Global Sustainable Bioenergy: Making it Work

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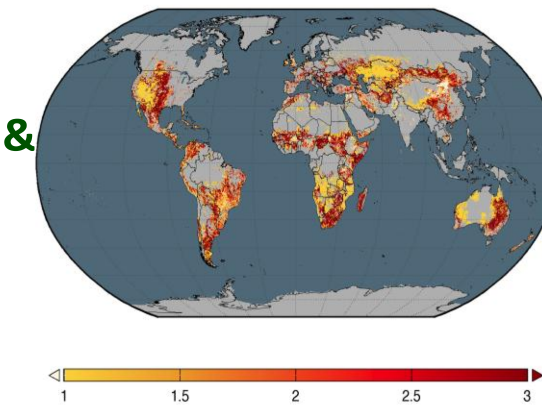
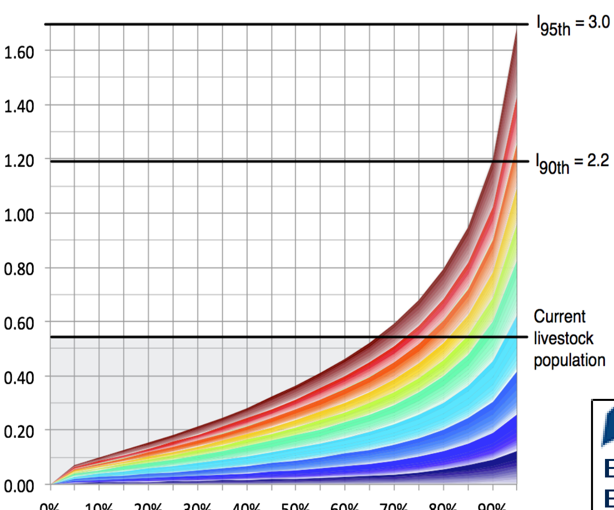


BIOEN-BIOTA-PFPMCG-SCOPE Biofuels & Sustainability Workshop

FAPESP
Sao Paulo, Brazil

February 26, 2013



I. Very large scale bioenergy: Discretionary or Obligatory?

II. 2^{nd} Gen Processing

III. Land

FAPESP
BIOEN-BIOTA-PFPMCG-SCOPE Joint Workshop on Biofuels & Sustainability
26/02/2013 - FAPESP - São Paulo

Very Large Scale Bioenergy: Discretionary or Obligatory?

IEA Energy Technology Perspectives June, 2012 http://www.iea.org.etp/

6^{o}C mean global temperature increase (6DS). Business as usual.

4 ^{o}C increase (4DS). Assumes adoption of a range of policies currently under consideration by governments worldwide.

2 ^{o}C increase (2DS).

Policies not specified. "Backcast" featuring aggressive, mutually-reinforcing measures:

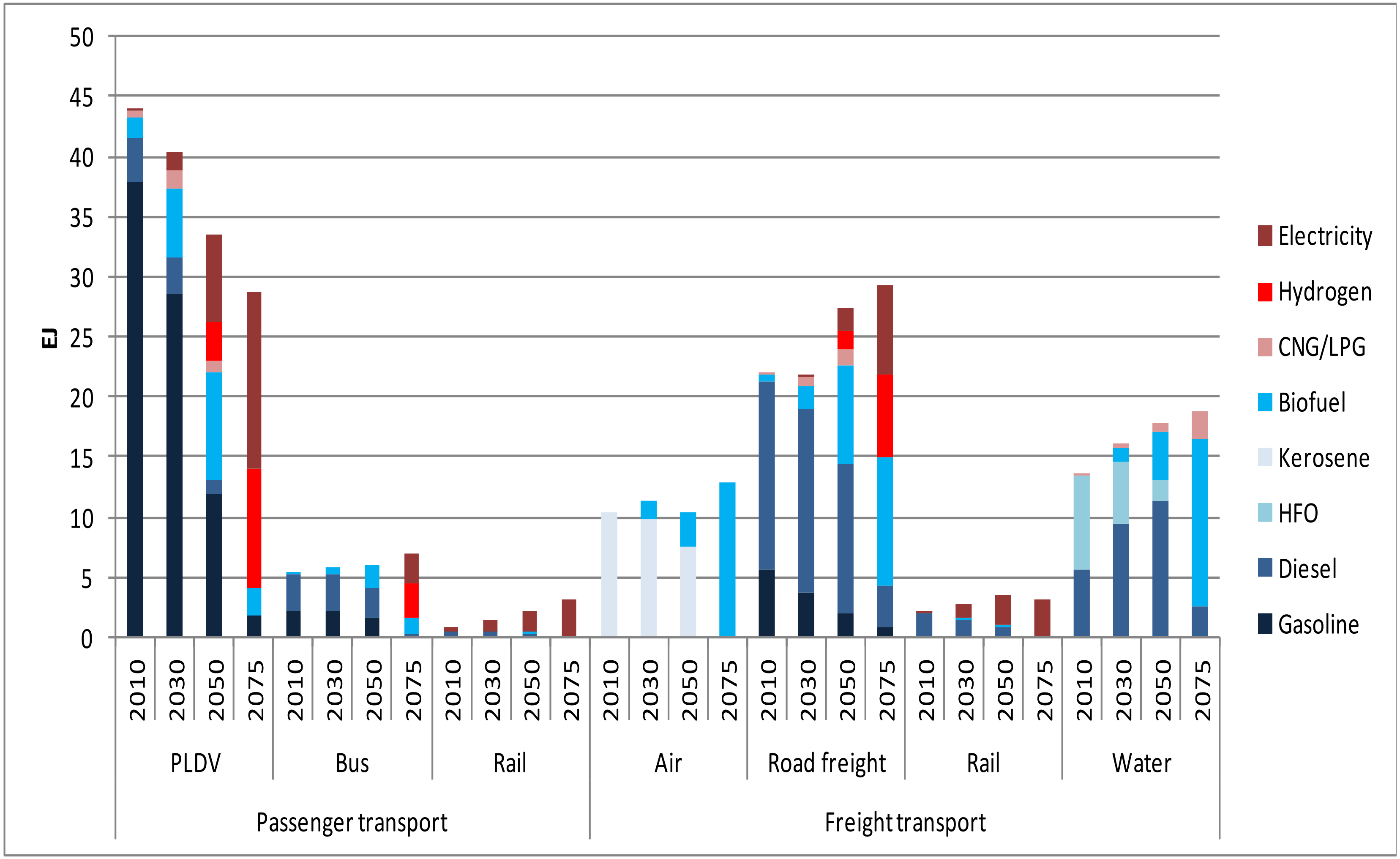
- ***Avoid*** energy use (decrease demand) via increased efficiency
- ***Shift*** from higher emission to lower emission modes (e.g. public transport, rail)
- ***Accelerate.*** Development and deployment of advanced, low-carbon technologies

About as little temperature increase as can be imagined

5.6^{o}C: Difference between the mean global temperature today & the last ice age

Very Large Scale Bioenergy: Discretionary or Obligatory?

Transport energy use by mode, vehicle type and fuel type, 2DS (Fulton et al., in prep.)

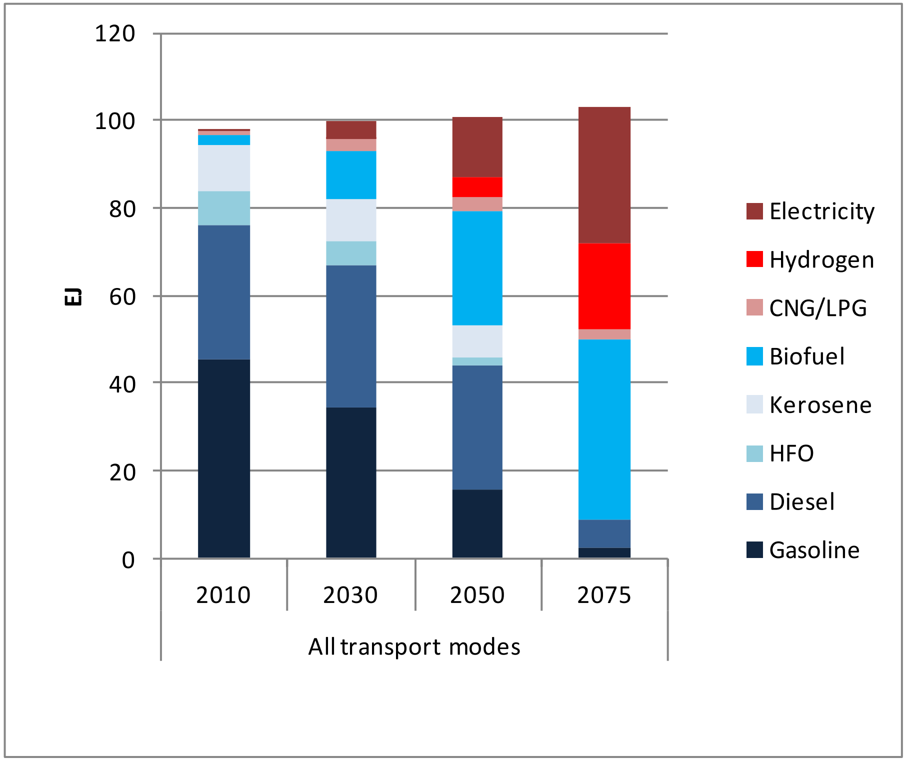


H2 + electricity, 2075: > 80% > 70% 100% 0% ~ 50% 100% 0%

Non-biofuel renewables used where they are likely to be feasible, biofuels for the rest.

Very Large Scale Bioenergy: Discretionary or Obligatory?

Aggregated transport energy use, 2DS (Fulton et al., in prep.)



Lots of time for non-biofuel renewables to overcome kinetic barriers by 2075. Further penetration faces steep technical hurdles.

Even with aggressive demand reduction, mode shifting, and market penetration by non-biofuel renewables, biofuels provide ~½ of transport energy in 2075

If fossil-derived liquids are used in lieu of biofuels, anticipated temperature increase from transport alone >2 ^{o}C

Carbon future	**Very large scale biofuel use**
Unconstrained	Discretionary
Constrained	Likely obligatory Very risky to plan without

What's Stopping Us?

Cost of processing 2nd gen feedstocks – the recalcitrance barrier

Concerns about land

2nd Gen Biofuels: Likely Necessary

Land Efficiency (GJ/ha)

- Sugar cane: Adding 2nd gen nearly doubles ethanol/ton
- Perennials > row crops
- Plants optimized for growth > plants optimized for ease of processing (e.g. maximizing sugar, starch, oil)
- Elegant integrated land use scenarios

Unlikely biofuels can provide needed global contribution without 2nd gen

Environment

- Residues → low carbon renewable process fuel → low ghg emissions
- Can improve soil & water quality

Broad site range

- Land too dry to grow row crops
- Land too cold to grow sugar cane

2^{nd} Gen Biofuels: Likely Doable

Cost-Competitive Feedstocks (now)

	($/Dry ton)	$/GJ	Equivalent Oil Price ($/bbl)
Cellulosic energy crops (e.g. grass)	60 to 80	4 to 5.3	23 to 31
Bagasse (brownfield)	40 to 60	2.6 to 4.0	13 to 19
Bagasse (greenfield with cogen)	~20	1.4	8

Cost-Competitive Processing (reasonable to expect in the future)

	Pretroleum	Cellulosic Biomass
Cost ($/GJ)	Feedstock (@ $100/bbl): **18** Processing: **6** **24**	Feedstock (@ $60/ton): **4** Allowable processing: **20**
Processing advantages	Fluid (more physically accessible)	More reactive chemical groups (more chemically accessible) Amenability to biotechnology

2nd Gen Biofuels: Necessary, Doable, Difficult

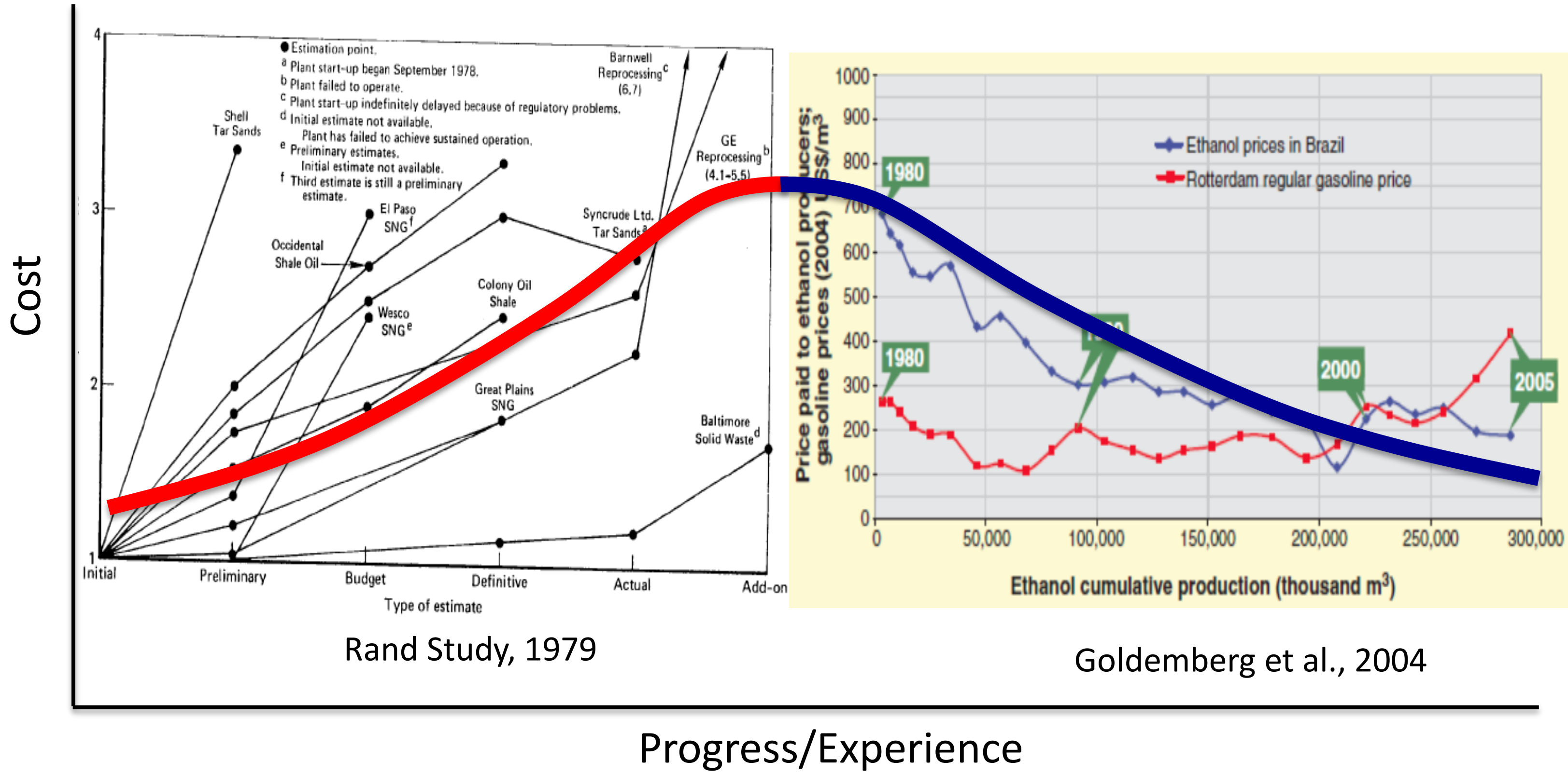
The Innovation Hump: From Initial Estimate to Nth Plant

Rand Curve

Estimated cost increases with experience, inversely related to ignorance

Brazil 1st Gen Ethanol Curve

Estimated cost decreases with experience



Rand Study, 1979

Goldemberg et al., 2004

2nd Gen Biofuels: Necessary, Doable, Difficult

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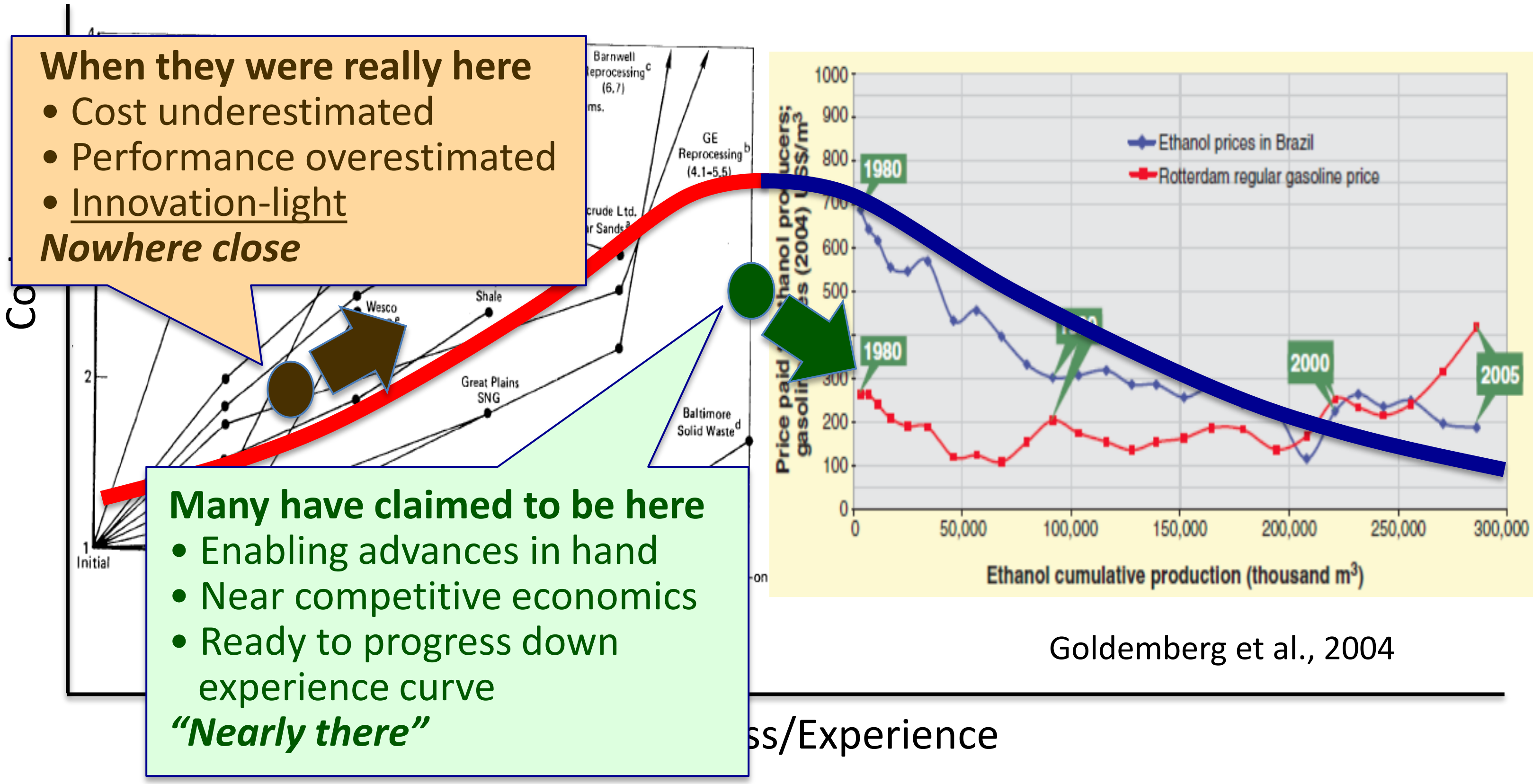


Goldemberg et al., 2004

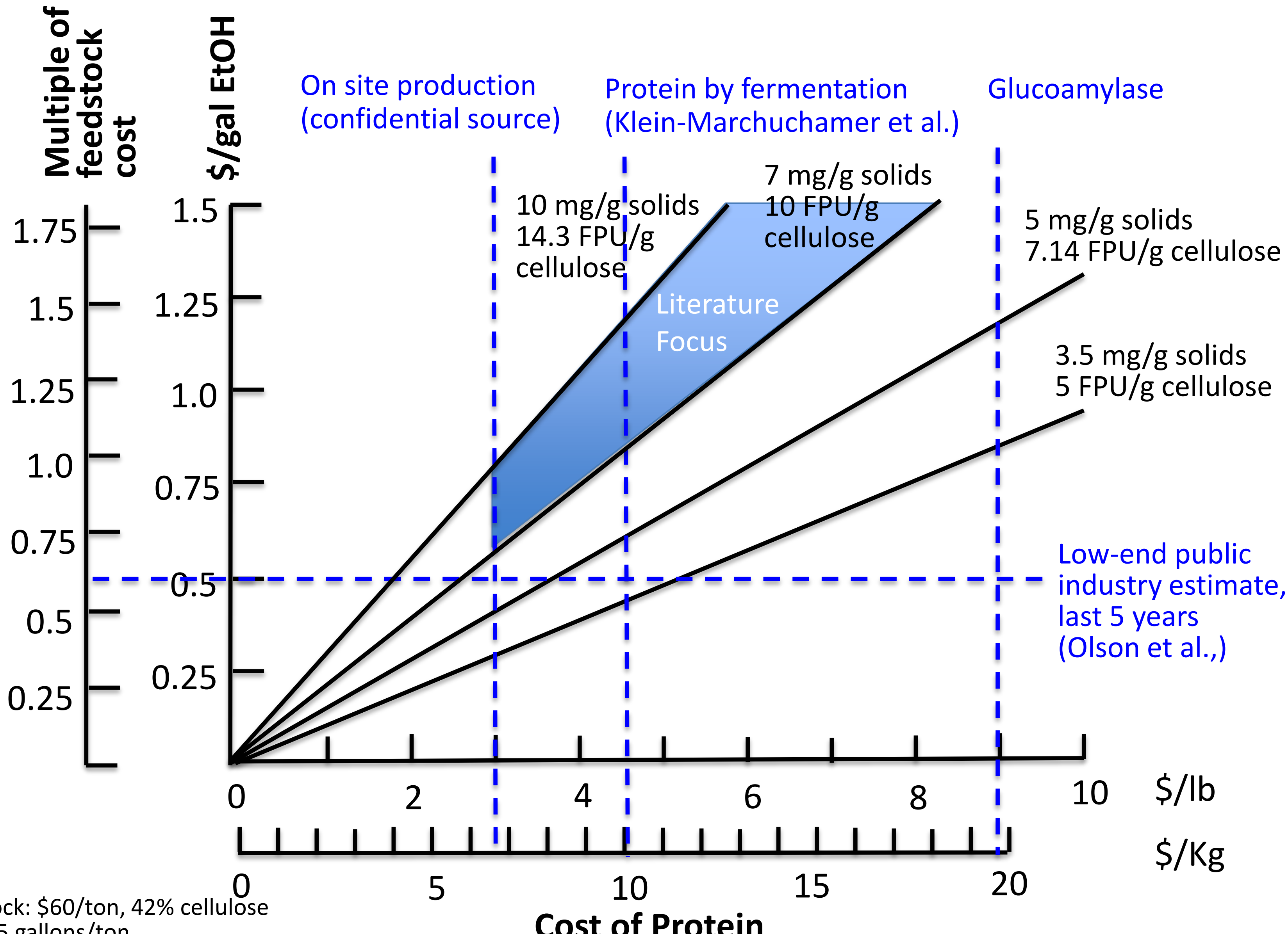
Needed

Aggressive innovation: Applied objectives→ Targeted understanding, new concepts

Commercial experience (learn by doing)

2nd Gen Biofuels: Necessary, Doable, Difficult

Cost of Added Cellulase

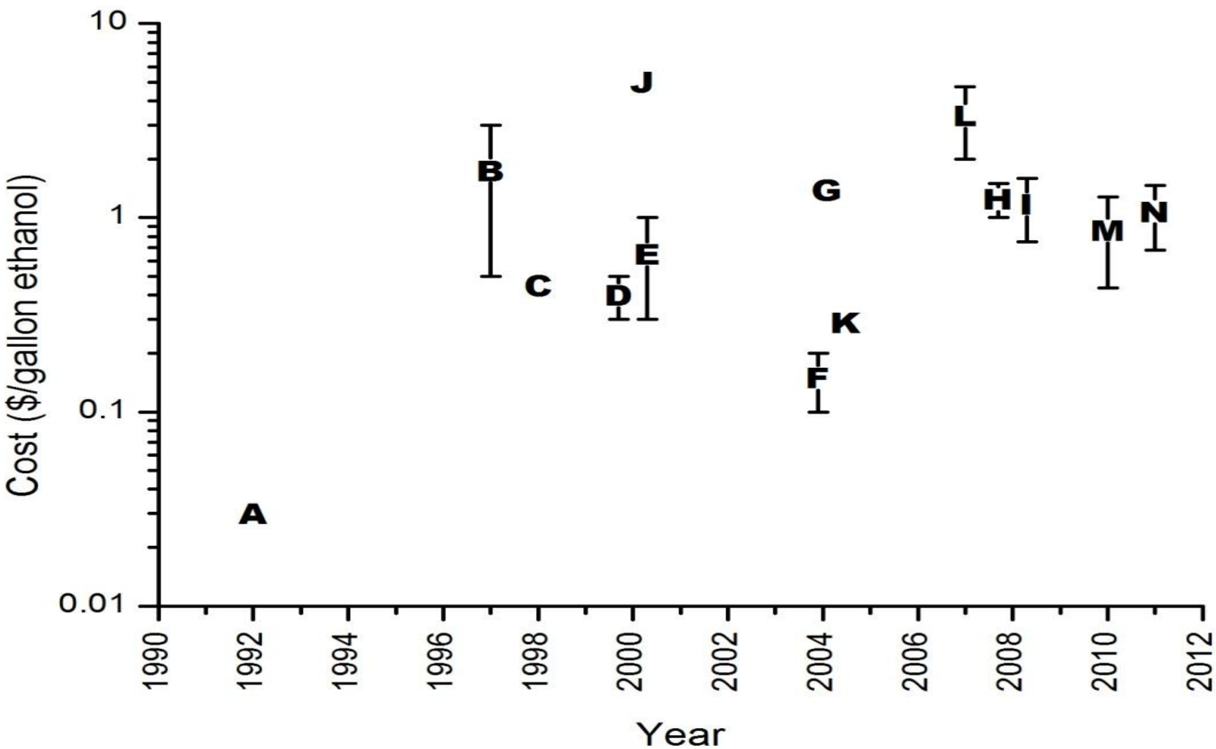


Feedstock: $60/ton, 42% cellulose
Yield: 75 gallons/ton

2^{nd} Gen Biofuels: Necessary, Doable, Difficult

Cost of Added Cellulase

Estimated Cost of Fungal Cellulase (Olson et al., Curr. Opin. Biotechnol., 2011)



A: Hinman 1992
B: Hettenhaus and Glasser 1997
C: Wiselogel 1998
D: Hettenhaus 2000
E: Tetarenko 2000
F: Nguyen 2004
G: Tuli 2004
H: Petiot 2008
I: Sheridan 2008
J: McMillan 2004
K: McMillan 2004
L: Bryant 2011
M: Bryant 2011
N: Klein-Marcuschamer et al 2011

After decades of research: Cost of catalyst ~= cost of feedstock

Prohibitive (and unprecedented) for a commodity process

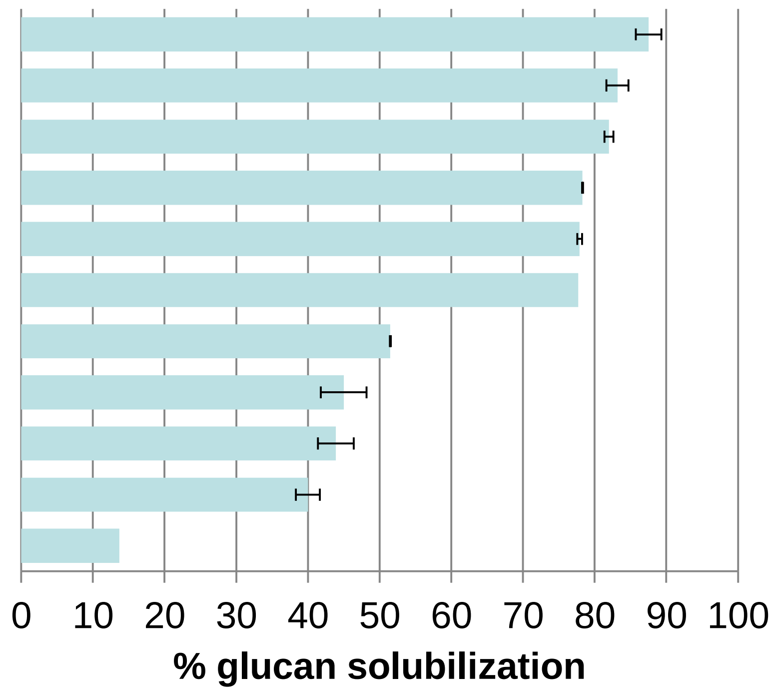
Designs with lower cellulase cost possible, but have cost penalties elsewhere in the process

2nd Gen Biofuels: Necessary, Doable, Difficult

Less well-studied approaches offer promise (thermochemical too)

Solubilization of unpretreated biomass feedstocks by *C. thermocellum (J. Paye, in prep.)*

	Max Particle Size (mm) .08	Max Particle Size (mm) ~1-2	Feedstock Growth stage mid	Feedstock Growth stage late	Washed	Partially optimized
Switchgrass		✓	✓			✓
Corn Stover		✓		✓		✓
Corn Cob		✓		✓		
Switchgrass		✓	✓		✓	✓
Winter Rye		✓	✓			
Bagasse		✓		✓		✓
Winter Rye		✓		✓		
Poplar	✓				✓	
Switchgrass	✓			✓		
Poplar	✓					
Poplar		✓				



- No added enzyme
- No pretreatment
- Controlled but not industrial conditions

What's Stopping Us?

Cost of processing 2nd gen feedstocks – the recalcitrance barrier

Concerns about land

Sustainable Solutions

Paths to a sustainable world (all resources, all sectors) entail

Doing things differently than we do them now. It is not reasonable to expect an extrapolated future to be different from the present

A systemic approach. Multiple mutually-reinforcing approaches used to achieve multiple mutually-reinforcing objectives

Increased efficiency along all steps in the supply chain

We need to think about land the way we think about energy

Integrated production (e.g. electricity and heat, ethanol and electricity)

Efficiency

Energy & Land Efficiency

Compared to Energy Efficiency, Land-Efficiency has Received Much Less Attention

Energy efficiency

Importance recognized for decades.

THE NEGAWATT REVOLUTION
Amory B. Lovins
Using existing technology, says this expert,
we can save three fourths of all electricity used today.
The Conference Board Magazine
XXVII, September 1990

Well-recognized public policy objective.

For immediate release
July 29, 2011
President Obama Announces Historic 54.5 mpg Fuel Efficiency Standard.

Public awareness, if not practice, widespread.

Land efficiency

Few countries have policies aimed at promoting land-efficient food production & consumption.

Scant motivation (most of last century)

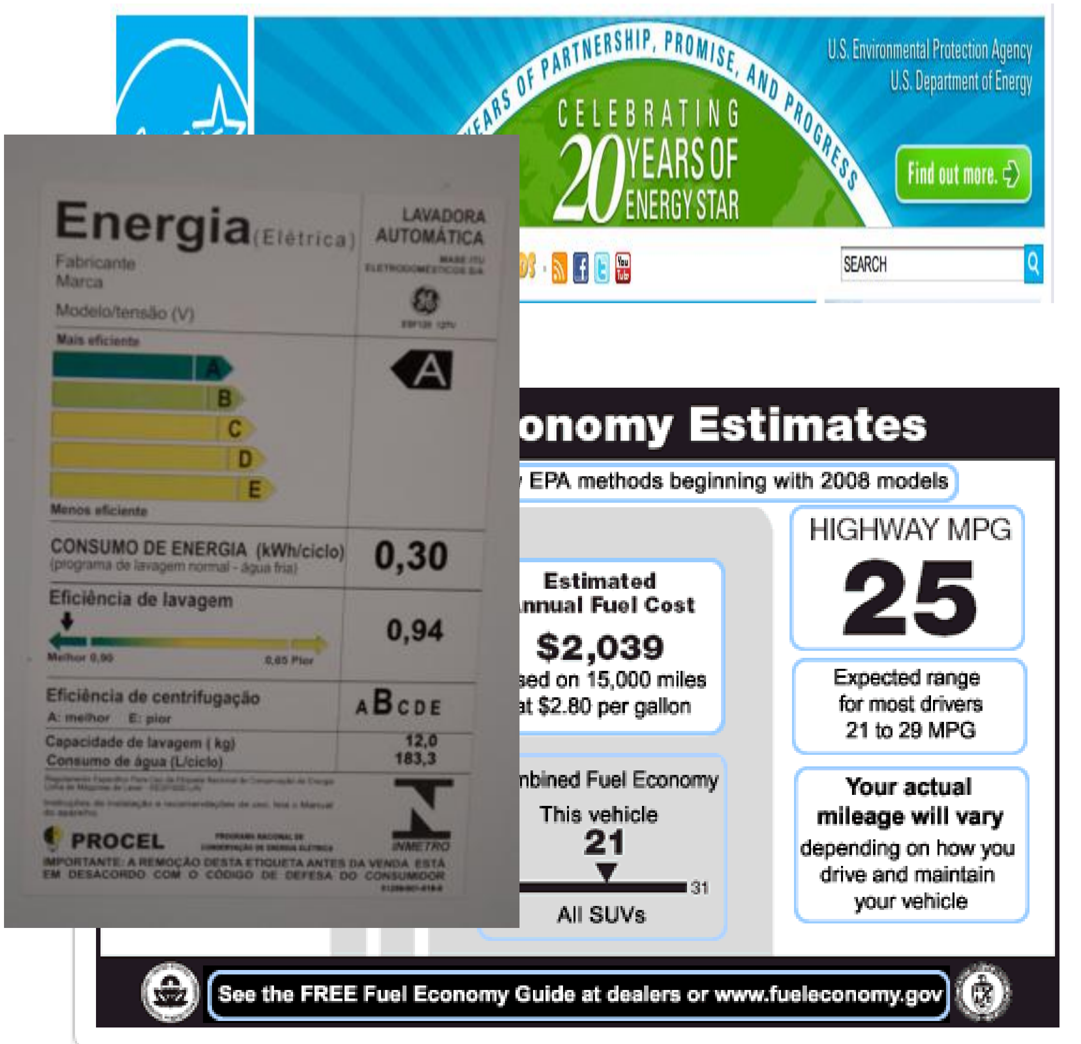
- Crop prices low
- Main policy challenge: Support farm prices in the face of excess capacity

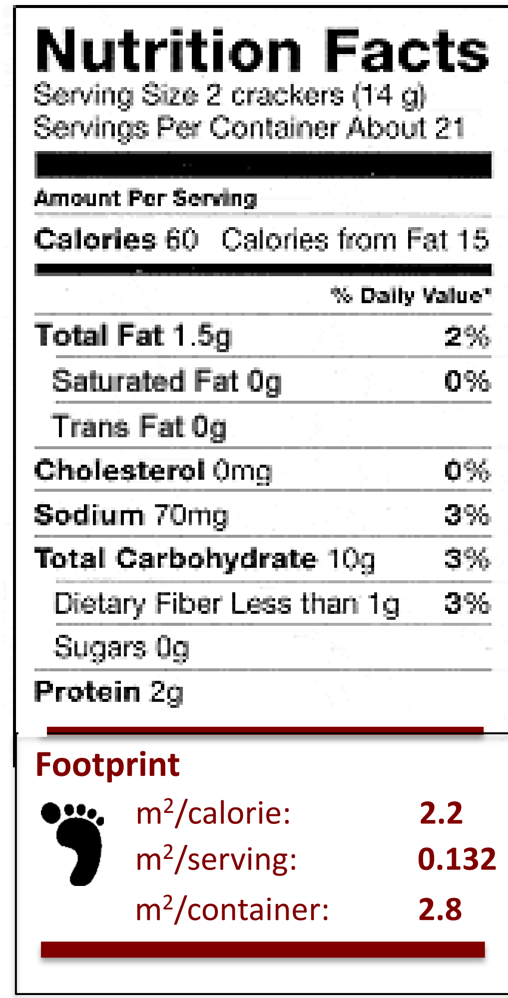
This is changing however

Energy & Land Efficiency

Compared to Energy Efficiency, Land-Efficiency has Received Much Less Attention

Energy efficiency – Evident to Consumers **Land efficiency – Not evident**





Land Utilization & Intensification

Analytical approach well established for row crops (Global Landscapes Initiative, U. Minnesota)

Climate binning

"Bin" land with similar properties (e.g. precipitation, degree days), inventory current production in each bin, order from low to high

Premise: Yields within a bin are attributable to factors other than climate, notably management

Intensification potential

Yield at x^{th} high percentile: Y_x

e.g. Y_{90} or Y_{95}

Actual yield: Y_A

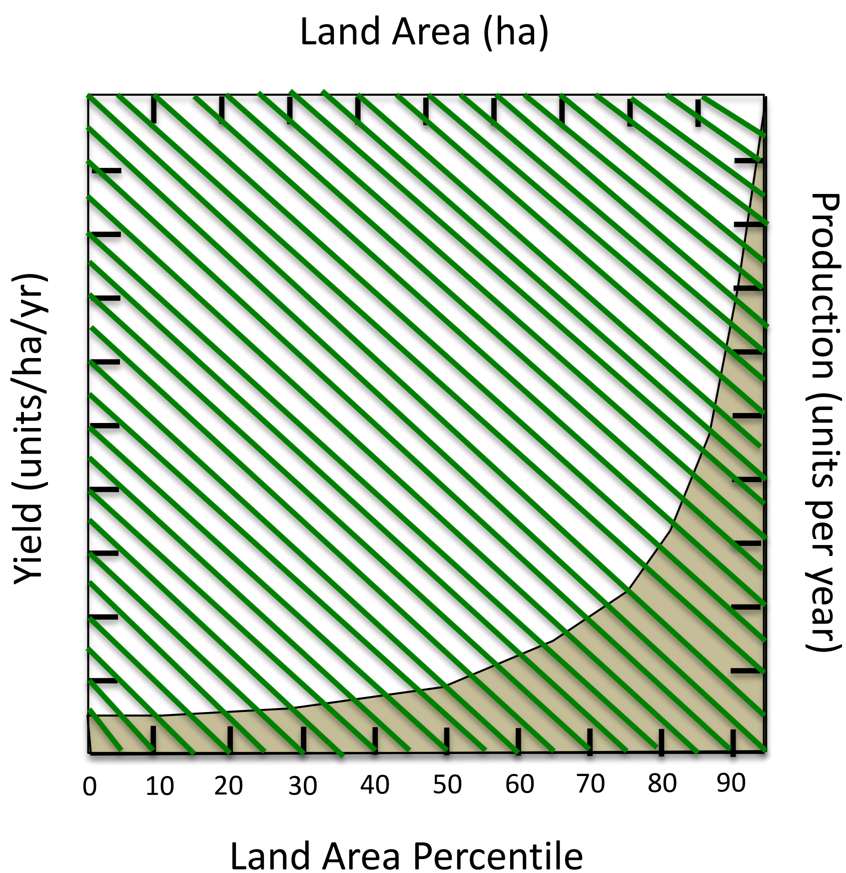
Yield gap: $G_x = Y_x - Y_A$

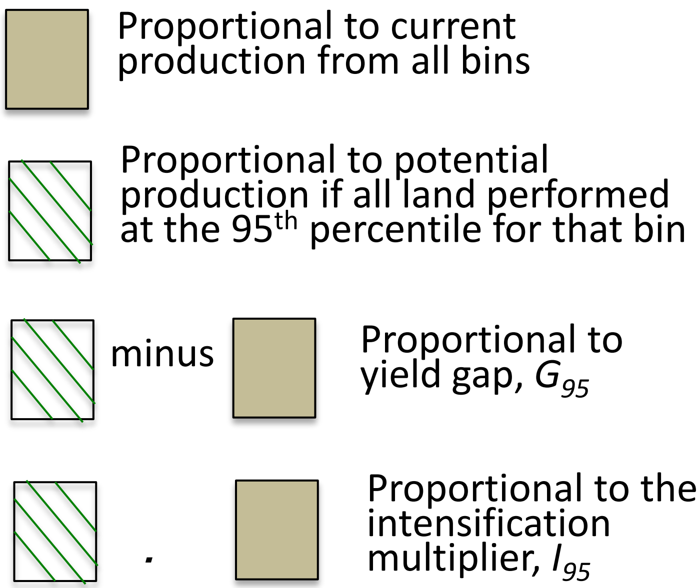
Intensification potential: $I_x = \frac{Y_x}{Y_A} = \frac{1}{1 - G_x}$

But has not been reported for pasture, livestock

Land Utilization & Intensification

Visualization of Yield Gaps and Intensification Potentials



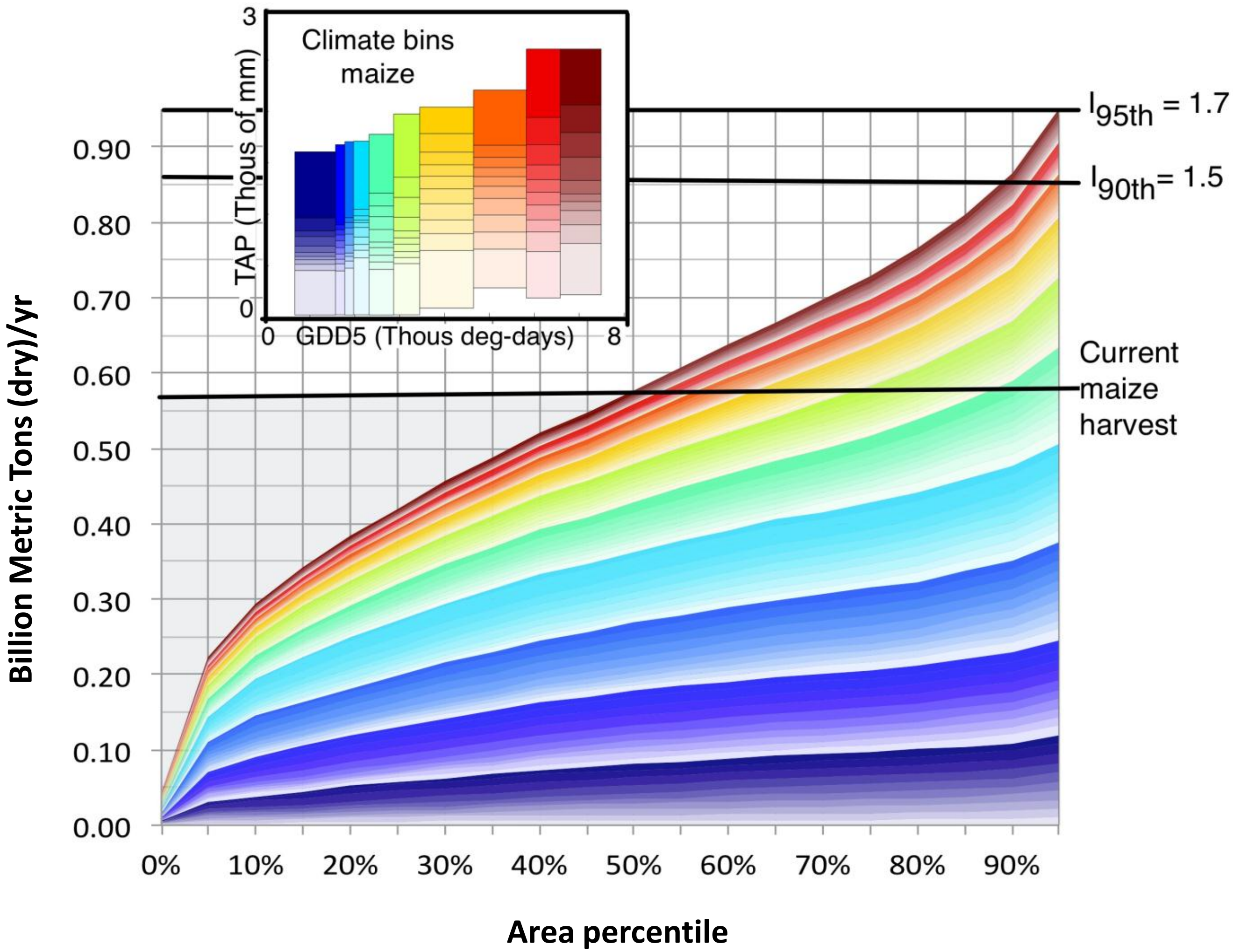


I_{95} for this example ~ 5.8

Informs the question "Is the world full?"

Land Utilization & Intensification

Maize Yield Distribution Plot



Morishige et al., in preparation

GLOBAL LANDSCAPES INITIATIVE
INSTITUTE ON THE ENVIRONMENT

UNIVERSITY OF MINNESOTA
Driven to Discover℠

Aggregate global maize intensification potential: 1.5 to 1.7

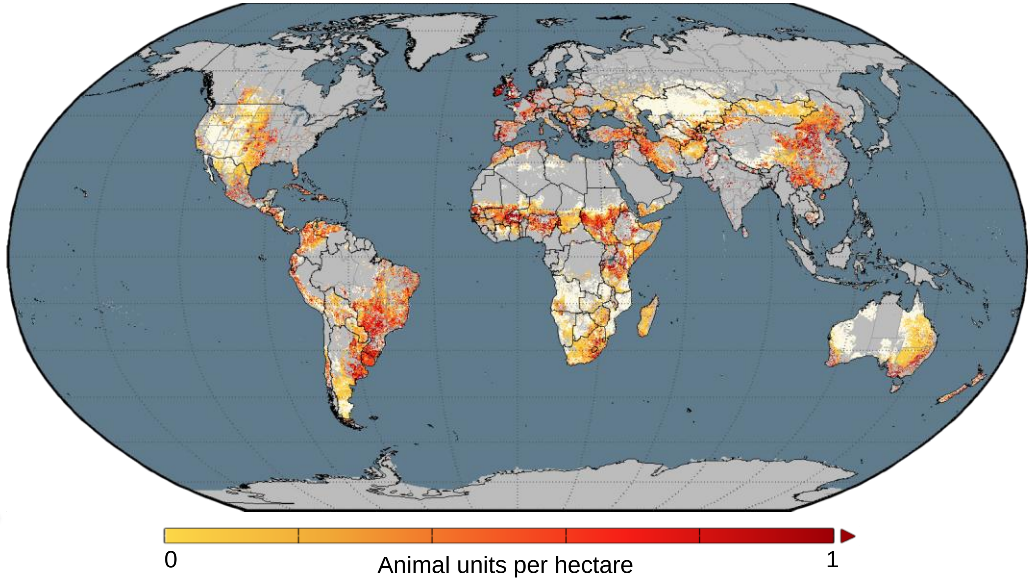
Land Utilization & Intensification

Applying the climate binning approach to pasture intensification

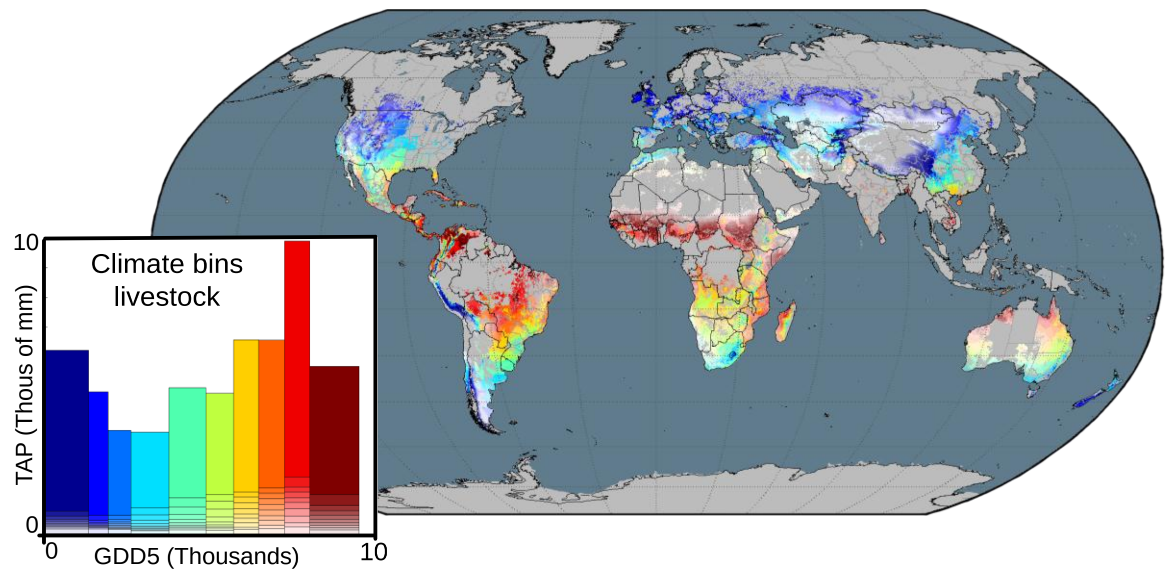
FAO Gridded Livestock (2007)

Ramunkutty et al. "M3" Land Classification (2008)

≤ 3 Animal Units (AU)/ha filter (cattle, sheep, and goats)



A. Geospatial distribution of livestock on pastureland



B. Geospatial distribution of climate bins and pastureland

Land Utilization & Intensification

Binned Pasture Data

Livestock Population

	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
P10	8.12	17.1	13.0	12.0	12.0	12.0	7.75	7.52	6.11	8.17
P09	4.83	6.13	10.1	15.1	12.8	5.53	6.67	11.0	6.49	8.45
P08	4.34	5.55	8.44	12.7	9.93	5.50	7.14	8.10	6.75	10.4
P07	3.88	3.67	6.50	8.66	8.57	5.49	4.69	5.39	6.06	11.1
P06	3.64	2.56	4.30	5.48	6.73	4.07	4.97	4.87	5.21	10.6
P05	3.11	1.99	2.04	4.22	4.96	2.31	4.16	5.97	5.56	9.75
P04	2.87	1.70	1.85	3.45	3.69	2.26	2.99	5.58	7.01	8.17
P03	2.97	2.04	1.98	1.68	3.19	1.65	1.97	3.13	6.79	5.89
P02	2.26	2.08	2.35	0.90	4.13	1.87	1.22	1.59	2.63	3.12
P01	2.82	2.39	2.56	3.07	1.69	1.17	1.54	2.12	2.98	1.58

Global total: 543 x 10^6 AU

Stocking Density of Occupied Pasture

	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
P10	0.52	0.86	0.61	0.55	0.55	0.60	0.43	0.45	0.37	0.40
P09	0.27	0.38	0.44	0.66	0.56	0.47	0.45	0.56	0.35	0.40
P08	0.26	0.33	0.37	0.56	0.43	0.26	0.50	0.49	0.33	0.48
P07	0.28	0.26	0.32	0.43	0.38	0.26	0.36	0.39	0.32	0.49
P06	0.29	0.23	0.29	0.31	0.32	0.19	0.31	0.33	0.33	0.46
P05	0.24	0.21	0.25	0.25	0.27	0.14	0.24	0.34	0.46	0.42
P04	0.21	0.19	0.27	0.25	0.26	0.14	0.20	0.32	0.48	0.40
P03	0.19	0.19	0.34	0.18	0.22	0.14	0.15	0.21	0.45	0.31
P02	0.15	0.14	0.26	0.16	0.27	0.16	0.27	0.23	0.26	0.20
P01	0.17	0.15	0.27	0.36	0.21	0.17	0.21	0.27	0.29	0.19

Global average: 0.35 AU/ha

Fraction Pastureland Occupied by Animals

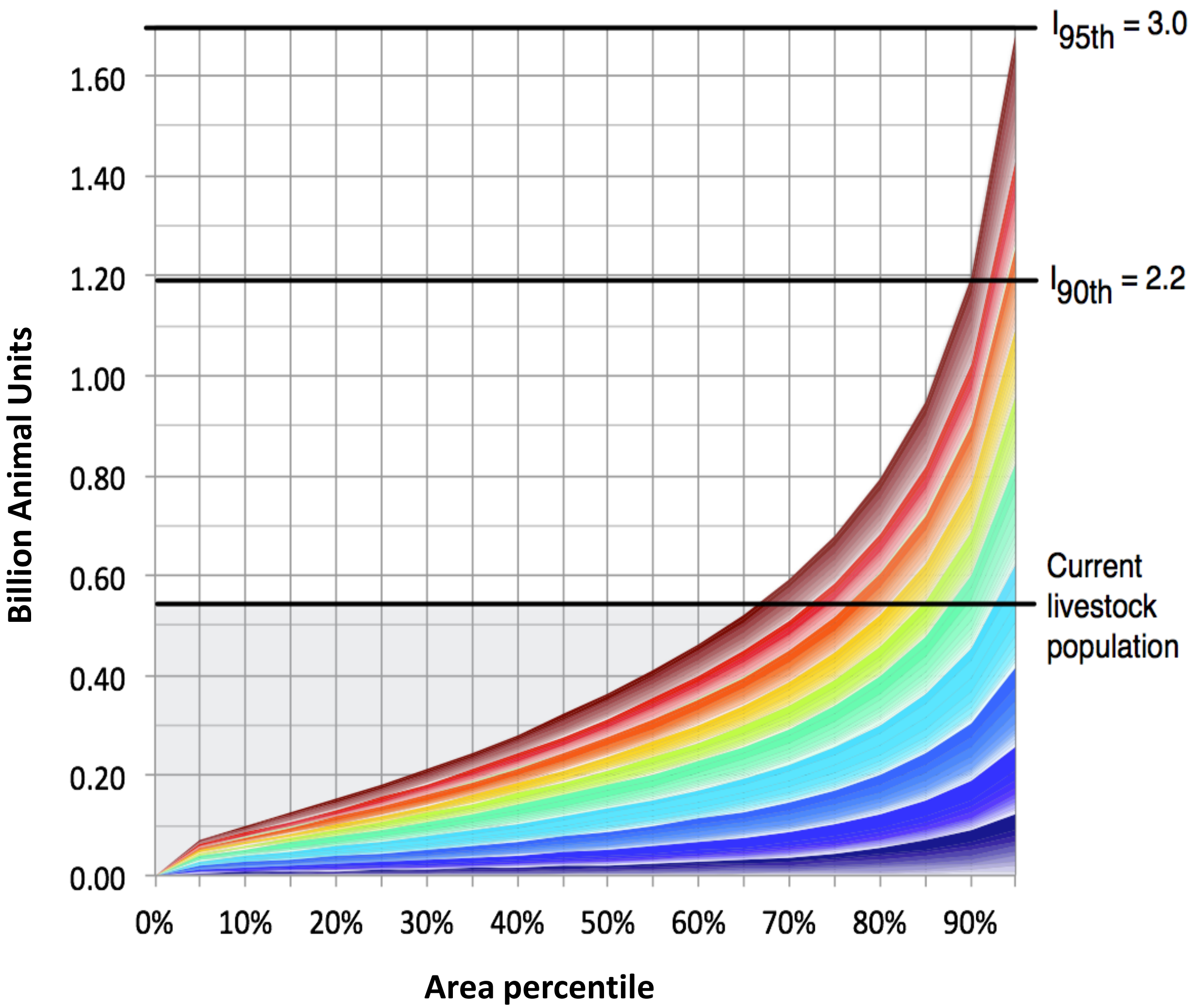
	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
P10	0.60	0.77	0.82	0.85	0.85	0.77	0.70	0.65	0.64	0.78
P09	0.70	0.62	0.89	0.90	0.89	0.45	0.57	0.76	0.72	0.82
P08	0.66	0.65	0.86	0.88	0.89	0.83	0.55	0.64	0.80	0.85
P07	0.54	0.54	0.80	0.78	0.88	0.83	0.50	0.54	0.74	0.89
P06	0.50	0.44	0.57	0.68	0.81	0.84	0.62	0.57	0.61	0.90
P05	0.49	0.36	0.32	0.65	0.72	0.65	0.66	0.68	0.47	0.89
P04	0.54	0.35	0.26	0.54	0.56	0.64	0.59	0.67	0.56	0.80
P03	0.59	0.41	0.23	0.34	0.57	0.47	0.49	0.57	0.59	0.73
P02	0.60	0.56	0.35	0.23	0.59	0.45	0.18	0.27	0.39	0.61
P01	0.64	0.61	0.37	0.34	0.31	0.27	0.28	0.31	0.40	0.33

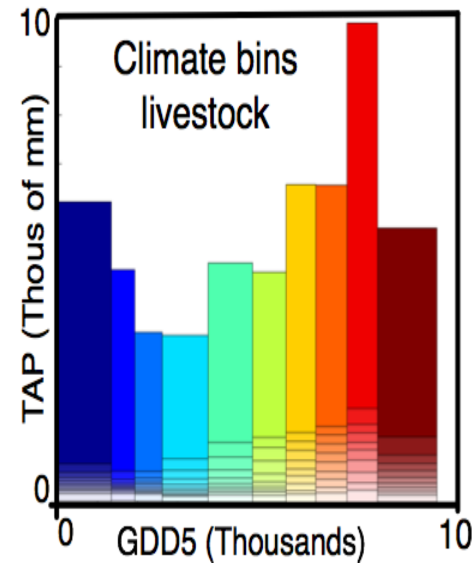
60 % occupied
40 % not occupied

Morishige et al., in preparation

Land Utilization & Intensification

Pasture Stocking Distribution Plot





Preliminary estimate of aggregated global pastured livestock intensification potential: 2.2 to 3.0

Not counting unoccupied pastureland

Morishige et al., in preparation

Land Utilization & Intensification

	Global Area (10^9 ha)	% Food Calories (US)[1]	Key Constraints	Intensification Potential
Cropland	1.5	**>98**	Food security	Significant but much or all needed for food
Forestland	3.9	--	Habitat Stored carbon	Plantations: Yes Unmanaged forests: No
Pastureland	3.4	**<2**	Much less evident	Preliminary analysis: Large

[1]Land areas from unhttp://faostat.fao.org/site/377/default.aspx#ancor. [2]Davis et al., in preparation;

Opportunities for graceful integration of bioenergy production into cropland agriculture and forestry exist, should be pursued in cases where key constraints can be honored, and can offer a distinctive set of benefits.

Graceful integration opportunities also exist for pasture – e.g. mixed crop/pasture systems

Land Utilization & Intensification

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Pastureland appears to be a particularly promising source of bioenergy feedstocks

- Large land base
- Less evident constraints, potential competing priorities
- Likely larger intensification potential (remains to be confirmed)

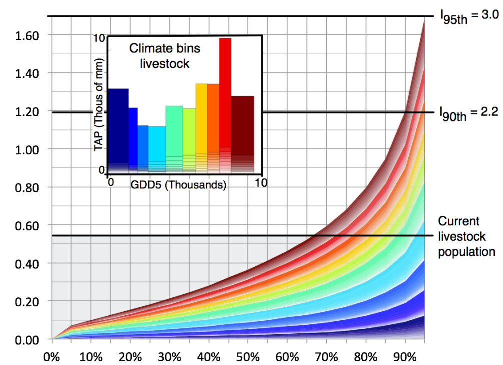
There are however large outstanding uncertainties. Land use and land cover data is limited generally, and this is particularly the case for pasture

High priority area for further study

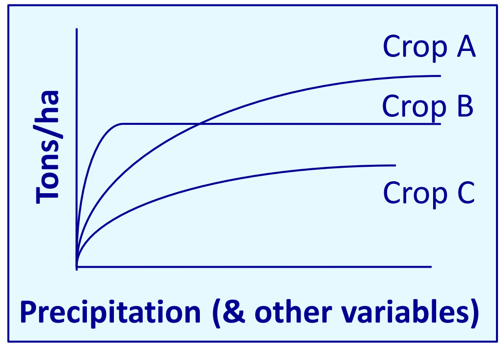
Land Utilization & Intensification

Future path of GSB pasture analysis (illustrative)

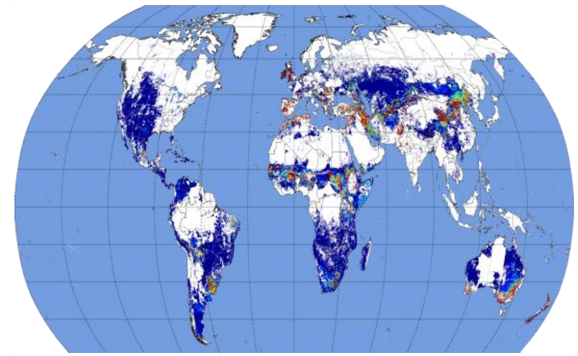
Climate binning pasture analysis

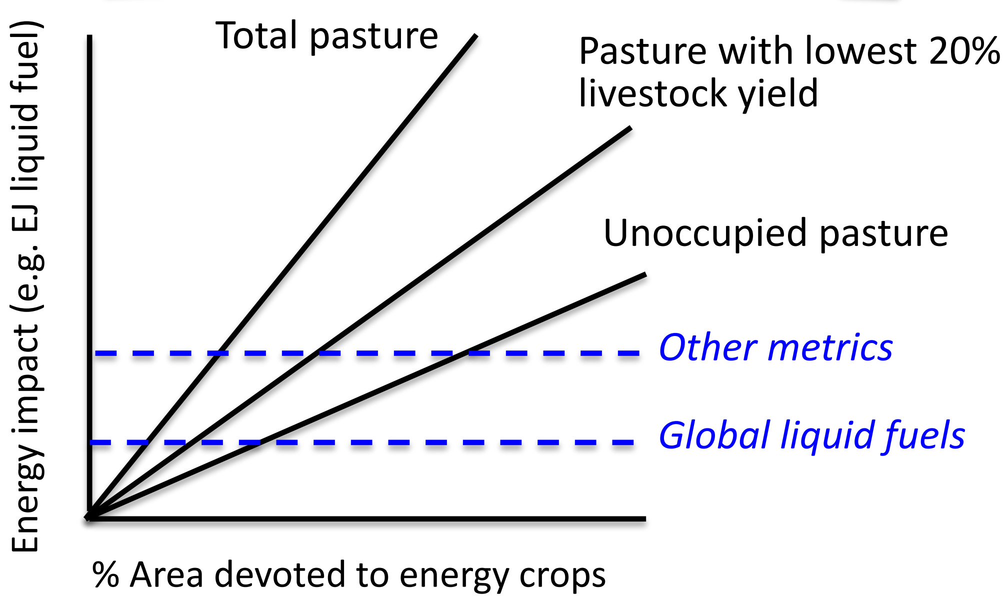


Global energy crop model



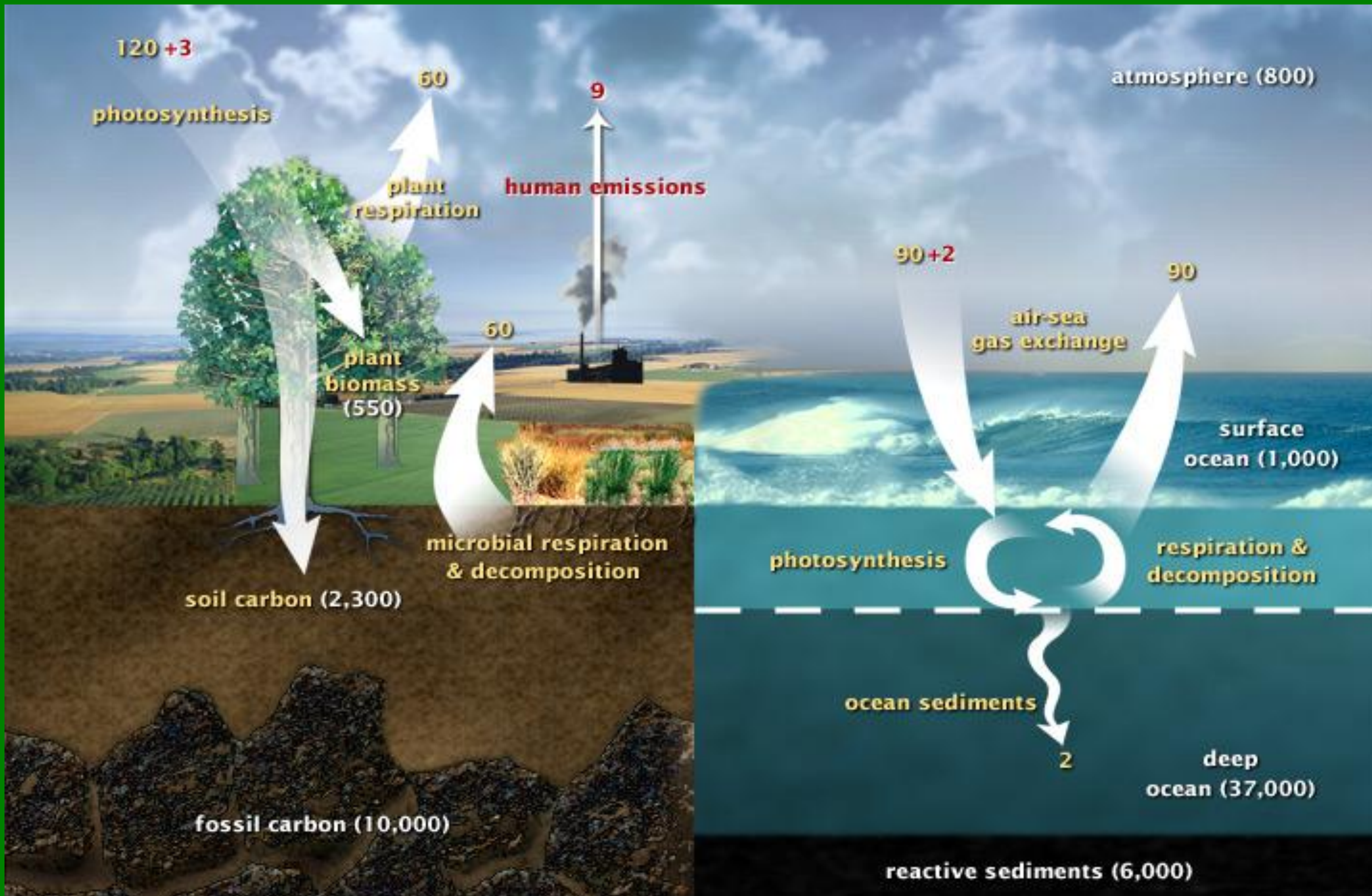
Improved data bases
(land use/cover, livestock)





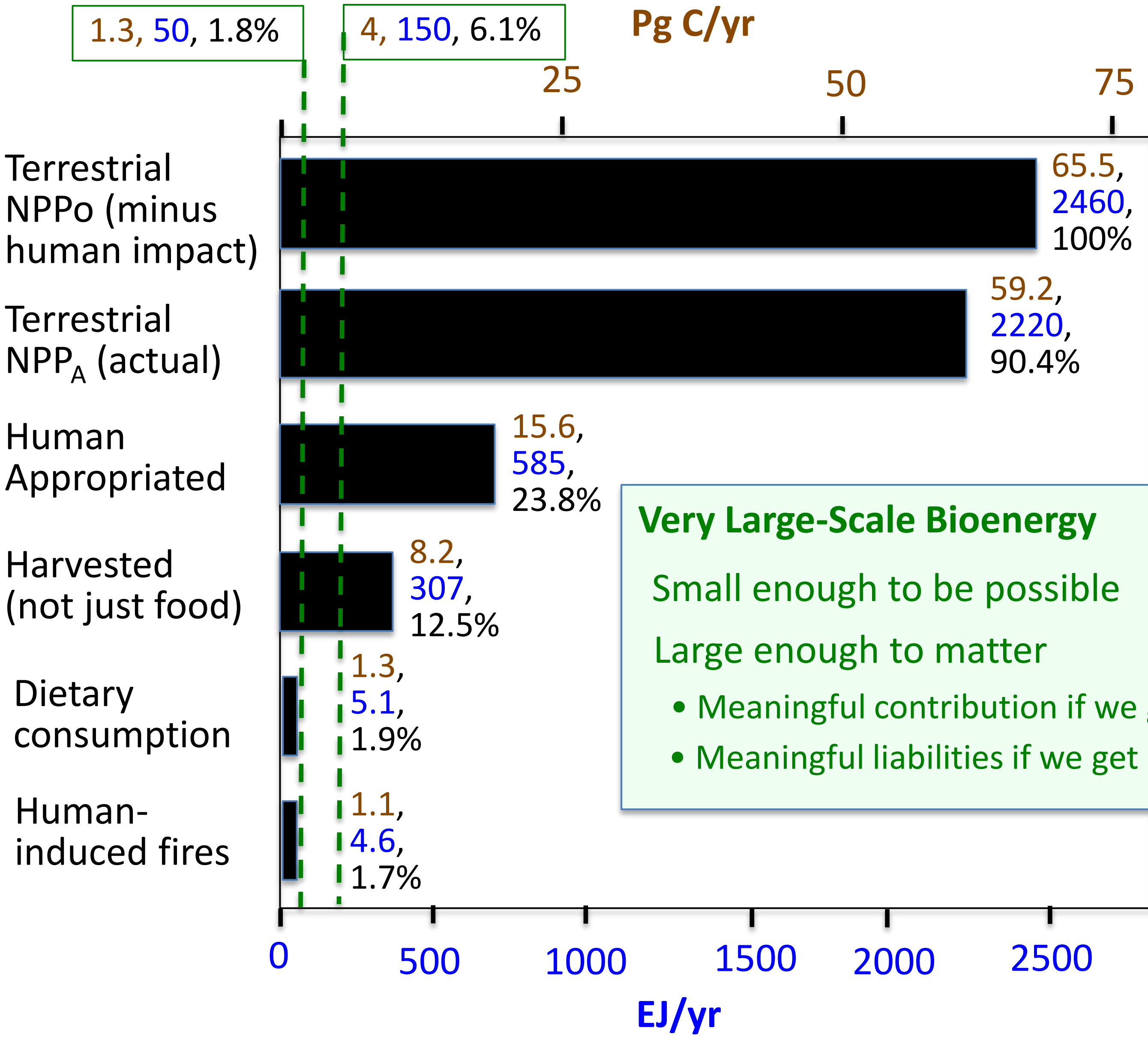
- Many scenarios
- Climate-explicit binning framework readily accommodates climate change

The Carbon Cycle



10^9 tons (Pg) C per year. Yellow: natural fluxes. Red: human contributions. White: Stored.
http://earthobservatory.nasa.gov/Features/CarbonCycle/

Bioenergy in the Context of Biogeochemical Carbon & Energy Flows



150 EJ
~ 25% primary energy supply in IEA low-carbon scenarios

50 EJ
½ mobility demand in IEA low-carbon scenarios

Very Large-Scale Bioenergy

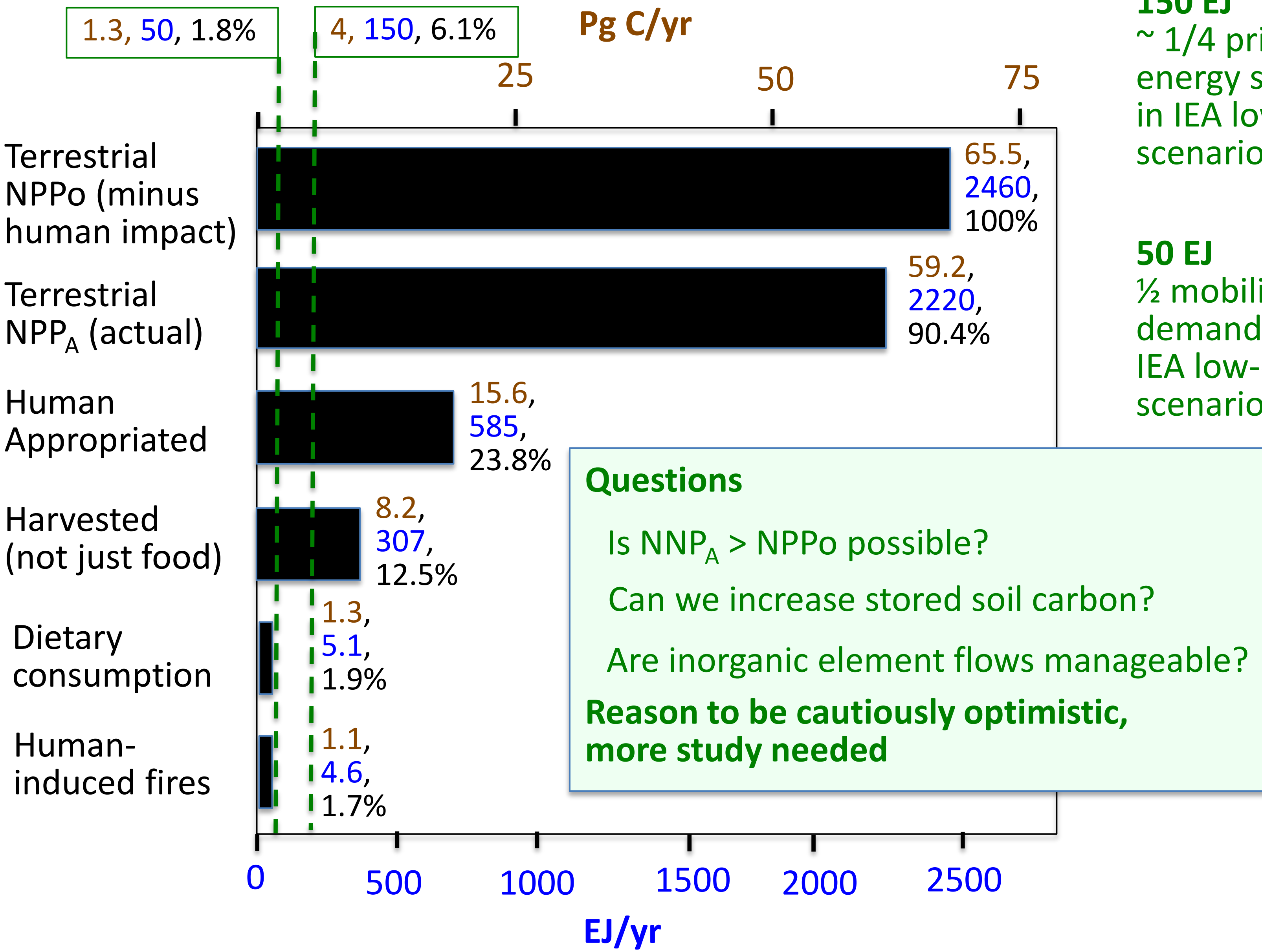
Small enough to be possible

Large enough to matter

- Meaningful contribution if we get it right
- Meaningful liabilities if we get it wrong

From Haberl et al. 2007. PNAS 104:12942-12947, except dietary data from Vitousek et al. 1986. Bioscience 36: 368-373, updated for a population of 7 billion. IEA scenarios: Blue Map, ETP 2010; 2DS, ETP 2012; Personal communication, Lew Fulton.

Bioenergy in the Context of Biogeochemical Carbon & Energy Flows



Questions

Is NNP_A > NPPo possible?

Can we increase stored soil carbon?

Are inorganic element flows manageable?

Reason to be cautiously optimistic, more study needed

150 EJ
~ 1/4 primary energy supply in IEA low-carbon scenarios

50 EJ
½ mobility demand in IEA low-carbon scenarios

From Haberl et al. 2007. PNAS 104:12942-12947, except dietary data from Vitousek et al. 1986. Bioscience 36: 368-373, updated for 7 a population of 7 billion. IEA scenarios: Blue Map, ETP 2010; 2DS, ETP 2012; Personal communication, Lew Fulton.

Global Sustainable Bioenergy (GSB) Project

(http://bioenfapesp.org/gsb/)

GSB

Global Sustainable Bioenergy

Focus	Model Development			Socioeconomic		Environmental		Integrated Analyses & Scenarios	
	Livestock Productivity	Energy Crop	Biofuel Production	Food security	Social Welfare & Economic Development	Soil Fertility	Water & GHG	Making Room for Biofuels	Multiple benefits
Global									
Local, "LACAf"* Countries									

*Latin America, Caribbean, and Africa

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GSB project: Board members Brito Cruz, Martin Keller, Luuk van der Weilen. And many others