Water Implications of Biofuels in the U.S.

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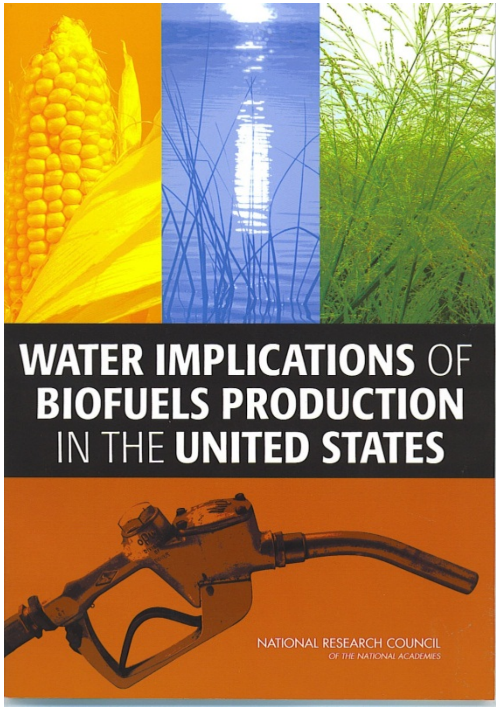
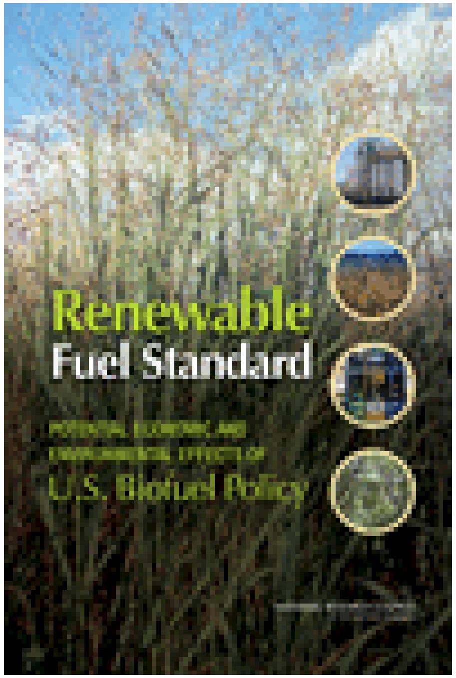
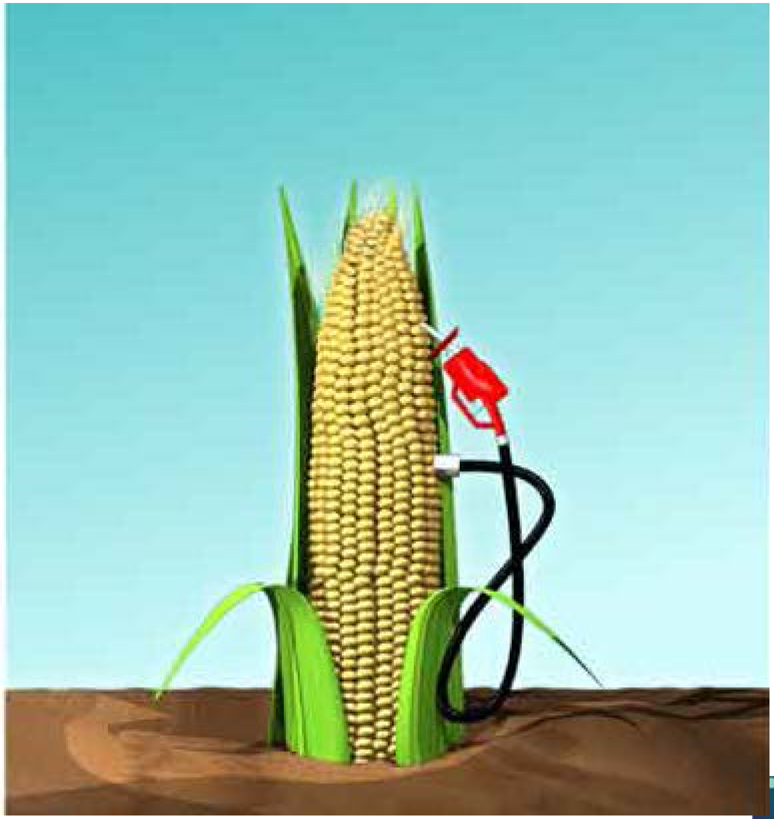
Two NRC Reports, 2008 and 2011





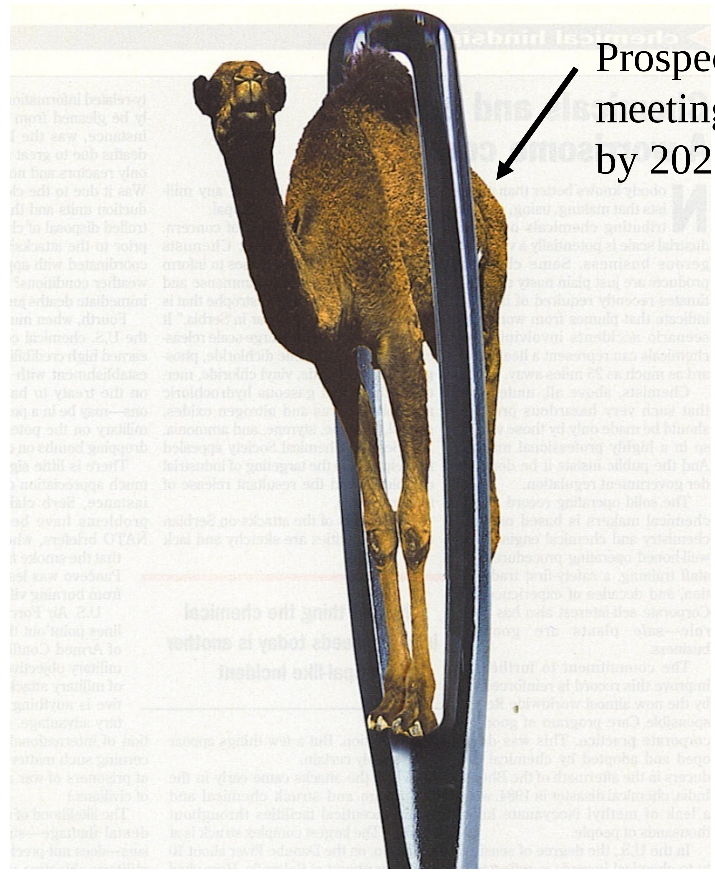
Biofuels and Water

- The Policy Setting: EISA (2007) and EPA's RFS2
- Impacts of Growing the Crops
  - Water Quantity
  - Water Quality
- Impacts of Biofuel Production
  - Water Quantity
  - Water Quality
- Sustainability Issues
  - Energy return
  - GHG metrics



Energy Security & Independence Act EISA 2007 & EPA Renewable Fuel Standard RFS2

- EISA requires 36 billion gal of biofuels by 2022 (~25% v/v by 2022)
- EPA's LCA specifies what constitutes a renewable fuel
  - Existing biofuel plants in 2007 were "grandfathered in"
  - 20% improvement in the LCA of GHGs required for new conventional biofuel plants
  - 60% improvement in LCA of cellulosic ethanol plants
  - 50% for advanced biofuels
- "Indirect land use" is considered in the determination



Prospects for meeting RFS2 by 2022

EPA Renewable Fuel Standard (RFS2) in billion gallons per year (bgy)

	2005	2010	2015	2020	2022
Conven-tional bio-fuels*	4	12	15	15	15
Biomass diesel [a]	0	1	1	1	1
Unspecific advanced[b]	0	0.1	1.5	3.5	4
Cellulosic Biofuels [c]	0	0.4	3	10.5	16
TOTAL			**20.5**		**36**

*Conventional biofuels in US are corn ethanol;
a+b+c = Total Advanced Biofuels

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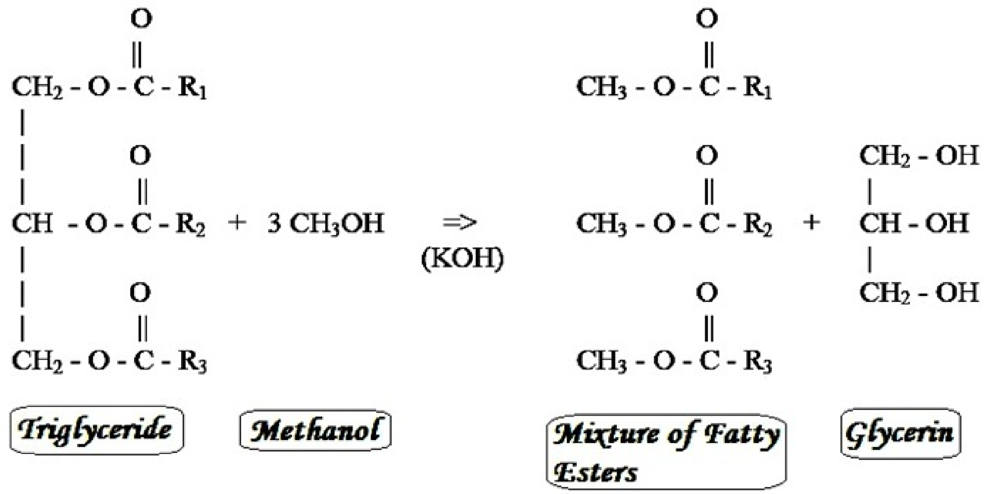
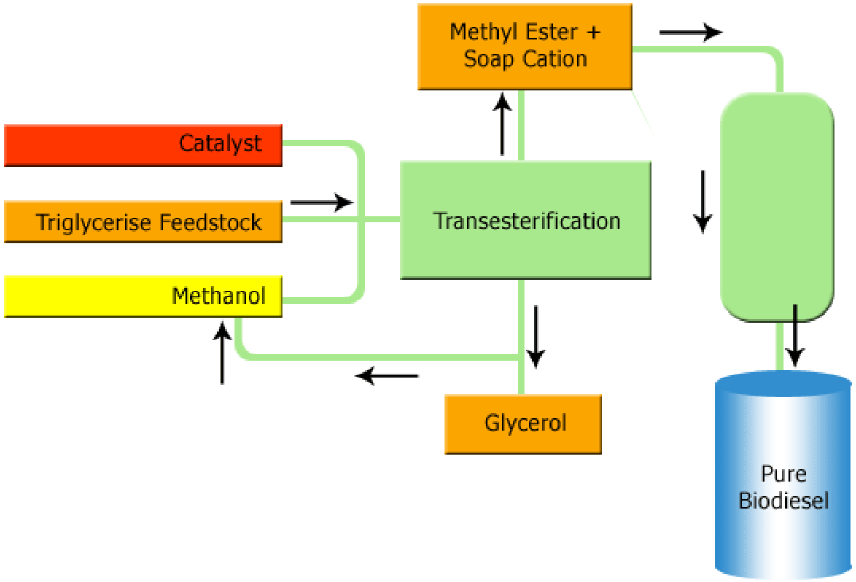
Biodiesel from soybean oil, waste fats and oils qualifies as Biomass Diesel or (unspecified) Advanced Biofuel under RFS2



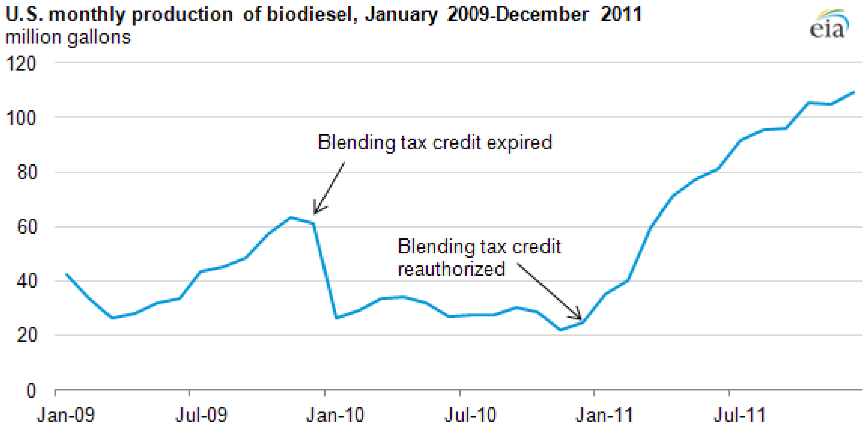
Soybean,
canola,
cooking oils
& animal fats

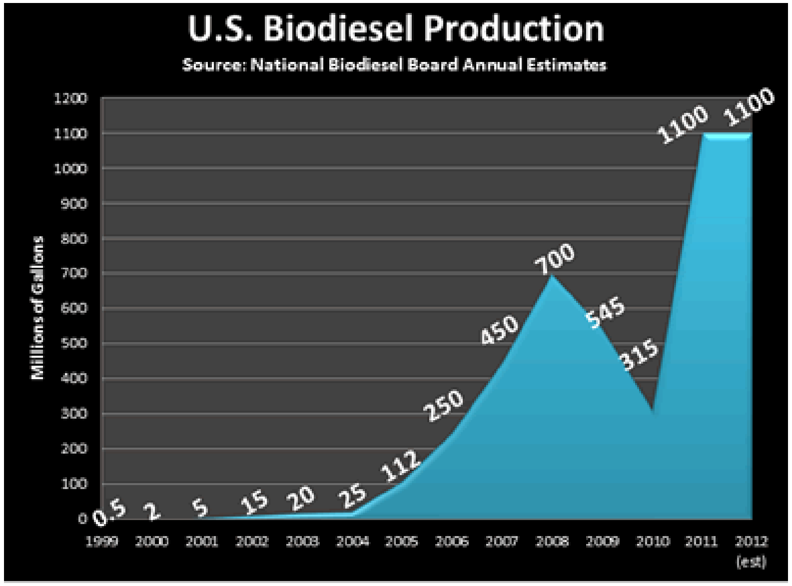
Biodiesel limitations and economics



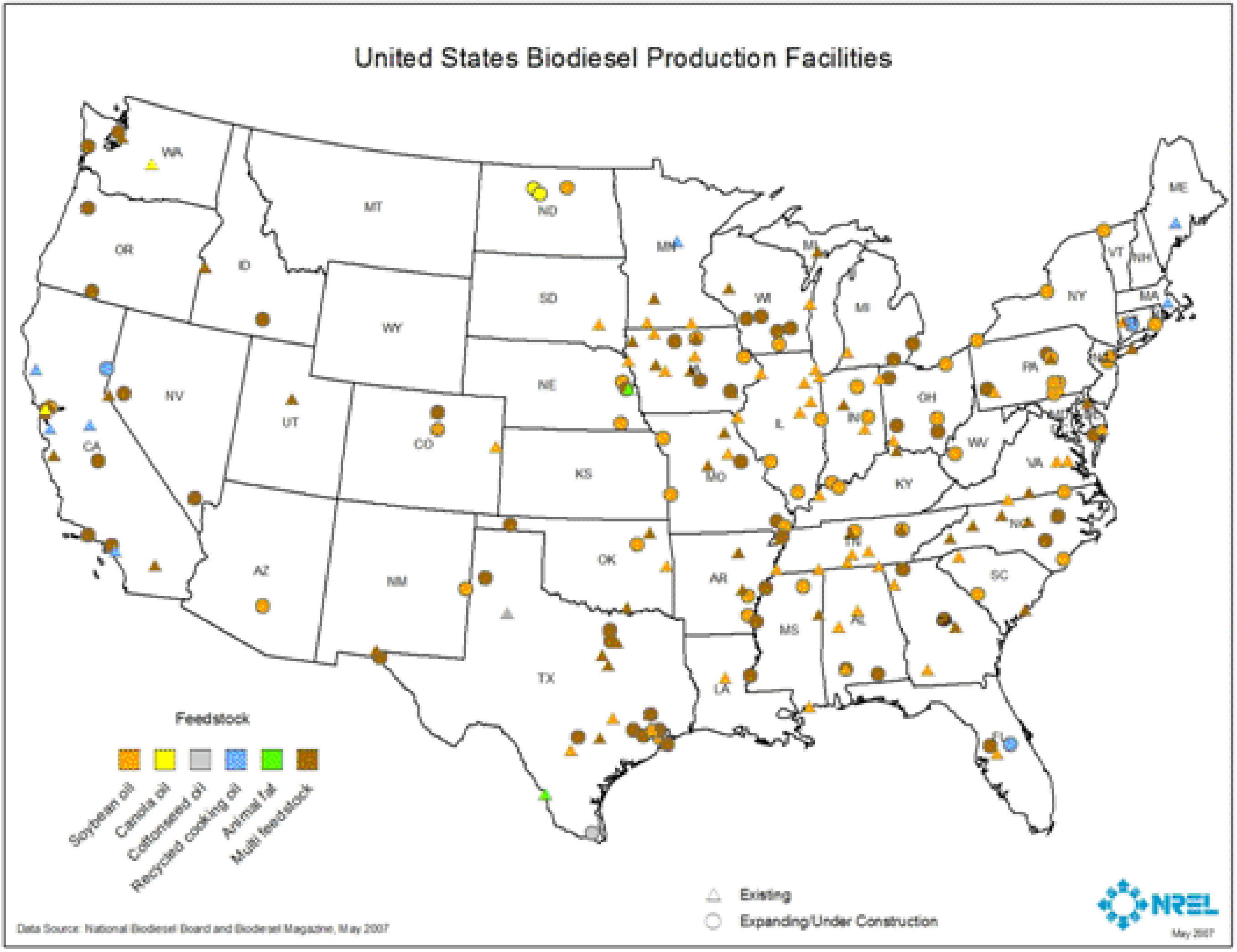
- The main problem with biodiesel is it's not very profitable when waste fats/oils are not available and soybean prices are high
- It requires a tax credit incentive to expand
- Also, there is a glut of glycerol by-product which sells for as little as 1 cent/lb

Biodiesel is growing rapidly now due to $1.01 per gal tax credit, but still a small fraction of total biofuels

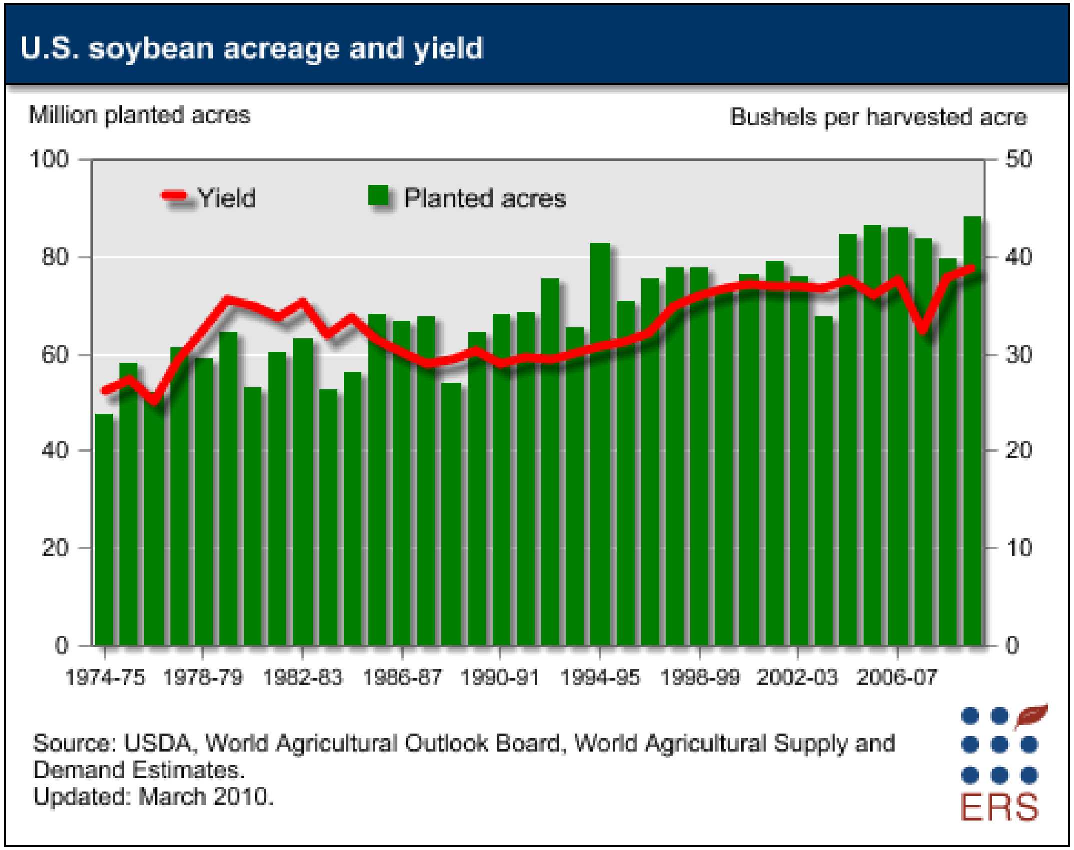




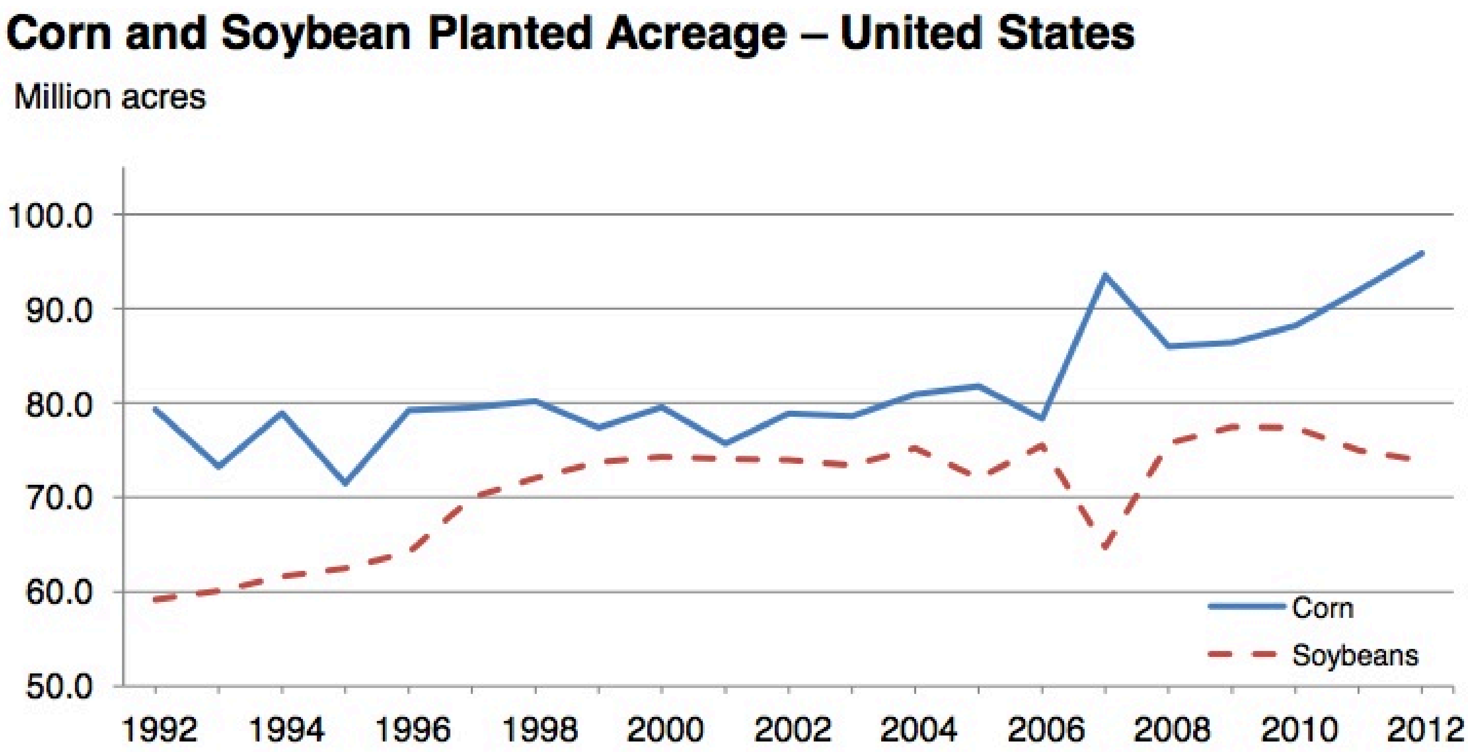
Biodiesel plants in U.S. from all feedstocks



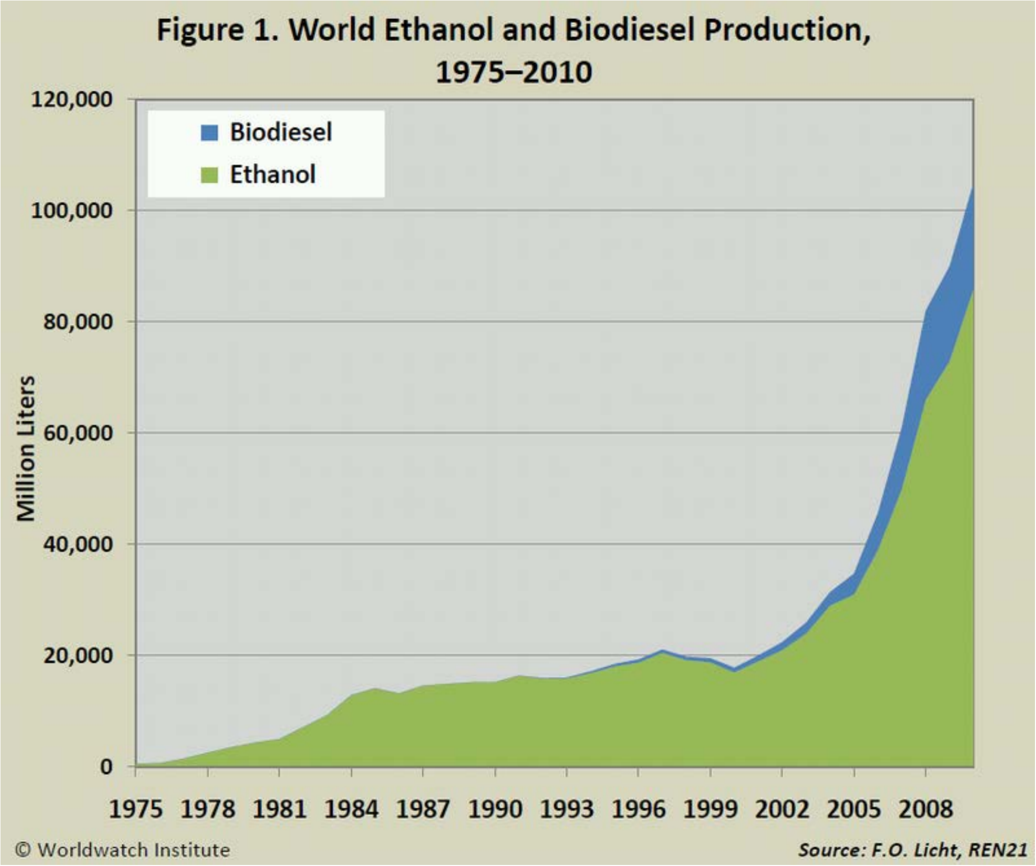
Soybean acreage and yields have been slowly increasing in the U.S.



Corn acreage has been increasing the fastest and it is the crop requiring the greatest "inputs"



Biofuels are still growing fast throughout the world -- biodiesel offers advantage of being a “drop-in” fuel



Corn ethanol production is largest among biofuels in the U.S. (~13 billion gallons per yr)

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Corn is a starch grain with many uses

- One bushel (~54 lbs) of corn equals:
  - 31.5 lbs starch/food
  - <u>Or</u> 33 lbs of sweetener
  - <u>Or</u> 2.8 gallons ethanol
    - + 13.5 lbs gluten feed
    - + 2.6 lbs gluten meal
    - + 1.5 lbs corn oil
    - <u>And</u> 40 permanent jobs for a 50 million gal/day production facility
- Tax Credit for blenders ended in U.S. as of 1/1/12, but biodiesel and cellulosic ethanol enjoy a tax credit ($1.01/gal)

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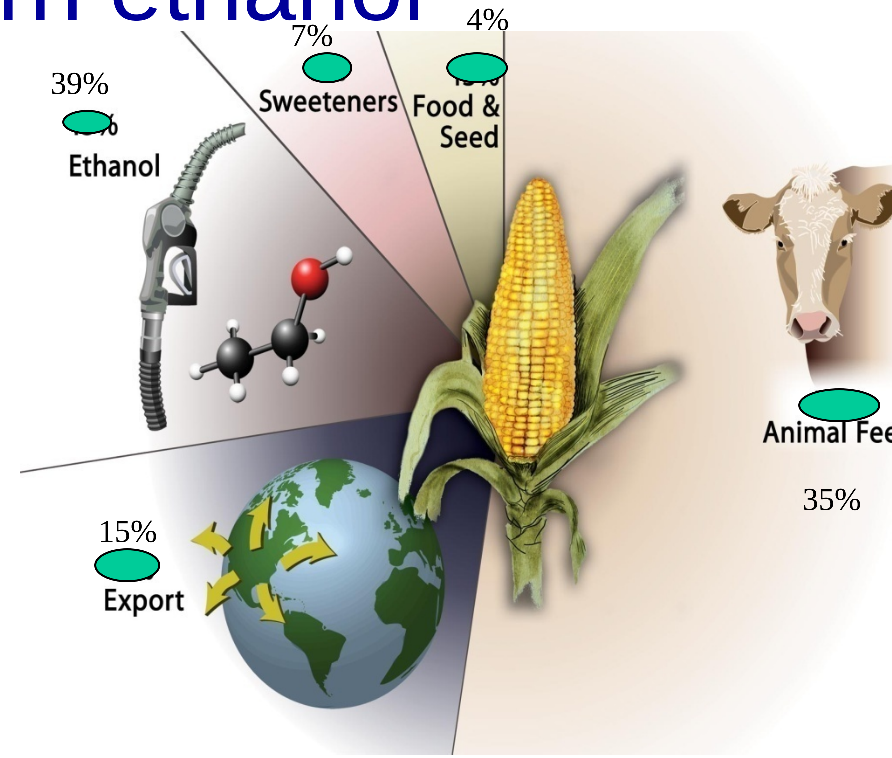
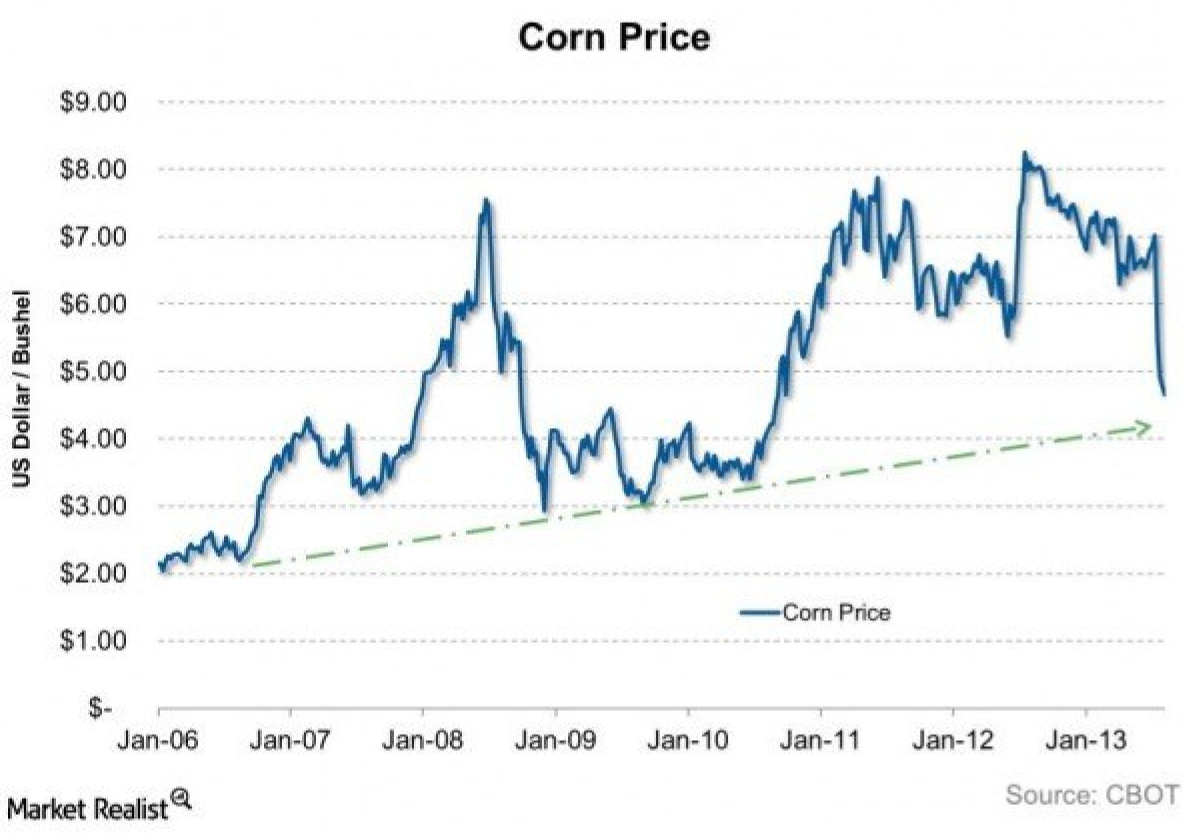
How is our corn being used today? Almost 40% for corn ethanol



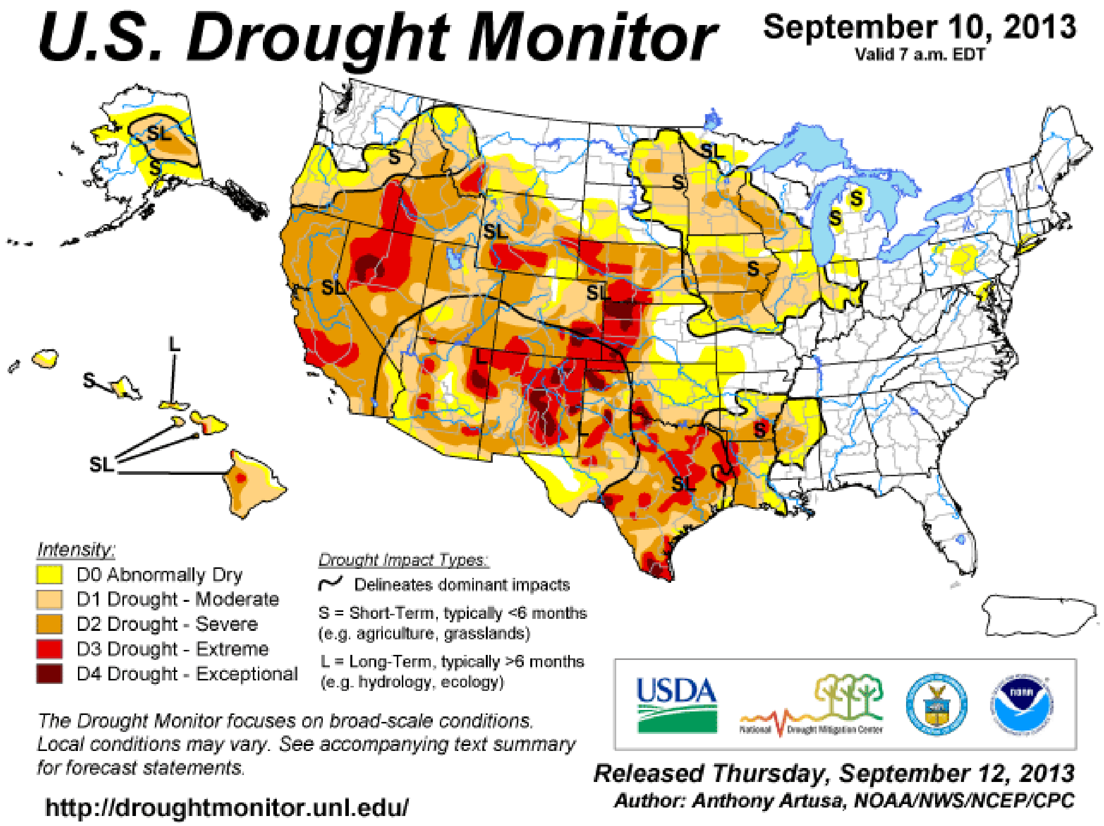
In 2013, U.S. growers planted a record 97 million acres of corn for ethanol, feed, export, and food products. Corn is also used for some industrial purposes and products including rubber, plastics, and clothing.

Credit: *Nicolle Rager Fuller, National Science Foundation*

Corn prices are high (in part) due to demand for biofuels; the dip in price recently makes corn ethanol profitable even without a tax credit



In 2012-13, drought has affected corn growing states



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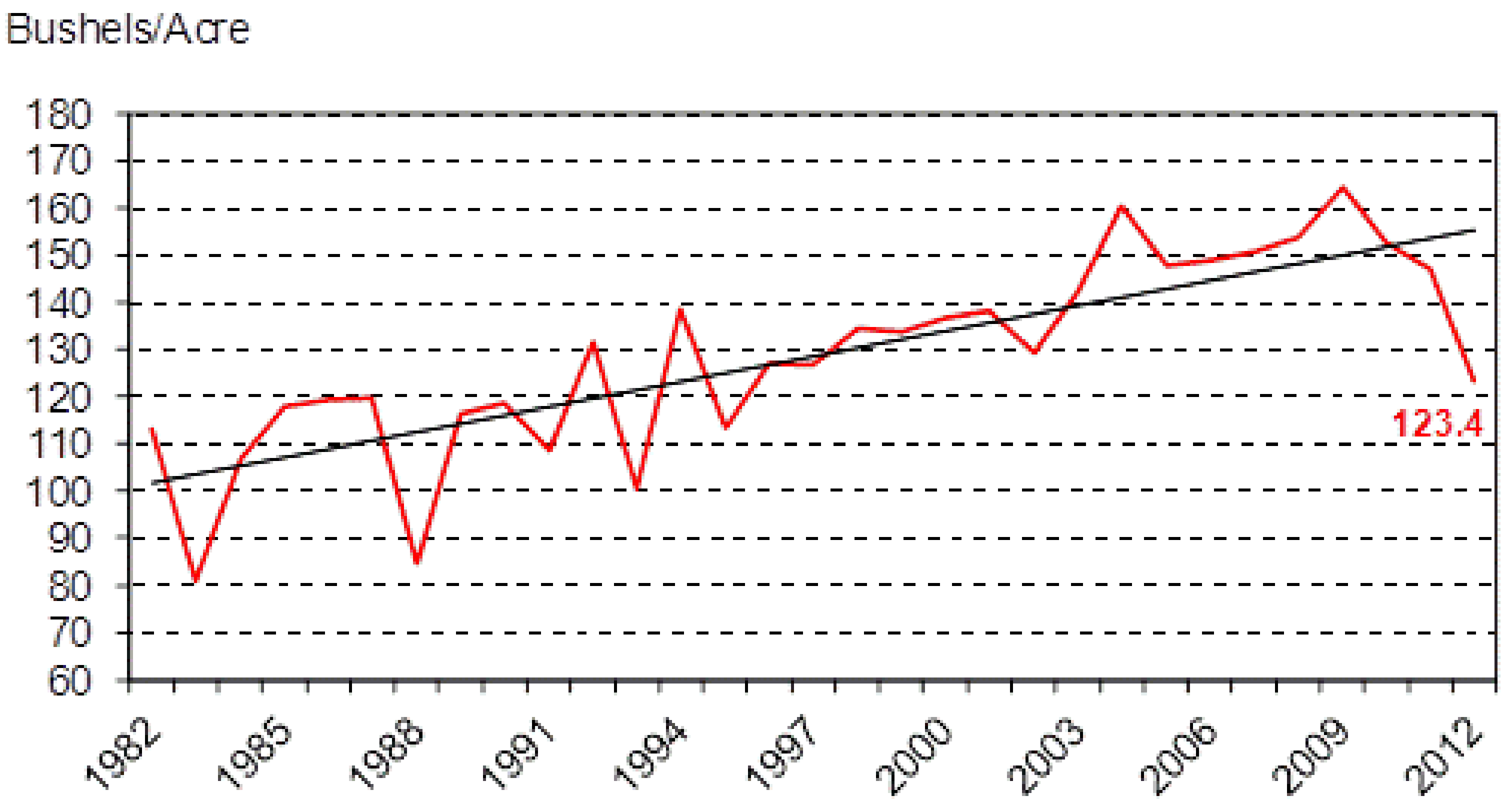
U.S. Corn Yield



USDA-NASS
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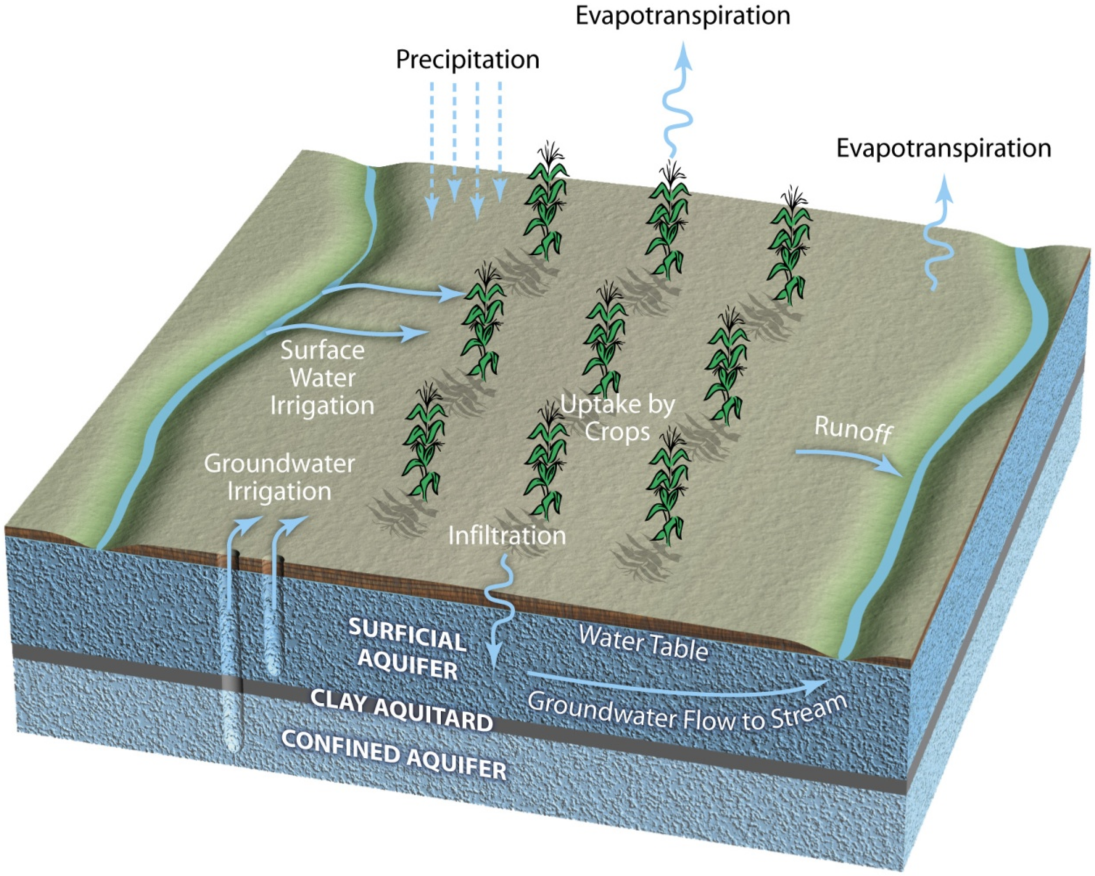
The Hydrologic Cycle for Irrigated Corn



Additional consideration: “blue water” versus “green water” inputs

Water Quantity Issues: Irrigated corn in the West requires a lot of groundwater

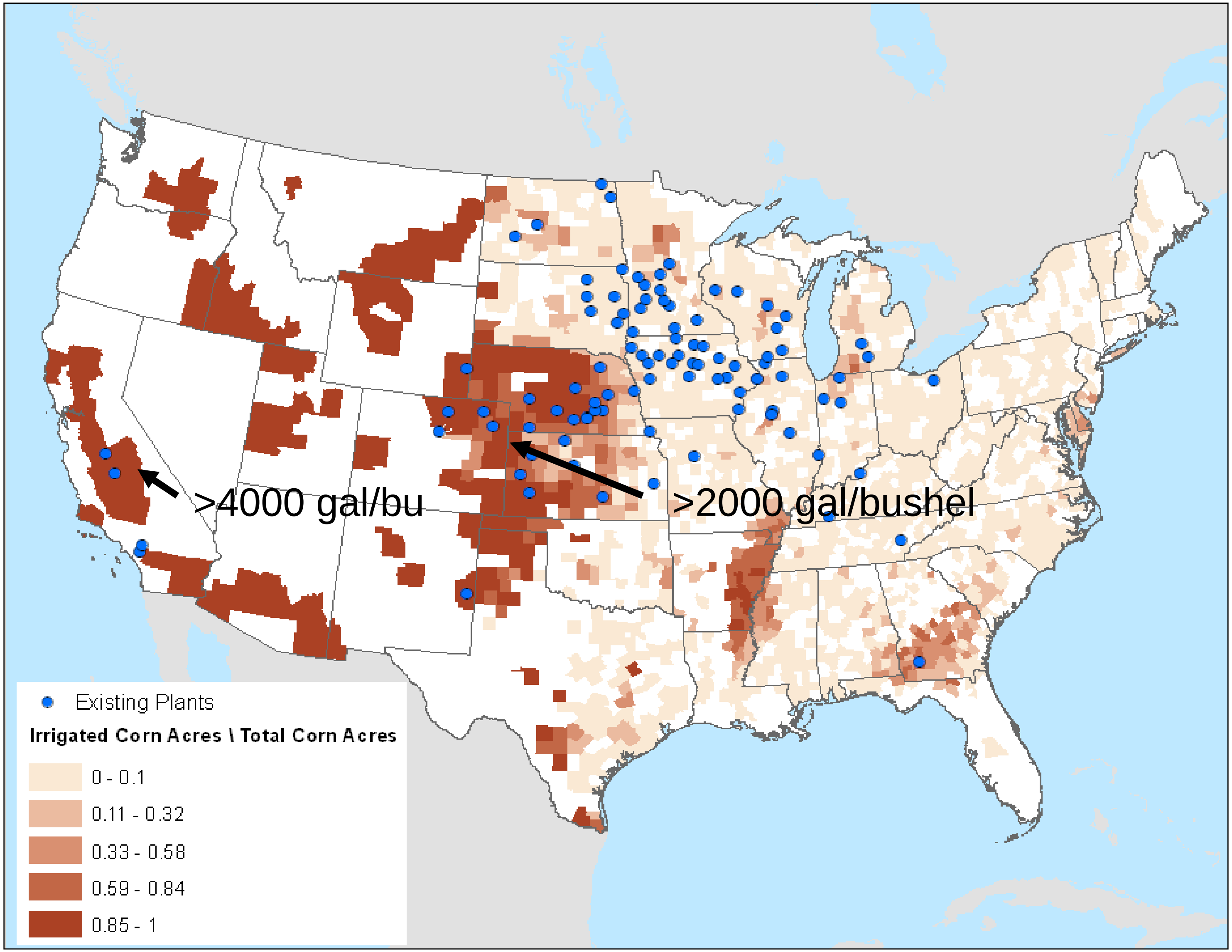
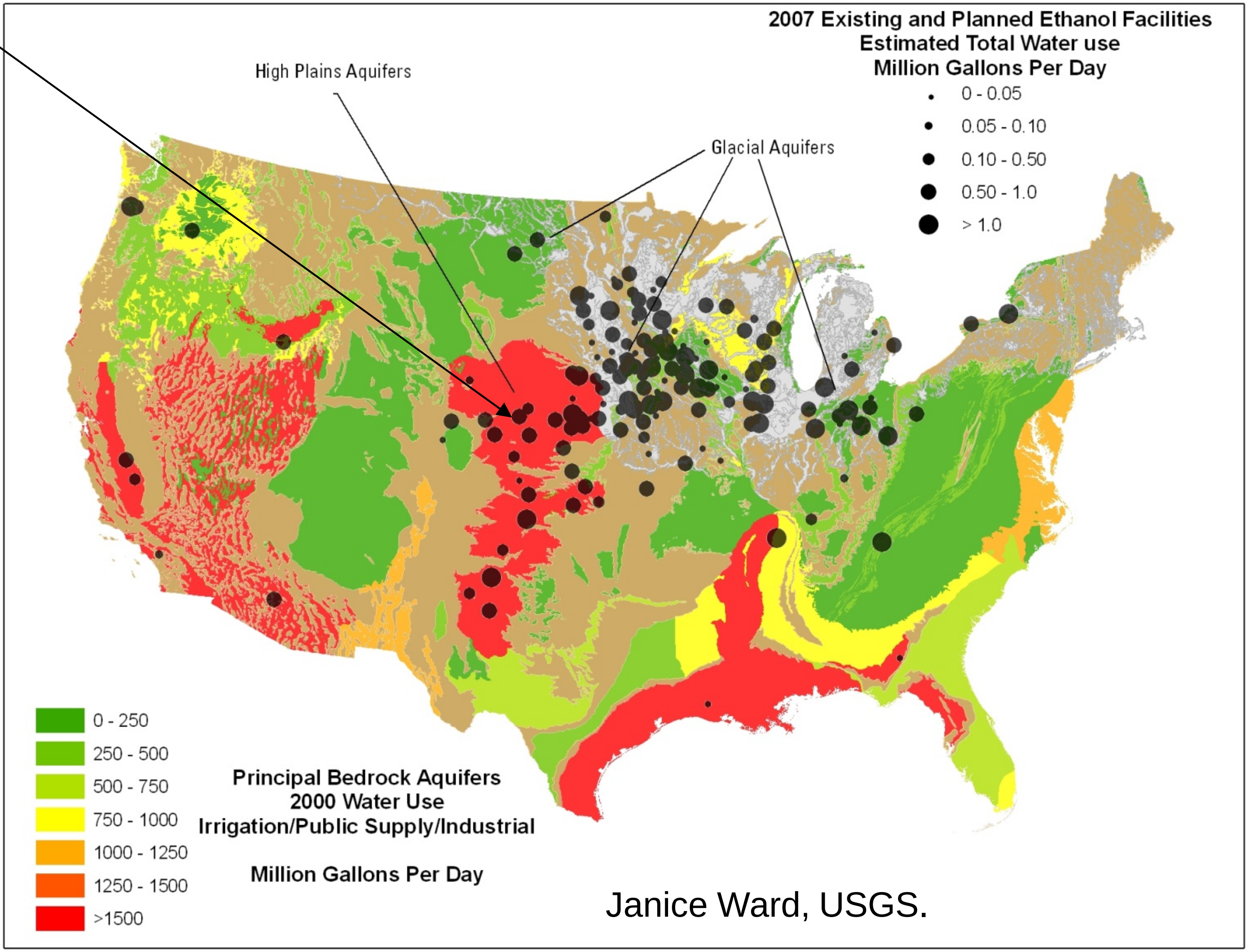


Figure source: N. Gollehon, USDA ERS

Ethanol Facilities and Major Aquifers – Production Facilities in Midwest require high quality water from glacial (confined) aquifers

100 mgy ethanol production in Nebraska requires irrigation water equivalent for city of 2 million



Janice Ward, USGS.

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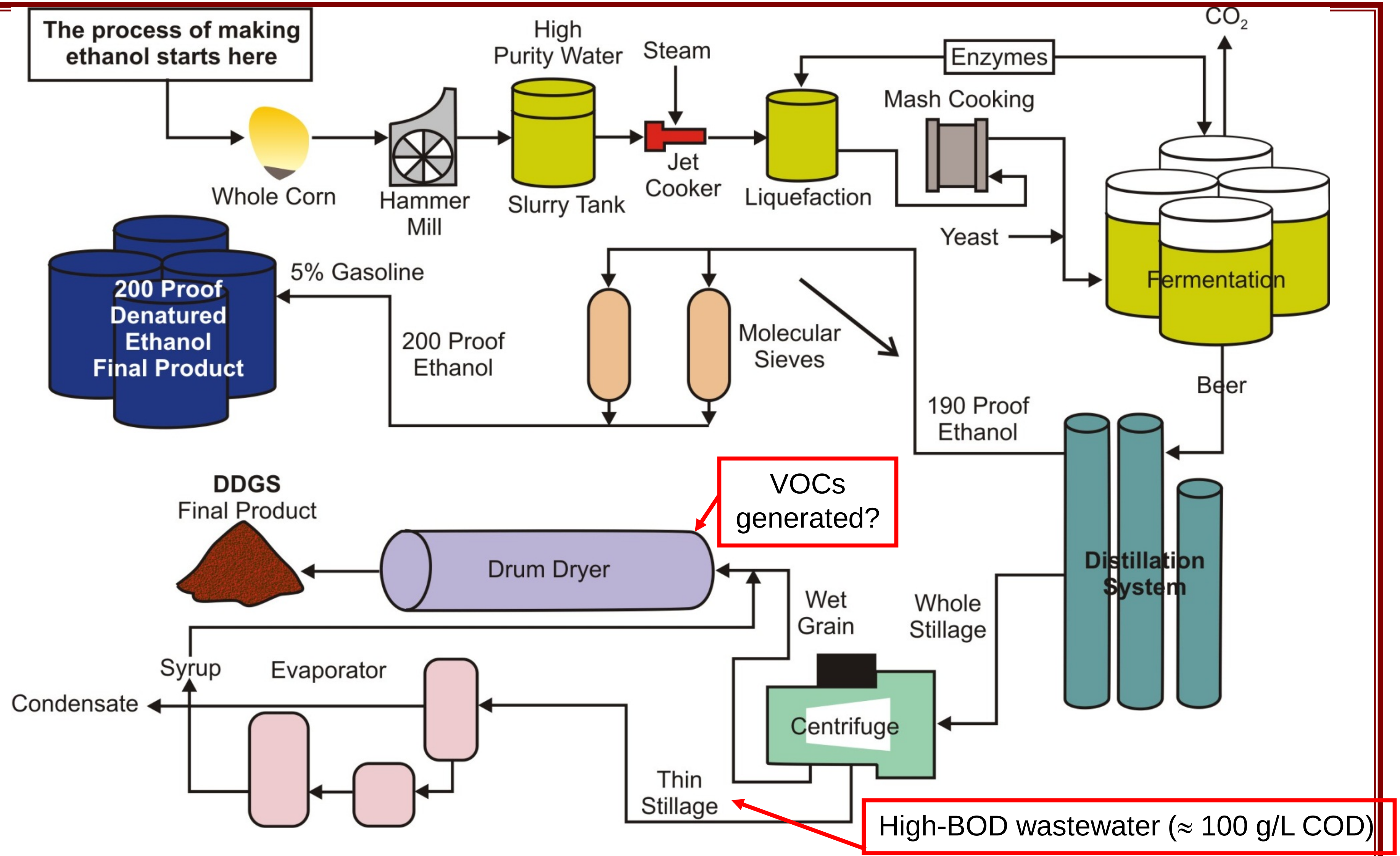

High-quality water to make ethanol results in discharges (Parkin, et al 2007)
- Reverse Osmosis or Ion Exchange results in TDS permitted discharges
Biodiesel refineries from soy beans result in high organic discharges

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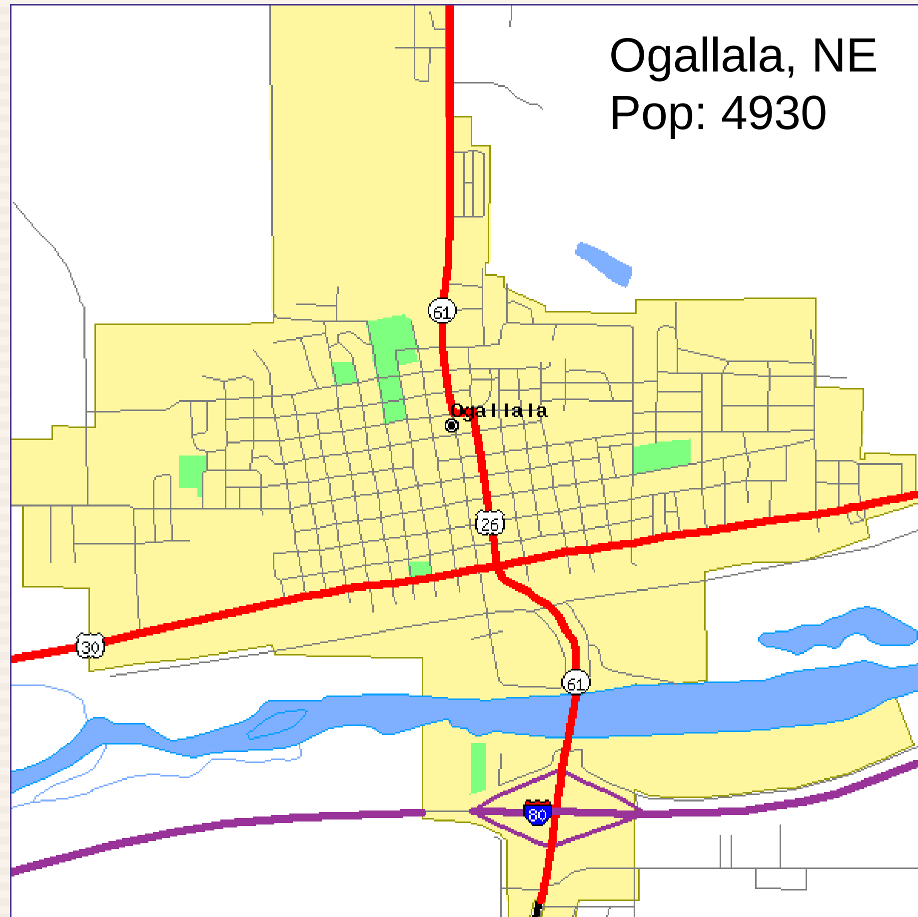
Lincolnway Energy Plant, 50 mgpy ethanol

18 million bushels of corn per year

150 million gallons water per year

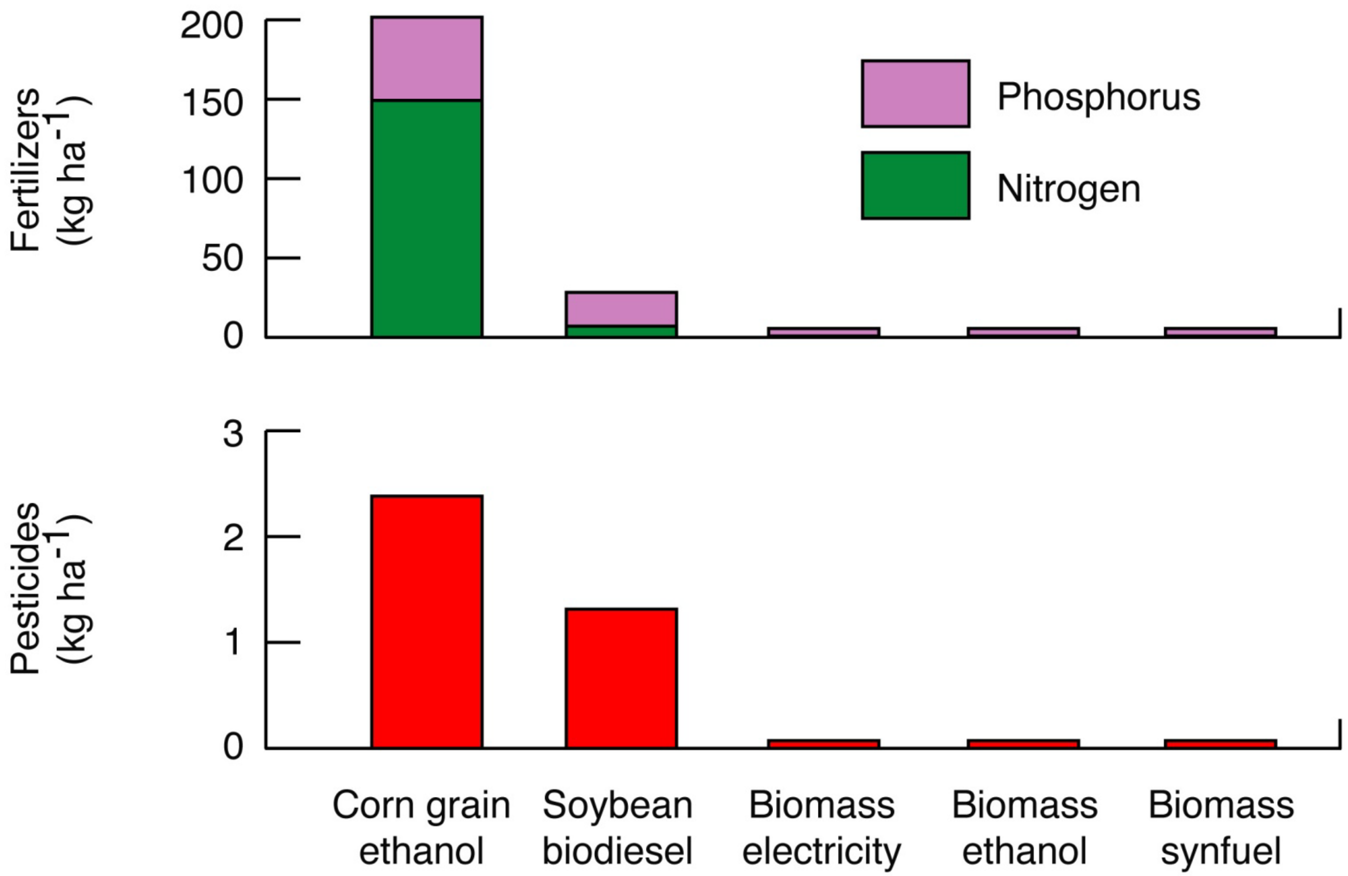
(3 gallons H_2O per gallon ethanol)



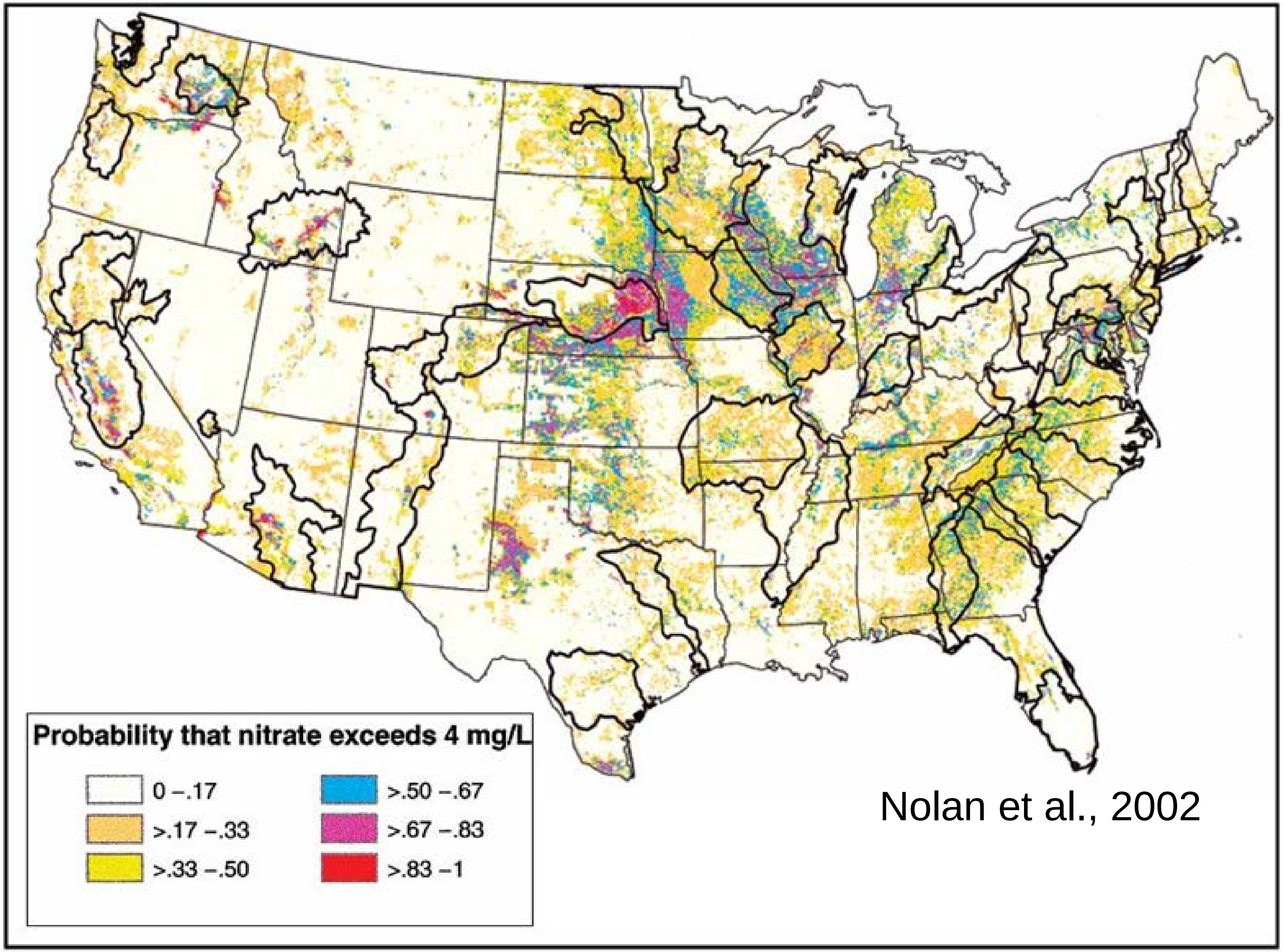
<u>Water Quantity for Production Facility:</u>
100 million gallon/year corn ethanol plant uses 300-400 million gallons of water, the equivalent of a town of ~5,000 people.

In addition, it uses ~100 billion gallons of water to irrigate the corn from the Ogallala aquifer; Total ~ 1000 gal/gal

<u>Water Quality</u>: Fertilizer and Pesticide Requirements for various energy crops (D. Tilman, *Science*, 2006)



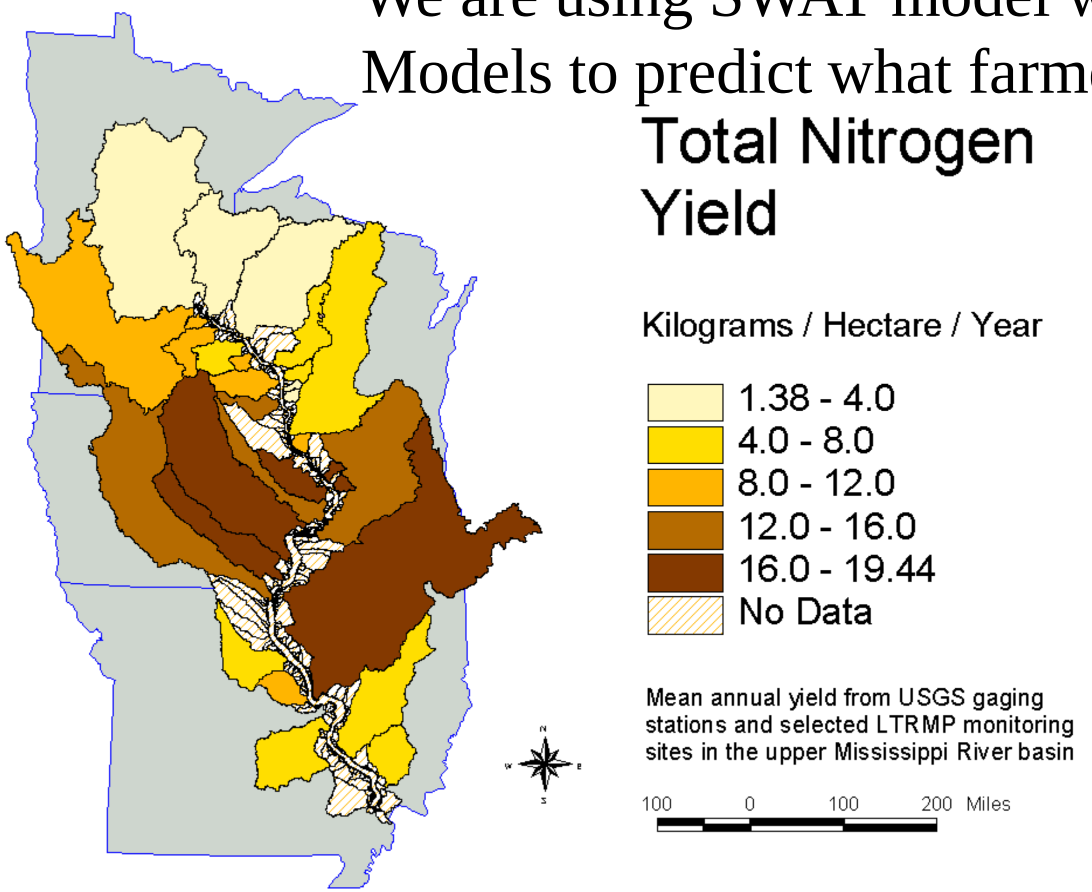
Nitrate leaches to groundwater in permeable soils



Nolan et al., 2002

Total N Yield from sub-basins to the Upper Mississippi River (in kg/ha-yr drainage area)

We are using SWAT model with Agent Based Models to predict what farmers will do…



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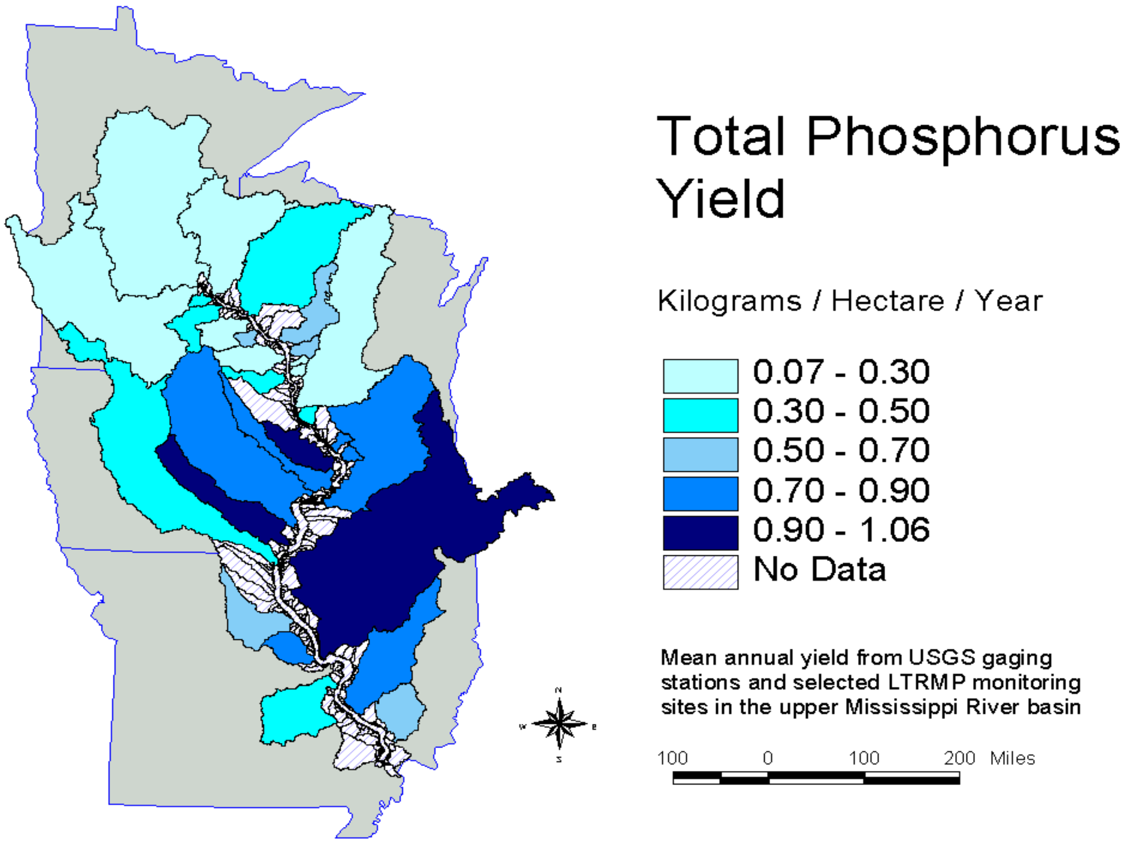
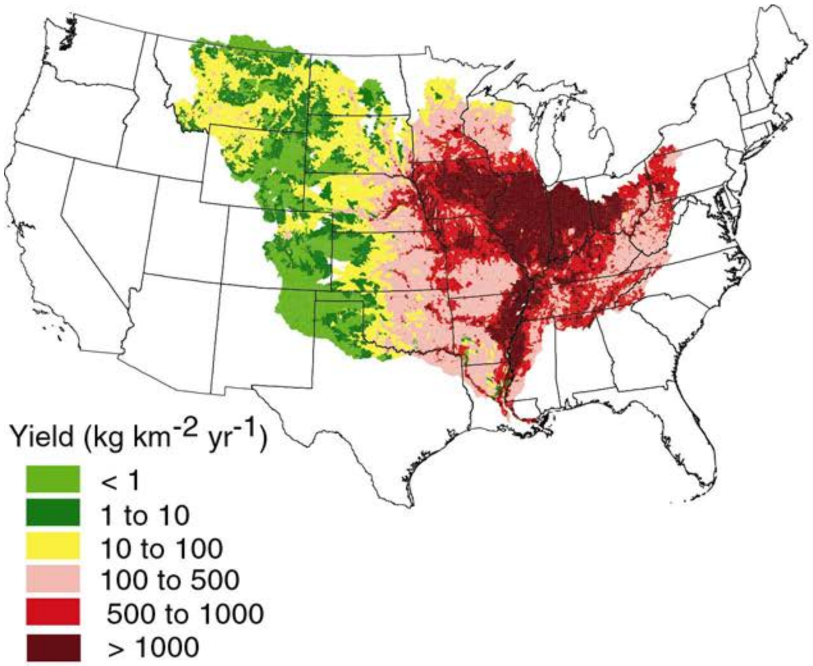
Total P Yield of sub-basins to Upper Mississippi River (in kg/ha-yr of drainage area)

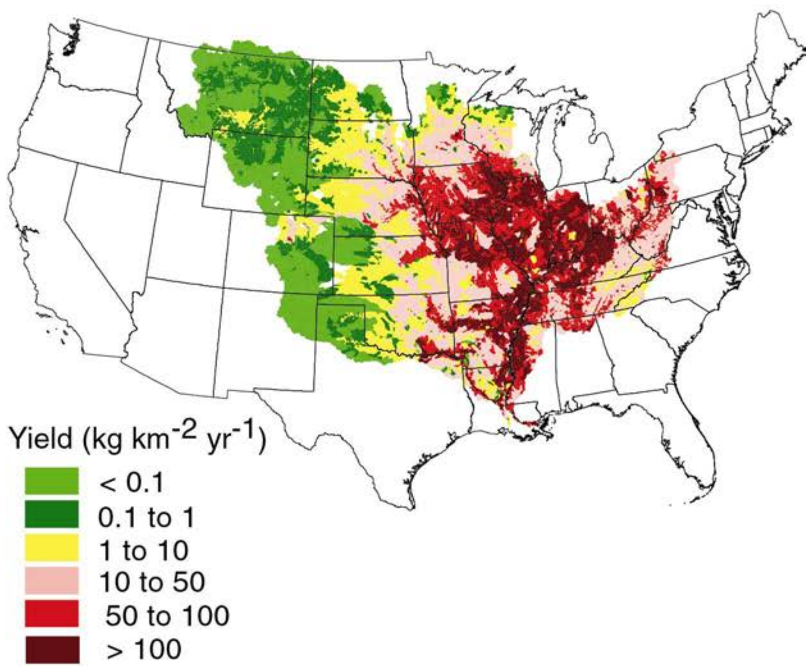


Nutrient Yield Delivered to the Gulf of Mexico

Total Nitrogen



Total Phosphorus



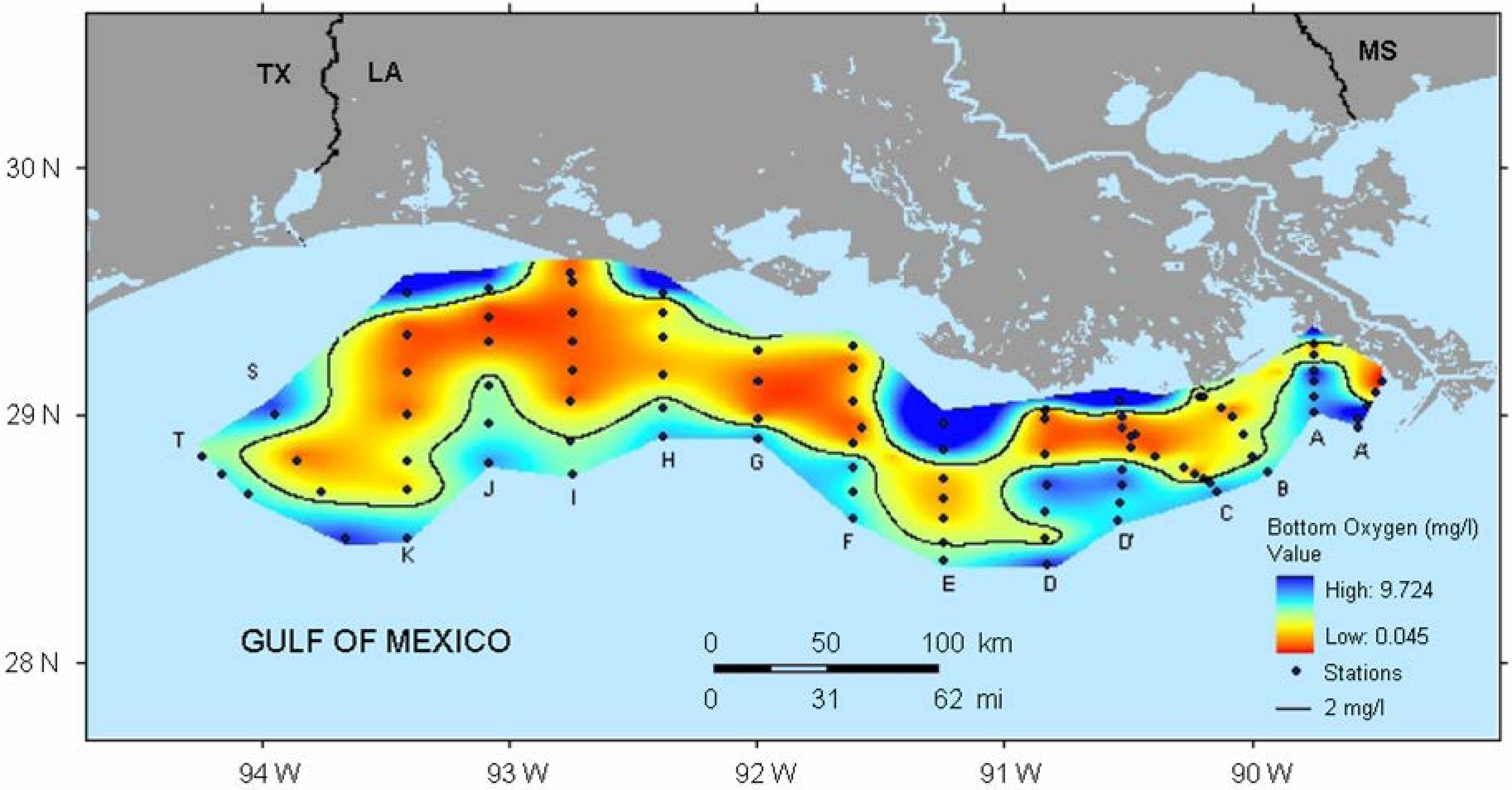
Source: Alexander et al., ES&T, 2008

Role of 2008 Flood on Gulf Hypoxia, NSF project

Bottle nose dolphin at the mouth of Mississippi R.

UI' s Aaron Gwinnup

20,000 km^2 Dead Zone, July 2007

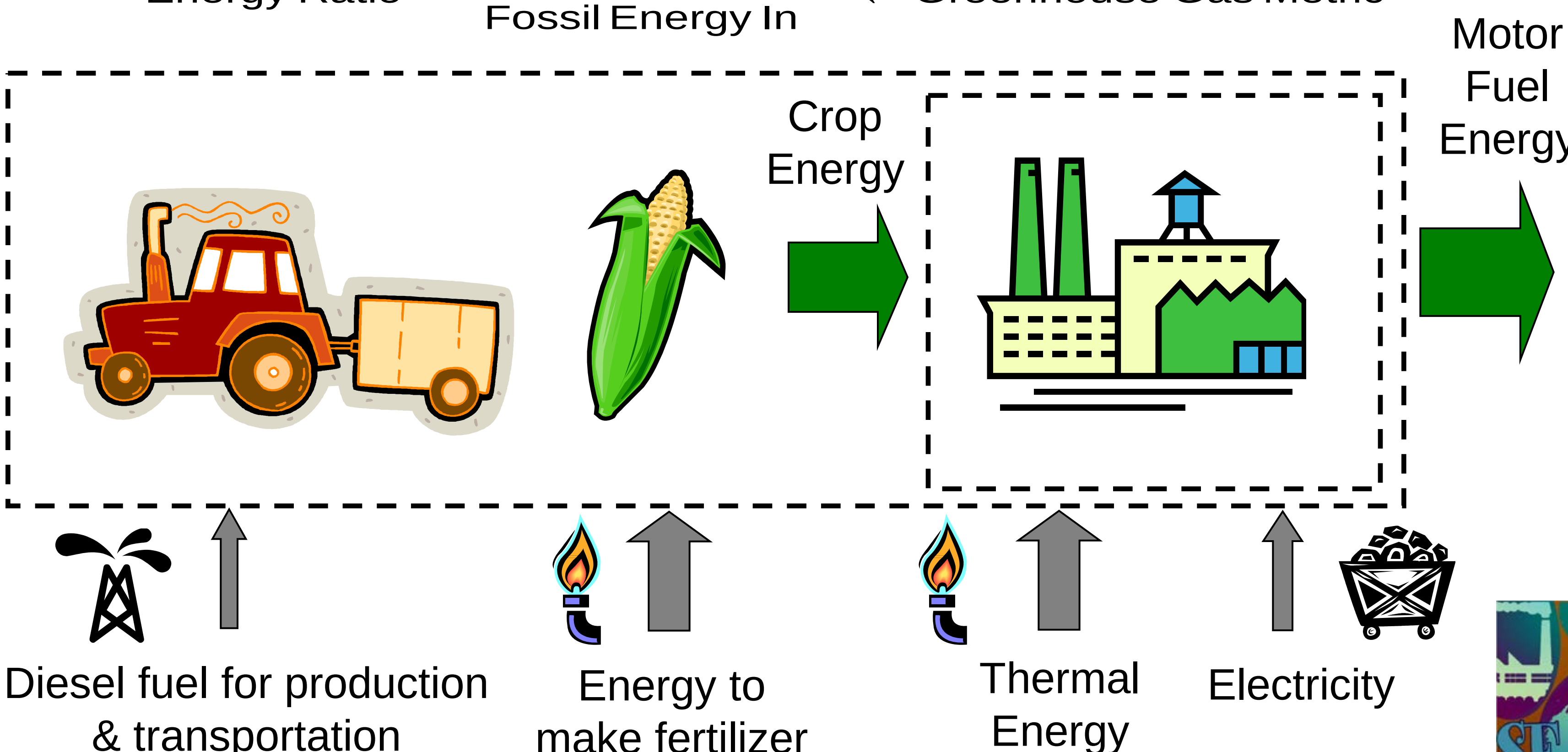


Courtesy of Nancy Rabalais

LCA Energy Analysis of Corn → Ethanol (Iowa Biofuels Task Force)

= 1.3 for corn ethanol

$$\text{Energy Ratio} = \frac{\text{Motor Fuel Energy}}{\text{Fossil Energy In}} \leftarrow \text{Greenhouse Gas Metric}$$



GHG emissions, N_2O from N-fertilizer on corn, and from indirect land use can cause the LCA of corn ethanol to become unfavorable

- **Research on GHG LCAs:**
- Schultz & Isenhart, Iowa State University, N_2O
- Searchinger et al., *Science* **319**, 2008. ILUC
- Fargione et al., *Science* **319**, 2008. ILUC
- Crutzen et al., *Atmos. Chem. Phys*, **8**, 2008.
  - Perhaps 4% of N-applied goes to N_2O, not 1.25% usually assumed

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Cellulosic Ethanol from corn stover, wood residues, and dedicated bioenergy crops are to provide 16 billion gal per yr (2007 EISA) by 2022, but progress is slow

- Biological – Homogeneous feedstock




- Thermochemical – Mixed feedstock




Slide courtesy of R. Cruse, ISU

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Cellulosic ethanol using corn stover (or wood wastes)… Cost, handling, storage, transportation and soil erosion???

A 40 mgpy plant will require enough biomass to fill hundreds of trucks per day to deliver enough biomass (corn cobs and stover for cellulosic material)

Switchgrass or mixed prairie grasses for cellulose may give higher yields w/ less irrigation than corn for ethanol, but we have little experience.

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Dedicated energy crops like poplars, willow and southern pine could be utilized and may use less fertilizers/pesticides/water

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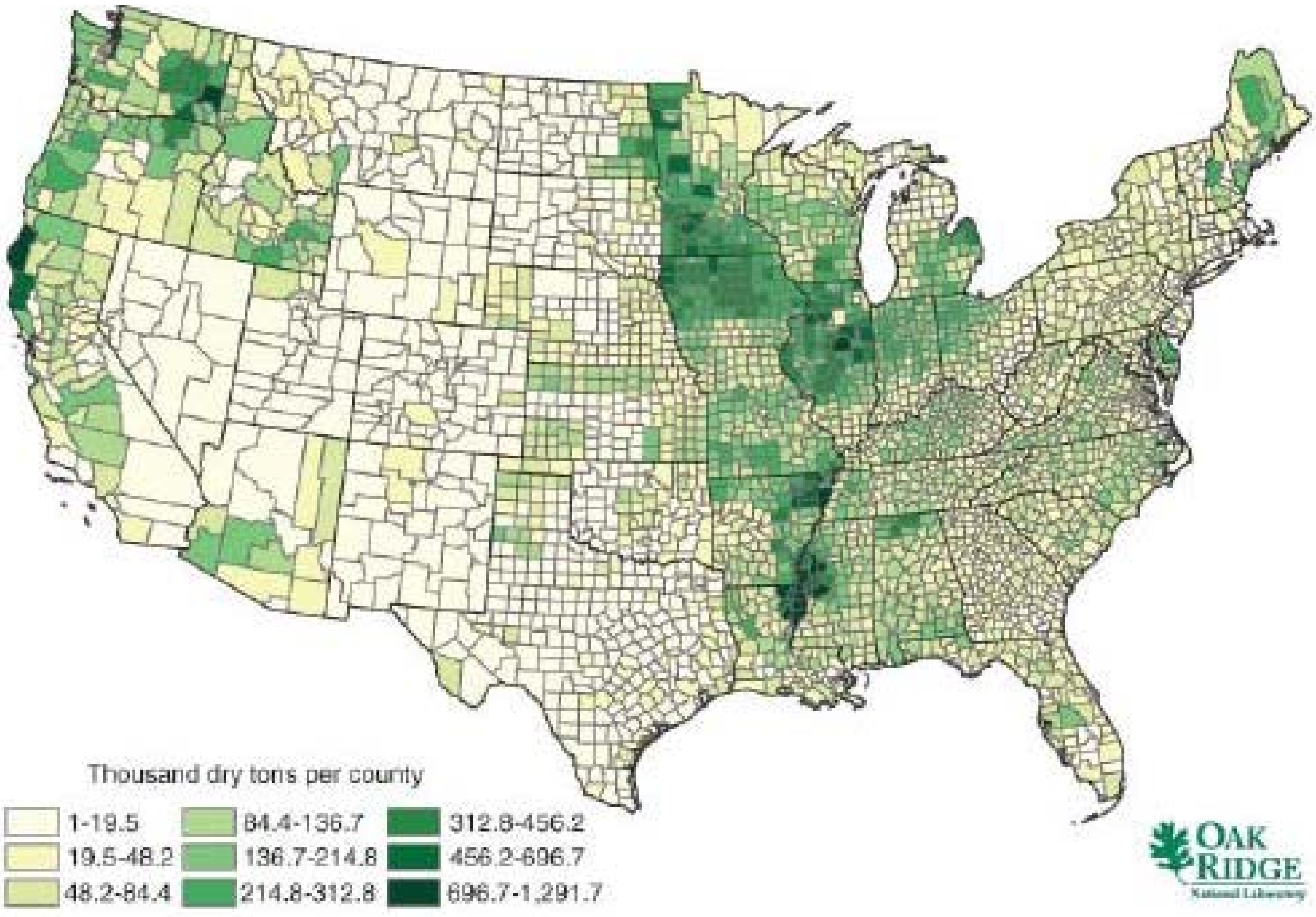
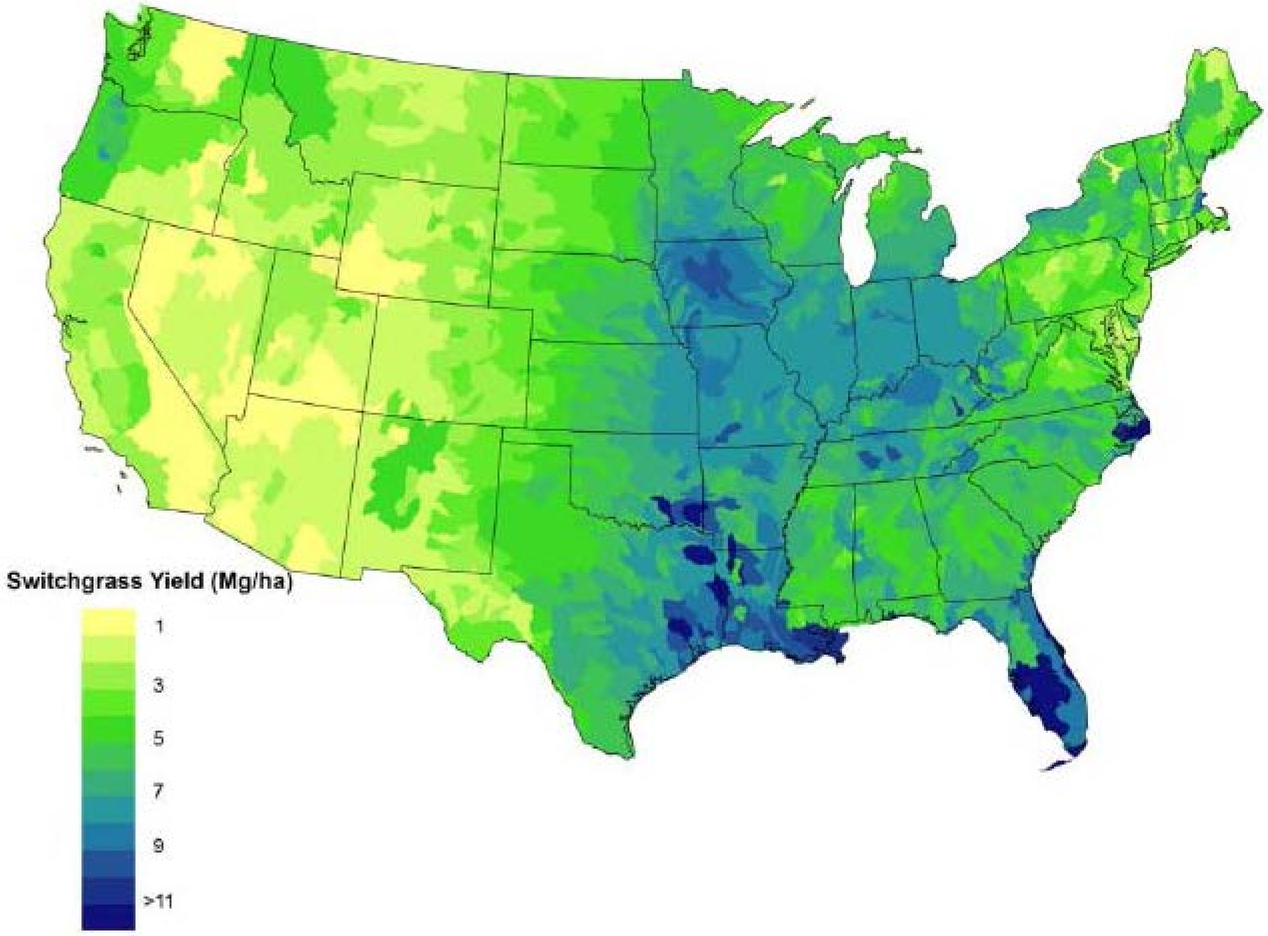
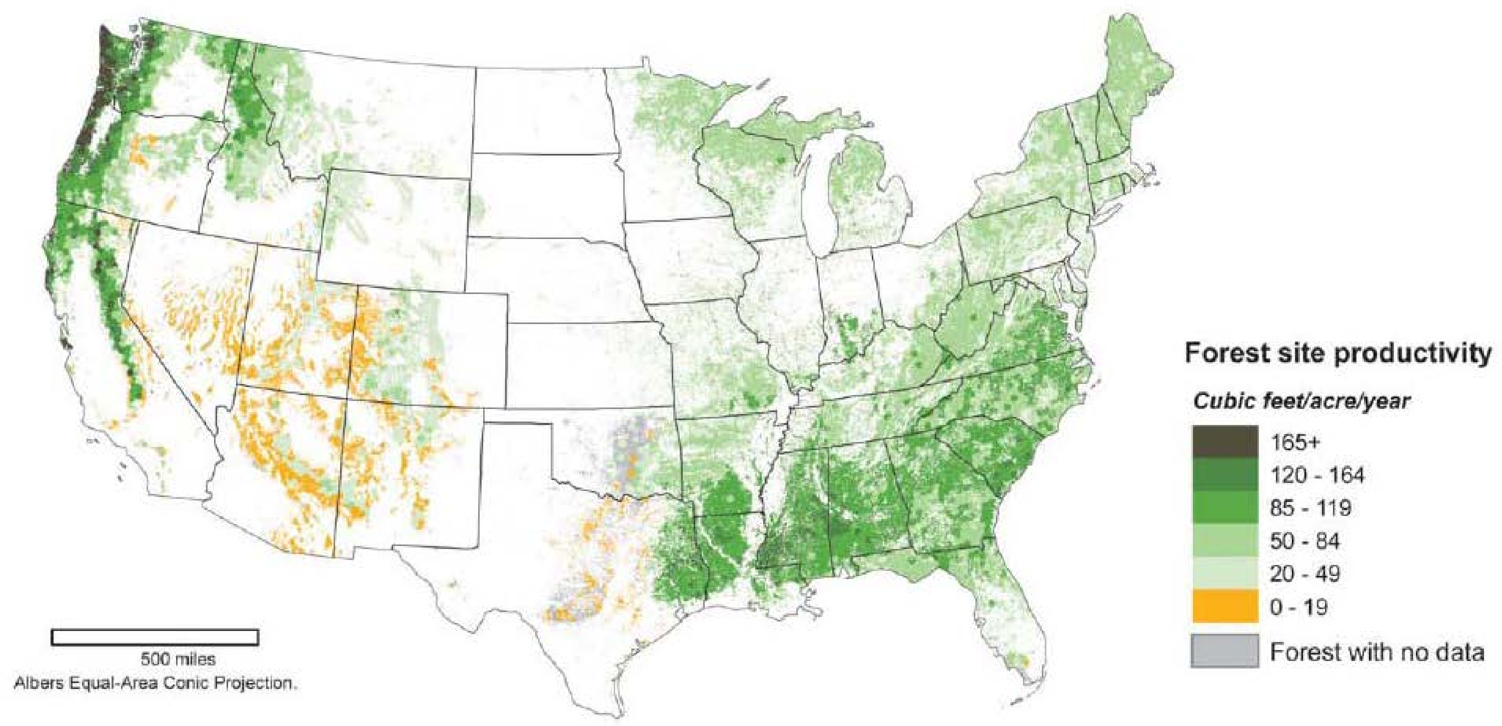
Do we have enough biomass to achieve RFS2? Potential U.S. Biomass Availability (500-600 million tons per year) from corn stover, dedicated energy crops, and forest residues (DOE estimates of locations)



U.S. Switchgrass Yields, 2010



U.S. Forest Productivity



Farmer Willingness to Accept (WTA) and Ethanol Suppliers Willingness to Pay (WTP) for Cellulosic Materials in Cellulosic Ethanol Future (NRC, 2011)

	WTA $/dry ton	WTP $/dry ton	Price Gap per dry ton	Price Gap in $/gal
Corn Stover	$92	$25	$67	$0.96
Switchgrass	$133	$26	$106	$1.51
Miscanthus	$115	$26	$89	$1.27
Wheat straw	$75	$27	$49	$0.70
Forest residues	$78	$24	$54	$0.77

Unfortunately, there is an economic problem. There is a large gap between what ethanol producers are willing to pay for biomass feedstock and the price farmers need for it.

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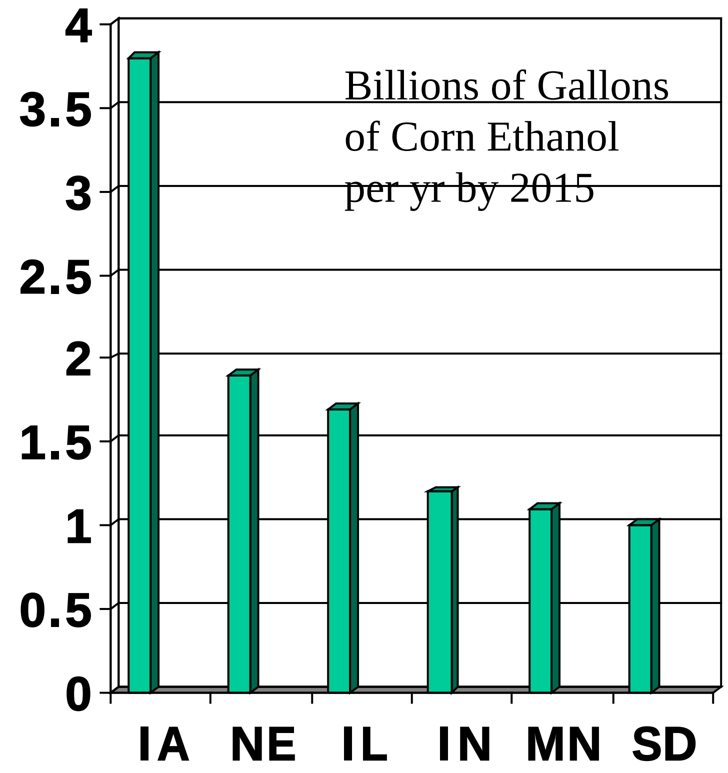
Corn Ethanol Production is peaking under RFS2. However, cellulosic biofuels are slow to develop

- Iowa is the leader in corn ethanol production
  - 3.7 Billion gal/yr in 2012
  - +1.7 B gal/yr of cellulosic ethanol projected for IA by 2022
- But Iowa uses a large fraction of its corn crop already and the water impacts are significant
- Ethanol industry faces large uncertainty in the future
  - E15, E85, "Blend wall"; distribution
  - Cellulosic ethanol slow to materialize ($ and tech problems)
  - Food prices, water, GHGs, ILUC
- EPA RFS2 will need to be modified
  - Drop-in fuels appear to have some long-term advantages (production of diesel from oil crops and algae)



EPA (2009)

Summary

- Biofuels and RFS2 face enormous challenges in future
  - Cellulosic biofuels likely will not be met by 2022
- Considerable groundwater is required for growing feedstock for conventional biofuels
- Plus local water problems (aquifer drawdown) from ethanol production facilities
- Water impacts:
  - 8 g N exported to Gulf of Mexico per gal ethanol
  - 20-40 lb of soil eroded per gal of ethanol produced
  - 3 gal/gal water usage + 1000 gal/gal irrigation H_2O

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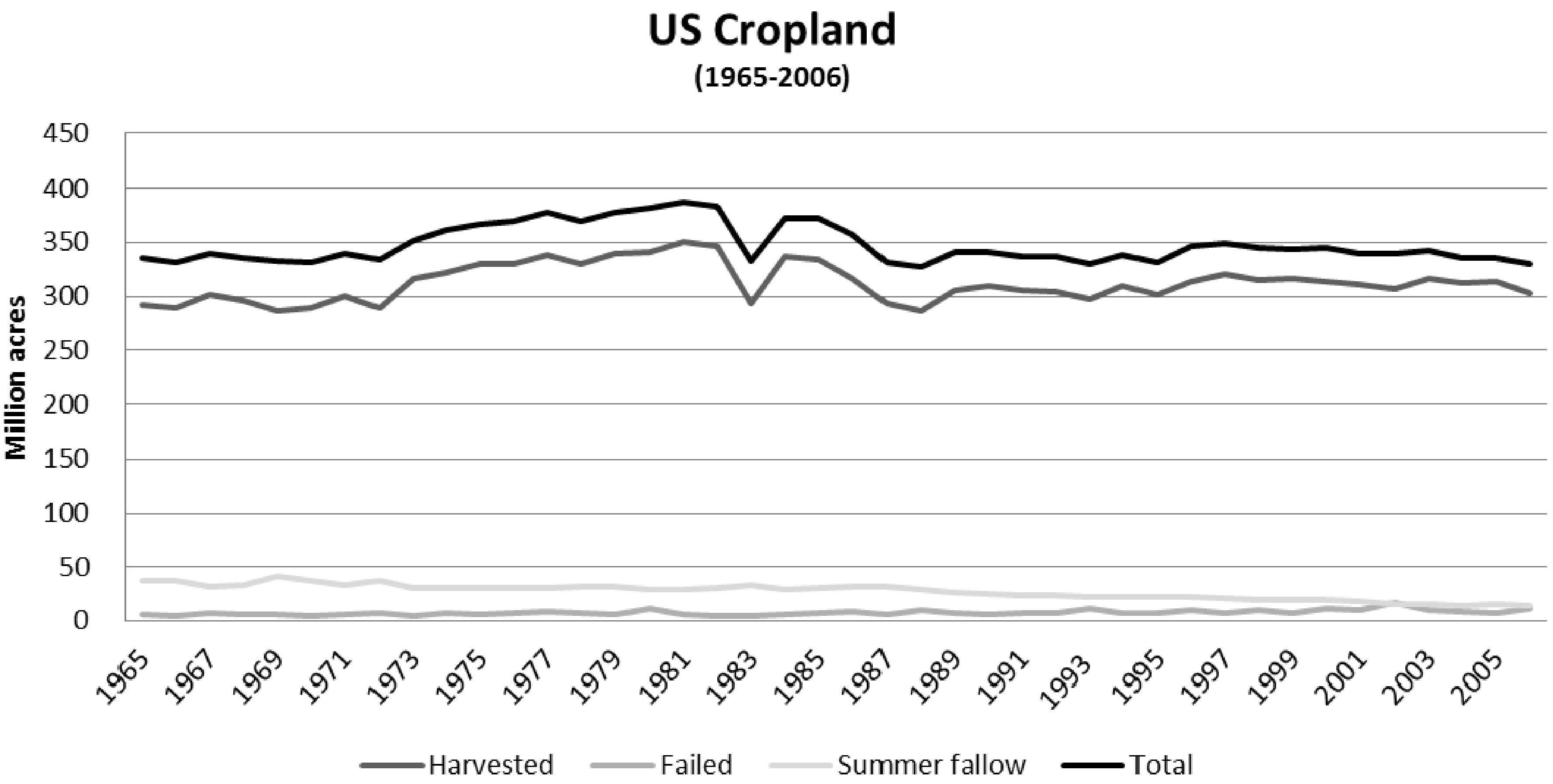
Acknowledgements

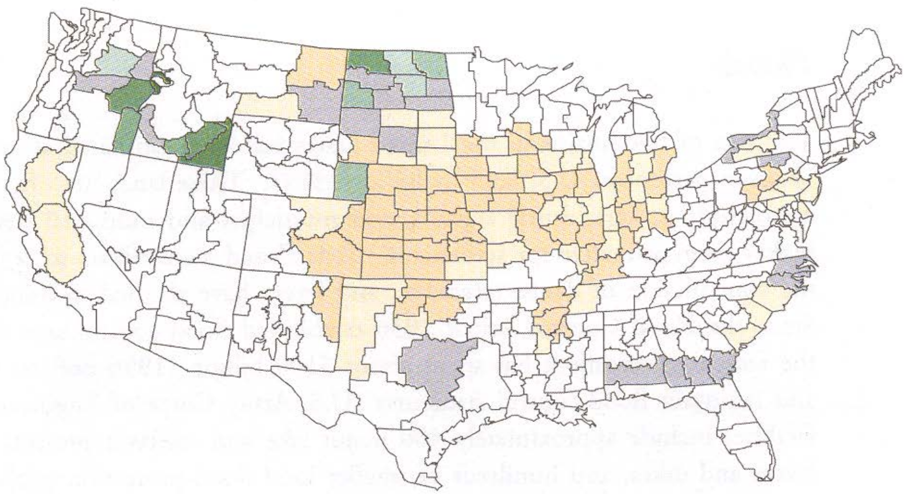
The National Science Foundation Cyber-Enabled Discovery and Innovation (CDI) and the NSF CNH Projects at the Univ of Iowa

CDI-Type II: Understanding Water-Human Dynamics with Intelligent Digital Watersheds. (#0835607)

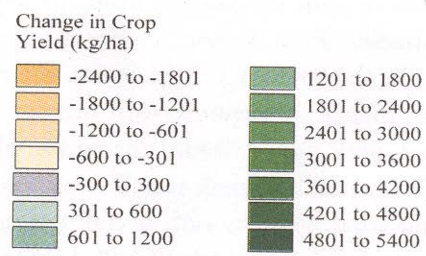
Total US Cropland has not been increasing, but corn has acreage has risen in recent years to make biofuel



Corn Yields are predicted to decrease as a result of climate change

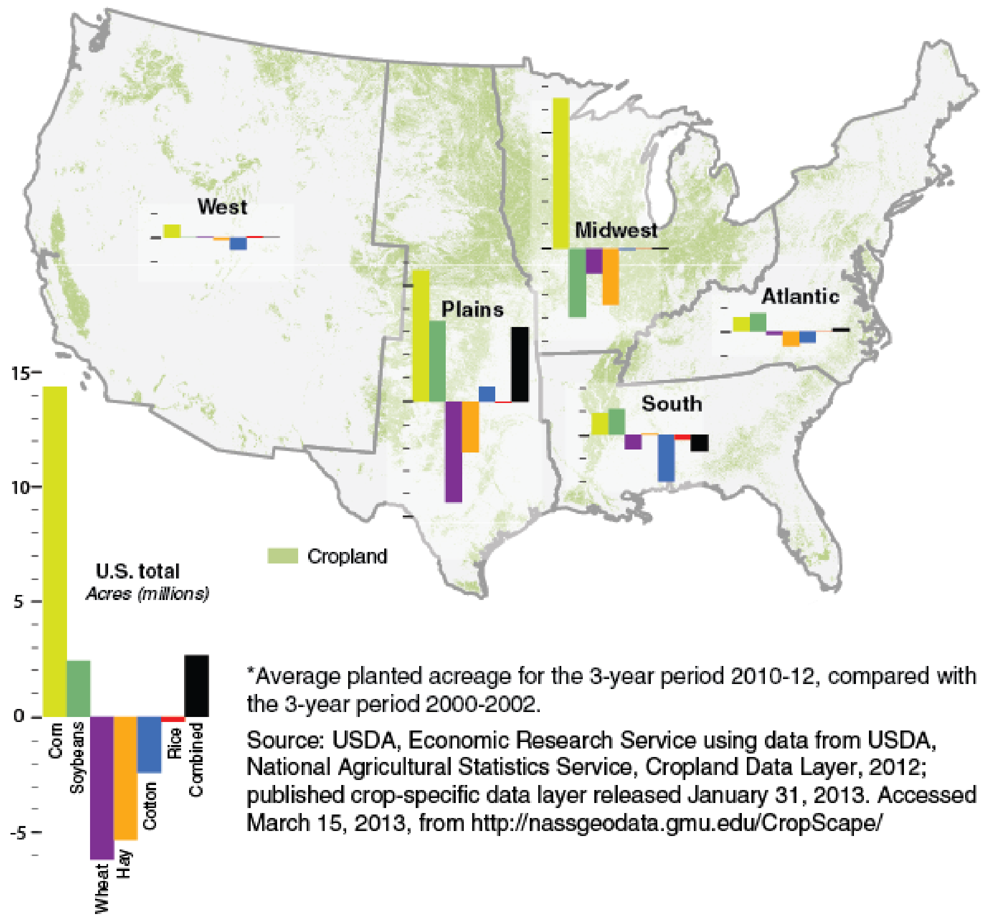


Brumbelow and Georgakakos (2000).



Total agricultural acreage planted in the U.S. has been roughly constant for decades but corn acreage has expanded

Acreage patterns have changed considerably since the early 2000s, dominated nationally and regionally by expanding corn acreage*



*Average planted acreage for the 3-year period 2010-12, compared with the 3-year period 2000-2002.

Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Cropland Data Layer, 2012; published crop-specific data layer released January 31, 2013. Accessed March 15, 2013, from http://nassgeodata.gmu.edu/CropScape/

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Comparison of Ethanol to Gasoline (Iowa Biofuels Task Force)

Stakeholder	Energy Ratio	Grain EtOH	Gas-oline
Plant Engineer	$\frac{\text{Motor Fuel Energy}}{\text{Feedstock Energy} + \text{Process Energy}}$	**0.38**	**0.84**
Environmentalist	$\frac{\text{Motor Fuel Energy}}{\text{Fossil Energy In}}$	**1.3***	**0.81**
National Security Advisor	$\frac{\text{Motor Fuel Energy}}{\text{Petroleum Derived Fuels In}}$	**14**	**0.81**

* Average of 14 *different* study groups. Range is 0.44 to 2.1. This energy ratio becomes very large (>10) as we replace fossil energy with renewable energy in the production of ethanol (or other renewable transportation fuels).

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