

Environmental Implications and Tradeoffs of Biobased Production

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Current status of bioproducts

	Corn	Soybean	Sugarcane, Sugarbeets	Cellulosic Material trees, grasses, crop residue	Starchy crops	Seeds sunflower, rape, safflower	New Crops Kenaf, cuphea, milkweed, sorghum	Algae	Food wastes	Animal byproducts manure, tallow, cheese whey
Energy										
Ethanol	●		●	▲	▲		▲		▲	
Biodiesel		●						▲	▲	
Other (gaseous, H ₂ , direct combustion)	▲	▲	▲	▲ ●	▲		■	■	■	▲ ●
Materials										
Aggregates for construction				▲		■	■			
solvents/inks/paints		●				■				
plastics/polymers	●				▲				▲	
lubricants		●				●		▲		▲
specialty chemicals		▲		■	▲		▲	■		▲

● Currently in production ▲ Active research area ■ Potential exists for further development

Major Associated Impacts

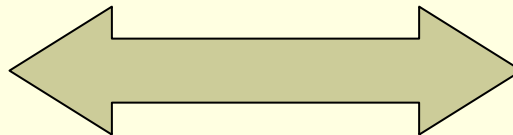
Fossil Fuels

Greenhouse Gas Emissions,
Fossil Fuel Depletion

Bioproducts

Eutrophication (N,P),
Land Use

Human Health, Acid Deposition, Smog Formation



What's been done to assess the environmental impact of bioproducts?



studies:	bio-product	Environmental impacts included						
		GW	FF	EH	HH	H ₂ O	EQ	LU
Akiyama (2003)	PHA	X	X					X
Dornburg (2003)	Polymers	X	X					X
Fu (2003)	Ethanol	X	X	X	X		X	
Gemgross (2000)	PHA, PLA	X	X					
Jungmeier (2001)	Bioenergy	X	X					X
Kadam (2002)	Ethanol	X	X	X	X		X	
Kim (2005 a)	Ethanol	X	X					
Kim (2005 b)	PHA	X	X	X	X		X	
Kurdikar (2000)	PHA	X						
Lynd (1996)	Ethanol	X	X		X*			
Lynd (2003)	PHA, ethanol		X					
McManus (2003)	Biolubricant	X	X	X	X		X	
Patel (1999)	biofuels & surfactants	X	X					
Shapouri (2002)	Ethanol		X					
Sheehan (1998)	Biodiesel	X	X		X	X	X	
Sheehan (2002)	Ethanol	X	X		X		X	
Sheehan (2003)	Ethanol	X	X		X		X	X
Slater (2002)	PHA, PLA	X	X					
van den Broek (2001)	bioenergy	X	X	X	X		X	
Vink (2003)	PLA	X	X			X		

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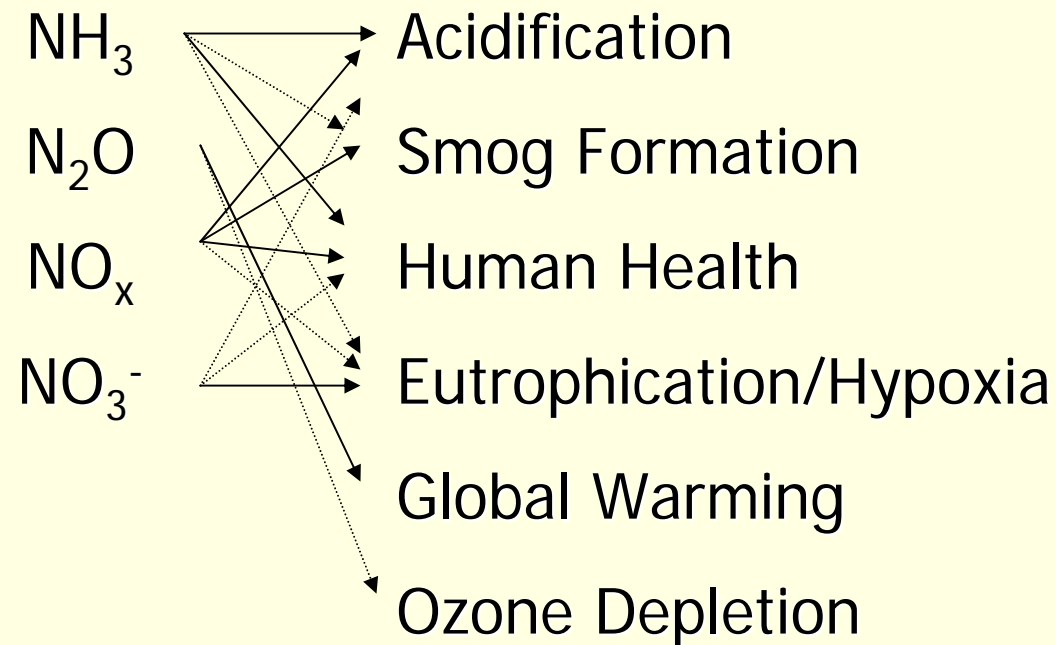


Disruptions in C and N Cycles

- CO₂ concentrations increased $31 \pm 4\%$ since 1750
- N₂O concentrations increased ~15%
- Flux of atmospheric N₂ to reactive nitrogen compounds has increased over 1100%
 - Nitrogen Cascade

Nitrogen-related Impacts

- Excess reactive nitrogen responsible for many environmental problems

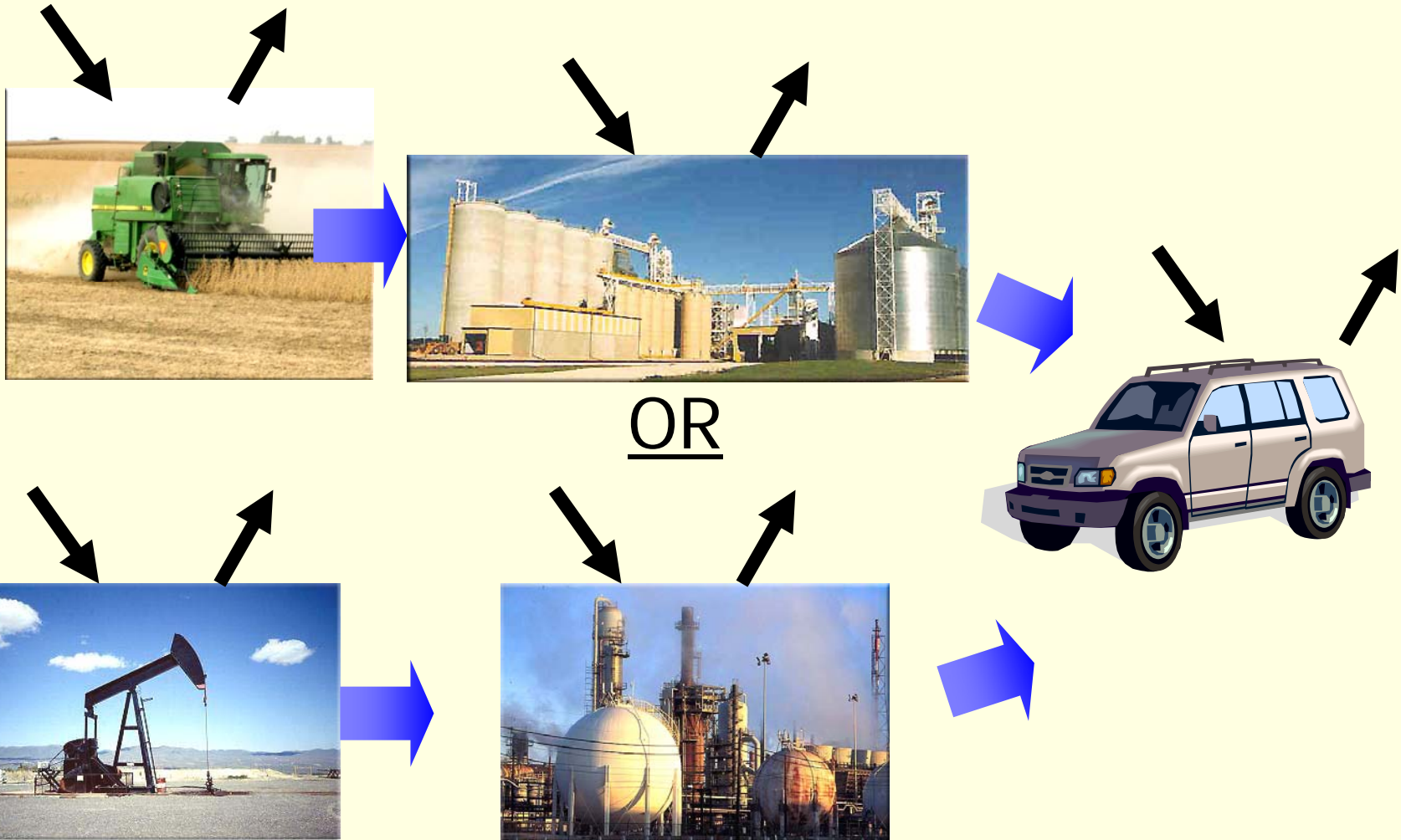




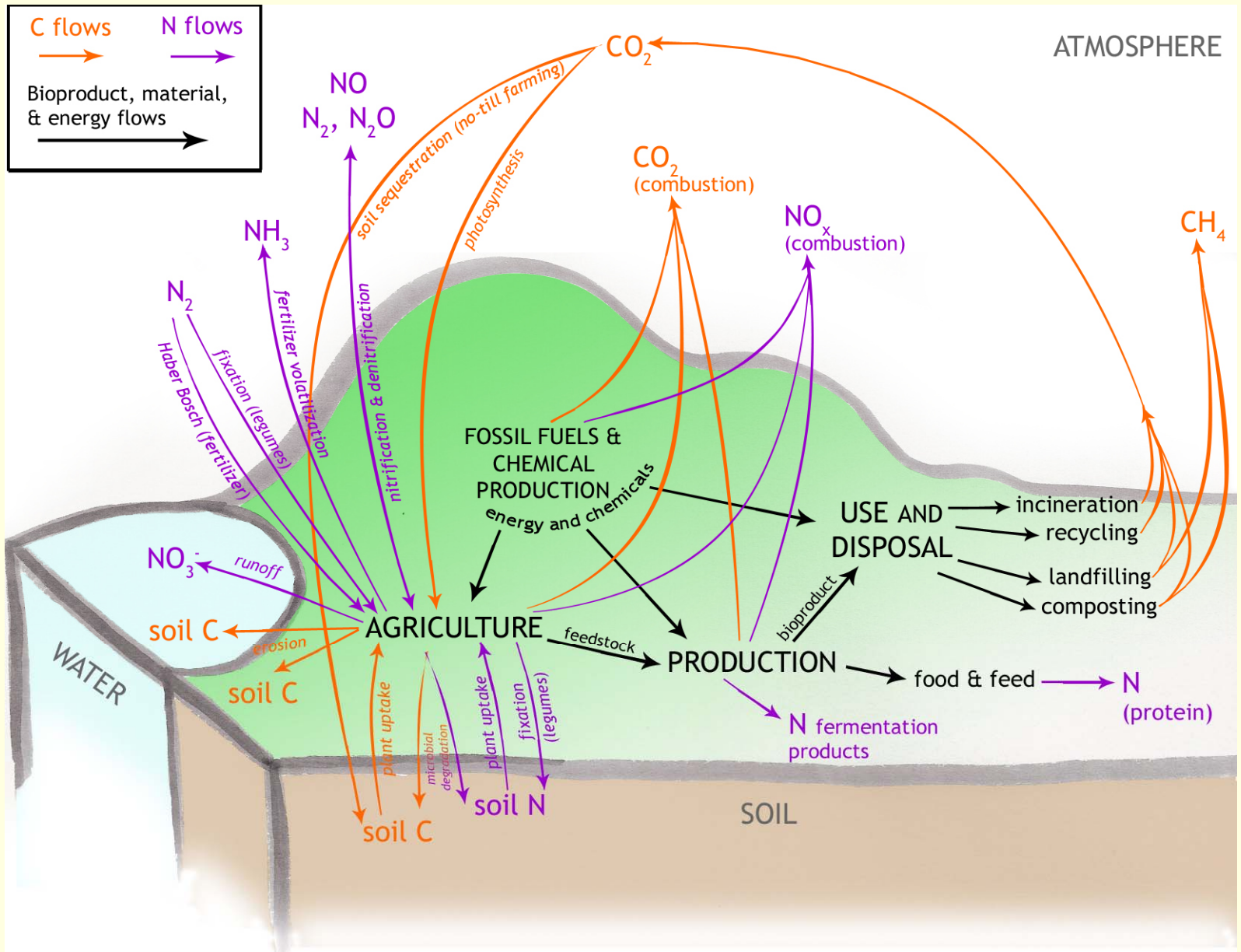
Disruptions in C and N Cycles

- Fossil fuel combustion responsible for majority of carbon cycle disruption
- Agricultural activities are responsible for ~75% of nitrogen cycle disruption
 - Haber-Bosch process
 - Increased cultivation of rice, soybeans (biological nitrogen fixation)
- C & N cycles in agriculture are highly linked

Life Cycle Approach



Life cycle carbon and nitrogen fluxes for bio-based products

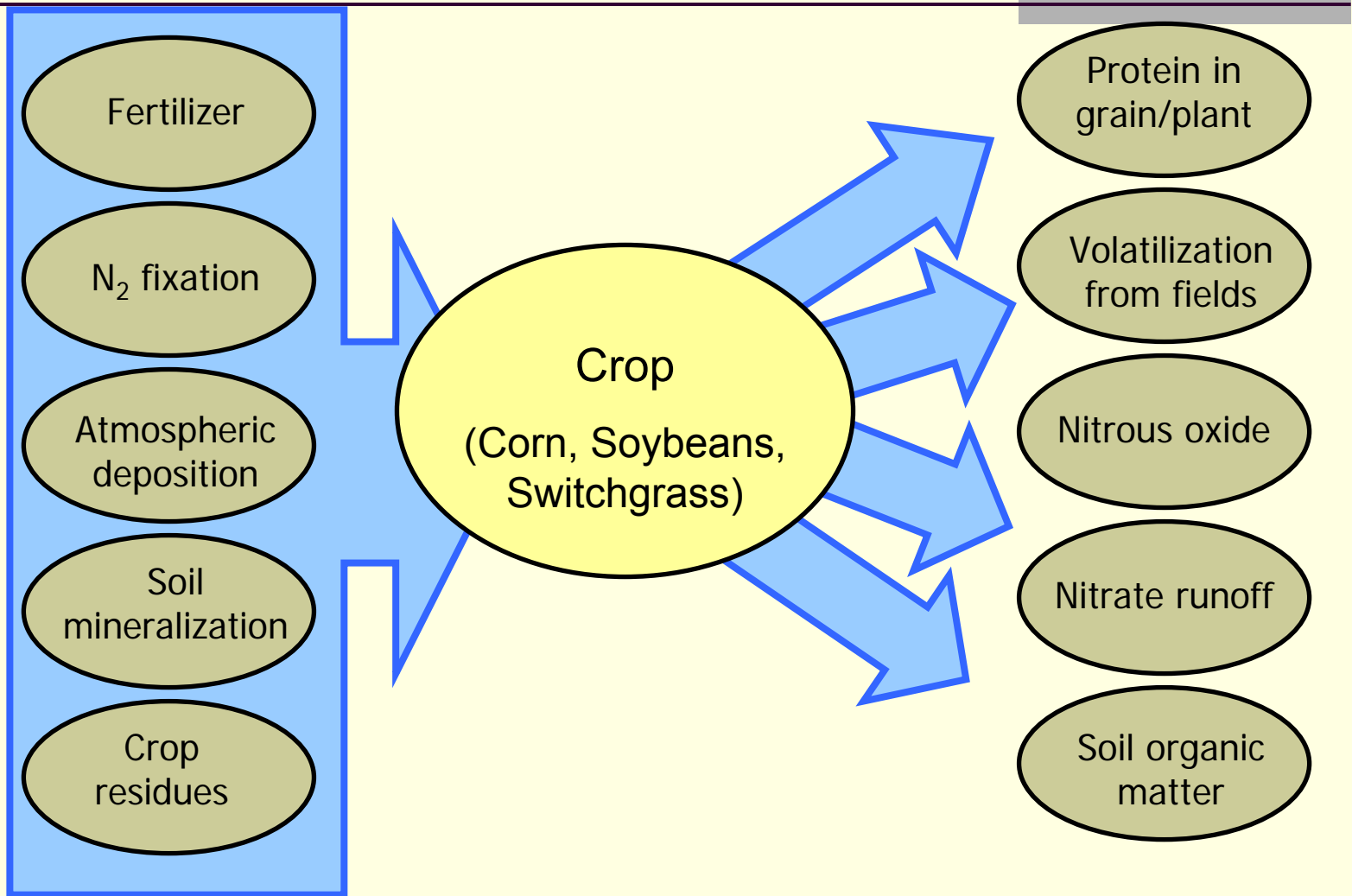




Generalized LCA Results

- Bio-based products have...
 - Reduced fossil energy consumption
 - Reduced CO₂ emissions
 - Significant NO₃⁻ emissions (not found in fossil fuel counterparts)
 - Greater disruptions of N cycle
 - Highly variable, difficult to measure, highly complex models
 - Generally not included

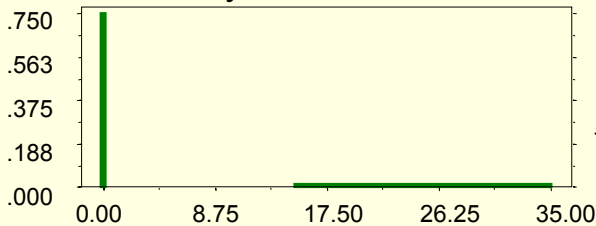
Linear Fractionation Model



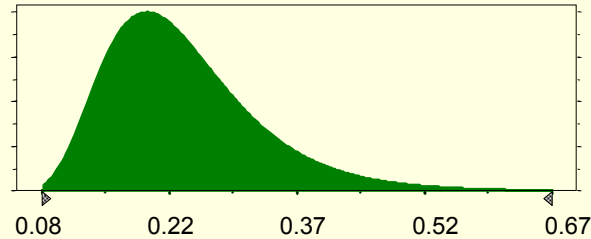
Nitrate example

$$N_{\text{NO}_3,s} = N_{f,s} \cdot f_{\text{NO}_3,s} + N_{\text{min}} \cdot f_{\text{NO}_3,s}$$

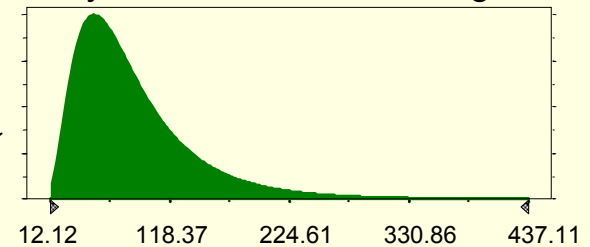
Soybean Fertilizer



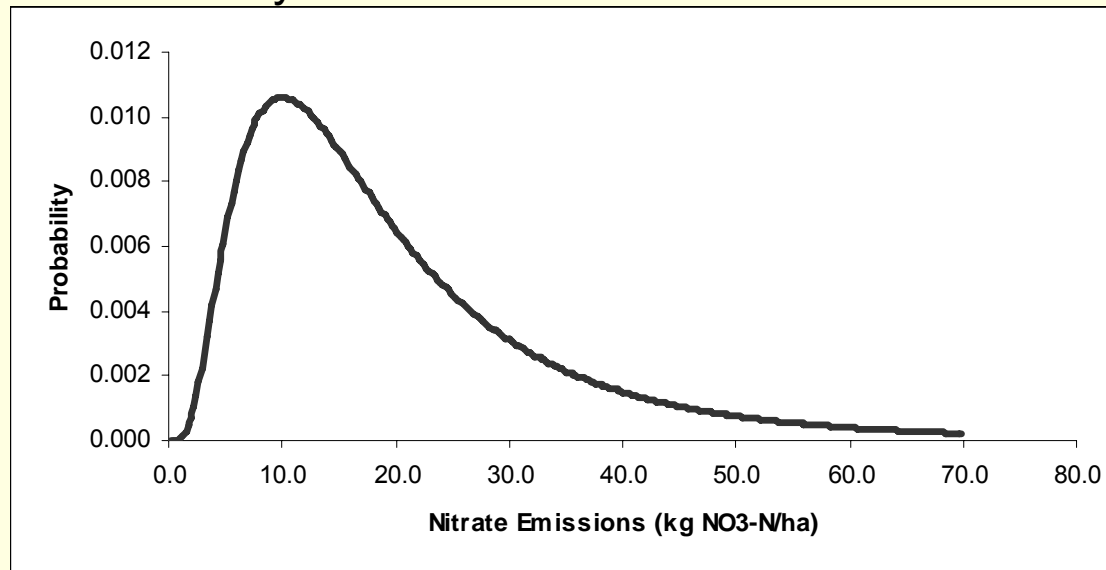
fraction mineralization to nitrate



Soybean mineralized nitrogen

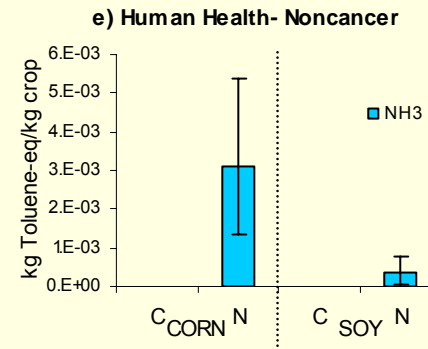
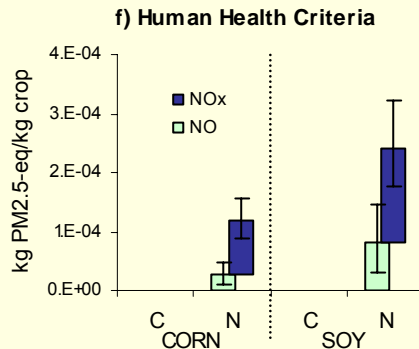
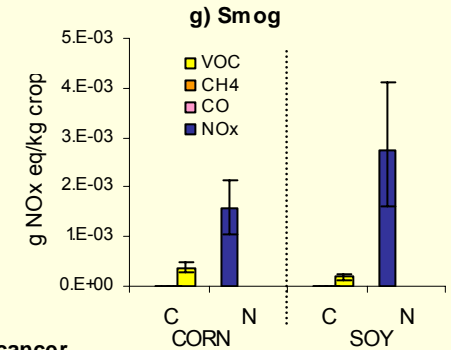
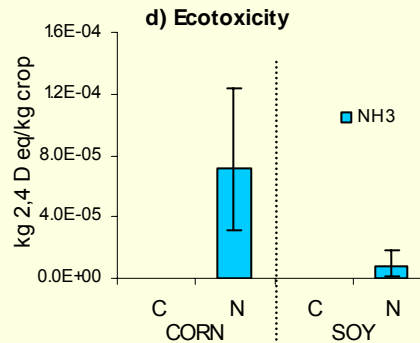
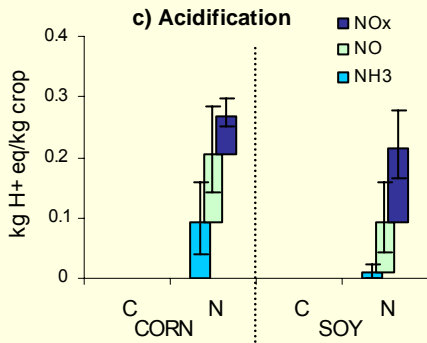
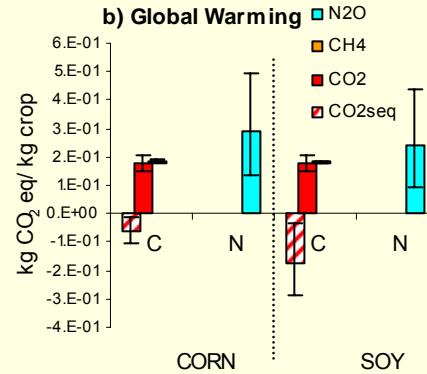
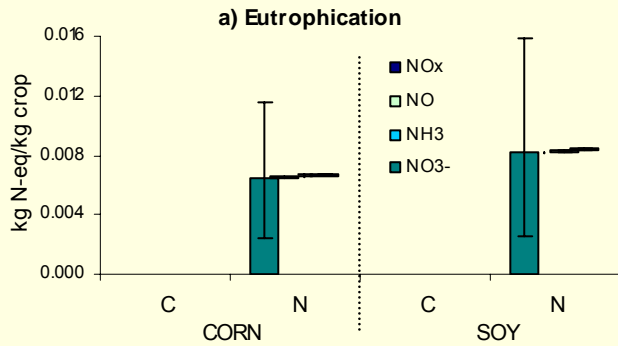


Soybean Nitrate Emissions



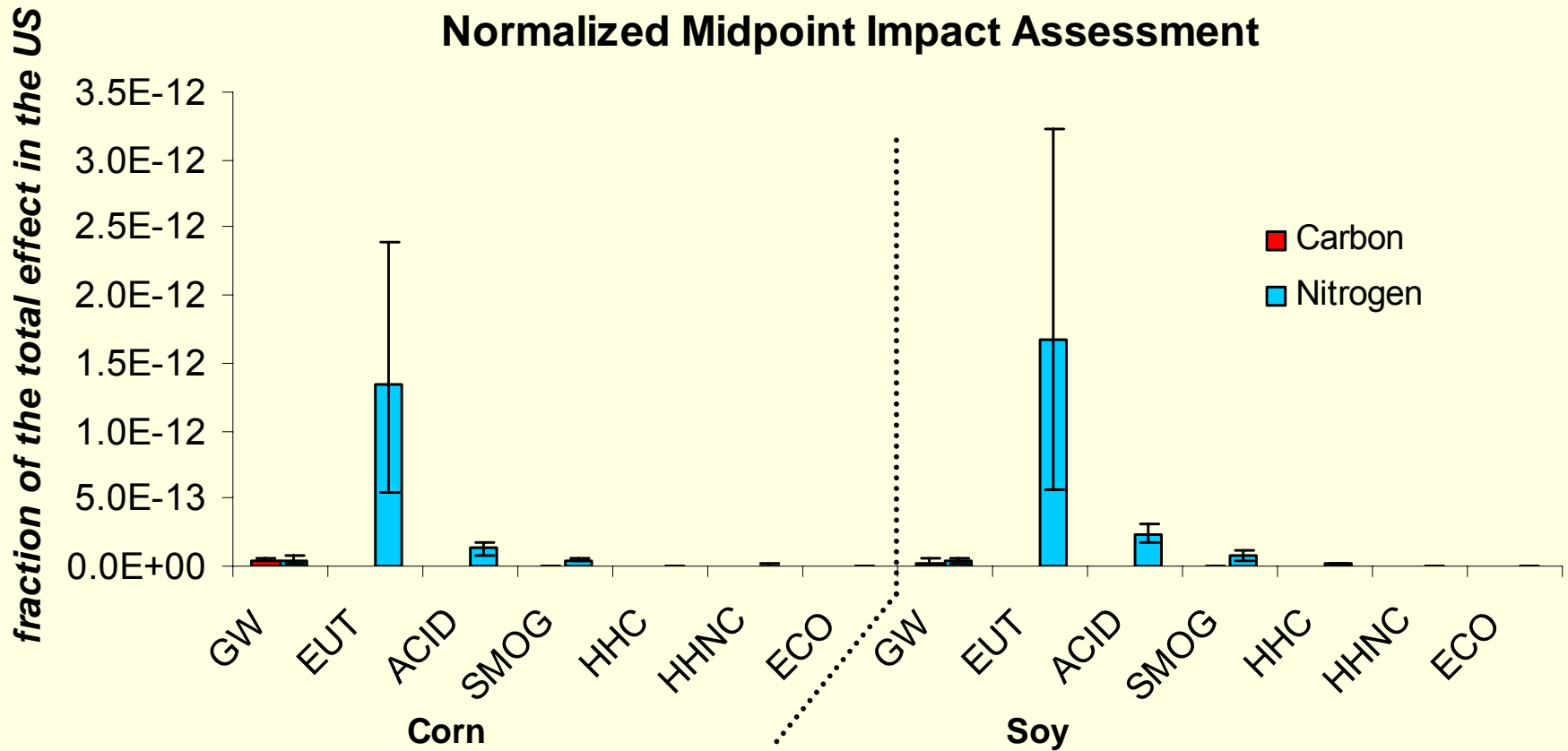
Agricultural Impacts

- NH3
- NOx
- NO
- P
- NO3-
- N2O
- CO2
- CO
- CH4
- VOC



From Landis et al 2007
Science of the Total Environment (under review)

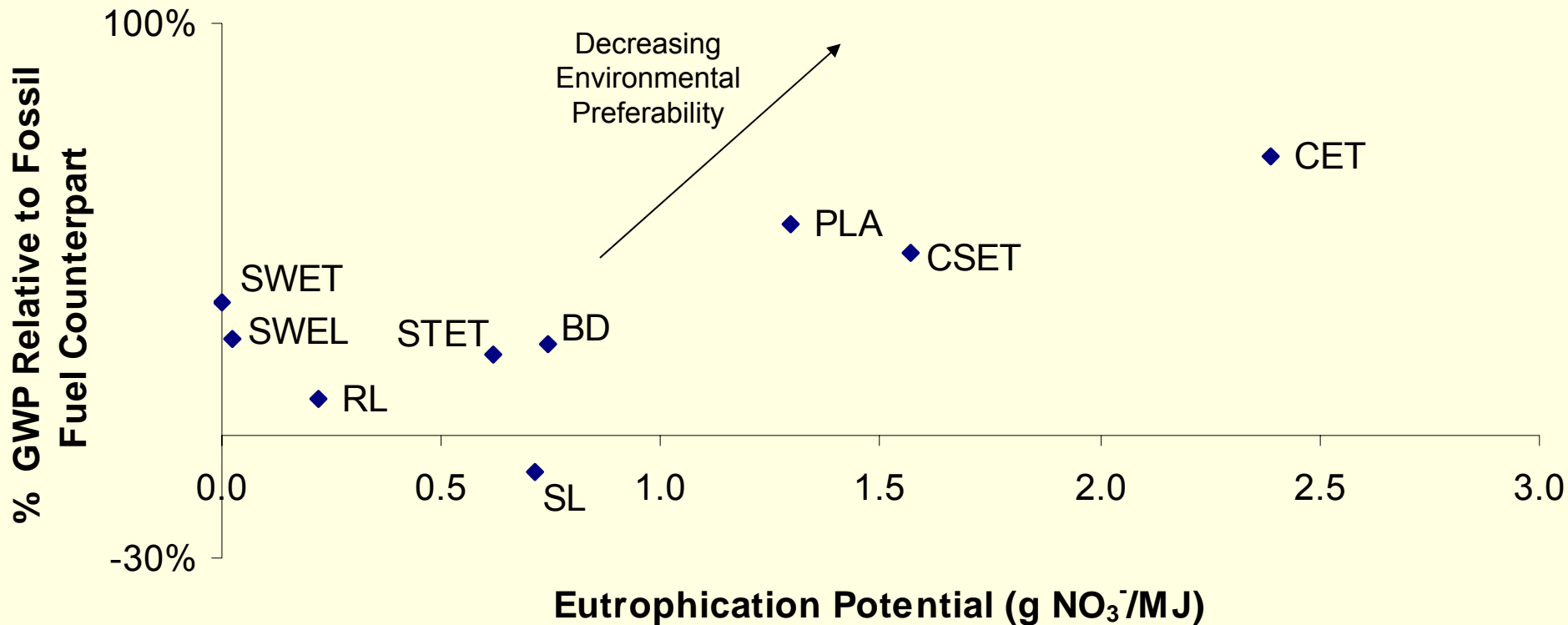
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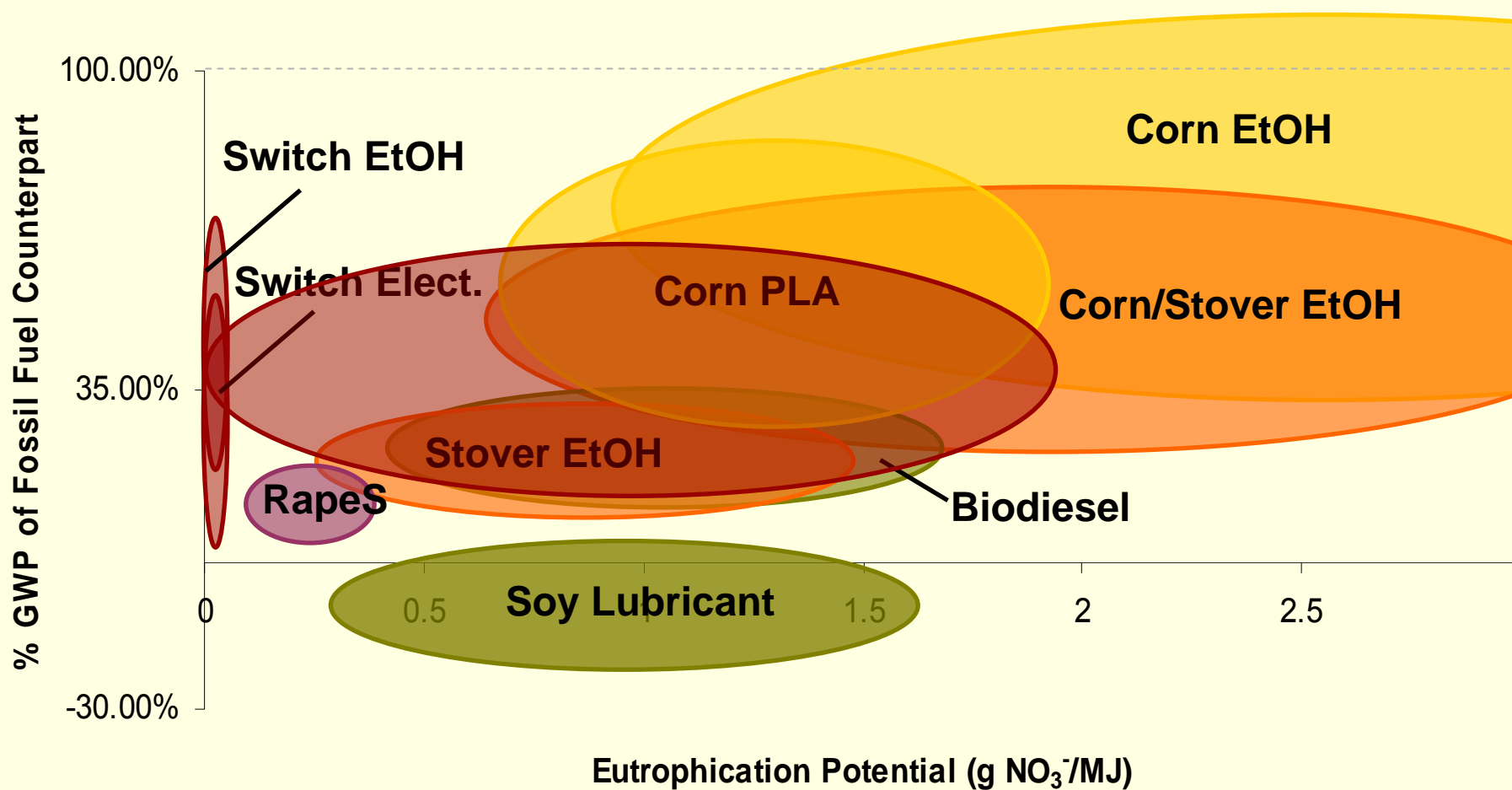
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Relative Environmental Profiles

Carbon Nitrogen Tradeoffs for Various Bioproducts



Product Variability Ranges





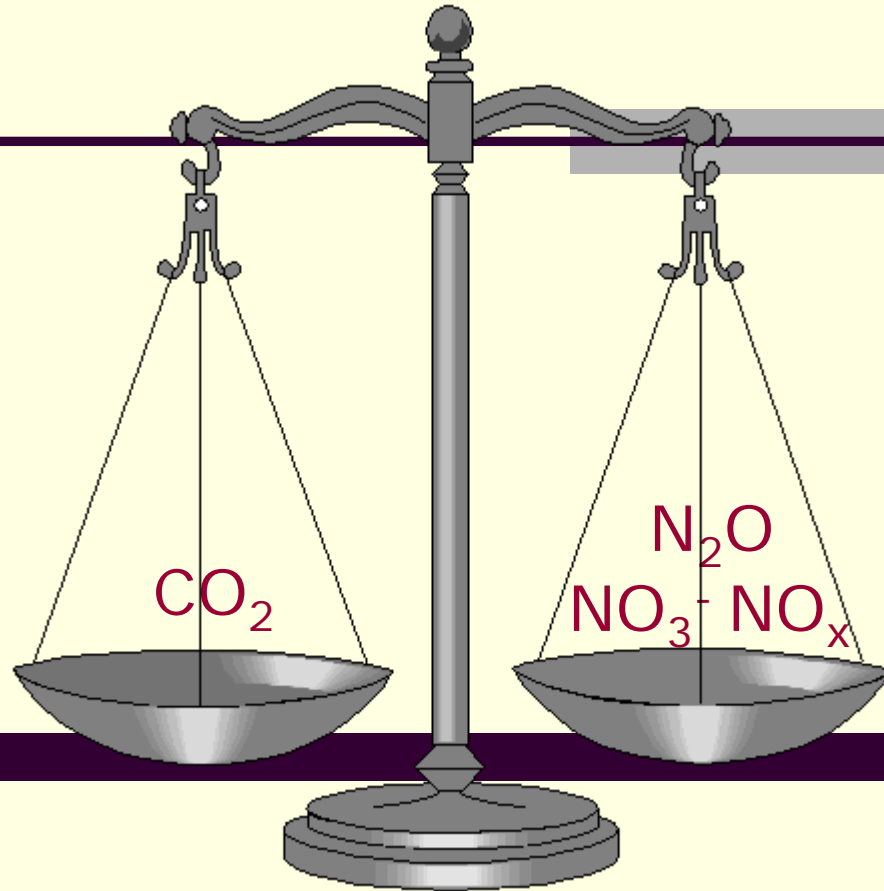
Summary

- Bioproducts have an inherent tradeoff between carbon and nitrogen impacts
- Not all bioproducts are created equal
- Corn is not an ideal crop
- Look at trends, not point estimates
- Evaluate metrics for comparison
- Agriculture needs to improve environmental profile, especially nitrogen efficiency
- There are no “magic bullets”



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