Gracefully Reconciling Large-Scale Bioenergy Production With Competing Demands

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Twice in history, major changes in the resources used by humanity have resulted in transformative changes in day-to-day life and societal organization, appropriately called revolutions

		Agricultural Revolutions		Industrial Revolution
	Hunting & Gathering	➔	**Preindustrial Agricultural** ➔	**Presustainable Industrial**
		~ 4000 BC…		1750 AD…
Population:		50 million		750 million
Duration:		Millennia		Several centuries
Scale of societal integration/ collapse:	Small groups		Farms/ villages	Cities/countries

Lynd, Bioenergy: In Search of Clarity, Submitted.

Today: There are abundant indications that a third revolution is required

	Agricultural Revolution	Industrial Revolution	**Sustainability Revolution**
	~ 4000 BC…	1750 AD…	**2010… ?**

Hunting & Gathering → **Preindustrial Agricultural** → **Presustainable Industrial** → **Sustainable Industrial**

Population:	50 million	750 million	**~7 billion**
Duration:	Millennia	Several centuries	**< a century**

Scale of societal integration/ collapse: Small groups | Farms/ villages | Cities/countries | **Global**

The sustainability revolution: More people, less time, higher risk

The defining challenge of our time

Lynd, Bioenergy: In Search of Clarity, Submitted.

The Sustainability Revolution

Our circumstances are changing radically

Past: Few resource constraints, low prices, resource capital

Future: Multiple resource constraints, high prices, resource income

Big systemic challenges require big systemic solutions

Viable paths to a sustainable world (all sectors, resources)

Almost never feature

- Single, isolated changes
- New supply without increased resource utilization efficiency

Almost always feature

Multiple, large, complementary and currently improbable changes

Embracing the improbable

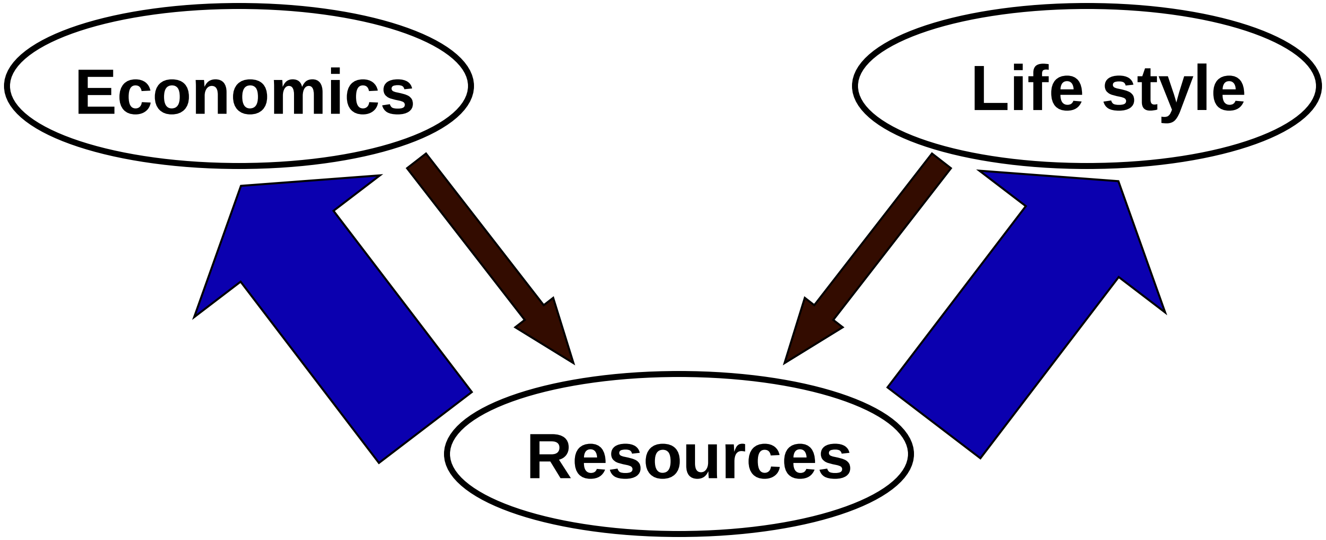
Currently probable trends are not sustainable

We must thus look beyond such trends to find sustainable futures

Business as usual is a fantasy rather than a baseline

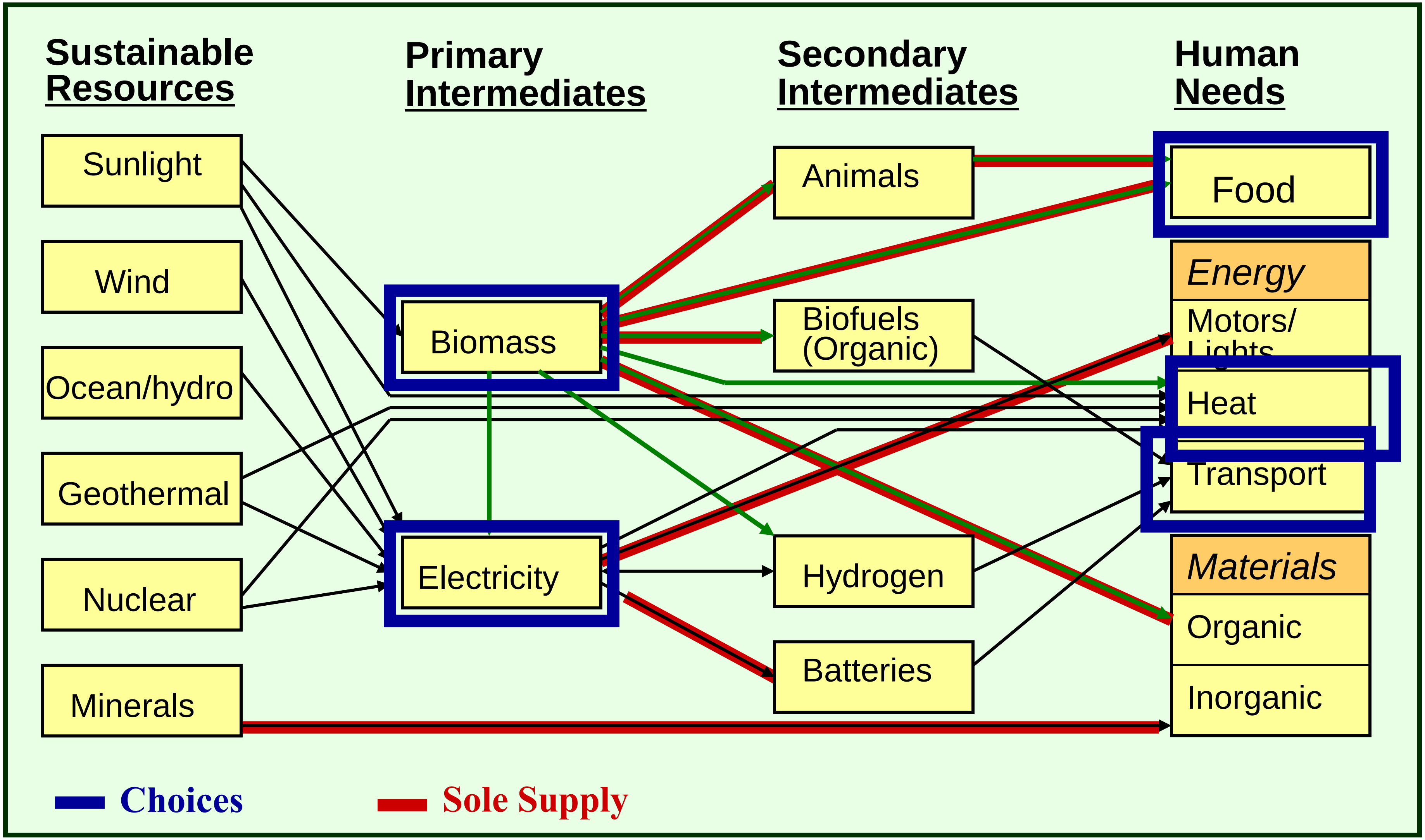
The first step in realizing currently improbable futures is to show that they are possible

We often think and plan based on economics and lifestyle choices determining resource consumption, which does occur in the short term



Over longer time periods, history clearly teaches us that the dominant direction of cause and effect is in fact the reverse: resource use and availability determine economics and lifestyle

Imagining a Sustainable World



Biomass

Central and essential role in a sustainable world

The only foreseeable sustainable source of food, organic fuels, and organic materials

Feedstocks: Dominant Determinants of Cost, Scale, Sustainability

	1st Generation (Deployed Now)				2nd Generation	
	Sugar Cane	Maize	Oil seeds	Palm Oil	Cellulosic	Algae
Feedstock production						
Rural economic development	Very favorable	Very favorable	Very favorable	Very favorable	Very favorable	Favorable
Low cost	Very favorable	Favorable	Very unfavorable	Favorable	Very favorable	Very unfavorable
Land efficiency (fuel/ha)	Favorable	Favorable	Very unfavorable	Favorable	Very favorable	Very favorable
Geographical range	Unfavorable	Favorable	Favorable	Unfavorable	Very favorable	Favorable
Sustainability & Environmental						
Manageable process effluents	Very favorable	Very favorable	Very favorable	Very favorable	Very favorable	Very favorable
Water quality & soil fertility	Favorable	Unfavorable	Unfavorable	Favorable	Very favorable	Unfavorable
GHG emission reduction	Very favorable	Unfavorable	Very favorable	Very favorable	Very favorable	Very favorable
Potential responsiveness to food/habitat concerns	Favorable	Very unfavorable	Very unfavorable	Very unfavorable	Very favorable	Very favorable
Processing cost (current)	Very favorable	Very favorable	Very favorable	Very favorable	Unfavorable	Favorable

Very favorable
Favorable
Unfavorable
Very unfavorable

- Sugar cane: Most meritorious of 1st gen. feedstocks, range restricted.
- Cellulosic biomass: Focus of all studies foreseeing very large-scale, widespread biofuel production
- Algae: Some distinctive & attractive features, worthy of study. The potential for algae production at a cost per unit energy $\leq$ foreseeable petroleum prices has not been presented.

Comparative Purchase Price of Energy Carriers

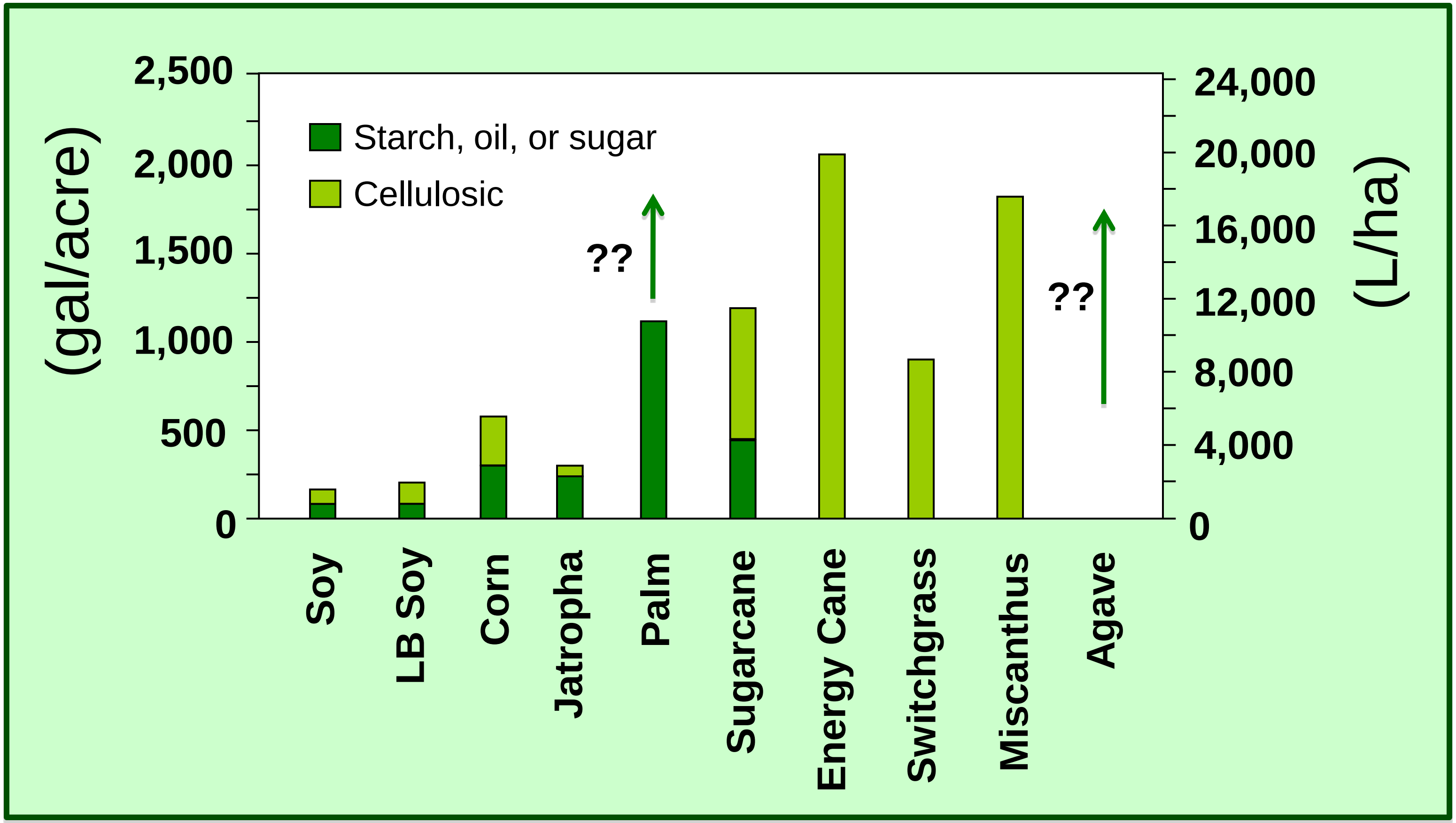
Energy Carrier	Representative Purchase Price: Common Units	$/GJ
Fossil		
Petroleum	$70/bbl	12.6
Natural gas	$10/kscf	11
Coal	$55/ton	2.5
w/ carbon capture @	$150/ton C	6.5
Electricity	$0.045/kWh	11 (generated)
	$0.085/kWh	23 (delivered)
Biomass		
Soy oil	$0.50/lb	30
Corn kernels	$3.5/bu	10
Sugar cane	$93/ton	6.0
Cellulosic crops[a]	$60/ton	4.0
Cellulosic residues		Most < 4

[a] e.g. switchgrass, short rotation poplar

Modified from Lynd et al., Nature Biotech., 2008

At $4/GJ, the purchase price of cellulosic biomass is competitive with oil at $23/bbl.

Comparative Land Productivity of Bioenergy Feedstocks



Acknowledging uncertainties & simplifications in single-valued representations, robust conclusions about land-efficient biofuel production can be drawn

Harvest the whole plant

Grow plants with composition optimized for photosynthesis rather than accumulation of sugar, starch, or oil

Fundamental rather than incidental

Bioenergy and CO_2 Emissions

Potential for a carbon-neutral cycle
Carbon must be removed from the atmosphere by photosynthesis before biomass can be converted to fuel/electricity and exit a tailpipe/smokestack

Potential for carbon-negative cycle
Soil carbon accumulation - e.g. with perennial crops - can sequester carbon, as can CO_2 recovery from processing facilities

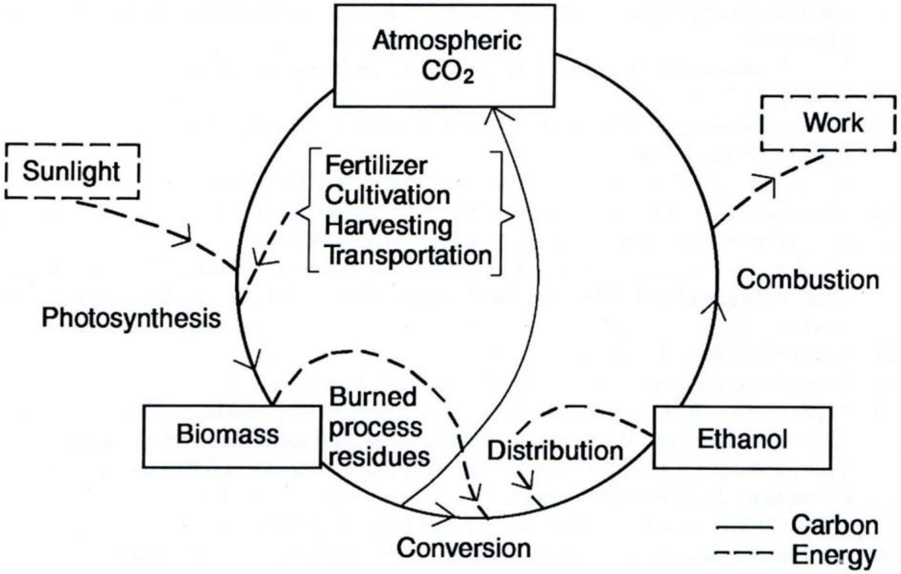


Fig. 2. Carbon and energy flows for production and utilization of fuel alcohol from biomass. [Adapted from (*53*) with permission of Humana Press, copyright 1989]

Lynd et al., Science, 1991

Tailpipe carbon capture not practical for mobile applications

Realization of the low carbon potential of bioenergy requires

Use low-carbon sources for process energy, e.g. process residues,

Avoid large carbon emissions in the course of land clearing

Notwithstanding its potential, anticipation and realization of large-scale cellulosic bioenergy production are impeded by two key factors:

Recalcitrance of cellulosic biomass

Difficulty of converting cellulosic biomass to reactive intermediates such as sugars or synthesis gas, addressable by improved processing technology

Land use concerns

Competition with food supplies

Carbon emissions & habitat loss from clearing of wild lands

Could we produce enough biomass to meaningfully impact “mega challenges”?

Focus of GSB, this talk

Strong Negative Assessments

"Use of biomass energy as a primary fuel in the United States would be impossible while maintaining a high standard of living" (Giampetro & Pimentel, 1990)

Power density of photosynthesis is too low for biofuels to have an impact on greenhouse gas reduction (Hoffert et al., 2002)

"Any substantial increase in biomass harvesting for the purpose of energy production would deprive other species of their food sources and cause the collapse of ecosystems worldwide" (Huesemann, 2004)

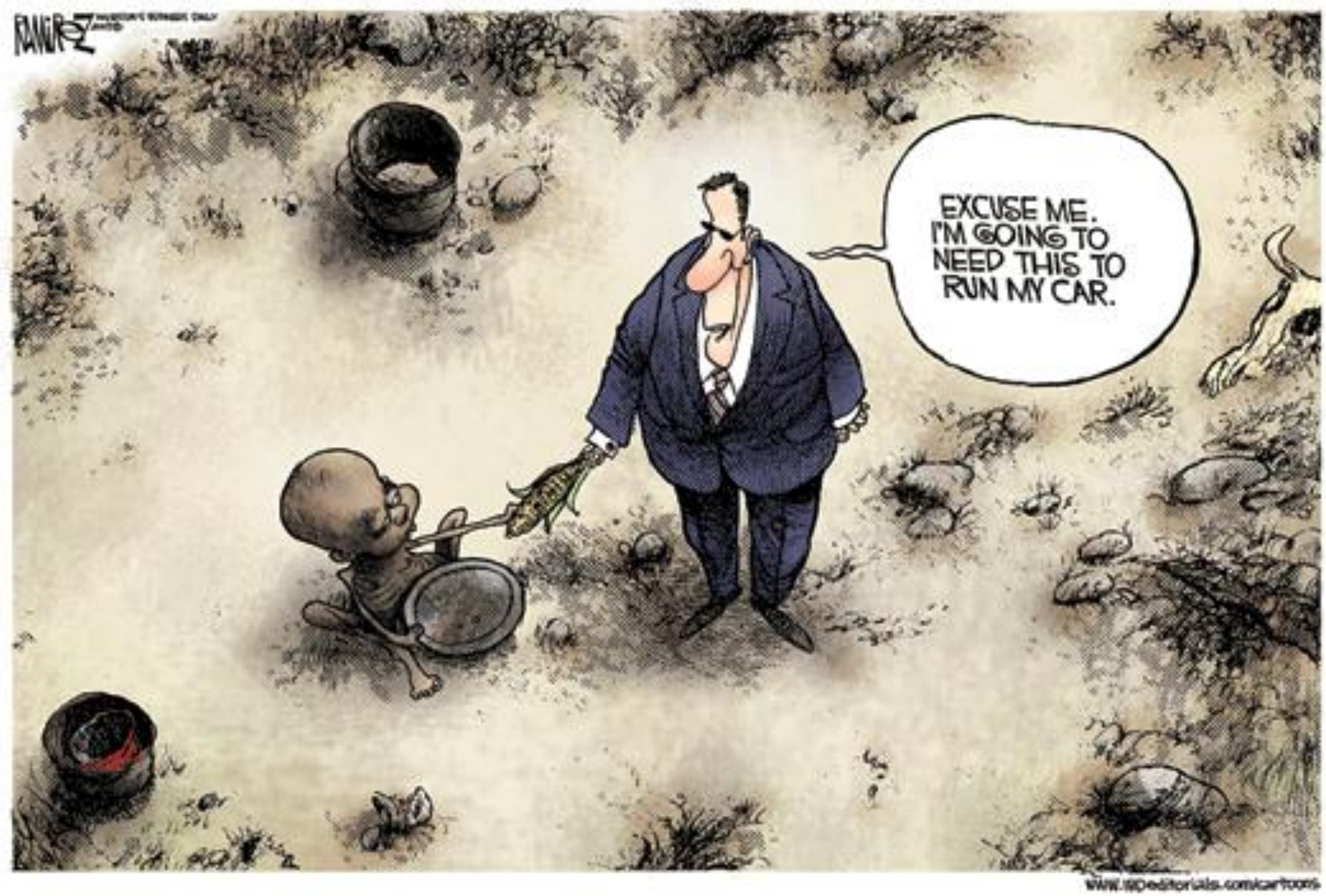
Impractically large land requirements for biomass energy production on a scale comparable to energy/petroleum use (Trainer, 1995; Kheshgi, 2000; Avery, 2006)

"National governments should cease to create new mandates for biofuels and investigate ways to phase them out." (Organization for Economic Cooperation and Development, August 2008)

"Mandating the use and production of these fuels without fully understanding their effect on food production and the environment - as current US biofuel policy does - is irresponsible and dangerous." (Statement by 5 environmental groups calling for biofuel policy revamp, 2009).

Strong Negative Assessments

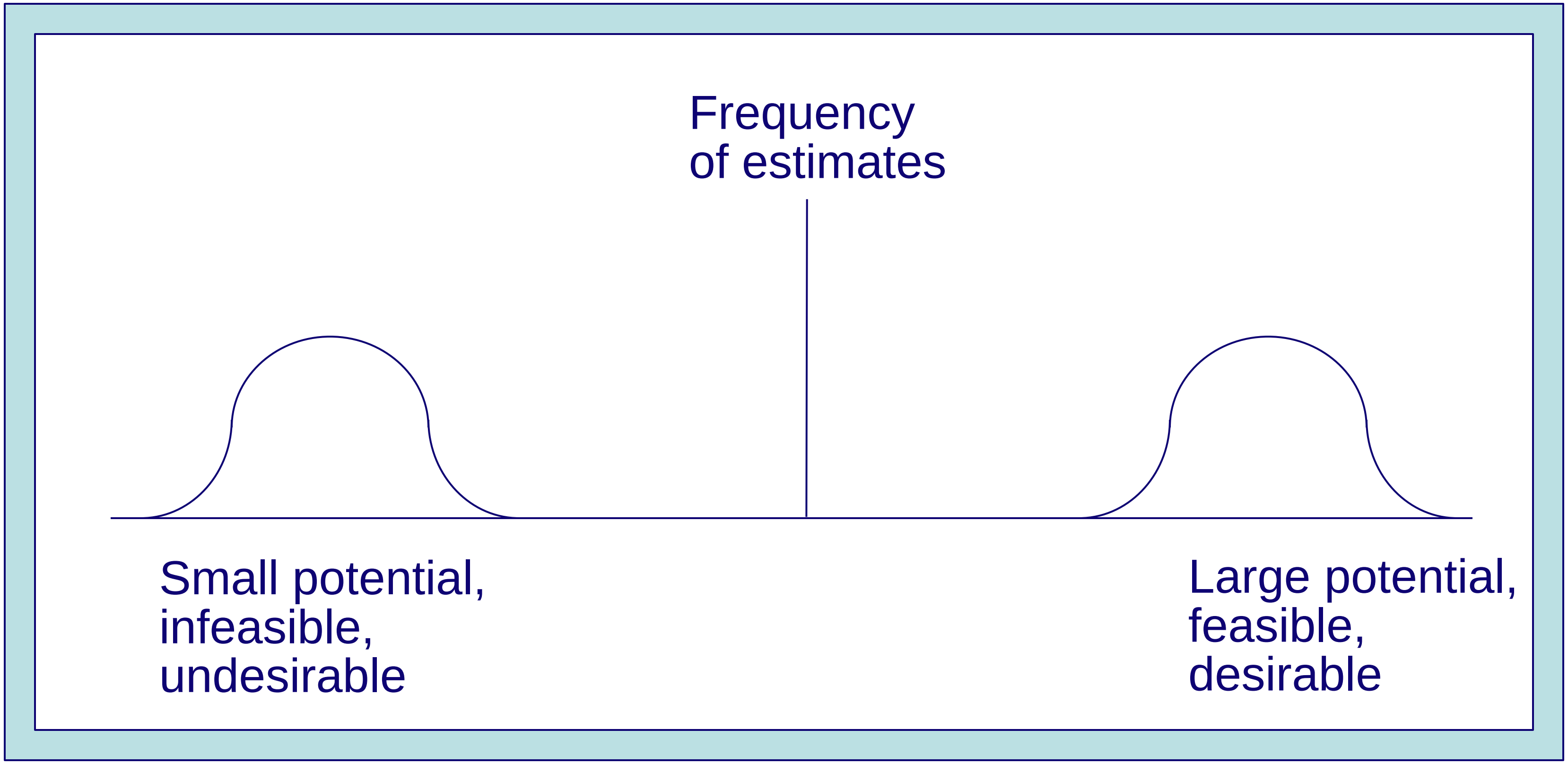
"[I]t's a crime against humanity to convert agricultural productive soil into soil… which will be burned for biofuel." (Jean Ziegler, UN Special Rapporteur, 2007)



There are also more positive assessments, considered subsequently

Sharply-Divergent Assessments of Bioenergy

Rather than clustering about a mean, estimates for the potential energy contribution of biomass exhibit a bimodal distribution with most such estimates envisioning a very small or very large energy supply role for this resource[1]



[1]Lynd et al. in Sovacol and Brown (eds.) Energy and American Society. Thirteen Energy Myths. Springer. 2007.

Sharply-Divergent Assessments of Bioenergy: Consequences

Policy makers are understandably confused

Absence of clear understanding leads to uncertainty with respect to

- Feasibility and desirability of a sustainable bioenergy-intensive future
- What should such a future look like?
- What should be done to realize it?

Strong and coherent support is difficult to motivate

We are likely

Underestimating & under-supporting meritorious options

Over-estimating & over-supporting non-meritorious options

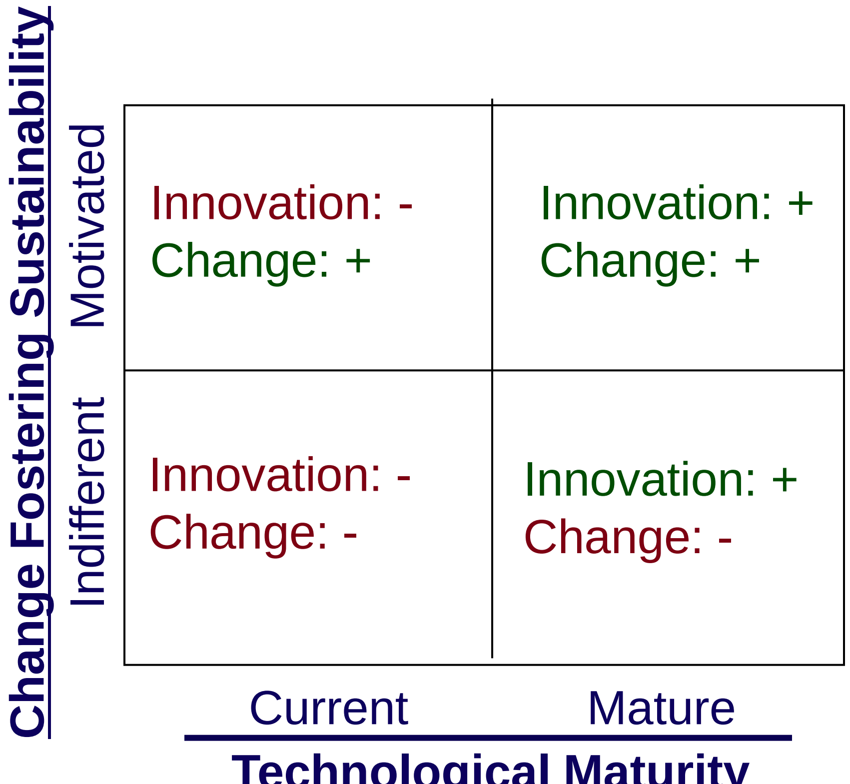
Both – in light of the diversity of bioenergy feedstocks & processes

This is an unacceptable state of affairs in light of the urgency of the challenges inherent in the sustainability revolution

Sharply-Divergent Assessments of Bioenergy: Understanding

How can presumably reasonable people with access to the same information reach such different conclusions?

What is versus what could be. Ultimately, questions related to the availability of land for biomass energy production and the feasibility of large-scale provision of energy services are determined as much by world view as by hard physical constraints… To a substantial degree, the starkly different conclusions reached by different analysts on the biomass supply issue reflect different expectations with respect to the world's willingness or capacity to innovate and change (Lynd et al., Thirteen Energy Myths).



Advanced technology and motivation to solve energy challenges may seem optimistic, or improbable

However, it is entirely unrealistic to expect to meet these challenges without both

Sharply-Divergent Assessments of Bioenergy: Understanding

How can presumably reasonable people with access to the same information reach such different conclusions?

What is versus what could be.

Low beam

High beam view

Sharply-Divergent Assessments of Bioenergy: Understanding

Many critics of bioenergy are responding to features of the substantial existing biofuels industry based on edible, 1st generation feedstocks.

Existing biofuel industries are in turn a response to government incentives motivated by a variety of objectives

- Rural economic development
- Energy security
- Balance of payments
- Large-scale sustainable energy supply

…of which the latter has seldom been the most important

Two key questions

Could we – that is, is it physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Must we produce bioenergy at large scale in order to have a reasonable expectation of achieving a sustainable world?

Answers to these questions would determine the answers to many others

Could we?	Do we have to?	Large Energy Supply Role	Impetus to Innovate & Change
No	Yes or no	No	Small
Yes	No	Maybe	Substantial (for alternatives too)
Yes	Yes	Yes	Large

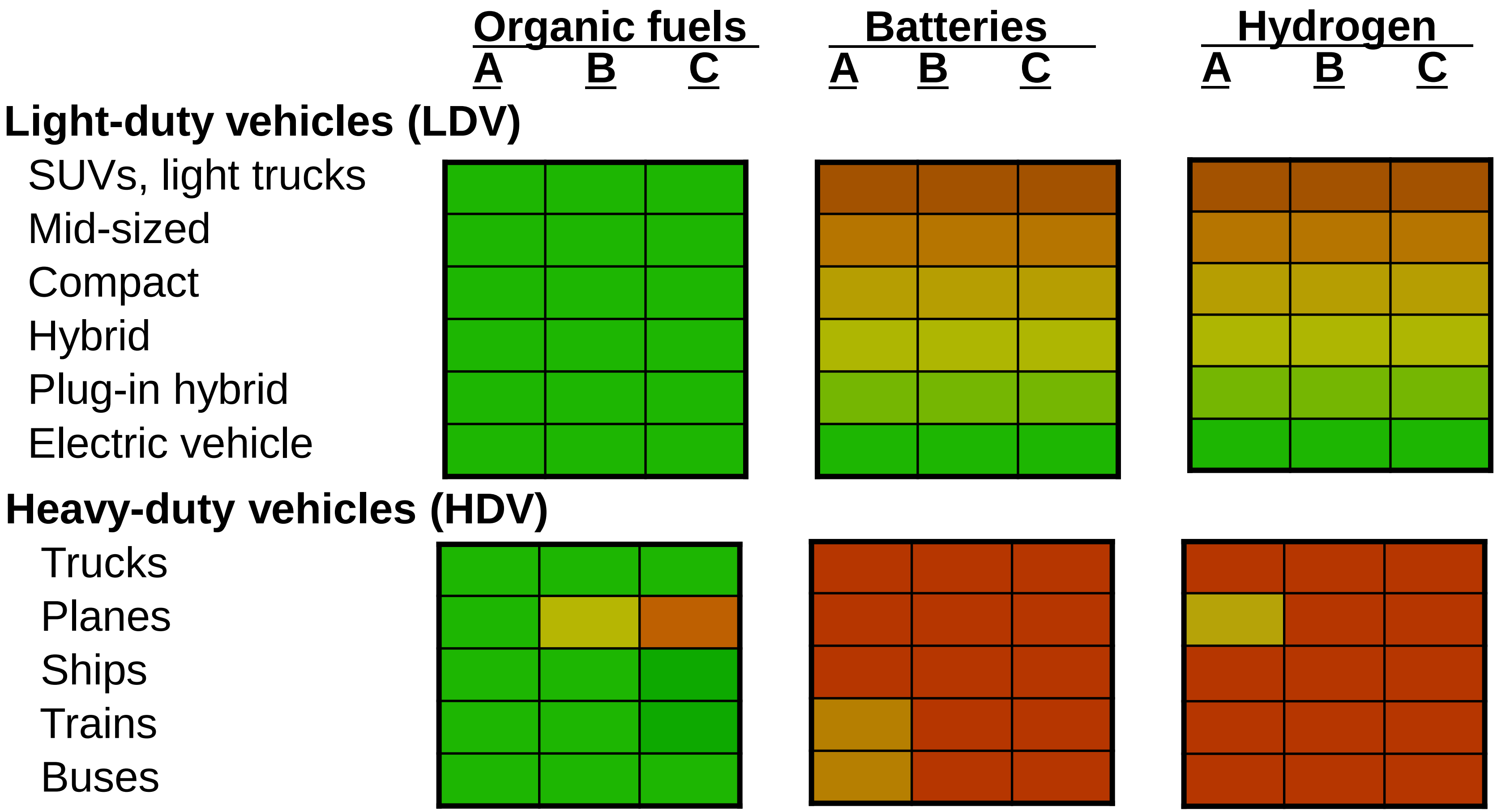
Prevailing view (my informal impression)

Could we? Maybe at best. See strong negative assessments.

Do we have to? Probably not. Many see bioenergy as at most an interim solution.

Lynd, Bioenergy: In Search of Clarity, Submitted.

Must we produce bioenergy at large scale in order to have a reasonable expectation of achieving a sustainable world?



Electrification (batteries) impractical for planes, many heavy duty applications

With ultimate foreseeable electrification of LDVs, organic fuels still $\geq$ 50% transport energy

Hydrogen faces many challenges, particularly for HDV, low-C

Without biofuels, achieving a sustainable transportation sector is unlikely

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – published studies

Biomass becomes the largest energy source supporting humankind by a factor of 2 by the middle of the 21st century (Johanssen et al., 1993)

Biomass potential comparable to total worldwide energy demand (Woods & Hall, 1994; Yamamoto, 1999; Fischer & Schrattenholzer, 2001; Hoogwijk et al., 2005)

Biomass will eventually provide over 90% of U.S. chemical and over 50% of U.S. fuel production (NRC, 1999, *Biobased Industrial Products*,).

20% of petroleum demand in 2025 (Lovins et al., 2004, *Winning the Oil End Game*).

50% US transportation sector energy use, and potentially nearly all gasoline, by 2050 (Greene et al., 2004, *Growing Energy*)

1.3 billion tons of biomass could be available in the mid 21st century - 1/3 of current US transport fuel demand (Perlack et al., 2005, *"Billion Tons Study"*).

30% EU transport demand by 2030 if 2nd generation lignocellulosic feedstocks grown on all areas available (REFUEL study, 2010)

Biomass the largest single energy source supporting humankind in 2050 (IEA, current "Blue Map" scenario, 50% reduction in CO_2 emissions)

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – in progress analysis and sketches

Crop residues burned in China would exceed current transportation energy demand if converted to fuel (Yan et al., 2006, 2009).

Grass burned in South Africa: 21 million tons annually, biofuel potential = 7 billion liters gasoline equivalent (54% SA petrol consumption, 39% SADC petrol)

Double crops and changed animal feed rations based on leaf protein recovery

Potential exceeds 67 billion GGE (gal gasoline equivalent) in the U.S., ~50% current consumption (Bruce Dale & colleagues, Michigan State University)

Photo: A. Heggenstaller, M. Liebman, R. Anex, Iowa State University

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – in progress analysis and sketches

Pasture intensification

Brazil: 200 million ha used for beef grazing now (1 animal per hectare), 4 million ha to grow sugar cane for ethanol. Doubling grazing intensity → 100 million ha → biofuel production potential ~2/3 global demand

(100 million ha) x (25 tonnes/ha) x (91 gal GGE/ton) = 228 billion gal gasoline equiv.

Global consumption (exclusive of diesel) : 330 billion gal gasoline

Estimates for the potential of Brazilian biofuel production – e.g. 5 to 10% global petrol – appear to me to be constrained by politics rather than geography

US: Biofuel production potential of similar magnitude would result from increasing the productivity of grazing lands to that of currently harvested forage in the same county, likely an underestimate of the overall potential for pasture intensification (based on analysis by Peter Vadas, US Dairy Forage Research Centre)

Global: Replacing current global petroleum use would require about 10% of pasture land with high but achievable biomass productivities and process yields (Richard Hamilton, Ceres)

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – in progress analysis and sketches

Dietary change (Ethan Davis, Lee Lynd et al.)

Halving US beef consumption with replacement by poultry would make available an amount of land with biofuel potential commensurate with global gasoline consumption.

Land required per kg beef protein is ~ 50 times greater than that required per kg poultry.

Many people will likely eat higher on the food chain rather than lower. However, the kind of animal protein people eat makes considerably more difference than the amount in terms of land requirements.

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – in progress analysis and sketches

Integrating bioenergy production with addressing other challenges

Decreasing the time required to regenerate fertility is a potentially powerful strategy to minimize impacts of slash-and-burn agriculture, particularly if coupled with revenues. (Peter Manang, Alternatives to Slash and Burn Agriculture Partnership)

The magnitude of soil carbon accumulation under temperate perennial grasses can be comparable to the magnitude of avoided emissions that would result from high-yield biofuel production from that grass (calculated from literature studies, Mark Laser & Lee Lynd, Dartmouth)

Improve water quality by incorporating perennial and/or double crops into the landscape (Chesapeake Bay Commission)

Alleviating causes of food insecurity

Bioenergy and food security

Factors Contributing to Food Insecurity*	Food Security Impact of Biofuel Production: Food crops	Cellulosic Crops: Cropland	Cellulosic Crops: Non-cropland
Poverty			
Rural unemployment	Green	Green	Green
Lack of marketable skills	Green	Green	Green
Low currency value	Green	Green	Green
High food prices	Red	Orange	Green
Local production undermined by foreign subsidies	Green	Green	Green
Poorly developed ag. infrastructure (Physical, market, knowhow)	Green	Green	Green
Degraded land	Orange	Green	Green

Bioenergy has clear potential to be developed in ways that are responsive to … [African] … challenges, including enhancing food security, but could also be developed in ways that exacerbate them." African GSB Convention

* Thurow, R, S. Kilman. Enough: Why the World's Poor Starve in an Age of Plenty. 2009. Public Affairs.

Bioenergy from Land that Can't Grow Food Crops

Example: Agave (Sisal)
5 to 10 times higher water use efficiency than most other plants due to understood mechanisms (crassulacean acid metabolism)

Photo: Arturo Velez, The Agave Project

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

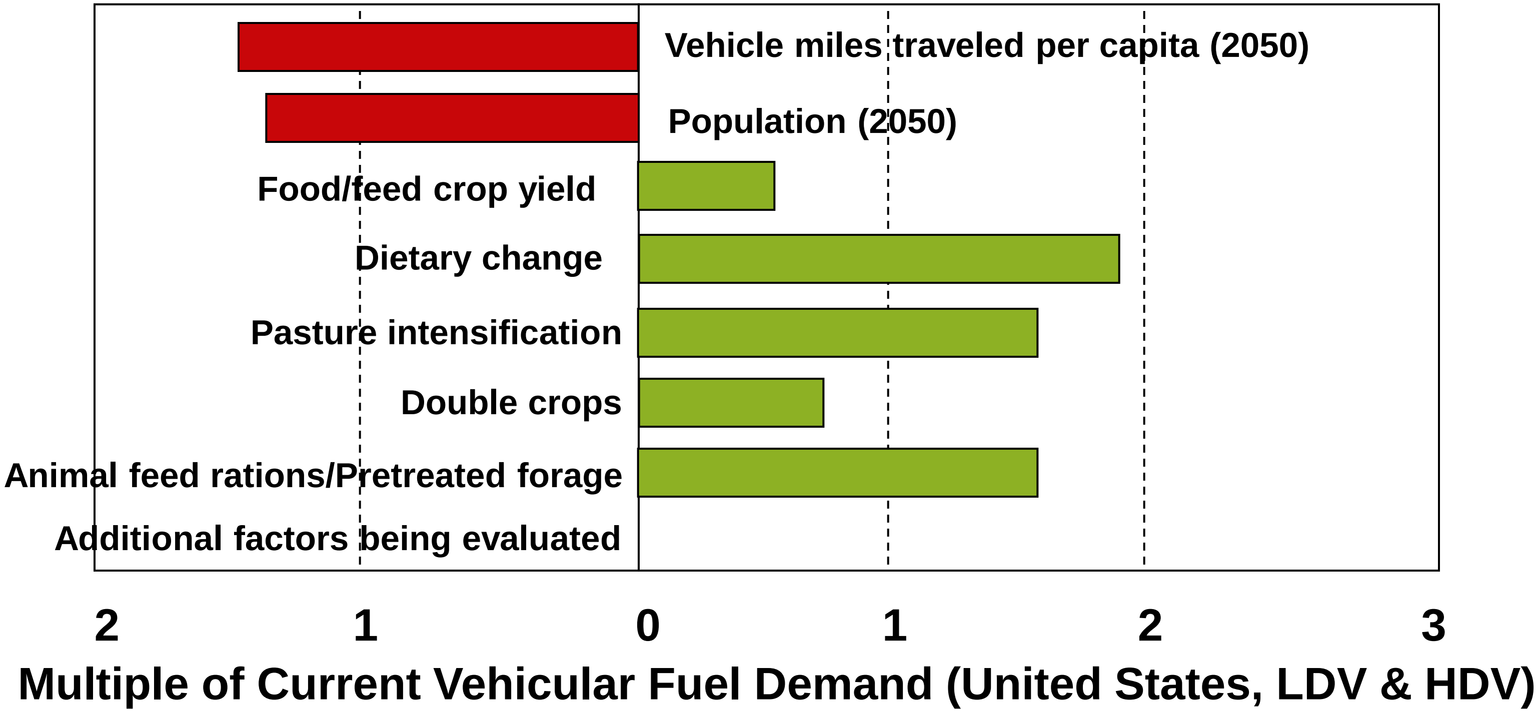
Favorable indications – in progress analysis and sketches

Factors that make satisfying mobility demand with bioenergy **more difficult**

Factors that make satisfying mobility demand with bioenergy **easier**

Current Vehicle Efficiency

Projected switchgrass productivity



Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting demands from managed lands, and preserving wildlife habitat and environmental quality?

Favorable indications – in progress analysis and sketches

Factors that make satisfying mobility demand with bioenergy **more difficult**

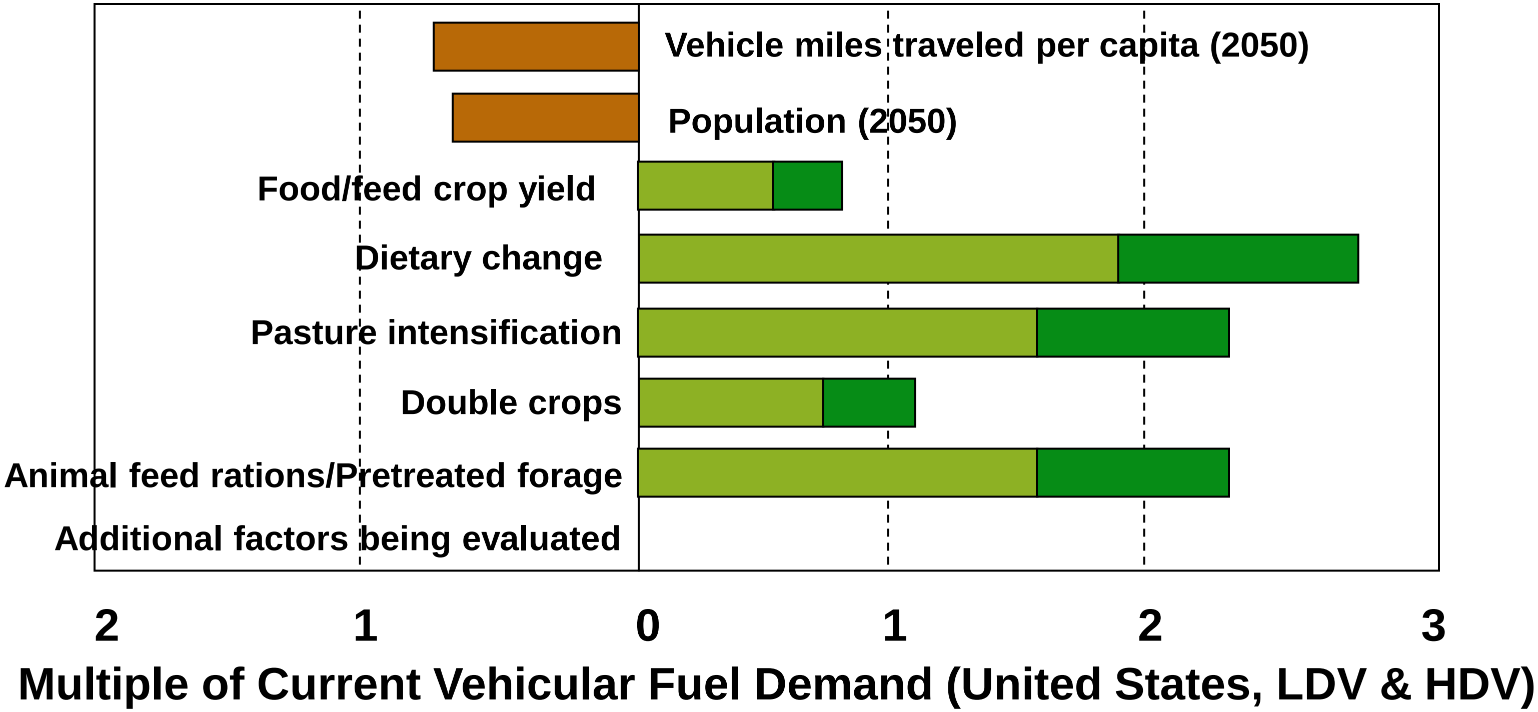
Current Vehicle Efficiency

2 x Vehicle Efficiency

Factors that make satisfying mobility demand with bioenergy **easier**

Projected switchgrass productivity

1.5 x projected switchgrass productivity



Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

Powerful bioenergy land efficiency levers

- Crop productivity
- Pasture intensification
- Double crops, leaf protein, alternative animal feed rations
- Diet
- Efficient processing technology
- Efficient vehicles

Most or all of these are often not considered in bioenergy resource analyses, and when they are considered ***no motivation to undertake changes to accomodate land-efficient bioenergy production is usually assumed.***

Few if any other renewable energy options are analyzed this way.

Paths to a Sustainable World: Big systemic challenges require big systemic solutions.

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

A conditional "yes" is a likely, and acceptable answer

An unconditional "yes" is hard to argue for in an extrapolated world, as for all sustainable energy technologies

An unconditional "no" is hard to accept in light of the urgency of sustainability challenges & the scarcity of alternatives to bioenergy, particularly for transportation

Beyond a conditional yes answer, there is great value in illuminating multiple complementary paths to an affirmative answer to the "Could we?" question

Could we – that is, is physically possible to – gracefully reconcile large-scale bioenergy production with feeding humanity, meeting needs from managed lands, and preserving wildlife habitat and environmental quality?

A more definitive answer is urgently needed

This should be approached in a manner consistent with common and required features of all paths to a sustainable world

- Global in scope
- Make use of the best science, and in particular global geographical data bases (many of which are newly improved or newly available)
- Consider what could be accomplished with innovation, change, and a desire to realize solutions - including gathering, scrutinizing, and generalizing in-process analyses and sketches
- Consider human as well as technical aspects
- Develop a clear vision of potential unconstrained by current realities and trends (GSB stage 2)
- Reexamine trajectories and policies in the light of this vision (GSB stage 3)