **Land Grant Biofuel LCA Working Group**

Proposed collaborators:

- Research resources at Land Grant universities
- USDA, DOE, EPA, DOT
- Midwestern Governors' Association — *LCFS Working Group*
- National Research Council
- Industry
- Roundtable on Sustainable Biofuels (EU)

How is our approach different than these groups?

- Critical mass of academic researchers that have: 1) *direct experience with biofuel LCA*, 2) *could provide sustained effort (~5+ yrs),* 3) independent from *oil* or *biofuel* industries

Goals, **Land Grant Biofuel LCA Working Group**

- To facilitate *well-informed* & *impartial discussion*, *evaluation*, and *analysis* of regulatory LCA methods
- Identify & develop appropriate background *theory*, *methodology (*e.g. *system boundaries*), identify *data gaps & data acquisition* approaches, provide *sensitivity* analysis, and hold yearly conferences to build on and engage others
- Our experience with the California LCFS regulatory process, which has strongly influenced the RFS2 approach, leads us to believe ***that regulators have limited experience with LCA of biofuels***, the current choice of LCA methods seem to be ***politically influenced (not derived from the most accurate methods found in the scientific literature)***, and ***more objective & sustained input from the scientific community is needed to ensure accuracy & fairness***

Funding support

- Western Governor’s Association
- US Department of Agriculture
- US Department of Energy
- DOE Great Lakes Bioenergy Research Center
- University of Nebraska Center for Energy Sciences Research
- Biomass Conversion Research Laboratory, Michigan State University
- Environmental Defense Fund

Research Collaborators

- Prof. Kenneth Cassman, Agronomy, Univ. Nebraska
- Dr. Seungdo Kim, Chemical Eng., Mich. State Univ.
- Prof. Richard Perrin, Ag. Econ., Univ. Nebraska
- Profs. Terry Klopfenstein & Galen Erickson, Animal Science, Univ. Nebraska

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- Kim, S. and Dale, B.E., **Life Cycle Assessment of Fuel Ethanol Derived from Corn Grain via Dry Milling**, *Bioresource Technology*, 99, 5250 – 5260, (2008)

Science of indirect effects is in its infancy, regulation of one indirect effect (deforestation) and one fuel (ethanol) is neither balanced nor equitable

Table 1. Additional factors and uncertainties that determine net changes in indirect greenhouse gas emissions from transportation fuel production. Emissions units in $TgCO_2e\ yr^{-1}$.

Factors Influencing Indirect GHG Emissions	Contribution to Atmospheric GHGs
Biofuels	**Marginal Changes Upon Biofuel Production**
Deforestation and Grassland Conversion	+ (127[†])
Rice Expansion[a]	+
Livestock Decline	– (58[†‡])
Reclamation of Dry and Degraded Lands[b]	–
Substitution of Corn for Soybean and Wheat[c]	–
Geographic Pattern of Land Conversion[d]	+/–
Climate Policies for Forest Maintenance[e]	–
Petroleum	**Additional & Marginal Emissions Not Currently Included**
Tar Sands and Unconventional Fuels[f]	+
Indirect Military Fuel Use and Infrastructure[g]	+ (187[§])
Processing and Transportation Losses[h]	+

US military fuel use / infrastructure to secure foreign oil: ~$104 billion per year [not including complete Iraq costs]

Source: Liska and Perrin, *Biofuels, Bioproducts, Biorefining* 3, 318-328 (2009)

Survey data needs for biorefineries

- Key parameters for individual biofuel producers, and regional crop/livestock, should be monitored on an <u>annual or biannual</u> basis to ensure accuracy:

<u>Biorefinery</u>:

1) grain used per unit of anhydrous ethanol yield, <u>kg L^{-1}</u>
2) natural gas use per unit of anhydrous ethanol, <u>MJ L^{-1}</u>
3) electricity use per unit of anhydrous ethanol, <u>kWh L^{-1}</u>

<u>Crop production and Livestock</u>:

4) on-farm fuel & nitrogen fertilizer use for corn production
5) types of co-products produced and their characteristics:

% wet, modified, & dry distillers grains (moisture %)

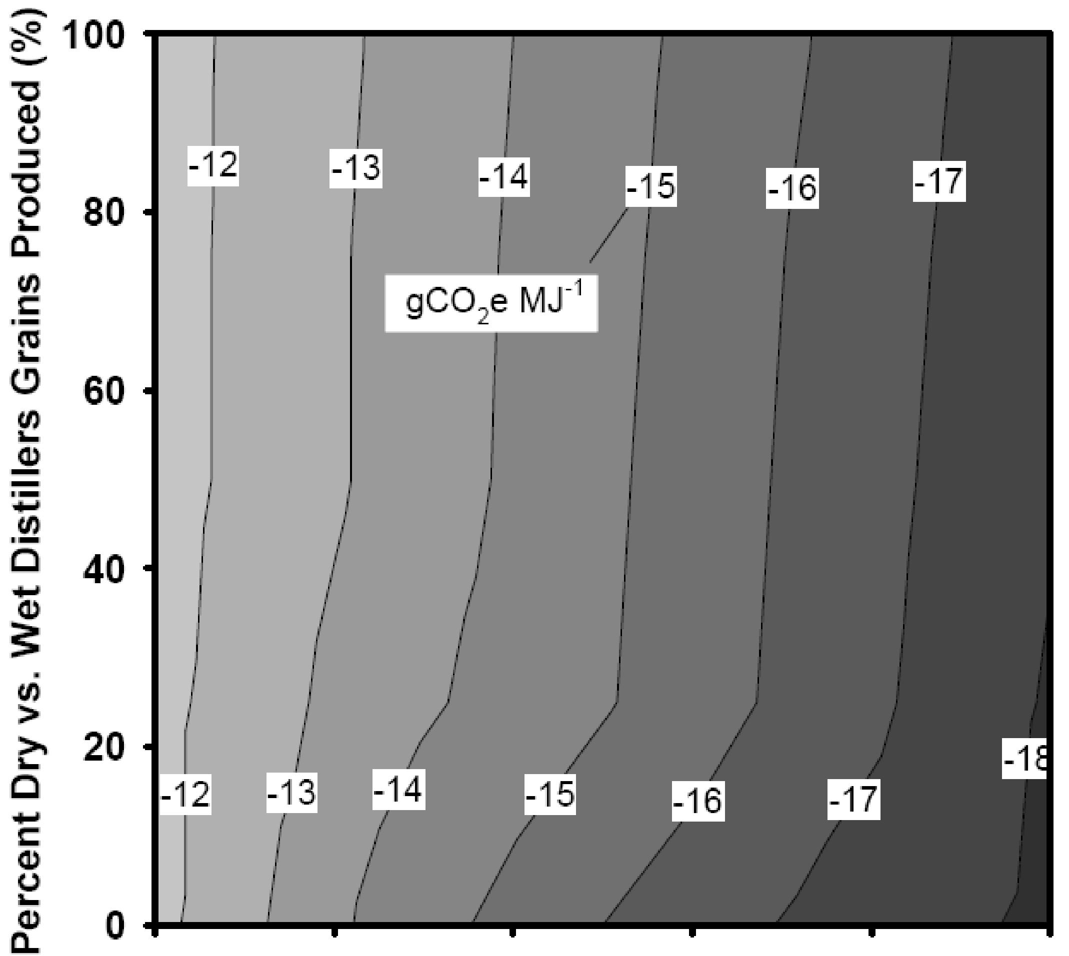
- <u>These surveys can be coordinated with EPA's *Mandatory Reporting of Greenhouse Gases**, starting in Jan. 2010</u>

*Proposed Rule, Federal Register / Vol. 74, No. 68, April 10, 2009, EPA-HQ-OAR-2008-0508

Variability in co-product GHG emissions credits for individual biorefineries/regions depends on *type of CP produced* and *livestock class fed*

DDGS

WDGS



dairy & swine

beef

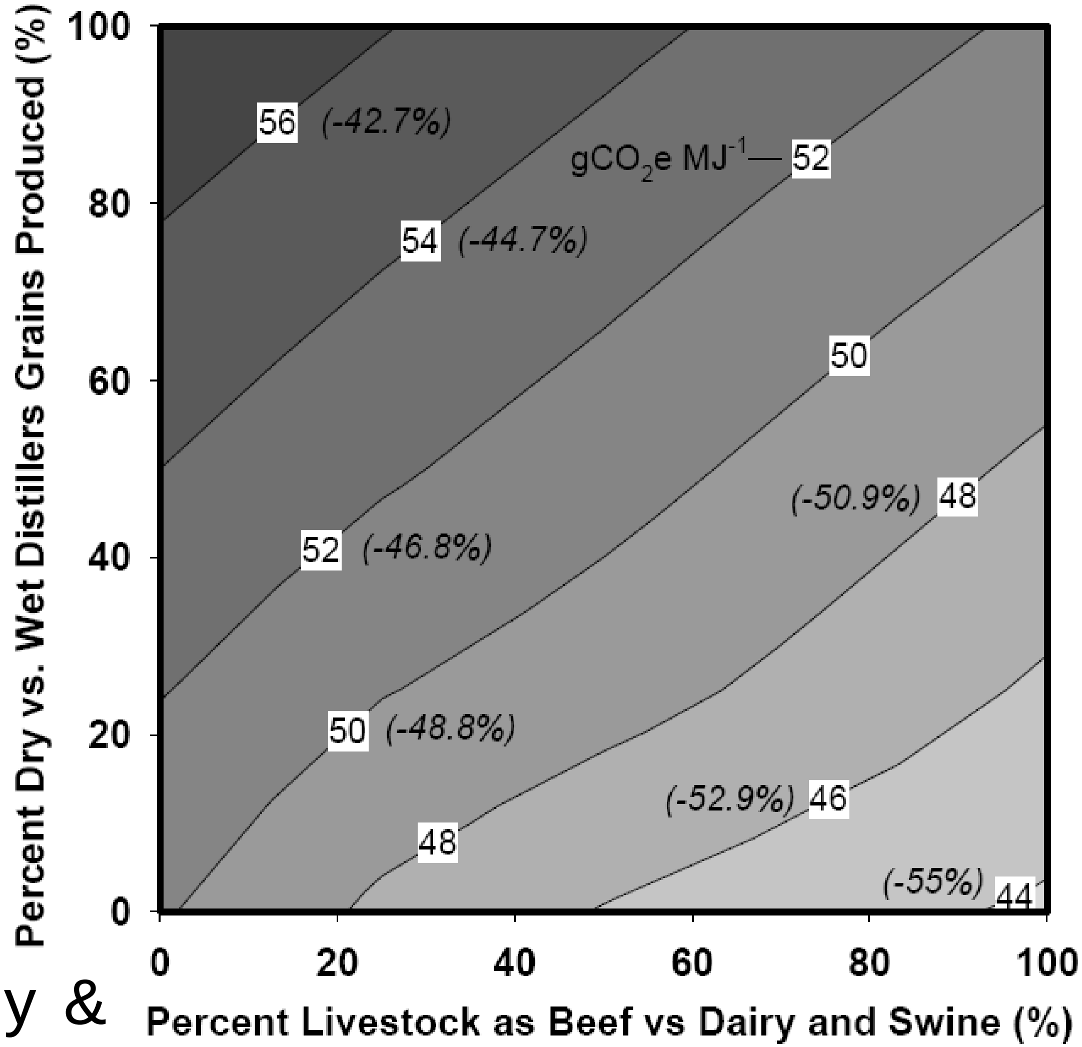
Results of BESS model simulations

Source: Bremer et al. *Journal of Environmental Quality*, 2010

Life cycle GHG emissions intensity and % reductions for corn-ethanol compared to gasoline, depends on *co-product variability* & *energy savings for drying CP*

DDGS

WDGS



dairy & swine

beef

Results of BESS model simulations

Gasoline:

97.7 gCO_2e/MJ

Source: Bremer et al. *Journal of Environmental Quality*, 2010