Sustainable biofuels from diverse mixtures of native prairie plants

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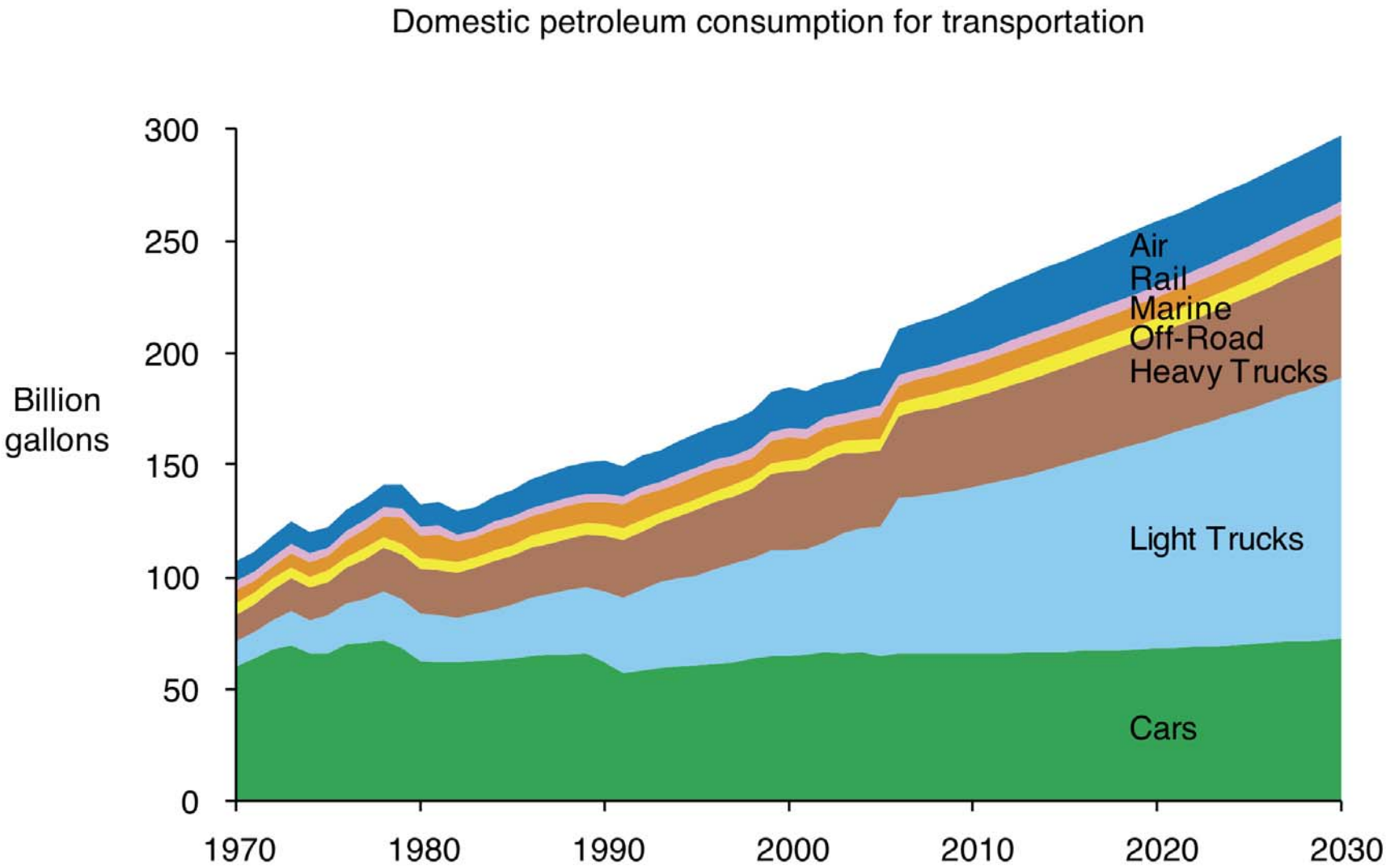
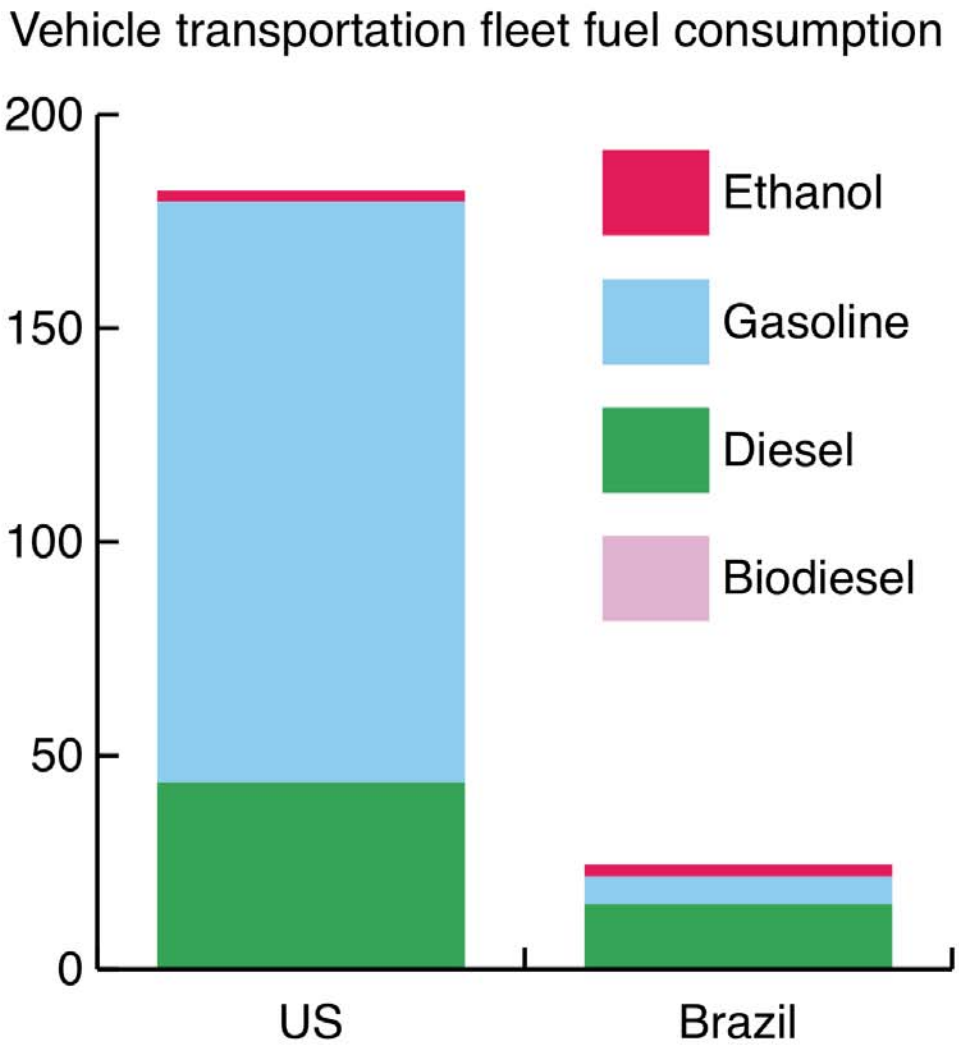
How can we produce sustainable biofuels?

US oil demand will grow 50% by 2030



Fuel demand outpaces biofuel production



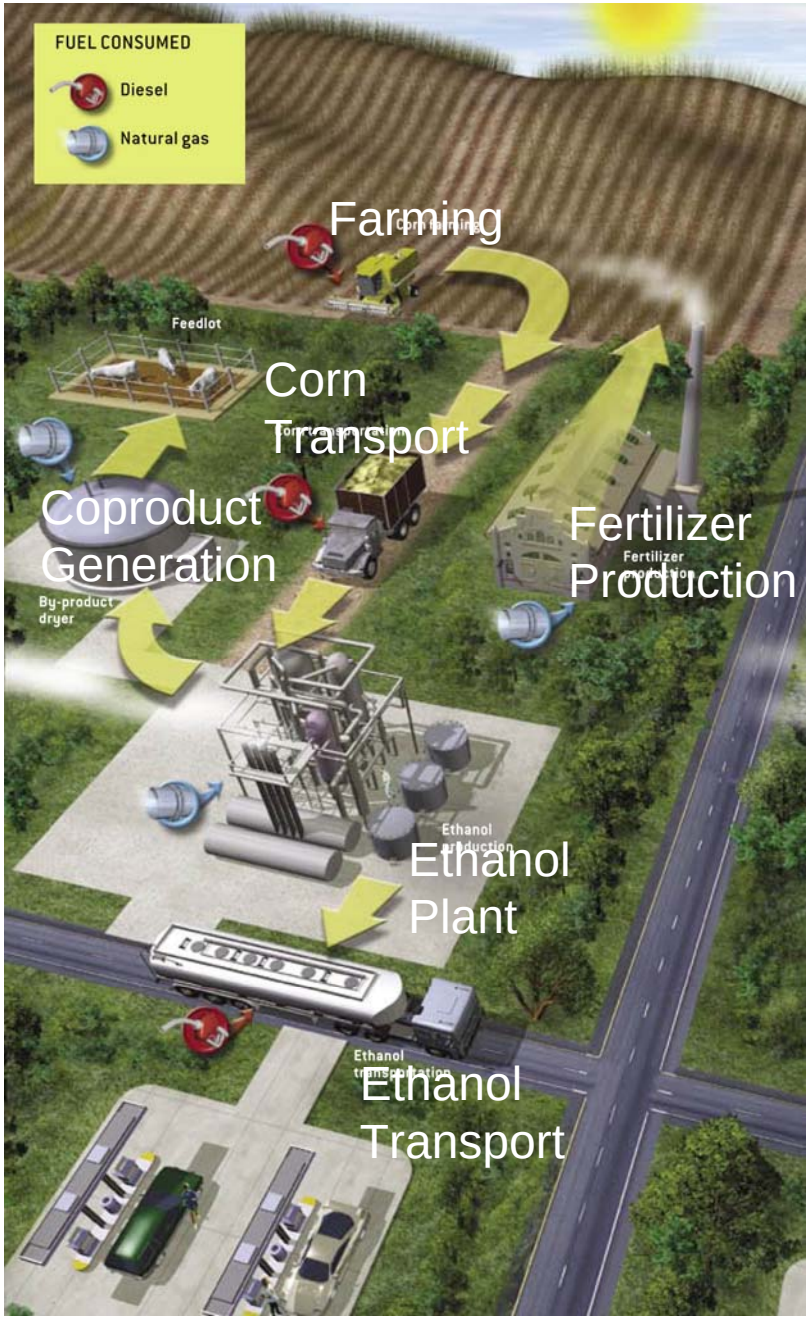
All values in billion gasoline equivalent gallons per year

Current growth rate of US fuel demand

Gasoline	2.3
Diesel	1.4

Current growth rate of US biofuel production

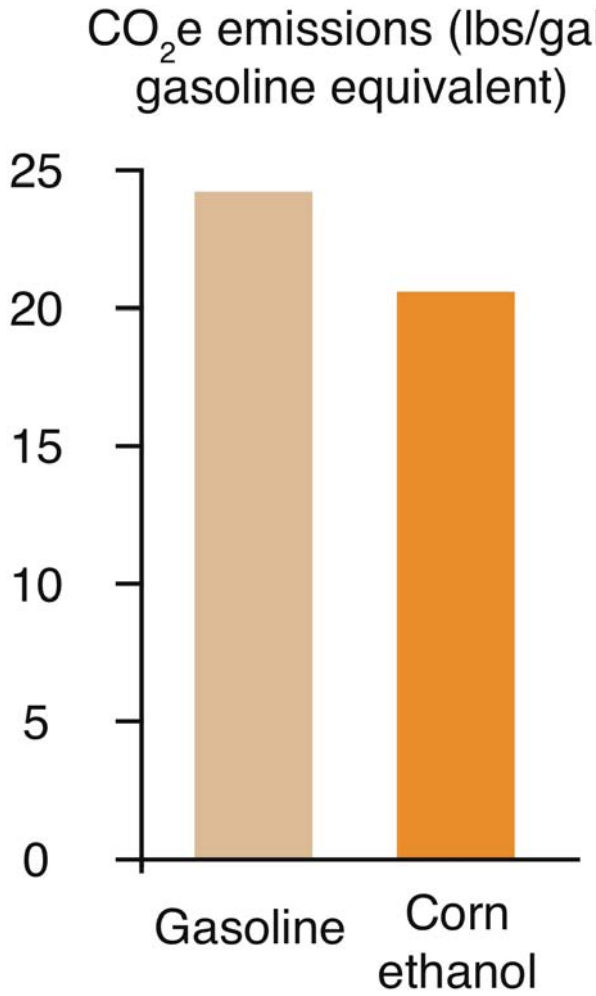
Ethanol	0.7
Biodiesel	0.4



Estimating the greenhouse gas (GHG) emissions from producing corn ethanol

Approximately 1/3 of emissions occur on farms and 2/3 in processing and transport

Current studies conclude corn ethanol emits less GHG than gasoline



Independent estimates of GHG reduction from corn ethanol

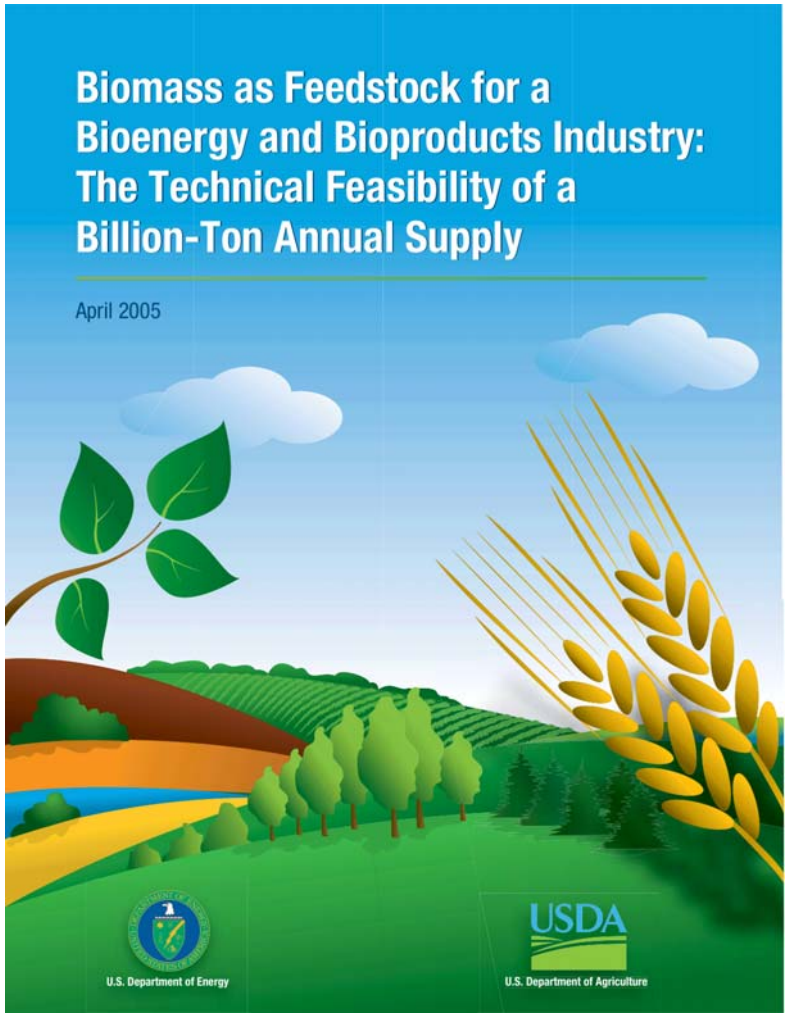
- 18% : Farrell *et al*. (2006)
- 12% : Hill *et al*. (2006)
- 19% : Wang *et al*. (2007)

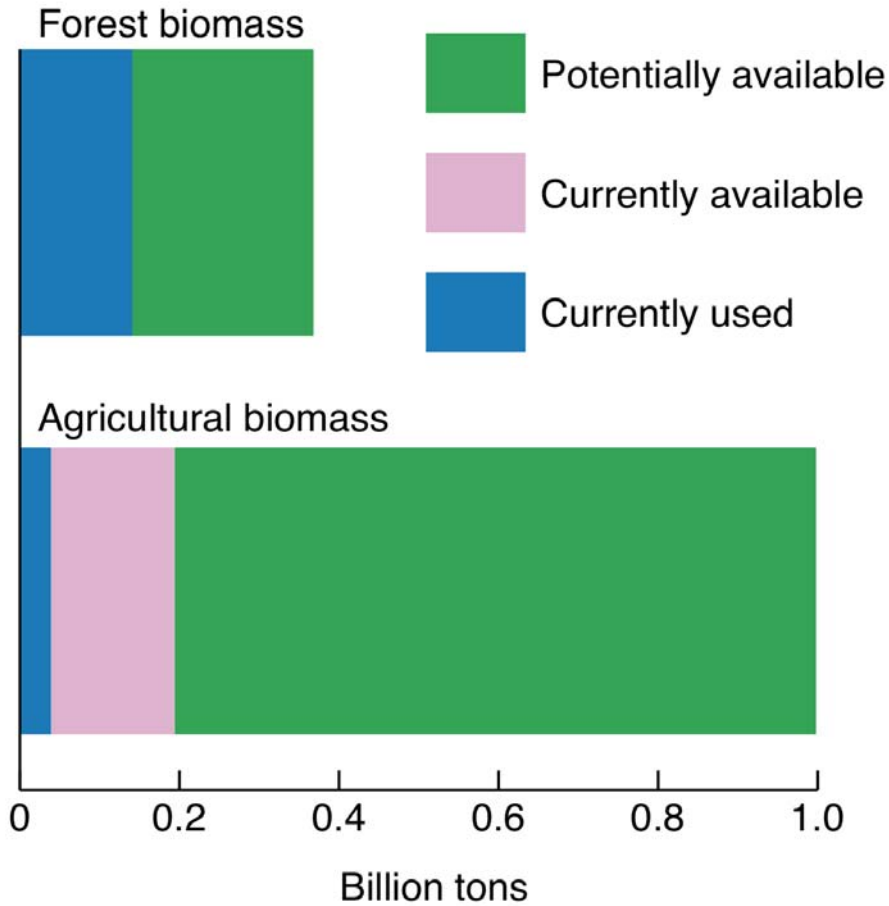
Effects of changing crop rotations

	Average yield of 9 top corn producing states (kg ha^{-1})	Average nitrogen fertilizer application (kg ha^{-1})	Greenhouse gas reduction of ethanol relative to gasoline
Corn following soybeans	8,900	145	19%
Corn following corn	8,000	200	5%

Agricultural land use change

Over a billion tons of biomass are needed to offset a third of today's US oil demand

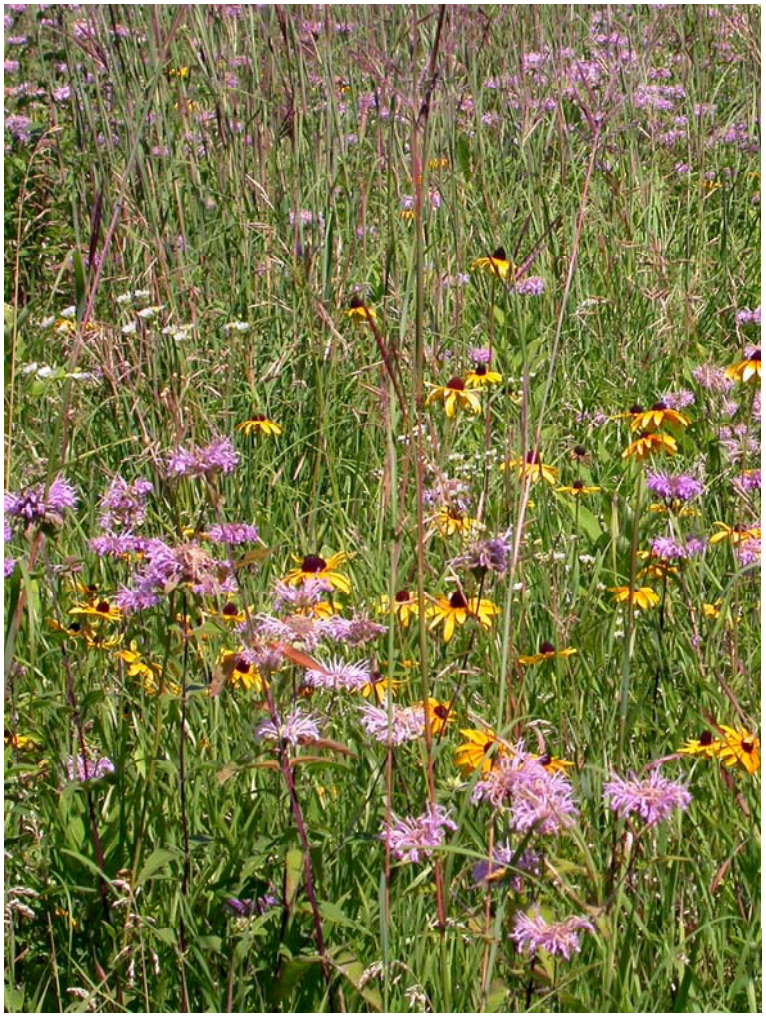




Sources of lignocellulosic biomass

Switchgrass Hybrid poplar Wheat straw Corn stover Diverse prairie

Biofuels from low-input polycultures



Biofuels from low-input polycultures

Cedar Creek Natural History Area in Bethel, MN

152 plots

10 yd x 10 yd

Planted to 1, 2, 4, 8, or 16 randomly chosen native perennial prairie plant species

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

Cedar Creek Biodiversity experiment

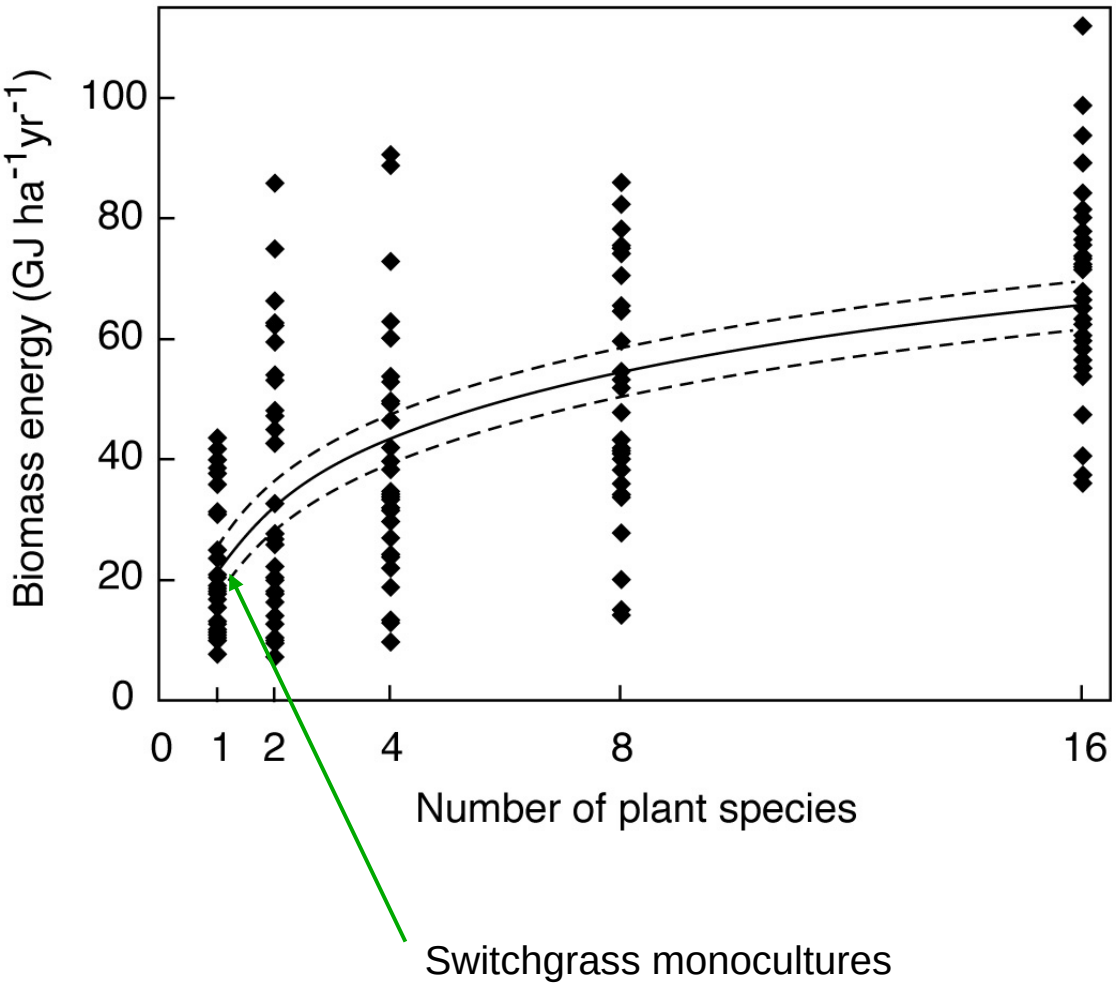
Species	Functional type
Lupinis perennis	Legume
Andropogon gerardi	C_4 grass
Schizachyrium scoparium	C_4 grass
Sorghastrum nutans	C_4 grass
Solidago rigida	Forb
Amorpha canescens	Woody legume
Lespedeza capitata	Legume
Poa pratensis	C_3 grass
Petalostemum purpureum	Legume
Monarda fistulosa	Forb
Achillea 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.

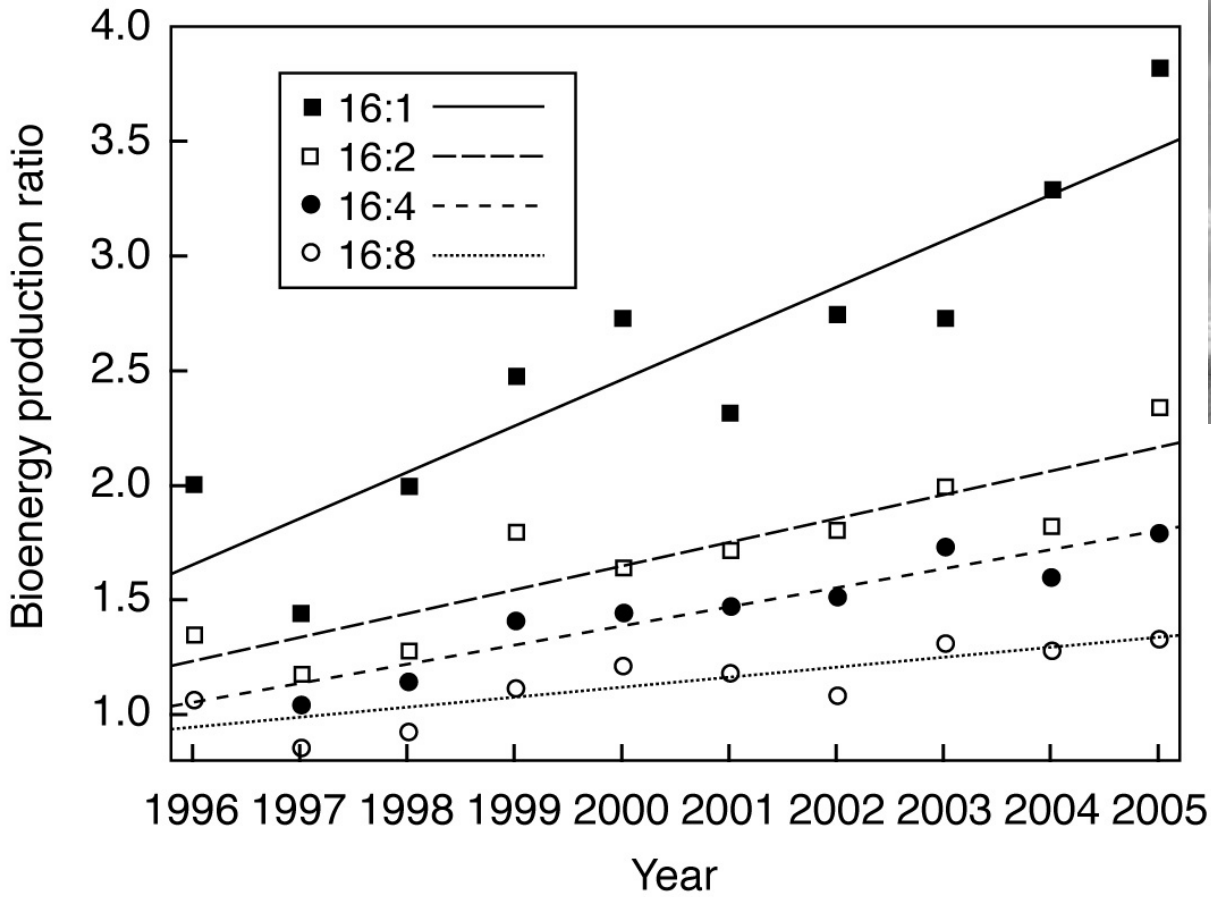
Corn and prairie nutrient requirements

average pounds of fertilizer per acre per year	Corn on fertile farmland	Highly diverse prairie on degraded farmland
Nitrogen	130	0
Phosphate	20	4
Potash	45	5

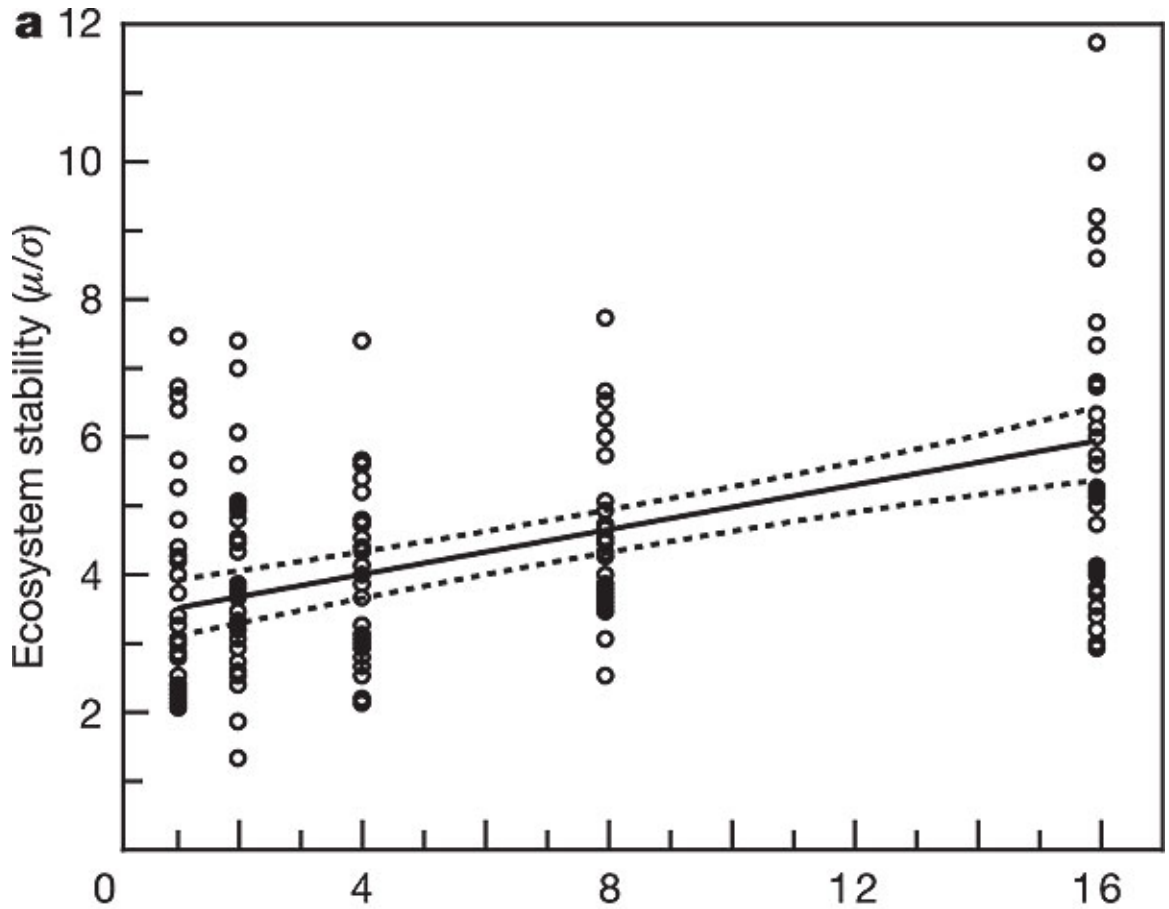
Diverse plots yield more energy



More diverse plots become more increasingly productive

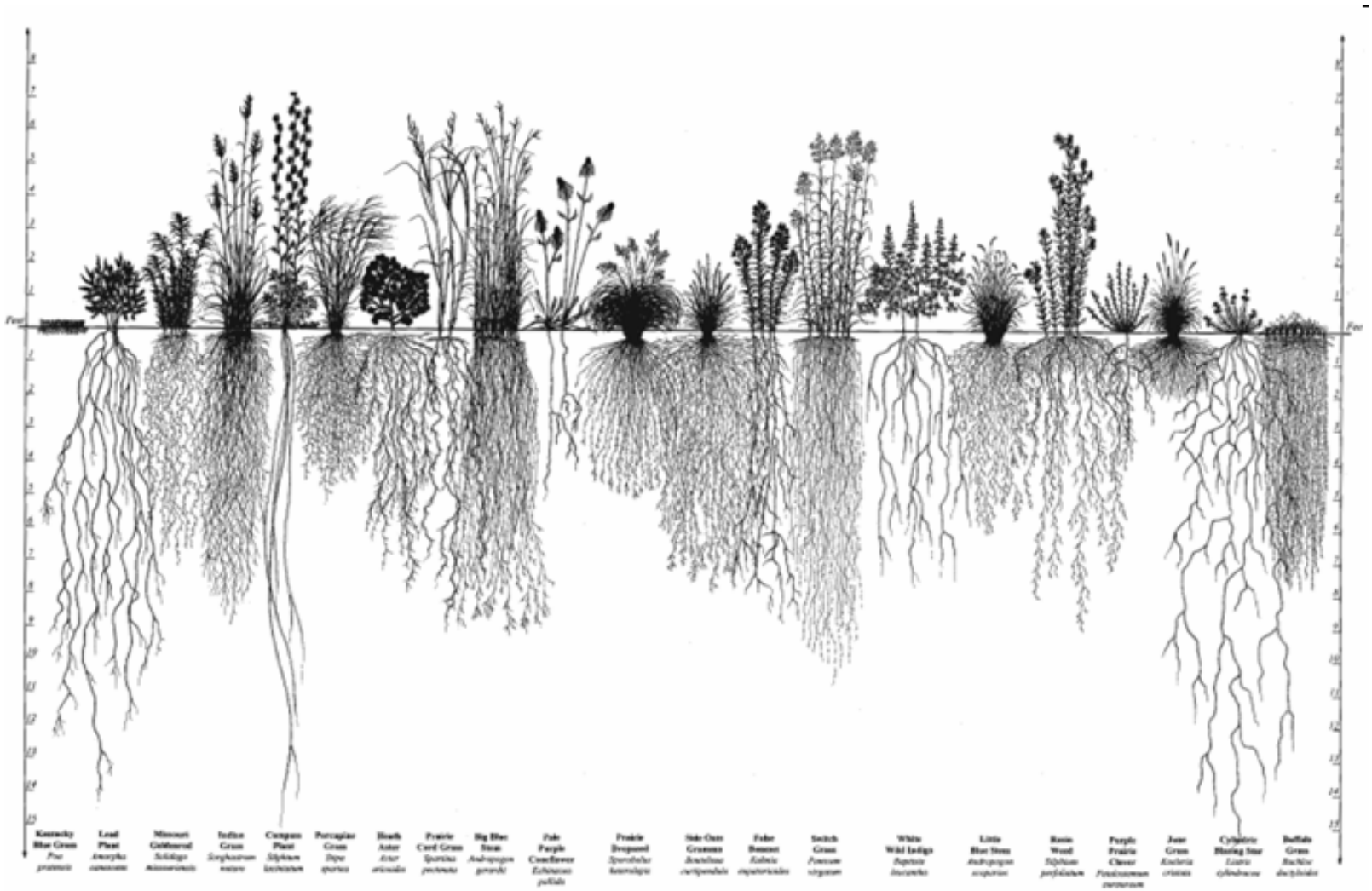


Primary productivity is more stable at greater diversity

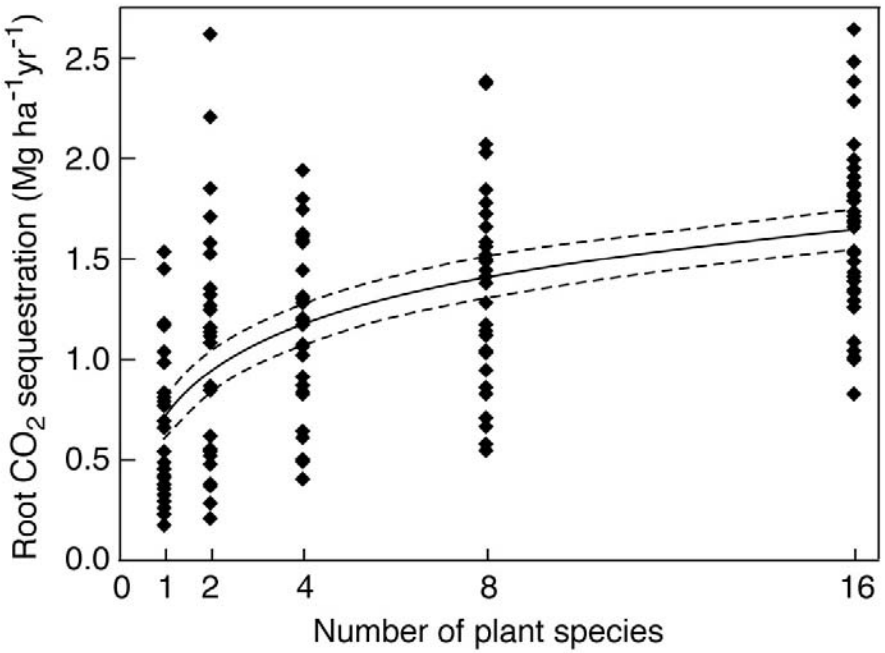


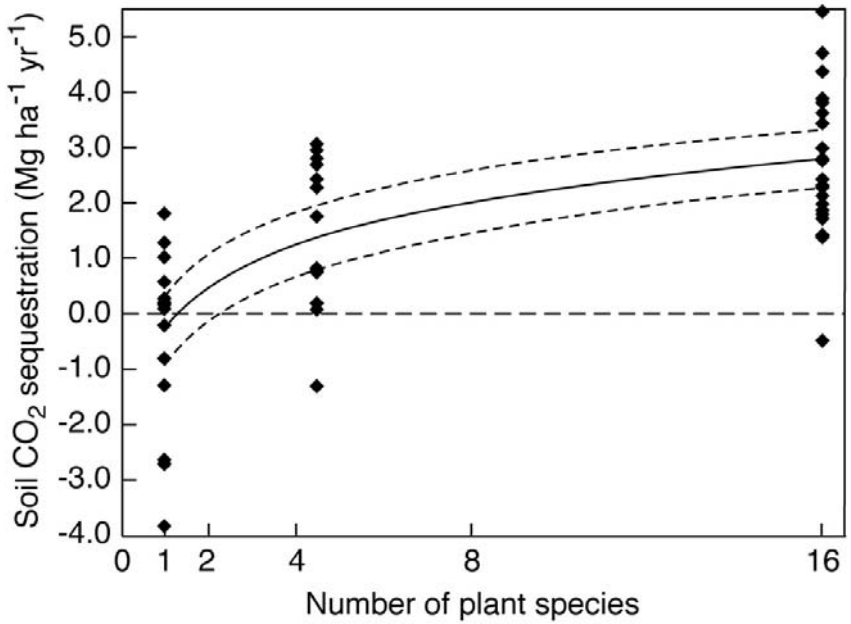
Tilman *et al*. (2006) *Nature* **441**:629.

2/3 of the prairie is below ground

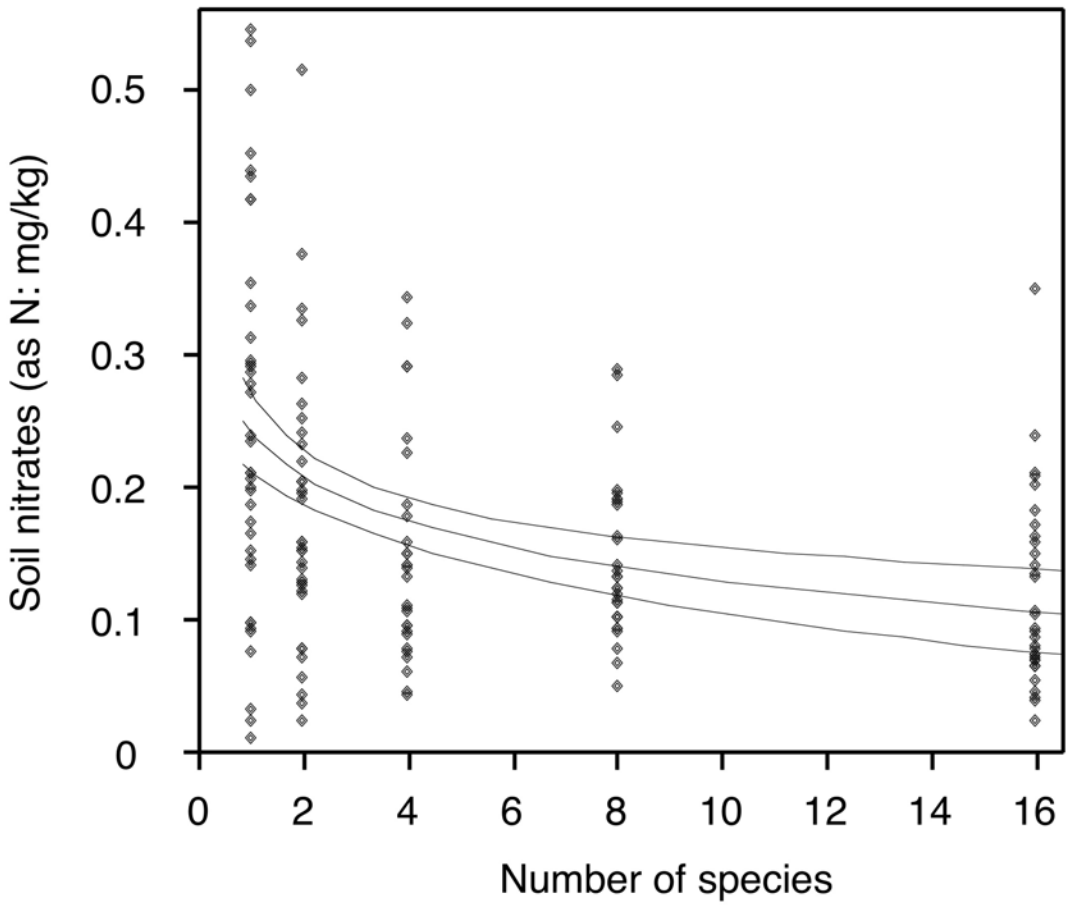


Diverse plots store more carbon

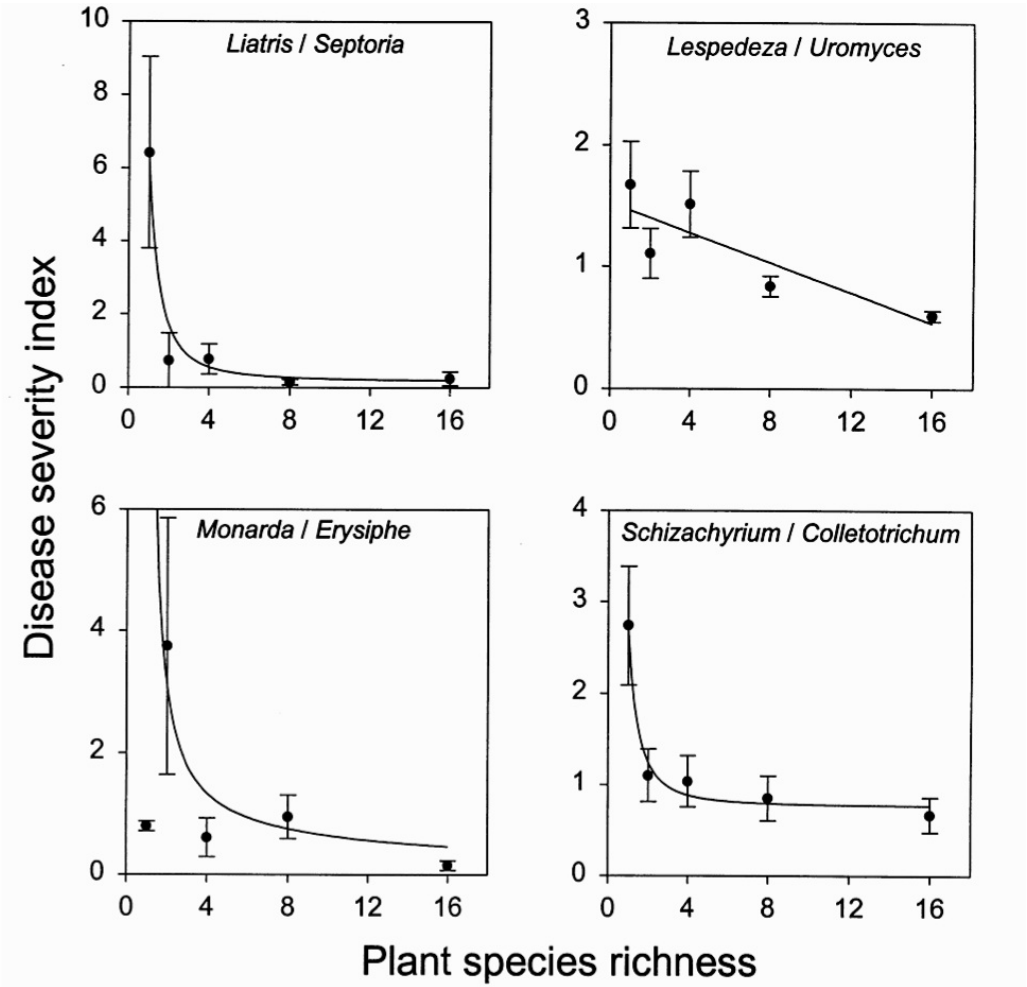




Higher diversity leads to greater use of soil nitrate and less leaching

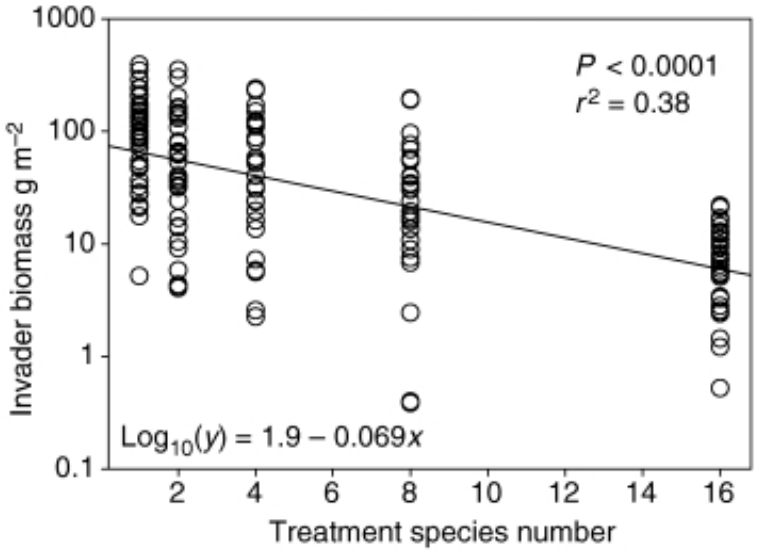


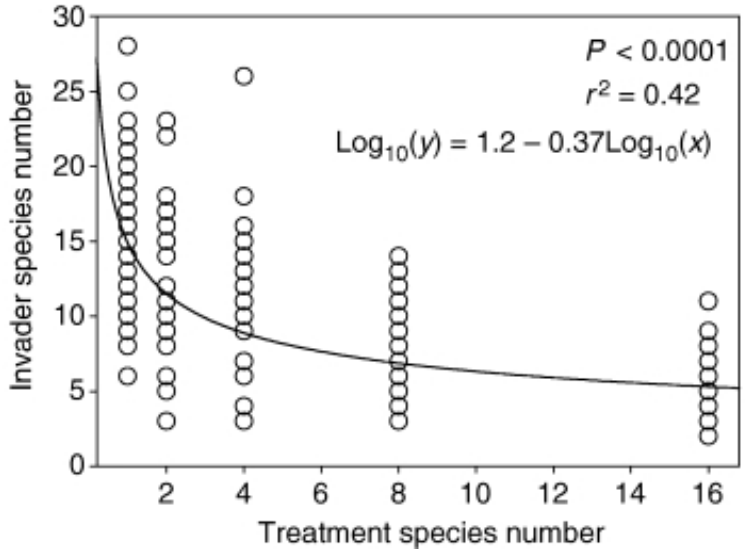
Plant disease incidents decrease with higher diversity



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

More diverse polycultures better resist invasive species





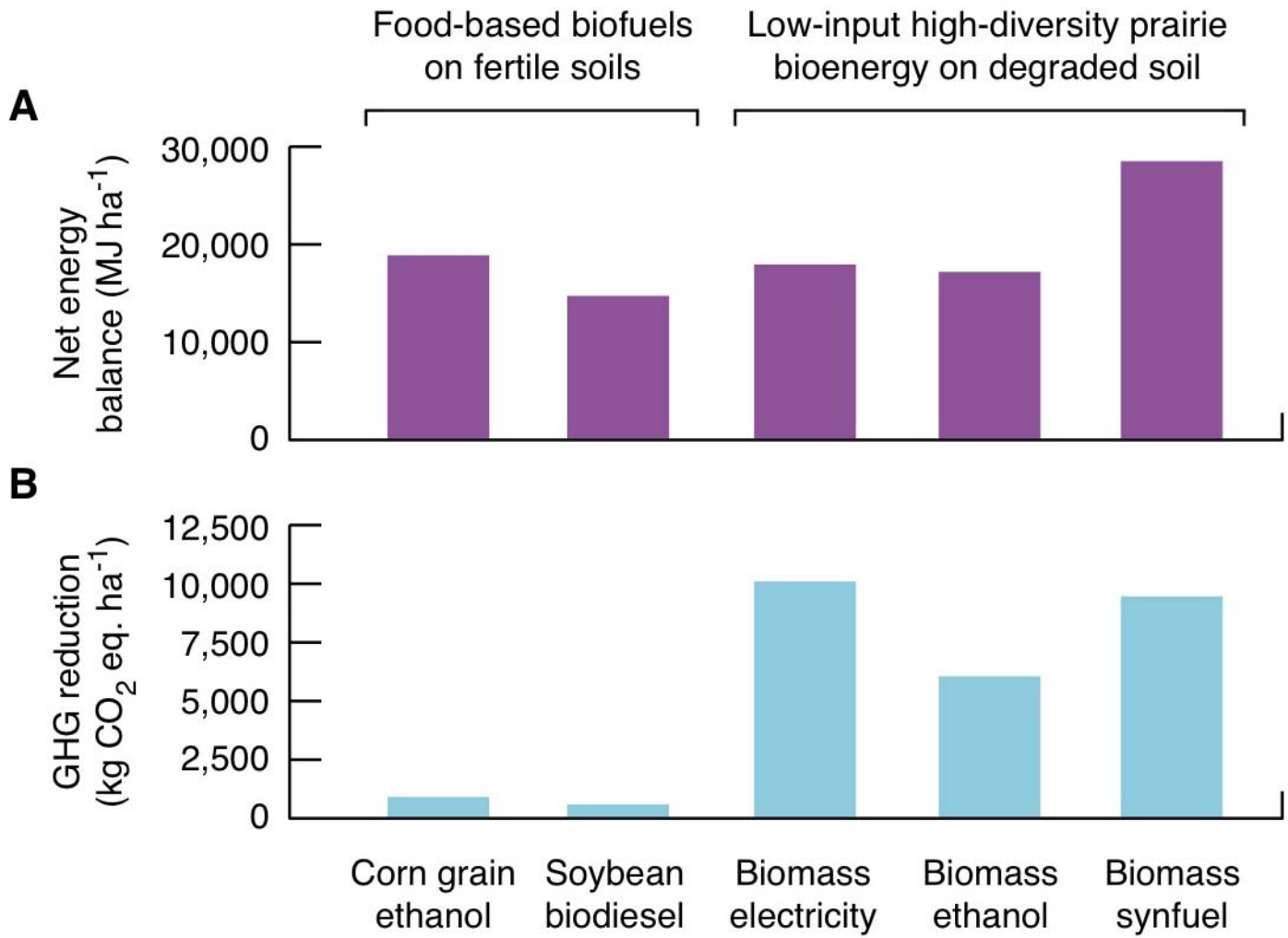
Fargione and Tilman (2005) *Ecology Letters* **8**:604.

Bird use of potential biofuel crops in Southern Wisconsin

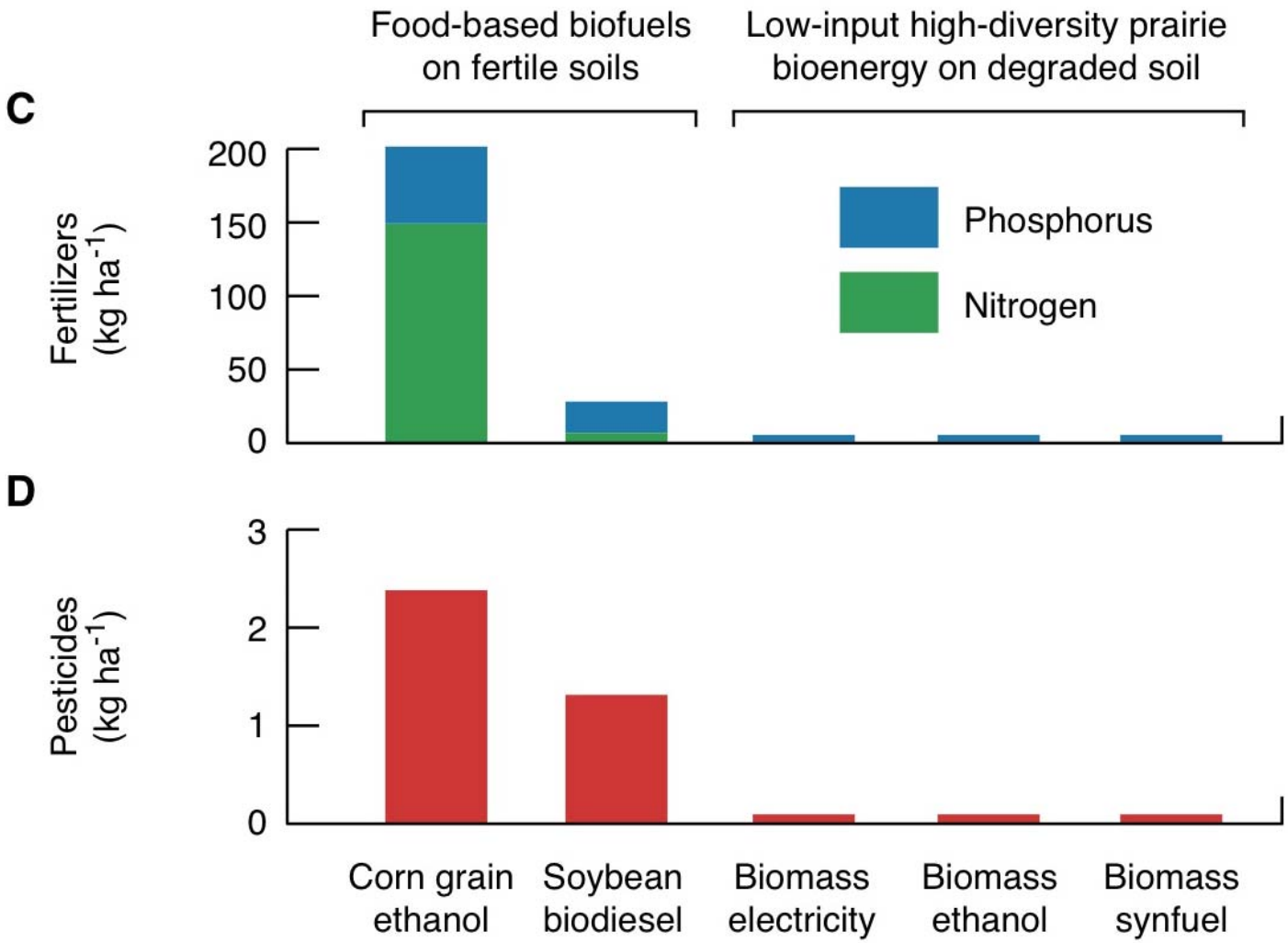
Habitat	# pairs / 40 ha	# species of greatest conservation need
Dense switchgrass (N=8)	224	5
Sparse switchgrass (N=8)	195	5
Mixed warm-season grasses (N=7)	195	8
Dry prairie (N=6)	153	7
Corn (N=16)	60	2

Sample *et al*. (In preparation).

Comparing current and LIHD biofuels



Comparing current and LIHD biofuels



Benefits of low-input high-diversity

- Producible on degraded agricultural lands, sparing both native ecosystems and prime farmland
- Highly sustainable and stable fuel supply
- Comparable 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.

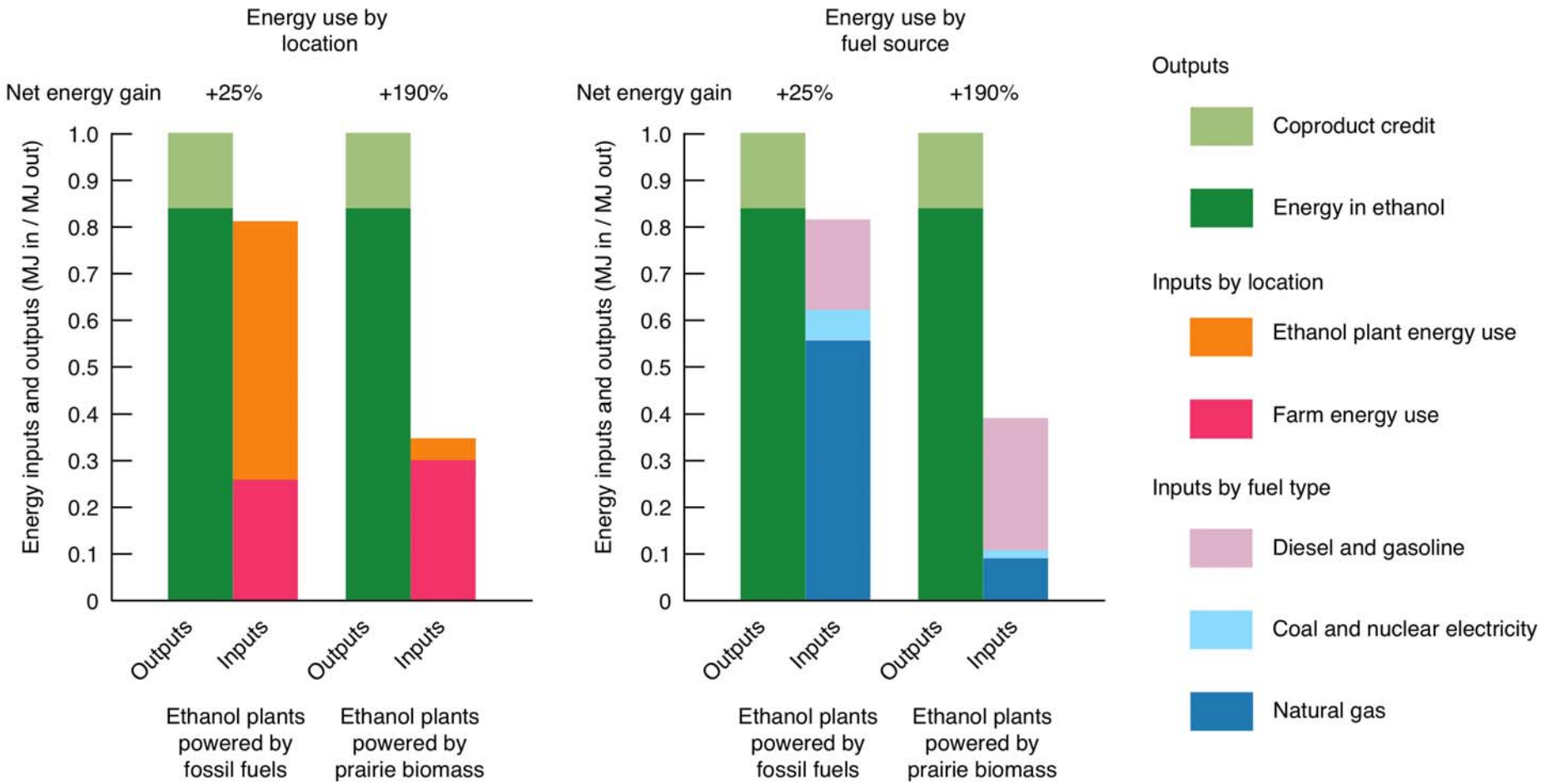
Building a lignocellulosic biofuel industry

- There is tremendous interest in developing liquid fuels that can fit into the existing transportation infrastructure.
- There is increased recognition in both the public and the political realms of the negative effects of global climate change
- Using degraded lands for biomass production spares fertile lands for food and feed production
- Transitioning to lignocellulosic bioenergy is hampered by a coordination problem between biomass suppliers and users
- Overcoming ths coordination problem can be accomplished by integrating biomass production into today's corn ethanol industry

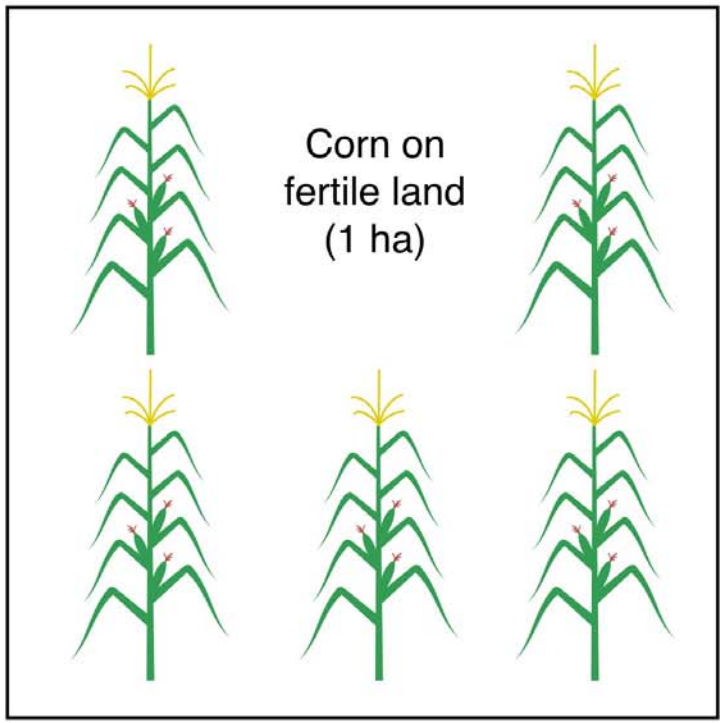
Prairie powered corn ethanol - A hybrid intermediate

- Power ethanol plants with prairie biomass
- Processing corn into ethanol: 18 million BTU/acre of corn
- Diverse prairie on highly degraded soils: 25 million BTU/acre
- Corn ethanol production: releases 1.3 tons/acre of CO_2
- Diverse prairie: stores 1.8 tons/acre of CO_2
- ¾ acre of diverse prairie on highly degraded soil can produce carbon-neutral ethanol

Energy use in corn ethanol production



Carbon-neutral corn/prairie ethanol



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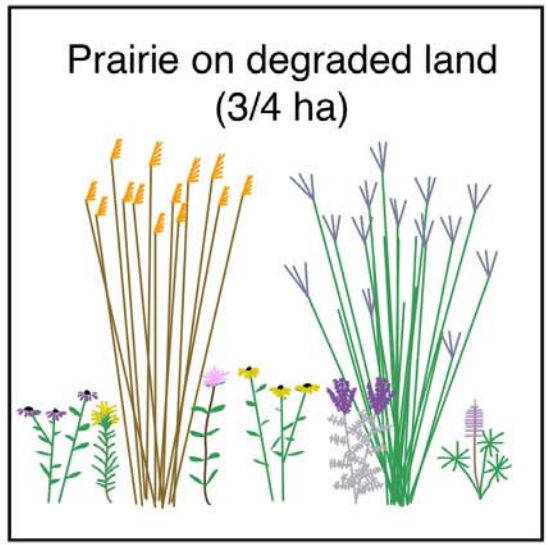

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Carbon neutral ethanol

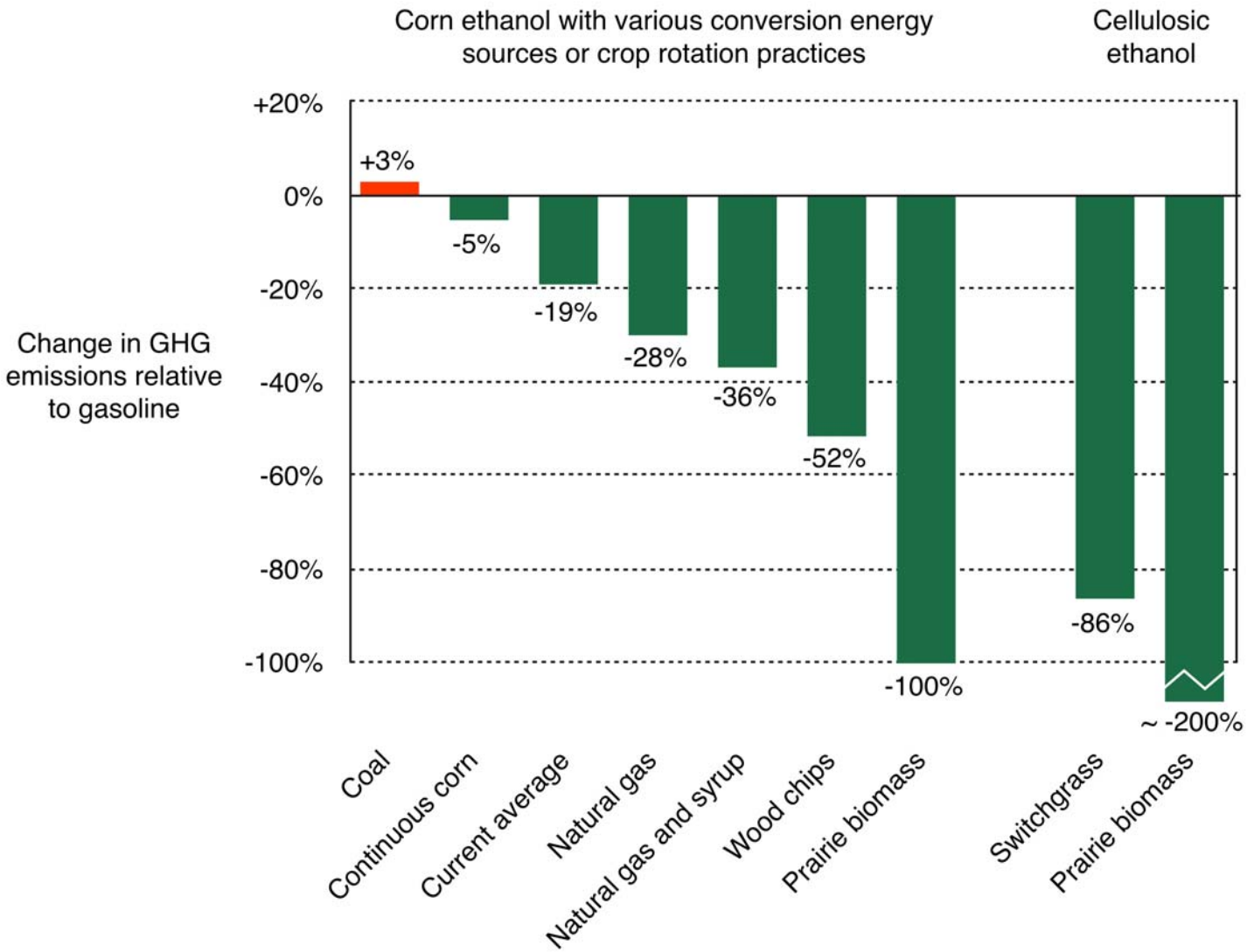
Net: 0

3,050 (Farming and transport)
2,900 (Processing using biomass)

200 (Farming and transport)
-2,900 (Aboveground biomass)
-3,250 (Soil and root C storage)

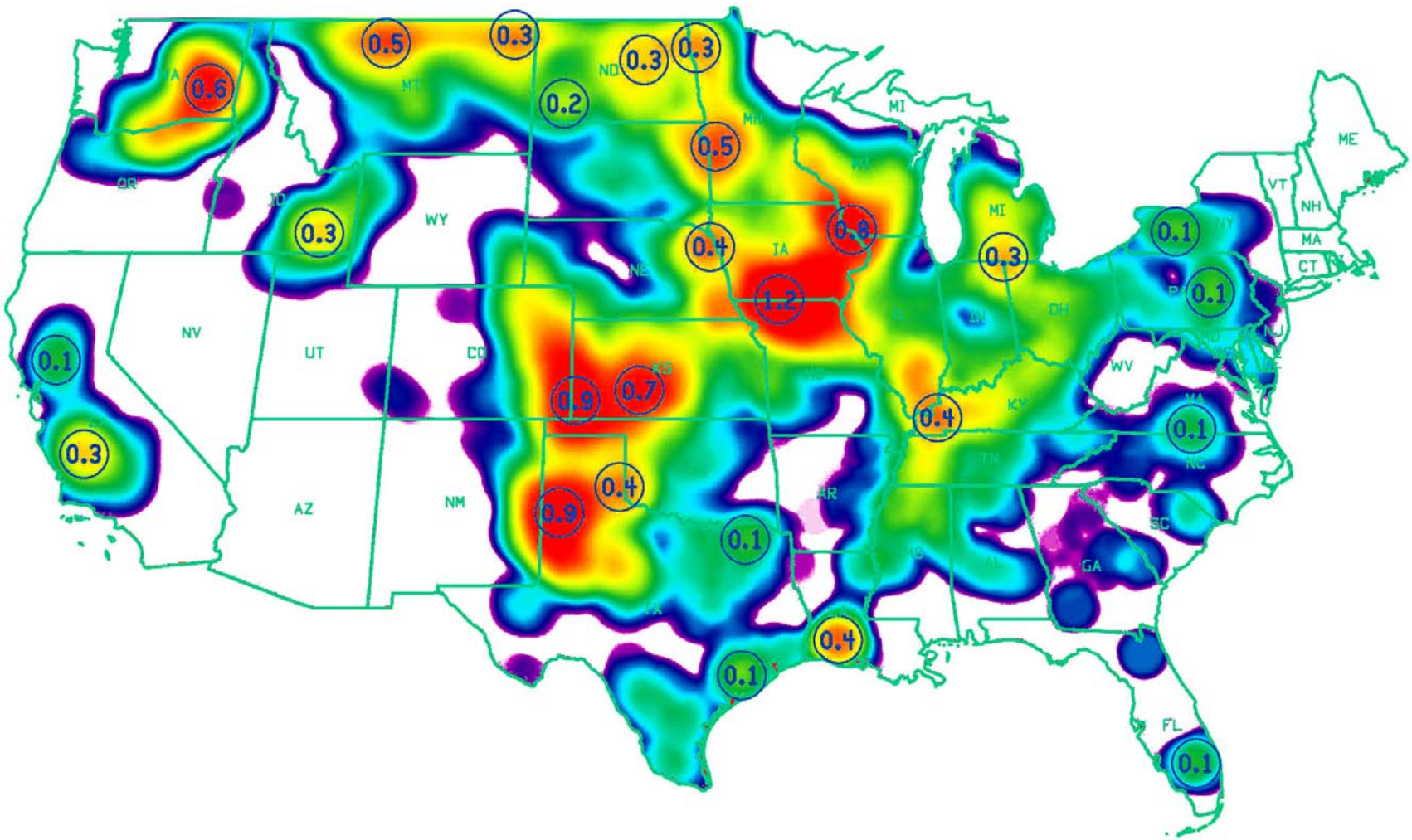
Greenhouse gases emitted to the atmosphere or sequestered (kg CO_2)

GHG effects of novel technologies

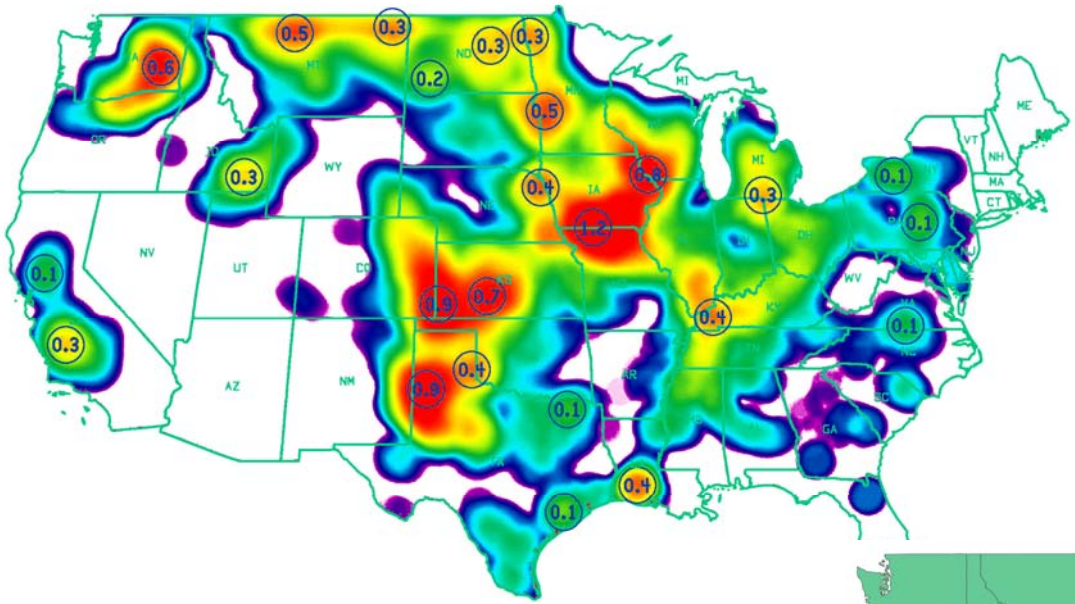


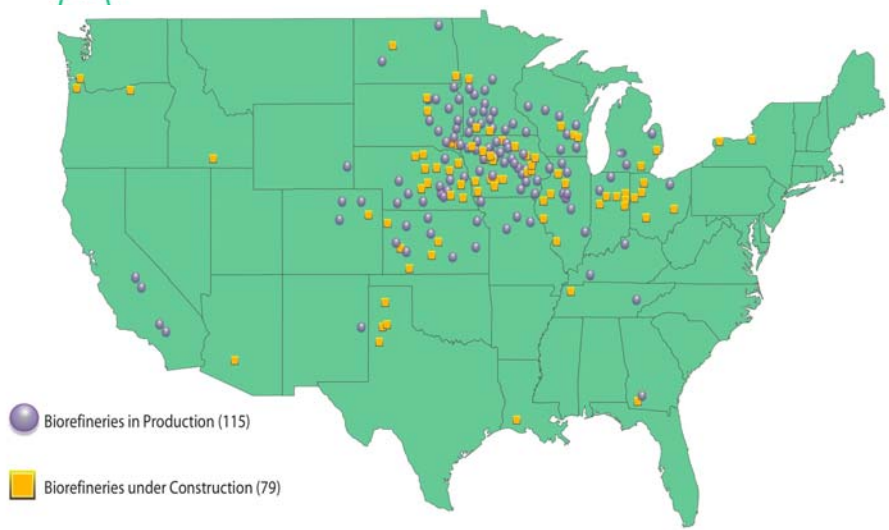
Adapted from Wang *et al*. (2007)

LIHD biomass production potential



LIHD biomass production potential





Conclusions

- Prairie biomass can be produced sustainably on less fertile lands, sparing the best farmland for food production.
- Low-carbon biofuel production is important to outcompeting production of biofuels in areas where native ecosystems are being converted to biofuel production
- Low carbon biofuels provide an opportunity for product branding
- We must recognize and value the ecosystem services that our land can provide
- Farmers, businesses, and the environment can all benefit from low-carbon biofuels