Gracefully Reconciling Very Large Scale Bioenergy Production With Other Priorities: From Vision, to Analysis, to Action

Lee Rybeck Lynd
Thayer School of Engineering, Dartmouth College
Global Sustainable Bioenergy Project
Bioenergy Science Center
Mascoma Corp.

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Twice in history, major changes in the resources used by humanity have transformed day-to-day life and societal organization

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

Lynd, Bioenergy: In Search of Clarity, Energy & Environmental Science, 2010.

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

	Agricultural Revolution		Industrial Revolution		**Sustainability Revolution**	
Hunting & Gathering	→	**Preindustrial Agricultural**	→	**Presustainable Industrial**	→	**Sustainable Industrial**
	~ 4000 BC…		1750 AD…		**Now**	

Population:	50 million	750 million	**~7 billion**	
Duration:	Millennia	Several centuries	**< a century**	
Scale of societal integration/ potential 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, Energy & Environmental Science, 2010.

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 look beyond them for sustainable futures

Business as usual is more properly regarded as a fantasy rather than a baseline

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

Biofuels

As I see it

Liquid fuels are much preferred compared to other modes of transportation energy storage for aviation, long-haul trucking, and sea transport

Biofuels are by far the most promising source of sustainable liquid fuels

For the indefinite future, biofuels will likely be needed to sustainably provide at least a third of transportation energy requirements and perhaps more

Achieving a sustainable transportation sector is much more likely with biofuels than without them

And yet assessments of the feasibility and desirability of large-scale biofuel production are sharply divided

There is an urgent need for greater clarity on whether & how biofuels can be sustainably produced on a scale large enough to meaningfully impact the challenges we face

The three pillars of sustainable development provide a useful framework for considering the status, merit, and potential of biofuels

- Economic
- Social
- Environmental

Economic Viability of Biofuels
(Price comparisons on a $/GJ/basis)

Sugar cane (Brazil)

Feedstock: Purchase price of sugar cane about a third of petroleum

Fuel: Ethanol sells at prices competitive with petroleum fuels (currently fixed below market)

Infrastructure*:* investment did not prevent emergence of a robust industry; feedstock infrastructure represents a barrier to expansion, although likely solvable

Grains & plant oils

Feedstock*:* Maize price roughly equal to that of petroleum; plant oils several fold higher

Fuels: Generally sold at prices higher than petroleum-derived fuels

Infrastructure: Currently seen as a major barrier to expansion of ethanol in the U.S. Key issues are anticipation (flex fuel vehicles) and “Who is going to pay?” (distribution)

Economic Viability of Biofuels

(Price comparisons on a $/GJ/basis)

Cellulosic feedstocks

Potential

Feedstock: Purchase price ~ 25% that of petroleum. $60/dry ton = $4/GJ = $23/barrel

Fuels: Cost-competitive fuel production may be anticipated

- Feedstock costs generally dominate economics of fuel production
- Compared to processing petroleum, processing biomass has some advantages (more reactive chemical constituents, much greater amenability to biotechnology) and thus may not be inherently more expensive

Infrastructure: Feedstock supply at the scale of individual commercial facilities is well established, vehicle & fuel distribution appear solvable as for 1st generation feedstocks

Realization

No operating commercial plants, although pioneer projects are being initiated

Has taken longer than some hoped/anticipated

The key barrier to realizing the considerable potential of cellulosic biofuels is the cost of processing, and in particular the cost of converting recalcitrant biomass into reactive intermediates

Comparative Purchase Price of Energy Carriers

Energy Carrier	Representative Purchase Price: Common Units	Representative Purchase Price: $/GJ
Fossil		
Petroleum	$90/bbl	16.2
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	$5.5/bu	15.8
Sugar cane	$25/wet ton	5.4
Cellulosic crops[a]	$60/dry ton	4.0
Cellulosic residues		Most < 4

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

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

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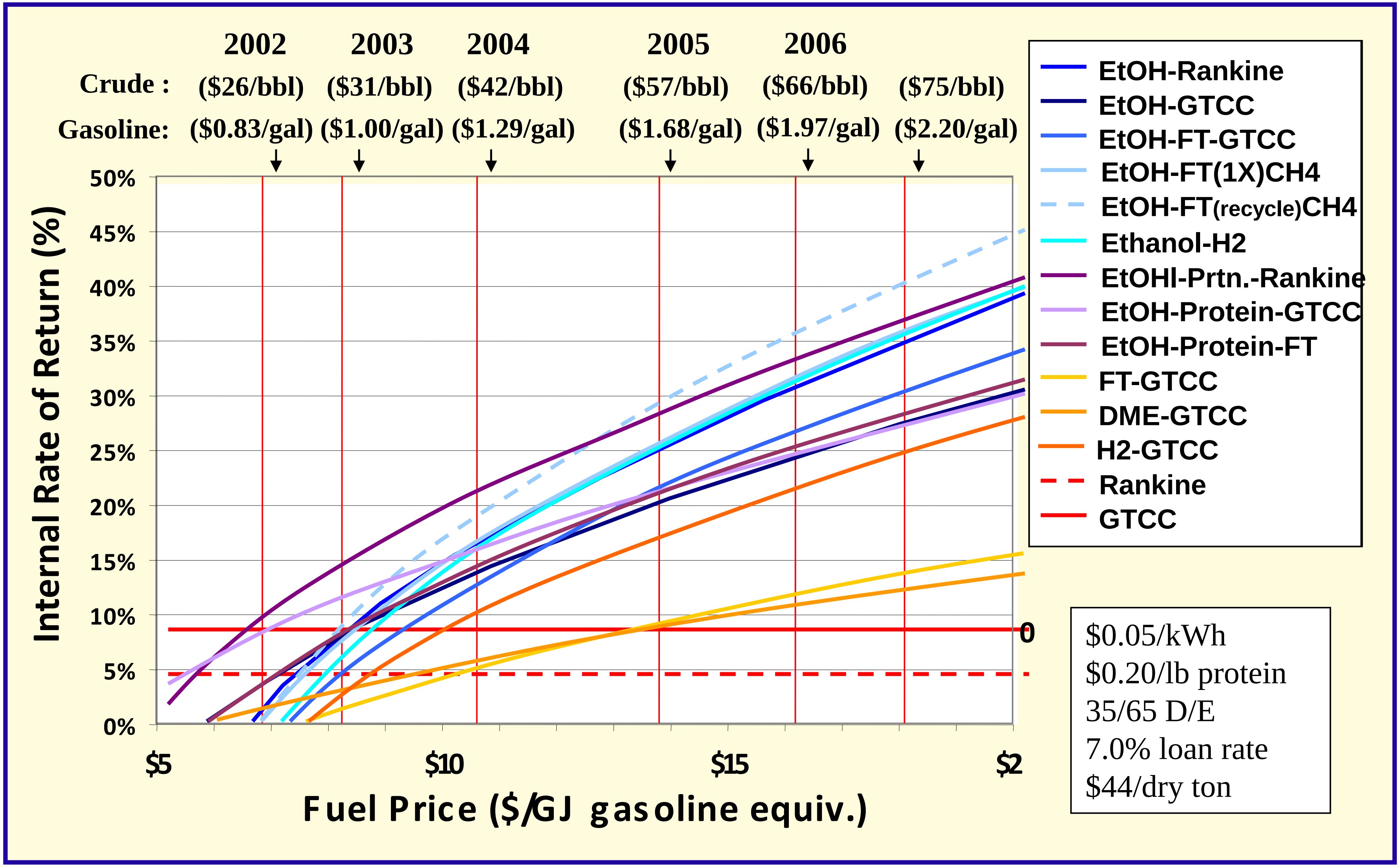
Mature Cellulosic Bioenergy Investment Returns

Laser et al., Role of Biomass in America's Energy Future Project, Bio FPr, 2009



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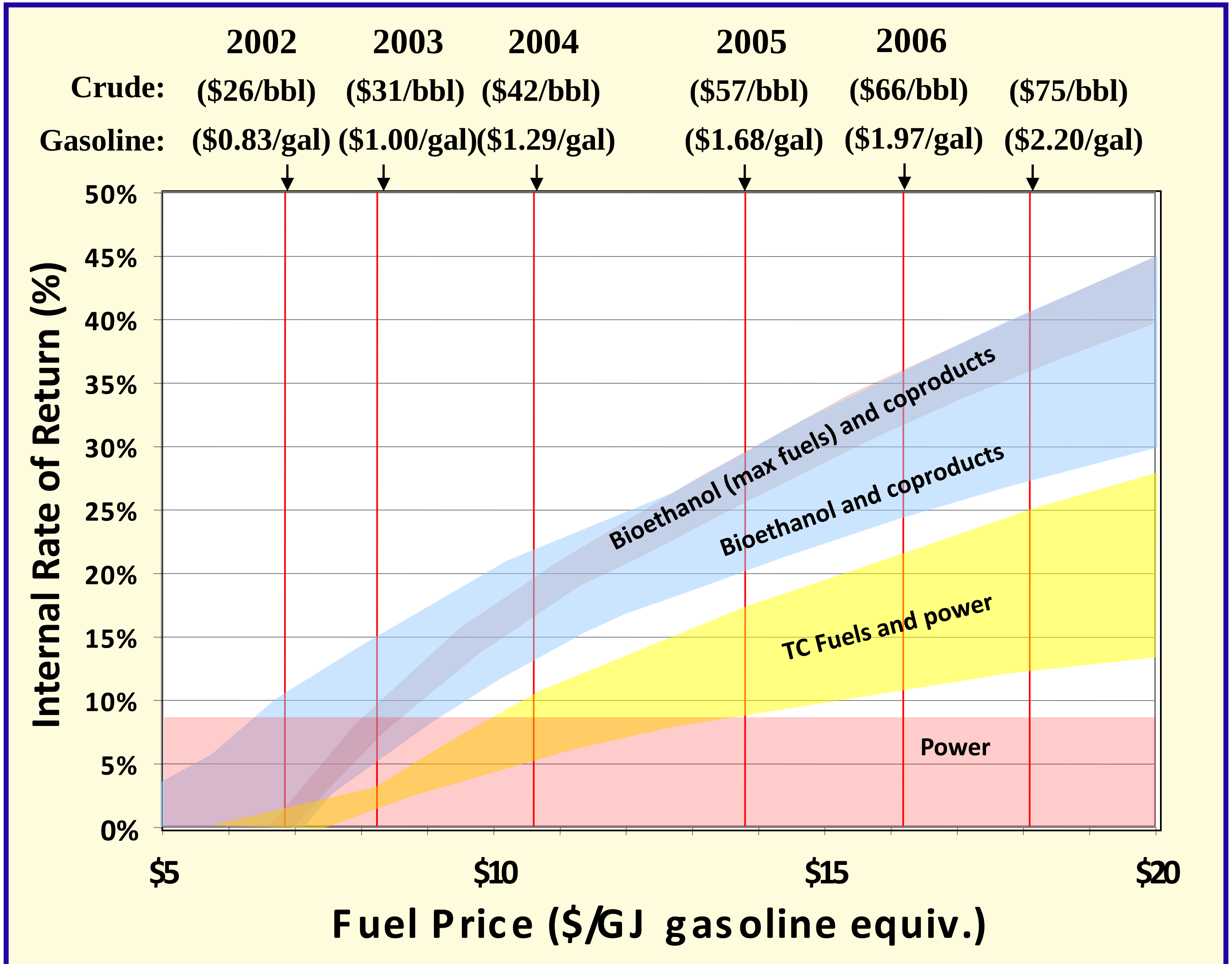

Social Viability of Biofuels

Potential benefits

Rural economic development & support of farm demand, prices – largest historical driver in the US & EU

Energy security (geographical & temporal)

Improved balance of payments and other benefits to the economy at large

Realization

Brazil - the most compelling example of beneficial biofuels, including careful documentation of benefits to the poor and land use issues

Nowhere else are the benefits of biofuels so widely-accepted

Concerns/potential liabilities

Cost of price supports

Benefits may not be realized by under served populations

By far the biggest social concern about biofuels is increased food insecurity for the poor

Food Security & Biofuels

Why are people hungry?

Poverty

All hungry people are poor

All wealthy people have access to food

Perpetuated and exacerbated when growing crops for sale - in excess of subsistence requirements - is not a viable enterprise, leading to a *loss of resilience* when crops fail

Household level – Poor subsistence farmers have no reserves of food or cash

Regional level – No excess productive capacity

After decades of neglect, there is an emergent consensus that the best way to fight hunger is to help the famine-vulnerable poor grow their own food
(Thurow & Kilman, Enough)

The problem

Food Security

Poverty

No skills

No opportunity

Growing crops for sale not viable

Low crop productivity
- Exhausted soil
- Lack of capital
- No access to latest seeds, techniques
- Collapsed ag. extension
- Poor farmers not rewarding private sector customers

Infrastructure poorly developed
- Storage & transport
- Energy

Poor farmers can't compete without benefits available to famers in developed countries
- Established markets
- Price supports
- Futures pricing
- Crop insurance
- Counter cyclical payments

Food aid
Needed in emergencies but perpetuates dependency, administered more to benefit producers than recipients

Remedies

Economic development

Jump start agriculture

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Remedies

Economic development

Jump start agriculture

Biofuels

Have marked potential to positively impact both

Food Security and Biofuels

Lynd & Woods, “A New Hope for Africa”, Nature, June 2011.

It has widely been assumed that increased production of energy from biomass requires a sacrifice in food security, especially for the world’s poor. Yet closer scrutiny suggests that modern bioenergy – in the form of fuel, electricity or heat – could be developed in ways that increase food security

Consideration of the impact of bioenergy on African food security has tended to focus on land competition and to overlook bioenergy’s marked potential to promote rural development.

However, potentially productive land is rather plentiful in much of Africa whereas lack of development is the most important underlying cause of hunger.

Africa has about 12 times the land area of India, similar land quality, and 30% fewer people - yet India produces enough food to feed itself and Africa does not. The green revolution bypassed Africa primarily due to serious organizational and institutional weaknesses, not geographically-limited capacity (A. Temu, ICRAF)

Bioenergy and Food Security

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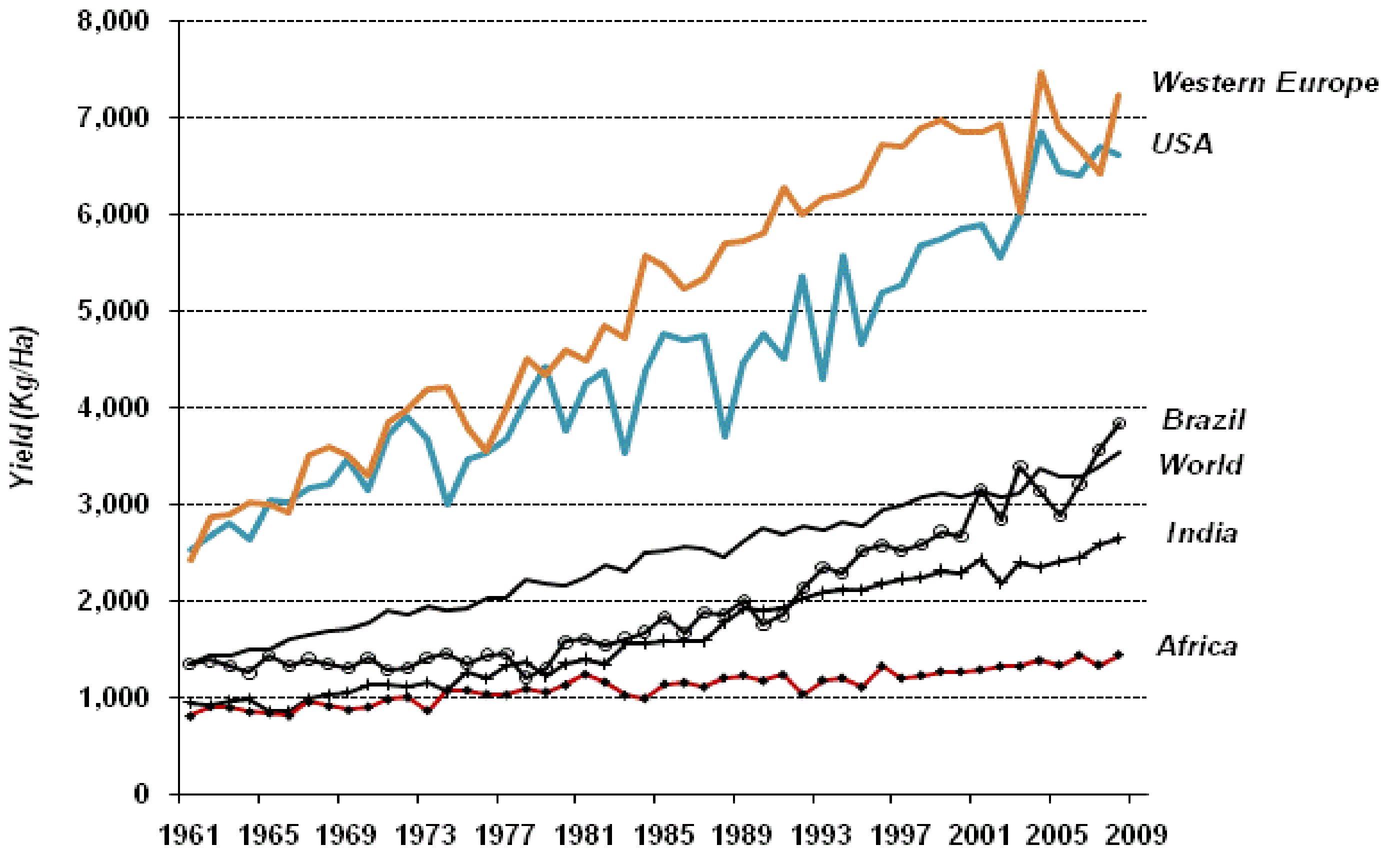


Figure 1 Cereal yield trends. Data from the Food and Agriculture Organization of the United Nations, (FAOSTAT), 2011

Food Security and Biofuels

Lynd & Woods, "A New Hope for Africa", Nature, June 2011.

Assessments of biomass production potential consistently identify Africa and Brazil as the two regions with the greatest capacity. Although each situation is different, Africa might hope to replicate aspects of Brazil's success.

We suggest that proposed bioenergy projects in Africa be expected to demonstrably improve food security at a local level.

- Honors the centrality of food security
- Moves the discussion from the abstract to the specific
- Is perhaps not hard to achieve
- Merits further thought & analysis

Intriguing question: How might an enterprise be configured with the dual goals of producing bioenergy and enhancing local food security?

Biofuels & The Environment

Potential benefits

Zero net carbon emissions when CO2 consumption by photosynthesis balances emissions from fuel production and combustion

Improved water quality - e.g. uptake of nutrients by perennial buffer strips

Improved soil fertility, land reclamation, and carbon sequestration – e.g.via perennial crops

Increased habitat diversity when incorporated into agricultural landscapes

Key determinants of the extent to which benefits are realized

Process residues used to provide process energy

Live roots in the ground year-round (perennials or nearly perennial) – erosion prevention, nutrient retention, carbon accumulation

Observation: Although sugar cane is often grouped with other “1^{st} gen” feedstocks, its environmental attributes are much more similar to “2^{nd} gen” lignocellulosic feedstocks

Biofuels & The Environment

Concerns/potential liabilities

Observation (sobering): Globally, it is much more common for environmental advocacy organizations to express opposition to biofuels than support

Life cycle concerns (impacts per unit of production)

- Some for grains and oil seeds (e.g. water quality)
- Fewer for sugar cane and lignocellulosics although diligence is still required

Scale concerns (number of units produced):

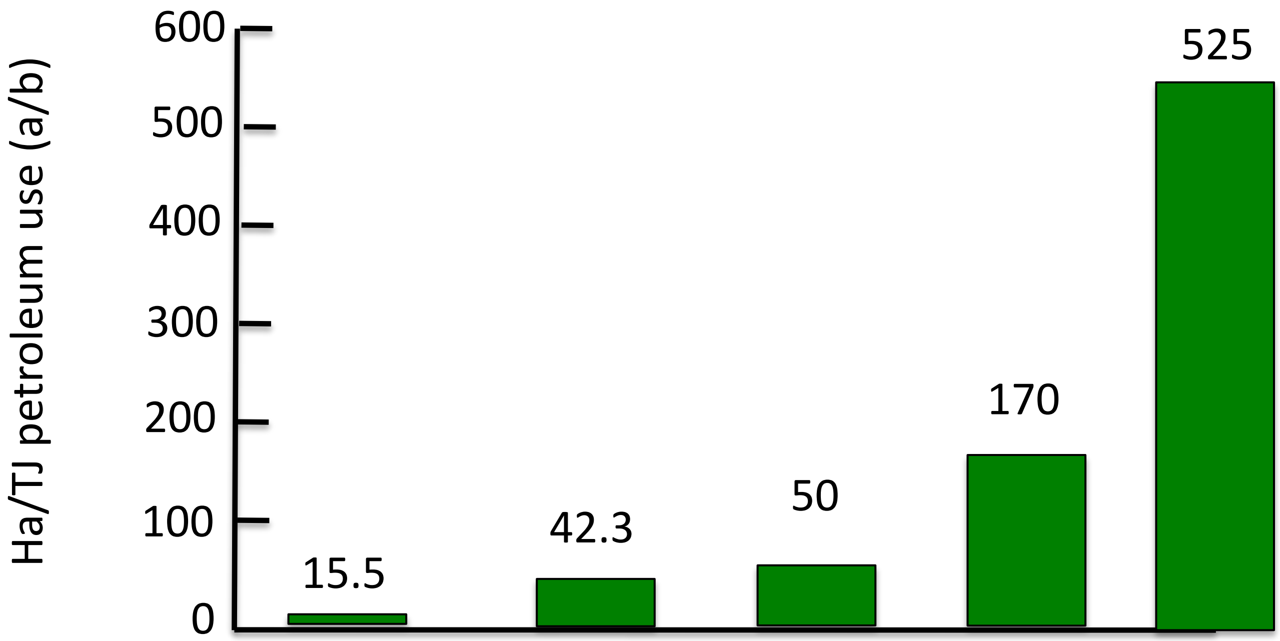
- Fertilizer requirements/recycling for very large scale bioenergy production via different crops need to be looked at more closely
- By far the strongest and most often expressed environmental concerns about biofuels are loss of carbon and habitat resulting from expansion of managed lands.

Consequences of expanding managed lands, along with food competition and security, are the two most important factors underlying opposition to biofuels

Biofuels and Land Availability

It matters where you view this issue from

	European Union	North America	Asia	South America	Africa
a. Total land (ha $capita^{-1}$)	0.9	6.0	0.8	4.5	3.1
b. Petroleum Use (TJ $capita^{-1}$ yr^{-1})	0.0581	0.142	0.016	0.0265	0.0059



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http://www.census.gov/ipc/www/idb/region.php
http://www.indexmundi.com/energy.aspx?region=sa&product=oil&graph=consumption
https://www.cia.gov/library/publications/the-world-factbood/oeos/ee.html

Biofuels and Land Availability

Land-efficient production of terrestrial biomass

Harvest the whole plant

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

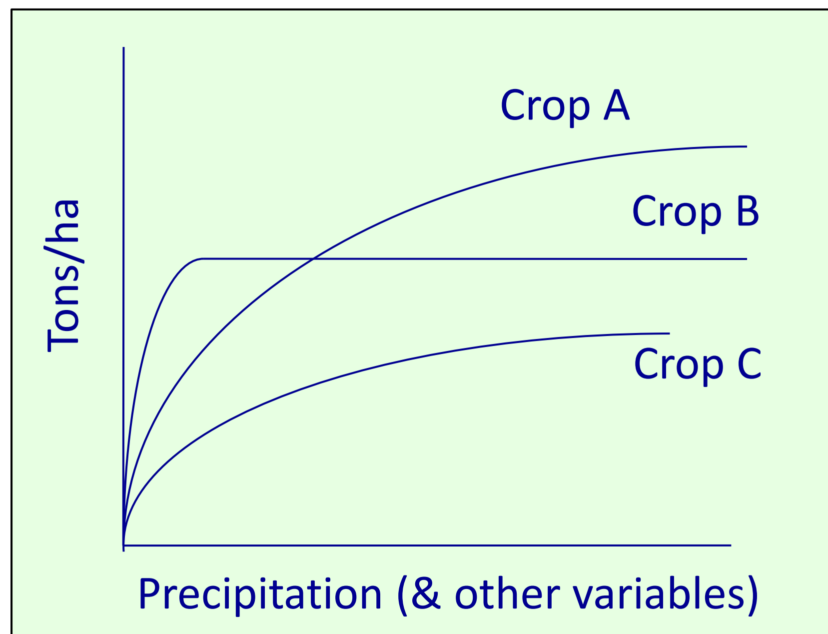
Perennials, C_4 plants

	Maximum Productivity (Mg/ha)
C_4 perennials	70
C_3 perennials	40
Most annual crops	< 20

Nobel et al., 1992

Evaluation of bioenergy potential would be facilitated by a global energy crop model

- Predict tons/ha for multiple energy crops as a function of geographically-distributed variables
- Useful to both aggregate available capability and highlight limitations of existing models



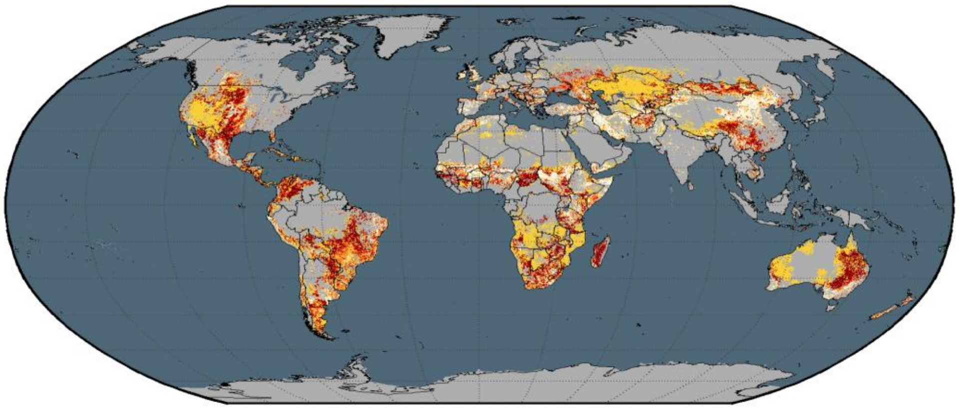
Notwithstanding concern over land-use issues, there appear to be many "levers" that could enable large-scale bioenergy production within existing managed land without decreasing food production, and with neutral or positive environmental impacts

Pasture intensification	10% of global pasture land → global petroleum	Richard Hamilton, Ceres
Underutilized managed land	Degraded Brazilian pasture → ¾ global gasoline	This presentation
Double crops	US implementation → current US + Brazilian ethanol	Richard et al., 2011
Changed animal feed rations	US implementation → 50% US gasoline	Dale et al., 2010
Burned & damaged lands	Global implementation → Global gasoline	Giglio et al., 2010 + preliminary calculation
Use crops that grow where food crops can't (e.g. CAM)	Powerful multiplier for other strategies	Somerville et al., 2010
Dietary choice & higher supply chain efficiency	US implementation → Global gasoline	Extensive analysis, in-preparation

First attempt at a global pasture productivity model Morishige et al. (in prep.)

ANPP method. Apply distributed models (e.g. Zaks et al., 2007; Del Grosso et al., 2008) for net primary productivity as a function of climate variables

Intensification Ratio, ANPP, 70% Forage Utilization

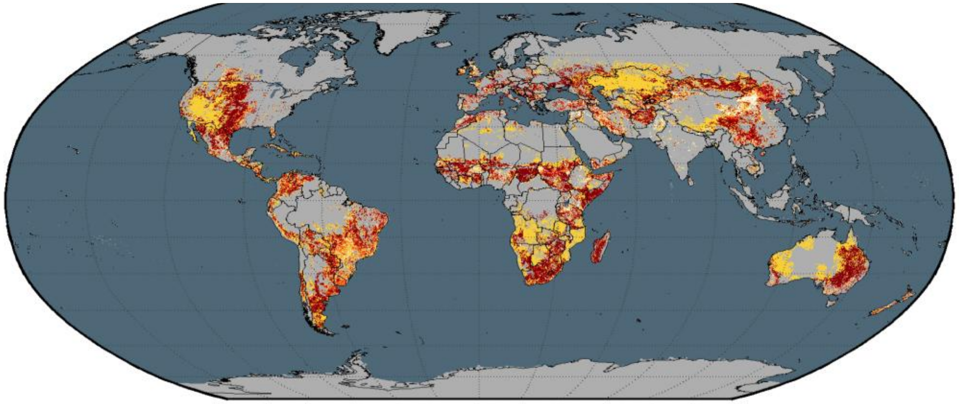


Global Intensification Ratio (relative to current)

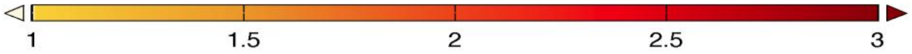
2.28

Climate zones method. Bin the world's pasture lands in terms of climate variables (degree days, rainfall), calculate "yield gap" relative to an assumed productivity percentile (method widely used for row crops, see Foley et al)

Intensification Ratio, Climate Zones, 90% percentile



2.57

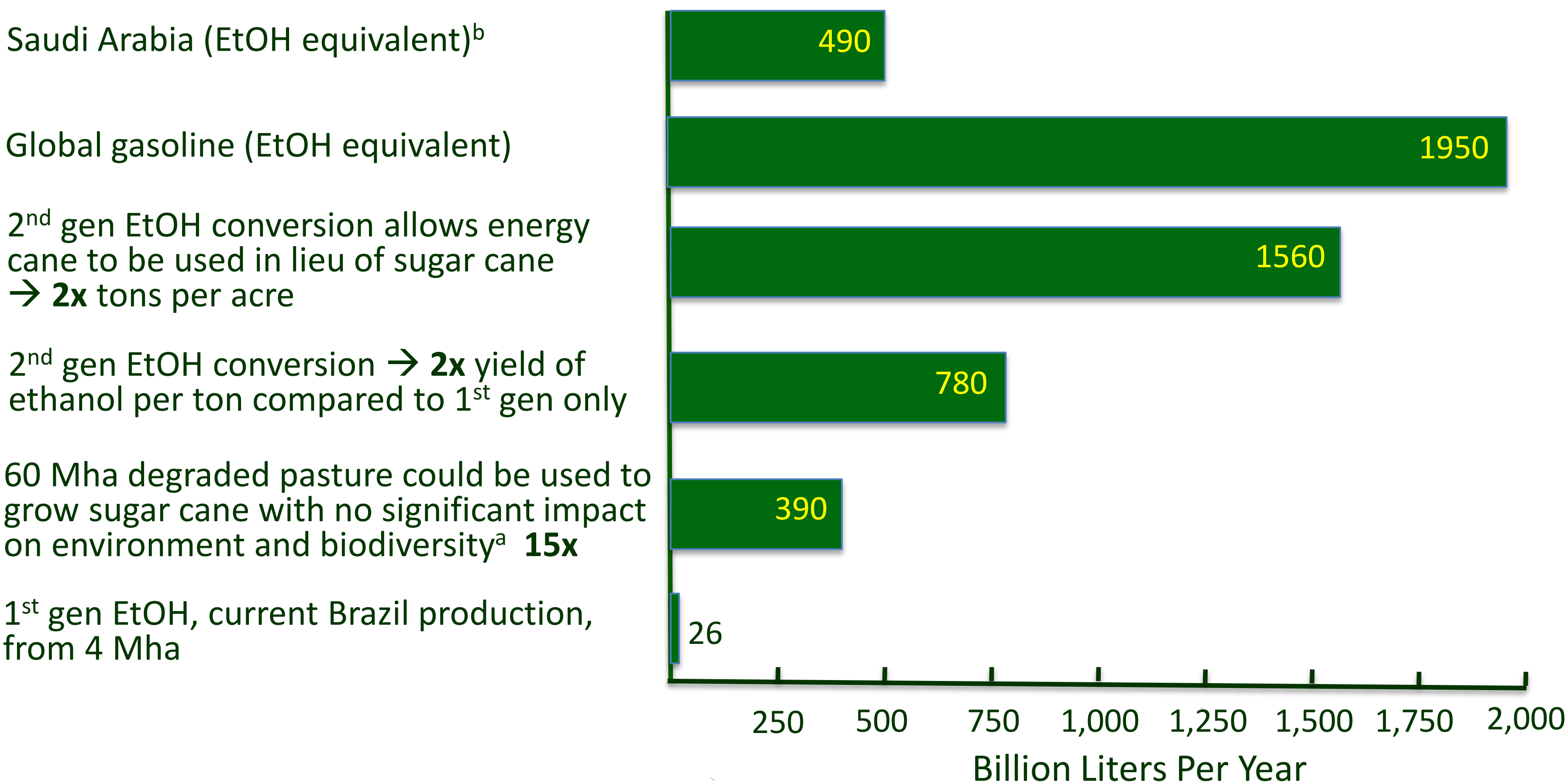


In combination with animal productivity models

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

Underutilized land. Empirical evidence indicates that the majority – and by some credible estimates as much as ¾ - of earth's non-forest land area that is suited and available for rainfed agriculture without deforestation, lies fallow, abandoned or is underutilized due primarily to political, socio-economic (market), and infrastructure constraints. (K. Kline, IS&T, 2009)

Ethanol Potential of Degraded Brazilian Pasture Land



[a]Eco-agricultural study for the Brazilian Ministry of Agriculture, described in Lynd et al., 2011.

[b]12.5 million barrels/day, 72 L gasoline/bbl, 1.5 L ethanol equivalent/L gasoline

Double crops – e.g. cool-season grass grown between row crop harvest & planting, temperate climates

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

Illustrative

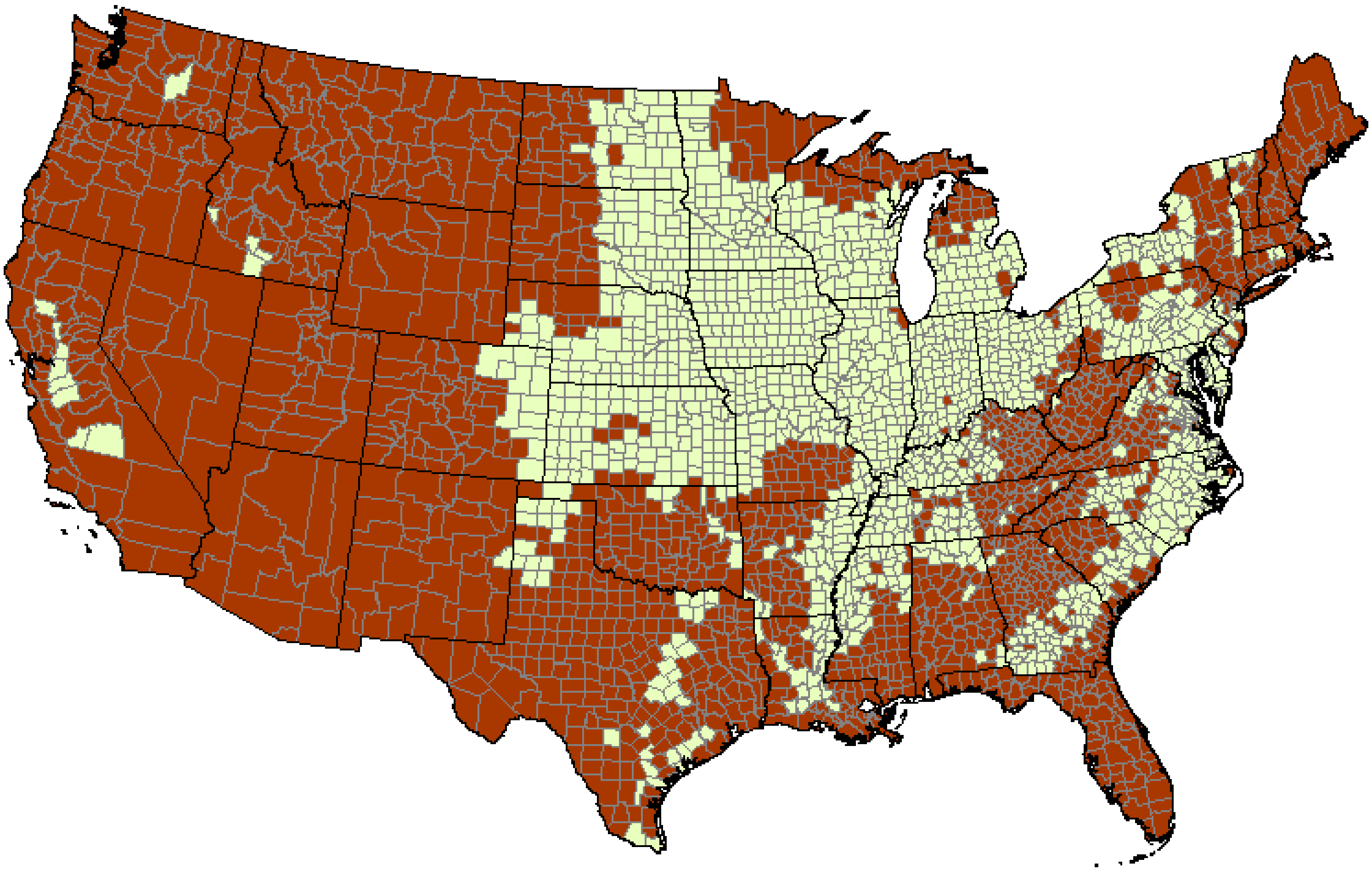
Importance of geographically-distributed productivity modeling & mapping

Potential for “win-win” solutions

Rye as a Double Crop on U.S. Corn & Soybean Land

Richard, Baxter, & Camargo, Penn State; Feyereisen & Baker, USDA ARS

Total land planted in corn and soy



Rye as a Double Crop on U.S. Corn & Soybean Land

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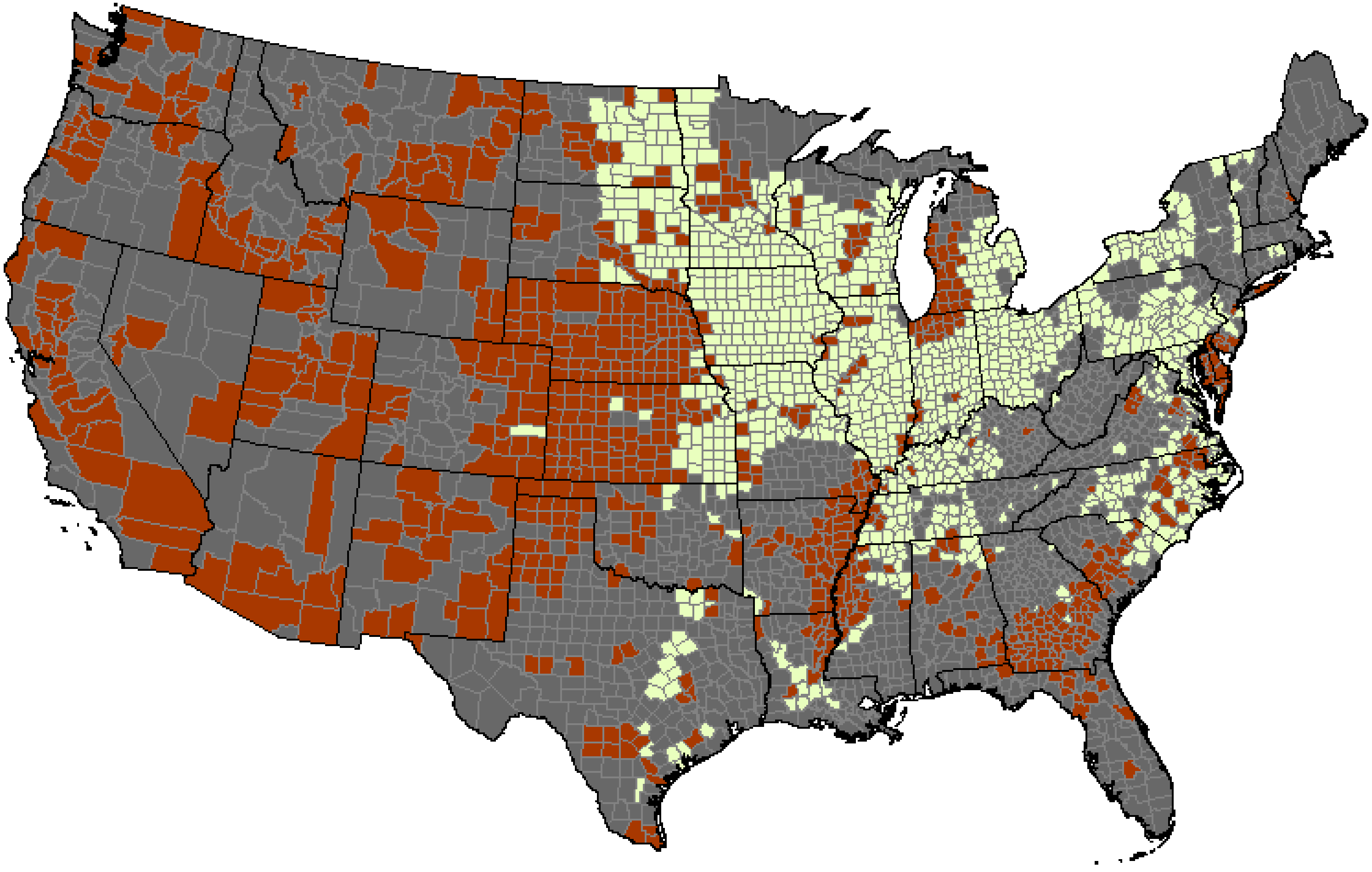
Less counties where winter rain not plentiful (> 5% corn acreage irrigated)



Rye as a Double Crop on U.S. Corn & Soybean Land

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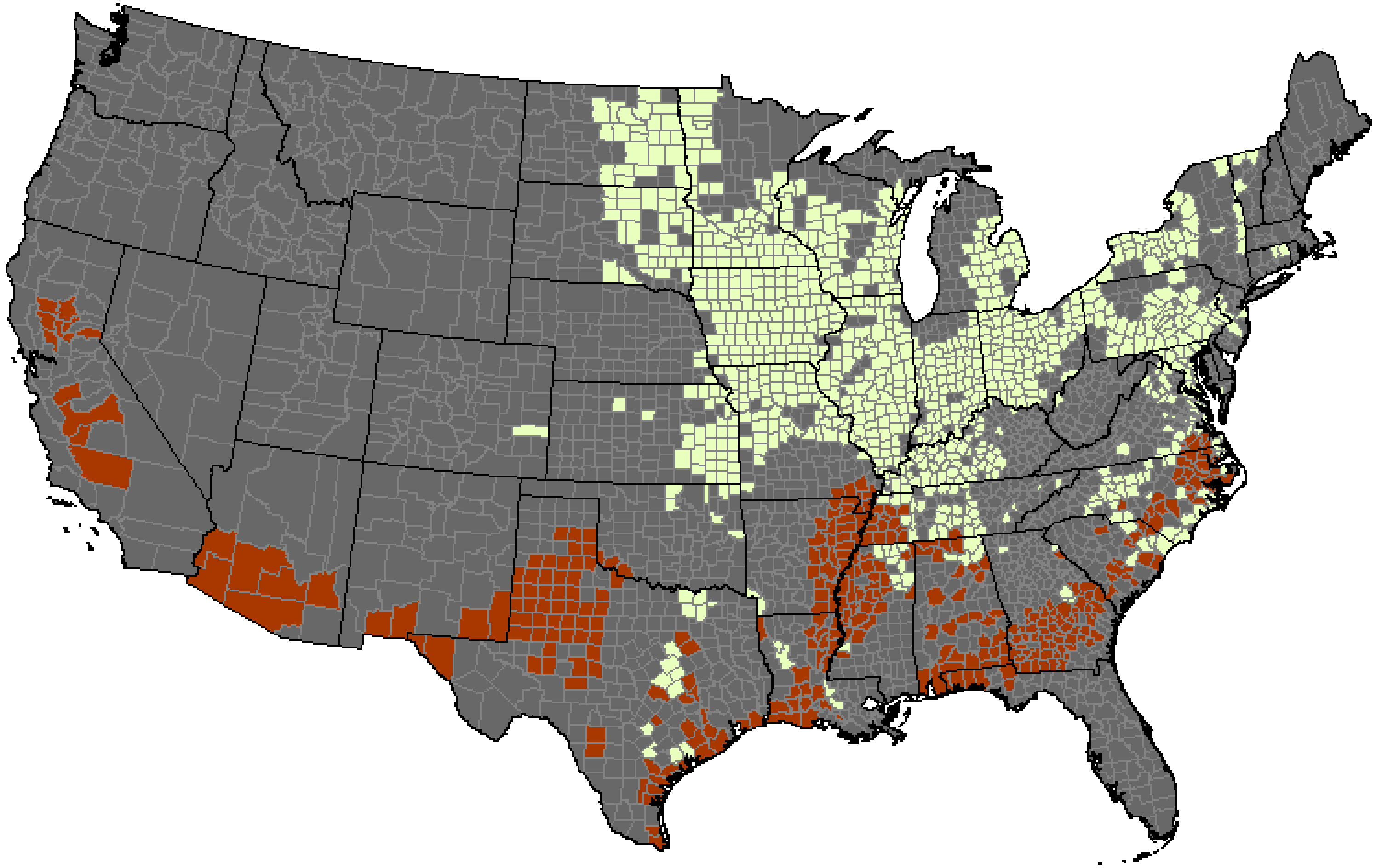
Less land currently planted in winter crops (excluding acres planted in winter wheat or barley, counties where > 10% of cropland is in rice or cotton)



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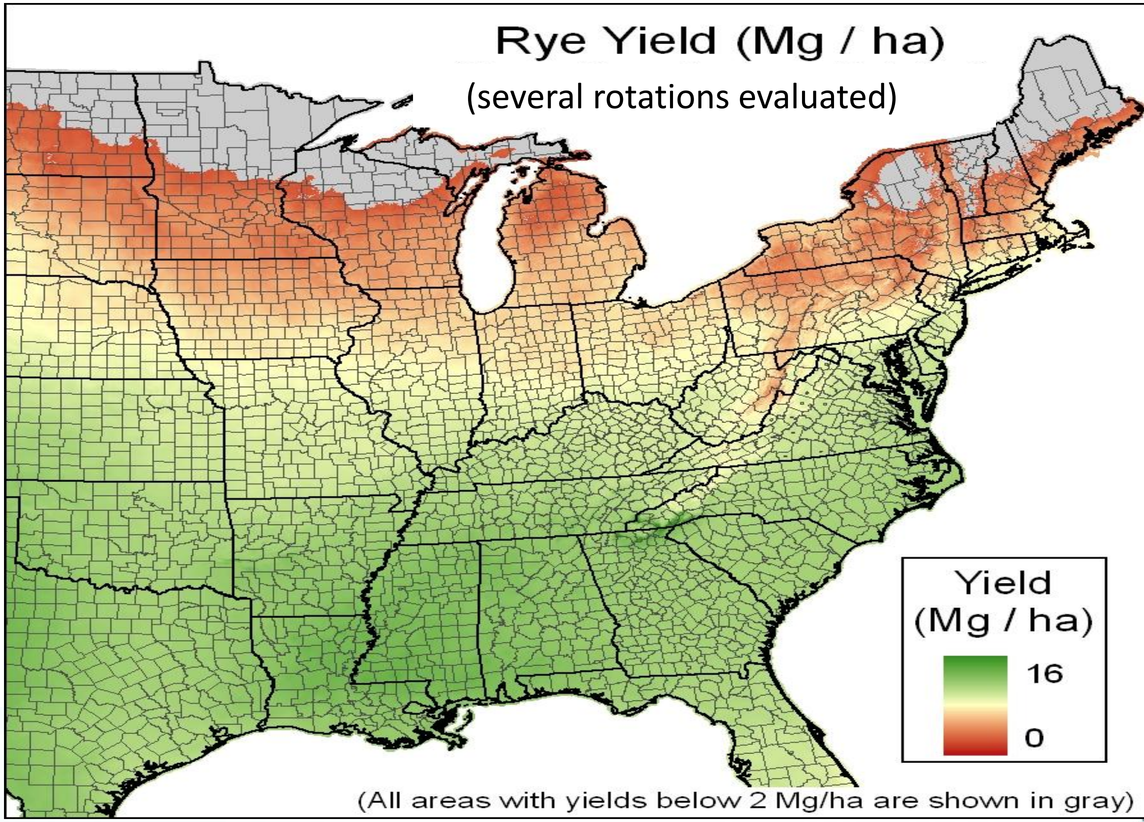

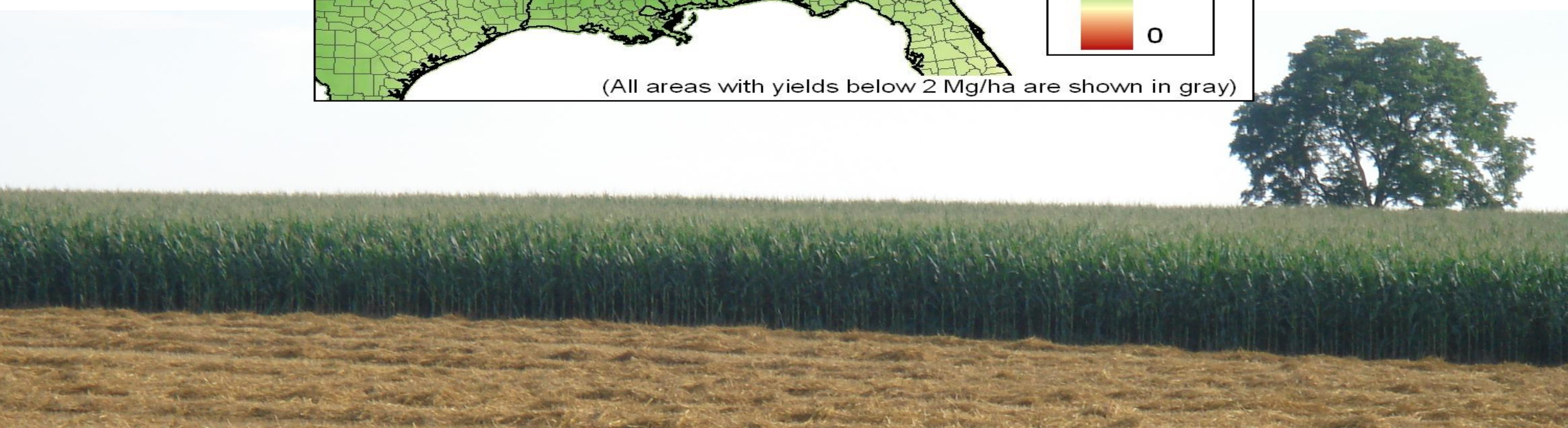

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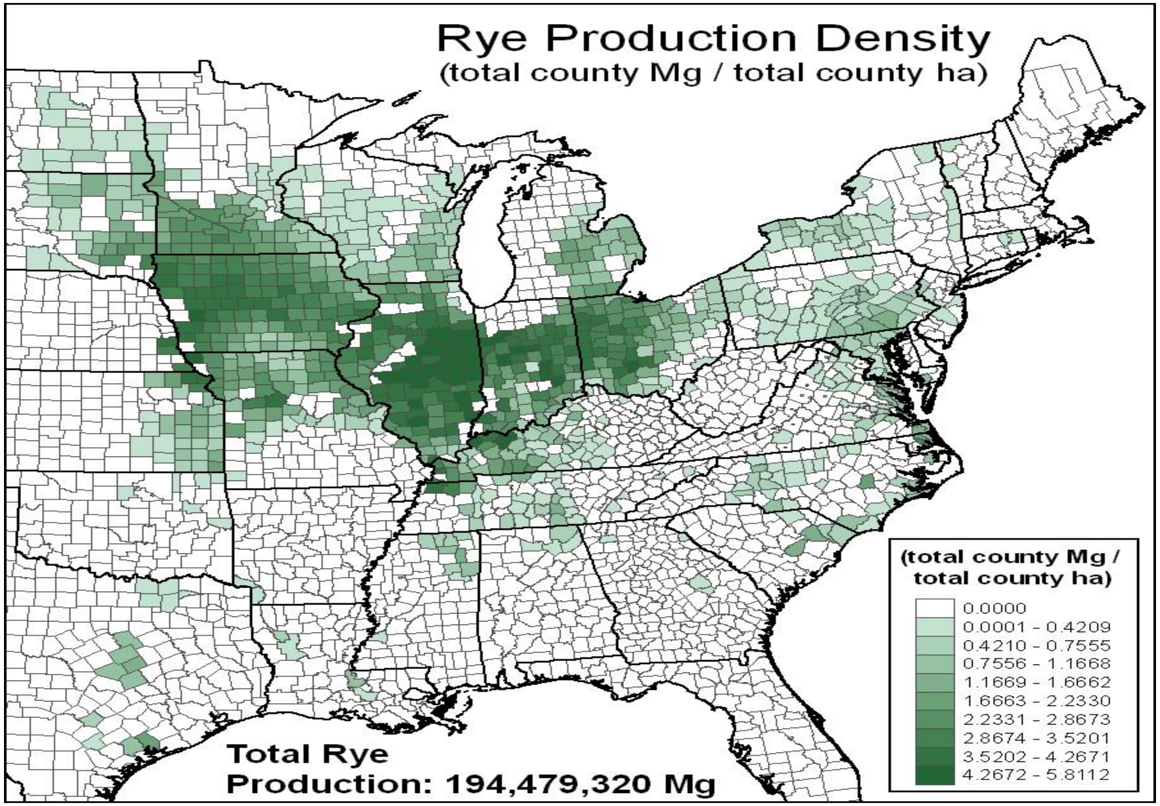


Conservative estimate: 200 million dry tons/year of rye grass in the US

Fuel potential: ~ current US + Brazilian ethanol industries combined

From existing managed lands, no substantial competition with food crops

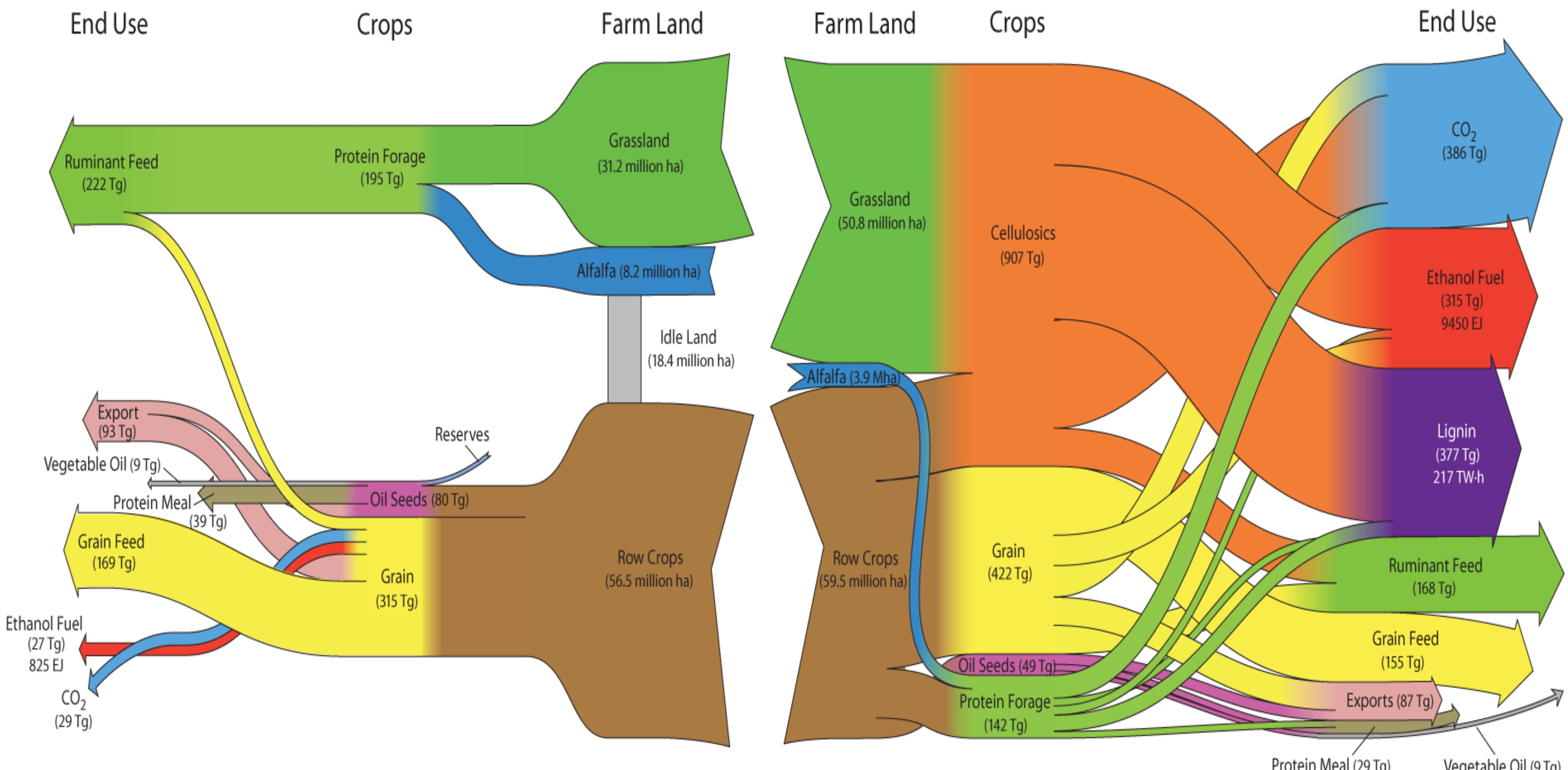
Improved water and soil quality, increased farm income, off-season jobs

Existing know-how & equipment: Could be planted this winter if demand were there

Different animal feed rations

Dale et al. (ES&T, 2010) explore potential ways to feed animals differently:
Leaf protein concentrate, pretreated forage, and double crops

Status Quo   Alternative



Same land base → Same amounts of the same food produced
50% gasoline, 5% electricity, 10% ghg reduction

Notwithstanding concern over land-use issues, there appear to be many "levers" that could enable large-scale bioenergy production within existing managed land without decreasing food production, and with neutral or positive environmental impacts

- Pasture intensification
- Underutilized managed land
- Double crops
- Changed animal feed rations
- Burned & damaged lands
- Use crops that grow where food crops can't (e.g. CAM)
- Dietary choice & higher supply chain efficiency

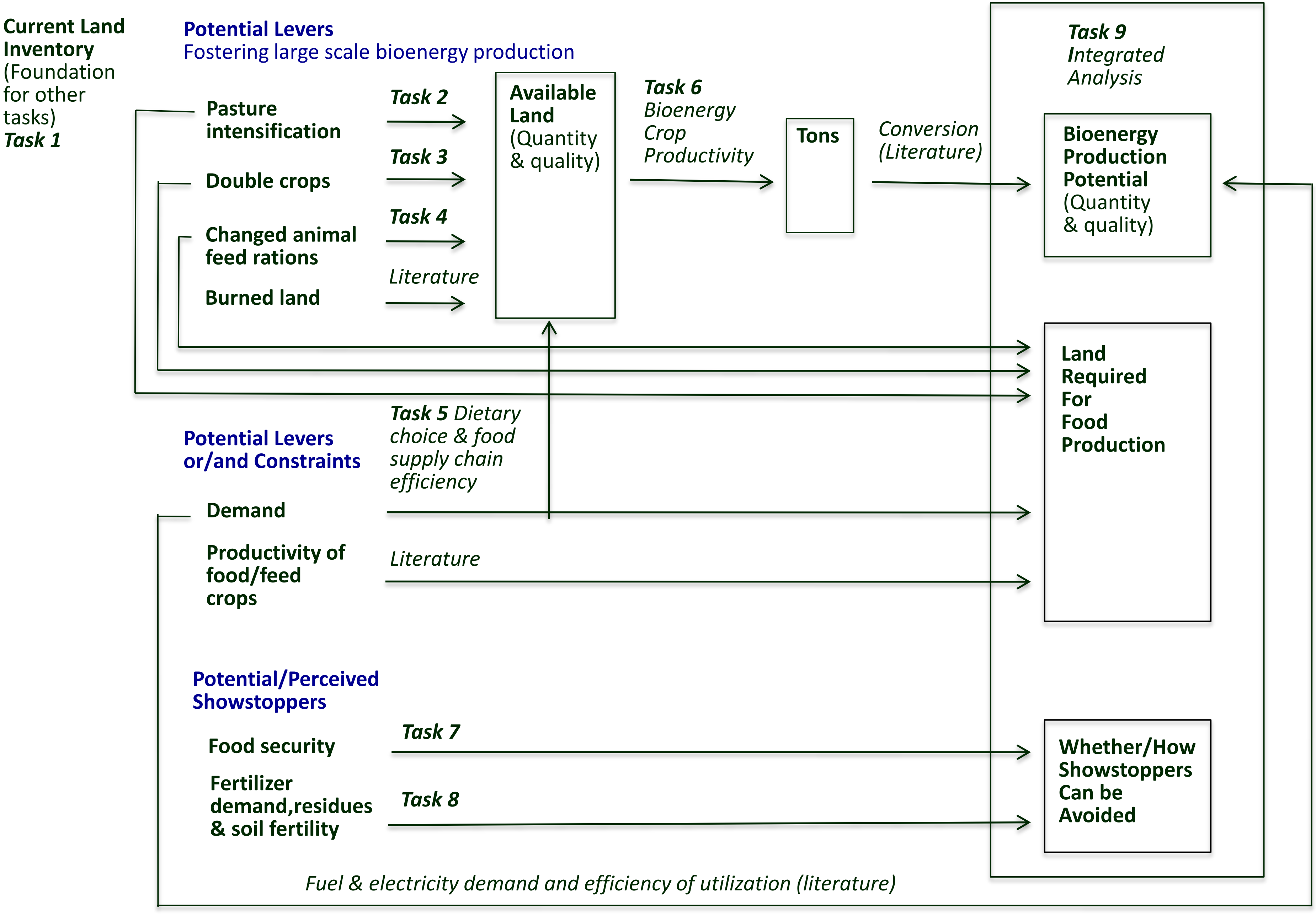
⋮

These levers

- Appear to have gigantic fuel production potential, with application of single levers in single countries significant relative to global fuel demand in several cases
- Have seldom been considered in analyses of "food vs fuel" and energy futures
- Merit more detailed analysis at a global scale

Providing such analysis is a key factor motivating the Global Sustainable Bioenergy project

Emergent GSB Structure



Future Vision Point of Reference: Extrapolated and Interpolated Resource Futures