The Role of Biomass in Meeting U.S. Energy Needs

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Growing the Bioeconomy
Ames, Iowa

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Introductory perspectives

Biorefinery analysis

Biomass as a major contributor of energy services

Reimagining agriculture with energy production incorporated

Seizing the moment

Additional information: http://www.nrdc.org/air/energy/biofuels/biofuels.pdf
http://engineering.dartmouth.edu/thayer/research/llrs.html

Biomass as an Industrial Raw Material

Benefits to farmers, ag. processors, and rural America

- Domestic food consumption is growing slowly, while ag. productivity is increasing
- Main sources of new demand are expanded exports and non-food uses
- Export growth is limited, hard to control, not very amenable to technological breakthroughs, often involves losses by farmers elsewhere if we make gains here

Arguments for expanded use of biomass for non-food uses have been made on behalf of farm constituents for some time

- Considerable success has been achieved to date
- Advocacy in this arena has been regarded by many as *provincial* - serving interests of a narrow constituency
- To broaden support, it would be very desirable to strengthen connections to issues of acknowledged *universal* importance/appeal

Universal Issues Potentially Impacted by Biomass Processing

Security

Petroleum use is the resource giving rise to by far the largest concerns

"Oil is a magnet for conflict." (Lugar & Woolsey, The New Petroleum)

"…a plausible argument can be made that the security of the United States is at least as likely to be imperiled in the first half of the next century by consequences of inadequacies in the energy options available to the world as by inadequacies in the capability of U.S. weapons systems."
President's Council of Advisors on Science and Technology, 1997

Sustainability

<u>Global climate change</u>

Renewable energy supply

These issues are dominated by ENERGY

Not by chemicals or materials

…although chemicals & materials may be important commercial opportunities and/or help energy production be cost-competitive

The bioeconomy must impact energy production to play more than a small role in responding to sustainability & security challenges

The Role of Biomass in America's Energy Future (RBAEF) Project

Multi-institutional

- Dartmouth
- Argonne National Lab
- National Renewable Energy Lab
- Union of Concerned Scientists
- University of Tennessee
- Natural Resources Defense Council
- Michigan State University
- Princeton
- USDA Agricultural Research Service
- Oak Ridge National Lab

Multi-sponsor

- Department of Energy
- The Energy Foundation
- National Commission on Energy Policy

Objectives

Identify & evaluate paths by which biomass can make a large contribution to future demand for energy services.

Determine what can be done to accelerate biomass energy use and in what timeframe associated benefits can be realized.

The RBAEF Project…

Task - Leader, Institution

Task 1. Biomass Production

- a. Technical analysis - Sandy McLaughlin, U. Tennessee/Oak Ridge Nat. Lab
- b. Environmental evaluation - Nathanael Greene*, Natural Resources Defense Council

➡ **Task 2. Biomass Processing**

- a. Process design, thermochemical fuels & power - Eric Larson, Princeton
- b. Process design, ethanol - Lee Lynd*, Dartmouth
- c. Mobility chain analysis - Michael Wang, Argonne National Lab
- d. Environmental evaluation - Nathanael Greene, NRDC

➡ **Task 3. Coproducts**

- a. Co-utililized crops - Bruce Dale, Michigan State University
- b. Biorefinery coproducts - Mark Laser, Dartmouth
- c. Environmental evaluation - Nathanael Greene, NRDC

➡ **Task 4. Biomass Resource Sufficiency**

- a. Sufficiency analysis - Lee Lynd, Dartmouth
- b. Environmental evaluation - Nathanael Green, NRDC

Task 5. Transition Dynamics - John Sheehan*, National Renewable Energy Lab

Task 6. Policy Development & Evaluation - Nathanael Greene, NRDC

* Steering Committee Member

Framing the Analysis

Broad range of technologies (but not all) considered in a common framework.

Diversity of participants

- **Technical**
- **Policy**
- **Environmental advocacy**

Emphasis on *mature technology*

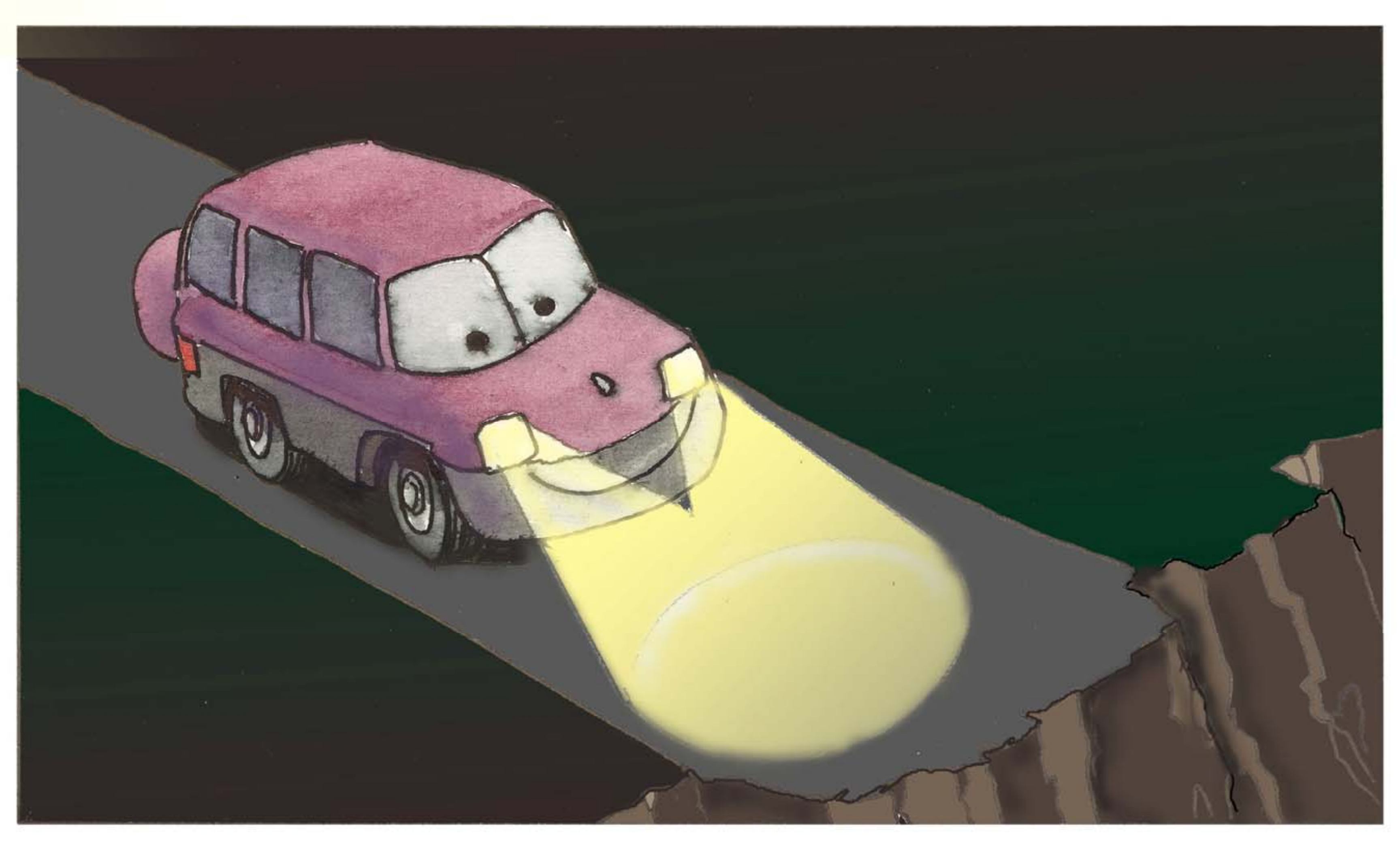
What: Asympotic state such that further research & experience yield but incremental improvement in cost/benefit realization.

Evaluation: Knowledgeable optimist's most likely estimate.

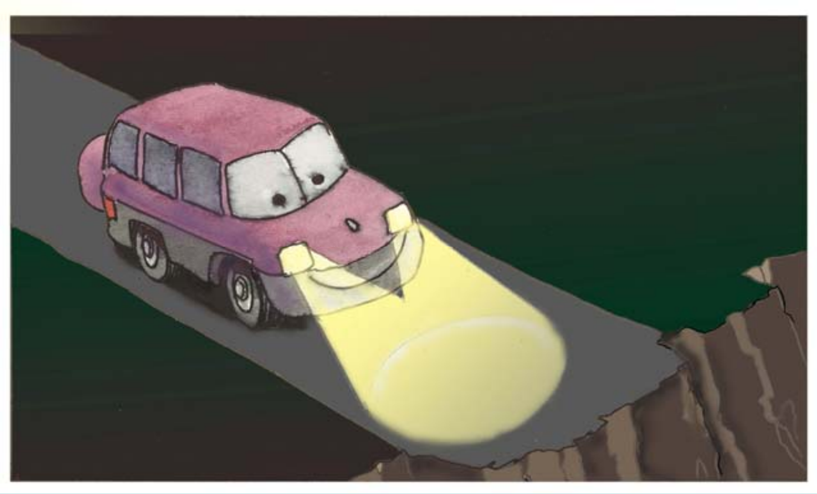
Importance: More important to know where we *can get* than where we *are* to evaluate

- **Appropriate levels of research effort, policy intensity for biomass-based options.**
- **The potential contribution of biomass to a sustainable world.**

Hazard of driving with the low beams on



Hazards of driving with the low beams on



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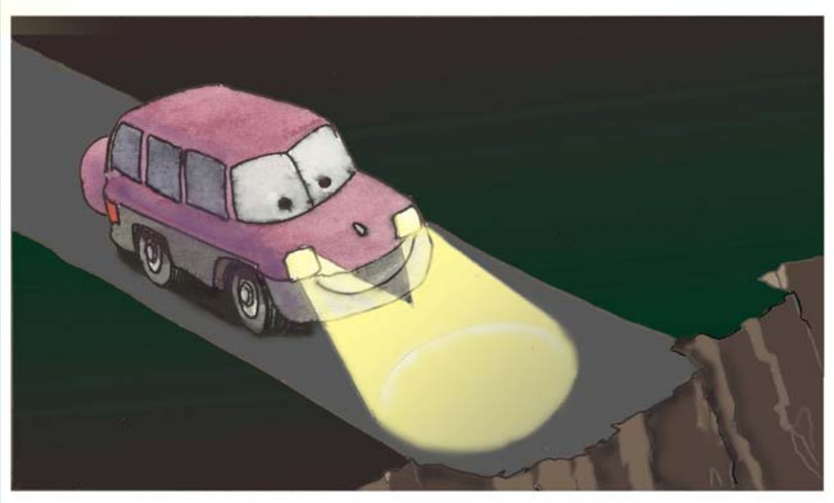
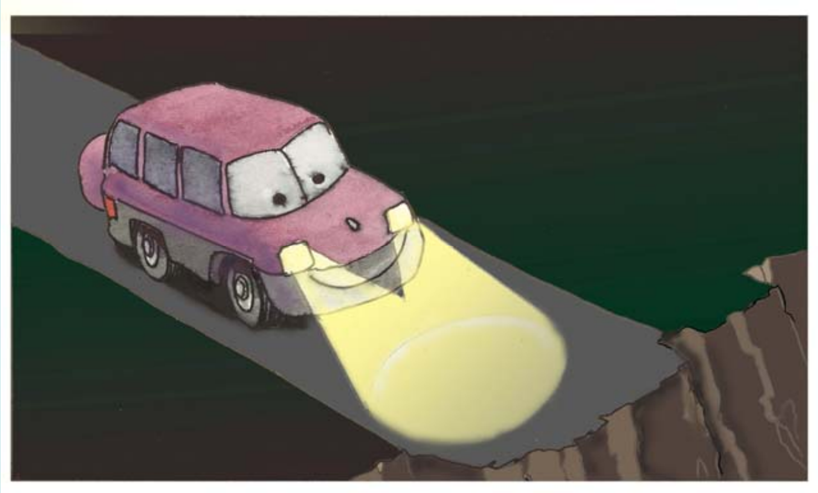
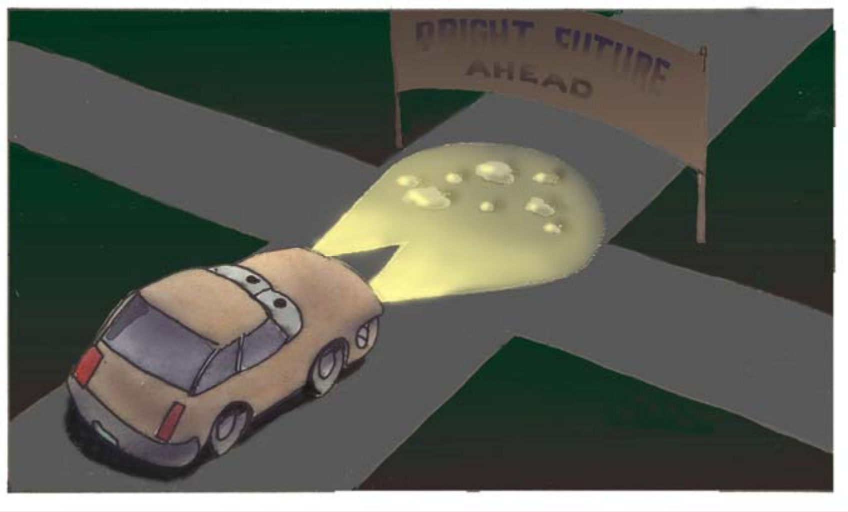


We seek to view the future with the high beams on…

Hazards of driving with the low beams on

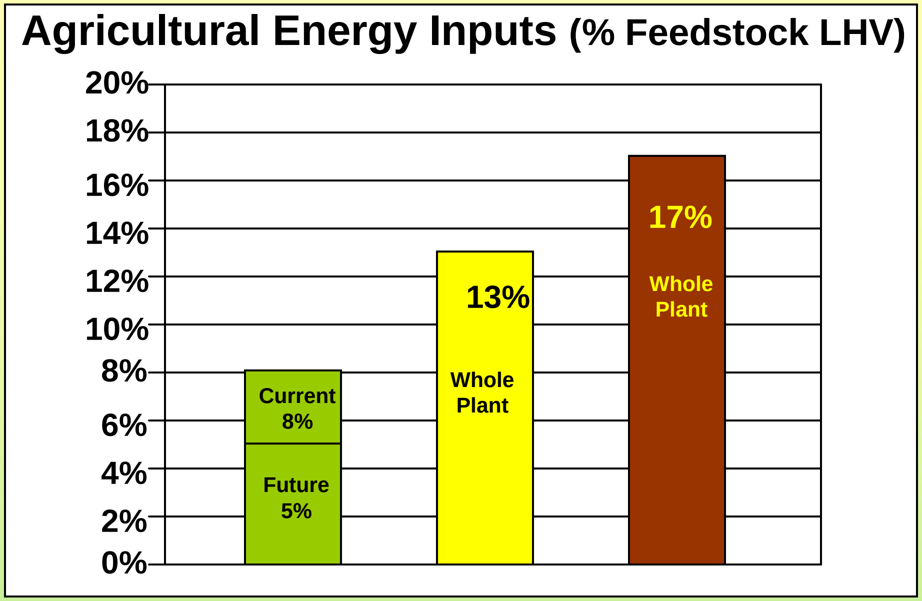


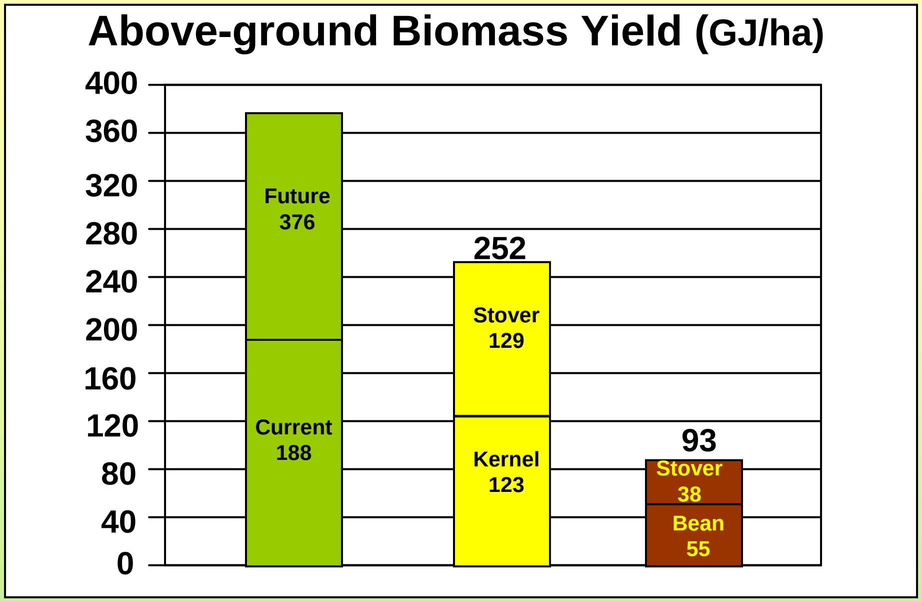
We seek to view the future with the high beams on…



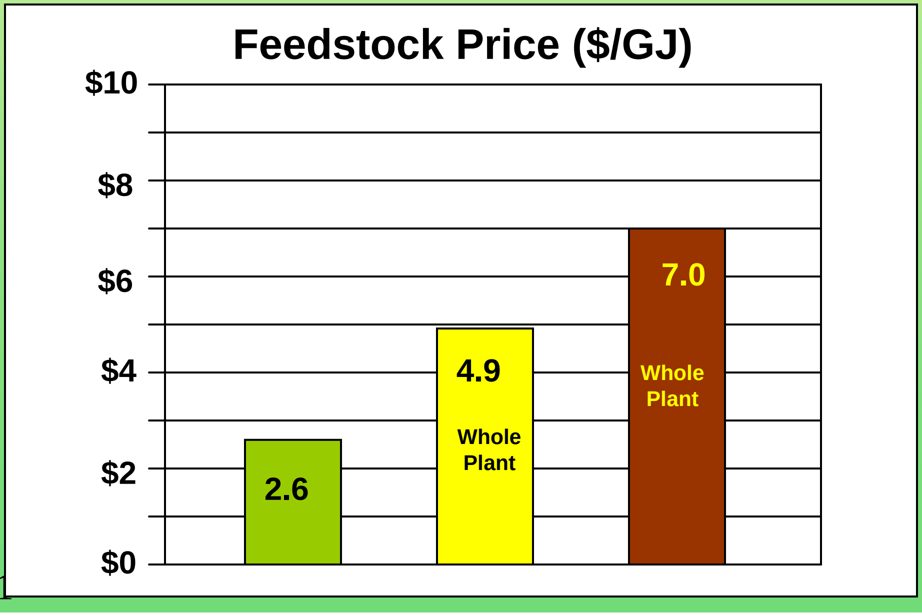
while avoiding invalid comparison

Comparative Features of Potential Bioenergy Feedstocks (draft)


Agricultural Energy Inputs (% Feedstock LHV)

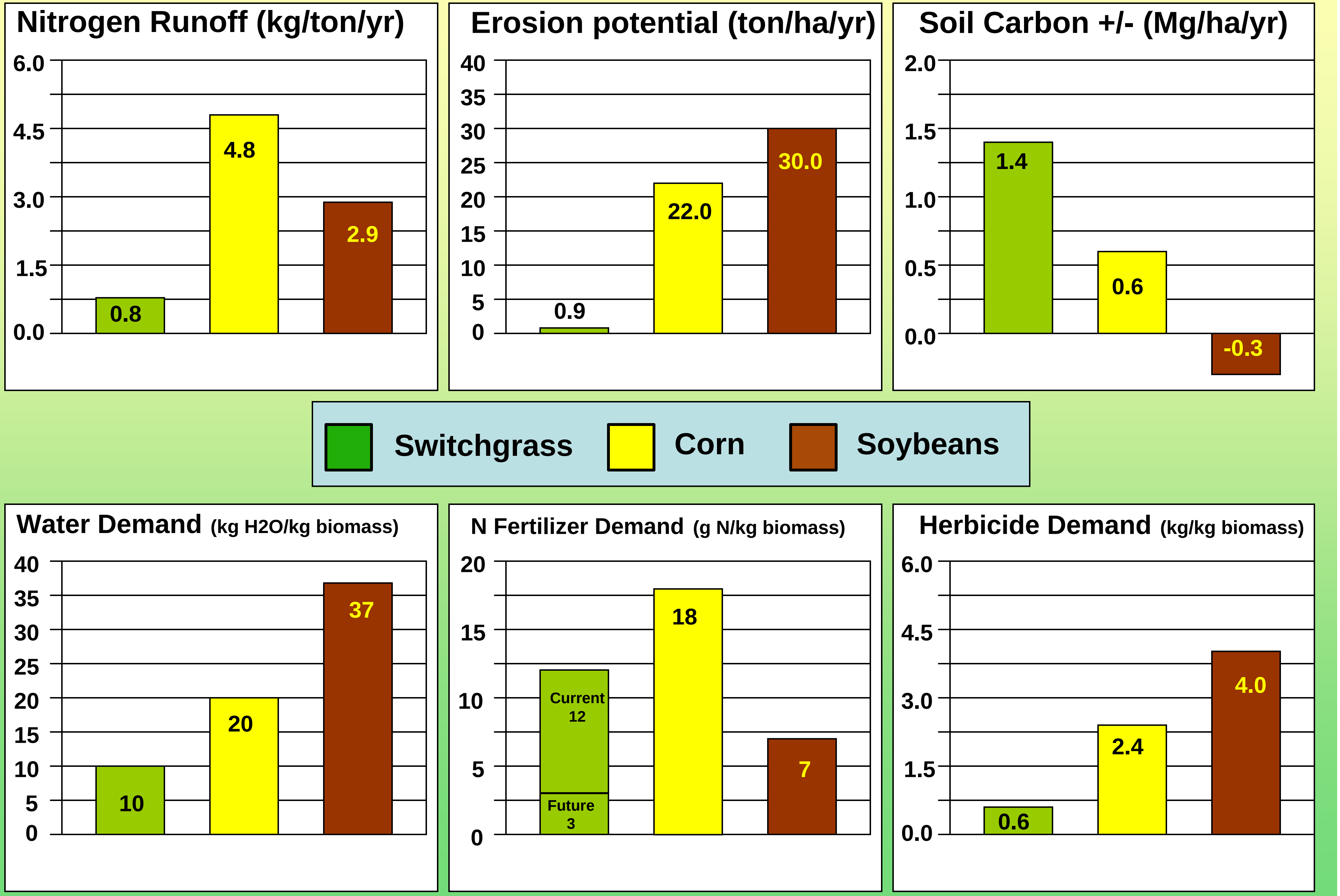

Above-ground Biomass Yield (GJ/ha)

🟩 Switchgrass 🟨 Corn 🟫 Soybeans


Feedstock Price ($/GJ)

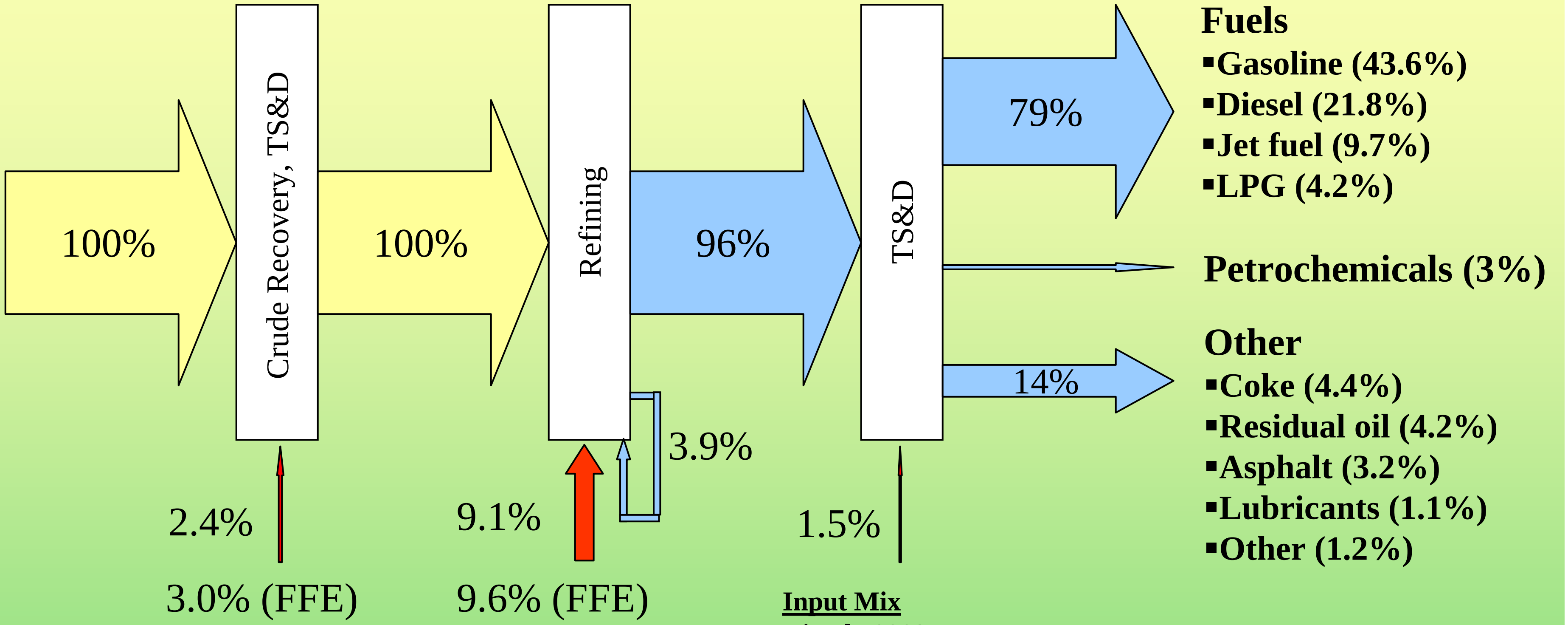
- Switchrass compares favorably with corn, soy on most metrics; focus of RBAEF study
- SG is, however, more difficult to convert to fuels - “not here yet”
- We should not be surprised if current crops are not the best for energy production, since they were chosen for other purposes

Comparative Features of Potential Bioenergy Feedstocks (draft)



Oil Refining

(Numbers Denote Energy Flows)



Fuels

- Gasoline (43.6%)
- Diesel (21.8%)
- Jet fuel (9.7%)
- LPG (4.2%)

Petrochemicals (3%)

Other

- Coke (4.4%)
- Residual oil (4.2%)
- Asphalt (3.2%)
- Lubricants (1.1%)
- Other (1.2%)

3.0% (FFE)

Input Mix	
Crude	**1%**
Residual oil	**1%**
Diesel	**15%**
Gasoline	**2%**
Natural gas	**62%**
Electricity	**19%**

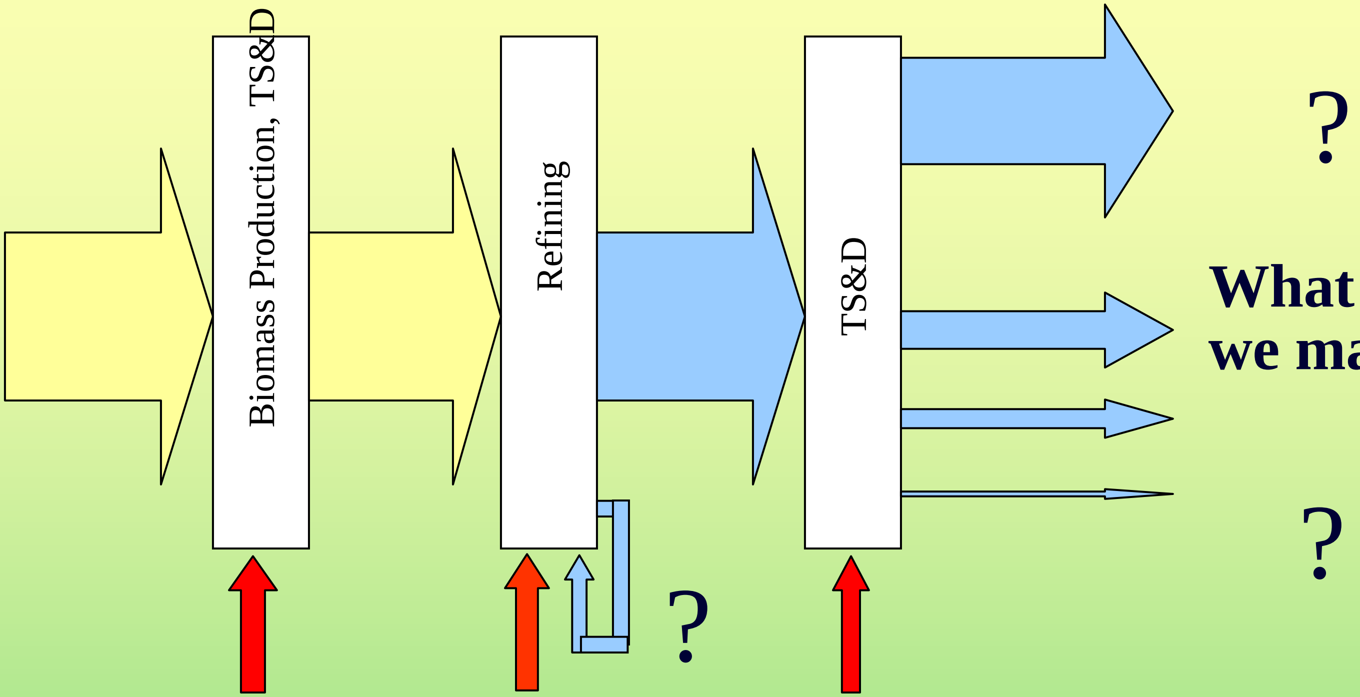
9.6% (FFE)

Input Mix	
Coal	**13%**
Residual oil	**3%**
Gasoline	**2%**
Natural gas	**78%**
Electricity	**4%**

Input Mix
Diesel 100%

Sources:
External energy inputs/efficiencies: GREET
Refinery outputs: API

Biomass Refining



What will we make

What inputs will be required?

What will it cost?

RBAEF Process Analysis

Material & Energy Balance Models

Implemented using ASPEN

Build on extensive prior work

- **Princeton (thermochemical fuels & power)**
- **NREL & Dartmouth (ethanol)**

Basis for

Thermodynamic analysis “energy balance”

Material flows for environmental analysis

Economic analysis

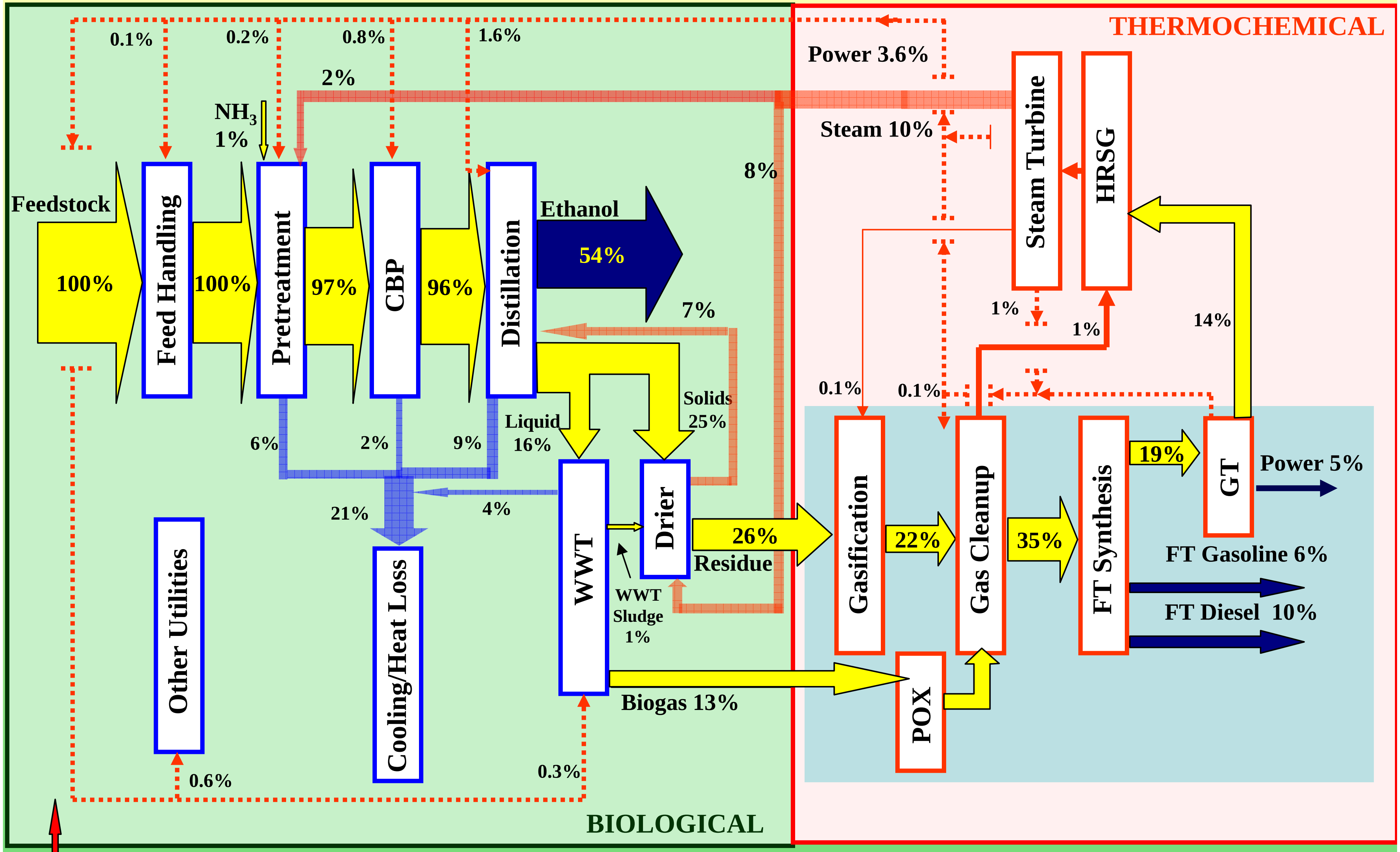
~7 person-year effort undertaken jointly by Dartmouth, Princeton

24 different scenarios including many product combinations

- **Electrical power**
- **Fischer Tropsch Fuels**
- **Ethanol**
- **Hydrogen**
- **Dimethyl ether**
- **Light gases**
- **Animal feed**

Unprecedented for mature biomass conversion technologies

Mature Biomass Refining Energy Flows (example scenario)

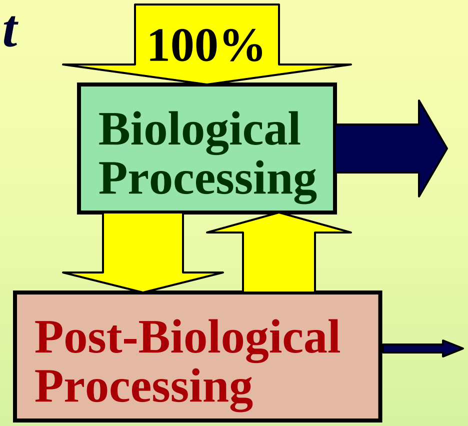


Ag Inputs (Farming, feedstock transport) ~ 5 %

Processing Residues from Biological Processing Offers Lots of Value

Maturation of biological conversion --> much larger opportunities

Current

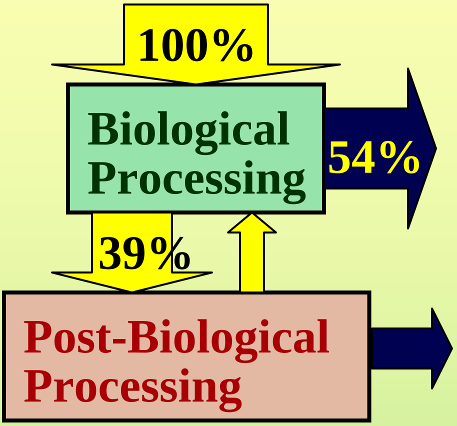


100%

Biological Processing

Post-Biological Processing

Mature



100%

Biological Processing

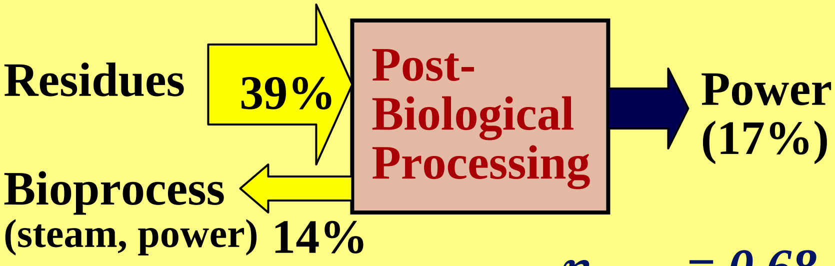
54%

39%

Post-Biological Processing

Internal cogeneration - most energy for biological processing is from *waste* heat accompanying power and/or FT fuel production

Power



Residues

39%

Post-Biological Processing

Power (17%)

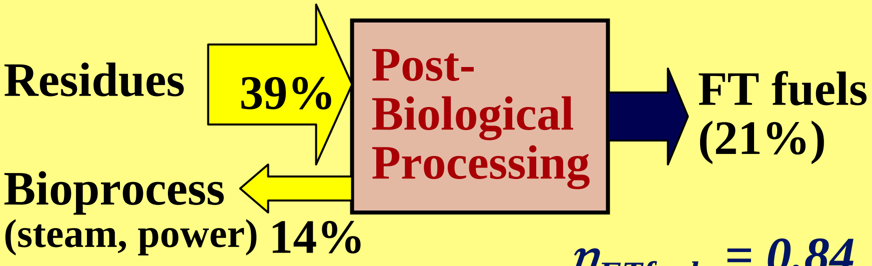
Bioprocess (steam, power) 14%

$\eta_{power} = 0.68$

0.75% power demand displaced for every 1 % transport fuel demand displaced (US)

<u>Large</u> baseload power contribution, compliments intermittent sources

Fischer-Tropsch fuels (diesel, gasoline)



Residues

39%

Post-Biological Processing

FT fuels (21%)

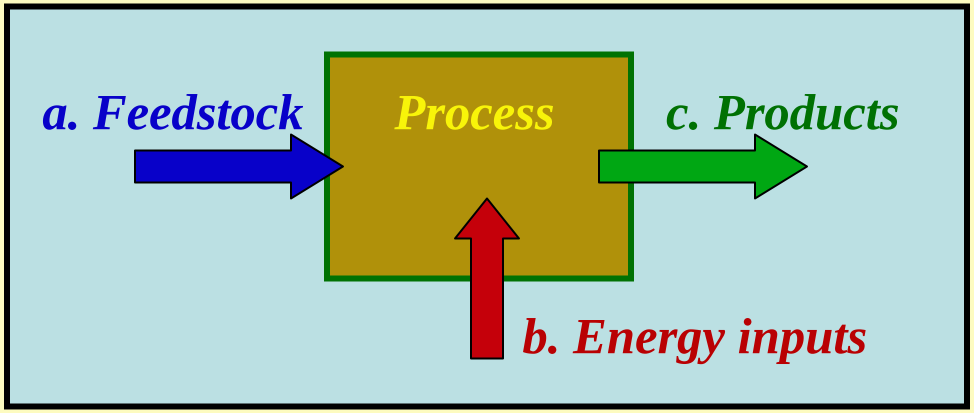
Bioprocess (steam, power) 14%

$\eta_{FTfuels} = 0.84$

Slate of fuels including bioethanol, FT diesel, FT gasoline (or added ethanol)

E90 entirely from renewables

Energy Balance



% Feedstock Low Heating Value

	Cellulosic Biomass		Petroleum
	Current	Mature	
b/a	4 to 8	≤ 5	11.4
c/a*	≥ 35	≥ 70	82 (96)
c/b	≥ 4	≥ 14	7.1 to 8.4

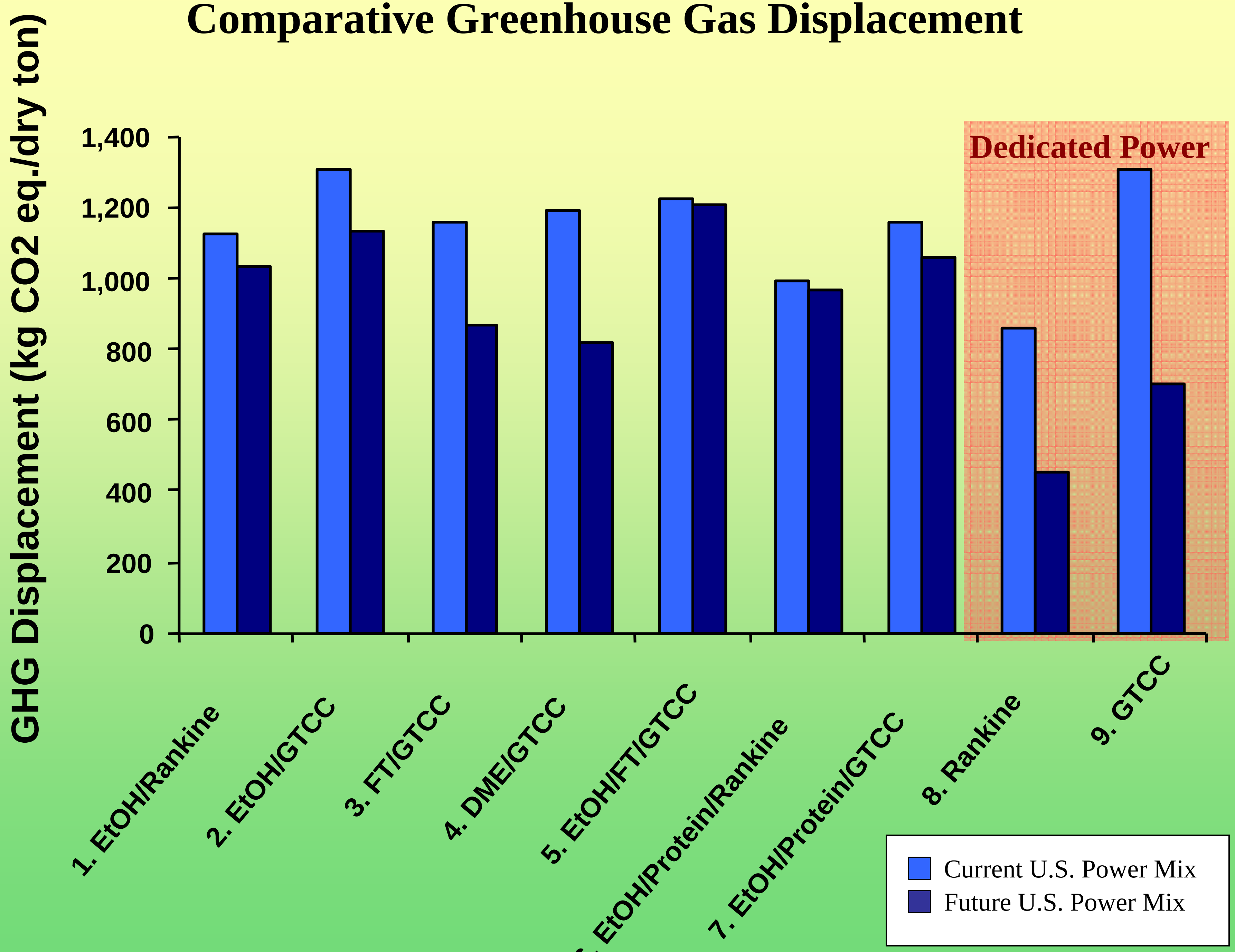
*** Biomass: Products = liquid fuels and power**

Petroleum: Products = liquid fuels & chemicals (+ lubricants, coke, asphalt…)

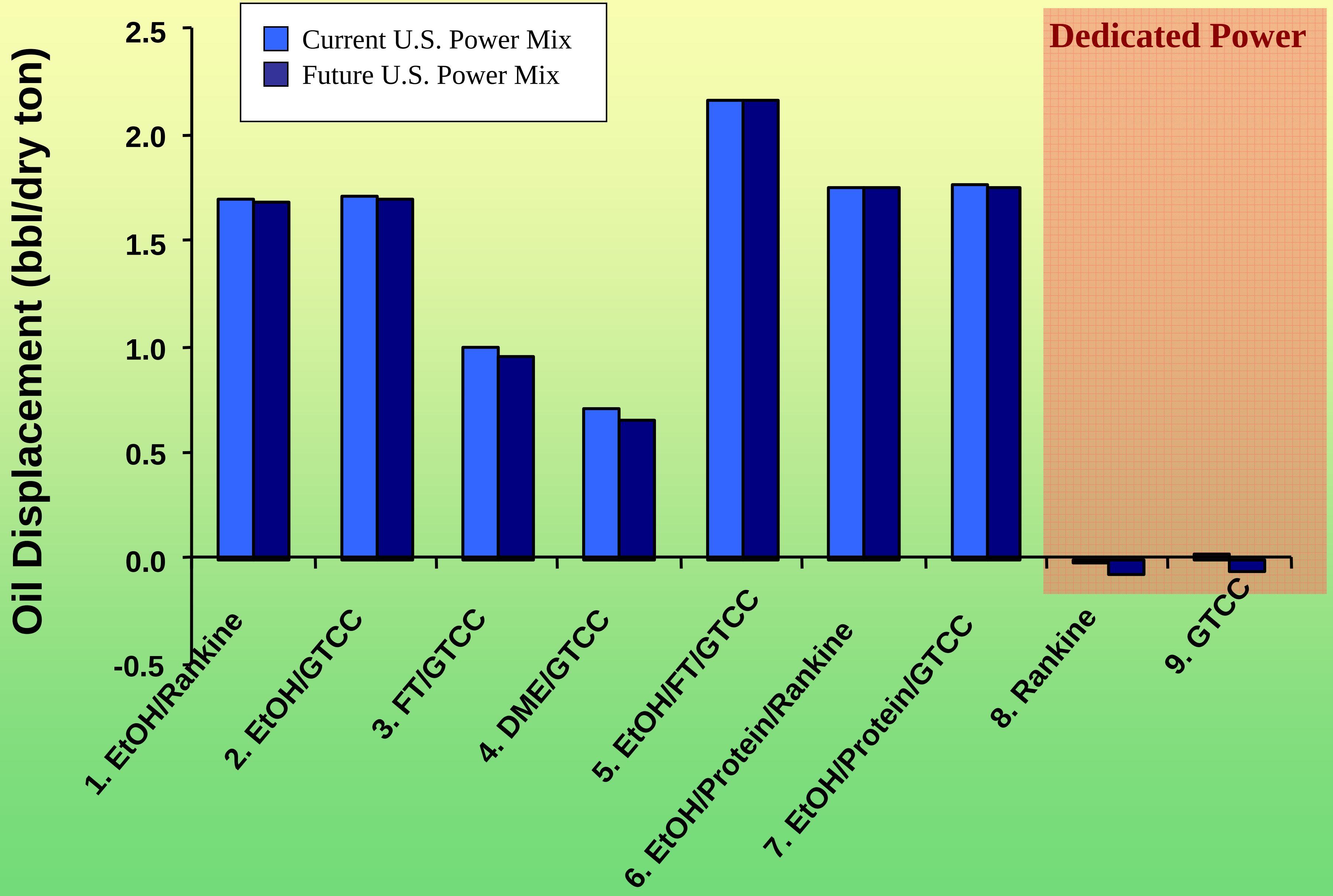
The process energy balance is decidedly favorable for processing cellulosic biomass via both current and mature technology.

The reasons this issue persists are not technical.

Comparative Greenhouse Gas Displacement



Comparative Petroleum Displacement



Economics

Salient Observation

Cellulosic biomass @ $40/ton = $2.3/GJ = oil @ $13/barrel

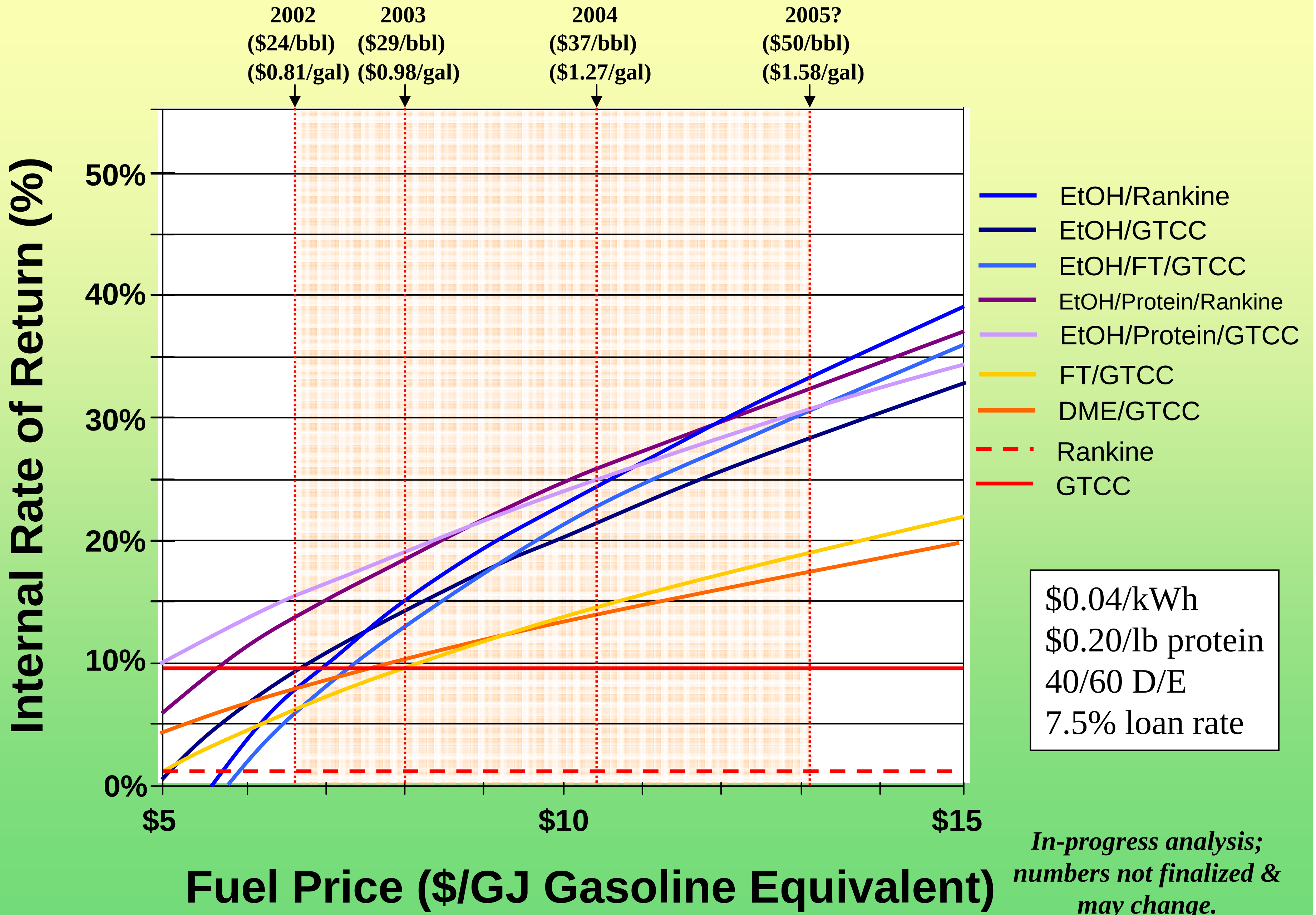
Approach

Capital (NREL, Princeton, vendors, literature) & operating costs estimated

Return on investment calculated based on cashflow analysis, as a function of

- **Fuel & power prices**
- **Scale**
- **Debt equity ratio & other financial parameters**

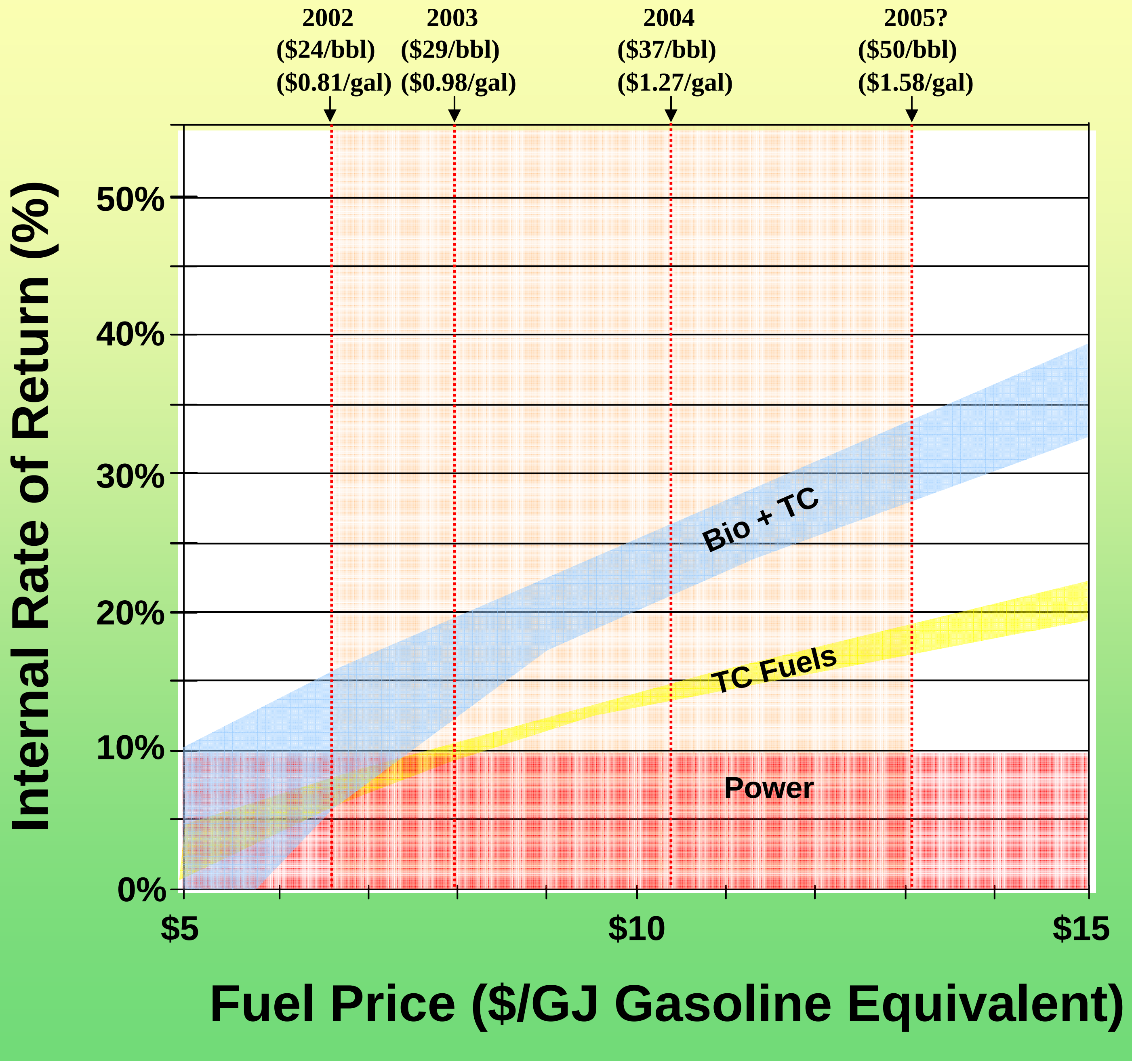
Scenario Comparison: Fuel price variable, power price constant, 5,000 tpd



$0.04/kWh
$0.20/lb protein
40/60 D/E
7.5% loan rate

In-progress analysis; numbers not finalized & may change.

Scenario Comparison: Fuel price variable, power price constant, 5,000 tpd



$0.04/kWh
$0.20/lb protein
40/60 D/E
7.5% loan rate

In-progress analysis; numbers not finalized & may change.

~ two dozen biomass processing scenarios are being developed based on performance & configurations anticipated for mature technology

The following working hypotheses are supported by our results

All the most cost-effective scenarios feature biological processing -
one cannot afford not to biologically process the carbohydrate fraction of biomass

However, post biological thermochemical processing is very important

- **Responsible for processing ~ 40% of the energy in the original feedstock**
- **Adds substantially to efficiency, revenues, greenhouse gas displacement**
- **Strong thermodynamic synergies with biological processing**

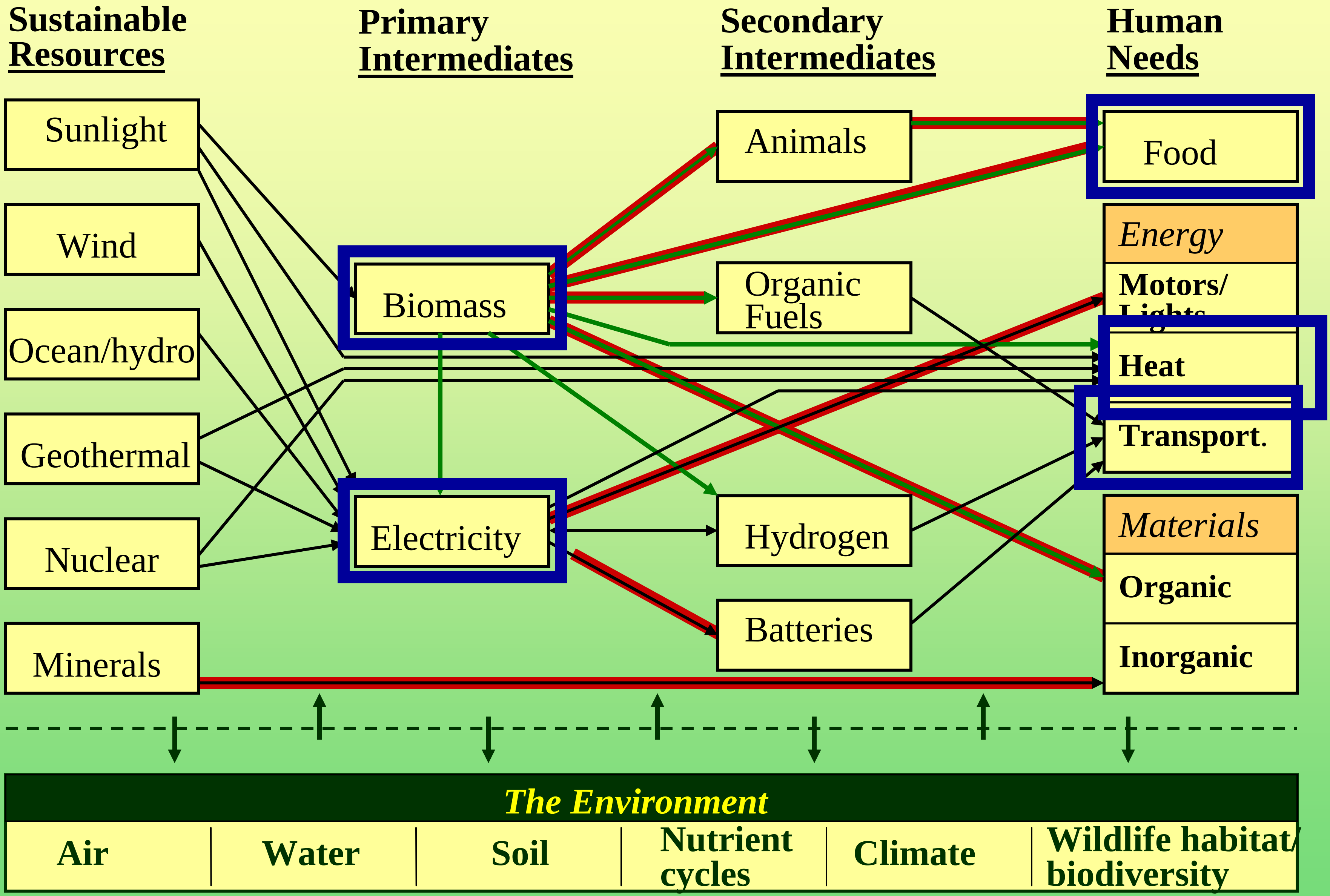
Production of ethanol in combination with several coproduct combinations is cost-competitive with gasoline over a range of oil & power prices

Metric	Biological & coproducts*	TF fuels & power	Power
GHG emission reductions**	+++	+++	+++
Relative cost effectiveness	+++	++	+
Petroleum displacement	+++	++	-

*Thermochemical fuels (TF) and/or power and in some cases protein

**Greenhouse gas emission reductions, per ton (or per acre) basis

Imagining a Sustainable World



Sustainable Resources

Sunlight

Wind

Ocean/hydro

Geothermal

Nuclear

Minerals

Primary Intermediates

Biomass

Electricity

Secondary Intermediates

Animals

Organic Fuels

Hydrogen

Batteries

Human Needs

Food

Energy

Motors/ Lights

Heat

Transport.

Materials

Organic

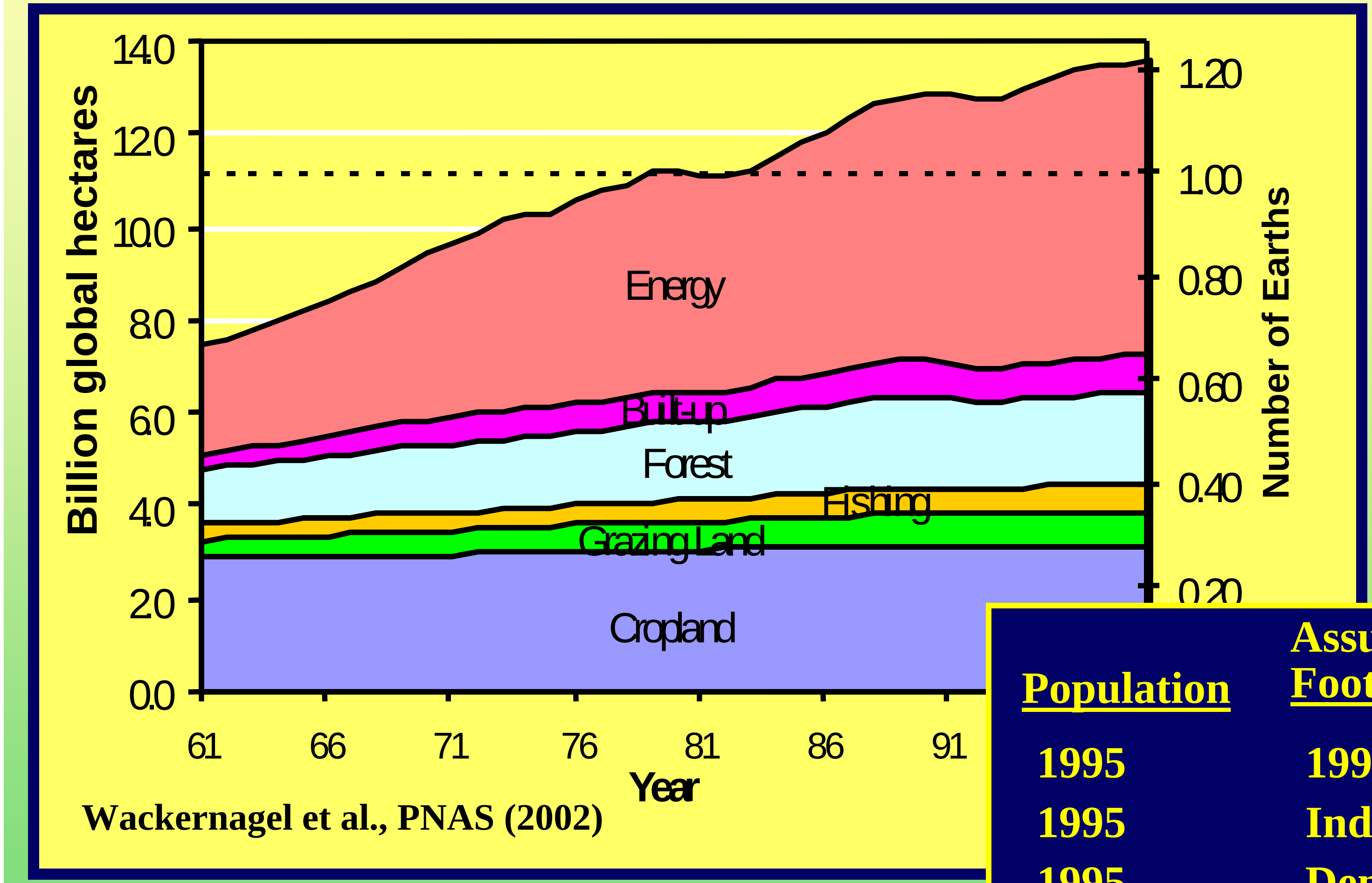
Inorganic

The Environment

Air | **Water** | **Soil** | **Nutrient cycles** | **Climate** | **Wildlife habitat/ biodiversity**

🟦 **Choices** 🟥 **Sole Supply**

Environmental “footprint”: Land area required to provide for resource consumption & waste assimilation on a sustainable basis



Wackernagel et al., PNAS (2002)

Population	**Assumed Footprint**	**Number of Earths**
1995	**1995**	**1.3**
1995	**India**	**0.29**
1995	**Denmark**	**2.4**
1995	**USA**	**3.7**
2 x 1995	**Denmark**	**4.8**

Wackernagel & Rees, 1996

The Next Industrial Revolution?

Hawkins, Lovins, and Lovins, “Natural Capitalism”

The first industrial revolution

Context: Resources plentiful, people scarce

Response

Dramatic increases in

- Labor productivity (output/person/hour): 100-fold higher
- Fraction of energy supply from non-sustainable sources: from 0 to ~80%)
- Resource consumption per capita
- Population
- Level of services (mobility, housing, dietary variety, information) expected

The second industrial revolution

Context: Resources scarce, people plentiful

Response

Population stabilization (appears to be happening)

Dramatic increases in

- Resource productivity (service delivered/resource invested)
- Reliance on sustainable resources, especially for energy

Environmental & Resource Considerations (NRDC)

Feedstock production (planting, cultivation, harvesting, transportation) - e.g. *per ton*

- **Fossil fuel inputs modest (~3% of the heating value of the feedstock)**
- **Chemical inputs(herbicide, pesticide), runoff much less than row crops**
- **Possibility for fertilizer recycle (e.g. nitrogen)**
- **Perennial grasses have a strong positive effect on soil carbon/fertility, enhanced by harvest**
- **Habitat enhancement opportunities substantially greater than row crops**

Conversion - e.g. *per gallon*

- **All effluents treatable with existing technology & responsible management**
- **Water demand much reduced by near-total recycle (as for recent existing biorefineries)**
- **Likely that a use will be found for (modest) solid waste flows (biosolids, ash)**

Utilization (transportation) - e.g. *per mile*

- **Criteria pollutants - Ease of achieving low emissions generally better than status-quo options**
- **Some addressable concern r.e. low-level blends during transition**
- **Greenhouse gases (life cycle, per unit biofuel) - Near zero for all options**

No showstoppers, many positives when looking at "per unit" effects

A more difficult question: How many units?

Biomass Availability: Radically different conclusions have been reached

- Biomass becomes the largest energy source supporting humankind in the Renewables-Intensive Global Energy Scenario of Johanssen et al. (1993).
- Biomass share of world energy supply will equal that of oil in 2050 and be as large as any other resource (Kassler, Shell Petroleum Ltd, 1994).
- Biomass will eventually provide over 90% of U.S. chemical and over 50% of U.S. fuel production (Biobased Industrial Products, NRC, 1999).
- Ethanol to replace all gasoline in the [U.S] light-duty fleet - would be necessary to process the biomass growing on 300 to 500 million acres. (Lave et al., 2002).
- Large scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it (Giampetro et al., ‘97).

Key variables impacting availability of biomass for non-food uses

Biomass productivity (tons/acre*yr)

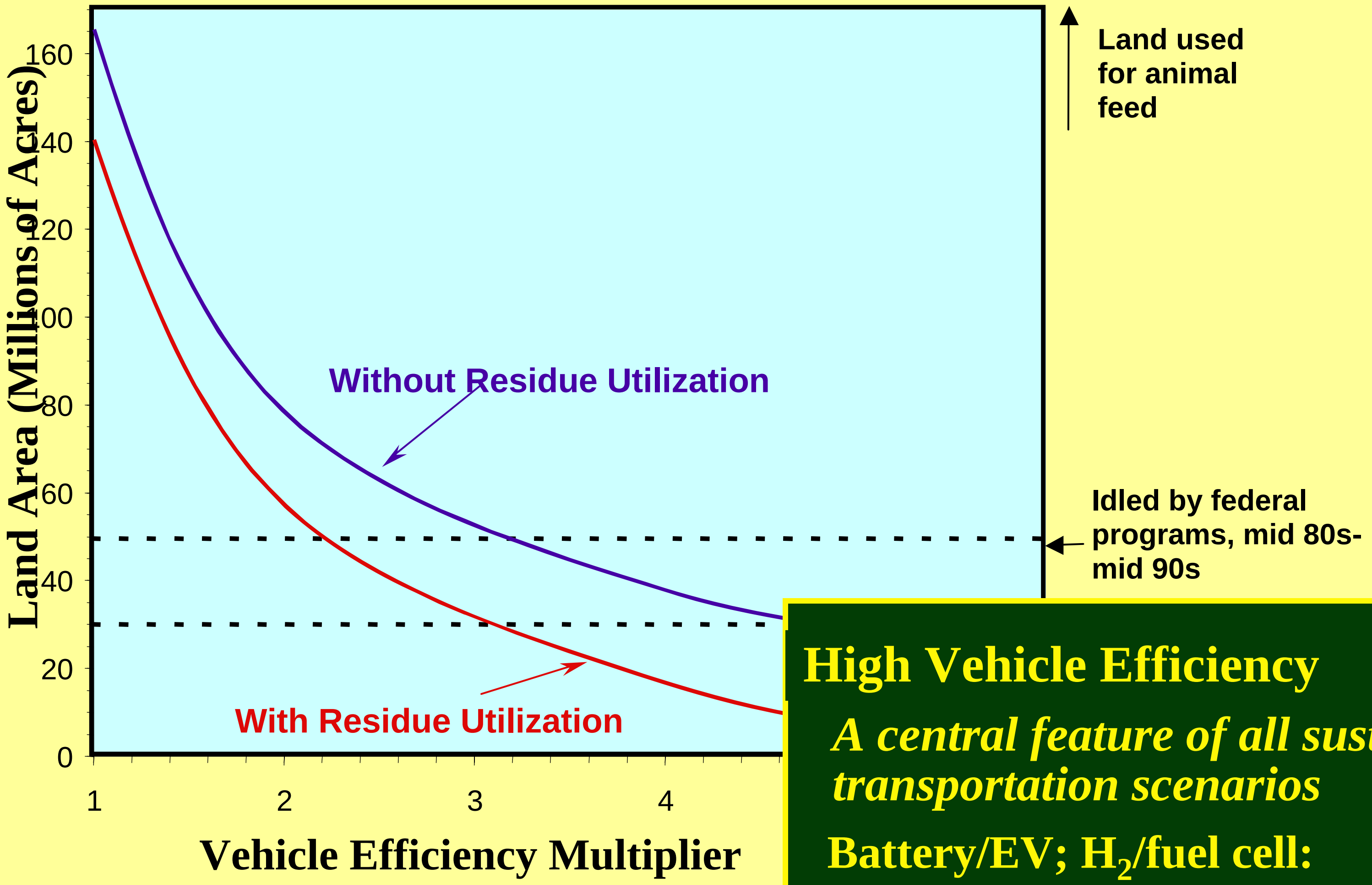
Vehicle efficiency (miles/gallon)

Land use

Food production efficiency (calories, protein/acre)

Integration of feedstock production into currently-managed lands

Land Area Required for Current U.S. Light Duty Mobility in Relation to Vehicle Efficiency



- •LDV VMT = 2.5 trillion vehicle miles traveled
- •Waste availability: 200 million dry tons
- •Switchgrass productivity: 10 dry tonss/acre/year
- •Fuel yield: 100 gallons/dry ton

High Vehicle Efficiency

A central feature of all sustainable transportation scenarios

Battery/EV; H_2/fuel cell:

Avoids otherwise small travel radius

Cellulosic biofuels

Avoids otherwise large footprint

Food Production Efficiency

Strongly impacted by dietary trends - the amount and kind of meat consumed in particular.

Tremendous potential elasticity

Land to feed U.S. population in the most land-efficient way possible: ~ 20 million acres

Land currently used: > 400 million acres

Food production is usually assumed to remain static in analyses of the role of biomass as an energy source.

However, demand for cellulosic feedstocks due to cost-competitive processing technology would very likely result in large changes.

Farmers would rethink what they grow and how they grow it.

➡ Feed protein/feedstock coproduction

Feedlot pretreatment to make calories more accessible

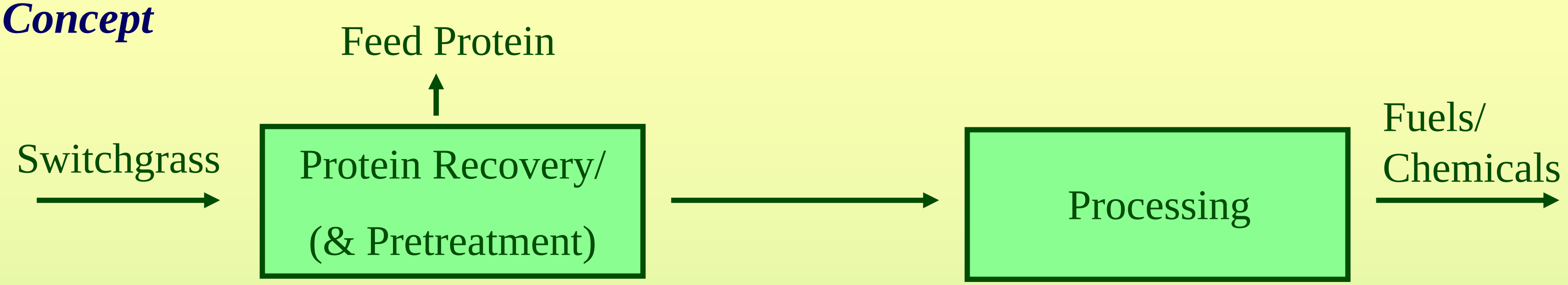
Increase production on under-utilized land (e.g. hay, pasture)

Winter cover crops

➡ Agricultural residue removal, enhanced by appropriate crop rotations

Feed Protein/Feedstock Coproduction

Concept



Feed Protein

Switchgrass

Protein Recovery/

(& Pretreatment)

Processing

Fuels/
Chemicals

Composition & productivity comparison

Crop	**Mass Productivity (tons/acre/year)**	**Protein (Mass Fraction)**	**Protein Productivity (tons/acre/year)**
Switchgrass	5.0 – 10	.08 -0.12 (early cut)	0.4 – 1.2
Soybeans	1.1 – 1.3	0.36 - 0.5 (bean only)	0.40 – 0.65

- **Consumption of calories and protein by livestock 10x that by humans in the U.S.**
- **Production of perennial grass could potentially produce the same amount of feed protein per acre while producing a large amount of feedstock for energy production**
- **Requires readily foreseeable processing technology to recover feed protein**
- **Many positive indications of feed protein quality, but not fully established**
- **Not pursued now because of absence of demand for cellulosic residues**
- ***Processing feedstock might also be coproduced from large biomass soybeans***

Removal of Agricultural Residues & Soil Fertility

Conventional: What fraction of residues can be removed for current crops/rotations without depleting soil carbon?

Cropping system	Allowable residue removal (%)
Corn/soy rotation, current practice	13%
Continuous corn, mulch tillage	46%

Sheehan et al., 2004

Alternative: What crops/rotations maximize allowable residue removal?

Corn/switchgrass rotation with 100% corn stover removal

Decreased soil carbon due to stover removal: 0.26 tons/acre/year

Increased soil carbon for switchgrass: 0.40 tons/acre/year

Winter cover crops w/ corn further improve carbon budget, nutrient retention

While switchgrass and corn may not be an ideal rotation, this example illustrates that residue harvesting can be profoundly impacted by crop rotations

Toward Reimagining Agriculture with Energy Production Incorporated

New demand --> new rewards & opportunities --> new agriculture

New uses for existing crops (e.g. corn stover)

New combinations of existing crops

New & improved crops & cropping systems

Grass & corn rotations common in Argentina (most beef grass-fed)

Energy crops easily rotated with row crops are likely desirable. Have not been a focus to date but are reasonable to target for development.

Desired features

Specific to rotation: Rapid establishment (harvest first year), easy disestablishment

General: High productivity, broad site range, soil carbon accumulation, low inputs

Hypothetical rotation based on combining properties of existing crops

September, harvest corn (including 100% stover), plant new crop

May, harvest 1 (~ 2 tons/acre, based on winter cover crops in Michigan)

September, harvest 2 (~ 7 tons/acre, U.S. average corn crop, grain + stover)

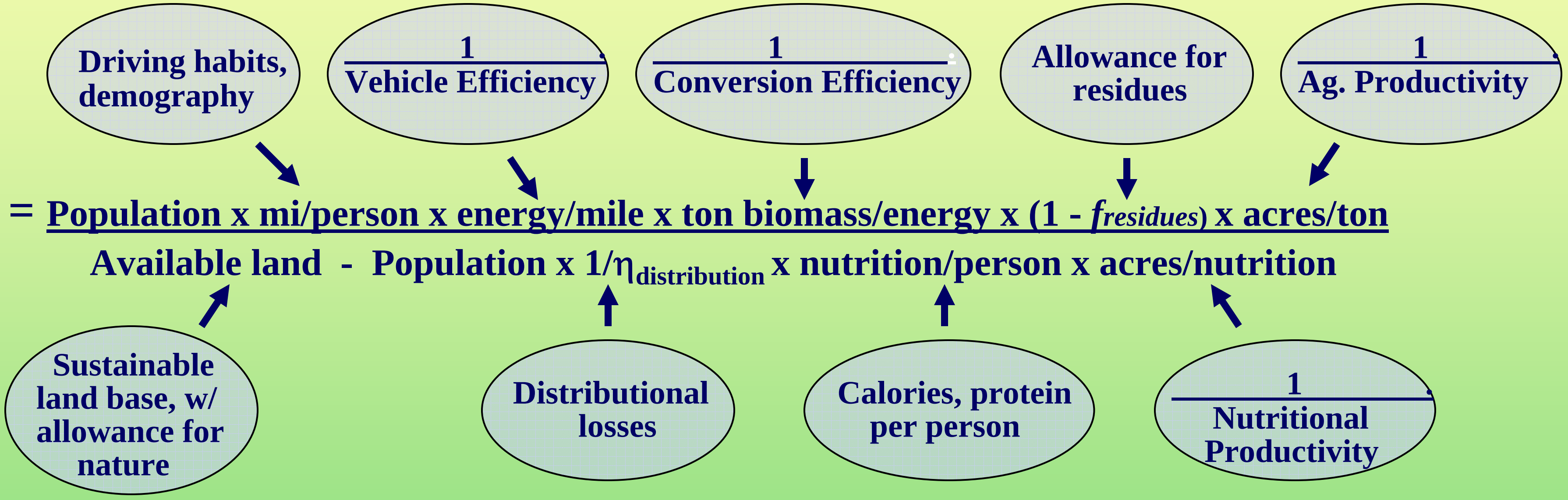
May, harvest 3, plow under (~ 3 tons/acre, likely > harvest 1; could also plow in)

Breeding target - 12 tons/acre + soil carbon benefits, 1 missed season

The Availability of Biomass for Non-Food Uses is a Much More Elastic Quantity Than Usually Assumed

***Would like to know*:**

$$\frac{\text{Land Required to Meet a Specified Need (e.g. Transportation)}}{\text{Land Available}}$$



Driving habits, demography

$$\frac{1}{\text{Vehicle Efficiency}}$$

$$\frac{1}{\text{Conversion Efficiency}}$$

Allowance for residues

$$\frac{1}{\text{Ag. Productivity}}$$

$$= \frac{\text{Population x mi/person x energy/mile x ton biomass/energy x } (1 - f_{residues}) \text{ x acres/ton}}{\text{Available land - Population x } 1/\eta_{distribution} \text{ x nutrition/person x acres/nutrition}}$$

Sustainable land base, w/ allowance for nature

Distributional losses

Calories, protein per person

$$\frac{1}{\text{Nutritional Productivity}}$$

Considering the range of values these largely independent parameters might be assumed to take in a future scenario (e.g. several decades hence):

$$= \frac{\text{1.5-fold x 3-fold x 4-fold x 2-fold x 2-fold x 5-fold}}{\text{3-fold - 2-fold x 1.5-fold x 1.5-fold } \geq \text{ 5-fold}} = \frac{\text{320-fold}}{\text{3-fold - 20-fold}}$$

Land to provide current U.S. mobility (LDV and HDV)

Scenario	Parameter Value		Additional Land[1,2] (MM acres)	
	Current	Advanced	LDV	LDV + HDV
a. Status quo (33 gal Geq/ton, current mpg, no ag. integration, 5 tons/acre*yr)			847	1,088
b. Improved conversion[3]	33 gal GEq/ton	96 gal GEq/ton	291	373
c. Improved vehicle efficiency	1X	2.5X	116	149
d. Ag. integration, incorporation into existing land uses.				
i. Soy->SG &/or large biomass soy		74 MM acres	42	75
ii. Corn stover utilization	None	72 to 100%	0 - 2	20 – 36
	(19 – 25 billion gal GEq = 40 – 55 MM acres @ 5 tons/acre*yr)			
Other (other residues, winter cover crops, underutilized land…)			???	???

GEq = gasoline equivalent

[1] Land in addition to current cropland; total U.S. cropland = 400 MM acres; idled CRP land = 30 MM acres

[2] Current gasoline demand = 140 billion gallons; vehicular HDV/LDV energy = 0.28.

[3] Includes co-production of FT fuels; product profile (% feedstock LHV): EtOH 56%; FT diesel 11%; FT gasoline 8%

Calibration: Total U.S. Cropland: ~400 MM acres; CRP land: ~30 MM acres

Projected growth rates for VMT and biomass productivity are similar.

We could…	By utilizing…	
Rapidly develop cost-competitive, efficient conversion technology	• Mature technology • Integrated biological, thermochemical processing	• Larger effort • RD&D + commercialization • Different processing paradigm
Make a large contribution to energy service provision with modest land investment	• High productivity energy crops	• Integration of feedstock production into currently-managed lands
	• High efficiency vehicles	

Innovation & Change

May seem aggressive, but consider the alternatives…

Approaches to Energy Planning & Analysis

1. Bury our heads in the sand. **Pretend that energy challenges are not real or will go away.**

2. Extrapolate current trends.

3. Hope for a miracle (e.g. Hoffert et al., Science, 2002).

- **Acknowledge the importance of sustainable and secure energy supplies**
- **Dismiss foreseeable options as inadequate to provide for the world's energy needs**
- **Call for "disruptive" advances in entirely new technologies whose performance cannot be foreseen.**

4. Innovate & change.

- **Define sustainable futures based on mature but foreseeable technologies in combination with an assumed willingness of society to change in ways that increase resource utilization efficiency**
- **Work back from such futures to articulate transition paths beginning where we are now**

#1 and #2 do not offer solutions to sustainability and security challenges.

#3 should be pursued but is too risky to rely on.

#4 is the most sensible choice if it is assumed that problems associated with sustainability and security are important to solve.

The "high beam" perspective revisited

Indispensible for identifying and motivating where we want to go

But…

Does not fully illuminate the path to get there, including transition issues

The path forward is blazed by major new legislation in the energy bill

- **Harkin/Lugar Bioenergy/Bioproducts Ammendment (S. Amdt 919, H.R. 6)**
  - **Authorizes ~ 4-fold increase in R&D funding**
  - **Cellulosic biofuel production incentives**
  - **Procurement of biobased products**
  - **Bioeconomy grants**
  - **Other provisions**
- **7.5 billion gallon renewable fuel standard**
- **Total support for biofuels > $4.4 billion over next 10 years**

A Chorus of Recent Studies Supports Potential for Major Impacts

In the last 2 years

RBAEF project

"Considers & supports the possibility of biomass fuels being a *primary* transport energy storage medium - not a bit player, not only a transition option

Environmental community - from ambivalence to champion.

"Cellulosic ethanol is at least as likely as hydrogen to be an energy carrier of choice for a sustainable transportation sector." (NRDC, UCS)

Rocky Mountain Institute/Amory Lovins

Biofuels prominently featured in "Winning the Oil End Game"

25 x 25 group

Clearest statement to date by the farm community of the possibility & desirability of large-scale energy production

DOE "Billion tons" report

Detailed report documenting large-scale biomass availability

Energy Future Coalition

Supports major biofuels push (R&D & deployment)

Today, there is *unprecedented* potential to advance biomass energy, resulting from the convergence of several factors

Greater appreciation of need

- Oil prices
- Energy security
- Greenhouse gas emissions

More thorough documentation of potential

Technical advances

Aggressive legislation

Realization of this potential will be fostered by

Appropriations following authorizations

Wise expenditures, based on technical merit not provincial agendas

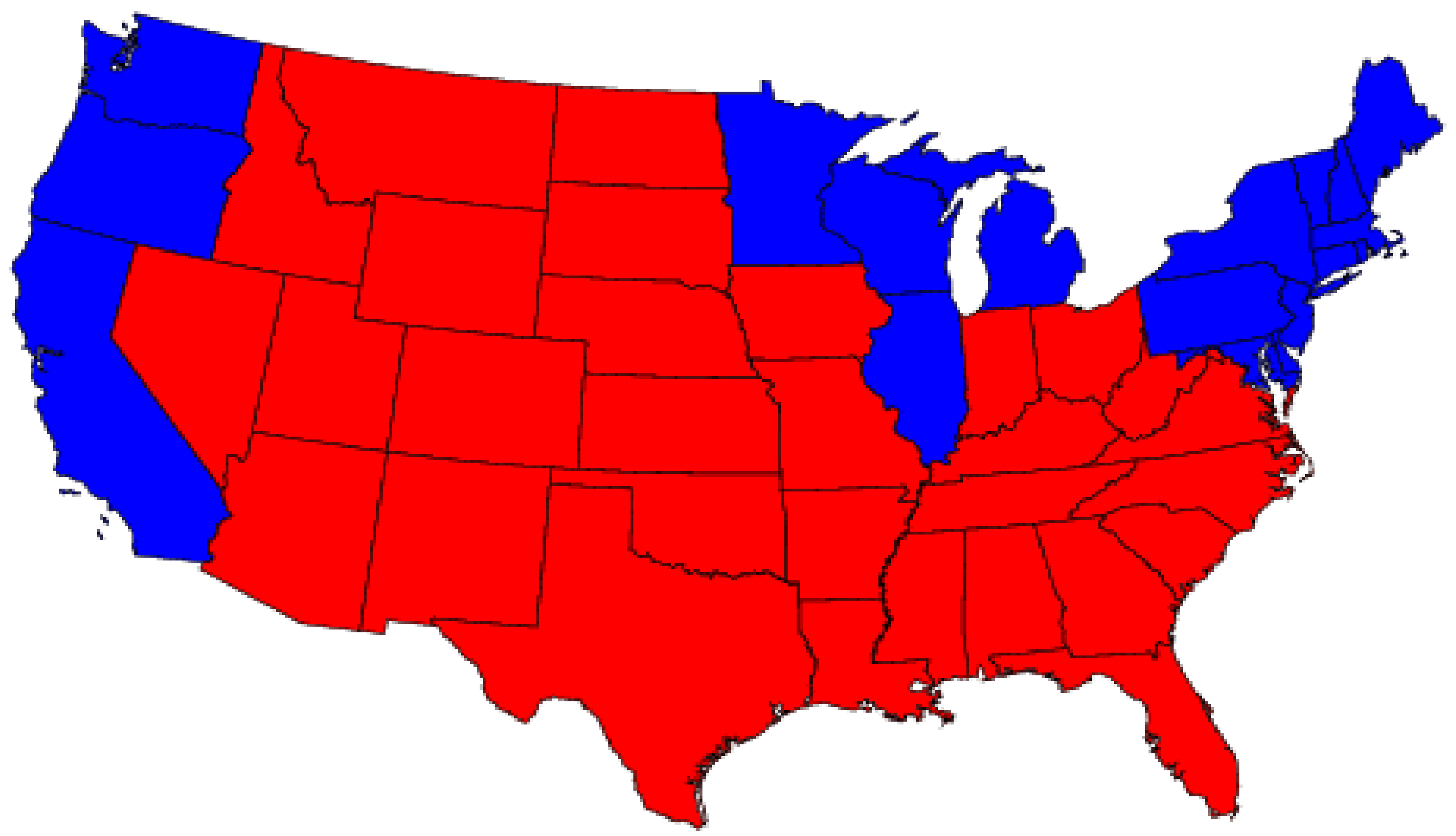
Broad political support

Farmers & ag. processors

Environmental advocates

Oil industry

Consider…



Farm interests have had more influence in red states

Environmental interests have had more influence in blue states

Imagine what could be accomplished if farm and environmental advocates formulated a common agenda

Advocacy by farm groups, environmentalists, and the oil industry: seldom aligned, often in conflict

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

To change this, we need to…

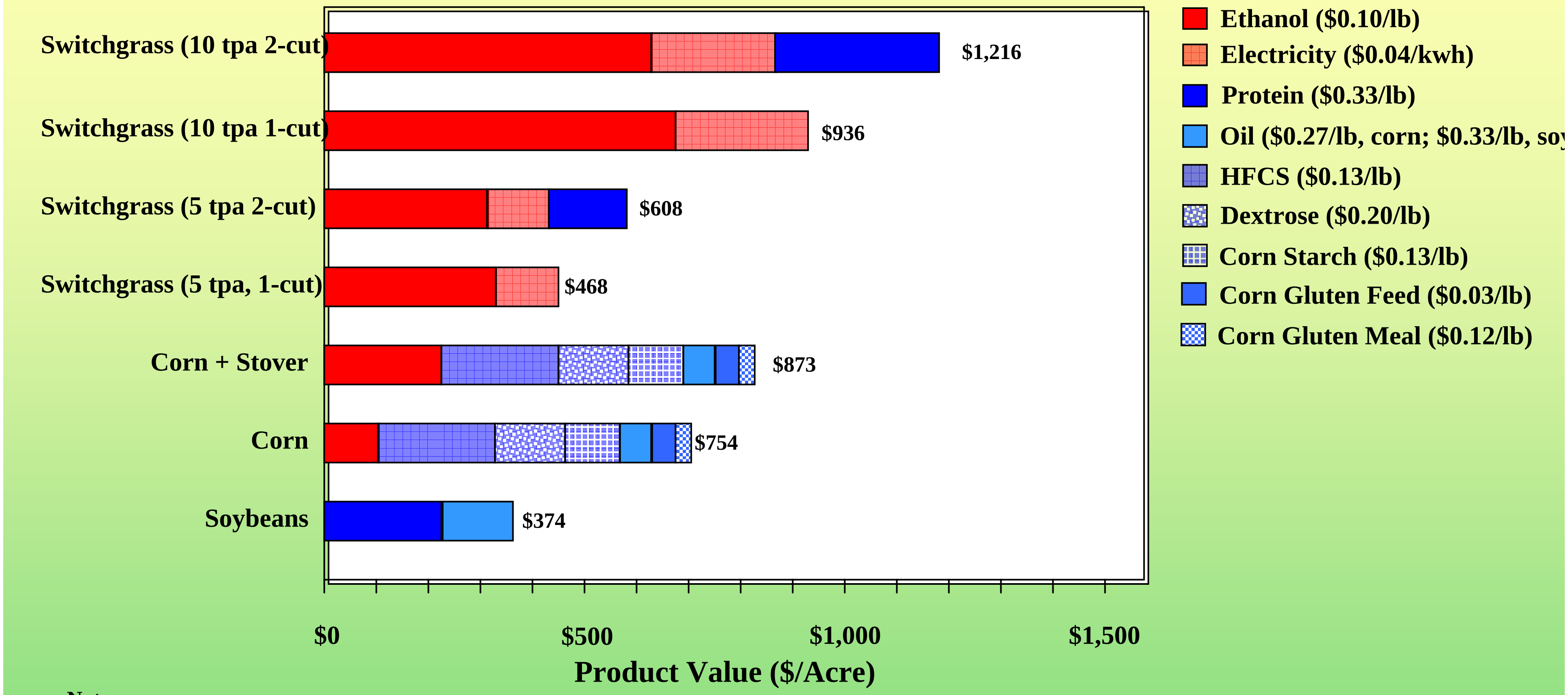
- **Find common ground around addressing universal issues**
  - **Security**
  - **Sustainability**
- **Honor core interests**
  - **Environmentalists: Sustainability**
  - **Oil: Cost-effectiveness at large scale**
  - **Farm: <u>Continuously</u> expanding opportunity**
- ***These interests are reconcilable***
- ***Such reconciliation will be more successful working toward a mutually attractive future than defending the imperfect present***

Parting Thoughts

If we rise to the challenges implicit in the new opportunities before us, we can aspire to redefine the relationship of agriculture to modern society, with permanent benefits of historic proportions to farmers & rural communities.

There is lots of work to do.

Product Value per Acre - Switchgrass Relative to Corn, Soy



Notes:

- Switchgrass protein recovery assumed to be 80%
- 2-cut switchgrass assumes 67% of total yield harvested in early cut
- Corn + stover scenario assumes 50% stover collected
- Ethanol price assumed to be $0.64/gallon (energy equivalent of gasoline at $1.00/gallon)

Sources:

- Corn yield: 2002 U.S. average, USDA-NASS
- Corn product yields: CRA
- HCFS, glucose, and dextrose prices: 2003 U.S. average, Milling & Baking News
- Starch, CGF, CGM prices: 2002 average, USDA Feed Situation and Outlook Yearbook, 2003
- Corn oil price: 2002 average, USDA Oil Crops Situation and Outlook, 2003
- Soybean yield: 2002 U.S. average, USDA—NASS
- Soy product yields: 2002 U.S. average, USDA Oil Crops Situation and Outlook, 2003
- Soy oil and protein prices: March 2004, Chicago Board of Trade

In-progress analysis, numbers not finalized & may change.