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# Life Cycle Assessment of Greenhouse Gas Emissions from Ethanol and Biopolymers

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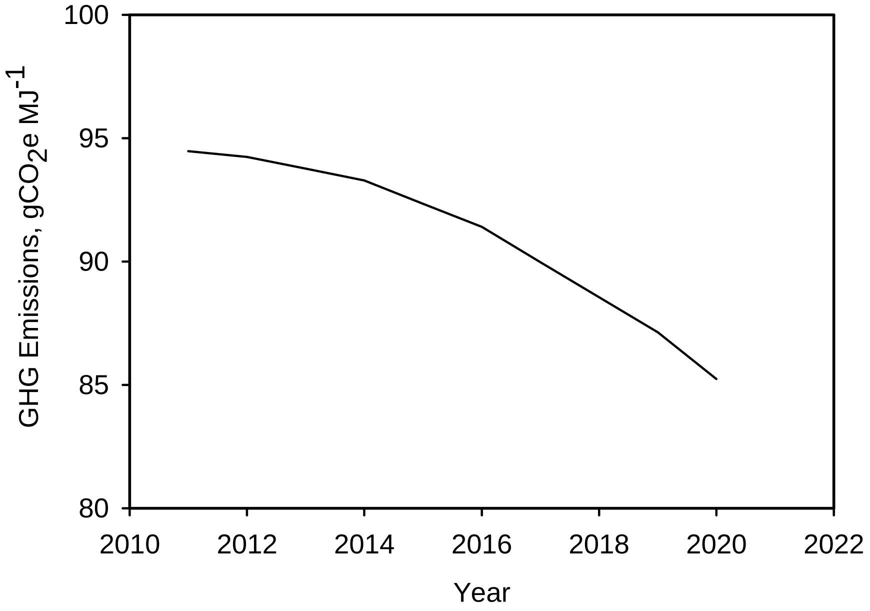
# Biobased chemicals and LCA

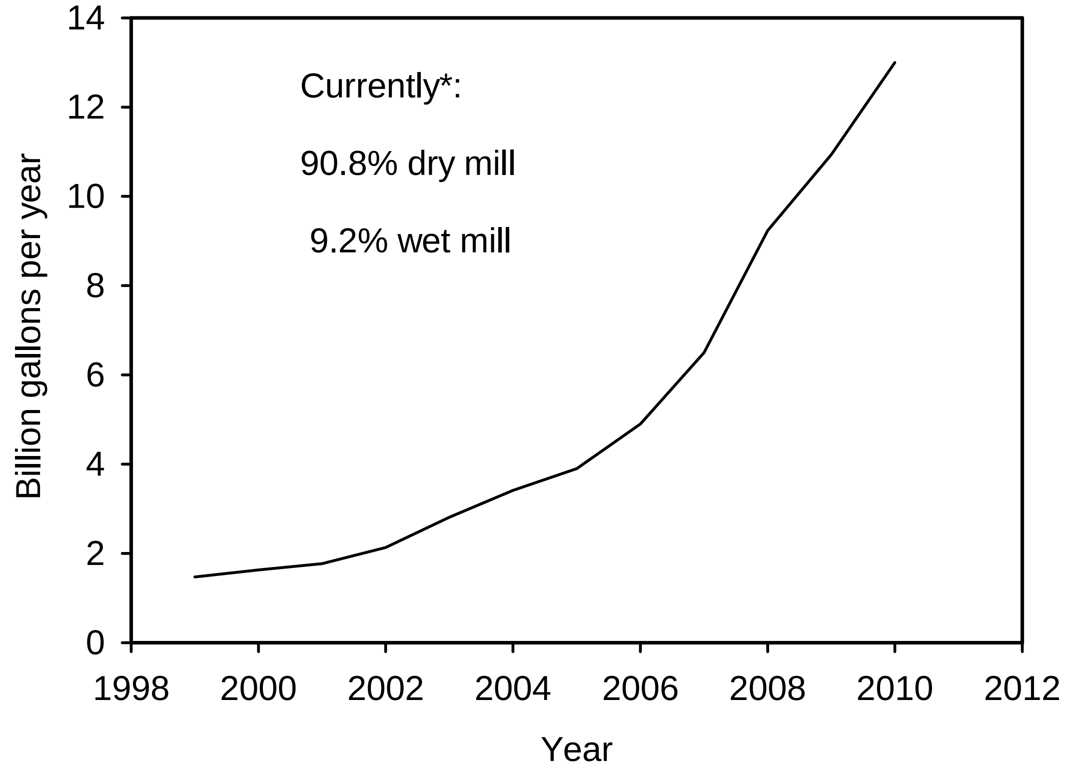
- Life cycle assessment (LCA) is now used in state and federal greenhouse gas (GHG) emissions regulations (*this is where LCA is most relevant today*):

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)

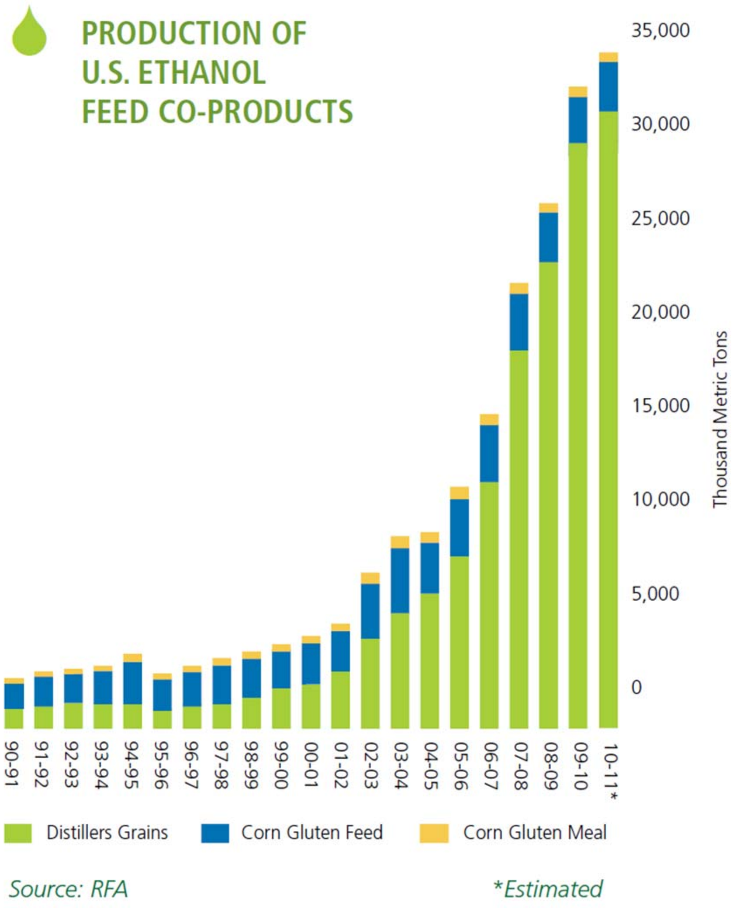


Currently*:

90.8% dry mill

9.2% wet mill

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

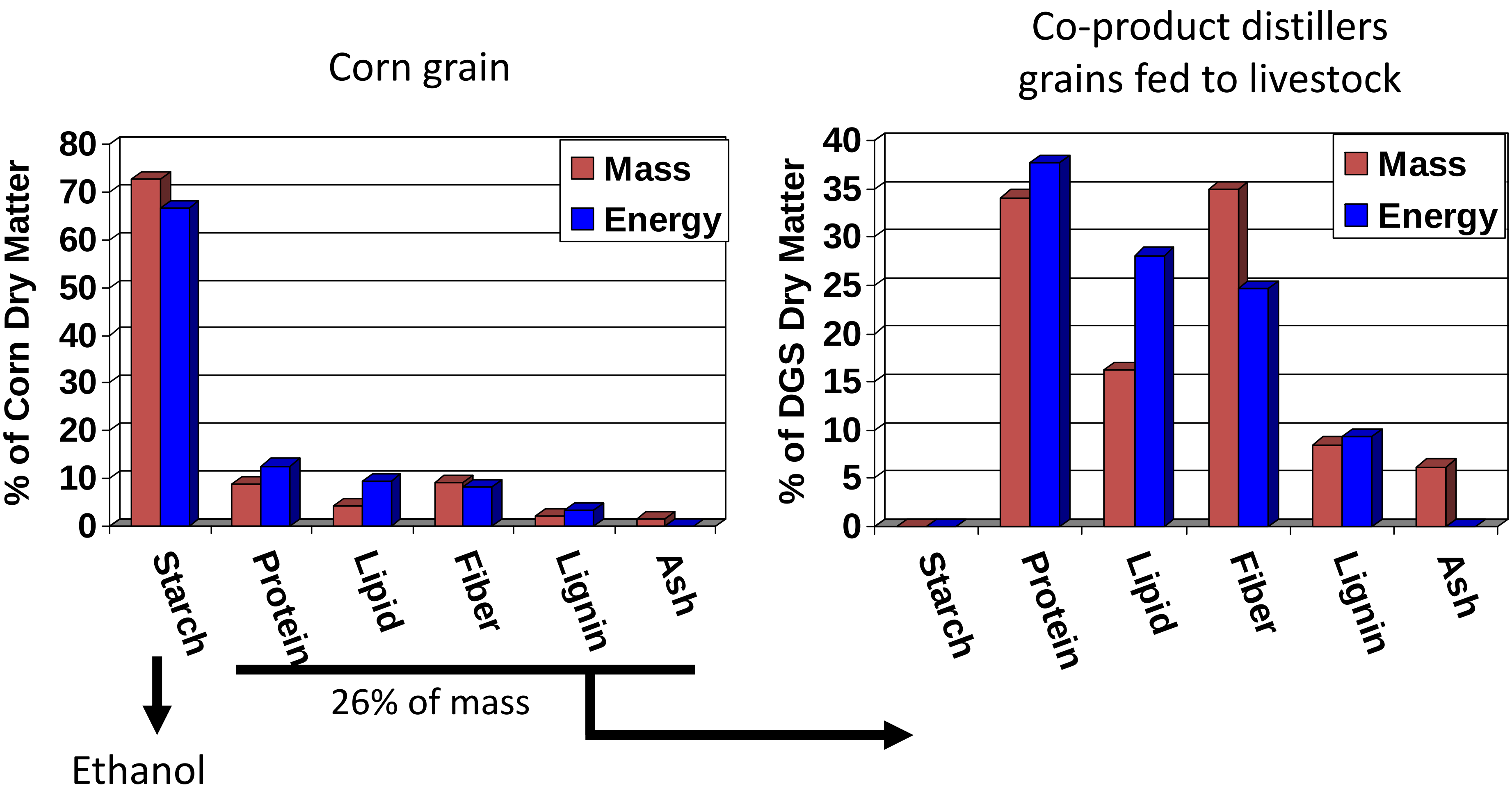

PRODUCTION OF U.S. ETHANOL FEED CO-PRODUCTS

Source: RFA

*Estimated

*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*)


Corn grain

Co-product distillers grains fed to livestock

26% of mass

Ethanol

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 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

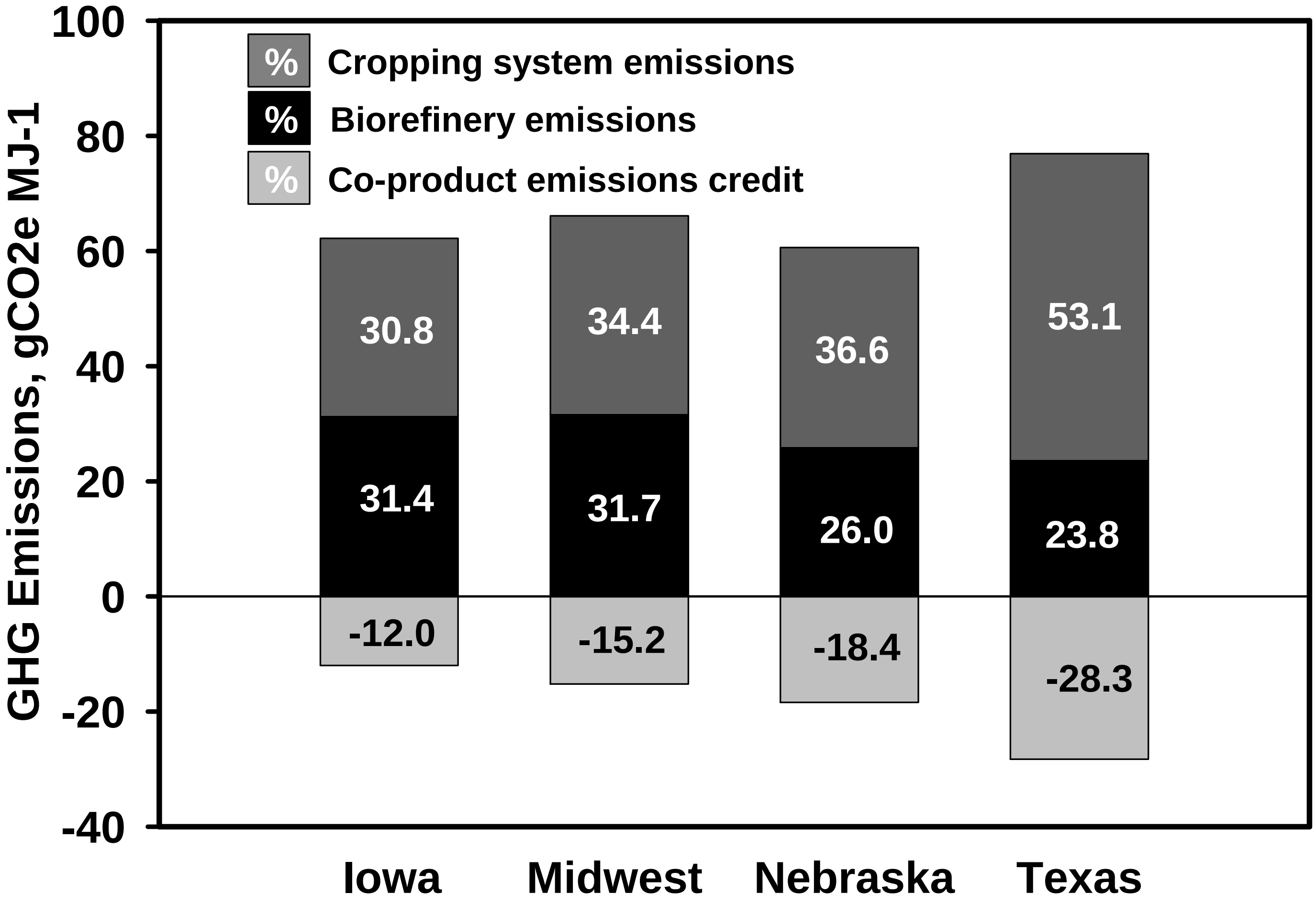
# Updated corn-ethanol GHG emissions credits and life cycle impacts based on beef, dairy, swine dietary substitutions

| 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 | kg$CO_2$e/kg | | kg$CO_2$e/kg | kg$CO_2$e/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*

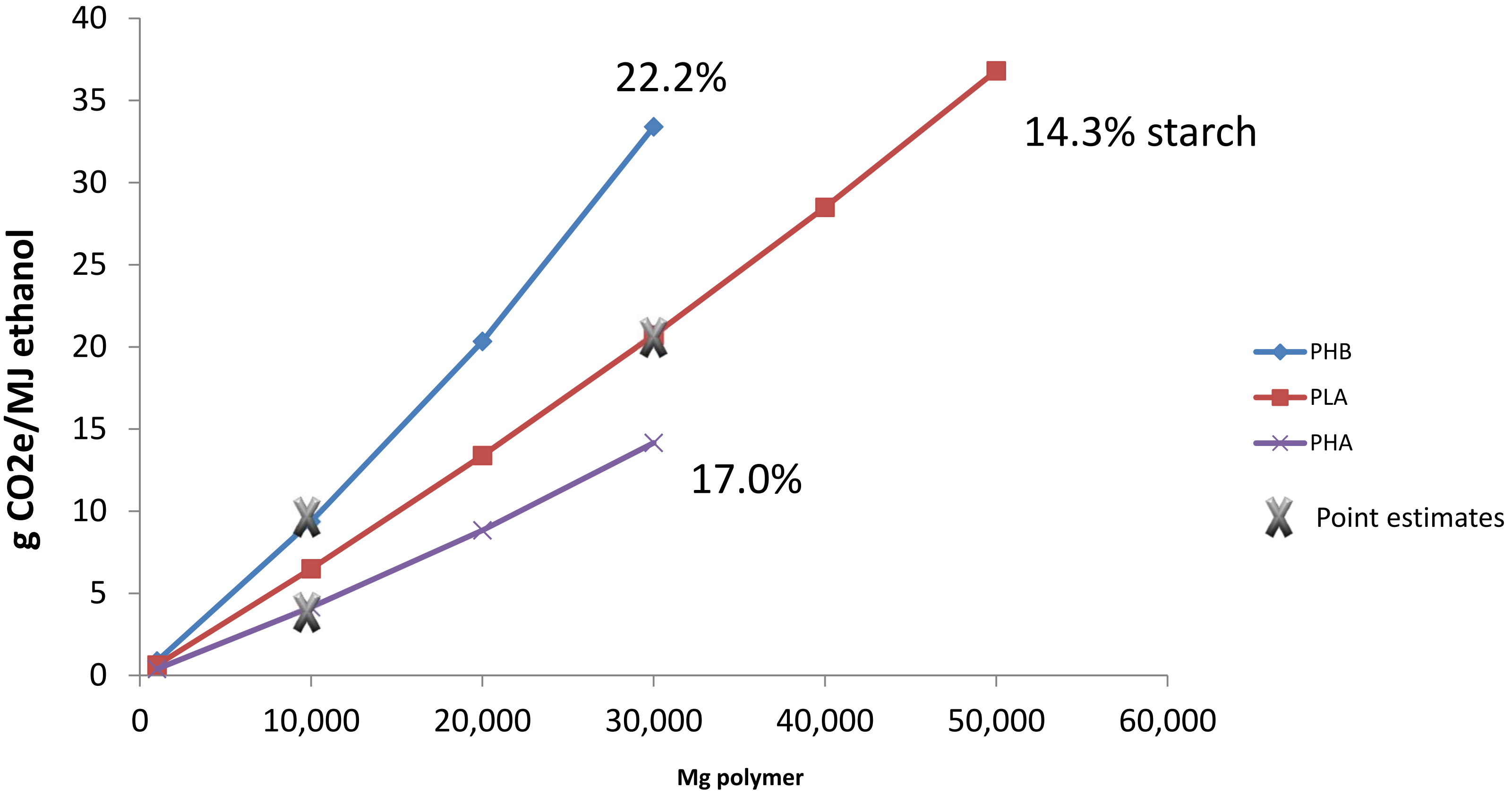
## (*in a parallel fermentation process, reduces ethanol output*)

| | **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

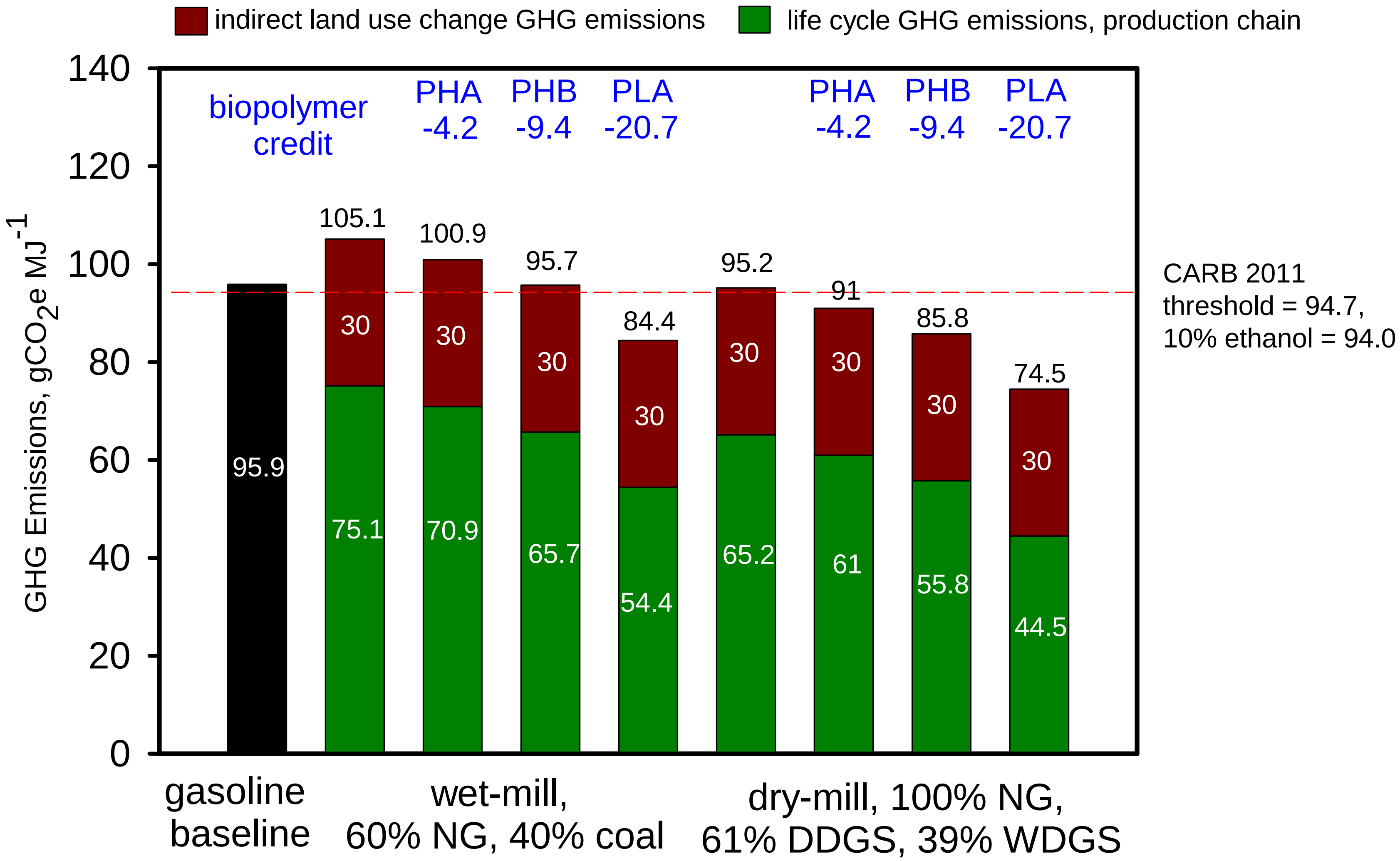
# Using this model, credits are proportional to polymer produced, but…



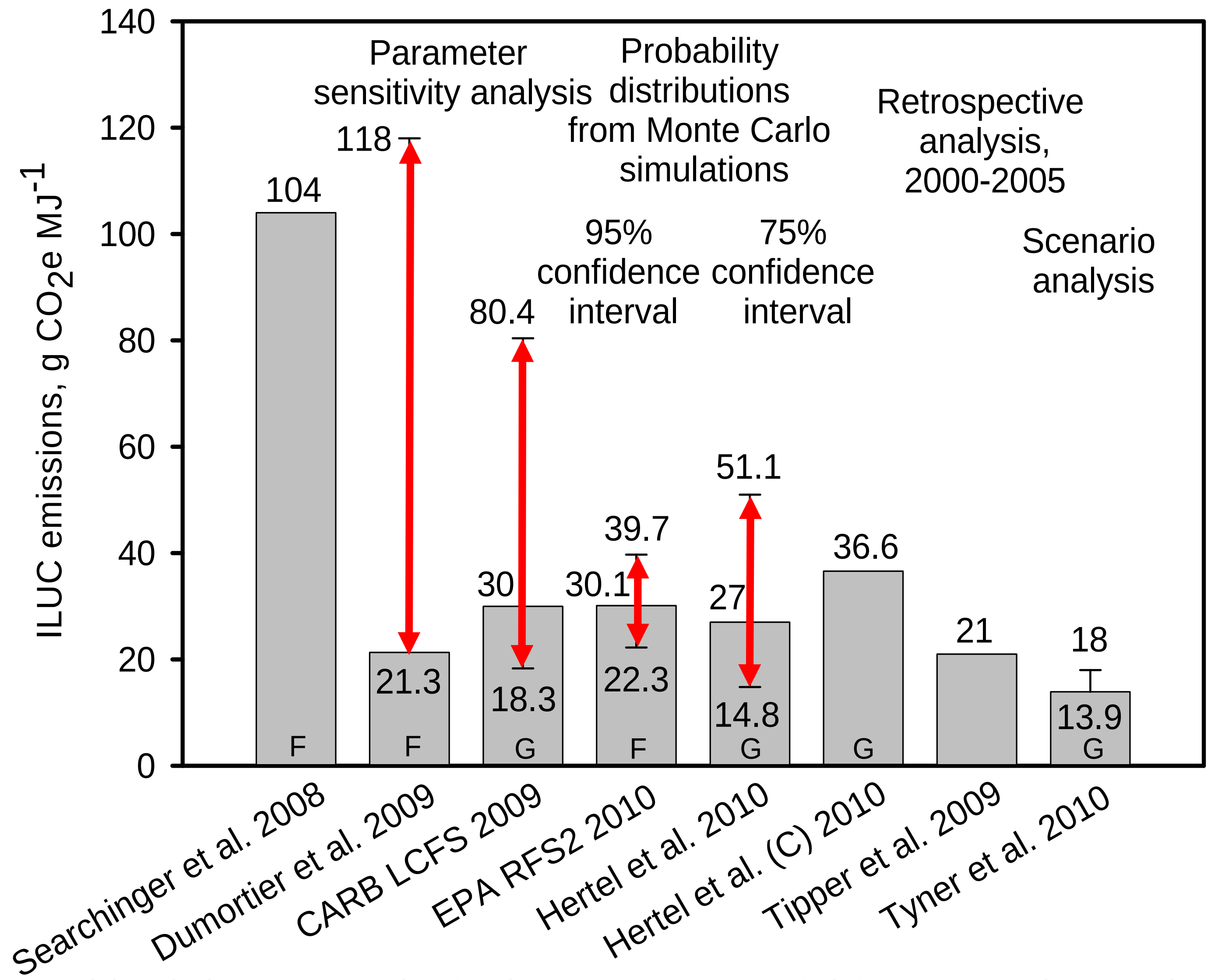
*At what threshold (e.g. %) is the co-product designated by EPA as a separate process and not a co-product of ethanol production?*

*(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.

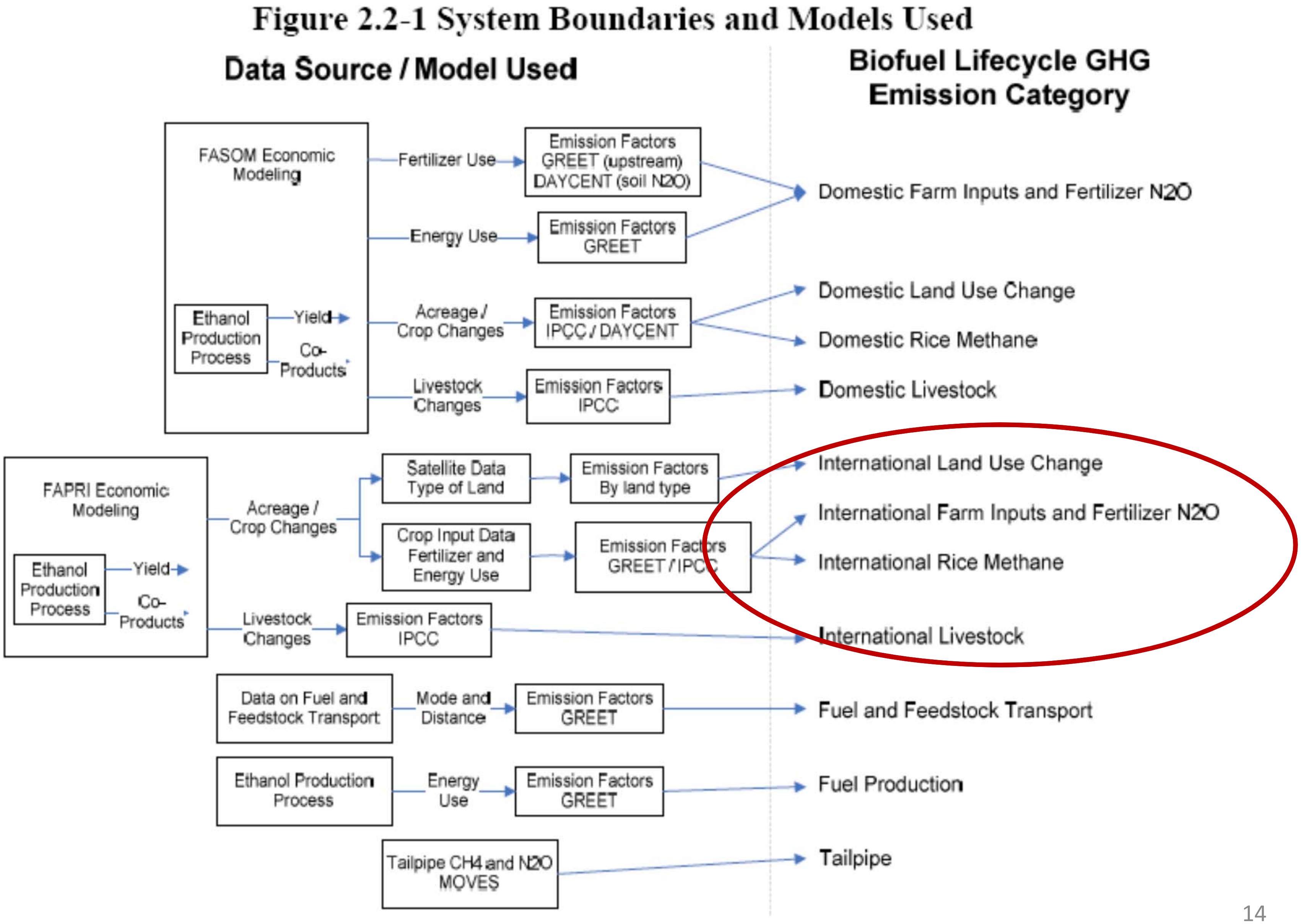
## ILUC is one of *many* indirect GHG emissions:

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

| **Corn-ethanol**<br>Indirect emissions | **Gasoline**<br>Indirect emissions |
|---|---|
| *+ Global land use (ILUC)* | Military security for foreign oil<br>(~$130 billion per year) |
| - Global livestock ($CH_4$, $N_2O$) | Unconventional sources of petroleum, tar sands |
| - Global soil carbon from crop substitutions:<br>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?<br>(another ~$100<br>billion per year in Iraq) |
| + Rice ($CH_4$) | |

# *EPA's macro-modeling framework recognizes multiple indirect emissions*

*(combines 8 models and tens of thousands of parameters)*



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

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

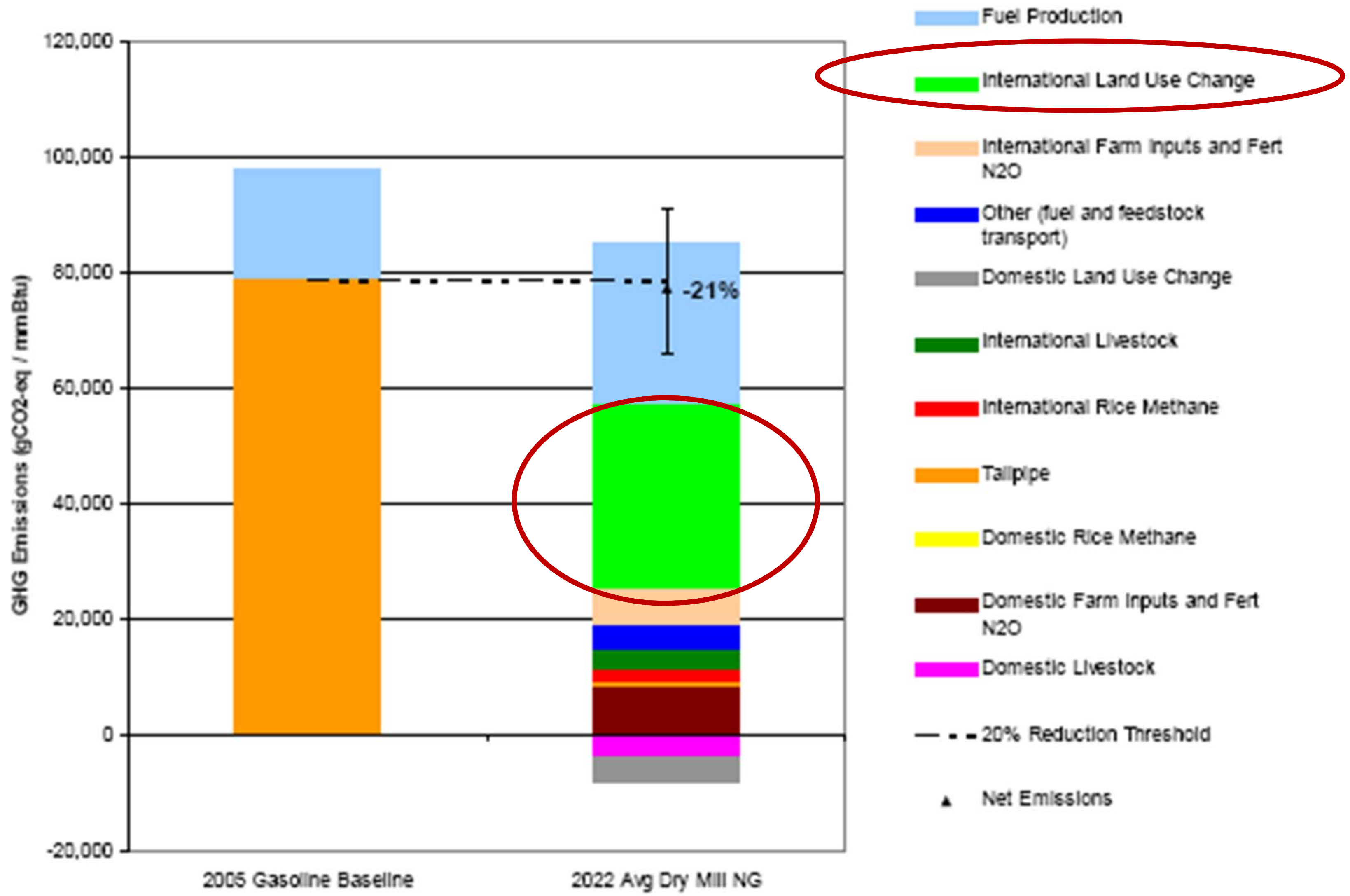


**Figure 2.6-2. Results for a New Natural Gas Fired Corn Ethanol Plant by Lifecycle Stage**
**Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)**

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**<br>**$gCO_2e/MJ$** | **Other Estimates**<br>**$gCO_2e/MJ$** |
|---|---|---|
| Global Land Use (ILUC) | + 30.1 | + 13.9<br>(Tyner et al. 2010) |
| Global Livestock | - 0.28 | - 47.5<br>(Liska and Perrin 2009 based on Searchinger 2008 and FAO 2007) |
| Military Security for Middle East oil | 0 | -17.5<br>*increase gasoline GHGs or reduction in military; based on LCA of US military and attribution of 20% (~$100B/yr) to oil security*<br>(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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- Profs. Galen Erickson & Terry Klopfenstein, Animal Science, Univ. Nebraska
- Prof. Kenneth Cassman, Agronomy, Univ. Nebraska

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