Biofuels from perennial prairie plant polycultures and the ecosystem services they provide

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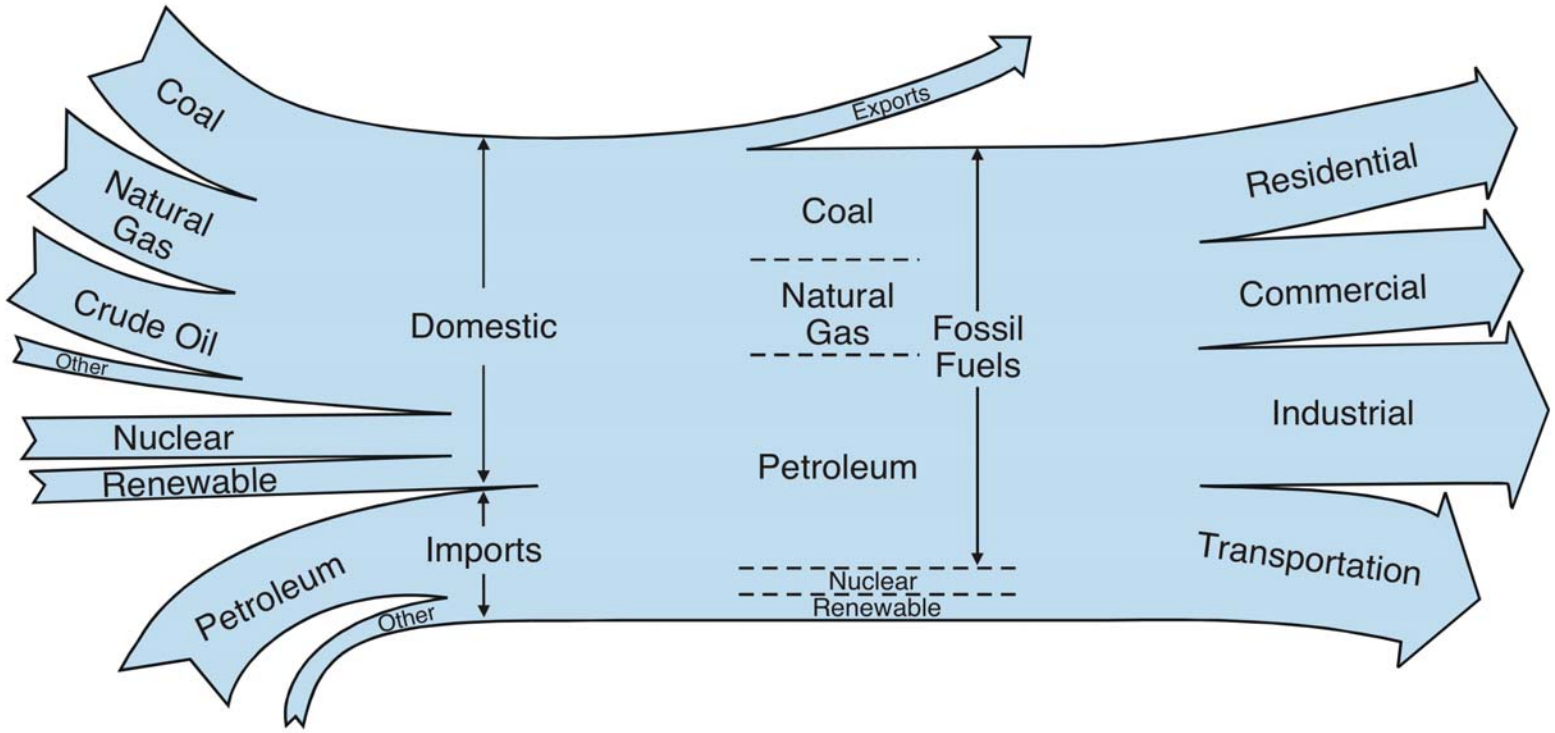
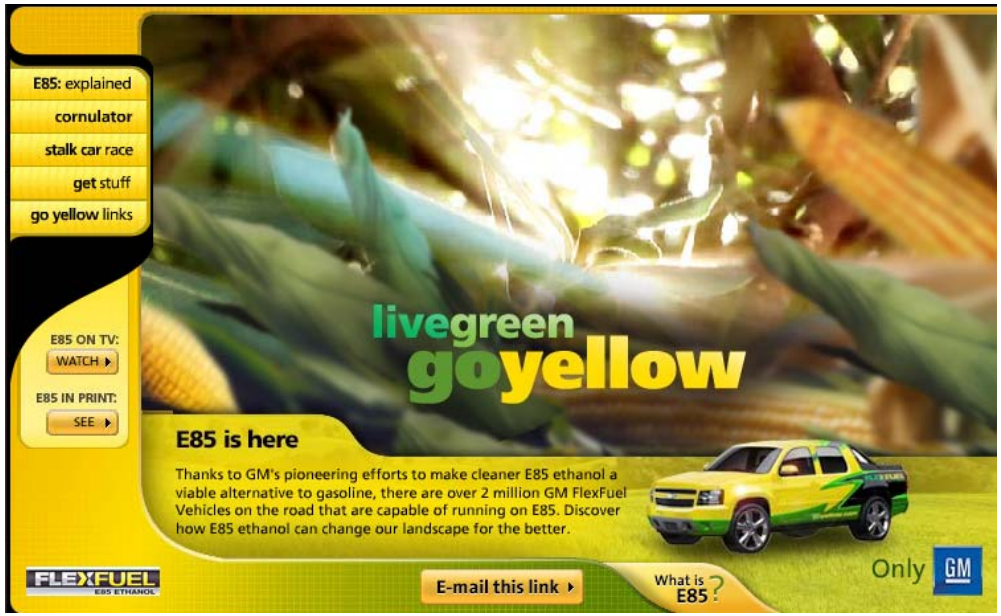
The search for renewable fuels…

- Overwhelming dependence on petroleum for transportation
- High energy prices and increasing energy imports
- Concerns about petroleum supply stability
- Environmental consequences of fossil fuels



Current food-based biofuels...



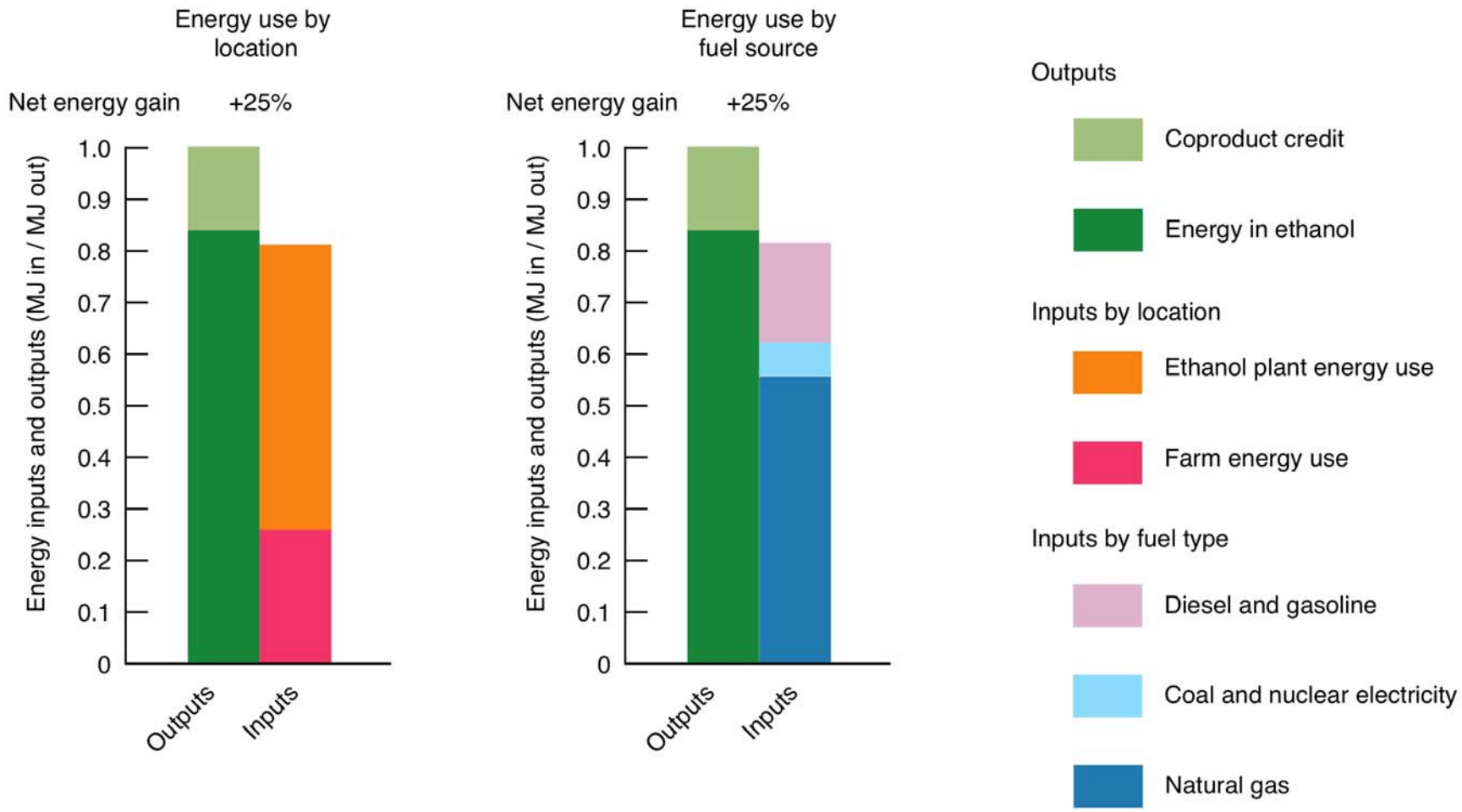
Biodiesel Facts
Amount per Gallon

	% Driving Values
Renewable Fuel	100%
Cleaner Burning	100%
Made in America	100%
Dependence on Foreign Oil	0%

Supplies of current biofuels...

	US production in 2006
Corn ethanol	17% of corn harvest Displaced 2% of gasoline use (gross) Displaced 0.5% of gasoline use (net)
Soybean biodiesel	5% of soybean harvest Displaced 0.5% of diesel use (gross) Displaced 0.2% of diesel use (net)

Energy use in corn ethanol production…



Hill *et al*. (2006) *PNAS* **103**: 11206.

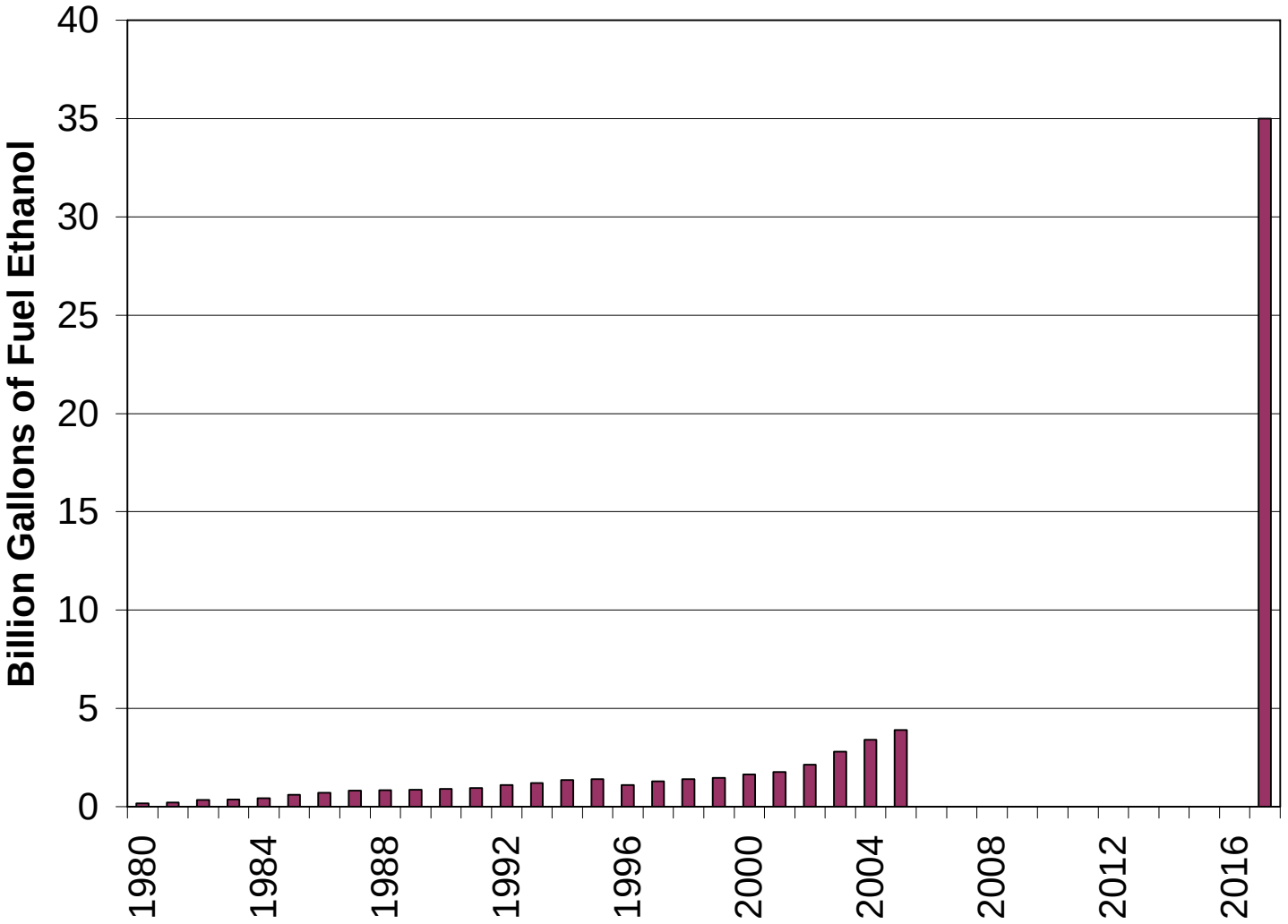
Supply limitations of current biofuels...

	US production in 2006	Devoting entire 2006 US crop production to biofuel
Corn ethanol	17% of corn harvest Displaced 2% of gasoline use (gross) Displaced 0.5% of gasoline use (net)	100% of corn harvest Displace 12% of gasoline use (gross) Displace 2.5% of gasoline use (net)
Soybean biodiesel	5% of soybean harvest Displaced 0.5% of diesel use (gross) Displaced 0.2% of diesel use (net)	100% of soybean harvest Displace 6% of diesel use (gross) Displace 3% of diesel use (net)

Feed, food, and fuel...

- 50% of US corn crop is used to feed livestock
- Remainder of corn is exported, processed for human consumption, or converted to ethanol
- Soybean oil constitutes 80% of US edible oil consumption

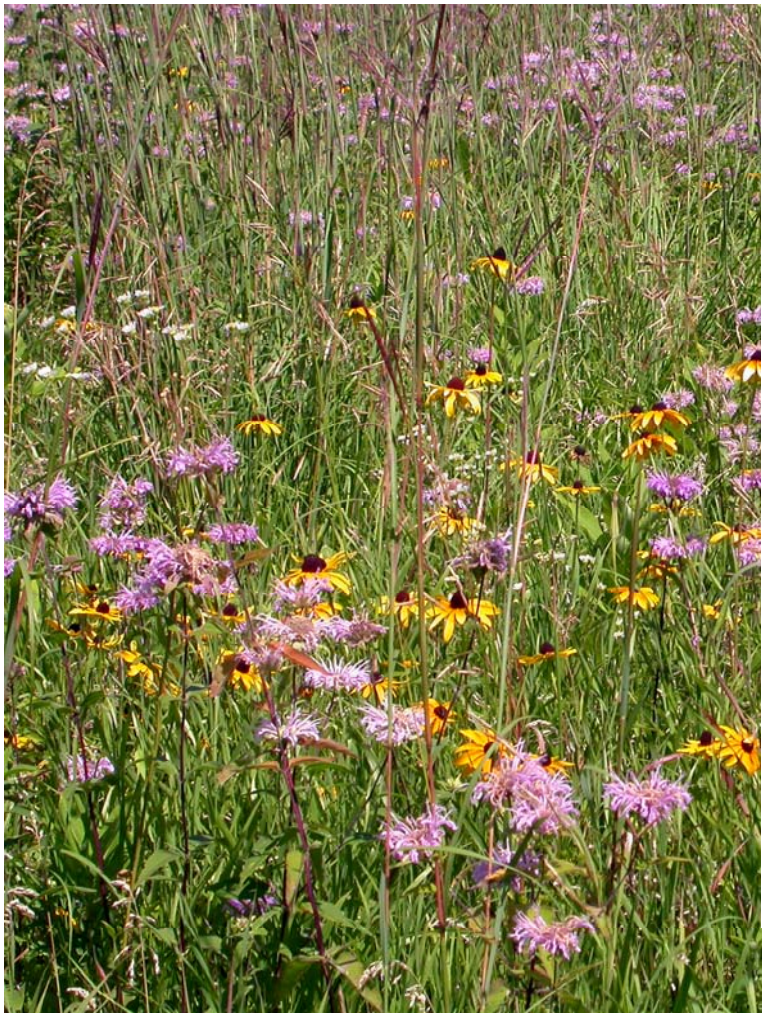
State of the Union Address 2007...



Biofuels from high-input monocultures...

Switchgrass Hybrid Poplar Wheat Straw Corn Stover

Biofuels from low-input polycultures...



Nutrient needs for HILD and LIHD...

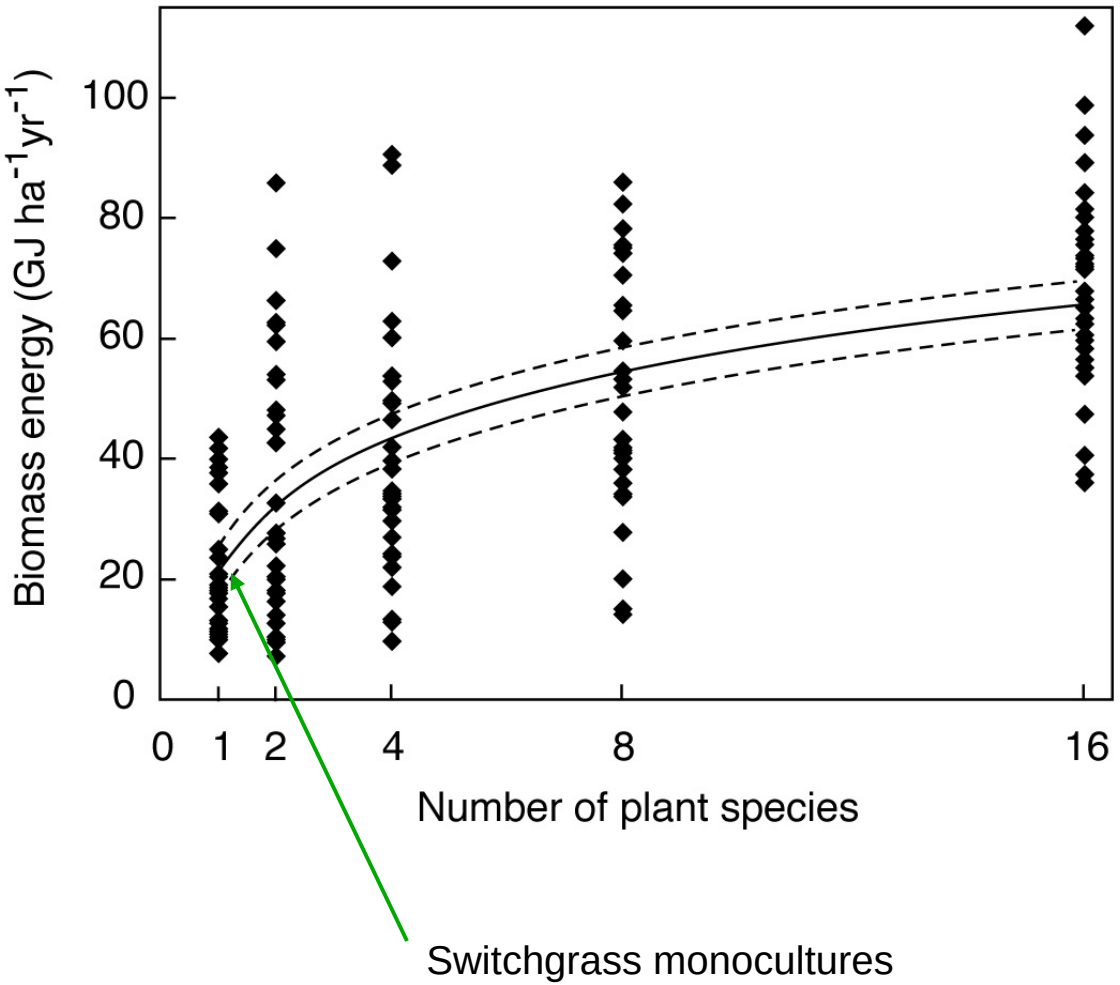
$kg^{-1}\ ha^{-1}\ yr^{-1}$	Monoculture corn on fertile farmland (HILD - High Input, Low Diversity)	Highly diverse prairie on degraded farmland (LIHD - Low Input, High Diversity)
Nitrogen	148	0
Phosphorus	23	4
Potassium	50	6

Cedar Creek Biodiversity experiment...

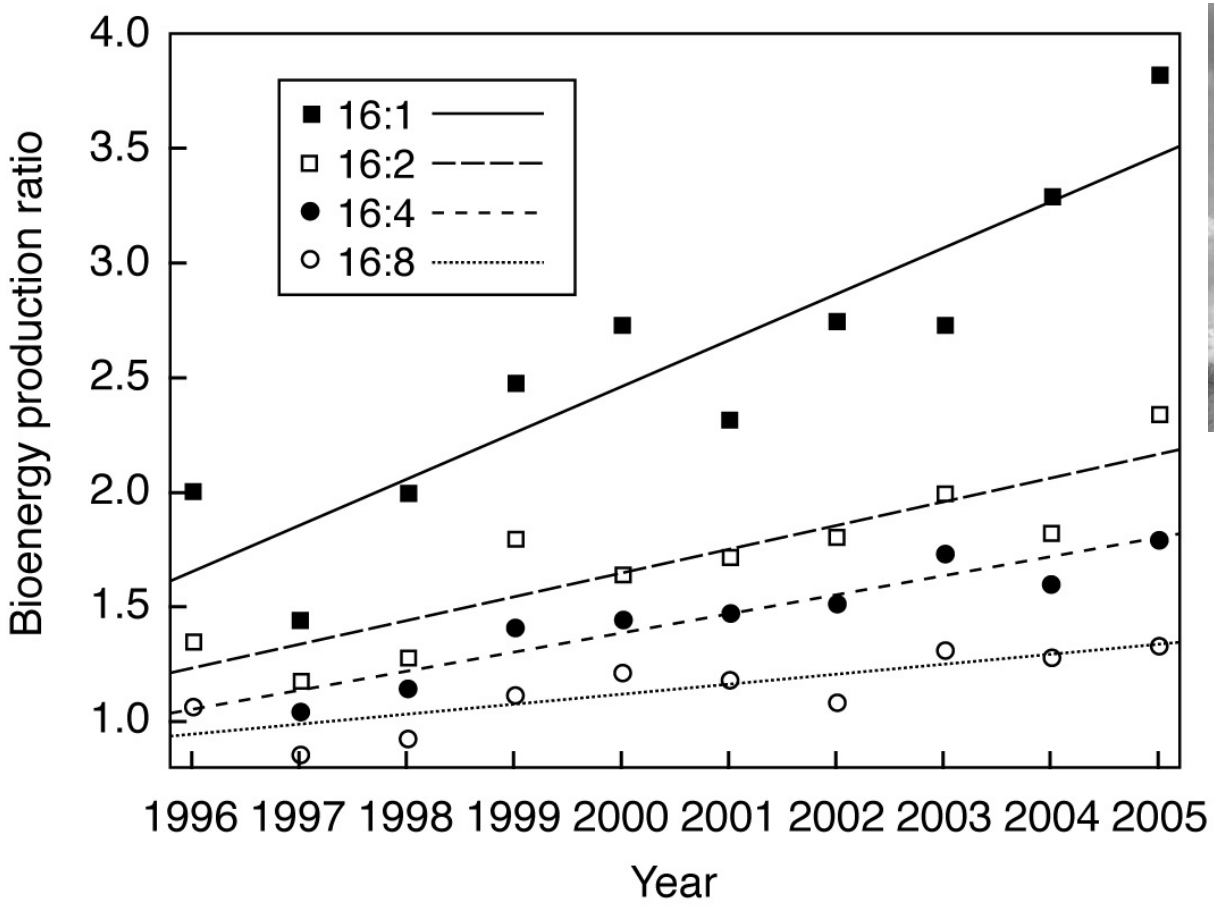
Species	Functional type
Lupinis perennis	Legume
Andropogon gerardi	C_4 grass
Schizachyrium scoparium	C_4 grass
Sorghastrum nutans	C_4 grass
Solidago rigida	Forb
Amorpha canescens	Woody legume
Lespedeza capitata	Legume
Poa pratensis	C_3 grass
Petalostemum purpureum	Legume
Monarda fistulosa	Forb
Achillea millefolium	Forb
Panicum virgatum	C_4 grass
Liatris aspera	Forb
Quercus macrocarpa	Woody
Koeleria cristata	C_3 grass
Quercus elipsoidalis	Woody
Elymus canadensis	C_3 grass
Agropyron smithii	C_3 grass

Tilman *et al*. (2006) *Science* **314**:1598.

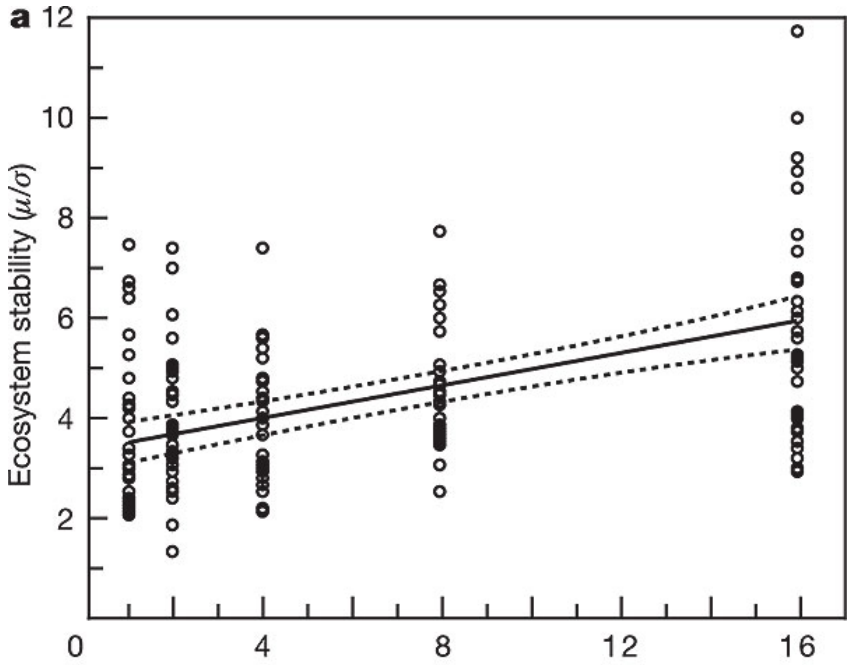
More diverse plots yield more energy...

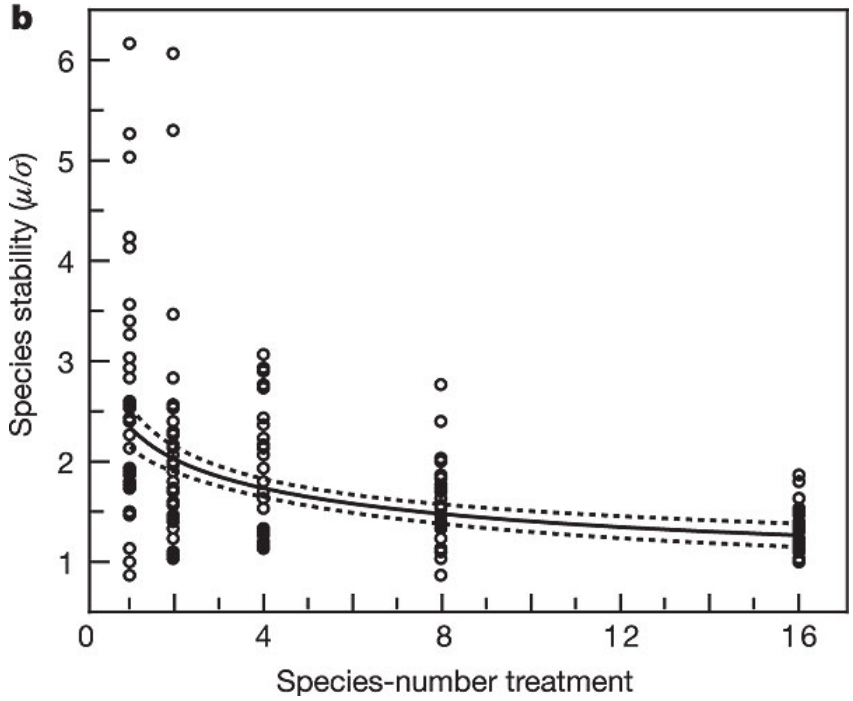


More diverse plots become more increasingly productive...



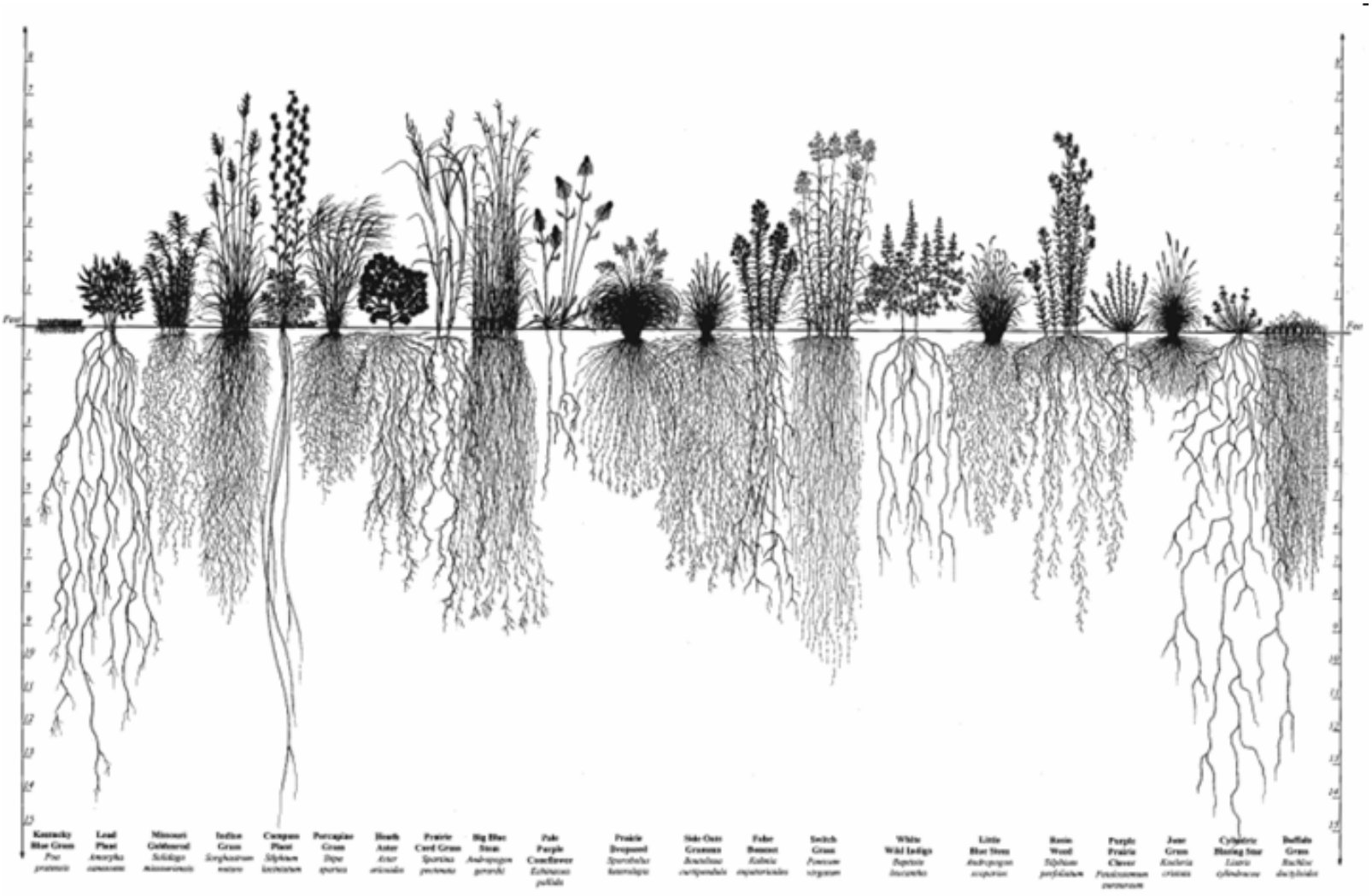
Primary productivity is more stable at greater diversity...



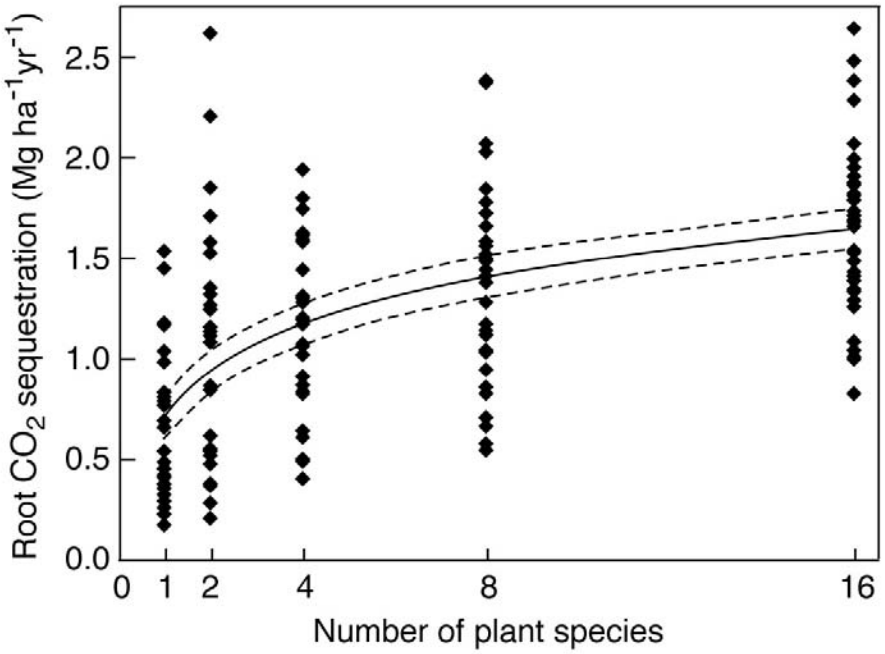


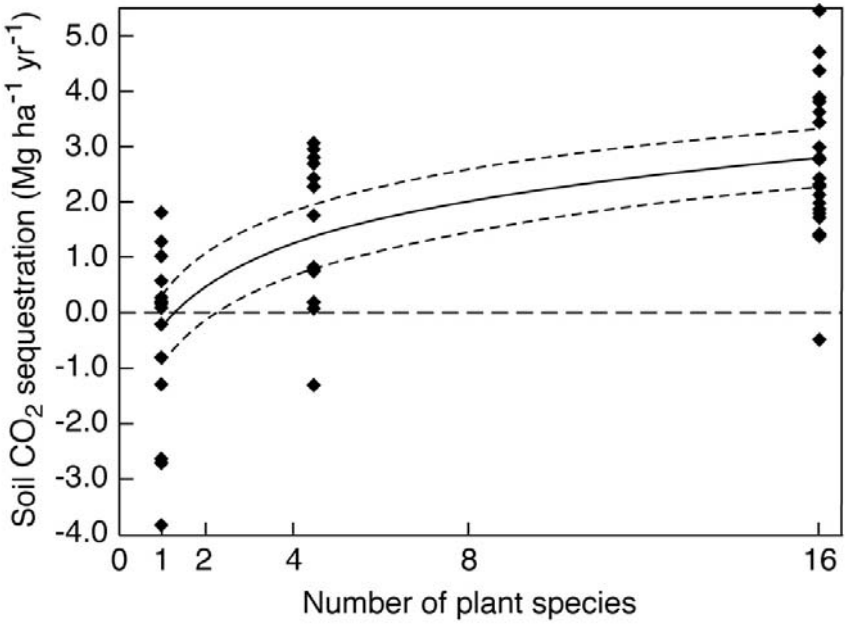
Tilman *et al*. (2006) *Nature* **441**:629.

2/3 of the prairie is below ground...

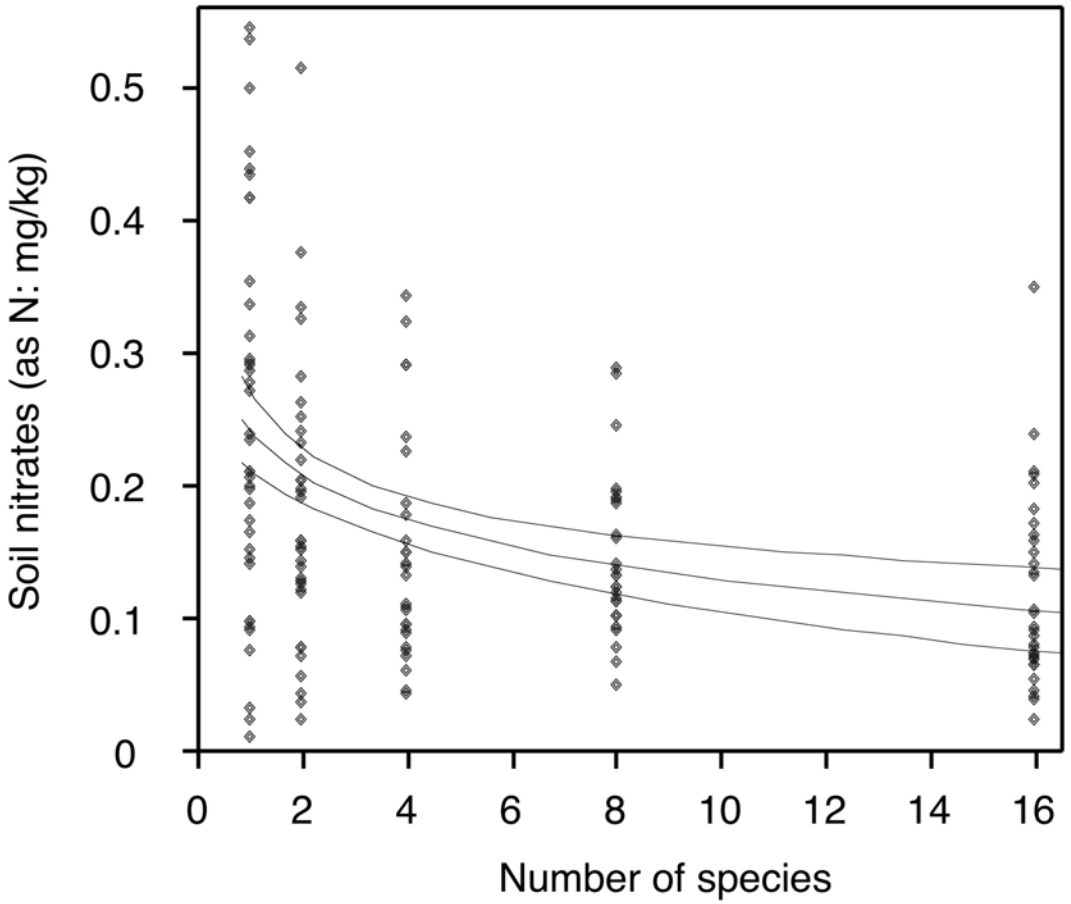


Diverse plots store more carbon...

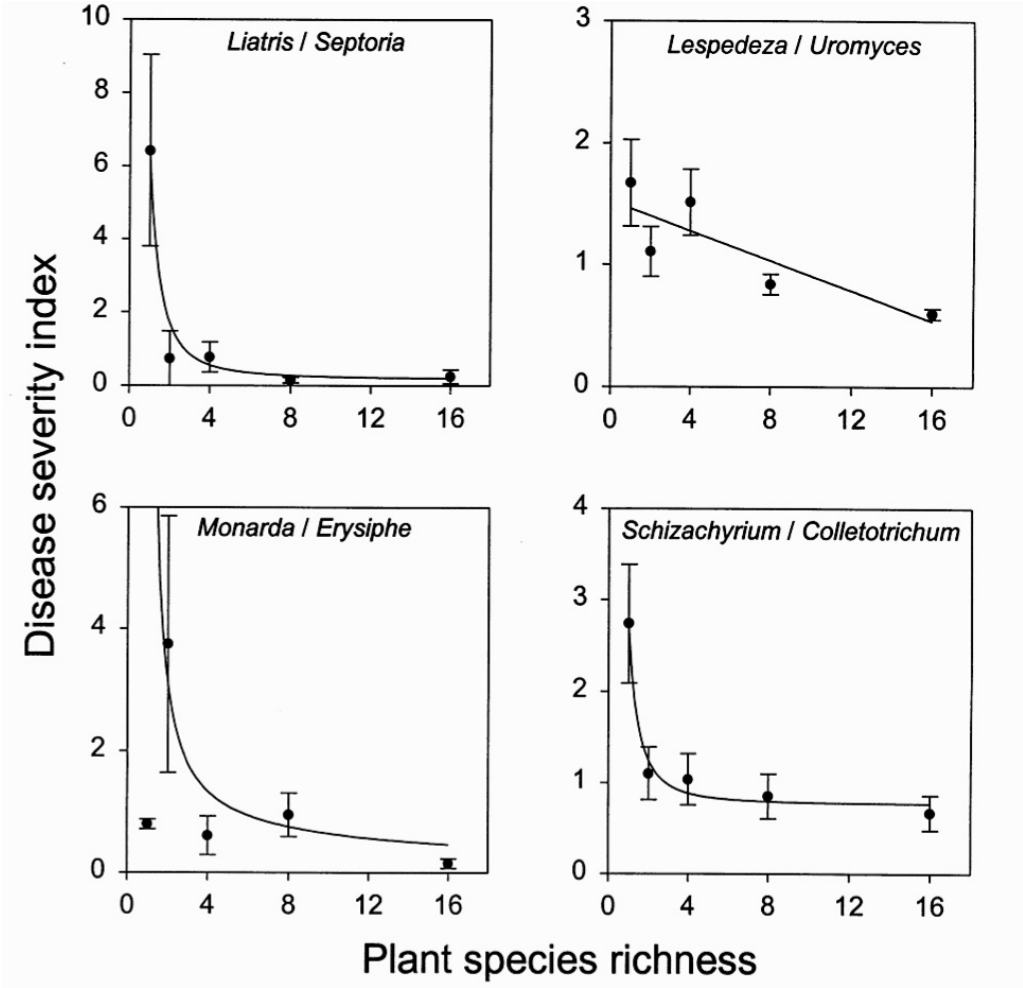




Higher diversity leads to greater use of soil nitrate and less leaching...

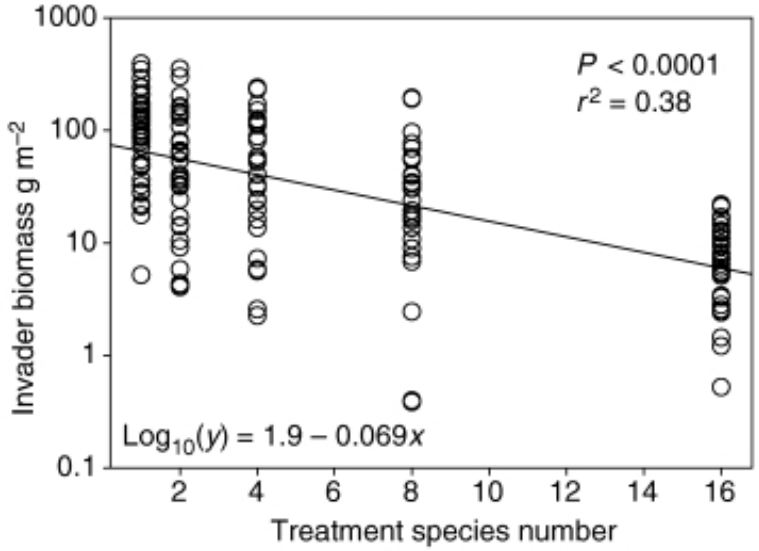


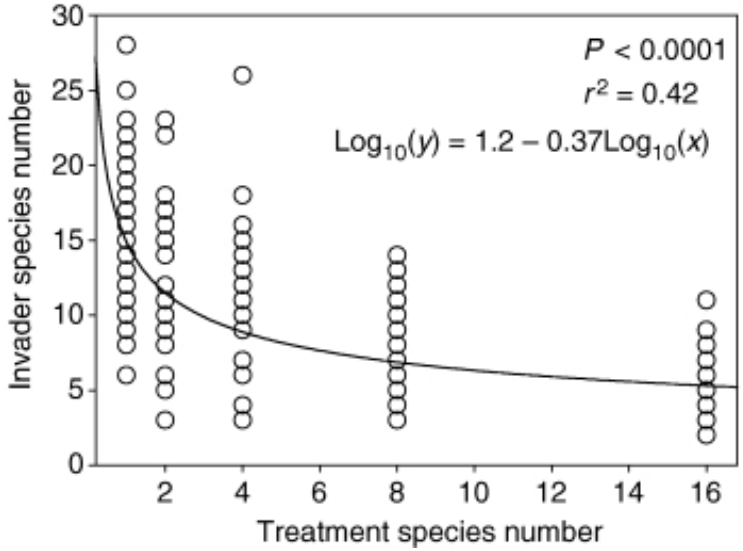
Plant disease incidents decrease with higher diversity...



Knops *et al*. (1999) *Ecology Letters* **2**:286.

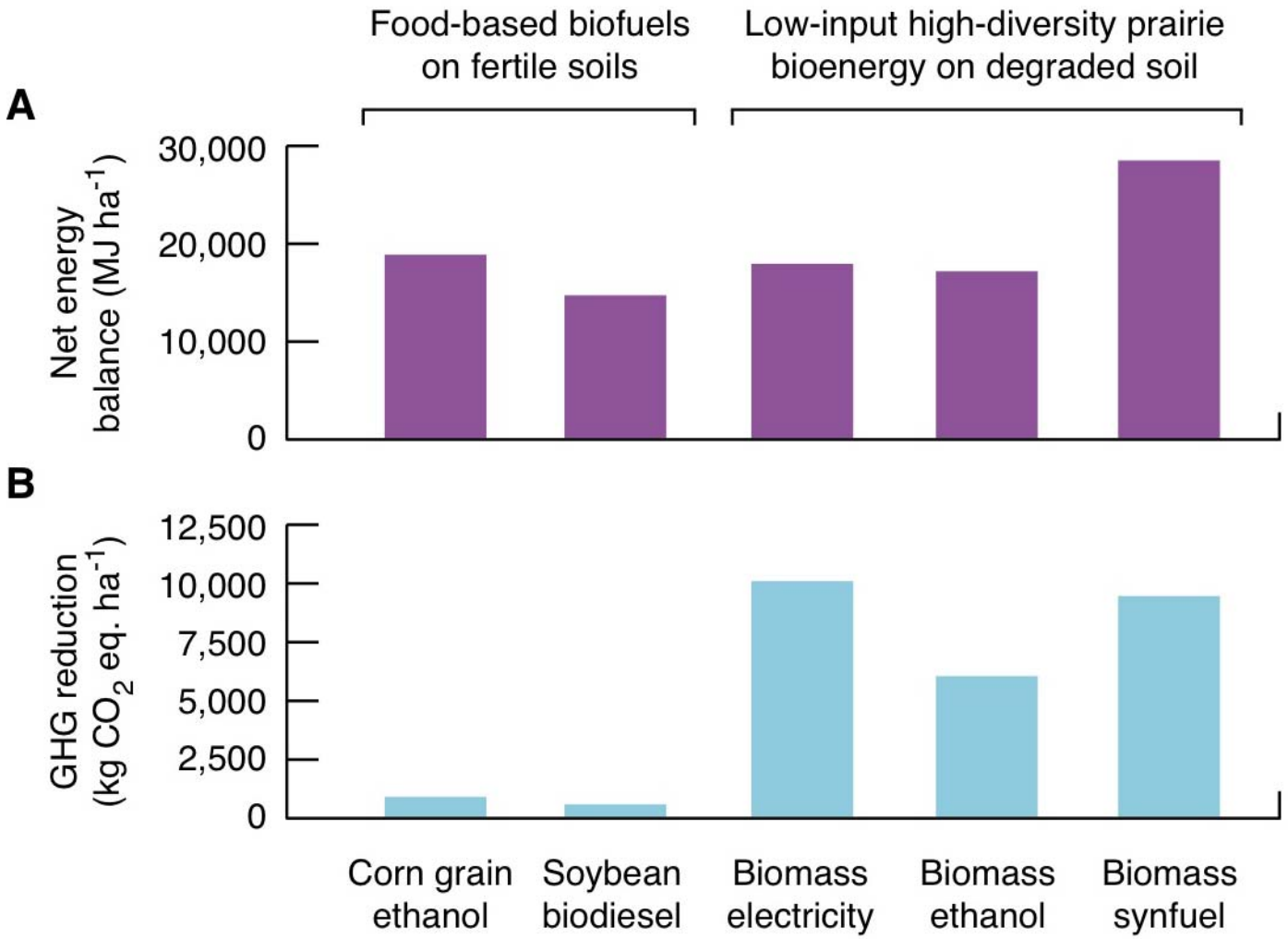
More diverse polycultures better resist invasive species...





Fargione and Tilman (2005) *Ecology Letters* **8**:604.

Comparing current and LIHD biofuels...



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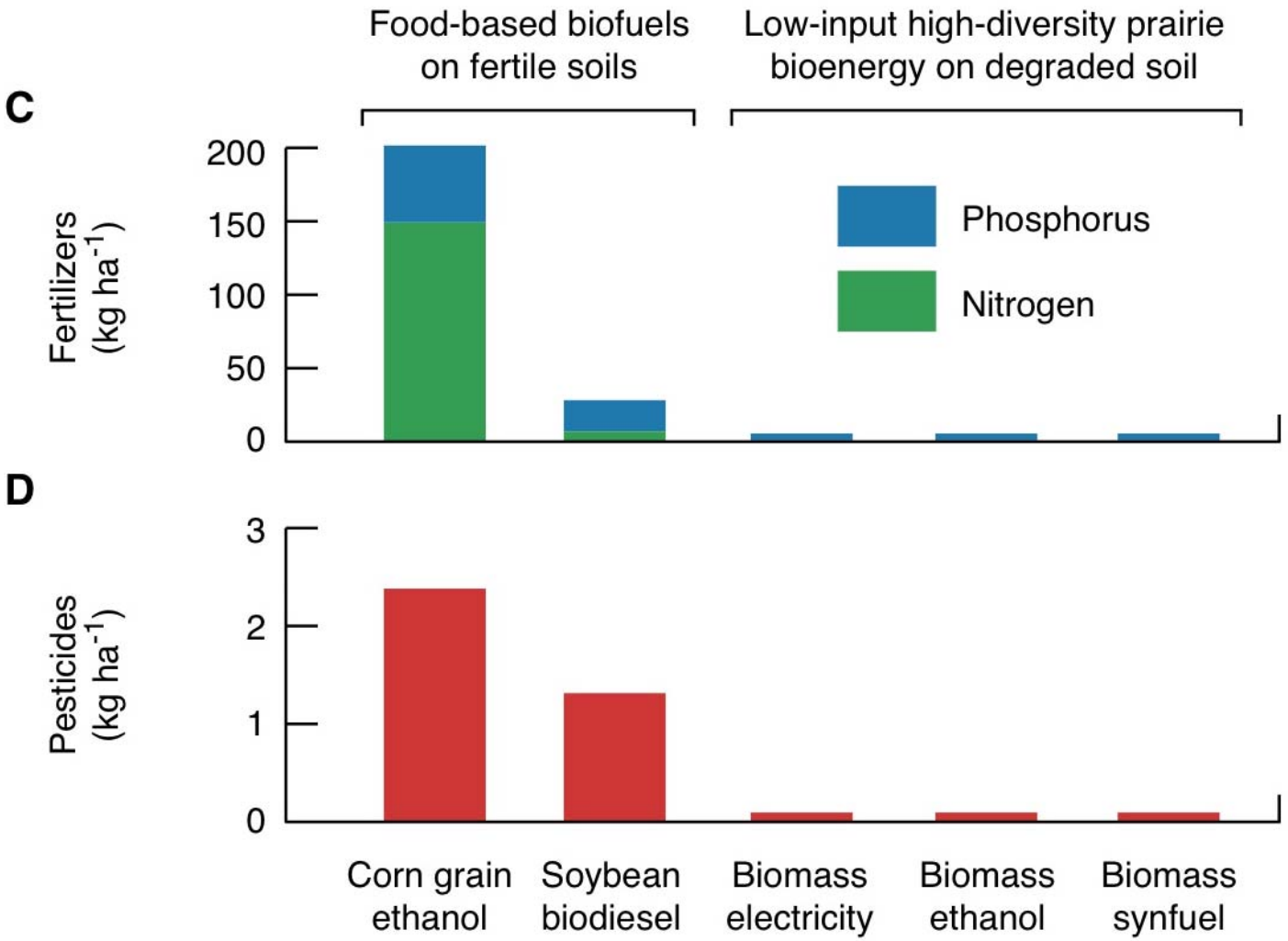


Bird use of potential biofuel crops in Southern Wisconsin...

Habitat	# pairs / 40 ha	# species of greatest conservation need
Dense switchgrass (N=8)	224	5
Sparse switchgrass (N=8)	195	5
Mixed warm-season grasses (N=7)	195	8
Dry prairie (N=6)	153	7
Corn (N=16)	60	2

Sample *et al*. (In preparation).

Benefits of low-input high-diversity…

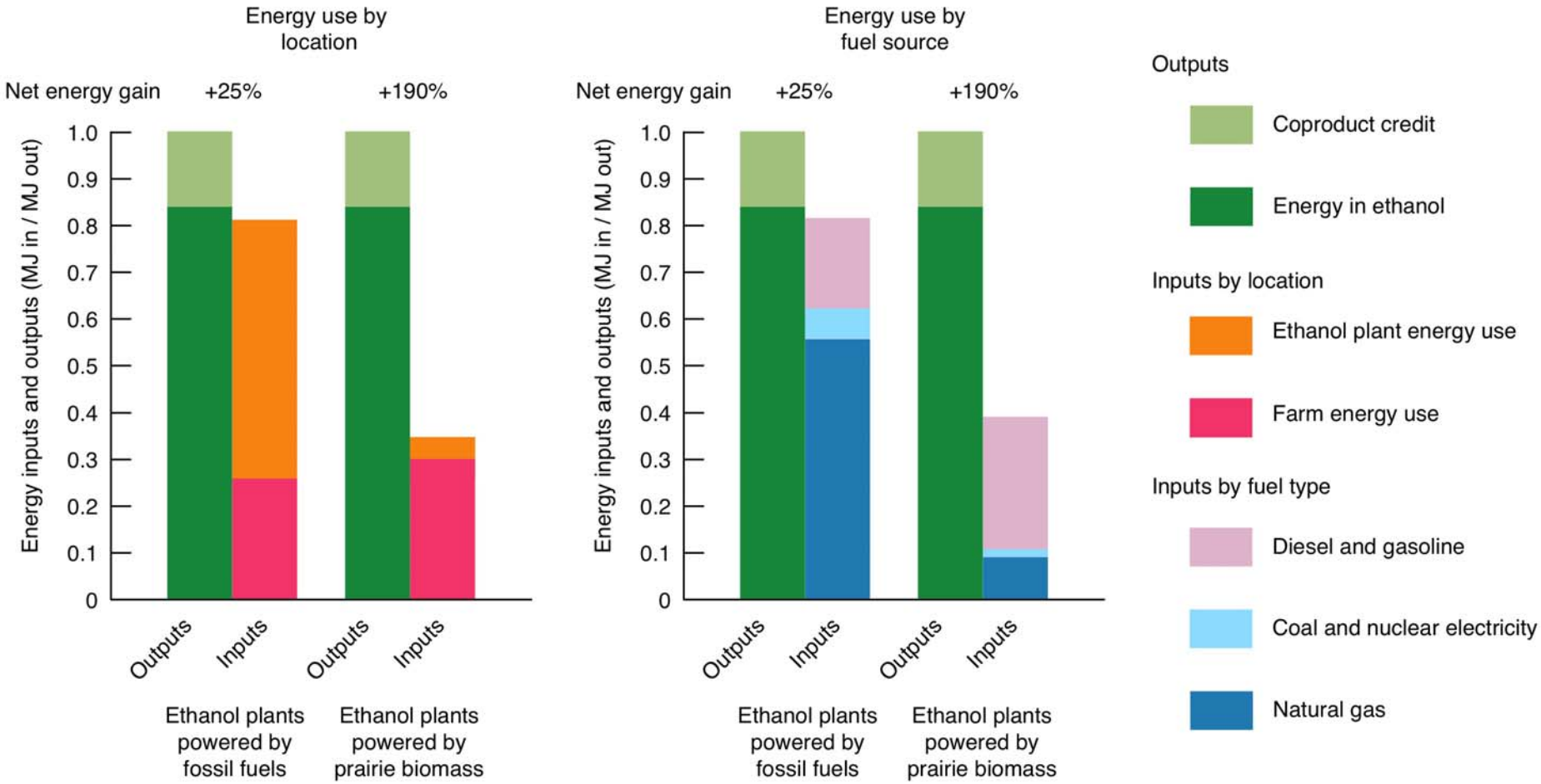
- Producible on degraded agricultural lands, sparing both native ecosystems and prime farmland
- Highly sustainable and stable fuel supply
- As much or more net energy gain per acre than current food-based biofuels
- Restoration of wildlife habitat
- Land in LIHD agriculture can supply of a host of ecosystem services (*e.g.*, soil C and N enrichment, agrichemical runoff mitigation, pollinator habitat)

Hill (2007) *Agron. Sust. Dev.* **27**:1.

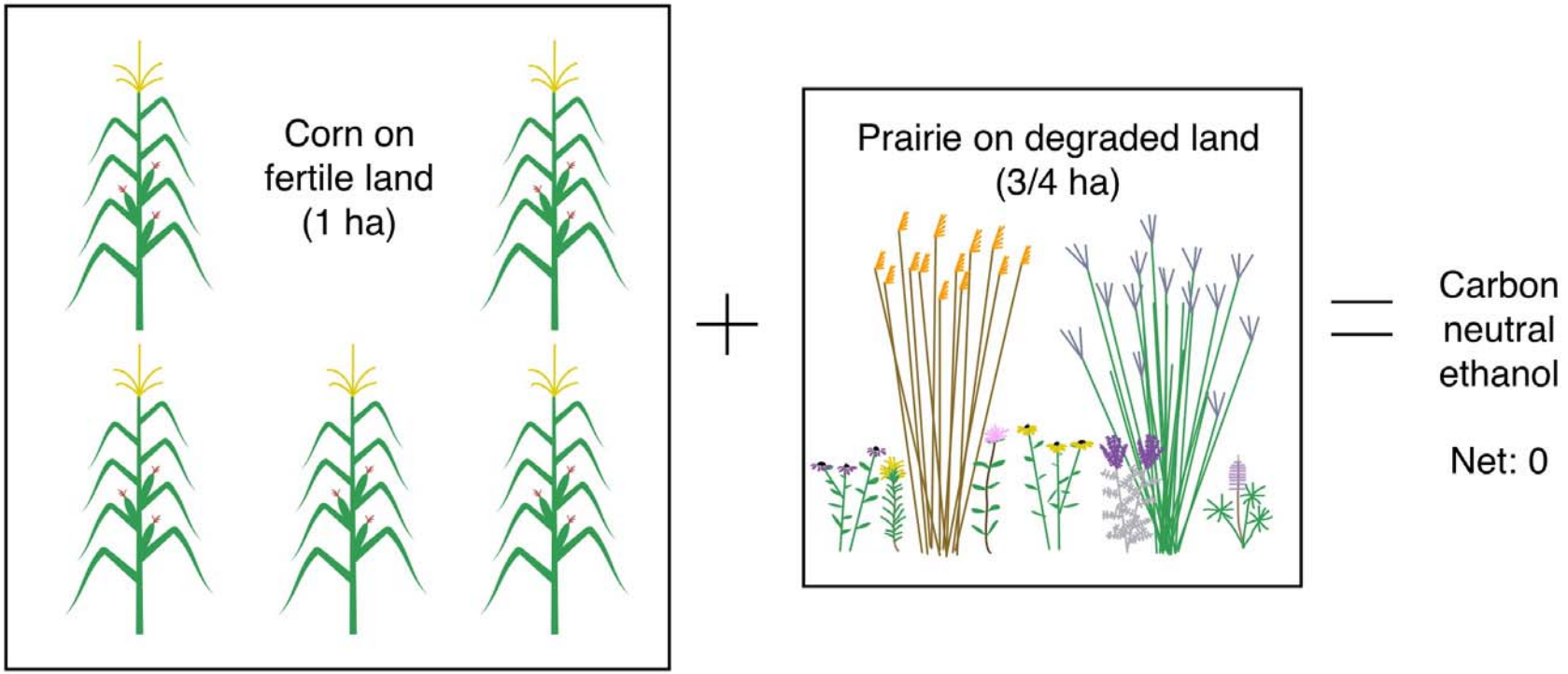
Realities in transitioning to LIHD...

- Corn is king. Corn ethanol is just as regal.
- Increasing incentives for farmers to use crop and reserve lands for corn production
- Tremendous interest in developing liquid fuels that can fit into the existing transportation infrastructure.
- Increasing recognition in both the public and the political realms of the negative effects of global climate change
- LIHD bioenergy systems will require time to implement
- Transitioning to LIHD bioenergy is hampered by a coordination problem between biomass suppliers and users

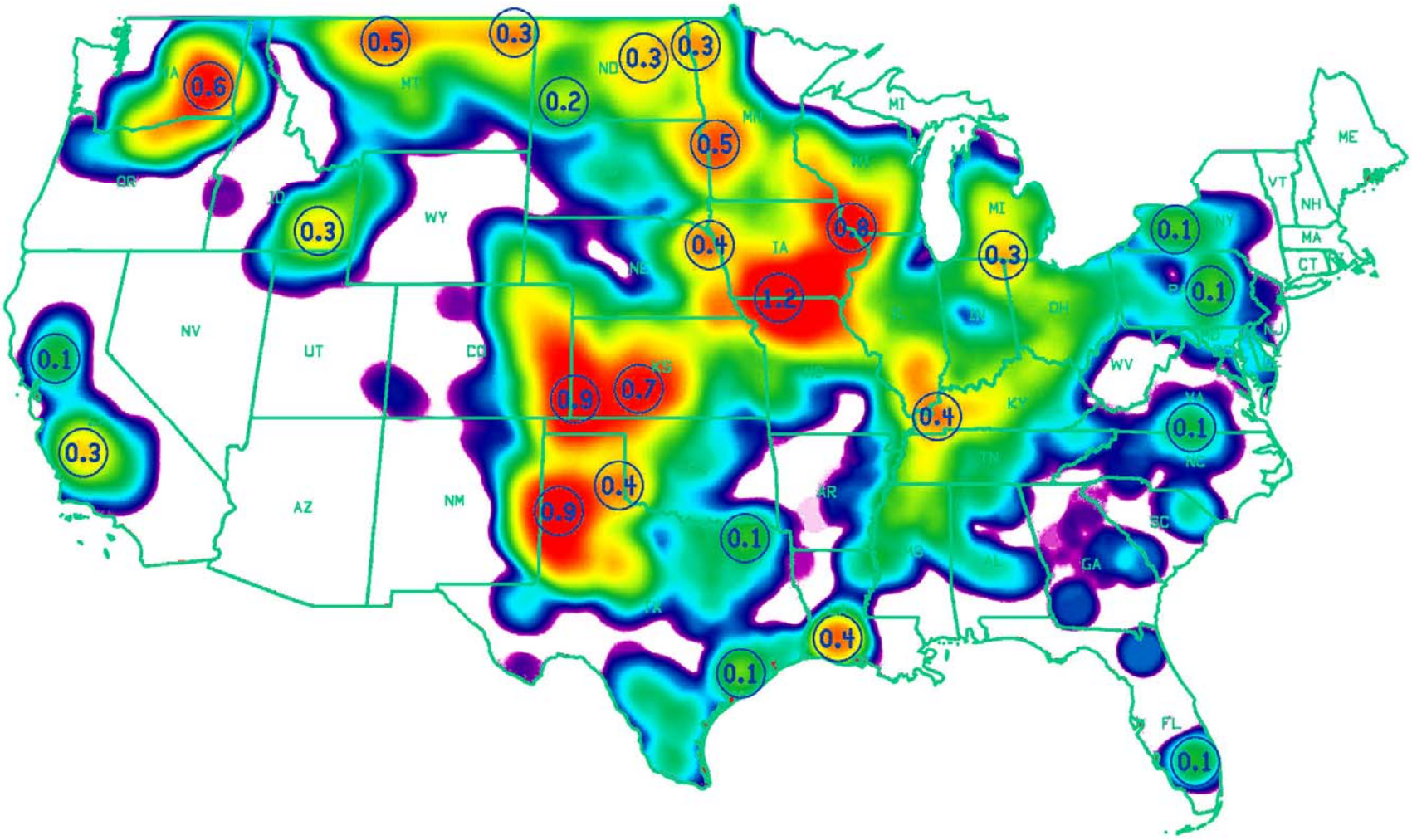
Energy use in corn ethanol production…



Carbon-neutral corn/prairie ethanol...



LIHD biomass production potential…



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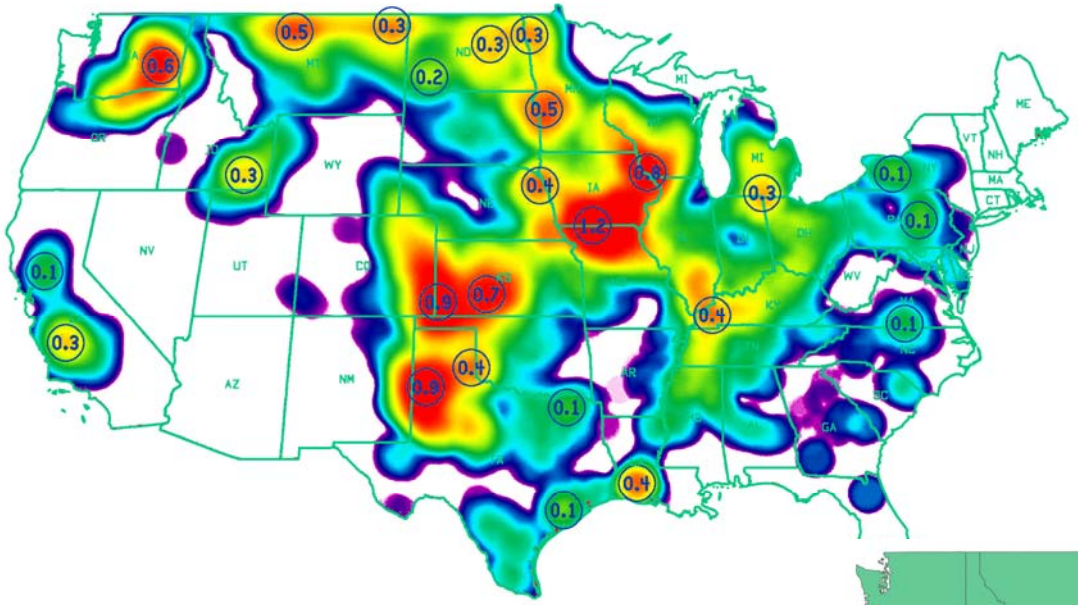

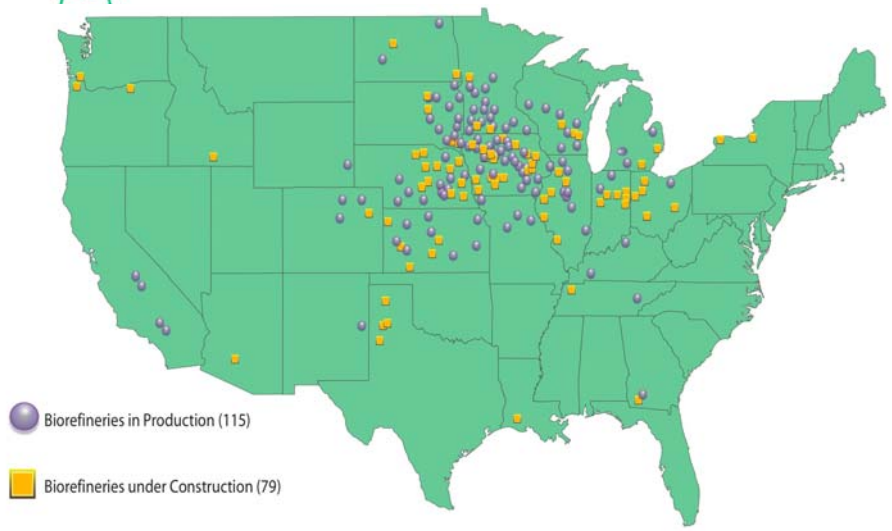

Conclusions…

- Current food-based biofuels can meet but a small portion of transportation energy needs and do so at great environmental cost.
- Biofuels made from mixtures of prairie plants have distinct advantages over current food-based biofuels.
- Choosing between high-input perennial lignocellulosic crops and low-input perennial lignocellulosic crops requires more detailed consideration of what priorities are in biofuel production.
- Research stresses the importance of applying ecological knowledge.
- Food-based biofuels such as corn ethanol made using biomass to power production facilities offer a promising hybrid transitional system.
- Making LIHD biofuels a reality will require recognition of the valuable ecosystem services provided by land used in bioenergy production.
- We must recognize and respond to our linked energy, food and environmental interests.

Gratitude…

- Initiative for Renewable Energy and the Environment (IREE)
- National Science Foundation
- Howard Hughes Medical Institute
- Bush Foundation

- David Tilman, Steve Polasky, Erik Nelson, Doug Tiffany, Clarence Lehman, Joe Fargione

- Kyla Bauer, Diego Bonta, John Carmody, Leah Dornfeld, Vernon Eidman, Darrell Gerber, Kshama Harpankar, Frank Kulacki, Jennifer Kuzma, Dan Petrolia, Sangwon Suh