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Energy & Earth Sciences 101
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Predicting & Mitigating Tradeoffs with Life Cycle Assessment (LCA)

Ian Monroe
Stanford University
imon@stanford.edu

Are Biofuels Better than Alternatives?

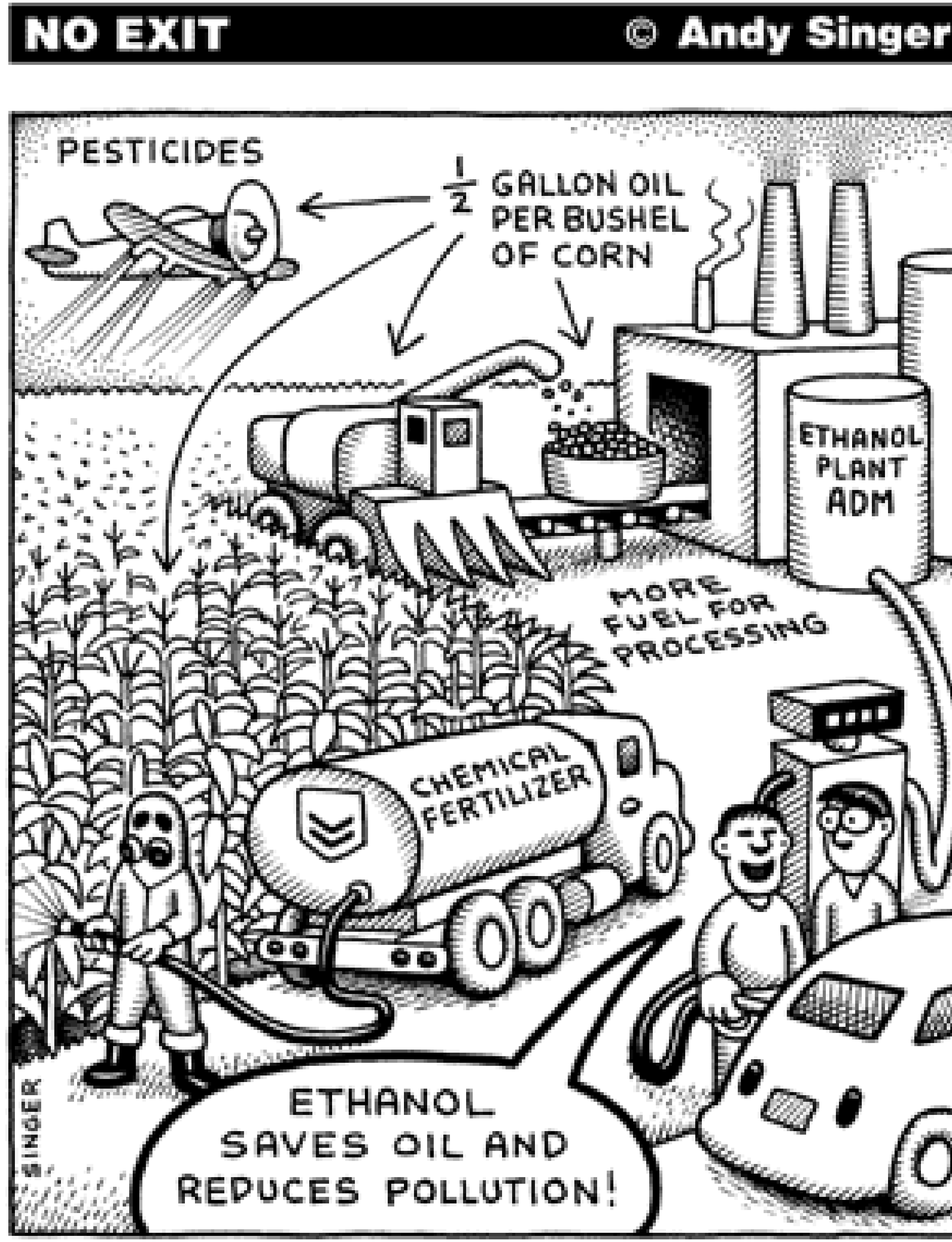
Answer depends on:

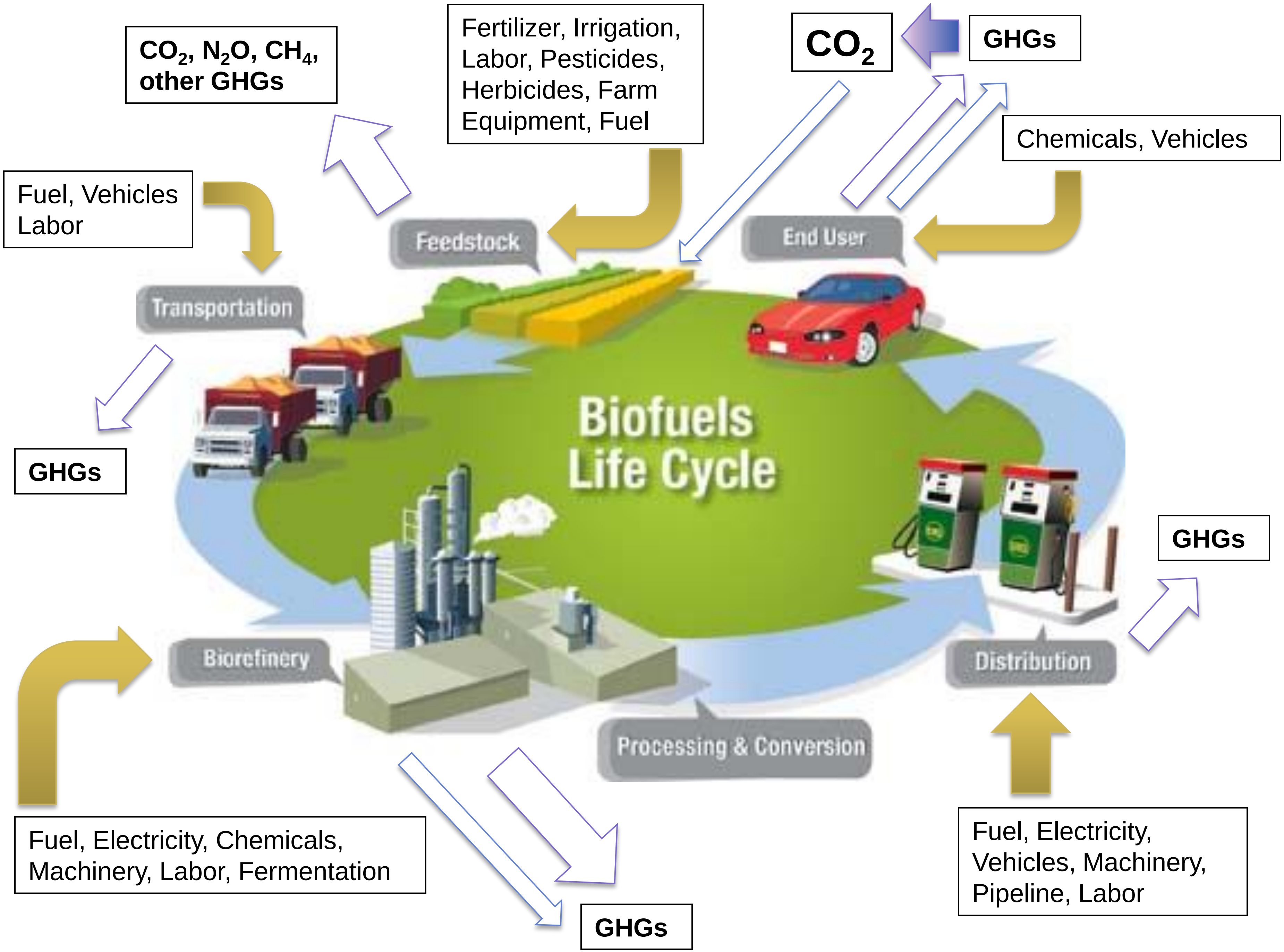
- *What type of biofuels?*
- *How are they produced?*
- *Where are they produced?*
- *What are the alternatives?*
- *Basis for comparison?*

Life Cycle Assessment (LCA) *is a valuable tool for comparison*

→ But LCA methodology changes can change your answers…

LCA incorporated into policy:
(CA LCFS, US RFS, UK RTFO, EU Biofuels Directive…)





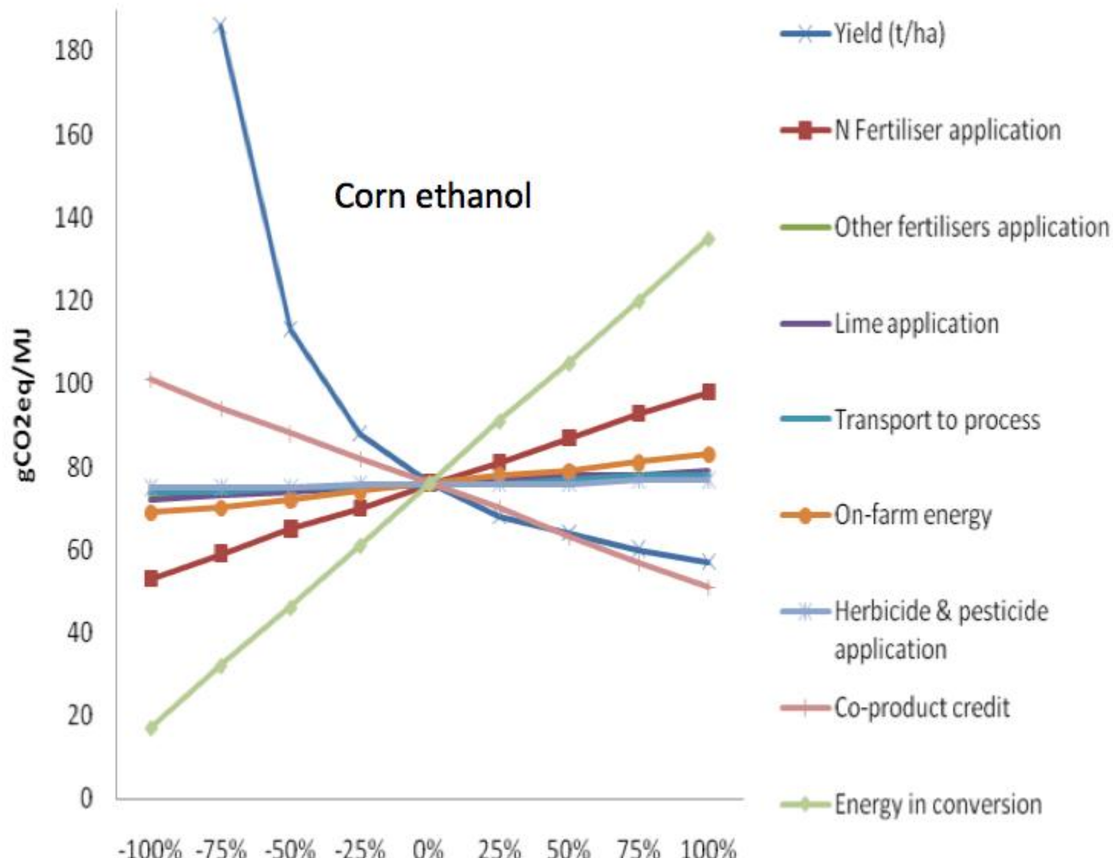
CO_2, N_2O, CH_4, other GHGs
Fertilizer, Irrigation, Labor, Pesticides, Herbicides, Farm Equipment, Fuel
CO_2
GHGs
Chemicals, Vehicles
Fuel, Vehicles Labor
Feedstock
End User
Transportation
Biofuels Life Cycle
GHGs
GHGs
Biorefinery
Distribution
Processing & Conversion
Fuel, Electricity, Chemicals, Machinery, Labor, Fermentation
Fuel, Electricity, Vehicles, Machinery, Pipeline, Labor
GHGs

Attributional LCA

*Life Cycle GHG **emissions are sensitive to inputs and outputs**, like:*

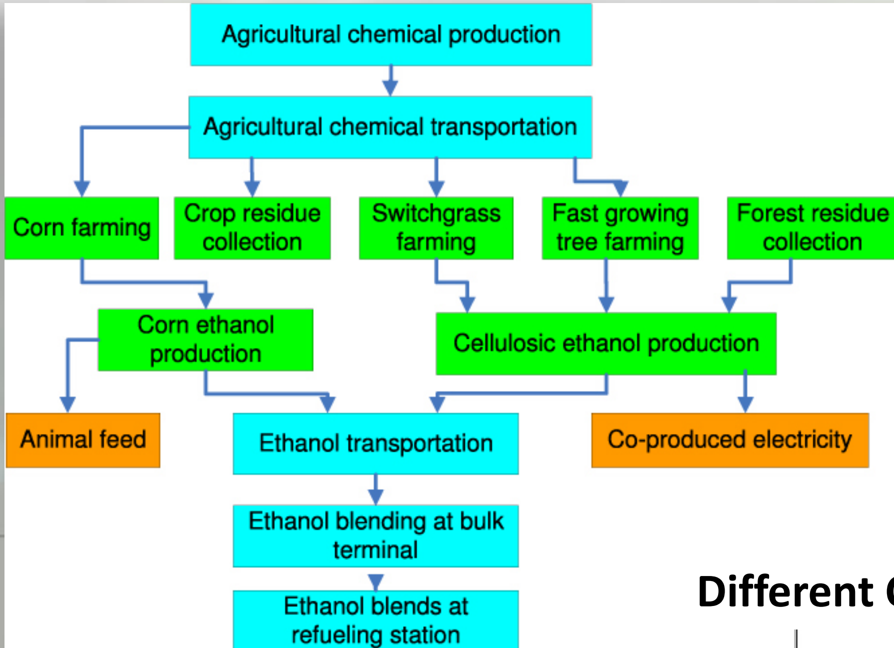
- ***feedstock type***
- ***nitrogen fertilizer***
- ***yield changes***
- ***fuel processing***
- ***co-products***
- ***land use / cover change***
- ***cultivation techniques***

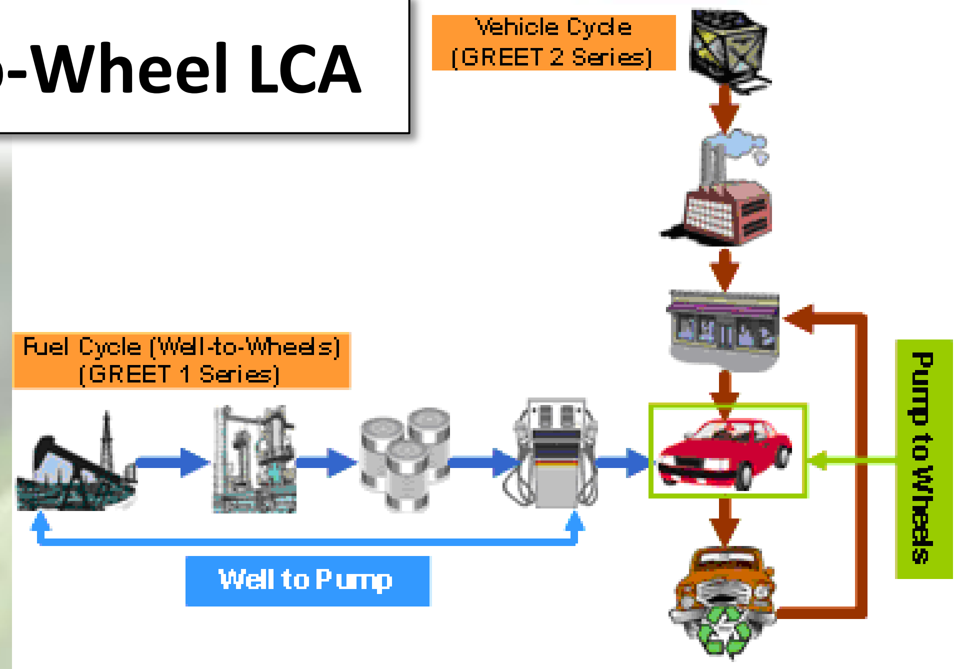
Corn Ethanol GHG: Sensitivity to Inputs



Winrock International 2009

DOE GREET Model: Well-to-Wheel LCA

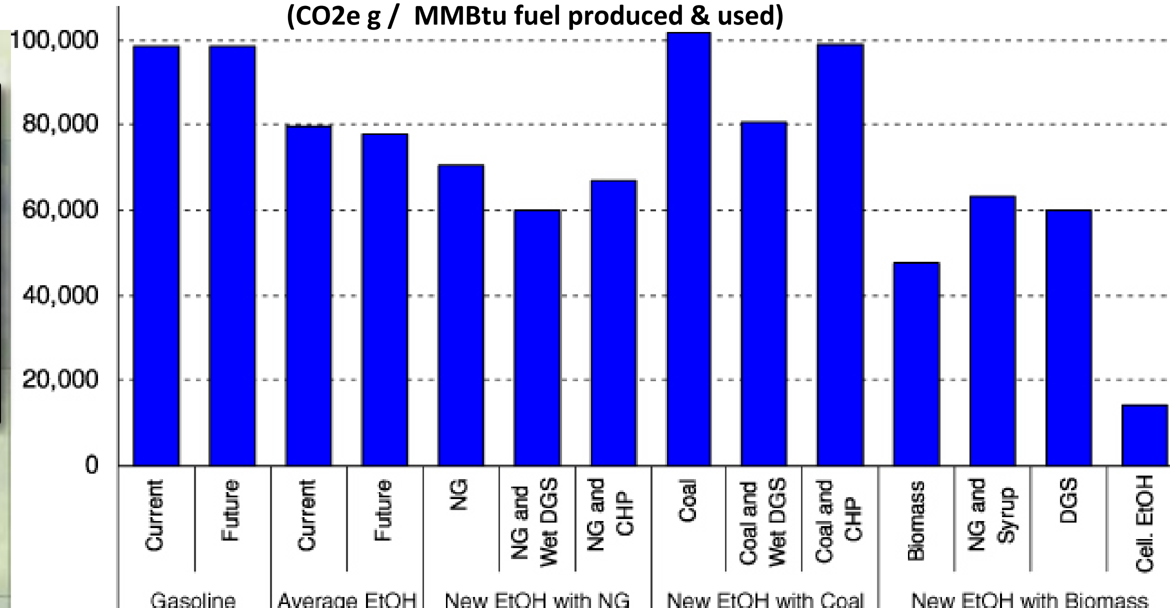




Fuel Processing & Co-Products

Different Corn Ethanol Plant Types Yield Different Results

(CO2e g / MMBtu fuel produced & used)



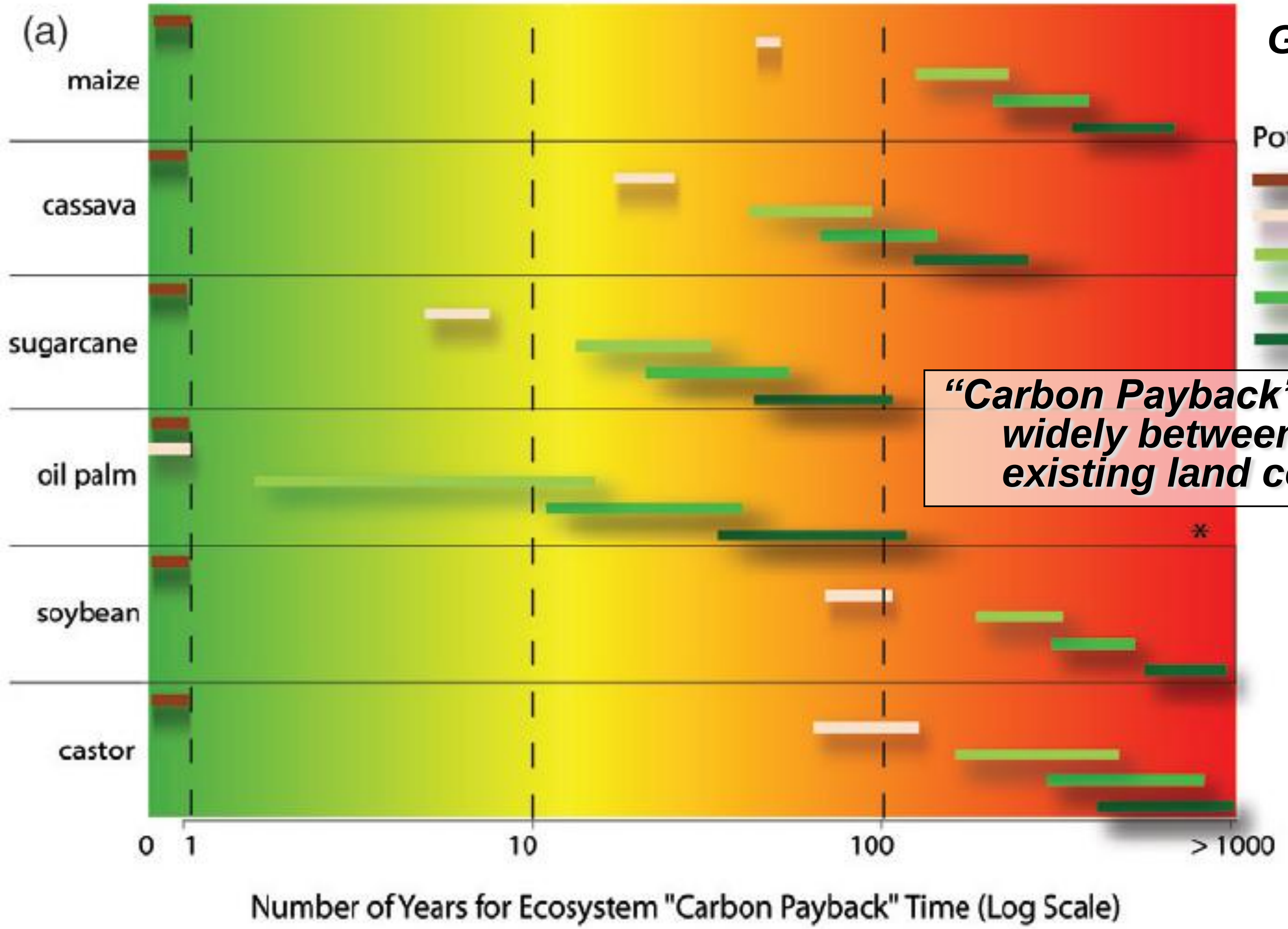
Wang et al 2007

Cultivation Techniques

Cane Field Burning =

N_2O = 298xCO_2GWP(100yr)

CH_4 = 25xCO_2GWP(100yr)



Gibbs et al 2008

"Carbon Payback" times also vary widely between feedstocks and existing land cover types

Land Use Change

Positive Land Use Change Impacts?

Philippines SCBI Reforestation =
~39 to 70 mt CO_2e/ha/yr sequestration

U.S. = ~19.3 mt CO_2e/yr per capita
China = ~5.0 mt CO_2e/yr
Philippines = ~0.8 mt CO_2e/yr
(World Bank 2007)

Attributional vs. Consequential LCA

Incorporating indirect impacts in LCA…

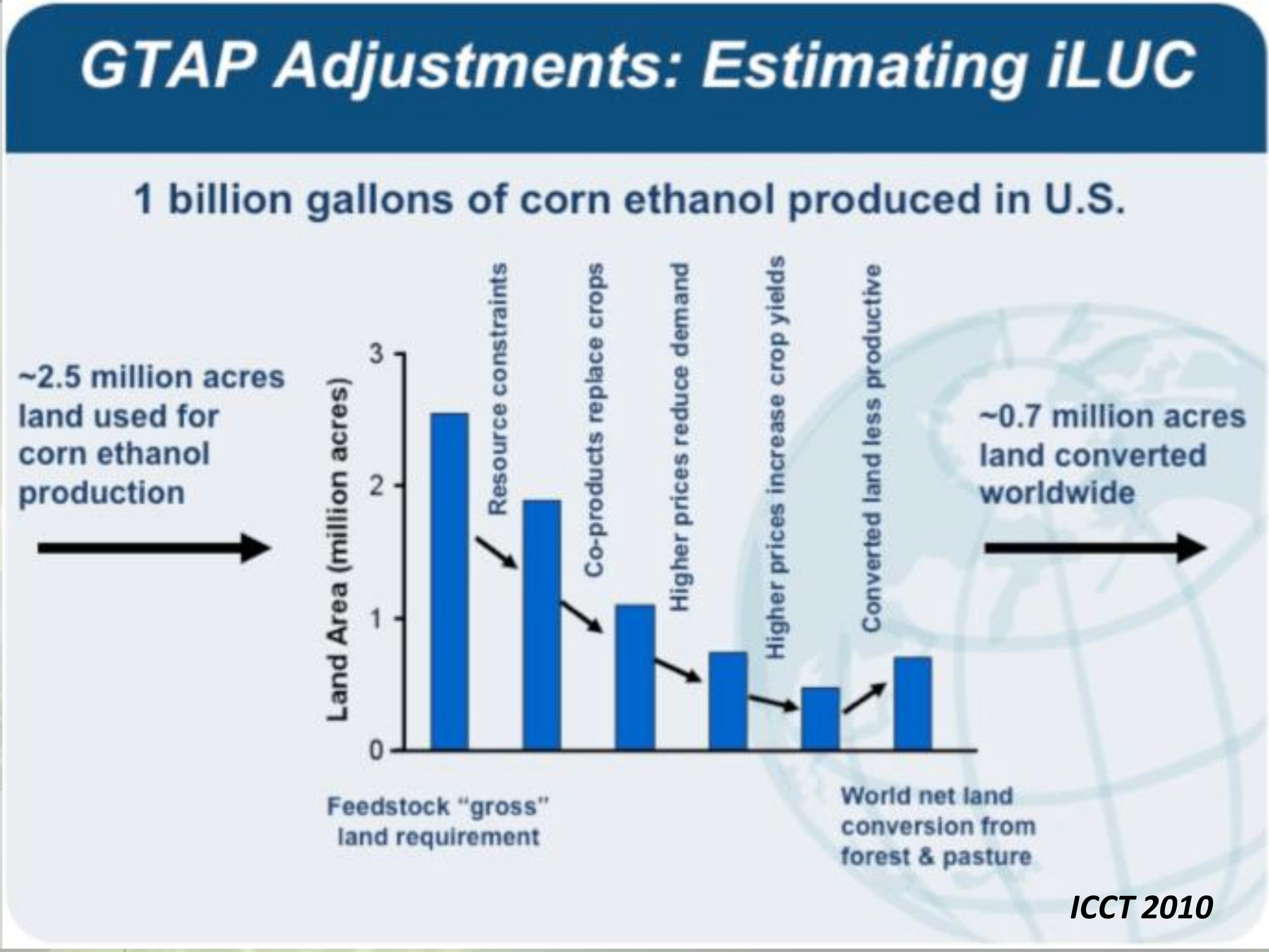
GTAP model used to for **indirect land use change(iLUC)** calculations

GTAP = a multiregion, multisector, computable general equilibrium model, with perfect competition and constant returns to scale

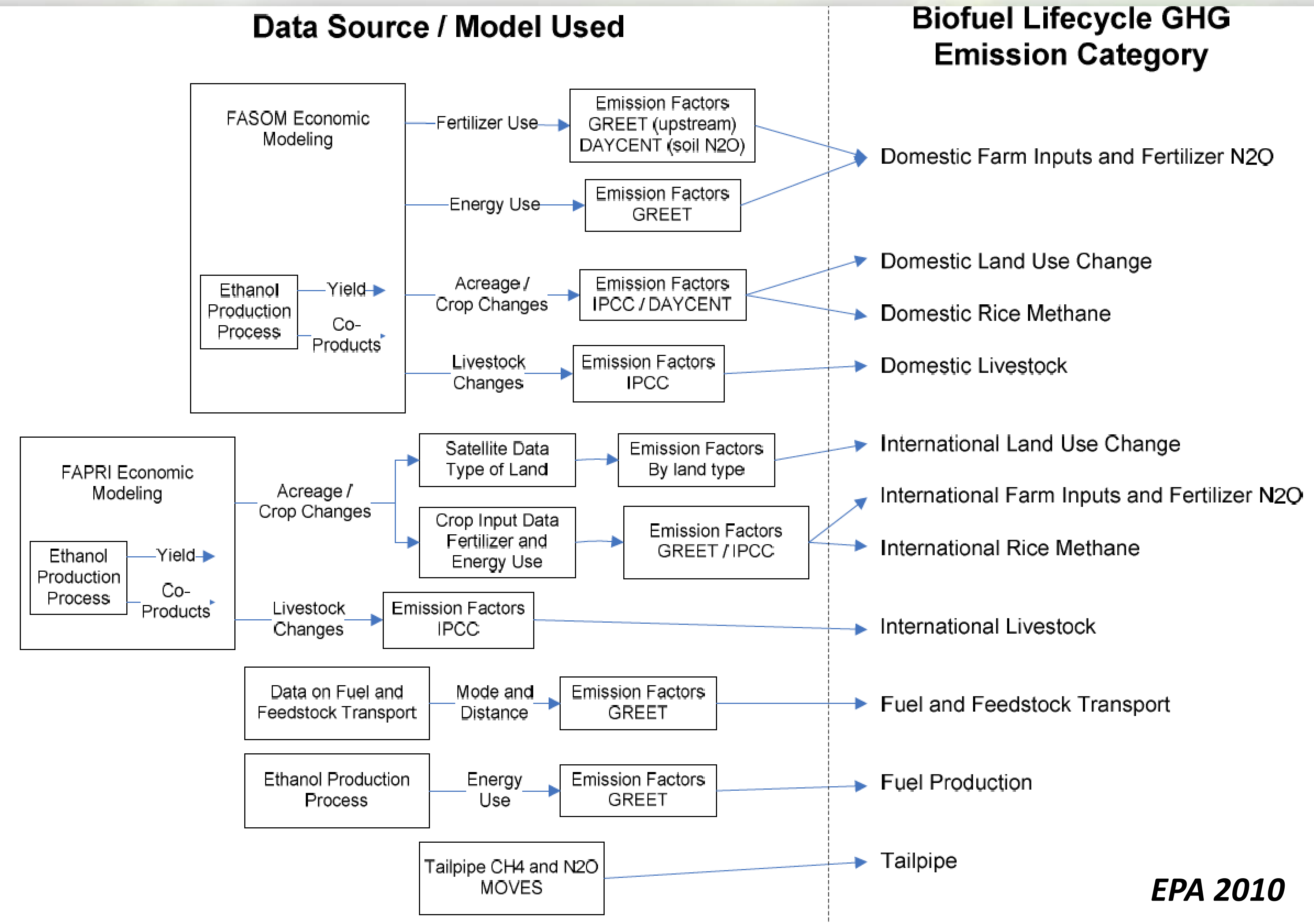
→ Models global impacts driven by economic effects

→ Many assumptions

→ Too complex to be well-understood by public and policy makers (and even many scientists)



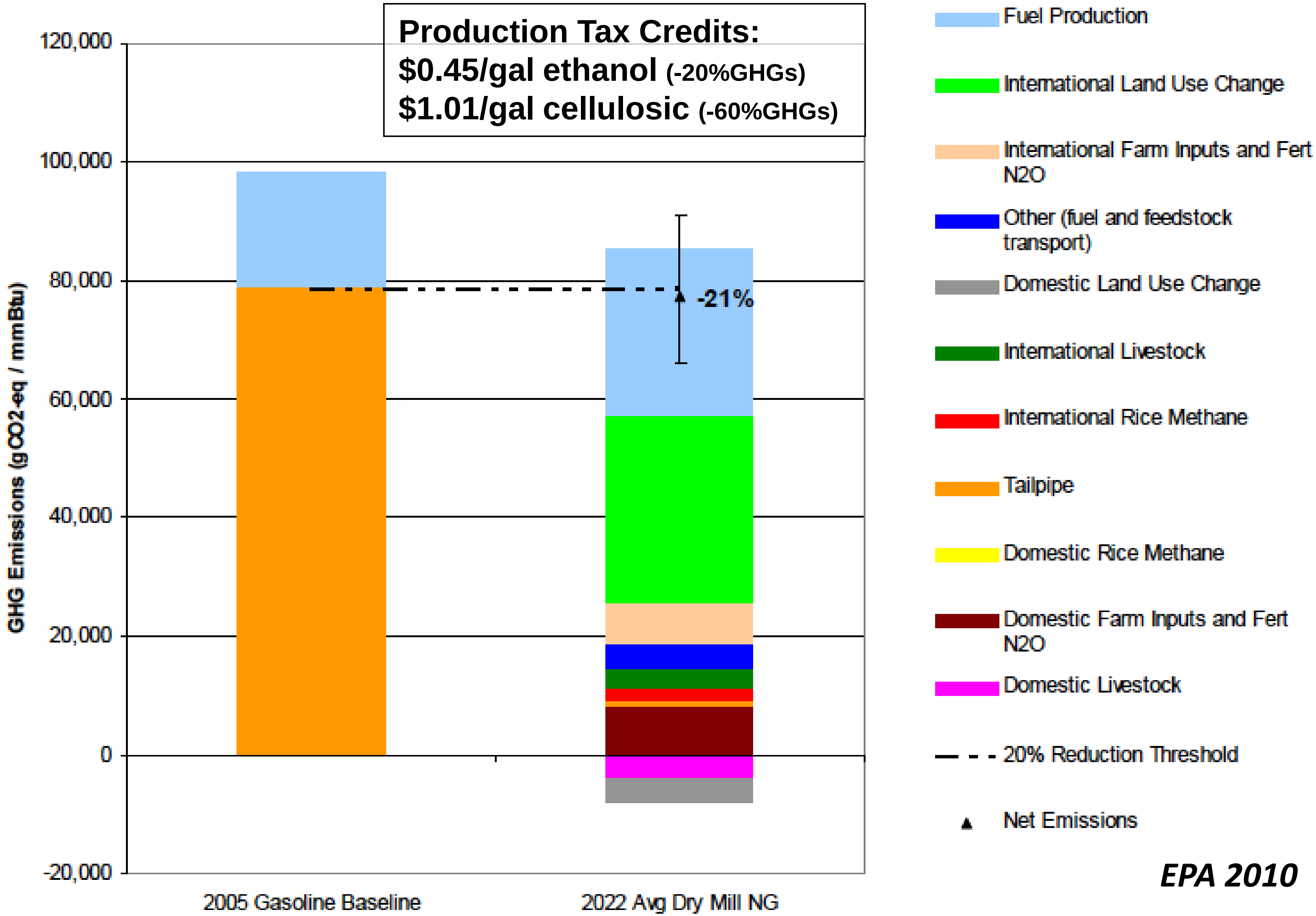
Expanding to Consequential LCA → US Renewable Fuels Standard (RFS)



EPA 2010

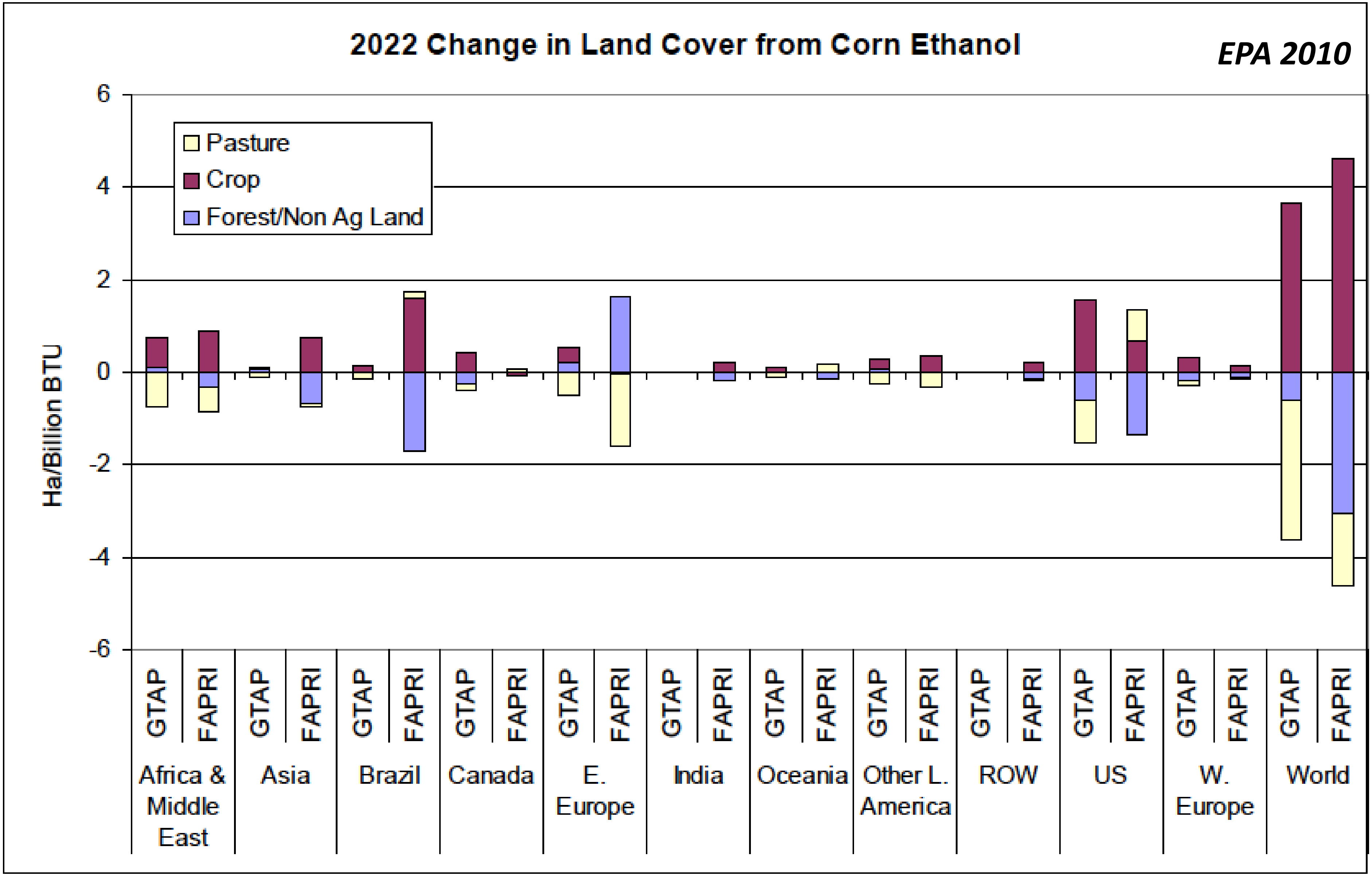
RFS Final LCA Results

Figure 2.6-2. Results for a New Natural Gas Fired Corn Ethanol Plant by Lifecycle Stage Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)



EPA 2010

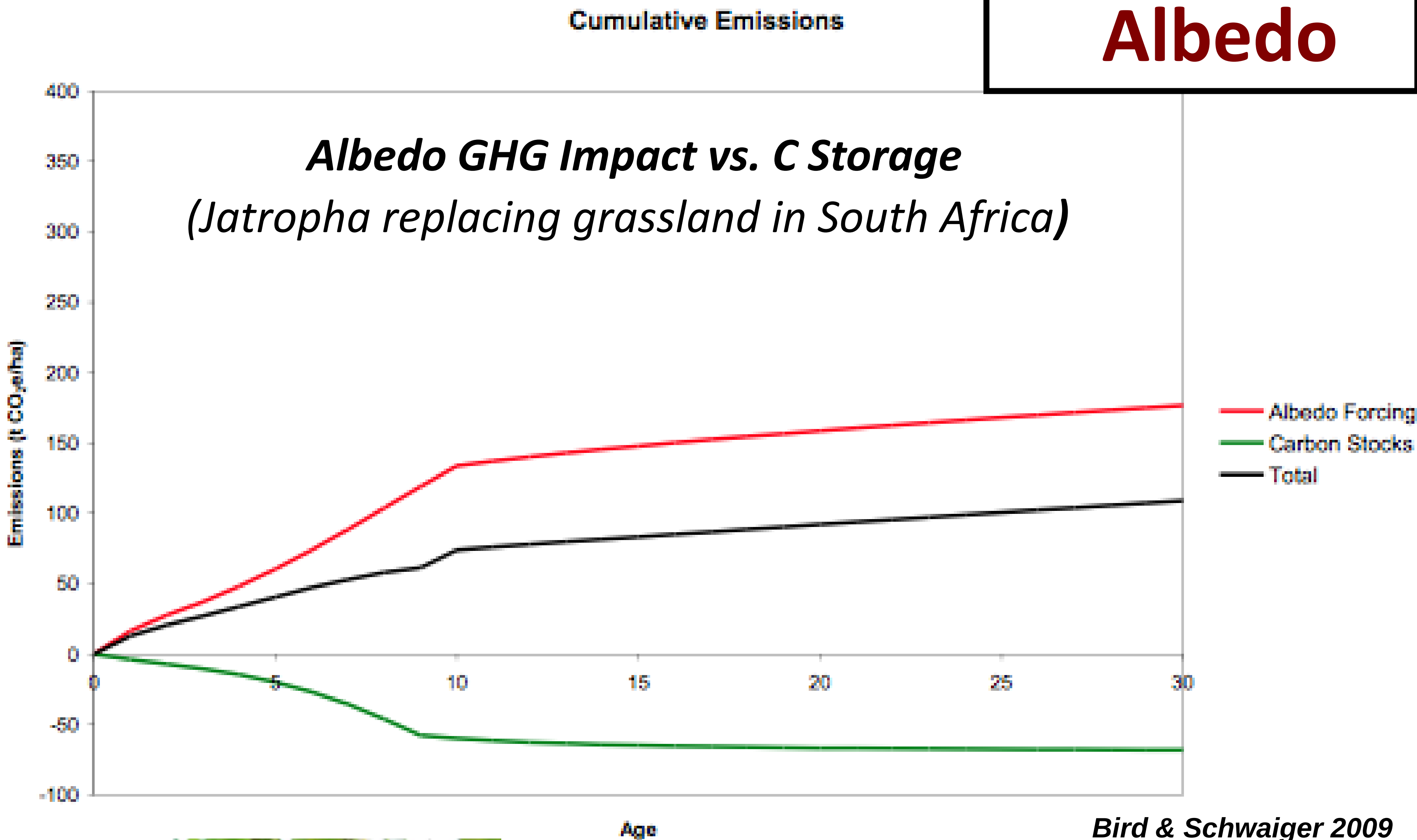
Indirect land use change results depend upon the model used…



Albedo

Albedo GHG Impact vs. C Storage

(Jatropha replacing grassland in South Africa)



Bird & Schwaiger 2009

LCA Beyond GHGs?

Habitat Loss & Biodiversity Impacts

Freshwater Use

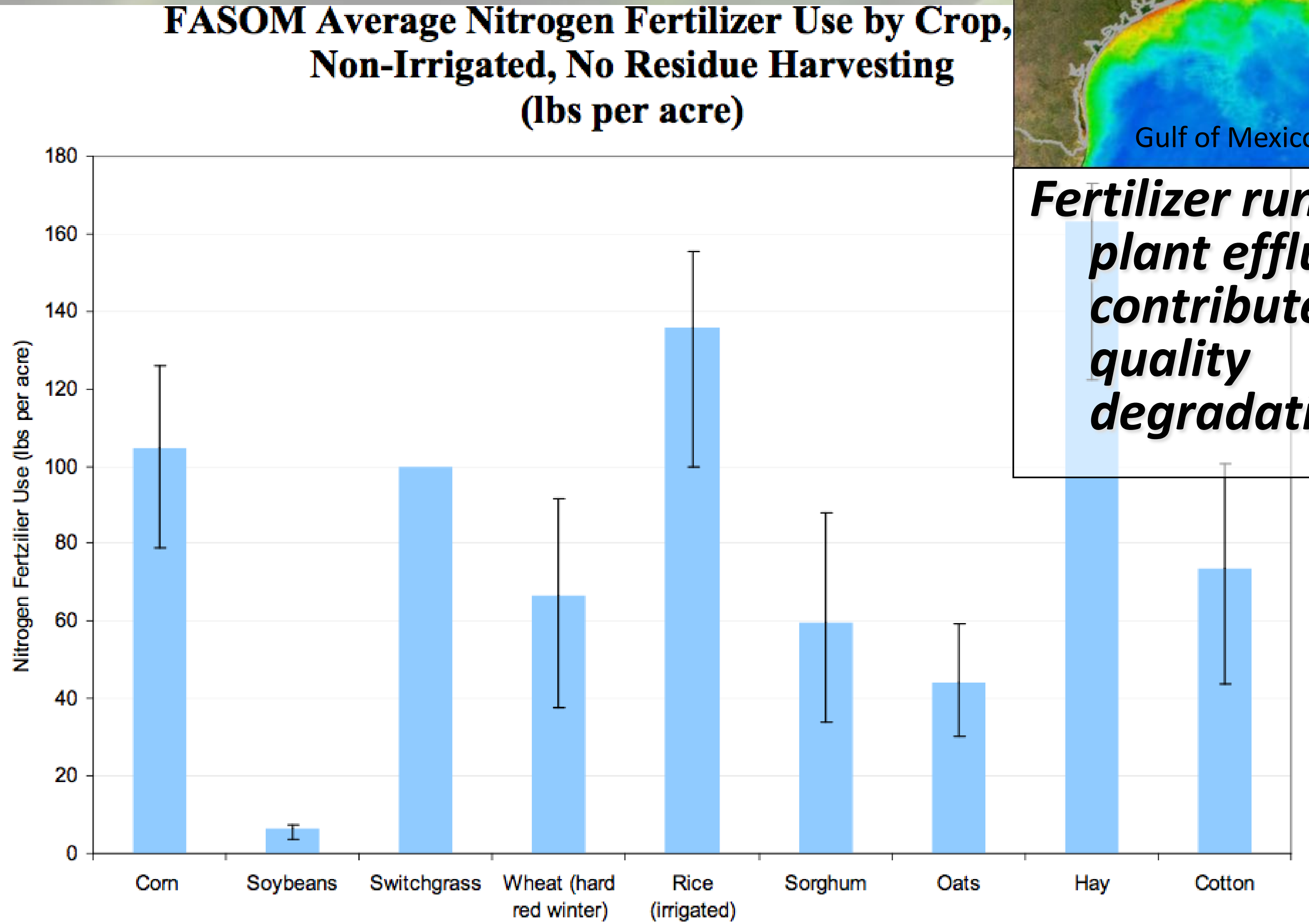
Crop	Total WF	Blue WF	Green WF	Total water
Ethanol		m³ per GJ ethanol		(L water per L fuel)
Sugar beet	59	35	24	1,388
Potato	103	46	56	2,399
Sugar cane	108	58	49	2,516
Maize	110	43	67	2,570
Cassava	125	18	107	2,926
Barley	159	89	70	3,727
Rye	171	79	92	3,990
Paddy rice	191	70	121	4,476
Wheat	211	123	89	4,946
Sorghum	419	182	238	9,812
Biodiesel		m³ per GJ biodiesel		
Soybean	394	217	177	13,676
Rapeseed	409	245	165	14,201
Jatropha*	574 **or 65 ??**	335	239	19,924

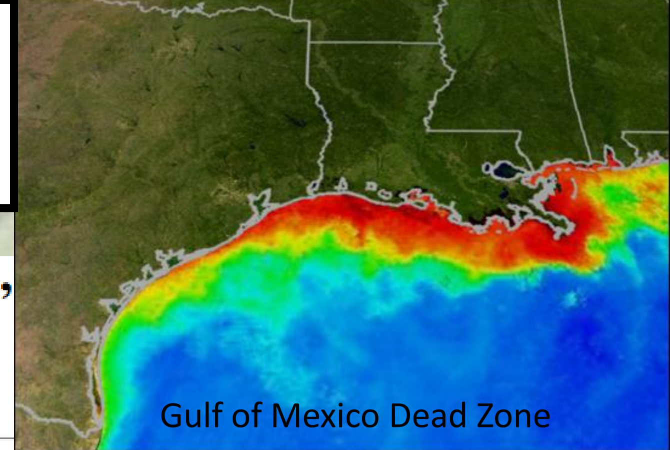
The table also shows the amount of water needed for a specific crop to produce 1 L of ethanol or 1 L of bio

*Average figures for 5 countries (India, Indonesia, Nicaragua, Brazil, and Guatemala).

Gerbens-Leenes et al 2009

Freshwater Quality





Fertilizer runoff and plant effluents can contribute to water quality degradation

EPA 2009

EPA 2009 "Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program"

Food vs. Fuel

More demand for ag land should lead to higher ag product prices (including food)

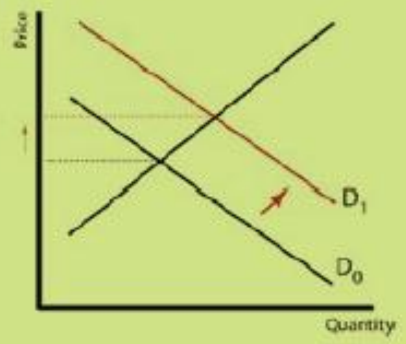
Higher prices bad for urban poor, but good for rural poor (net producers)?

Haiti 2008

Tunisia 2011

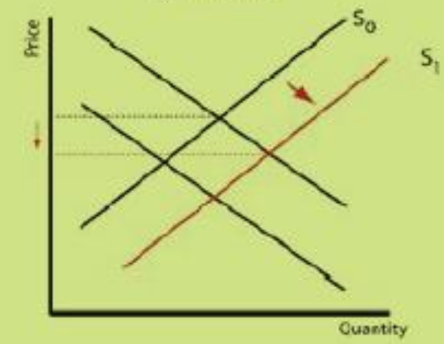
Dynamics of a biofuels-induced increase in demand for maize, wheat, and soybeans in the United States

(1) Maize



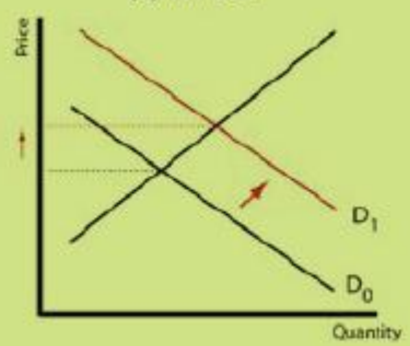
Rising demand for maize leads to growth in supply along the curve that includes production a higher marginal costs.

(2) Maize



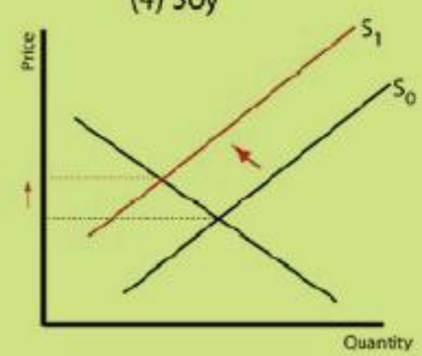
Longer-run shift in supply due to technical change induced by higher prices.

(3) Wheat



Higher maize prices increase demand for wheat in livestock markets, causing wheat prices to rise.

(4) Soy



Greater area sown to maize reduces area planted to soy, causing soy prices to rise.

Naylor et al 2007

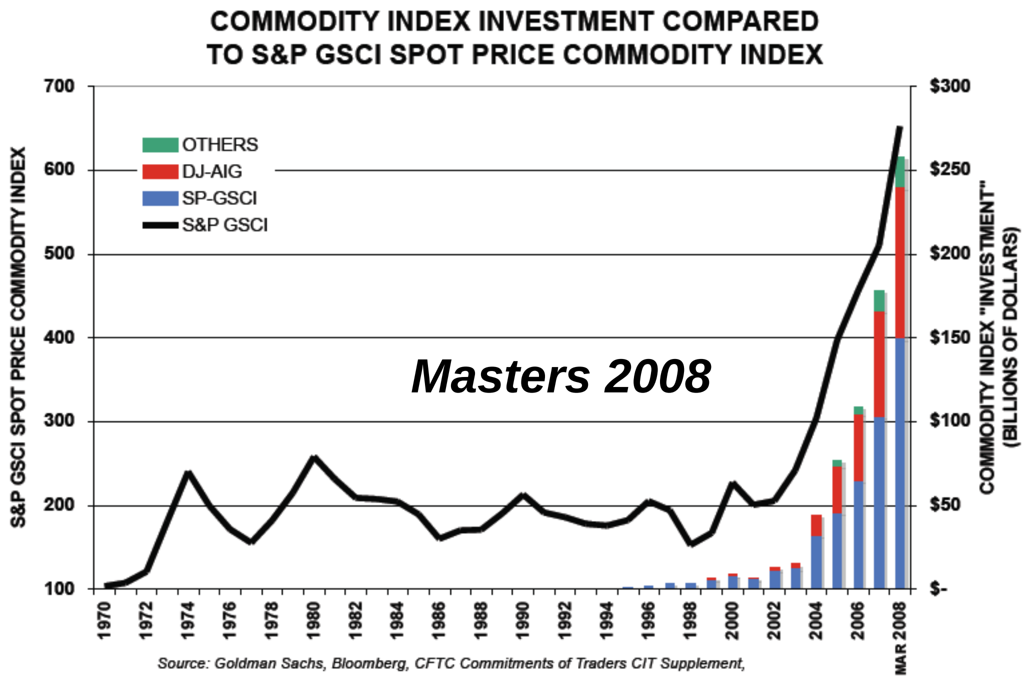
Table 1. Predictions of price changes under various biofuels-related scenarios

Source	Scenario	Projected price increase
M. W. Rosegrant, S. Msangi, T. Sulser, and R. Valmonte-Santos, *Biofuels and the Global Food Balance* (Washington, DC: International Food Policy Research Institute, 2006).	4 percent U.S. gasoline replacement by biofuels, 20 percent elsewhere, up to 58 percent in Brazil (biodiesel in EU, ethanol elsewhere), no technology improvement, projected to 2020.	Corn, 41 percent; wheat, 30 percent; soy (oilseeds) 76 percent; sugar (sugarcane), 66 percent; cassava, 135 percent
	Same as above, but with cellulosic technology online by 2015, and crop productivity improvements, projected to 2020.	Corn, [illegible] percent; wheat, [illegible] percent; soy (oilseeds) 43 percent; sugar (sugarcane), [illegible] percent; cassava, [illegible] percent
M. Von Lampe, *Agricultural Market Impacts of Future Growth in the Production of Biofuels* (Paris: Working Party on Agricultural Policies and Markets, AGR/CA/APM(2005)24/FINAL, Committee on Agriculture, Organization for Economic Cooperation and Development, 2006).	Constant $60 per barrel price of oil, projected to 2014.	Corn, [illegible] percent; wheat, [illegible] percent; soy (oilseeds) 19 percent; sugar, 20 percent; vegetable oil, 22 percent
	Growth in line with publicly stated goals, [illegible] gigaliters in the United States by 2012, projected to 2014.	Corn, [illegible] percent; wheat [illegible] percent; soy (oilseeds) 1.1 percent; sugar, 4 percent; vegetable oil, [illegible] percent
Food and Agricultural Policy Research Institute (FAPRI), *Implications of Increased Ethanol Production for U.S. Agriculture* (Columbia, MO: University of Missouri, FAPRI-UMC Report #10-05 2005)	7 billion gallon U.S.-produced ethanol use, 7.5 billion gallon biodiesel and ethanol imports by 2012, projected from 2012 to 2015, relative to baseline.	Corn, 5.4 percent; wheat, 1.7 percent; soy -0.2 percent; sorghum, 4.2 percent
A. Elobeid, and S. Tokgoz, *Removal of U.S. Ethanol Domestic and Trade Distortions: Impact on U.S. and Brazilian Ethanol Markets* (CARD Working Paper 06-WP 427, Center for Agricultural and Rural Development, Iowa State University, 2006).	Long-run oil price of $60 per barrel with the United States using 30 billion gallons of ethanol, projected to 2015, relative to baseline.	Corn, 58 percent; wheat, 20 percent; soy (meal) -42 percent; soy (oil) 20 percent
U.S. Department of Agriculture, Agricultural Baseline Projections: U.S. Crops, 2007–2016, http://www.ers.usda.gov/Briefing/Baseline/crops.htm.	12 billion gallons of ethanol, 700 million gallons of biodiesel in the United States, projected to 2016.	Corn, 65 percent; wheat, 33 percent; soy, 19 percent; sugar, -8 percent; sorghum, 64 percent

If a biofuel crop is grown on land that would otherwise be used to grow food, then it will impact food prices…

Naylor et al 2007

Food, Fuel, Prices & Commodity Speculation



***Price** = a major driver of*

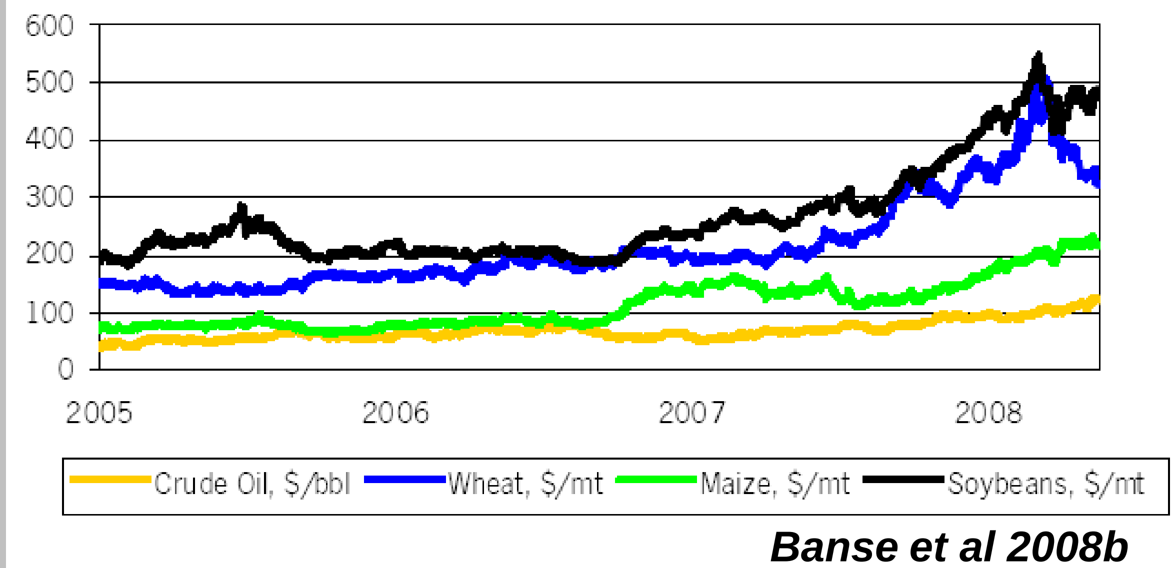
1) Food security

- distributional impacts TBD

2) Land use change

- both direct and indirect

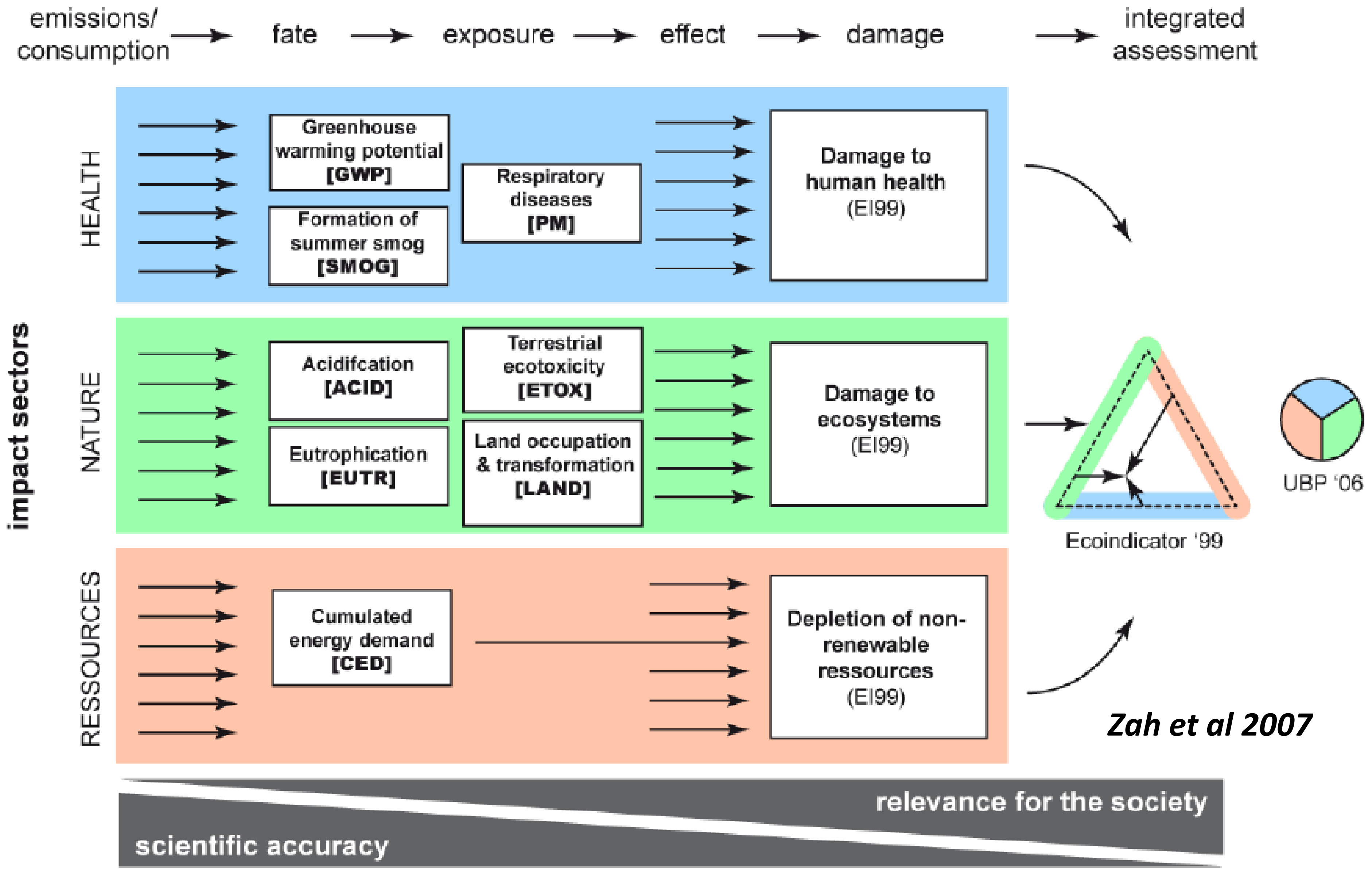
Daily Price Notations for Crude Oil, Wheat, Maize and Soybeans; Spot prices, 2005-2008, at current USD



Source: World Bank data base (2008) from January, 1 2005 to May, 15 2008.

Price volatility driven by biofuels or other global trends, like commodities investment?

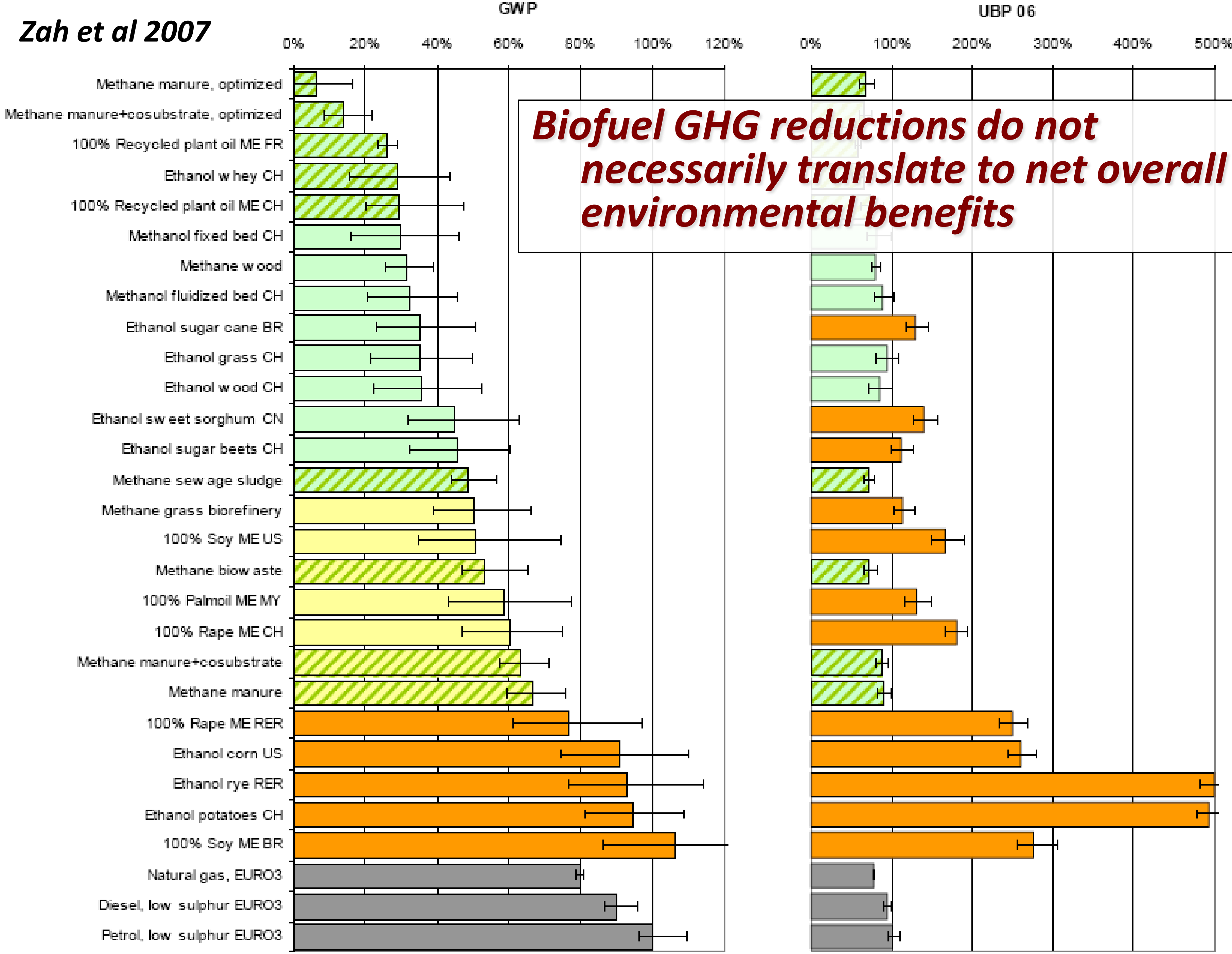
How Should We Weight Different LCA Impacts?



Zah et al 2007

Zah et al 2007

Biofuel GHG reductions do not necessarily translate to net overall environmental benefits



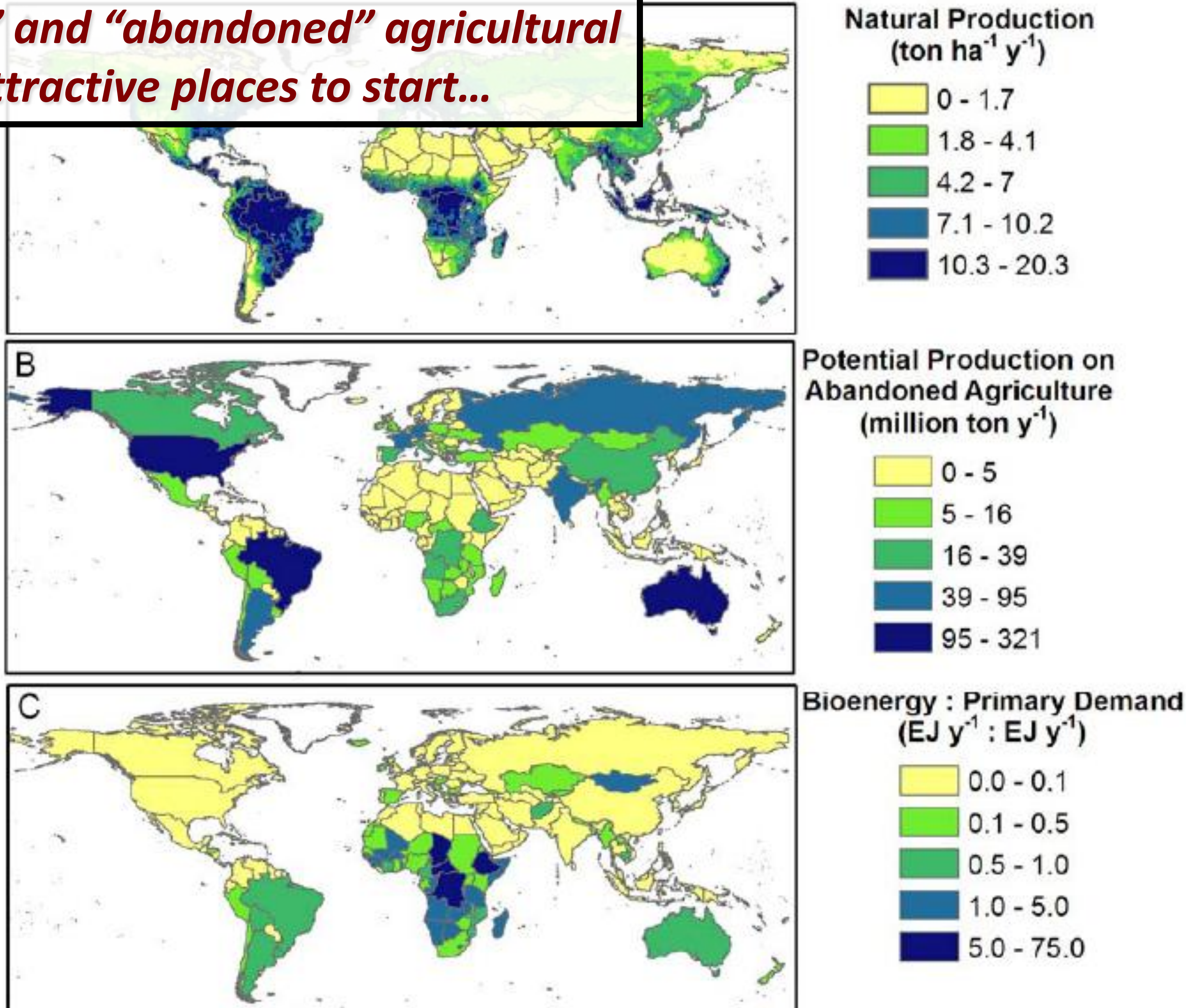
Spatially Variable Impacts: Water

Water Use Environmental Impacts (per kg finished cotton textile)[a]

Country	Cotton Water Use (m^3/kg)	Water Deprevation (m^3/kg)	Ecosystem Quality (PDF*m^3*yr/kg)	Human Health (10^{-6} DALY/kg)	Water Use % of LCIA (Eco-indicator99)
Argentina	6.1	2.0	2.7	0.2	12%
Australia	3.9	1.4	5.1	0.0	14%
Brazil	0.6	0.0	0.0	0.0	0%
China	2.4	0.9	0.4	0.6	5%
Egypt	10.8	10.2	87.1	18.4	77%
Greece	4.9	3.2	0.8	0.1	9%
India	5.7	5.2	2.1	11.9	24%
Mali	4.1	1.0	3.3	5.7	14%
Mexico	4.5	3.1	2.6	0.7	13%
Pakistan	9.9	9.2	15.7	20.7	52%
Syria	8.4	8.0	8.2	7.8	41%
Turkey	7.3	5.4	3.7	3.7	21%
Turkmenistan	14.1	13.7	13.6	12.3	53%
United States	1.9	0.8	0.5	0.0	4%
Uzbekistan	11.1	10.6	10.8	11.7	45%
Average	***8.5***	***3.5***	***3.9***	***5.7***	***17%***
$US_{CROPWAT}$	8.9	3.7	4.9	0.0	23%
$US_{estimation}$	3.3	2.5	3.6	0.0	19%

[a] *Pfister et al (2009)*

“Degraded” and “abandoned” agricultural areas are attractive places to start…

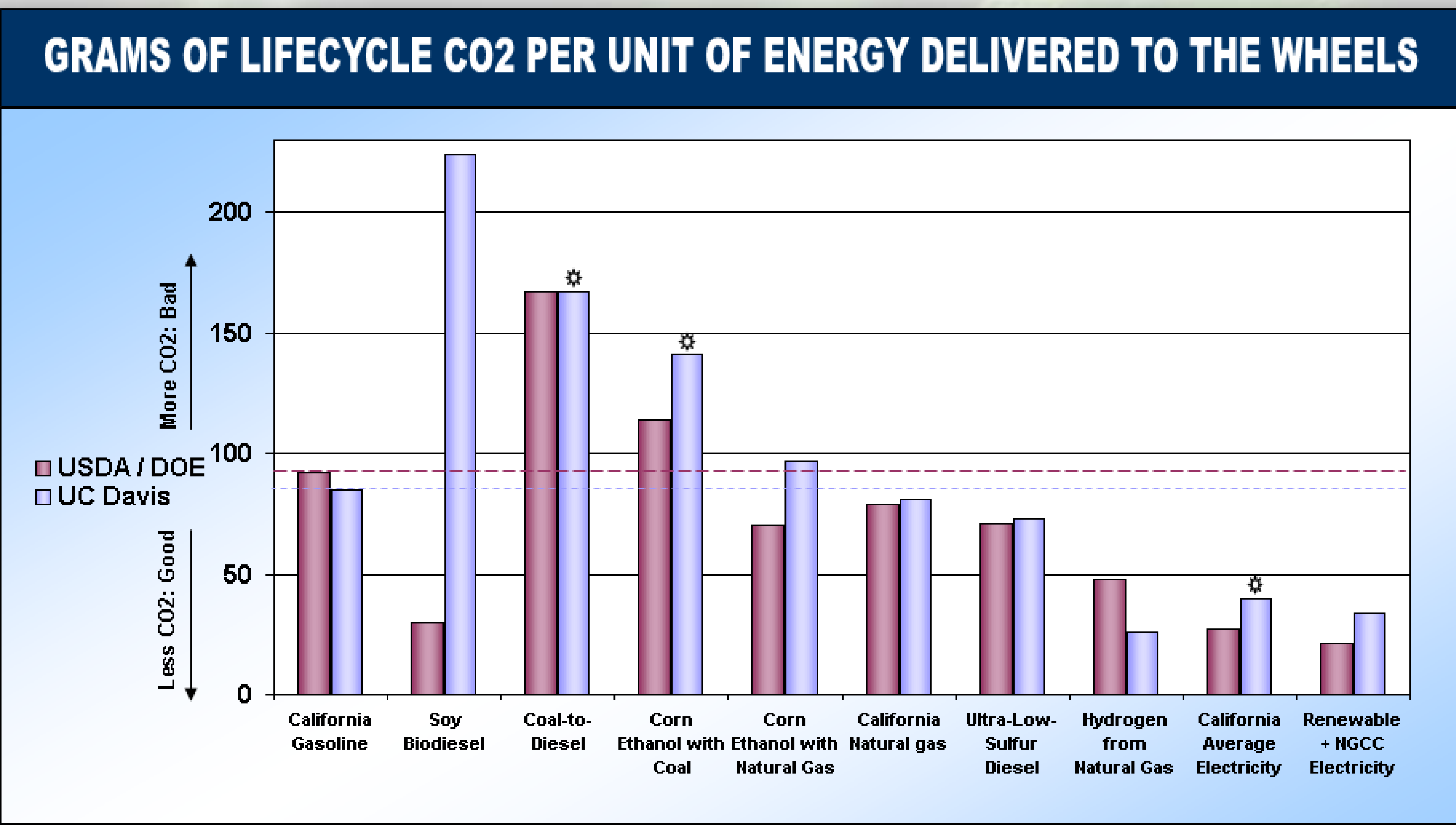


But…

- albedo?
- land use change?
- water use impacts?
- yields?
- Is land really unused?

Campbell et al 2008

Biofuel Performance vs. Other Alternatives?



SOURCE:
A Low-Carbon Fuel Standard for California : Table ES-3
Alexander E. Farrell, UC Berkeley; Daniel Sperling, UC Davis
http://www.energy.ca.gov/low_carbon_fuel_standard

PRIMARY DIFFERENCE BETWEEN CHART MODELS:
The USDA/DOE model discounts the effects of land use, soil carbon sinks, and fertilizer N2O emmisions (A Greenhouse Gas 296x more potent than CO2)

☼ Extrapolated

DOE/USDA: Michael Wang 2006
UC Davis: Mark Delucchi 2005

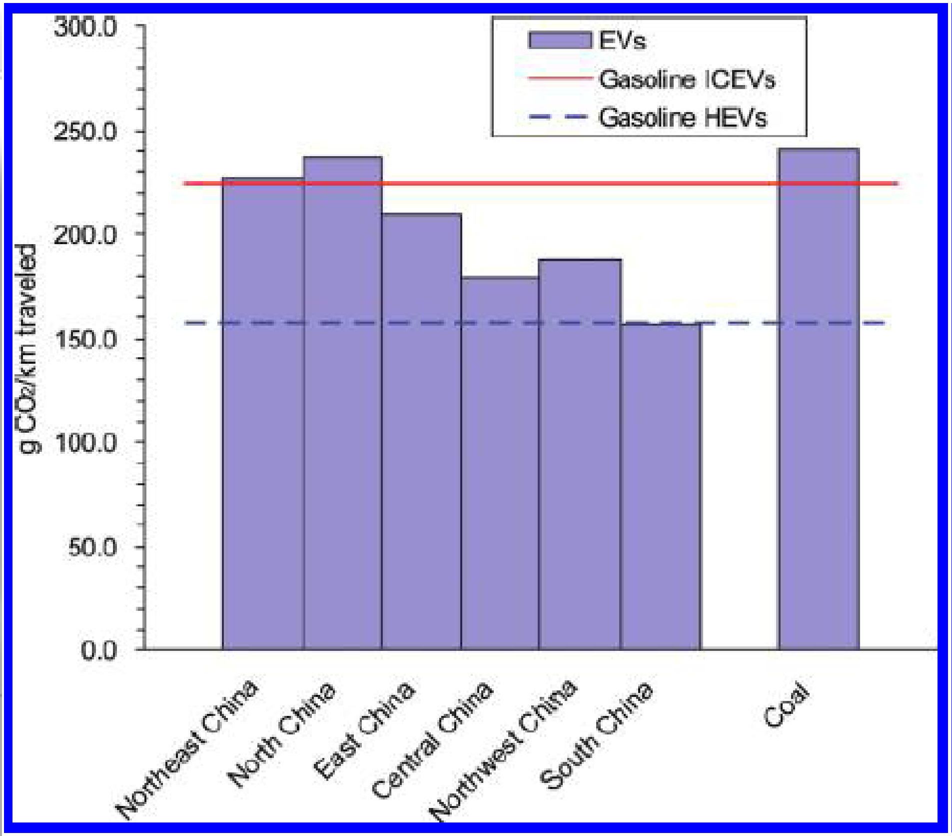


FIGURE 2. Fuel-cycle CO_2 emissions of EVs with the current electricity generation mix in China.

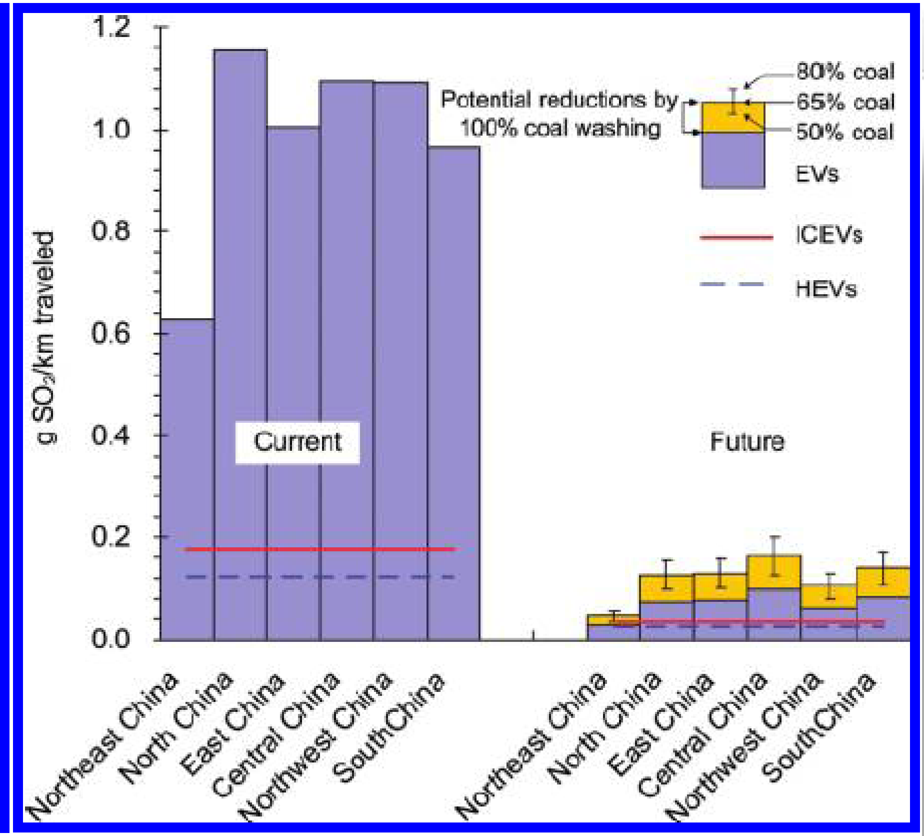


FIGURE 4. Fuel-cycle SO_2 emissions of EVs compared to those of gasoline ICEVs and HEVs in China.

Huo et al (2010)

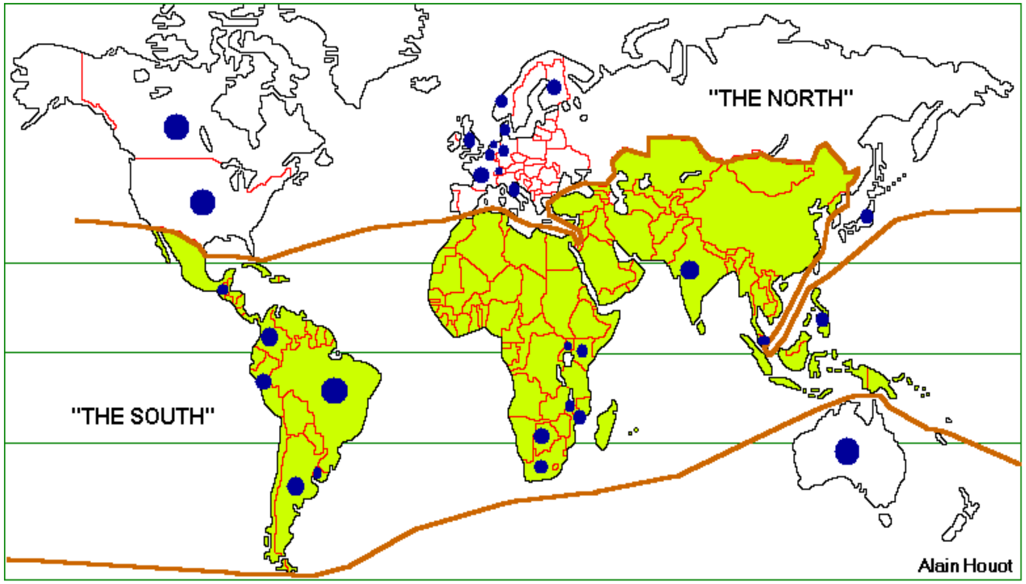
Spatial & temporal variability of impacts…

→ Whether a technology is a net environmental solution or liability may depend on your location

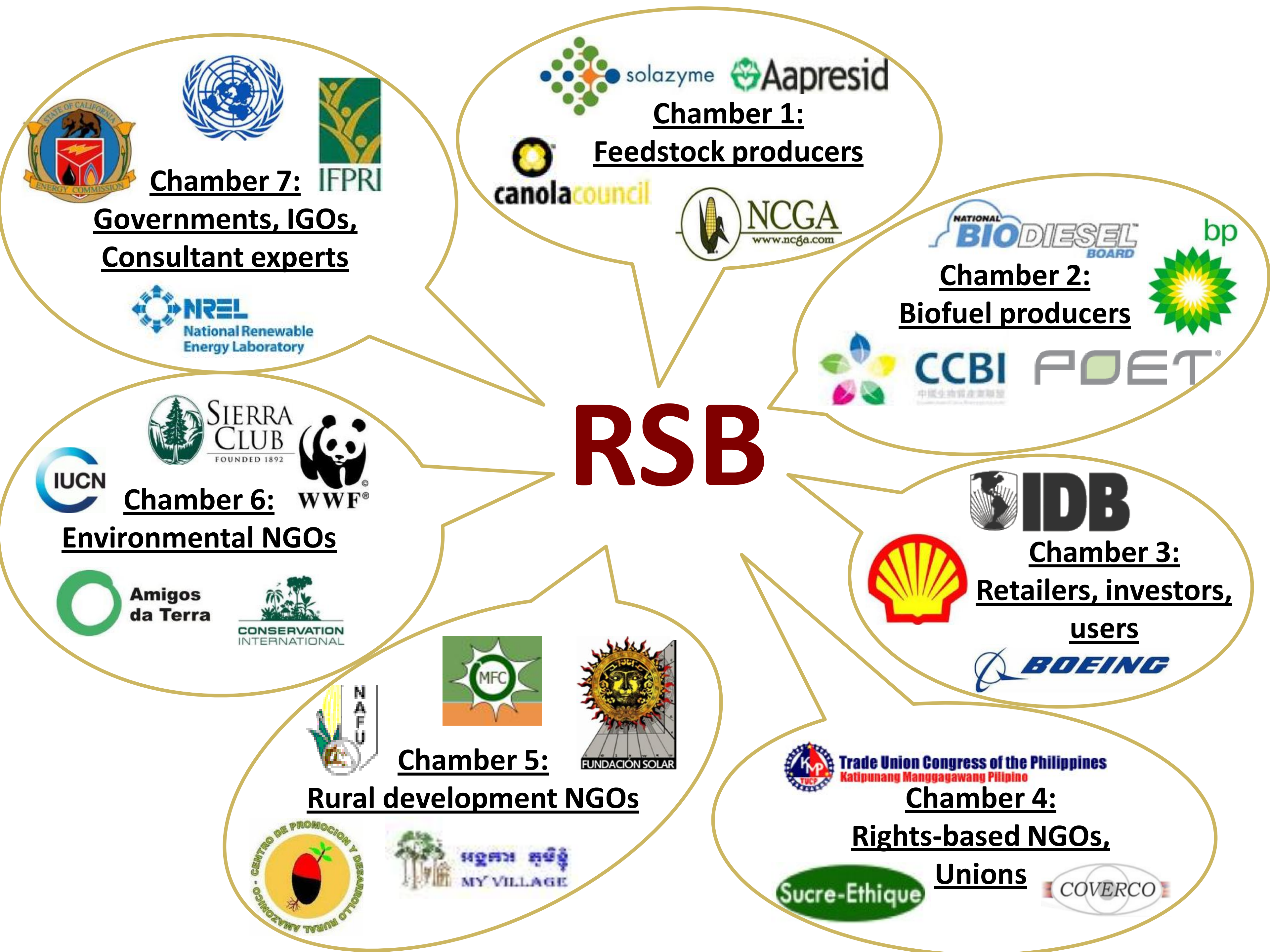
Stakeholder Engagement

RSB
ROUNDTABLE ON SUSTAINABLE BIOFUELS

- Principle 1: **Legality**
- Principle 2: **Planning, Monitoring and Continuous Improvement**
- Principle 3: **Greenhouse Gas Emissions**
- Principle 4: **Human and Labour Rights**
- Principle 5: **Rural and Social Development**
- Principle 6: **Local Food Security**
- Principle 7: **Conservation**
- Principle 8: **Soil**
- Principle 9: **Water**
- Principle 10: **Air**
- Principle 11: **Use of Technology, Inputs, and Management of Waste**
- Principle 12: **Land Rights**



→ ***Sustainability Certification***



RSB
solazyme
Aapresid
Chamber 1:
Feedstock producers
canolacouncil
NCGA
www.ncga.com
NATIONAL BIODIESEL BOARD
bp
Chamber 2:
Biofuel producers
CCBI
POET
IDB
Chamber 3:
Retailers, investors, users
BOEING
Trade Union Congress of the Philippines
Katipunang Manggagawang Pilipino
Chamber 4:
Rights-based NGOs, Unions
Sucre-Ethique
COVERCO
MFC
NAFU
FUNDACION SOLAR
Chamber 5:
Rural development NGOs
CENTRO DE PROMOCION Y DESARROLLO RURAL AMAZONICO
MY VILLAGE
SIERRA CLUB
FOUNDED 1892
IUCN
Chamber 6:
WWF®
Environmental NGOs
Amigos da Terra
CONSERVATION INTERNATIONAL
STATE OF CALIFORNIA
ENERGY COMMISSION
IFPRI
Chamber 7:
Governments, IGOs, Consultant experts
NREL
National Renewable Energy Laboratory

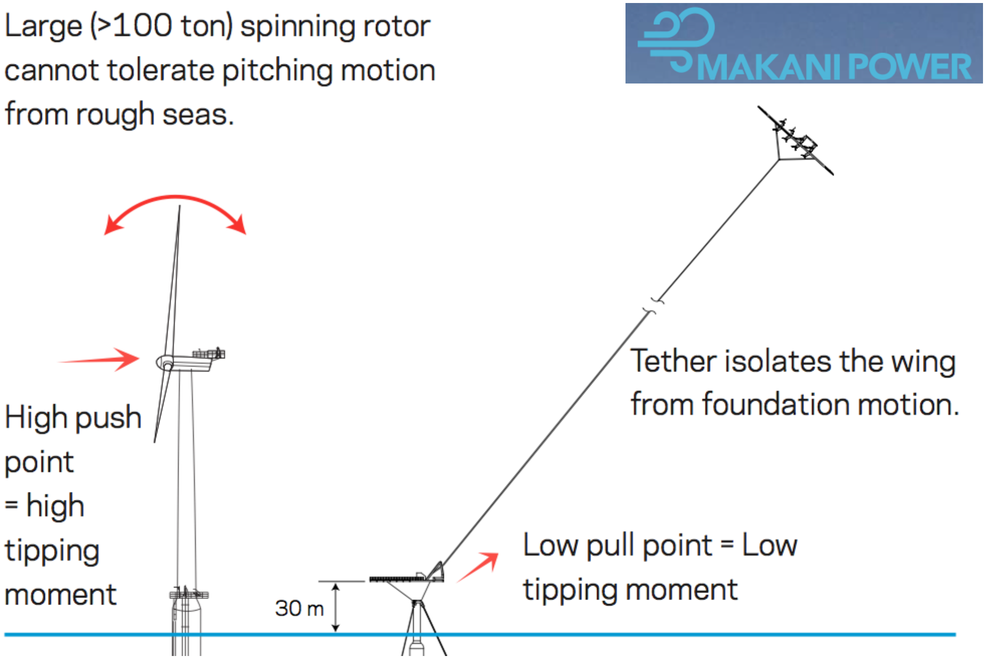
The Road Ahead?

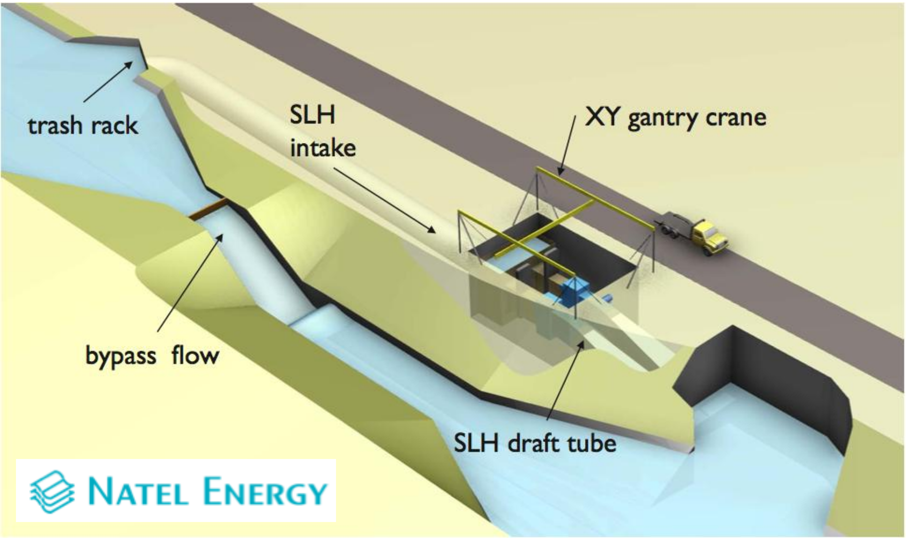
Account for improving technologies…

Advanced Biofuels vs. …

Tethered Wind Power

- *Higher capacity*
- *Cost-competitive offshore wind = lower impact?*
- *Less concrete and steel*





Low-Head Hydro

- *Multiple, small dams and diversion canals to replace one large one;*
- *70% – 85% of large dam w/ only 5% – 10% of the flooded area;*
- *Less concrete, steel & fish impact*

& improve LCA information flow…

Apply LCA to <u>all</u> products and services!

***Open data** can empower companies, investors & policy-makers* *(top down) …*

… and all the rest of us!

(bottom up)

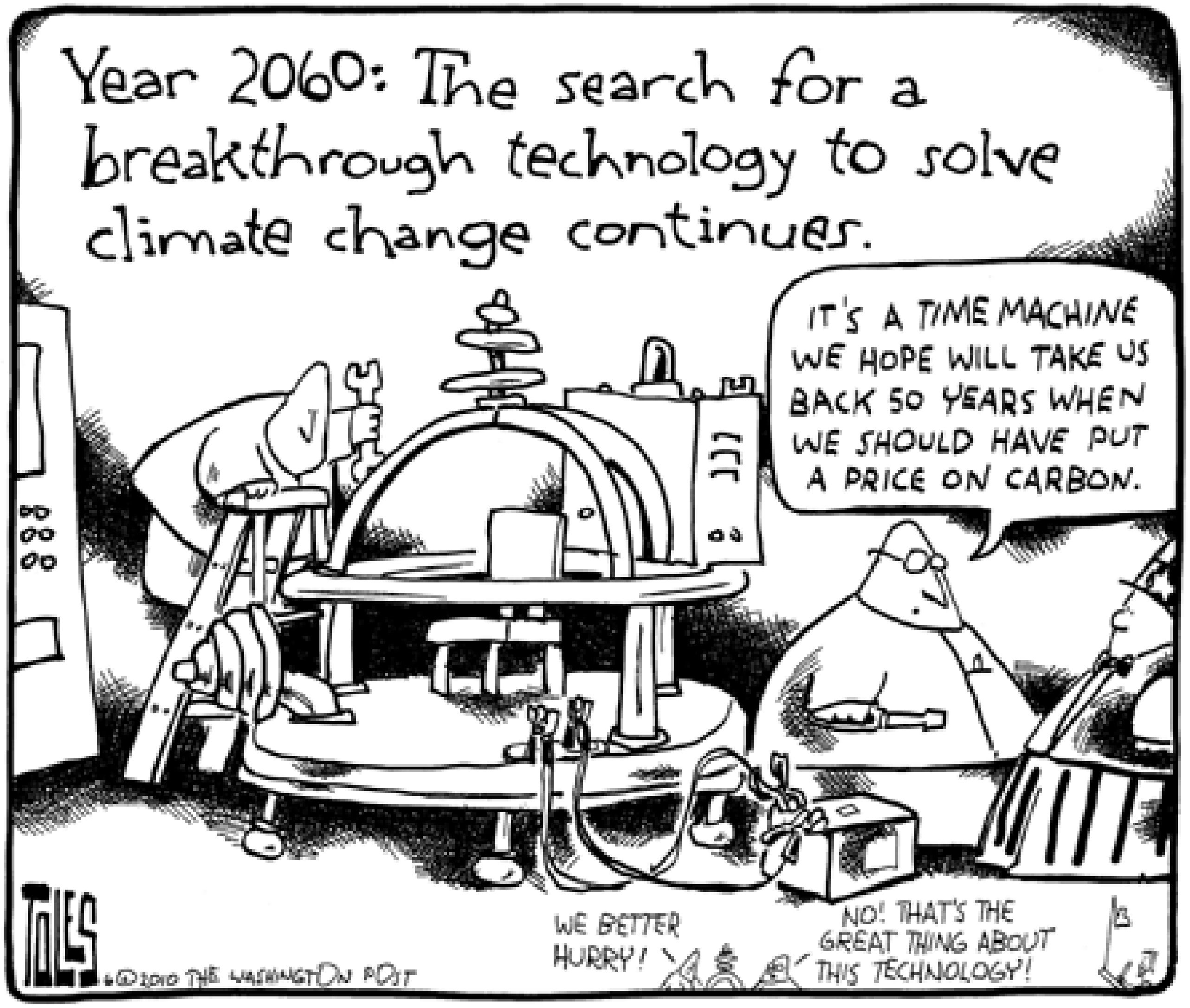
a powerful tool for conveying info and aligning incentives → → →

How should we choose between options?

- ***Quantify tradeoffs, share data***
- ***Account for spatial variation***
- ***Engage stakeholders****

*(*aka, all of us)*

McKinsey & Company (2010)



Not enough time to wait for perfect information!

Thanks!

Corpoica, The David and Lucile Packard Foundation, SCBI, GENESYS, Stanford University, University of Amsterdam, Global Climate and Energy Project (GCEP), and all of you!

Ian Monroe – Stanford University – imon@stanford.edu

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