Empirical Data and Decomposition Analysis of U.S. Corn Use for Ethanol Production from 2001-2008

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U.S. DEPARTMENT OF ENERGY

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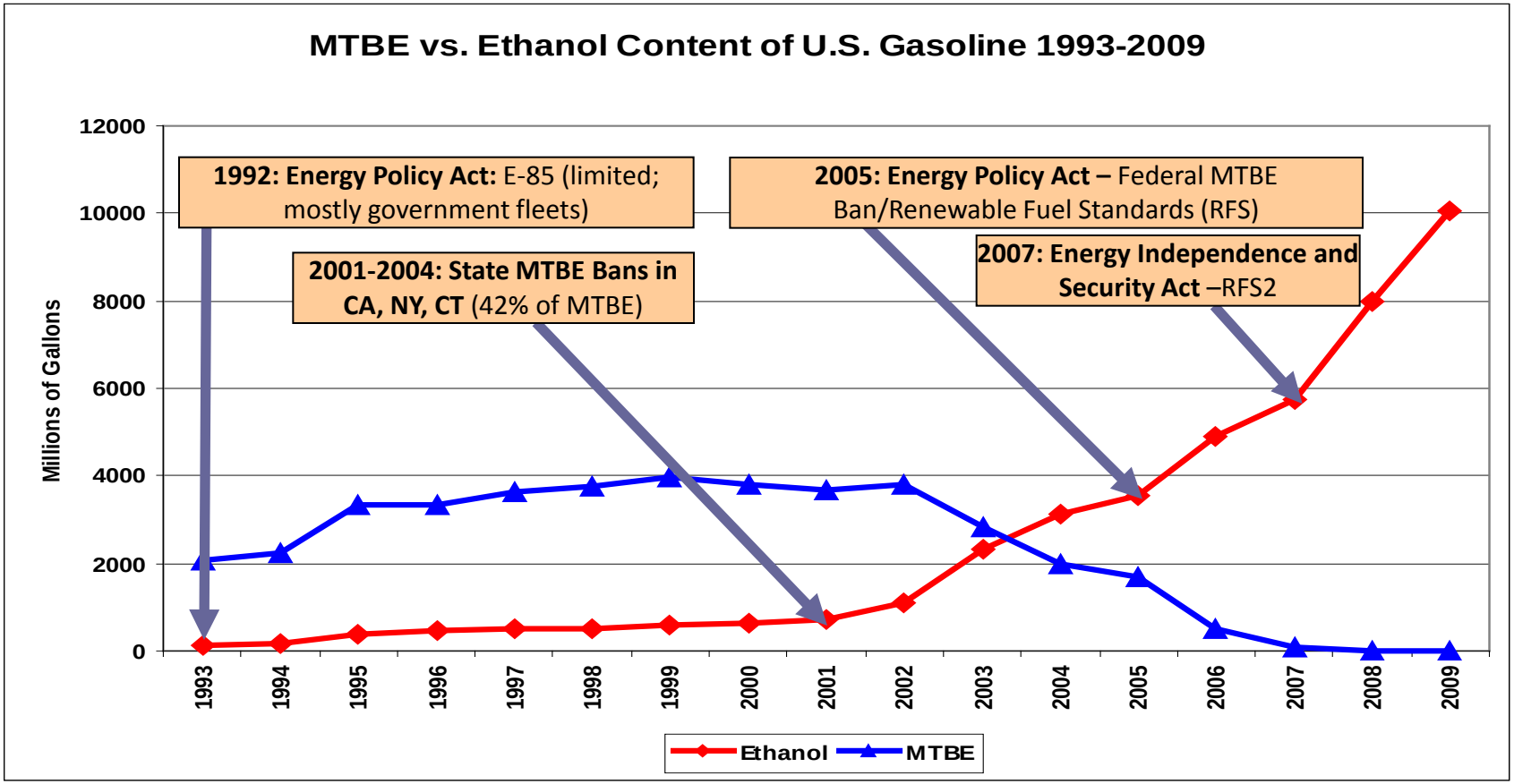
Abstract

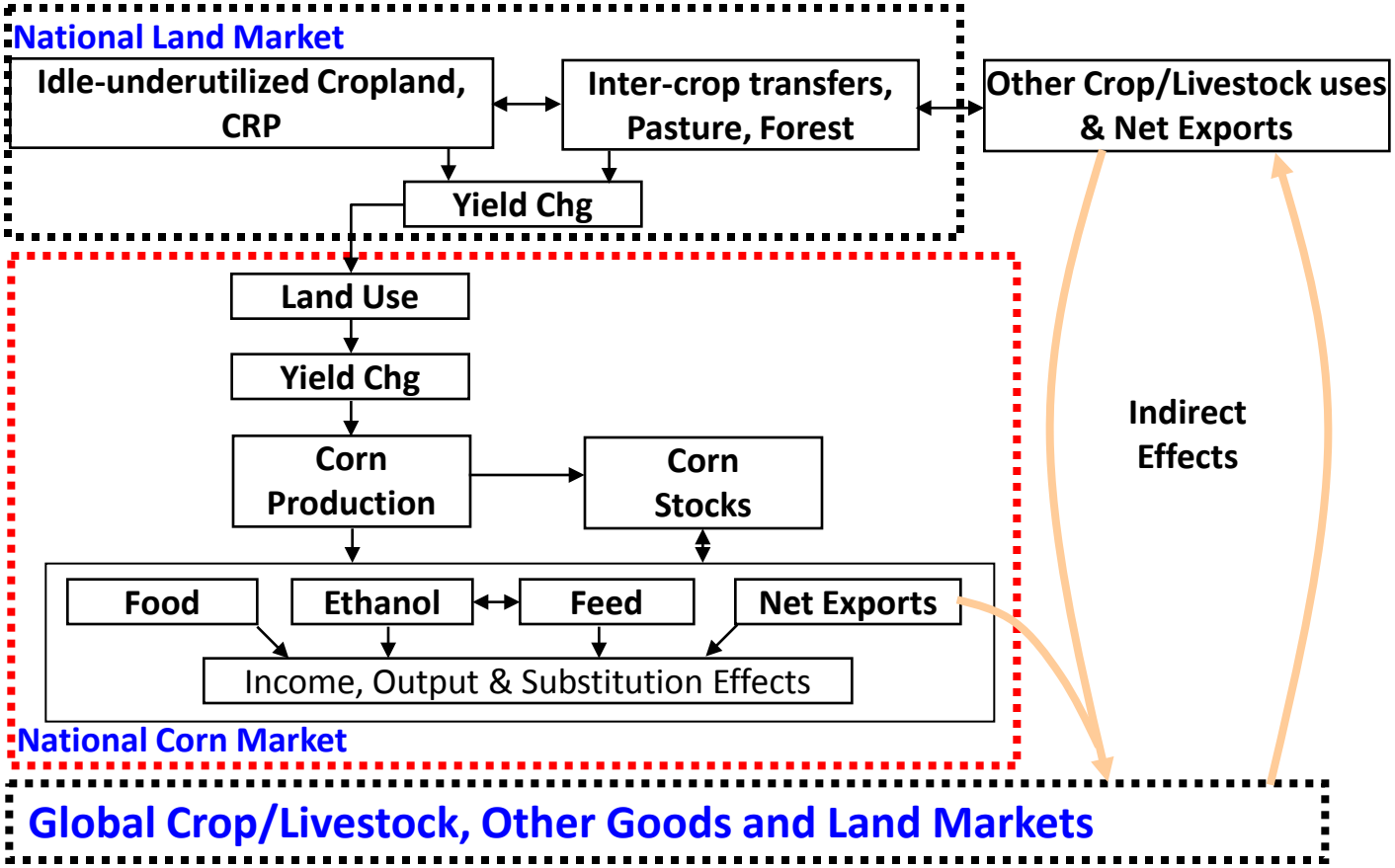
Corn use for ethanol production in the United States more than quintupled between 2001 and 2009. As the world's largest producer, the increase in U.S. corn use for ethanol generated debate about welfare and environmental implications. Concerns about “food versus fuel” tend to flare whenever food prices have increased in recent years. And with growing concerns about deforestation, the possibility that the conversion of new land (forest and grasslands) would necessarily result from the use of corn for ethanol production in the U.S. (referred to as indirect land-use change or ILUC) merits study. These two concerns rely on assumptions that feedstock used for ethanol production in the U.S. comes primarily from reducing exports and displacing other crops. The current study tests the veracity of these assumptions through a review and systematic decomposition analysis of empirical data between 2001 and 2008, a period during which corn ethanol production in the U.S. increased at an average rate of 25 percent per year. The review showed that corn exports grew (by 50% from 2002 to 2007), even as corn use for ethanol production accelerated. In addition, the total harvested land under the major crops grown in the United States, including coarse grains, changed little. A decomposition analysis based on the logarithmic mean divisia index (LMDI I) was used to estimate contributions of different factors in meeting the corn demand for ethanol production. The factors analyzed include: 1) the distribution of total domestic corn among different uses; 2) the domestic share of total corn supply; 3) stock withdrawals; 4) land use, and 5) corn yield. The decomposition showed that about 85 percent of the change in corn use for ethanol production over the 2001-2008 period can be allocated to changes in the distribution of domestic corn use. The remaining contributions were: 12 percent due to corn production increases, 5 percent from an increase in the domestic share of total U.S. corn supply, and -2 percent net from stock withdrawals (stocks increased during the period). The results also highlighted the importance of yield change: a little more than half of the 12 percent production contribution was due to yield and the remainder allocated to cropland re-distribution (with corn primarily displacing other feed grains). The results of this study provide little support for estimates that assume large land use conversion or diversion of corn exports due to ethanol production in the U.S. over the past decade. Results illustrate how the economy responded to biofuel policy in a manner distinct from what was assumed to generate ILUC estimates. Understanding direct land-use change dynamics is a prerequisite to estimating ILUC.

Major Policy & Market Developments: Rapid Increase in Ethanol Use from 2001 - 2009

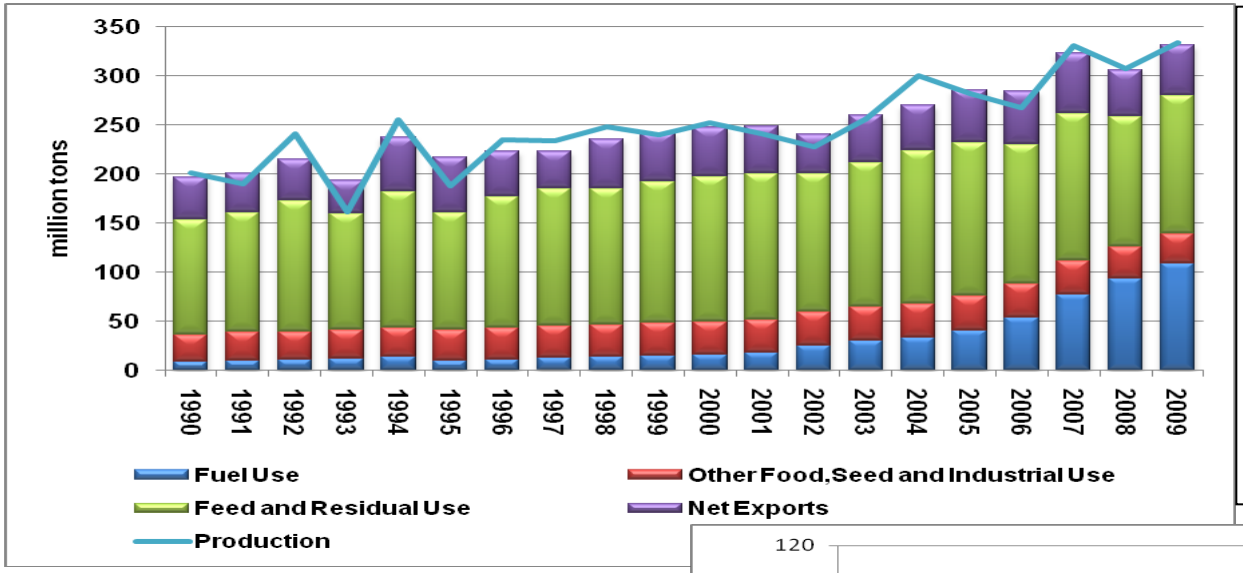


- Increase in corn ethanol production began in 2001
- Production surpassed 10.5 billion gallons in 2009
- Production grew at average rate of 25% per year between 2001 and 2009

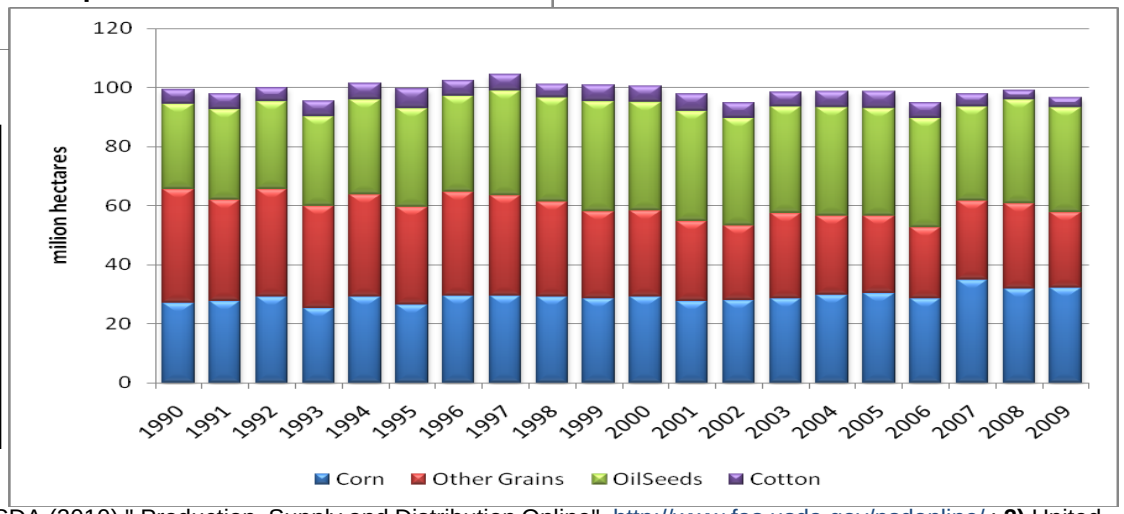
Indirect Land Use Change Estimation: Complicated by Multi-Market, Local, National and Global Dimensions



Empirical Corn Data: Corn Use for Ethanol Quintupled as Exports Increased



- Production and exports surged as corn use for ethanol increased
- Corn exports reached record levels in 2007
- 2008-09 exports, affected by global recession, but still large



- Total harvested cropland changed little since 1990
- Most increase in corn acreage was within the grain category
- 2007 was an outlier for corn

Data Sources: **1)** United States Department of Agriculture - USDA (2010) " Production, Supply and Distribution Online", http://www.fas.usda.gov/psdonline/ ; **2)** United States Department of Agriculture - USDA (2010a) " Feed Grains Database", http://www.ers.usda.gov/Data/FeedGrains/; **3)** FAO - Food and Agricultural Organization (2010) "FAOSTAT - Food and Agricultural Commodities Production", http://faostat.fao.org/site/339/default.aspx

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Index Decomposition Analysis of Empirical Corn Data: Logarithmic Mean Divisia Index (LMDI I)

- Index Decomposition Analysis
  - Allocates Changes in an Aggregate Variable to Each Contributing Component If All Other Components Were Held Constant
  - Especially Useful for Relationships of the Form: $y(x_1, x_2 \ldots x_n) = x_1.x_2 \ldots x_n$
- Decomposition based on the total differential:

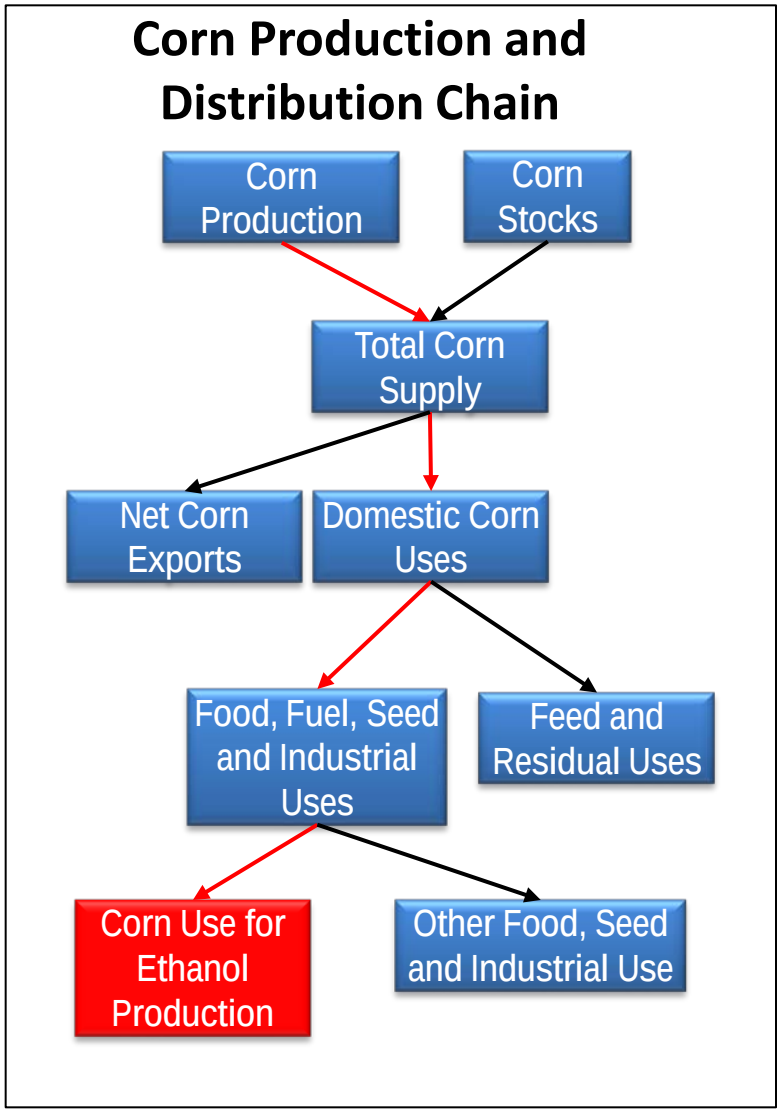
$$dy = \sum_{i=1}^{n} \prod_{j=1, j \neq i}^{n} x_j dx_i$$

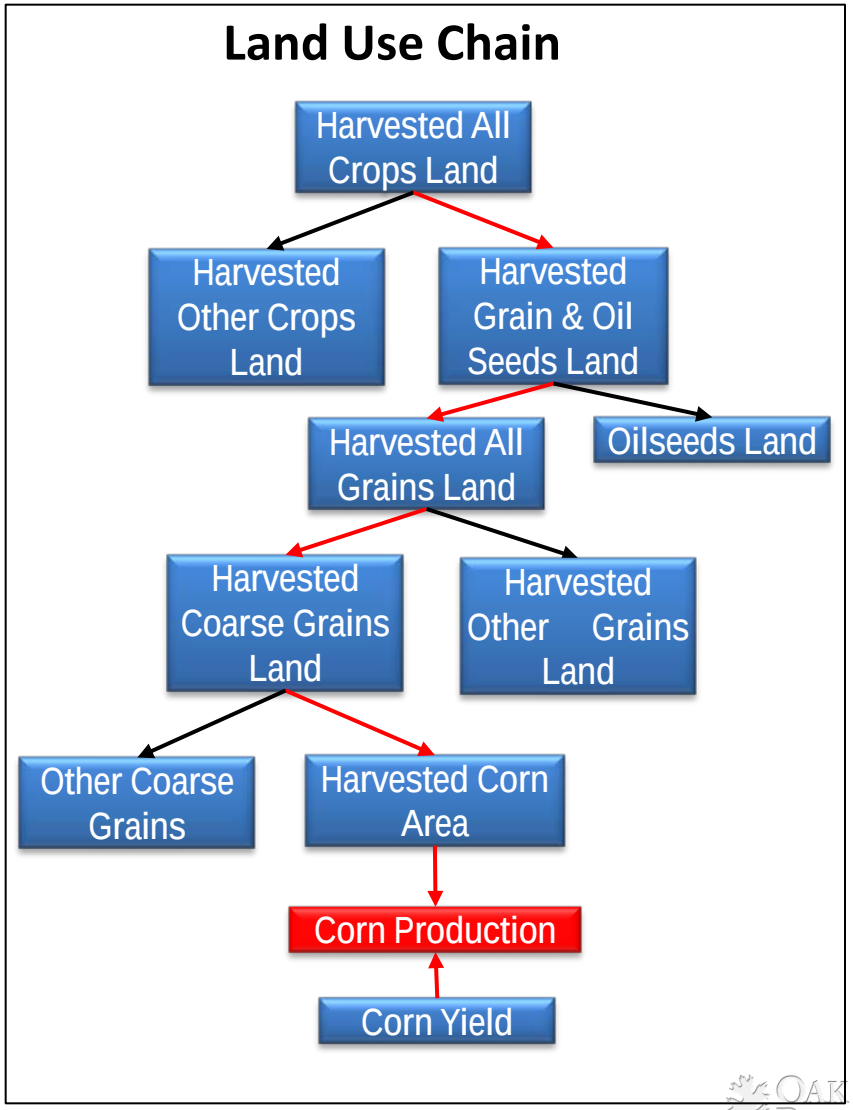
- Application to Discrete Data Leads to Different IDA Formulations
  - Depending on How the Integral is Approximated
- The Logarithmic Mean Divisia Index (LMDI I) Uses the Approximation:

$$\Delta y^D = \sum_{i=1}^{n} \left(\frac{(y_{t1} - y_{t0})}{ln\left(\frac{y_{t1}}{y_{t0}}\right)} \right) ln\left(\frac{x_{i,t1}}{x_{i,t0}}\right) = \sum_{i=1}^{n} \Delta y \frac{g_{xi}}{g_y}$$

- Similar to the GTAP Linearization (Percentage Change) Solution Approach
- Adopted for energy decomposition by national and international agencies

Decomposition Analysis of Empirical Corn Use for Ethanol Data with LMDI I: Linkages in the Chain





Decomposition Analysis of Empirical Corn Use for Ethanol Data with LMDI: Chain Relationship of Corn Use Distribution/Land Use Variables

$$Q_{ce} = \left(\frac{Q_{ce}}{Q_{ffsi}}\right)\left(\frac{Q_{ffsi}}{Q_{dom}}\right)\left(\frac{Q_{dom}}{Q_{prd+stc}}\right)\left(\frac{Q_{prd+stc}}{Q_{prd}}\right)Q_{prd}$$

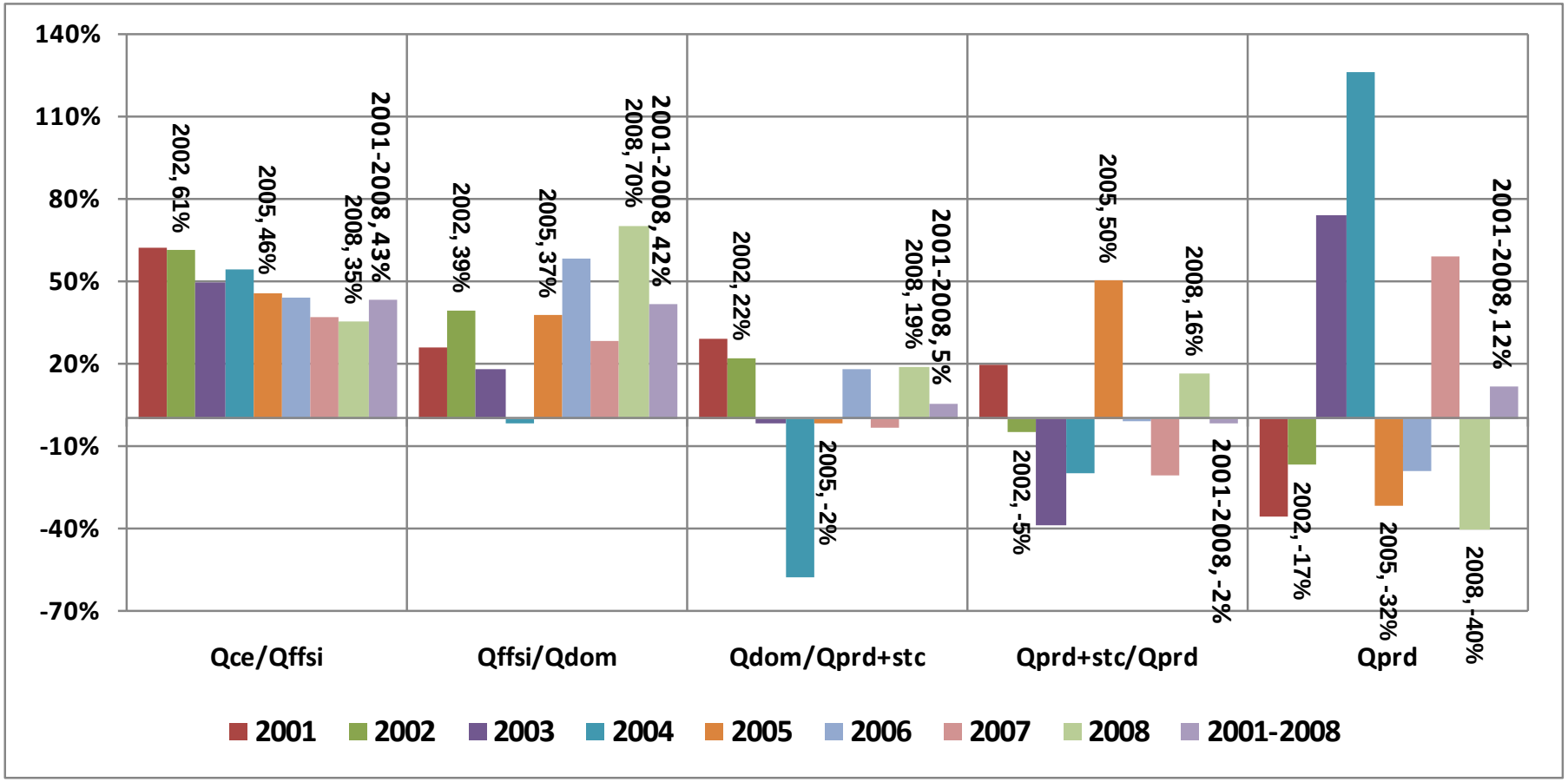
$$Q_{prd} = Y_{corn}\left(\frac{A_{corn}}{A_{cgrn}}\right)\left(\frac{A_{cgrn}}{A_{grn}}\right)\left(\frac{A_{grn}}{A_{grn+oilsd}}\right)\left(\frac{A_{grn+oilsd}}{A_{all}}\right)A_{all}$$

where:

Q_{ce} = Annual corn use for ethanol production (10^3 tons);
Q_{ffsi} = Annual corn use for food, fuel, seed and industrial purposes (10^3 tons)
Q_{dom} = Annual total domestic corn use (10^3 tons)
Q_{prd} = Annual total corn production (10^3 tons)
$Q_{prd+stc}$ = Annual corn production plus net stock withdrawal i.e. total supply (10^3 tons)
Y_{corn} = Annual corn yield in (tons/ha)
A_{corn} = Annual corn harvested area (ha)
A_{cgrn} = Annual coarse grain harvested area (ha)
A_{grn} = Annual all grain* harvested area (ha)
$A_{gn+oilsd}$ = Annual all grain plus oilseeds** harvested area (ha)
A_{all} = Annual total harvested cropland area (ha)

* Grains include corn, barley, oats, rye, sorghum (coarse grains), wheat, milled rice (other grains)
** Oilseeds include soybean, cottonseed, peanut, rapeseed, and sunflower seed

Decomposition Results of Corn Use for Ethanol: Domestic Adjustments Consistently Account for Most Change



- Contribution across all years, 2001-2008
  - Domestic Reallocation: 85%; Production: 12%;
  - Domestic Corn Use Share: 5%; Corn Stock Withdrawals: -2%;

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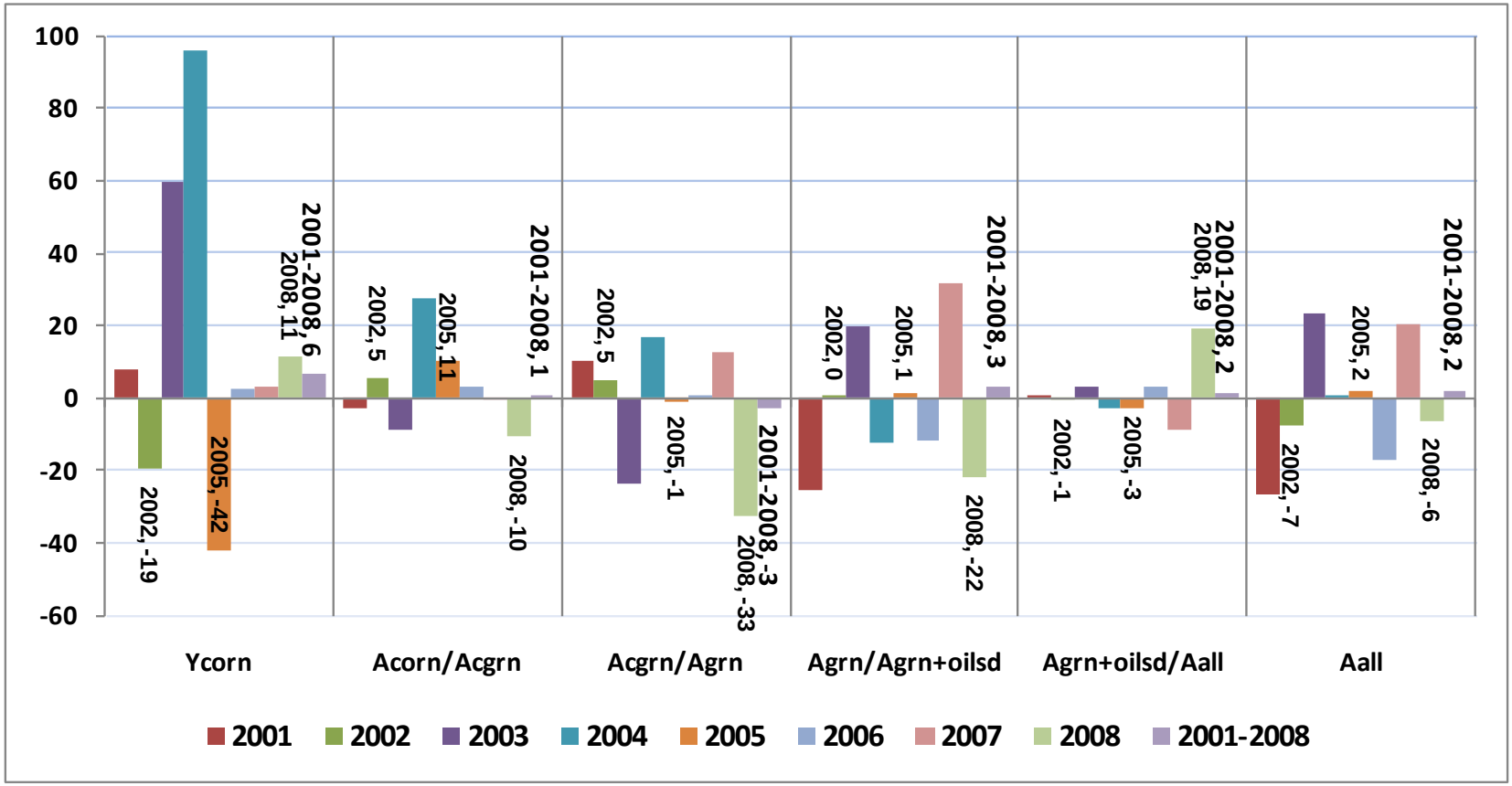
Decomposition of Corn Use for Ethanol Production: Yield Contributions and Land Use Change Contributions Are Variable, Relatively Small



- **Net Production Contribution between 2001-2008 (12%)**
  - **Yield: 6%; Total Cropland: 2%; Others: 4%**

Conclusions: Decomposition analysis of empirical data does not support key ILUC assumptions

- **The analysis of empirical data (2001-2008) indicates that:**
  - **Feedstock for ethanol expansion was mainly derived from domestic reallocations (85%) and increased yields (6%)**
  - **Empirical evidence does not support significant effects on:**
    - **US commodity exports**
    - **Other crops or cropland expansion in the U.S.**
- **Understanding the interactions of policy with baseline trends is crucial to improve estimates of policy effects on land use**
  - **Models calibrated to historic data could not adequately capture implications of large, new changes in the economy (such as the 78 million ton increase in corn use for ethanol)**
  - **Analysis of the data can illustrate how the economy actually adjusted to biofuel policy that increased demand (and supply) of corn for ethanol**
    - **More detailed analysis of policy effects on prices is needed**
- **The analysis suggests minimal to zero indirect land use change was induced by use of corn for ethanol over the last decade**

Recommendations

- Analysis of policy effects (intended and unintended costs and benefits), including actual land use and emissions, need to be updated frequently and focus on manageable time horizons (4-6 years)
  - Assess factors affecting progress toward meeting goals
  - Consider regulatory options that reduce uncertainty and transaction costs, and facilitate evaluation of performance
- Apply the analysis of recent empirical evidence to adapt regulations to better fulfill goals for an effective, efficient, performance-based, LCFS
- Research is needed to clarify interactions among policy, shifting production, domestic and global markets. For example, to:
  - Better reflect trends and production capacities in baselines
  - Distinguish how current economy responded to “advance notice” (versus an imposed “demand shock” on prior economy)
  - Assess how an expanding production base interacts with cyclic markets, volatility and risks to disruption (from weather, policy)
  - Refine policy to provide incentives for improved efficiency, competitiveness and more sustainable land management practices
- The CARB ILUC approach needs to better incorporate ongoing gains in knowledge and experience

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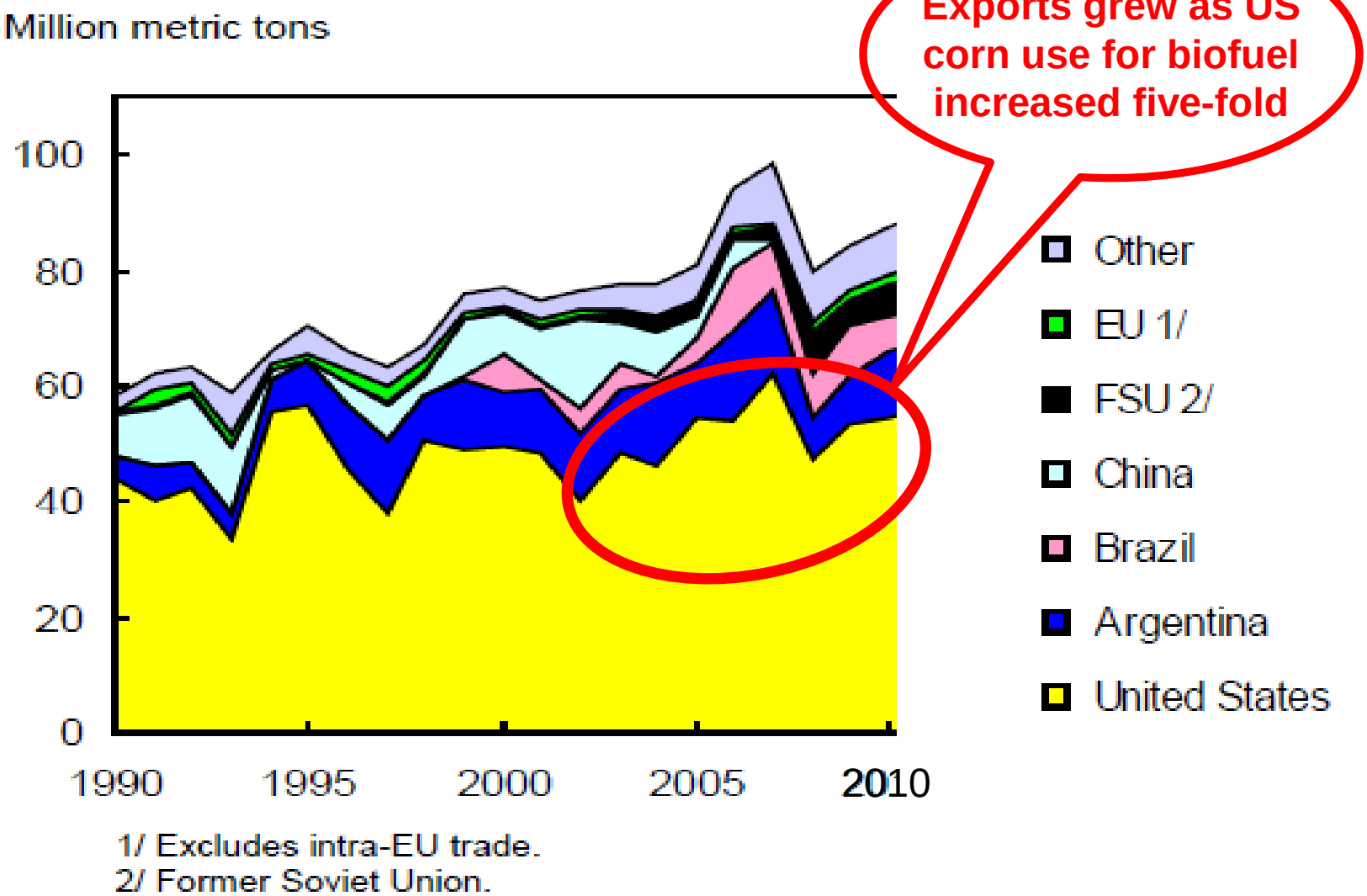
Additional empirical data
and trends from USDA and other sources
follow as food for thought.
Correlation does not imply causation.

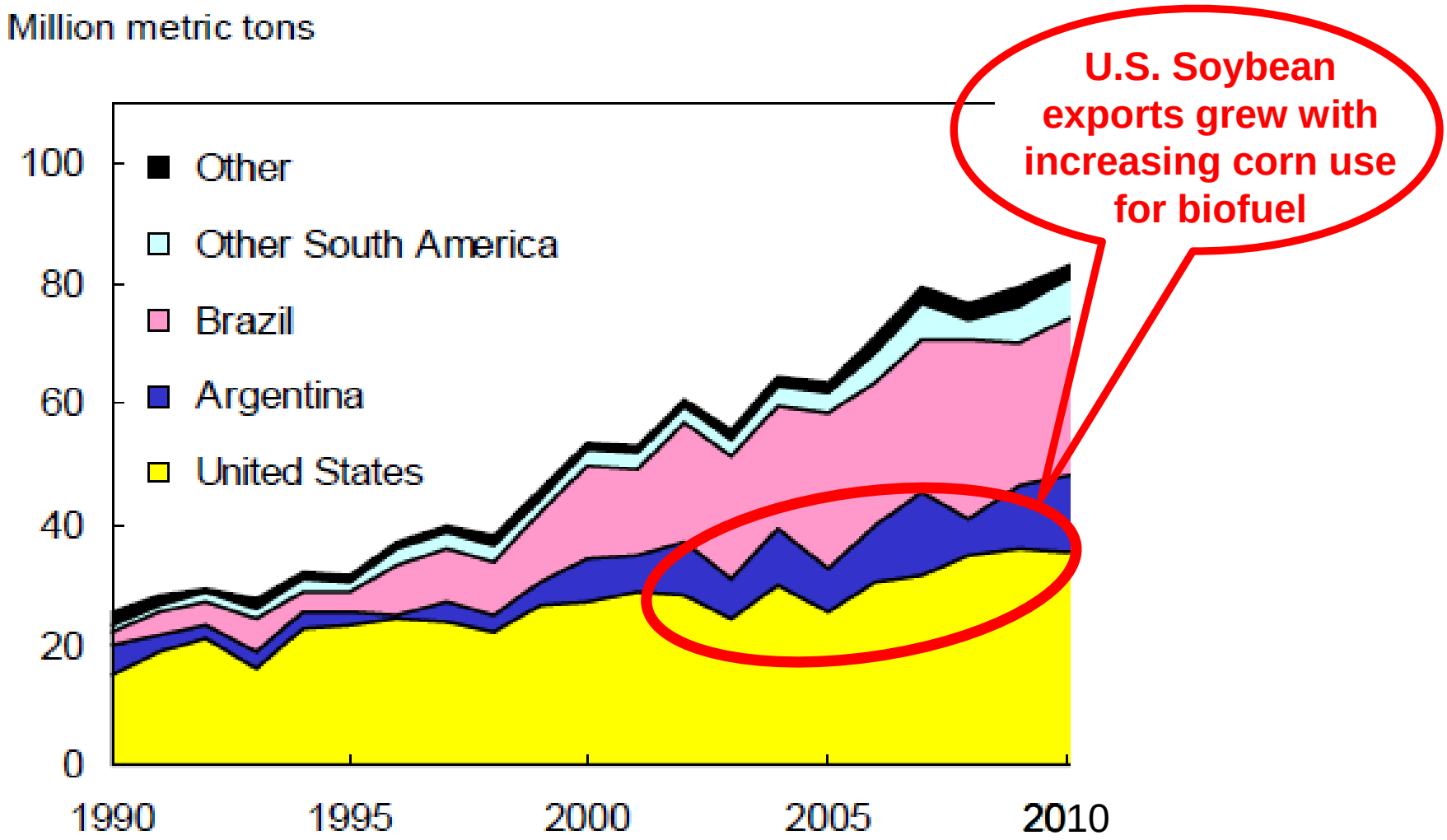
Global corn exports (historic data)



1/ Excludes intra-EU trade.
2/ Former Soviet Union.

Source: USDA Long-term Projections, 2010.
http://www.ers.usda.gov/publications/oce101/

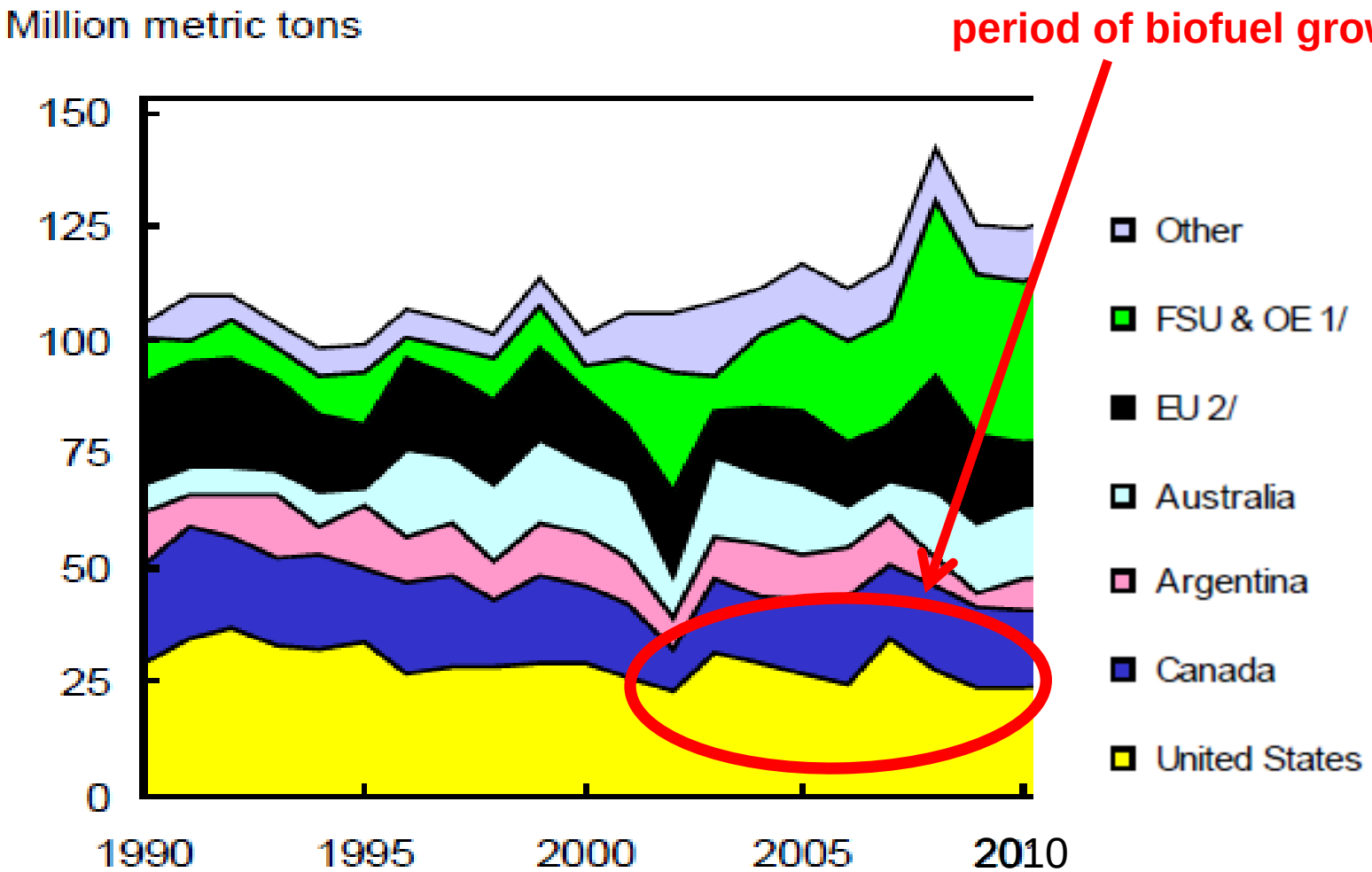
Global soybean exports (historic data)



Source: USDA Long-term Projections, 2010.
http://www.ers.usda.gov/publications/oce101/

Global wheat exports (historic data)

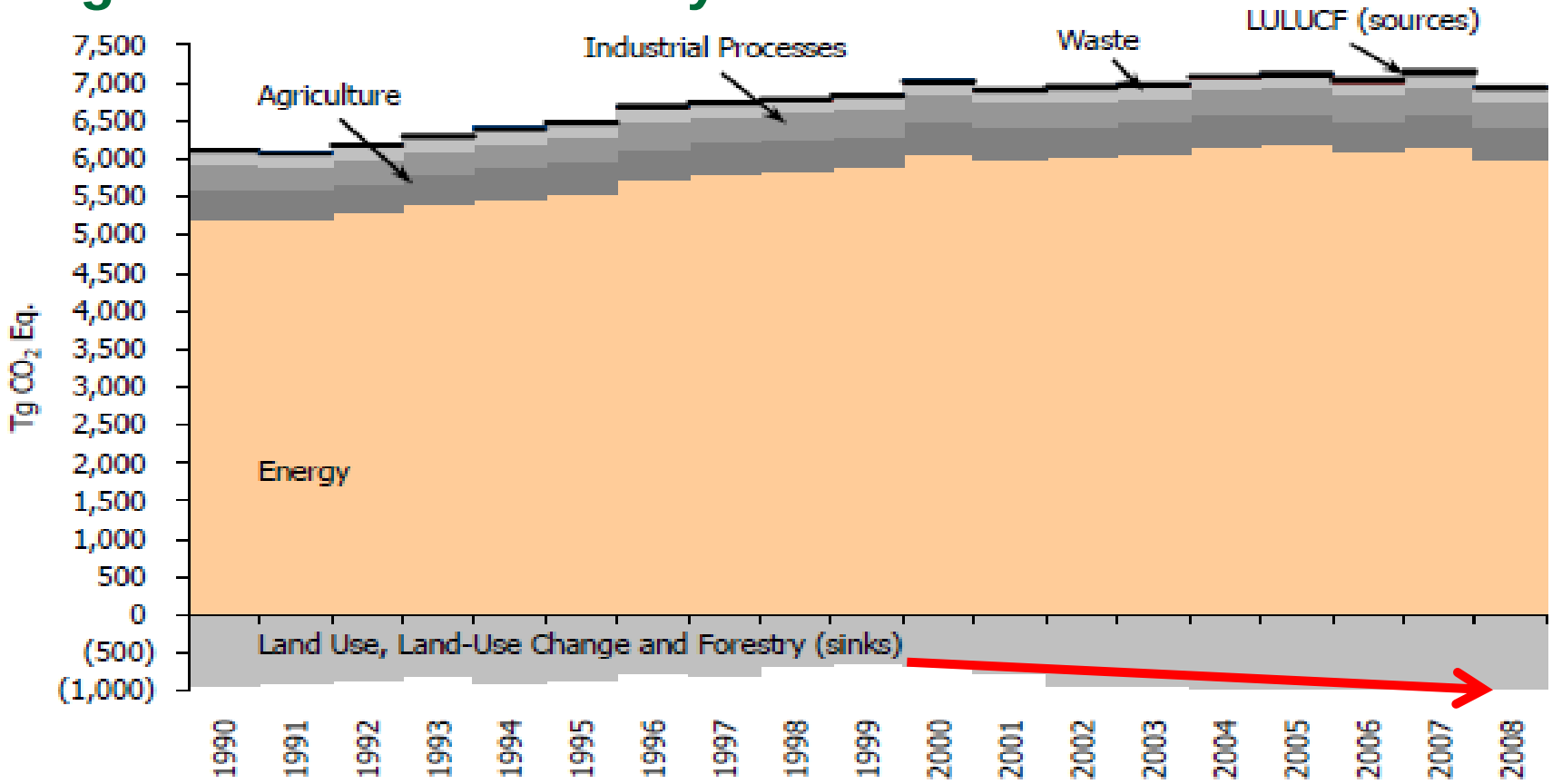
U.S. Wheat exports fluctuate with little net change over period of biofuel growth



1/ Former Soviet Union and other Europe; prior to 1999, includes Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia.
2/ Excludes intra-EU trade.

Source: USDA Long-term Projections, 2010.
http://www.ers.usda.gov/publications/oce101/

U.S. Land-Use/LUC/Forestry Sinks (below line) have Grown since 2000 while LULUCF Sources and Agriculture are relatively small and stable



U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector

Source: INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2008 (April 2010) U.S. EPA # 430-R-10-006 (Figure 2-4)

As biofuel output grew 500% (2001-2009) U.S. Land-Use/LUC/ Forestry Sink Value Grew 43% (2000-2008)

Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO_2 Eq.)

Chapter/IPCC Sector	1990	1995	2000	2005	2006	2007	2008
Energy	5,224.1	5,545.8	6,087.5	6,187.9	6,089.1	6,182.9	5,999.0
Industrial Processes	318.3	339.1	351.9	334.7	339.7	350.9	334.5
Solvent and Other Product Use	4.4	4.6	4.9	4.4	4.4	4.4	4.4
Agriculture	387.8	407.7	410.9	419.7	417.2	423.0	427.5
Land Use, Land-Use Change, and Forestry (Emissions)	15.0	17.2	36.3	28.6	49.8	47.6	32.2
Waste	177.2	174.5	153.0	158.0	159.7	159.3	159.1
Total Emissions	**6,26.8**	**6,488.8**	**7,044.5**	**7,133.2**	**7,059.9**	**7,168.1**	**6,956.8**
Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Sinks)*	(909.4)	(842.9)	(664.2)	(950.4)	(959.2)	(955.4)	(940.3)
Net Emissions (Sources and Sinks)	**5,217.3**	**5,646.0**	**6,380.2**	**6,182.8**	**6,100.7**	**6,212.7**	**6,016.4**

* The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Please refer to Table 2-9 for a breakout by source.

U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector

Source: INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2008 (April 2010) U.S. EPA # 430-R-10-006

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Livestock Production Contributes a Majority of Agricultural Emissions via Shares of Soil Management + CH_4 and Manures

Table 2-8: Emissions from Agriculture (Tg CO_2 Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CH_4	**169.6**	**185.9**	**183.7**	**186.7**	**188.1**	**194.2**	**194.0**
Enteric Fermentation	132.4	143.7	136.8	136.7	139.0	141.2	140.8
Manure Management	29.3	33.9	38.6	42.2	42.3	45.9	45.0
Rice Cultivation	7.1	7.6	7.5	6.8	5.9	6.2	7.2
Field Burning of Agricultural Residues	0.8	0.7	0.9	0.9	0.9	1.0	1.0
N_2O	**218.3**	**221.8**	**227.2**	**233.0**	**229.1**	**228.8**	**233.5**
Agricultural Soil Management	203.5	205.9	210.1	215.8	211.2	211.0	215.9
Manure Management	14.4	15.5	16.7	16.6	17.3	17.3	17.1
Field Burning of Agricultural Residues	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Total	**387.8**	**407.7**	**410.9**	**419.7**	**417.2**	**423.0**	**427.5**

Note: Totals may not sum due to independent rounding.

In 2008, agriculture contributed 427.5 Tg CO2eq or 6.1% of total U.S. GHGs
Livestock represents 96% of CH4 emissions
Between 1990 and 2008, emissions from manure management increased >40%, enteric fermentation varied with animal population (slight increase) and soil emissions fluctuated with weather (slight increase)

Source: INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2008 (April 2010) U.S. EPA # 430-R-10-006

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Majority of N2O Emissions are Attributable to Livestock Production

Table 6-15: N_2O Emissions from Agricultural Soils (Tg CO_2 Eq.)

Activity	1990	1995	2000	2005	2006	2007	2008
Direct	**156.7**	**161.8**	**165.8**	**170.5**	**166.0**	**167.2**	**170.4**
Cropland	103.0	109.8	115.6	117.9	114.7	116.7	118.3
Grassland	53.7	51.9	50.2	52.6	51.3	50.5	52.1
Indirect (All Land-Use Types)	**46.7**	**44.2**	**44.3**	**45.4**	**45.2**	**43.8**	**45.5**
Cropland	36.0	33.9	35.7	35.4	35.3	34.1	35.1
Grassland	10.4	9.7	8.0	9.3	9.2	9.0	9.6
Forest Land	+	0.1	0.1	0.1	0.1	0.1	0.1
Settlements	0.3	0.5	0.5	0.6	0.6	0.6	0.6
Total	**203.5**	**205.9**	**210.1**	**215.8**	**211.2**	**211.0**	**215.9**

+ Less than 0.05 Tg CO_2 Eq.

Cropland accounted for 69% of total direct N20 emissions while grassland accounted for about 31%

Majority of U.S. cropland is dedicated to coarse grains, feed and fodder for livestock production

Source: INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2008 (April 2010) U.S. EPA # 430-R-10-006

Hertel 2010 Land Use Change Numbers, 13.52 billion gallons corn ethanol production

Region	New Cropland Area	Forestland Area Converted to Crops	Pastureland Area Converted to Crops or Forestry	Forest Reversion From Pasture
	ha	ha	ha	ha
USA	1,457,967	-566,569	-964,629	73,194
RoAFR	82,692	-3,676	-79,098	93
SASIAEEX	-12,164	0	-12,544	24,716
RoHIA	209	-28	-187	6
RoASIA	23,488	-7,304	-18,153	1,984
Oceania	102,221	-1,252	-102,846	1,874
Total	3,834,850	-1,288,506	-3,115,394	569,004

Hertel et al. 2010 GTAP Simulation Results for LUC:

Hertel:	**13.52**	**b gallons/yr ethanol increase from 2001 to target (15 bgal/y)**
	8.83	**b gallons/yr = actual increase in output from 2001-2009**
Pro-rated	**65%**	**of Hertel et al. simulated increase was produced in 2009**
Pro-rated	**947,679**	**hectares of new cropland area in USA**
Pro-rated	**368,270**	**hectares of forestland converted to cropland**
Pro-rated	**627,009**	**hectares of pastureland area converterd**

Corn area expansion displaces other crops and drives ILUC in other nations

Actual changes in US cropland* 2001-2009

(Caveat: better to consider trends over time rather than simple two-point comparisons)

USDA data: output >36 billion liters/yr; soy & wheat output up; grain exports up total US cropland fell slightly…

*Per Searchinger et al. (pro-rated) 8.3 million ha corn expansion and "sharp declines in soy, wheat…" would be needed to reach actual 2009 ethanol output

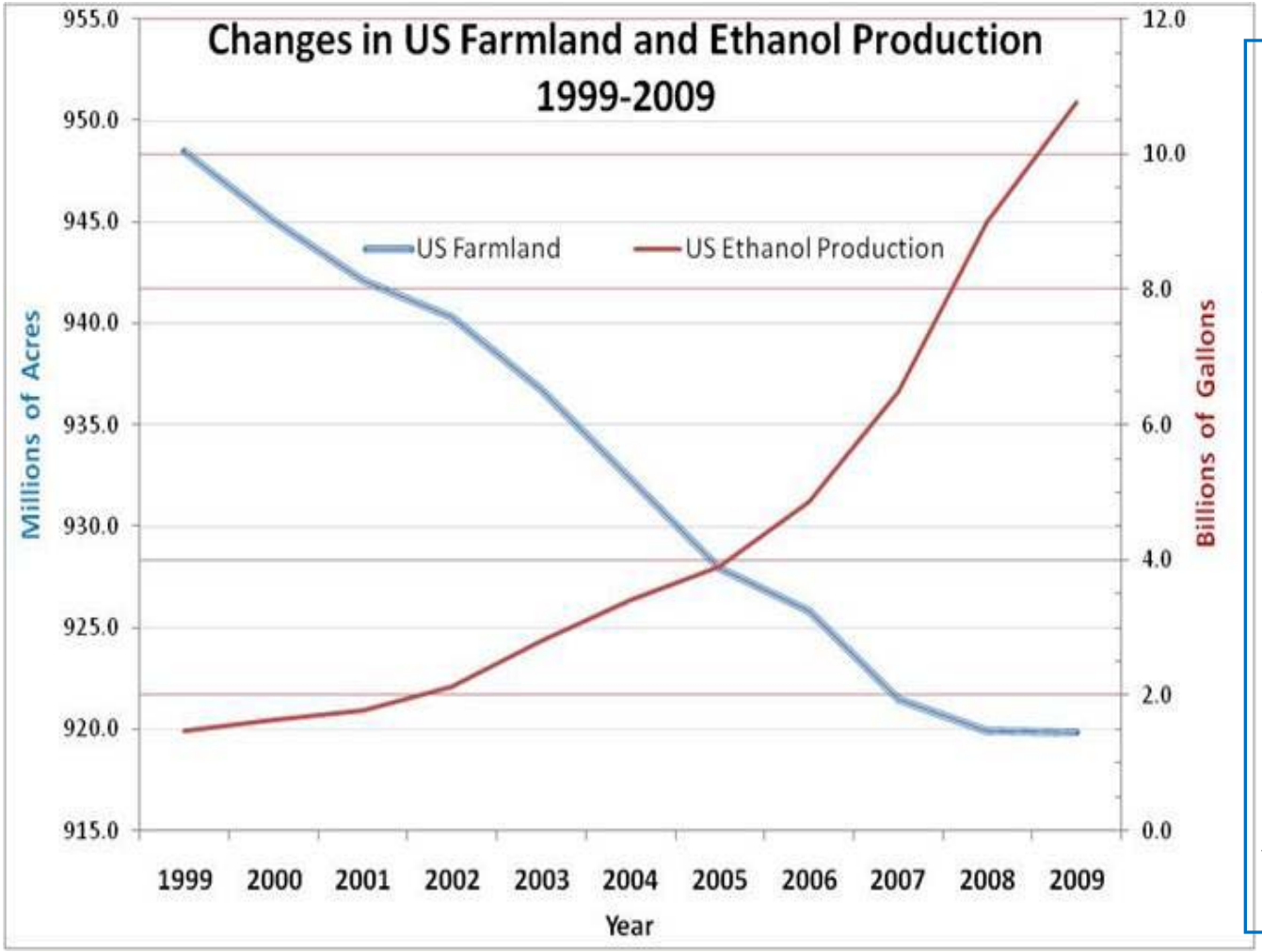
USDA NASS "Area Planted"	% change	Change in Area
Change from 2001 to 2009 in:	Percent	Hectares x 1000
USDA Total for all crops	-1%	-1,321
USDA "Principal Crops"	-1%	-1,500
Losing acreage 2001-2009:		
Cotton All	-43%	-2,718
Other Coarse Grains (not corn)	-28%	-2,491
Hay All (Dry)	-5%	-1,352
Oilseeds & peanuts exlcuding soy*	-28%	-748
Rice All	-9%	-128
Sugarcane + sugar beets	-14%	-139
Tobacco, potatoes, all others	-14%	-106
Gaining acreage 2001-2009:		
All corn (grain + silage)	13%	4,369
Soybeans	5%	1,477
Edible beans, peas, lentils	50%	377
Wheat All	1%	139

***Source: USDA total planted area: http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp**

Record thus far fairly consistent with BRDI projections.

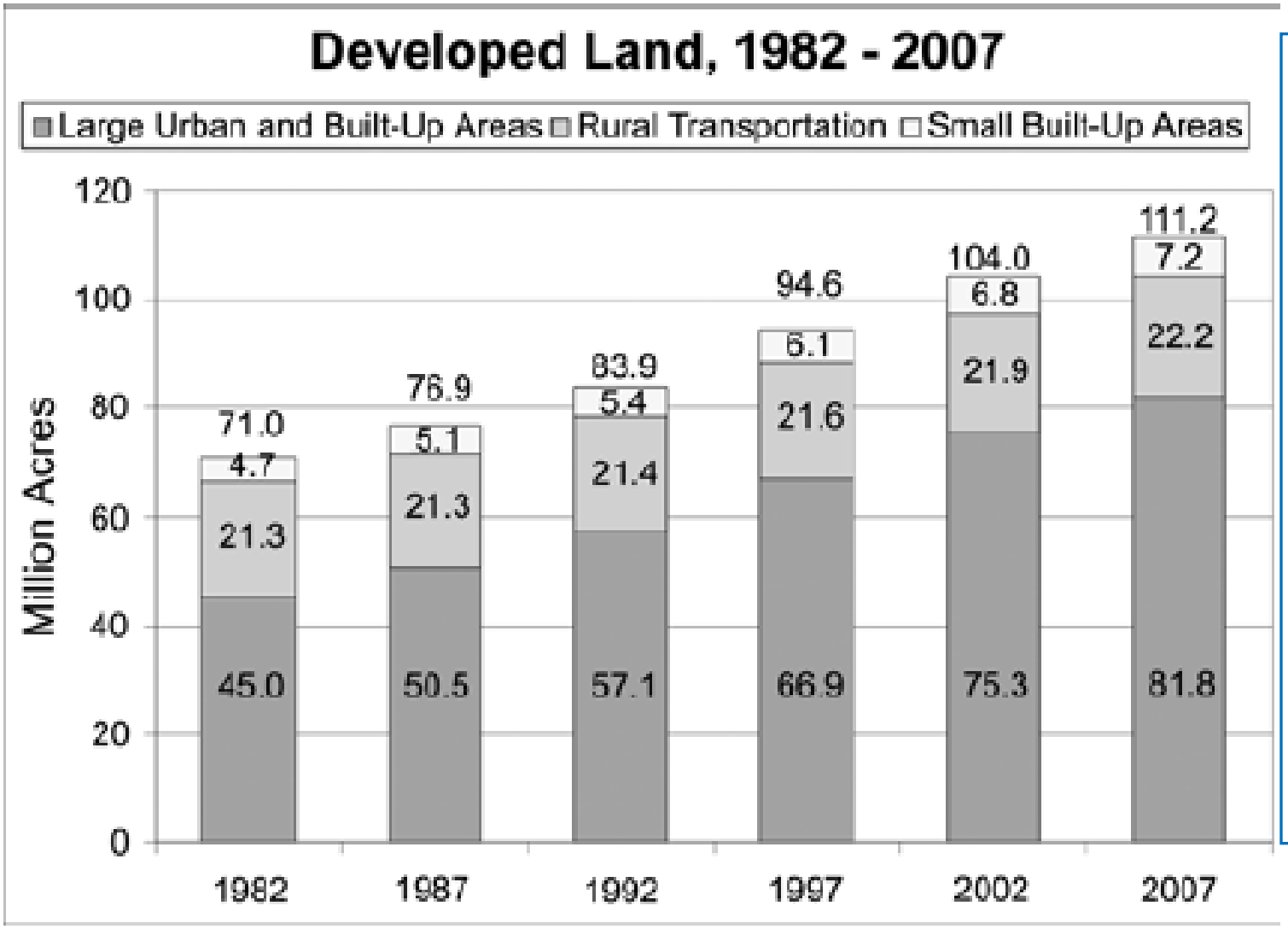
LUC analysis and baseline trends

- What are historic trends?
- How are they affected by policy?
- How do emission fluxes change with actual LUC?



US farmland was lost at avg. rate of 3.4 M acres per year (1999-2007) as biofuel production soared

(Sources: USDA NASS 2010: "Farms, Land in Farms, and Livestock Operations - 2009 Summary: Feb 12, 2010. Renewable Fuels Assoc. for US ethanol output data)

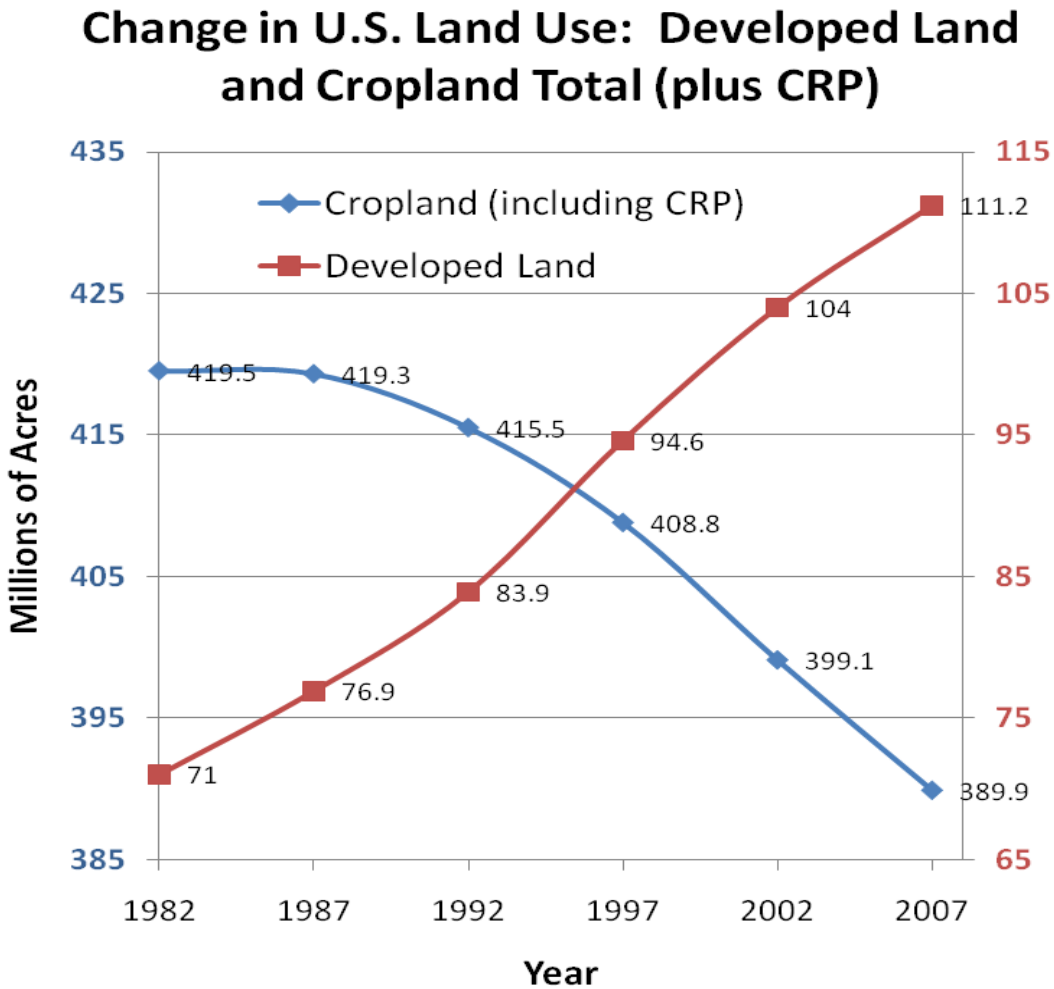


Source: U.S. Department of Agriculture. 2009. Summary Report: 2007 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 123 pages. (NRI 2009)

NRI 2009 indicated that since 1982, the U.S. lost over 14 million acres of prime farmland and "most of this loss was due to development"

- Has bioenergy policy helped slow the conversion of forest and farmland to "development"?
- If so, what are the implications for GHG emissions and other environmental services?
- How can benefits be increased with least risk?

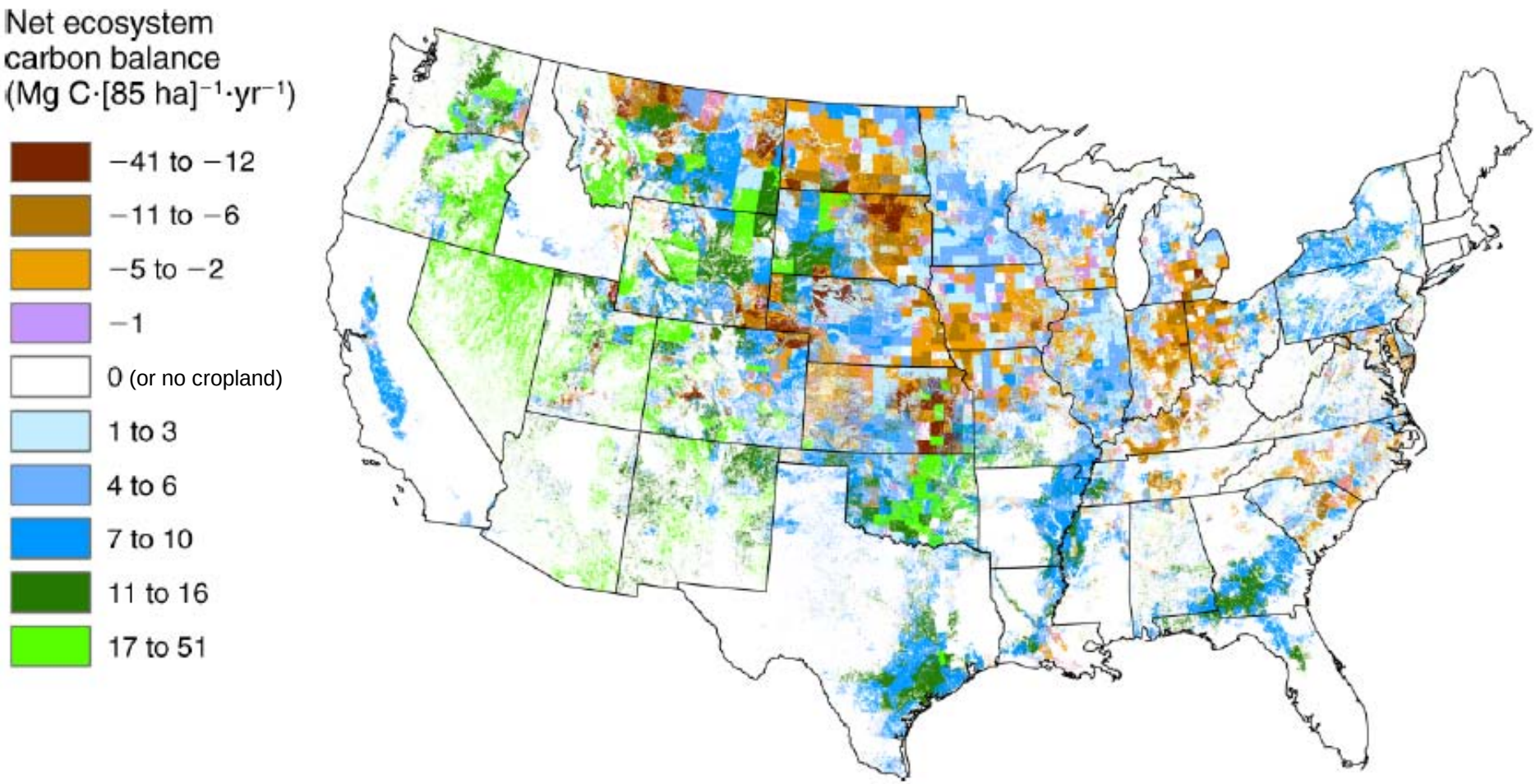
The U.S. continues to lose cropland to development in spite of higher demand for commodities



Source: Chart prepared by ORNL based on data from: U.S. Department of Agriculture. 2009. Summary Report: 2007 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 123 pages.

NRI 2009: U.S. Cropland Total and CRP area combined fell by over 9 million acres from 2002 to 2007, while Developed Land area increased by over 7 million acres.

Performance metrics that can be measured: Cropland can be net sink (or source) of carbon



Source: Energy Use and Carbon Dioxide Emissions from Cropland Production in the United States, 1990–2004 in J Environ Qual 38:418-425. R.G.Nelson, C.M.Hellwinckel, C.Brandt, T.West, et al. (2010)