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Life Cycle Assessment of Greenhouse Gas Emissions from Ethanol and Biopolymers

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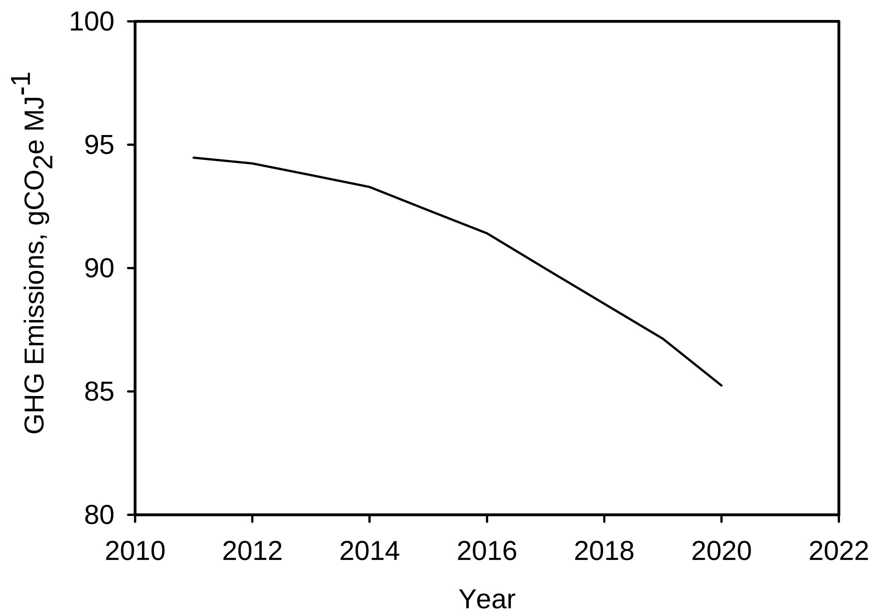
Biobased chemicals and LCA

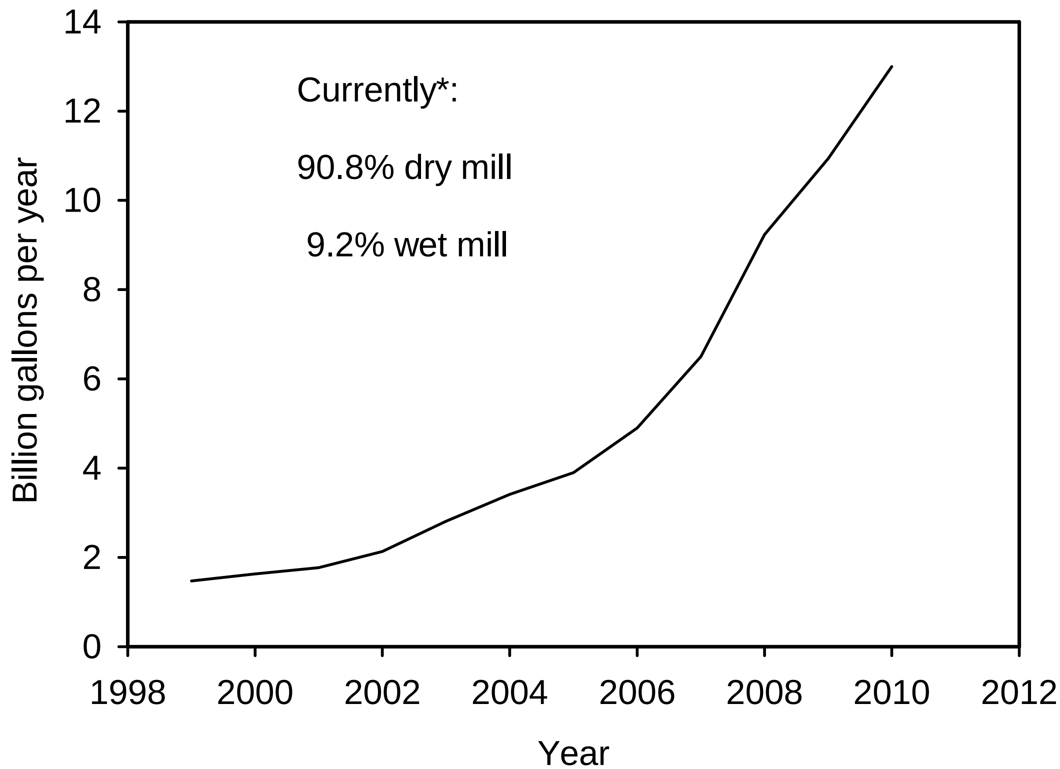
- Life cycle assessment (LCA) is now used in state and federal greenhouse gas (GHG) emissions regulations (*this is where LCA is most relevant today*):

1) *Energy Independence and Security Act* of 2007 (EPA) requires a 20% reduction in GHG emissions for corn-ethanol compared to gasoline
2) Low Carbon Fuel Standard (California Air Resources Board; CARB) requires 10% reduction in gasoline GHG emissions by 2020

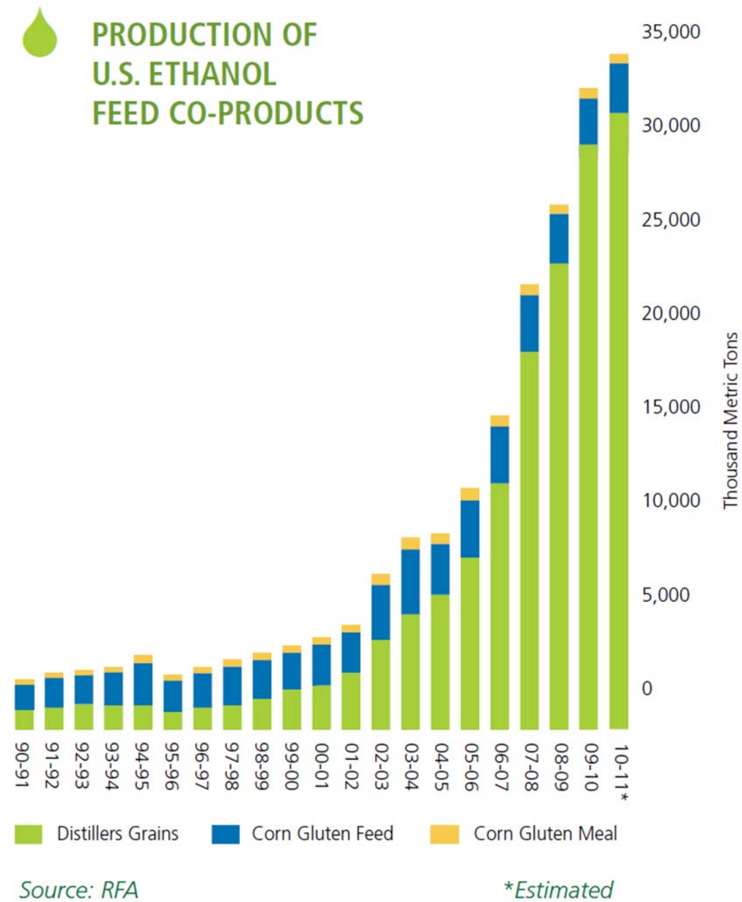


Regulatory LCA is not likely to be used for non-fuel chemicals in the near future

US ethanol industry capacity is predominantly dry mills (202 biorefineries total)

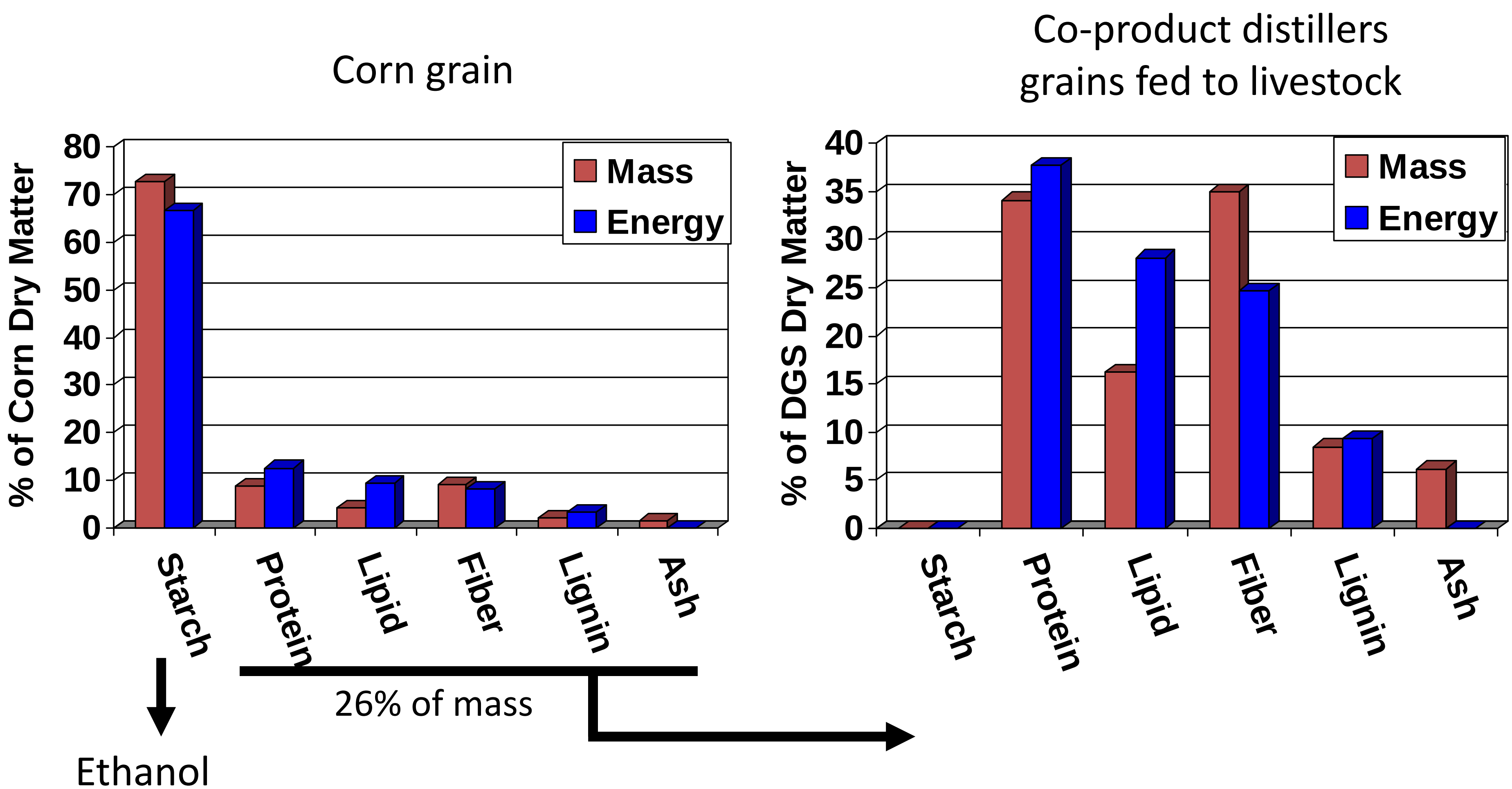


*as of Feb. 2011 (88% natural gas powered,10.5% coal, 1.5% biomass),
Geoff Cooper, Renewable Fuels Association, personal communication, March 16, 2011



Corn Gluten feed is proportional to wet mill capacity

GHG emissions credits for distillers grains co-products from dry mills (*similar life cycle emissions credits exist for wet mills*)



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

Simplest inventory of life cycle GHG emissions for dry mill corn-ethanol

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%

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

Crop production inputs

Fossil Fuel inputs

Biorefinery emissions

GHG emissions credits: Co-product substitutes for conventional livestock feed (beef cattle)

Gasoline

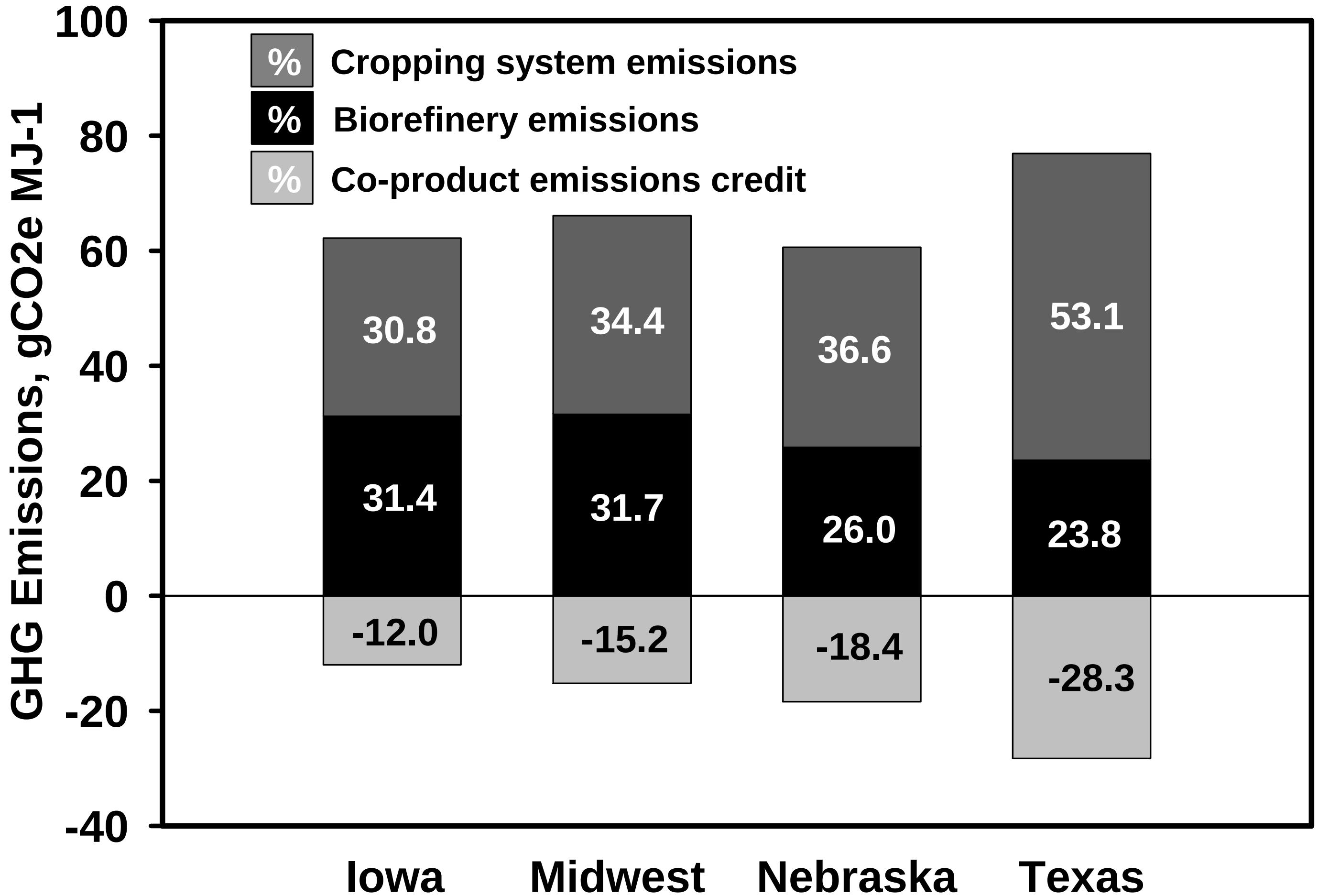
Updated corn-ethanol GHG emissions credits and life cycle impacts based on beef, dairy, swine dietary substitutions

Regions	Midwest	Iowa	Nebraska	Texas
GHG emissions credit, $gCO_2e\ MJ^{-1}$				
Corn (regional sources)	9.64	6.50	12.8	22.1
Soybean meal	2.82	4.56	0.91	0.21
Urea	1.60	0.52	2.43	2.85
Diesel fuel	-0.10	-0.04	-0.21	-0.26
Enteric fermentation	1.27	0.424	2.52	3.42
Total	15.2	12.0	18.4	28.3
Biorefinery thermal energy* $MJ\ L^{-1}$	7.72	7.60	5.70	4.91
Net ethanol Intensity, $gCO_2e\ MJ^{-1}$	52.3	51.6	43.7	50.0
GHG Reduction relative to gasoline, %	46.5%	47.2%	55.3%	48.8%

More beef cattle compared to swine and dairy, more wet distillers grains compared to dry, and therefore more corn substituted relative to IA and NE

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

Variable GHG emissions credits and life cycle impacts: Similar methods employed in GREET model used by regulators



Chemicals produced from <u>protein and lipid *would reduce*</u> the existing co-product credit; those from starch <u>*could increase* credits</u> per unit energy

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

Starch-based biopolymers and substituted petroleum polymers determine GHG emission credit per kg

Biobased polymers	Ferm. Yield	GHG intensity* A	Petroleum substitutes	GHG intensity B	GHG credit* B - A
	kg starch/ kg polymer	$kgCO_2e/kg$		$kgCO_2e/kg$	$kgCO_2e/kg$
poly lactic acid (PLA)	1.53*	-1.2	Low density polyethylene (LDPE)	3.84	5.04†
polyhydroxyalkanoates (PHA)	3.04**	2.85	Polystyrene (PS)	5.98‡	3.13††
polyhydroxybutyrates (PHB)	3.97***	-3.27	polypropylene (PP)	3.65‡‡	6.92‡‡

*Cargill case study, http://www.wbcsd.org/web/publications/case/natureworks_full_case_web.pdf
**Gerngross, T. U. Can biotechnology move us toward a sustainable society? *Nature Biotechnology*, 17, 541-544, 1999
***Kim Beom Soo, Production of Poly(3-hydroxybutyrate) from inexpensive substrates. *Enzyme and Microbial Technology* 27, 774-777, 2000
†Dornburg V., Lewandowski I., Patel M. Comparing the land requirements, energy savings, and greenhouse gas emissions reduction of biobased polymers and bioenergy. *Journal of Industrial Ecology* 7 (3-4), 93-116, 2004
‡Patel, M., Bastioli, C., Marini, L., Würdinger, E. Life-cycle assessment of bio-based polymers and natural fiber composites. Biopolymers Online. 2005.
††Kim, S.; Dale, B. E. Life cycle assessment study of biopolymer (polyhydroxyalkanoates) derived from no-tilled corn. *Int. J LCA* 10 (3), 200-210, 2005
‡‡Kim, S.; Dale, B. E. Energy and greenhouse gas profiles of polyhydroxybutyrates derived from corn grain: A life cycle perspective. *Environ. Sci. Technol.* 42, 7690-7695, 2008 (uses corn residue as fuel)

Why is the carbon intensity of biopolymers less than petroleum chemicals?

1) carbon in polymers is GHG neutral (originates from atmosphere)
2) energy efficiency of the process

Warning: GHG intensities of biopolymers are uncertain based on inconsistent use of system boundaries in analysis; To obtain GHG credits for ethanol systems, standardized LCA of biopolymers should be developed and defined with EPA for consistency

Significant GHG emission credits for corn-ethanol can be obtained by using only roughly 6-9% of initial starch for production of biopolymers*

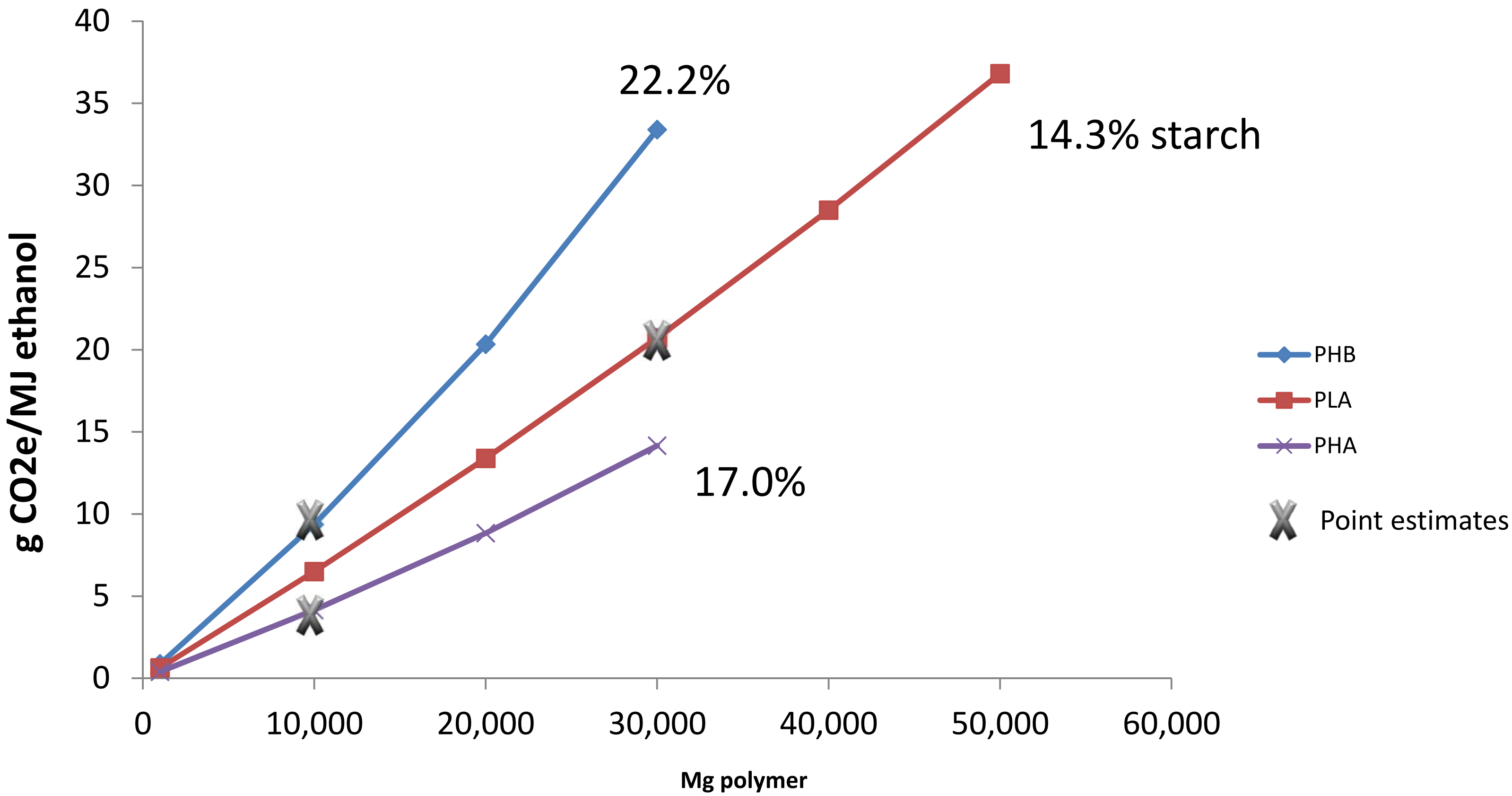
(*in a parallel fermentation process, reduces ethanol output*)

	Ethanol	E + PHA	E + PHB	E + PLA
Mg polymer[1]	-	10,000	10,000	30,000
Mg starch/Mg polymer[2]	-	3.04	3.97	1.53
Mg starch for polymer[(1*2)]	-	30,370	39,683	46,010
polymer starch, % total	-	5.7%	7.4%	8.6%
kgCO_2e/kg polymer credit[3]	-	3.13	6.92	5.04
kgCO_2e credit [(1*3)]	-	31,300,000	69,200,000	151,200,000
g CO_2e/MJ[(1*3/4)]	-	**-4.2**	**-9.4**	**-20.7**
gal/yr	100,000,000	94,347,191	92,613,738	91,435,938
MJ ethanol[4]	7,986,350,000	7,534,896,893	7,396,457,284	7,302,393,995

[3]*calculated on previous page*

*these calculations follow LCA theory and related co-product analysis, but EPA's decision on the analysis is what is important

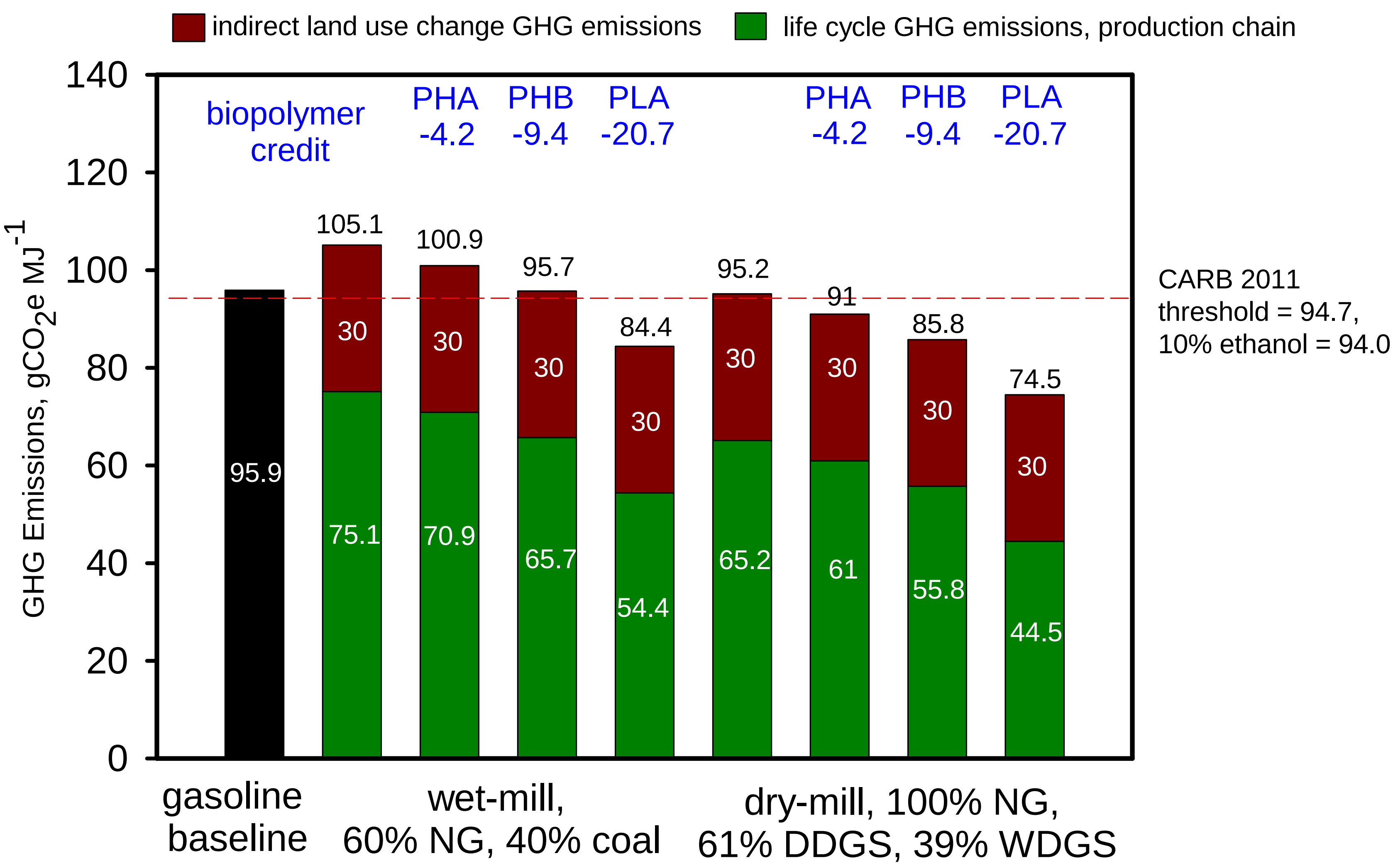
Using this model, credits are proportional to polymer produced, but…



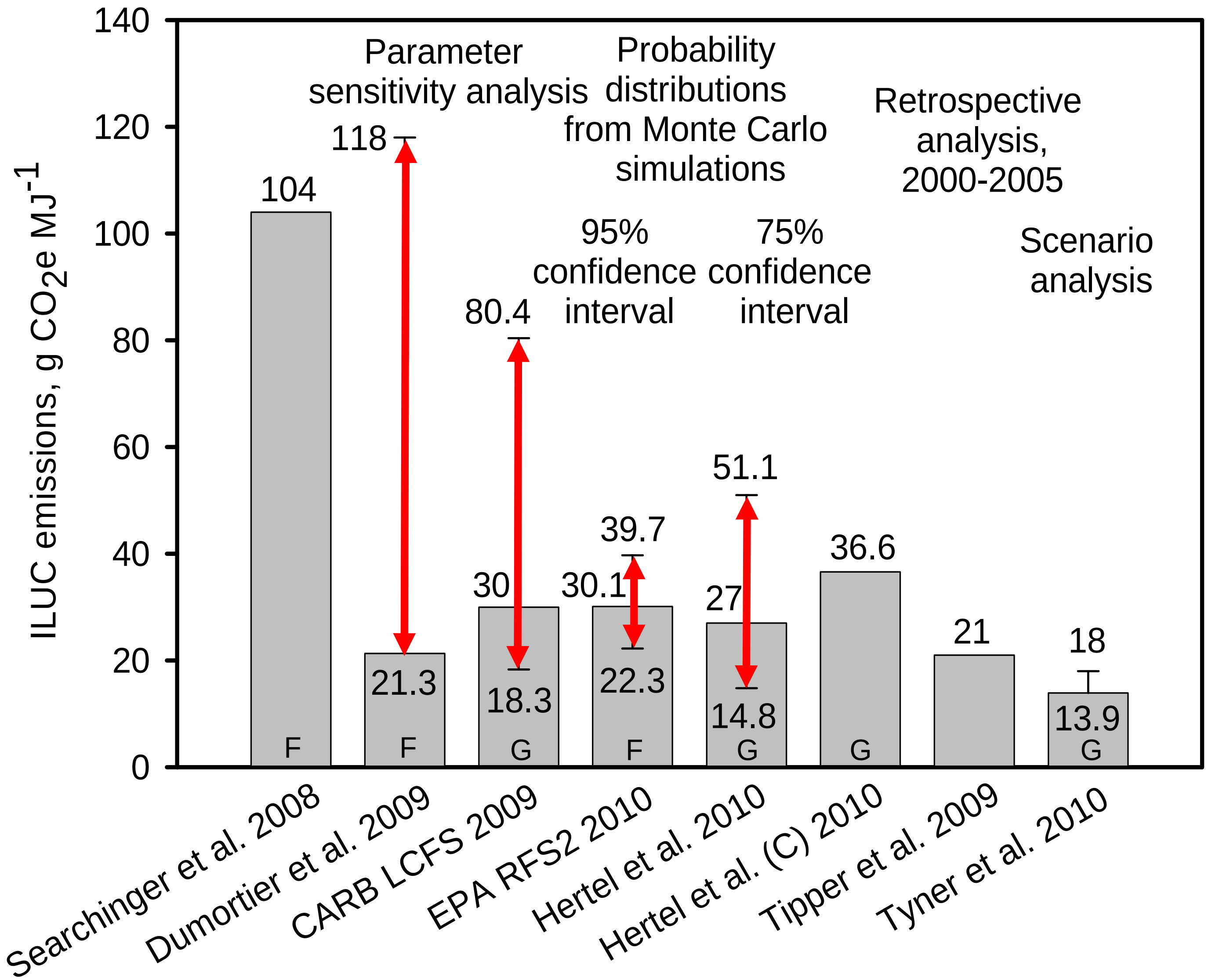
At what threshold (e.g. %) is the co-product designated by EPA as a separate process and not a co-product of ethanol production?

(this is not clearly defined in LCA theory)

CARB-defined ethanol GHG emissions intensities can be lowered below regulatory thresholds using 6-9% starch for biopolymers



International indirect land use change (ILUC) GHG emissions from corn-ethanol are uncertain projections of future change in land use due to higher prices



Source: Liska AJ. Eight Principles of Uncertainty for Life Cycle Assessment of Biofuel Systems, chapter 22 in: *Biofuels: Environmental Implications and Impacts*, Brouder et al. (eds.), Cambridge University Press. submitted.

ILUC is one of *many* indirect GHG emissions:

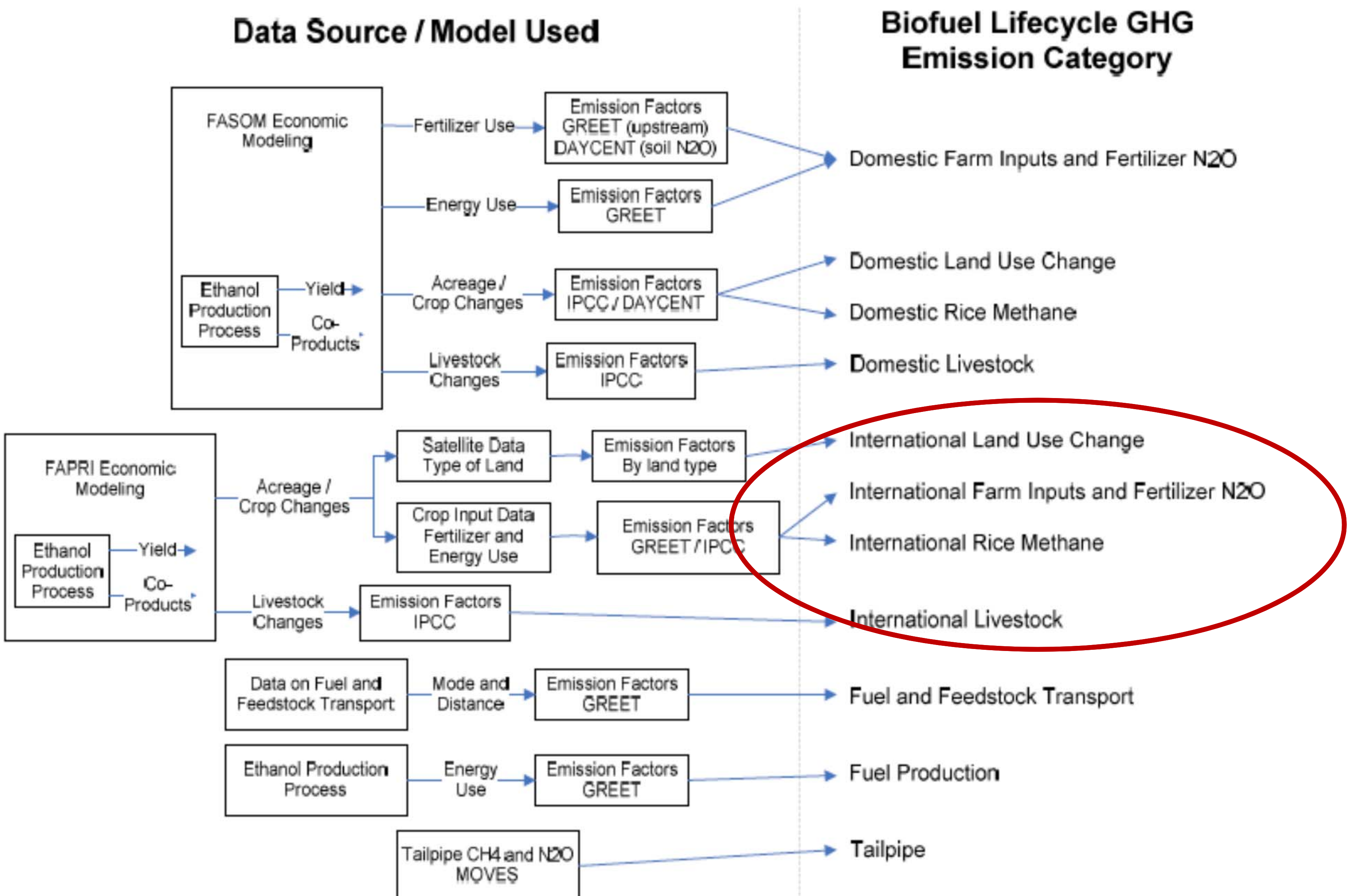
All global indirect GHG emissions from both biofuels and gasoline need to be accounted for and compared

Corn-ethanol Indirect emissions	**Gasoline** Indirect emissions
+ Global land use (ILUC)	Military security for foreign oil (~$130 billion per year)
- Global livestock (CH_4, N_2O)	Unconventional sources of petroleum, tar sands
- Global soil carbon from crop substitutions: more corn, less soybean	Processing emissions not included, e.g. oil spills
- Global soil carbon sequestration from reclamation of dry lands	Wars for foreign oil? (another ~$100 billion per year in Iraq)
+ Rice (CH_4)	

EPA's macro-modeling framework recognizes multiple indirect emissions

(combines 8 models and tens of thousands of parameters)

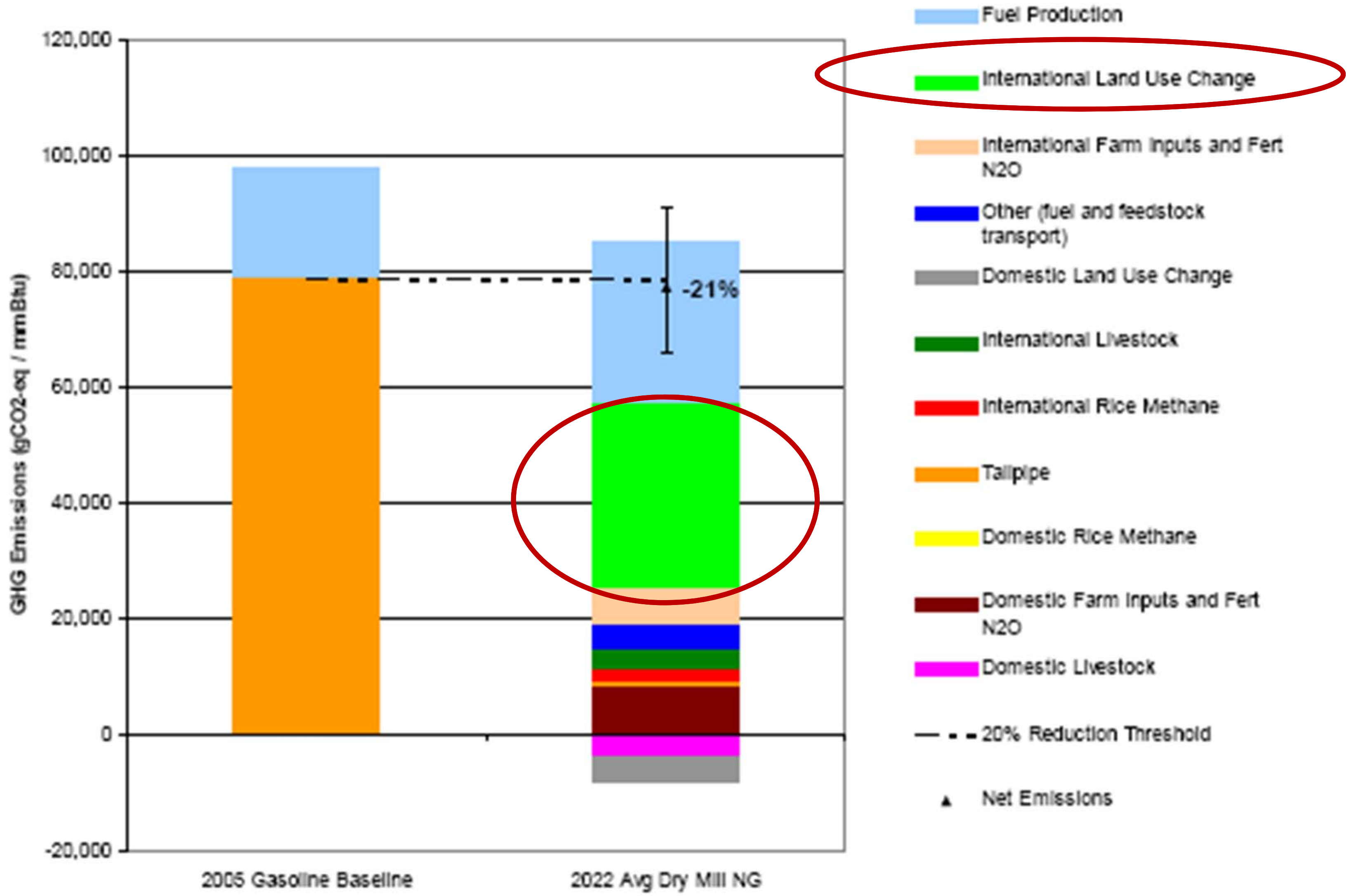
Figure 2.2-1 System Boundaries and Models Used



Source: http://www.epa.gov/otaq/renewablefuels/420r10006.pdf

EPA's New Life Cycle Emissions Results (Feb. 2010)

Figure 2.6-2. Results for a New Natural Gas Fired Corn Ethanol Plant by Lifecycle Stage Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)



Source: http://www.epa.gov/otaq/renewablefuels/420r10006.pdf

Other **estimates** and **factors** not included by EPA (2010):

Corn-Ethanol vs. *Gasoline* from Middle East (12% of US)

3 Indirect Effects	**EPA 2010** **gCO_2e/MJ**	**Other Estimates** **gCO_2e/MJ**
Global Land Use (ILUC)	+ 30.1	+ 13.9 (Tyner et al. 2010)
Global Livestock	- 0.28	- 47.5 (Liska and Perrin 2009 based on Searchinger 2008 and FAO 2007)
Military Security for Middle East oil	0	-17.5 *increase gasoline GHGs or reduction in military; based on LCA of US military and attribution of 20% (~$100B/yr) to oil security* (Liska and Perrin, 2010)
	+29.8	-51.1

Indirect effects are associated with a large degree of uncertainty and more research is clearly needed

Sources: Sanchez et al. submitted; Liska & Perrin, *Biofuels, Bioproducts, Biorefining* 2009; Liska & Perrin *Environment* 2010.

Conclusions

- Regulatory LCA is not likely to be used for non-fuel chemicals alone in the near future
- Significant GHG emission credits for corn-ethanol can be obtained by using only roughly 6-9% of initial starch for production of biopolymers based on previous LCA theory
- Pay close attention to values in calculating credits per kg—*these have to stand up in litigation to ensure the credit*
- Credits are proportional to the mass of polymer produced
- Many theoretical issues are uncertain and credits will only be determined in conjunction with EPA
- Indirect emissions are uncertain and are a dominant factor in determining total life cycle GHG emissions and the importance of potential co-product credits from biopolymers

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- Prof. Kenneth Cassman, Agronomy, Univ. Nebraska

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