Bioeconomics of Biofuels: Grassland Restoration and Renewable Energy

Stephen Polasky
University of Minnesota
Cedar Creek LTER

The Energy Problem

- How will society meet growing energy demands in a sustainable manner?
- Fossil-fuels currently supply ~80% of world energy demand.

The Problems of Addiction to Fossil-Fuels

- Climate change: carbon emissions from fossil-fuels
- Other environmental impacts (SOx, NOx, particulates…)
- Energy security: large fraction of oil comes from the Middle East
- Supply availability: finite stock
  - US has had declining oil production since the 1970s
- Even with finite supplies, we have more than enough coal to do serious long-lasting environmental damage

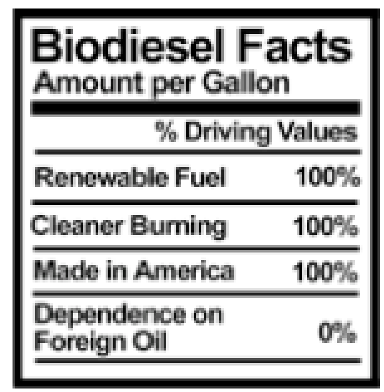
The Energy Problem

- "Sustainable carbon-neutral energy is the most important scientific challenge we face today"
  - – Steven Chu, Director Lawrence Berkeley National Laboratory (9 Feb 2007 *Science*)

Desperately Seeking Alternatives

- To be an attractive alternative, an energy source must be:
- Producible in large quantities
- Environmentally benign
- Cost-competitive

Are Biofuels the Answer?...



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Biofuels as an Alternative

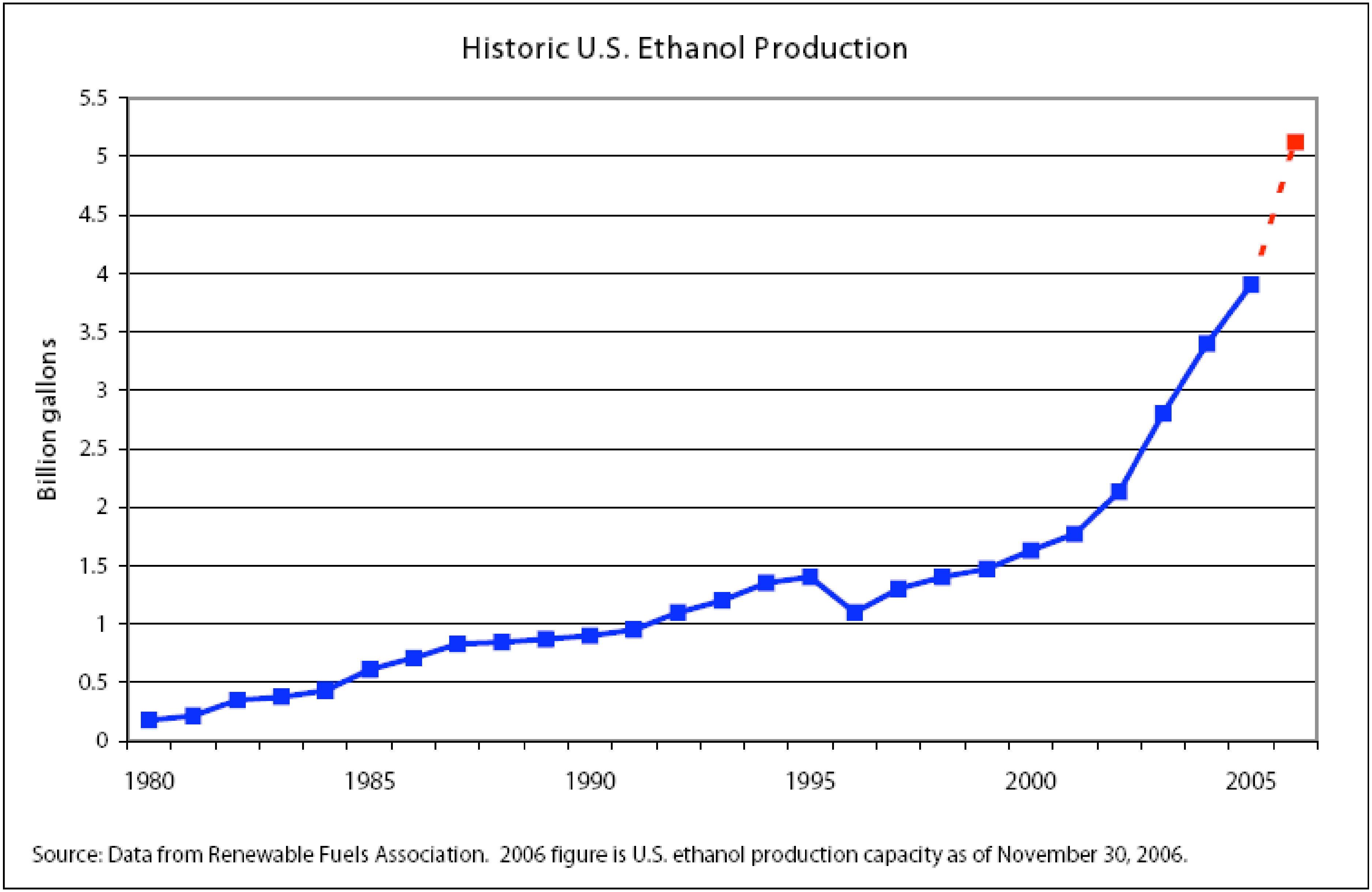
- Biofuels are not THE answer to sustainable energy, but biofuels may be part of the answer
- Biofuels may offer advantages over fossil fuels, but the magnitude of these advantages depends on how a biofuel crop is grown and converted into a usable fuel

Analysis of Alternative Biofuels

- “First generation” biofuels: food-based biofuels that are currently commercially available:
  - Corn-grain ethanol
  - Soy Biodiesel
- “Second generation” biofuels: cellulosic biofuels of the future
  - Diverse prairie biomass

Analysis of First Generation Biofuels

- Hill, Nelson, Tilman, Polasky and Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *PNAS* 103: 11206-11210.
- Comparison of
  - Corn-grain ethanol v. gasoline
  - Soy biodiesel v. diesel
- Criterion:
  - Energy supply
  - Environmental impact
  - Cost



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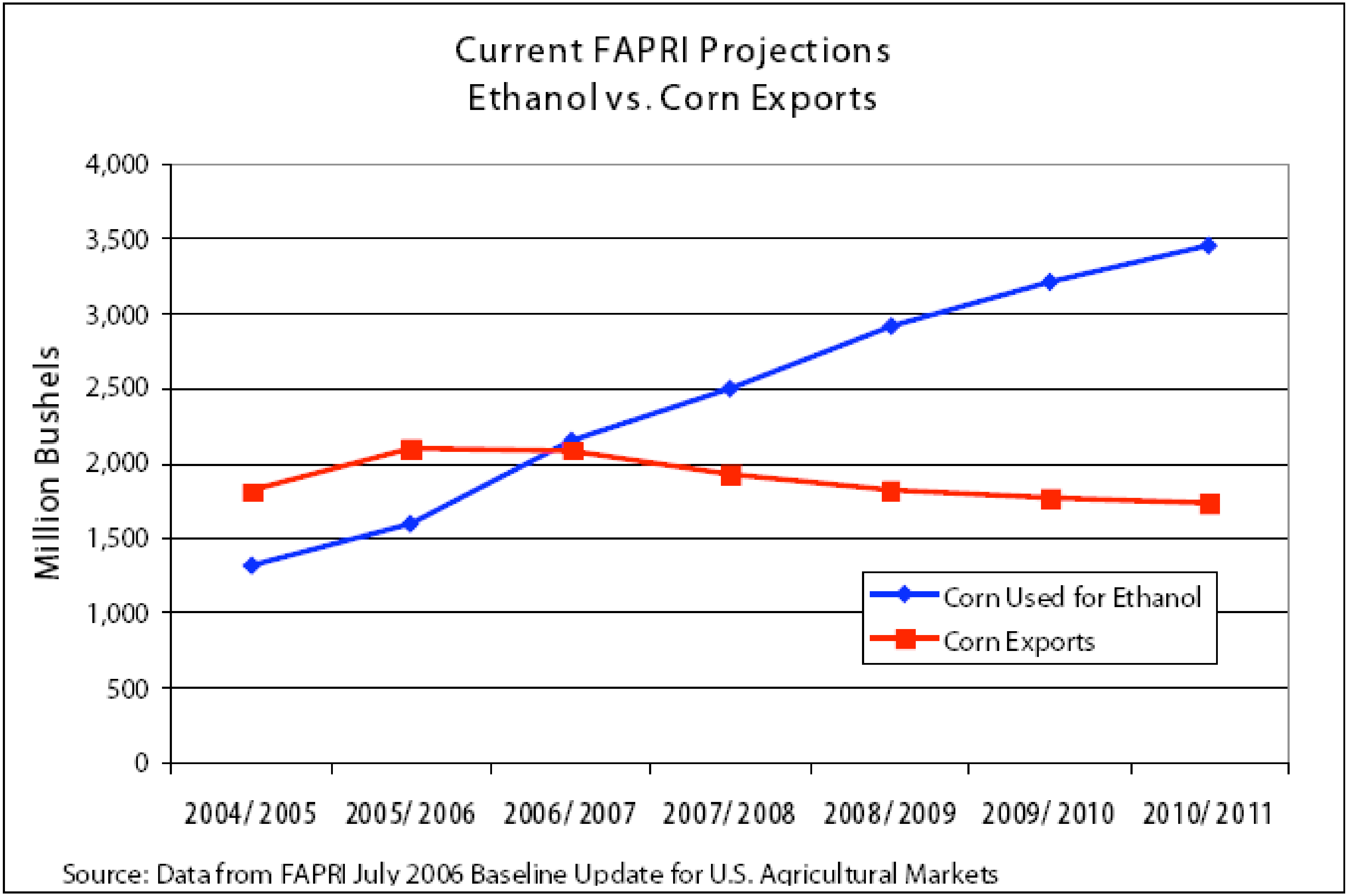

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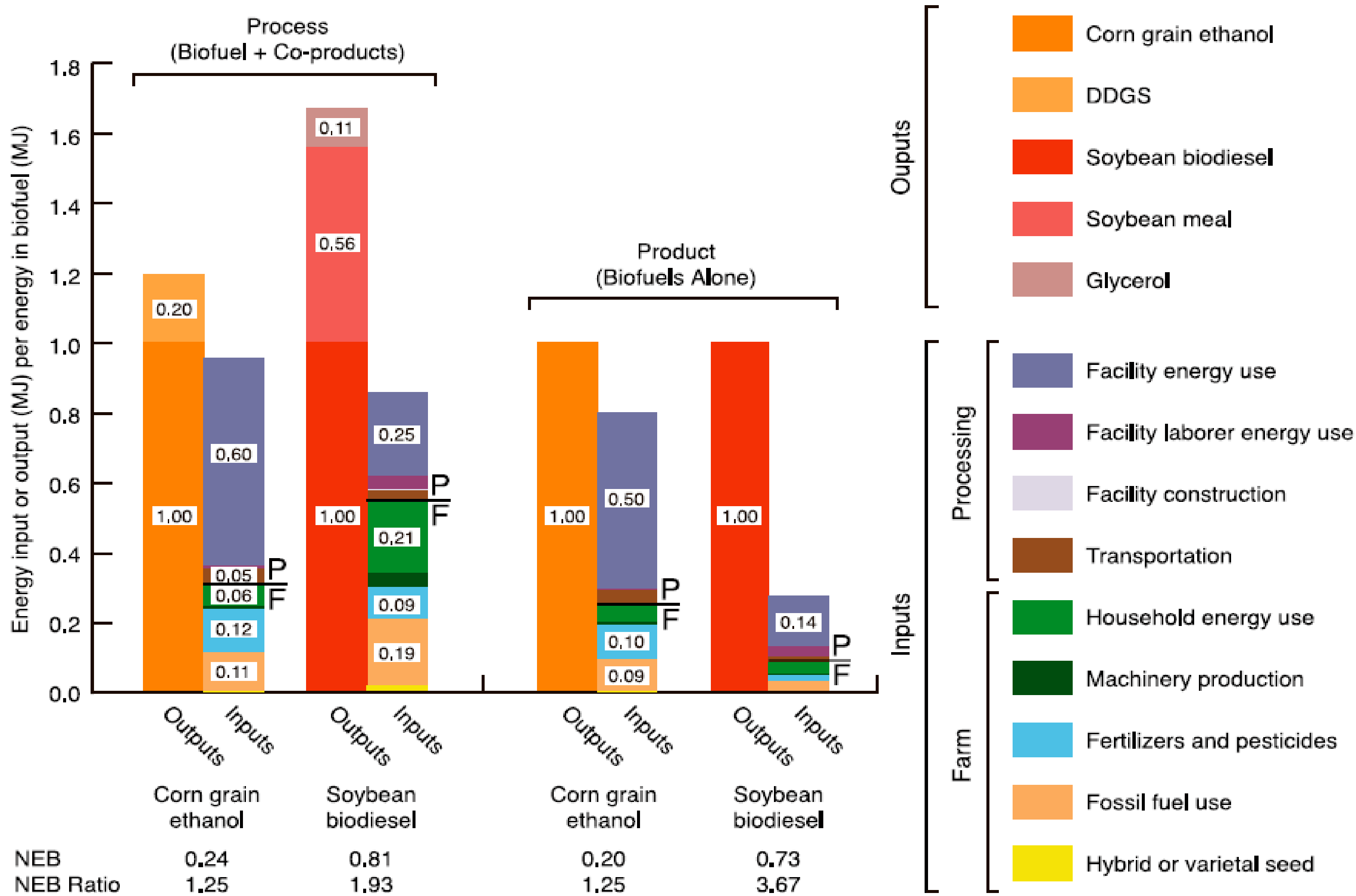
Are Biofuels Net Energy Sources?

- Controversy over whether biofuels are a net energy source or a sink
- Net Energy Balance (NEB): energy output – energy inputs
- Positive NEB means that biofuel is a source: more useful energy output than the energy input to create it

Are Biofuels Net Energy Sources?

- Lifecycle assessment of all energy inputs
  - Energy to grow crops (fertilizer, farm equipment…)
  - Energy to convert crops to biofuel
  - Energy for transportation (crop to production facility, and fuel from production facility to end user)
- Assessment of all energy outputs
  - Energy content of the fuel itself
  - Co-products

Net Energy Balance for Corn Grain Ethanol and Soy Biodiesel



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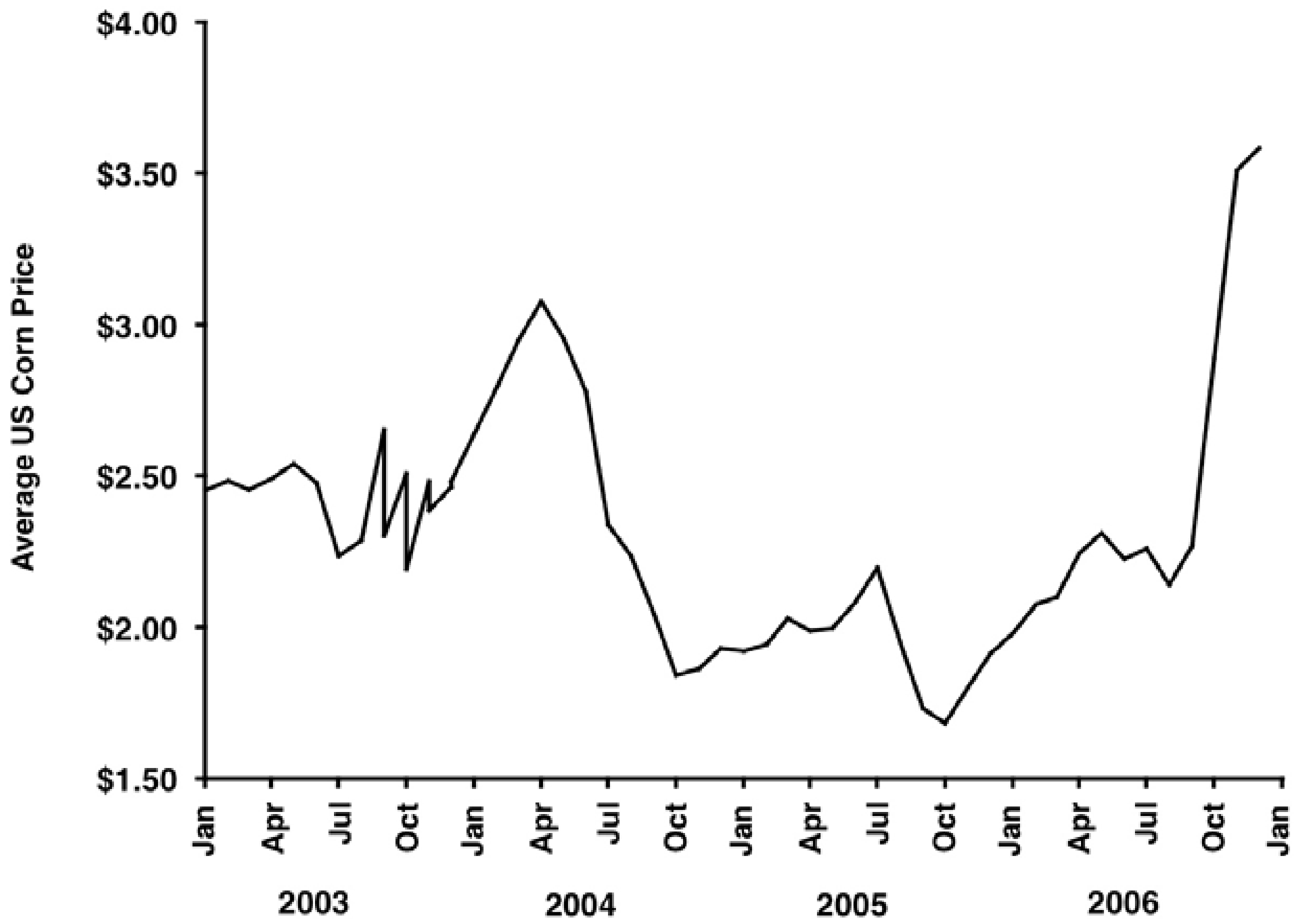
How Much Do They Supply?

- Corn grain ethanol (2005):
  - 14.3% of the US corn harvest was used to produce 1.48×10^{10} L of ethanol annually
  - Energetically equivalent to 1.72% of US gasoline use
- Soy biodiesel (2005)
  - 1.5% of the US soybean harvest produced 2.56×10^{8} L of biodiesel annually
  - 0.09% of US diesel use

But How Much Could They Supply?

- Devoting all US corn and soybean production to biodiesel and ethanol would generate:
  - 12% of US gasoline consumption
  - 6% of US diesel consumption
- In terms of net energy gain:
  - 2.4% of US gasoline consumption
  - 2.9% of US diesel consumption

Food vs. Fuel: Impact on Corn Prices



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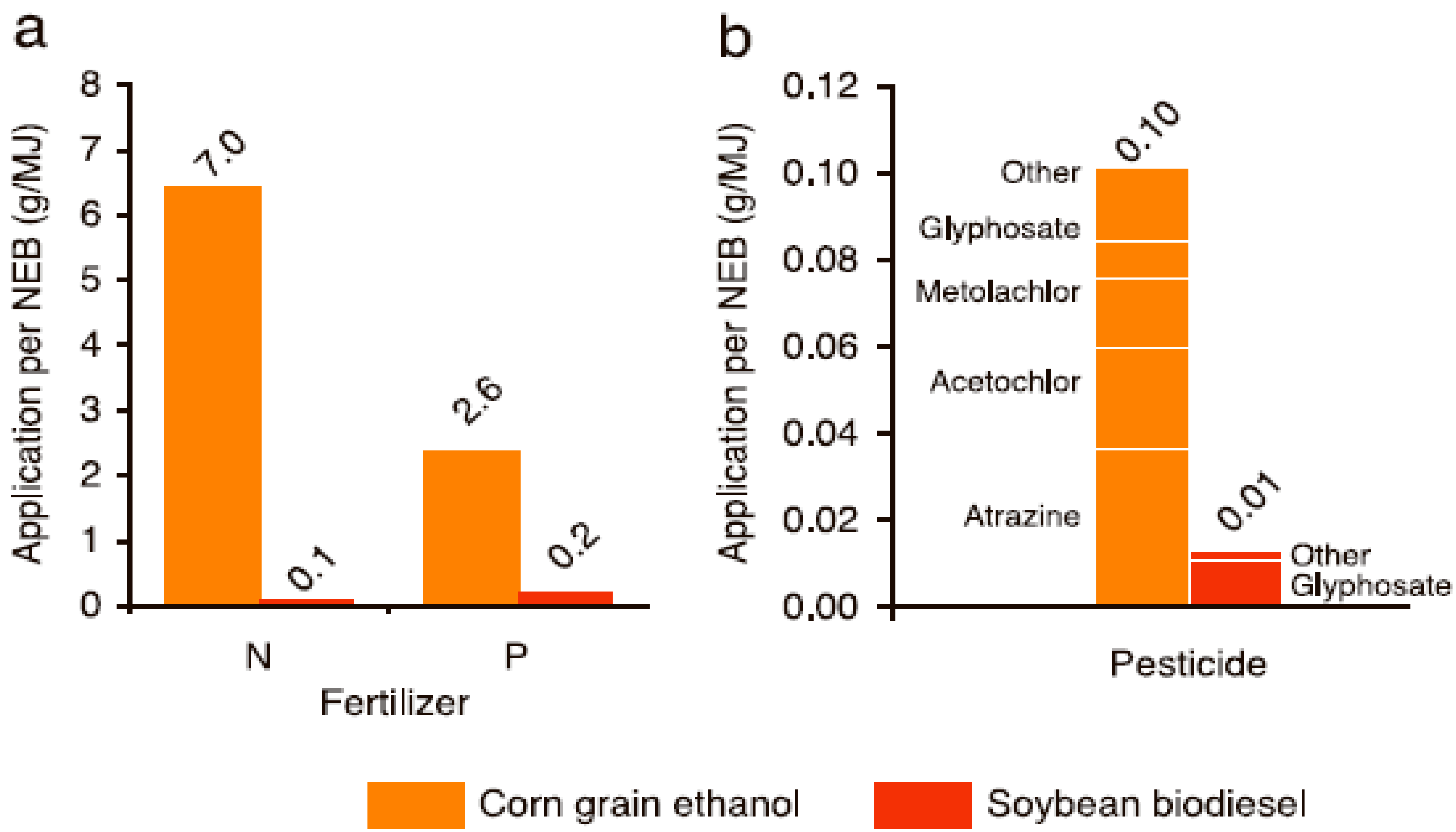
Ethanol Demand and Corn Prices

- Large increase in demand for corn for ethanol production
  - Production capacity over 5 billion gallons
  - Projected to increase to over 9 billion gallons with current plants under construction
- Corn prices in January 2007 topped $4/bushel
- Price has doubled since early 2006

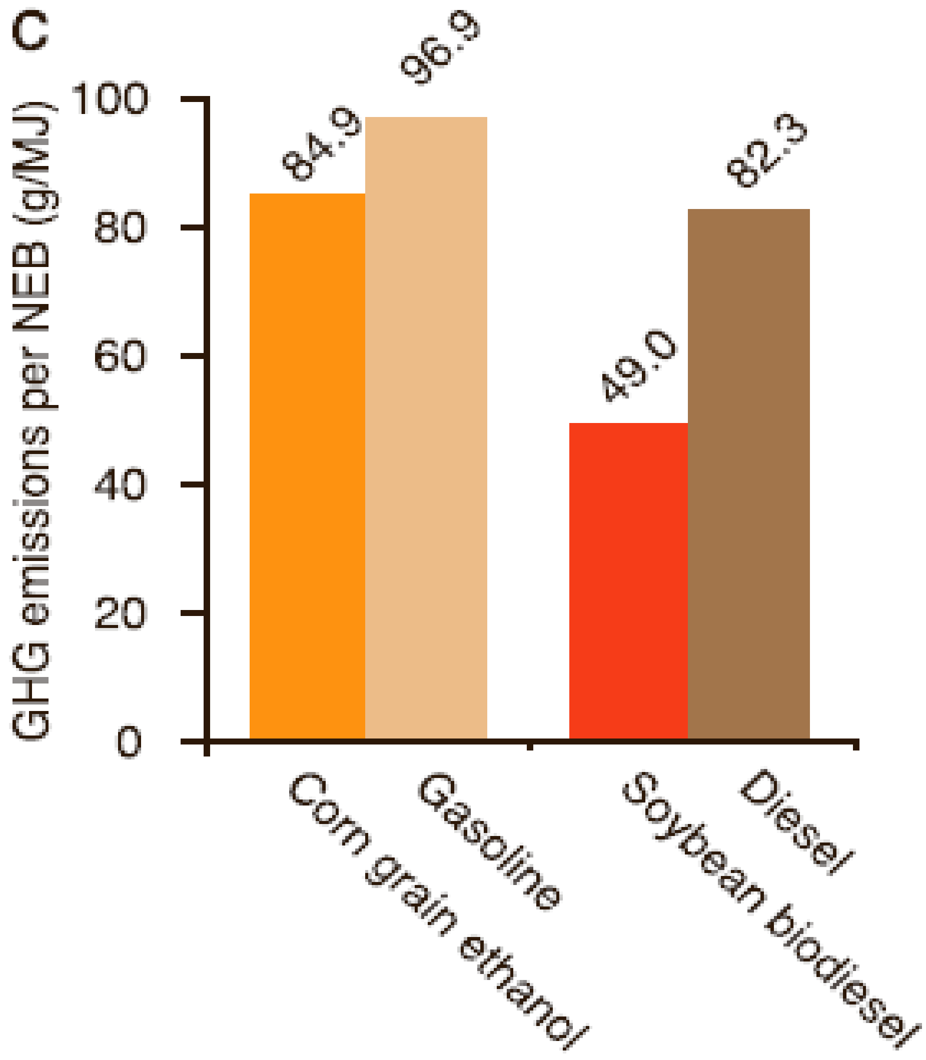
Environmental Consequences

- At first glance, we might think that biofuels are environmentally friendly
- Is this correct?
- It depends on how biofuels are produced

Environmental Consequences per Unit Energy



Greenhouse Gas Emissions per Unit Energy



Environmental Consequences per Unit Energy

- All else equal, an NEB > 1 should mean lower CO_2 emissions (replace fossil fuel use)
- But: increased N_20 and methane emissions from crop production
- Lifecycle greenhouse gas emissions
  – Ethanol: 88% of gasoline
  – Soy biodiesel: 59% of diesel

Are Biofuels Cost Competitive?

- In 2005, neither biofuel was cost-competitive with petroleum – but as petroleum prices increased the gap closed
- Ethanol:
  - Estimated ethanol production cost in 2005 was \$0.46 per gasoline energy equivalent L
  - Wholesale gasoline prices averaged \$0.44/L in 2005
- Soy biodiesel
  - Estimated soybean biodiesel production cost in 2005 was \$0.55 per diesel EEL,
  - Diesel wholesale prices averaged \$0.46/L in 2005
- Recent price effects unfavorable for biofuels:
  - Lower fossil-fuel prices
  - Higher corn prices

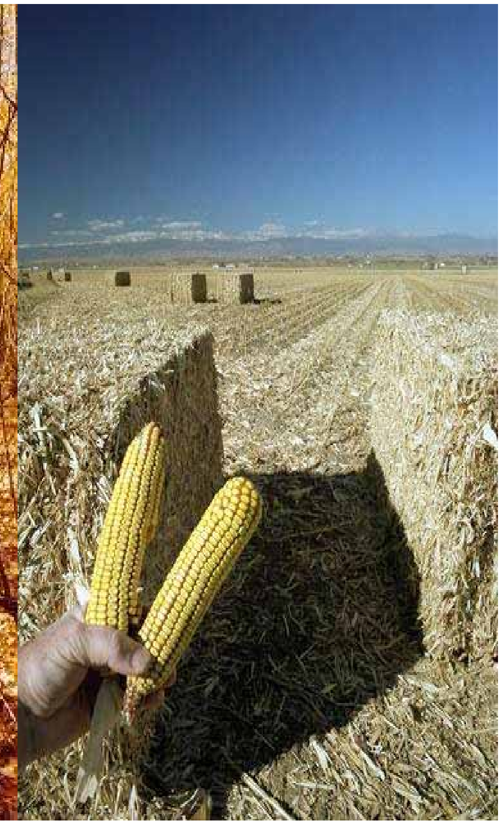
Are Biofuels Profitable?

- Though not cost competitive, biofuels can be profitable given subsidies (and are profitable given subsidies and current high oil prices)
- Federal government provides subsidies of
  - $0.20 per EEL for ethanol
  - $0.29 per EEL for biodiesel
- Demand, especially for ethanol, generated by laws or regulations mandating blending of a biofuel with petroleum
- Ethanol and biodiesel producers also benefit from federal corn and soybean subsidies
  - Corn prices are approximately half of ethanol production's operating costs

Summary

- Corn grain ethanol and soy biodiesel can make up only a small portion of fuel supply
- Subsidize environmentally friendly biofuels
  - Subsidy for corn grain ethanol does not appear justified
  - Subsidy for soy biodiesel may be justified
- Should look to other sources

Second Generation Biofuels: Cellulosic Feedstock…



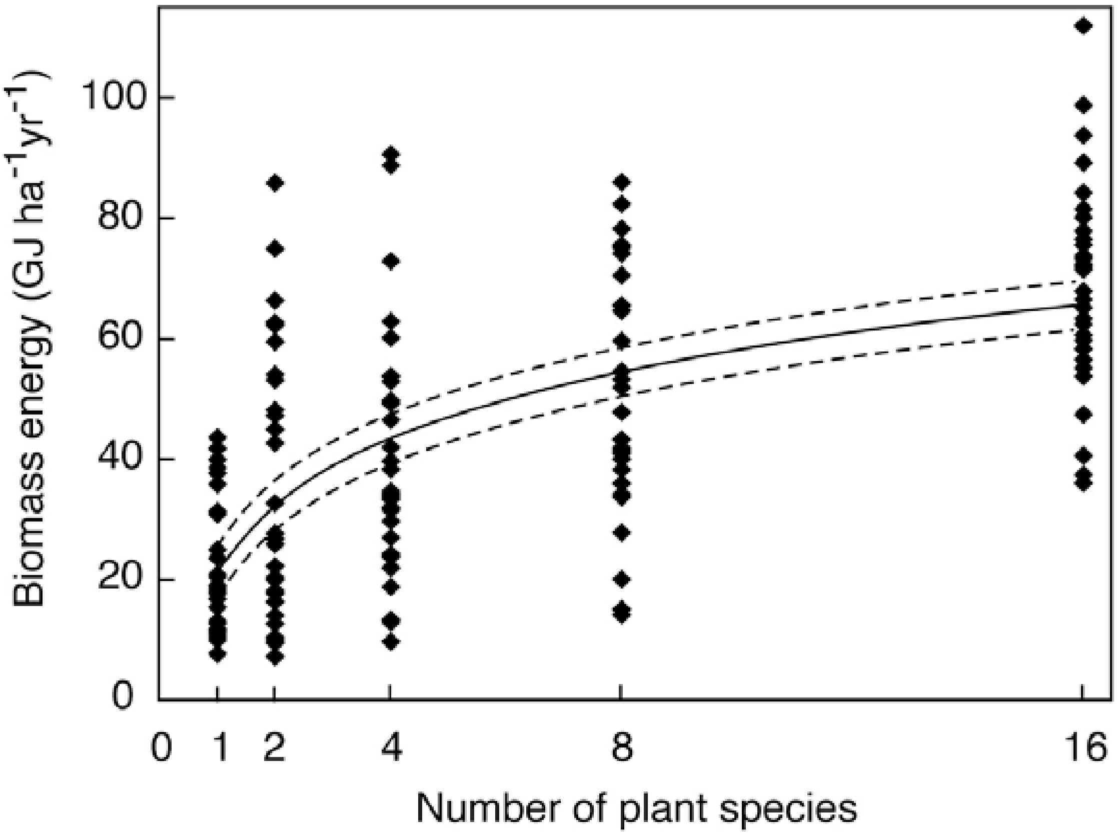
Switchgrass Wheat Straw Hybrid Poplar Corn Stalks

Analysis of a Second Generation Biofuel: Energy from Prairie Grasses

- Tilman, Hill and Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314: 1598-1600.

Cedar Creek Biodiversity Experiment...

More Diverse Plots Yield More Biomass Energy



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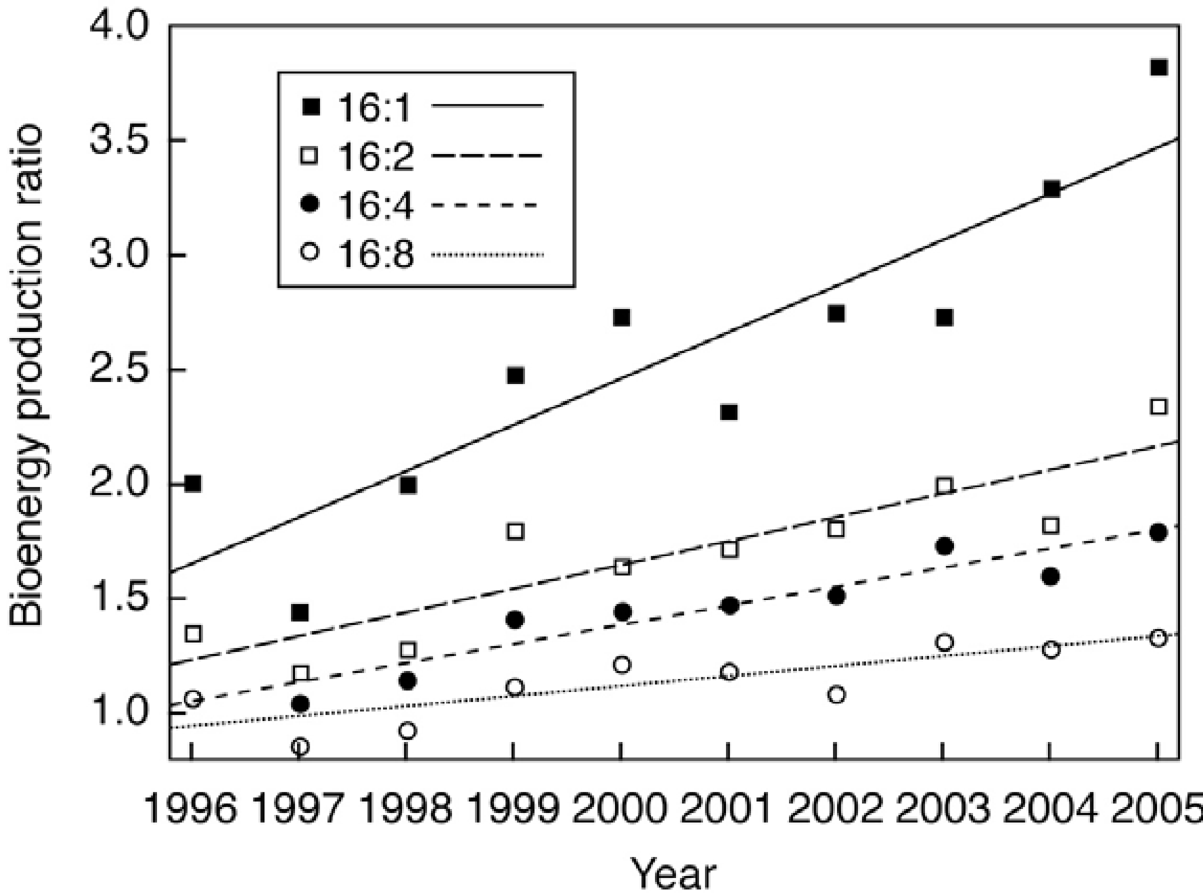
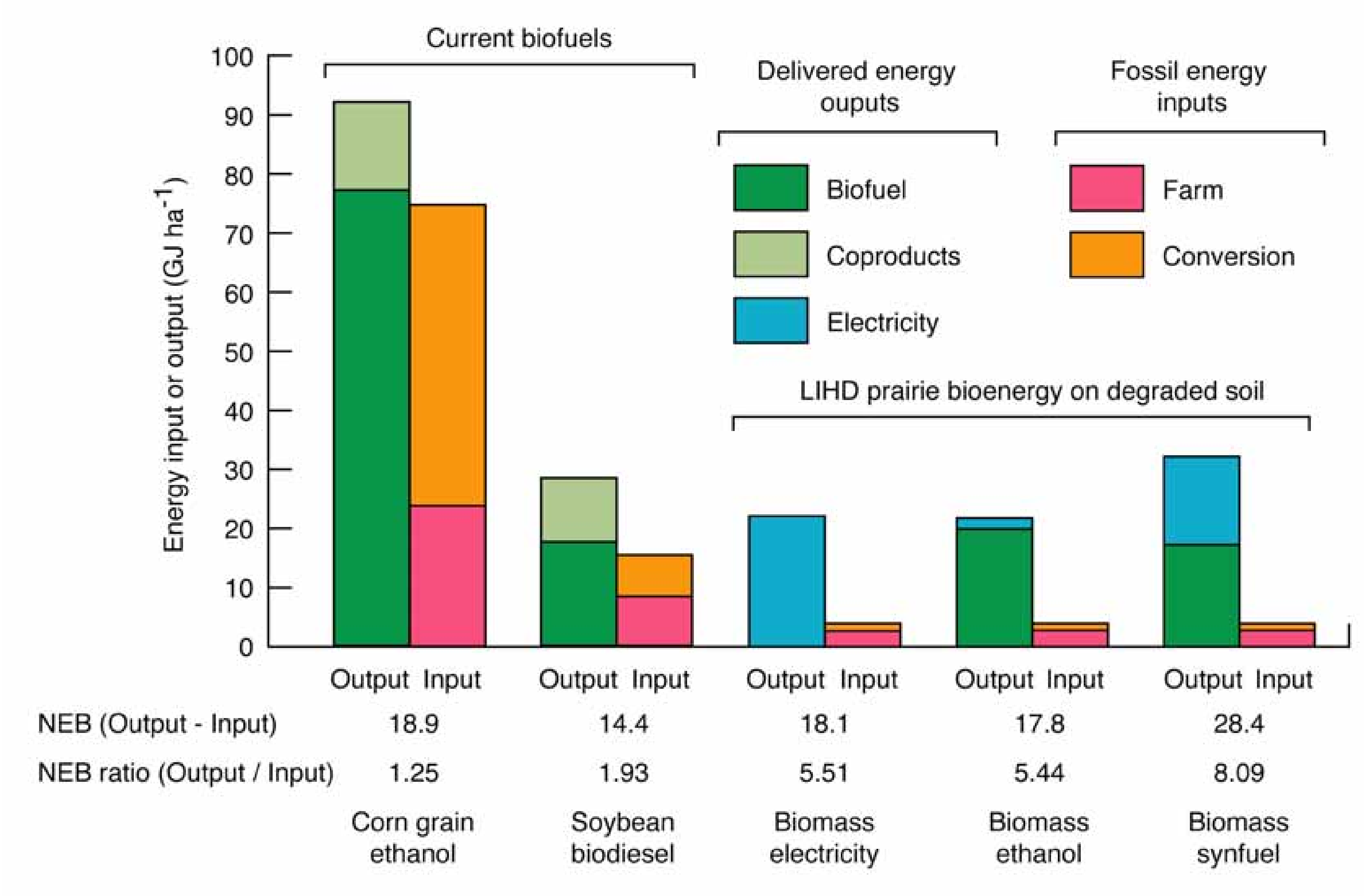
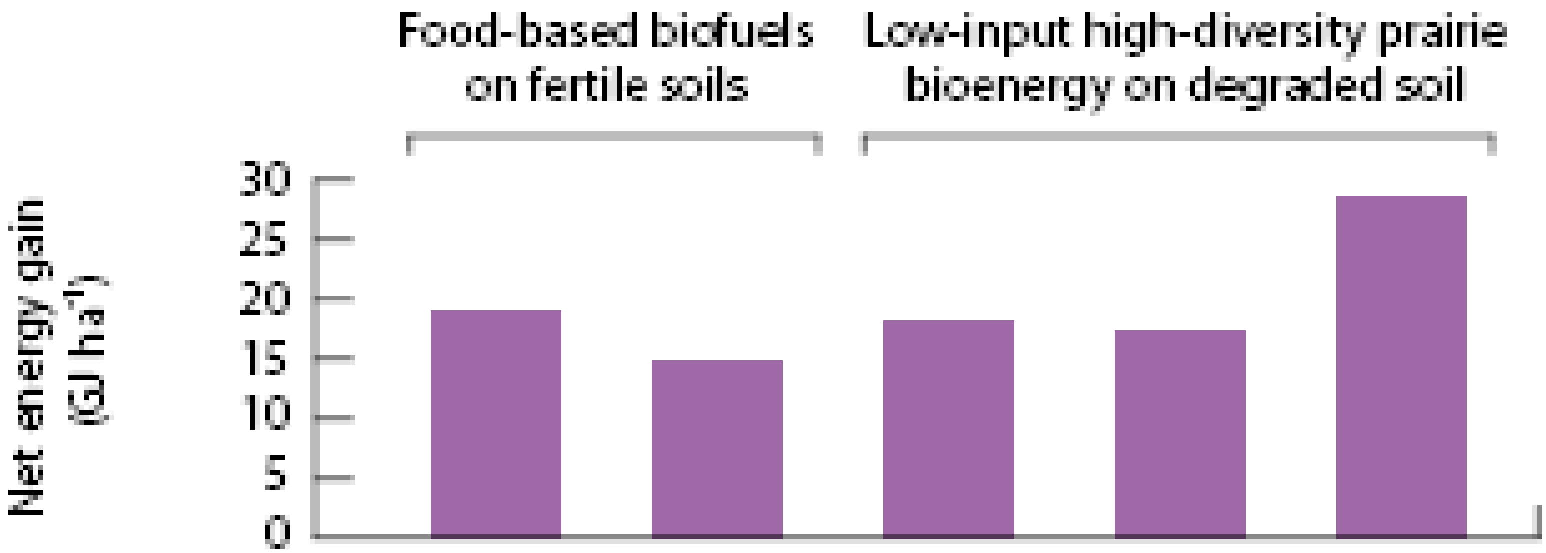
More Diverse Plots Become Increasingly Productive



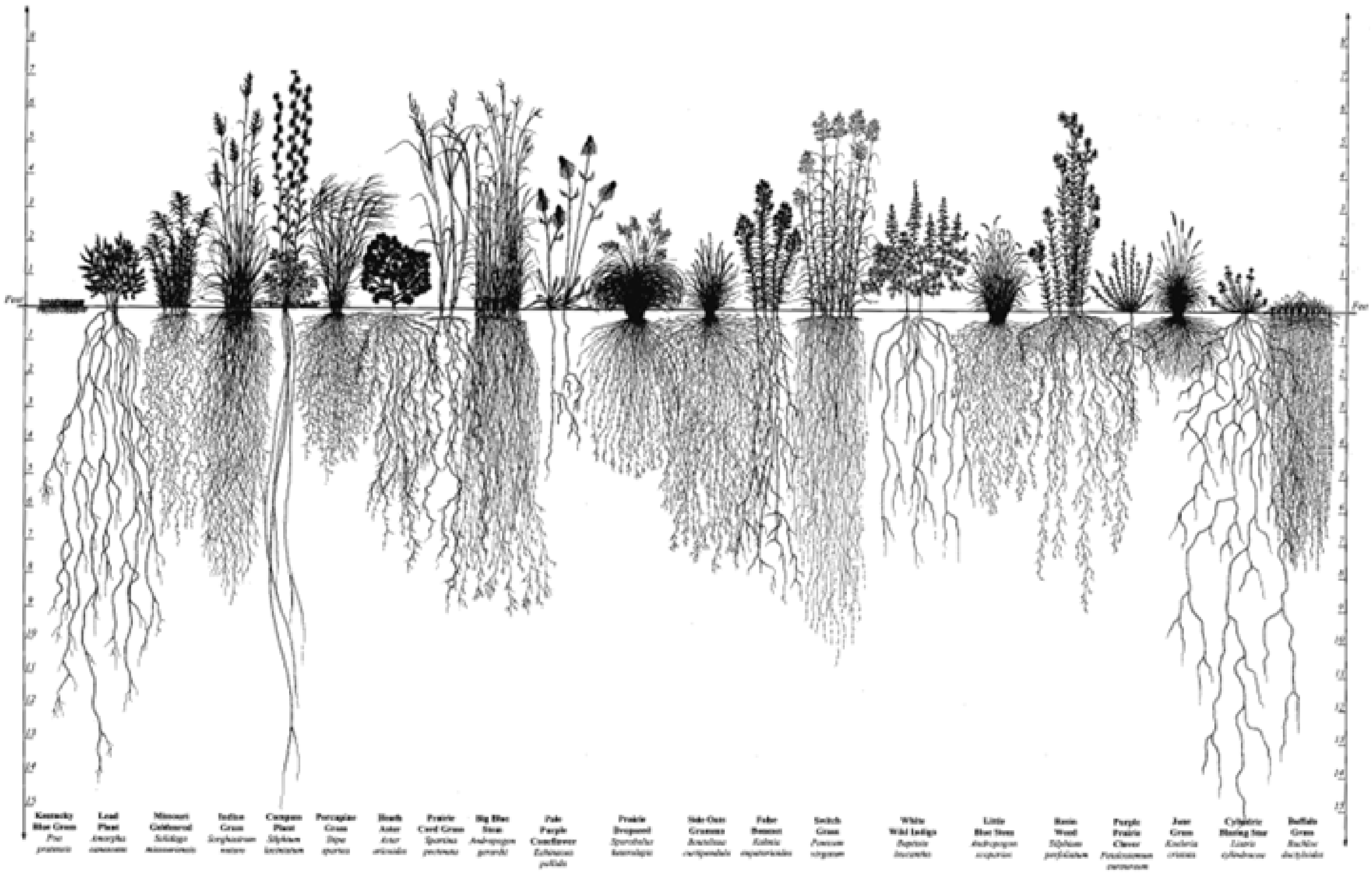
Energy Input and Output: First and Second Generation Biofuels



Net Energy Per Hectare



2/3 of the Prairie is Below Ground



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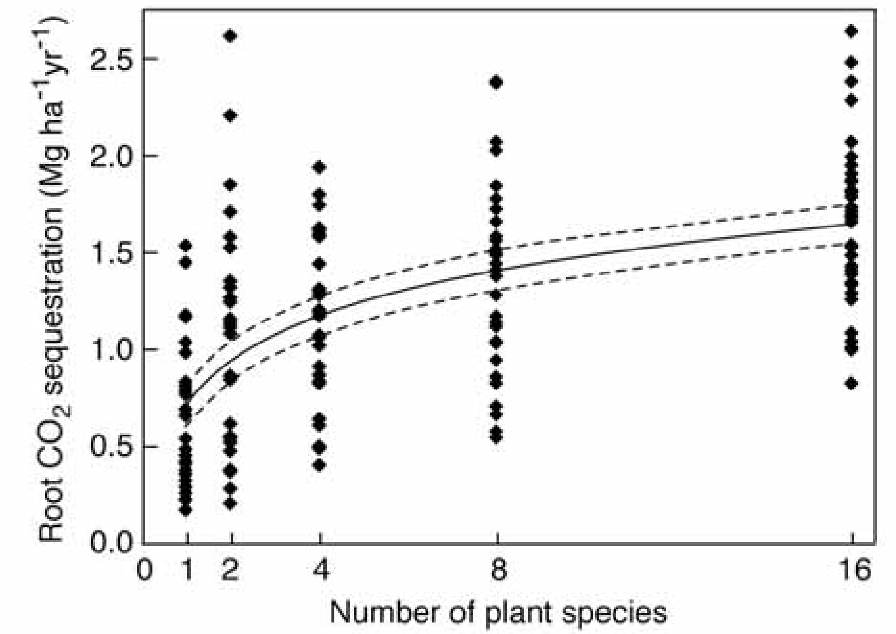
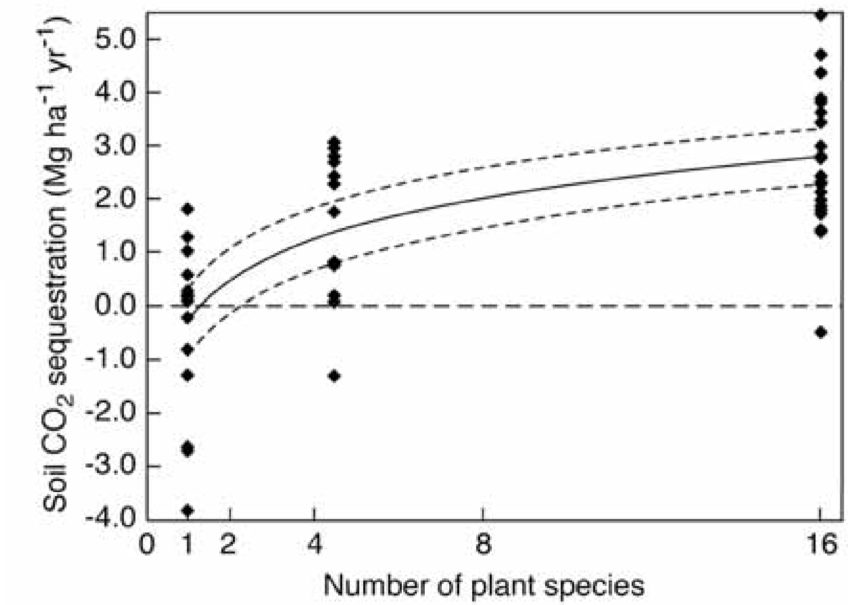
Carbon Storage





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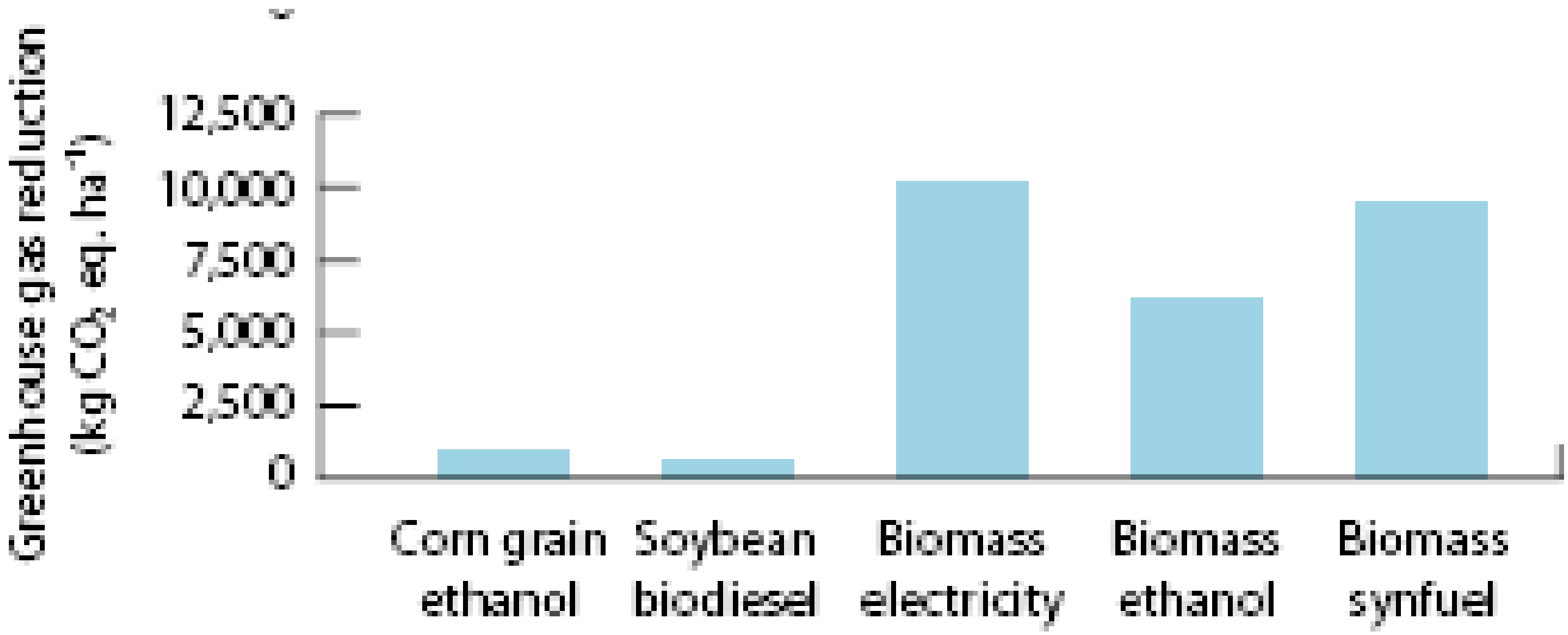
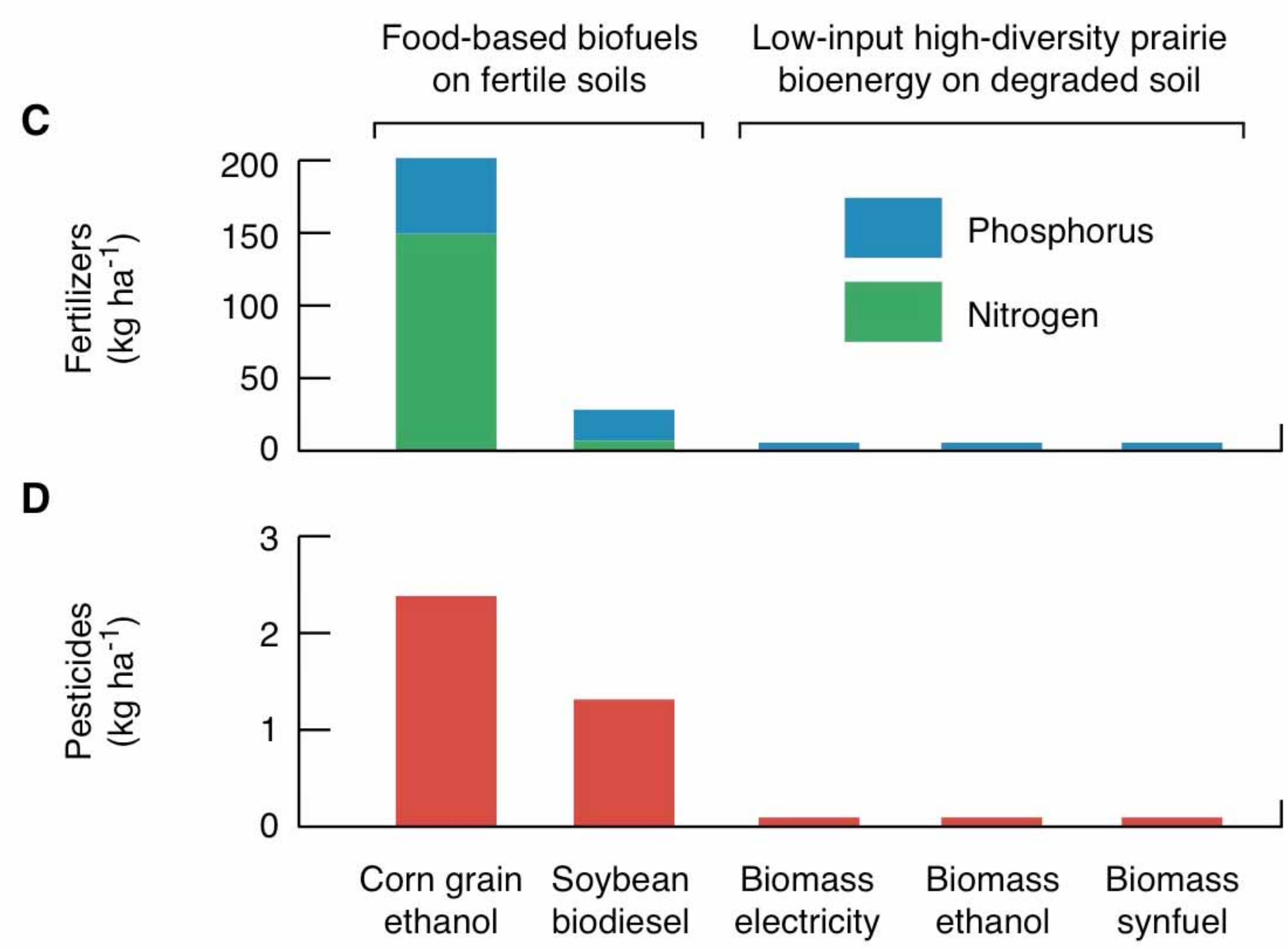
Greenhouse Gas Reduction From Biomass Energy to Replace Fossil-Fuel Consumption



Nutrient Input

kg ha^{-1} yr^{-1}	Corn	LIHD Prairie
N	148	0
P	23	4
K	50	6

Comparing Current and Future Biofuels



Summary: Benefits of Low-Input High-Diversity Grassland Biomass

- Producible on degraded agricultural lands
  - Reduce competition with food production
  - Can be done in a manner consistent with environmental values (cropping in the fall after bird fledging…)
- Carbon-negative fuel when produced on degraded lands
- Low inputs – low export of nutrients
- More net energy gain per acre than food based-biofuels

Summary: Open Questions

- Economics: is it cost-competitive?
- Technology: turning lignocellulosic biomass into hydrocarbon fuel presents significant challenges
  - But electricity production can be accomplished with existing technology

Conclusions…

- Current food- and feed-based biofuels can meet but a small portion of transportation energy needs and do so at great environmental cost
- Next generation lignocellulosic biofuels from waste and prairie grasses have distinct advantages over current biofuels

Final Thought

- "Agriculturalists are the *de facto* managers of the most productive lands on Earth. Sustainable agriculture will require that society appropriately rewards ranchers, farmers and other agriculturalists for the production of both food and ecosystem services." (Tilman et al. Nature 2003)

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