

Biomass-Derived Transportation Fuels to Meet Sustainability & Security Objectives

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**ASPO World Energy Meeting
Boston, Mass**

October 26, 2006

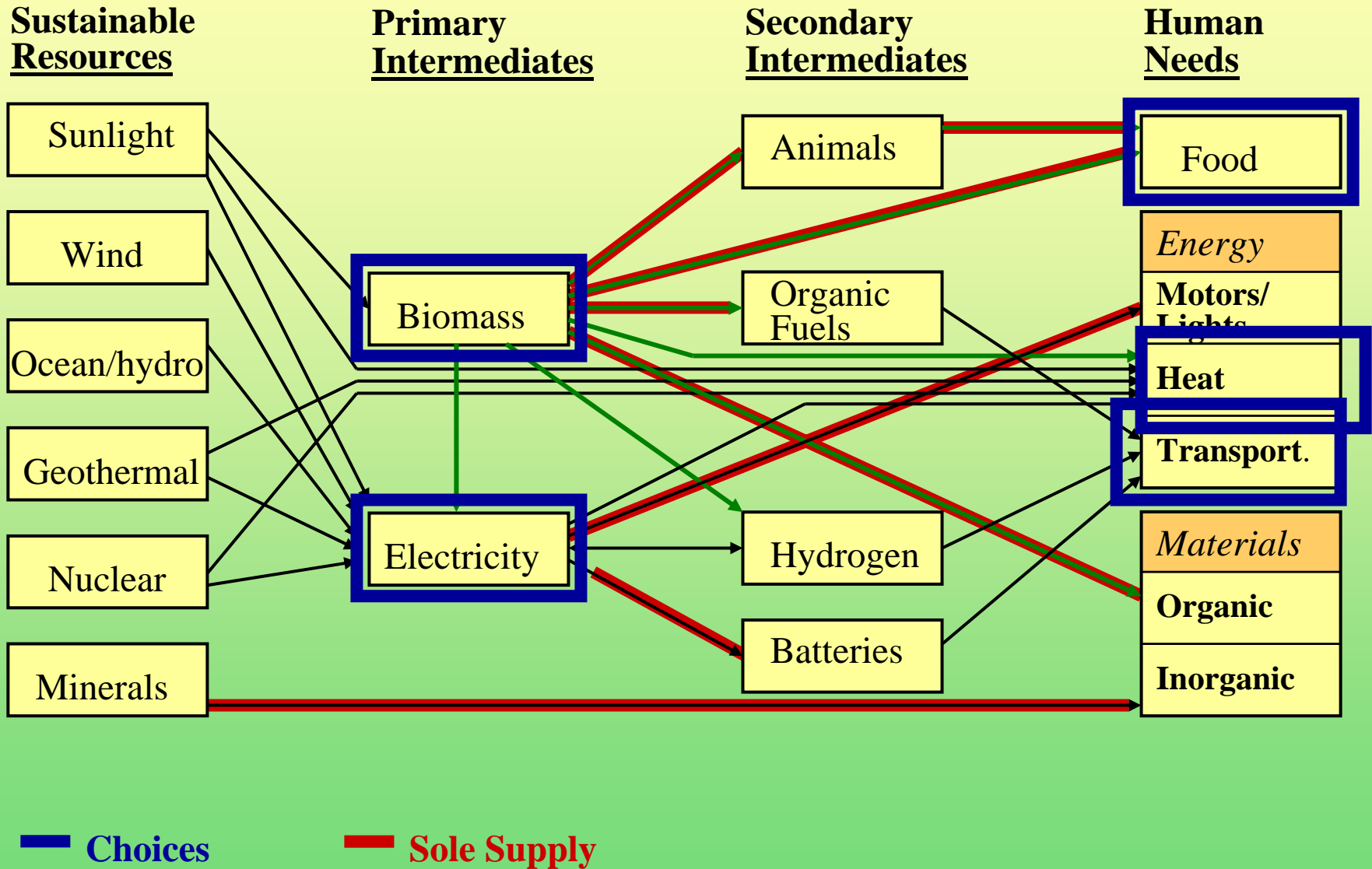
Biomass Feedstocks

Envisioning Mature Biomass Refining

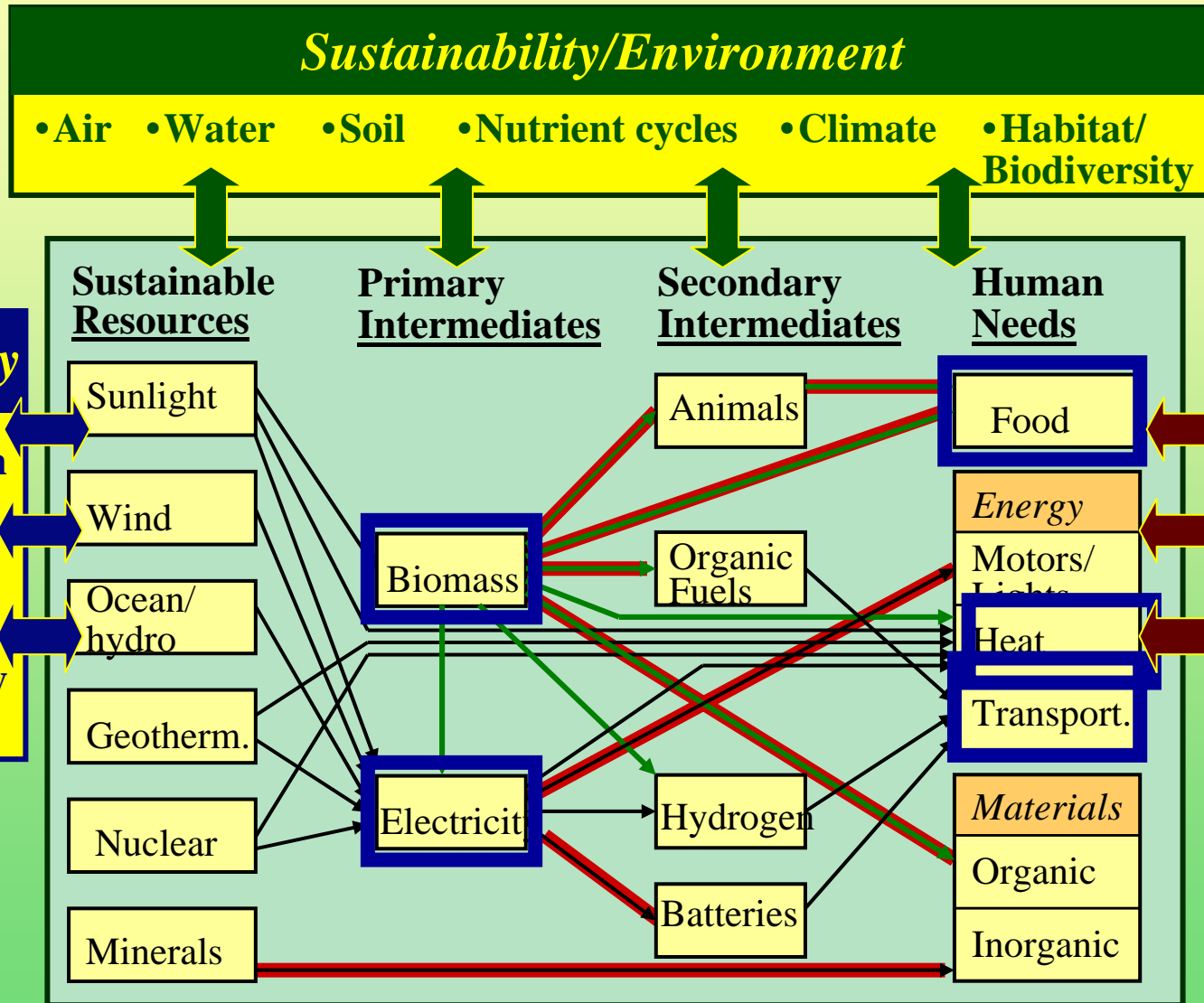
Evaluation of Potential

- **Normalized metrics (Energy out/energy in, \$/ton, ghg/ton)**
- **Resource considerations**

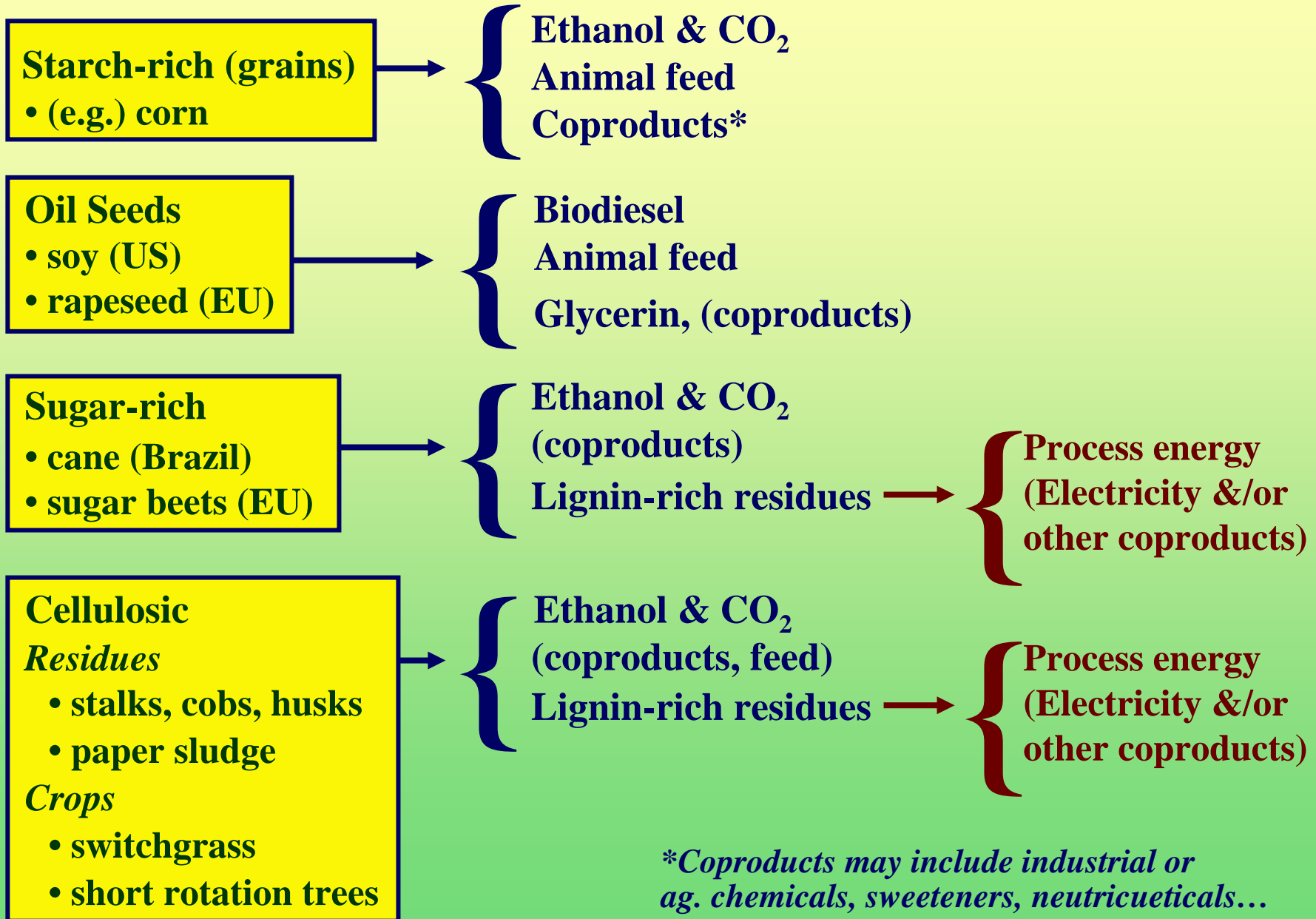
Imagining a Sustainable World



Energy Conversion, Utilization & Access Underlie Great Challenges (Now & Always)



Biofuel Feedstock & Product Options



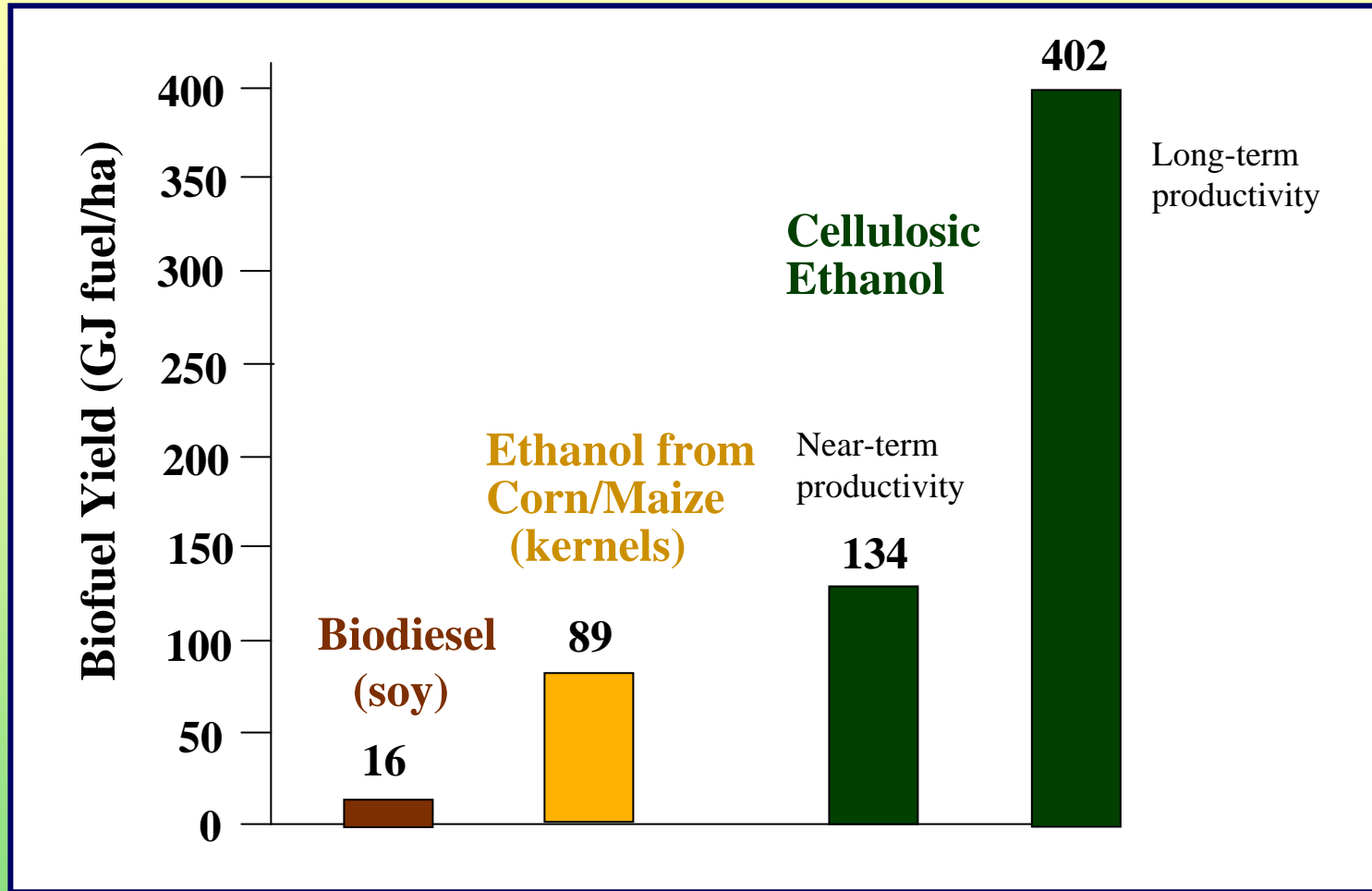
Biomass Feedstocks, Especially Cellulosic, are Cost Competitive with Oil & Gas

<u>Energy Carrier</u>	<u>Price</u>		<u>Cost/Difficulty of Subsequent Conversion</u>
	<u>Common</u>	<u>\$/GJ</u>	
<i>Fossil</i>			
Petroleum	\$50/bbl	\$8.8	Low
Gasoline	\$1.67/gal ^a	\$13.8	-
Natural gas	\$7.50/scf	\$7.9	Low
Coal	\$20/ton	\$0.94	Moderate to high; Higher w/ CO ₂ capture
<i>Electricity</i>	\$0.04/kWh	\$11.1	Very low for many applications; High for storage as H ₂ , batteries
<i>Biomass</i>			
Soy oil	\$0.23/lb	\$13.8	Very low
Corn kernels	\$2.25/bu	\$6.5	Low
Cellulosic crops ^b	\$40/tonne	\$2.4	High now; Moderate/low in the future
Cellulosic residues	≤ crops, some < 0		

^aWholesale

^b e.g. switchgrass, short rotation poplar

Comparative Land Productivity of Biofuel Options



Crop Yields (U.S.)

Near-term cellulosic: 5 dry ton/acre
 Long-term cellulosic: 15 dton/acre
 Corn yield: 160 bushel/acre
 Soy yield: 42 bushel/acre

Fuel Yields

Cellulosic ethanol from RBAEF
 Corn ethanol: 2.8 gal/bushel
 Soy oil: 18% of bean (dry basis)
 Biodiesel yield: 0.95 kg/kg soy oil

Different Plant Feedstocks are Responsive to Different Objectives

	Large Scale Production		Rural Economic Development		Petroleum Displacement (Security)		Fossil Fuel Displacement/ GHG Reductions		Soil Fertility & Ag. Ecology	Low Cost Fuels (feedstock & conversion)	
	Per unit	Total	Now	Future	Per unit	Total	Per unit	Total		Now	Future
Cellulosic	very good	very good	fair	excellent	excellent	excellent	excellent	excellent	excellent	fair	excellent
Starch-rich	very good	fair	very good	good	excellent	good	fair	fair	fair	good	good
Sugar-rich	good	fair	very good	good	excellent	good	fair	fair	very good	good	good
Oil seed	poor	poor	good	fair	good	poor	good	poor	good	poor	poor

Ratings:

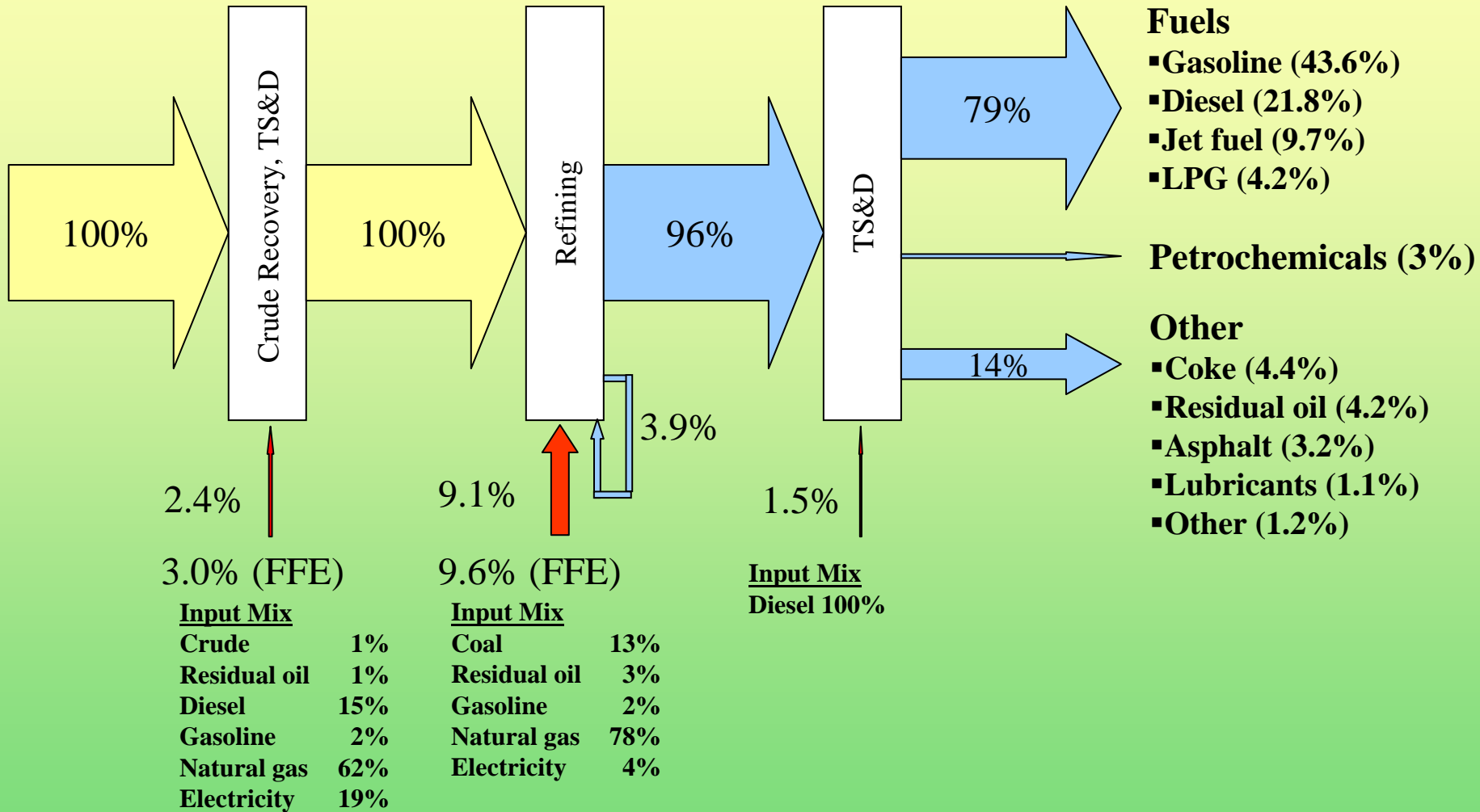
	excellent
	very good
	good
	fair
	poor

Cellulosic biomass is the focus of all studies foreseeing (very) large-scale widespread energy supply from plants.

- Environmentally benign/beneficial production; low inputs
- Low purchase cost
- New opportunities for ag. integration; Broad site range
- Large-scale production --> large benefits

Oil Refining

(Numbers Denote Energy Flows)

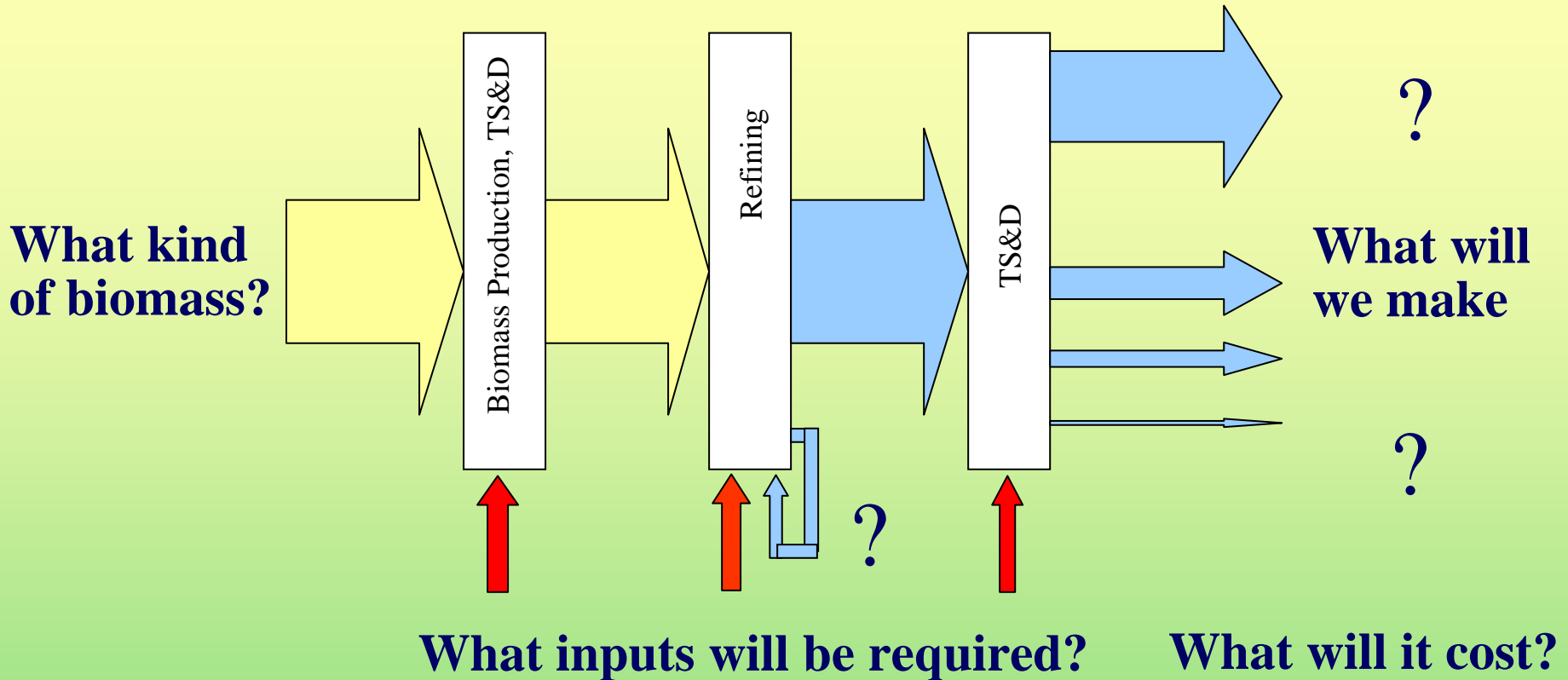


Sources:

External energy inputs/efficiencies: GREET

Refinery outputs: API

Biomass Refining



Role of Biomass in America's Energy Future Project

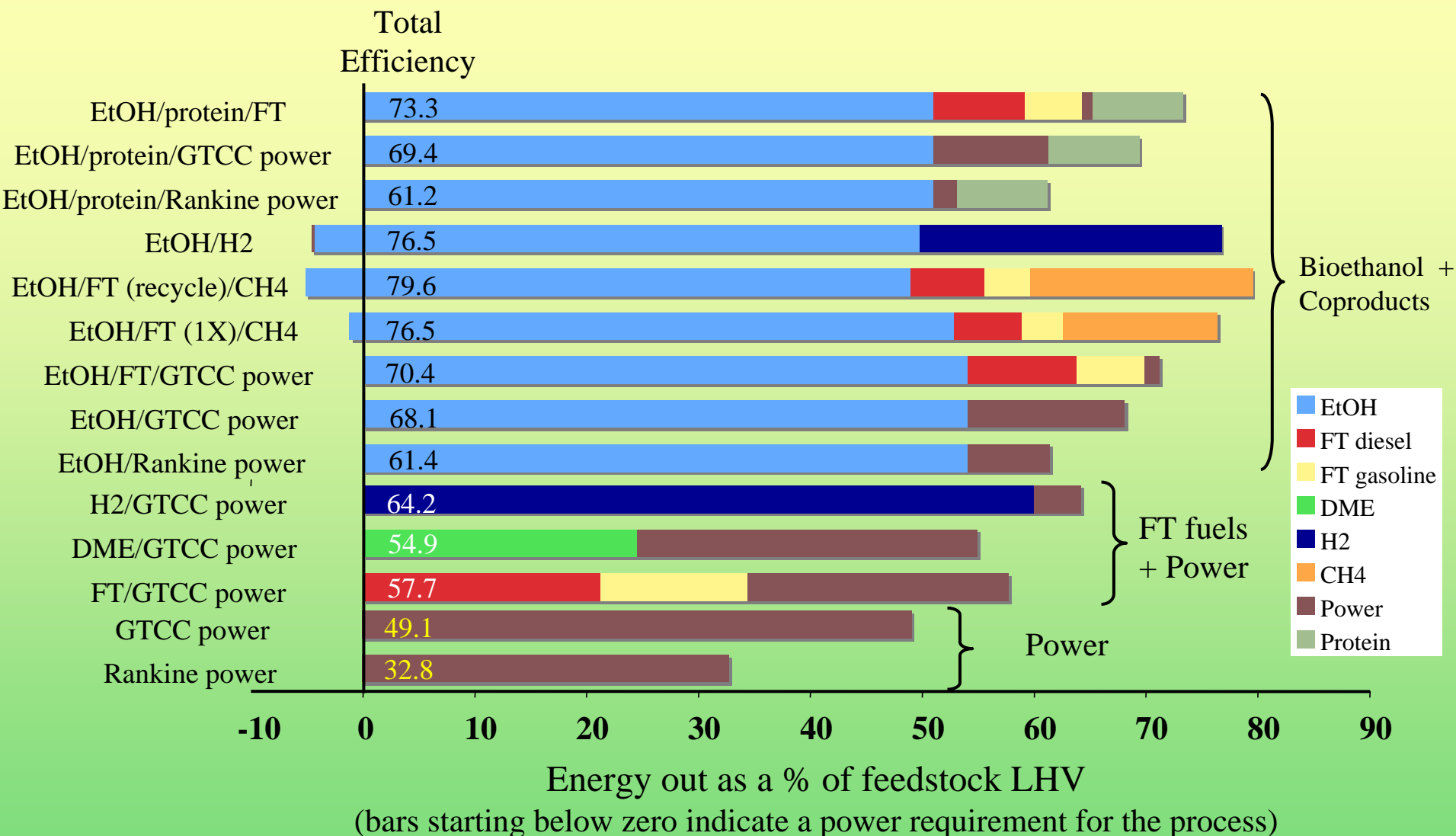
Unprecedented analysis of mature biomass conversion technology

Lead institutions: Dartmouth, Natural Resources Defense Council

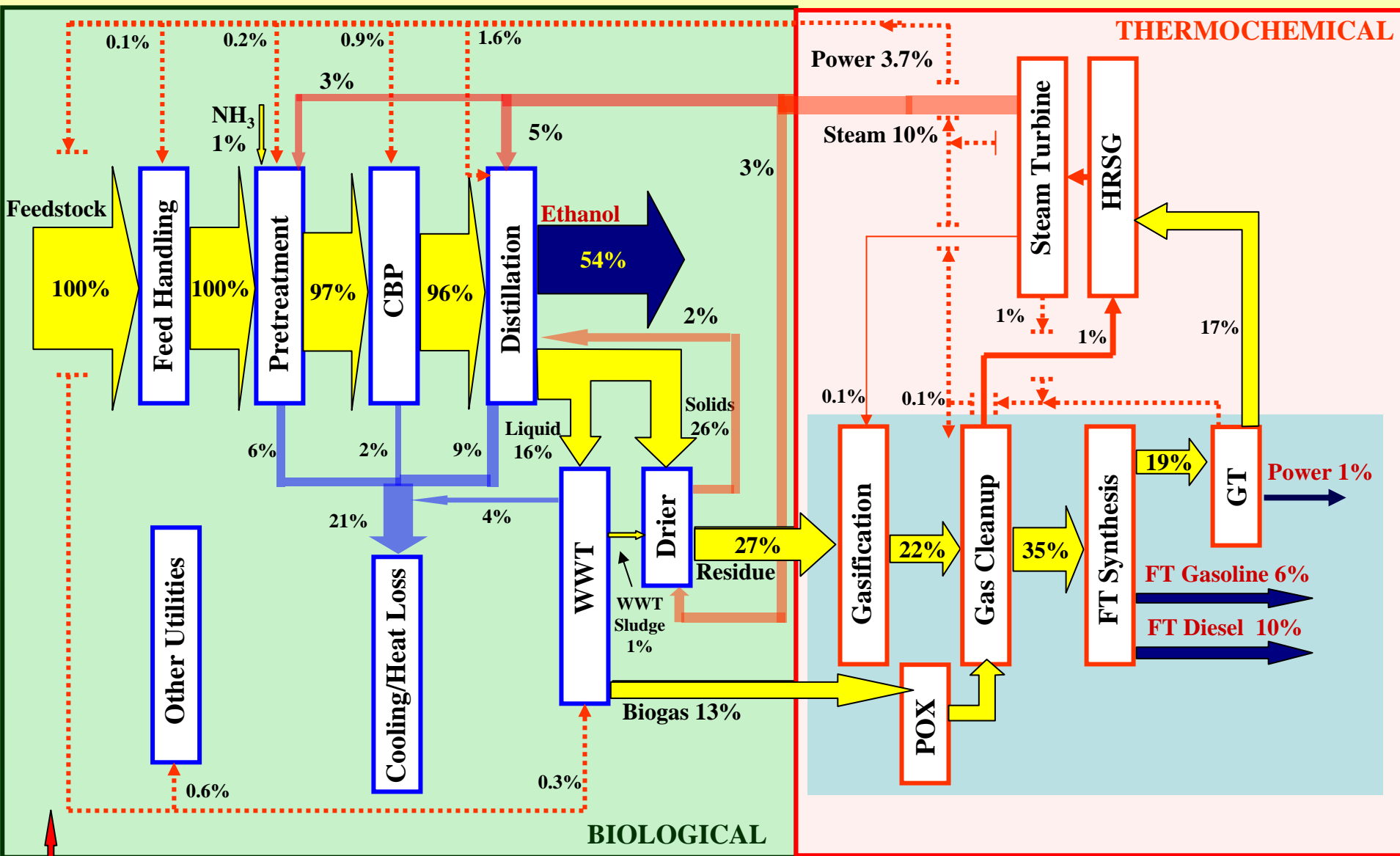
Participants: Auburn U., ANL, Iowa State U., Michigan State U., NREL, ORNL, Princeton, Union of Concerned Scientists, USDA, U. of Tennessee,

Sponsors: DOE, Energy Foundation, National Commission on Energy Policy

Efficiency of Mature RBAEF Process Scenarios

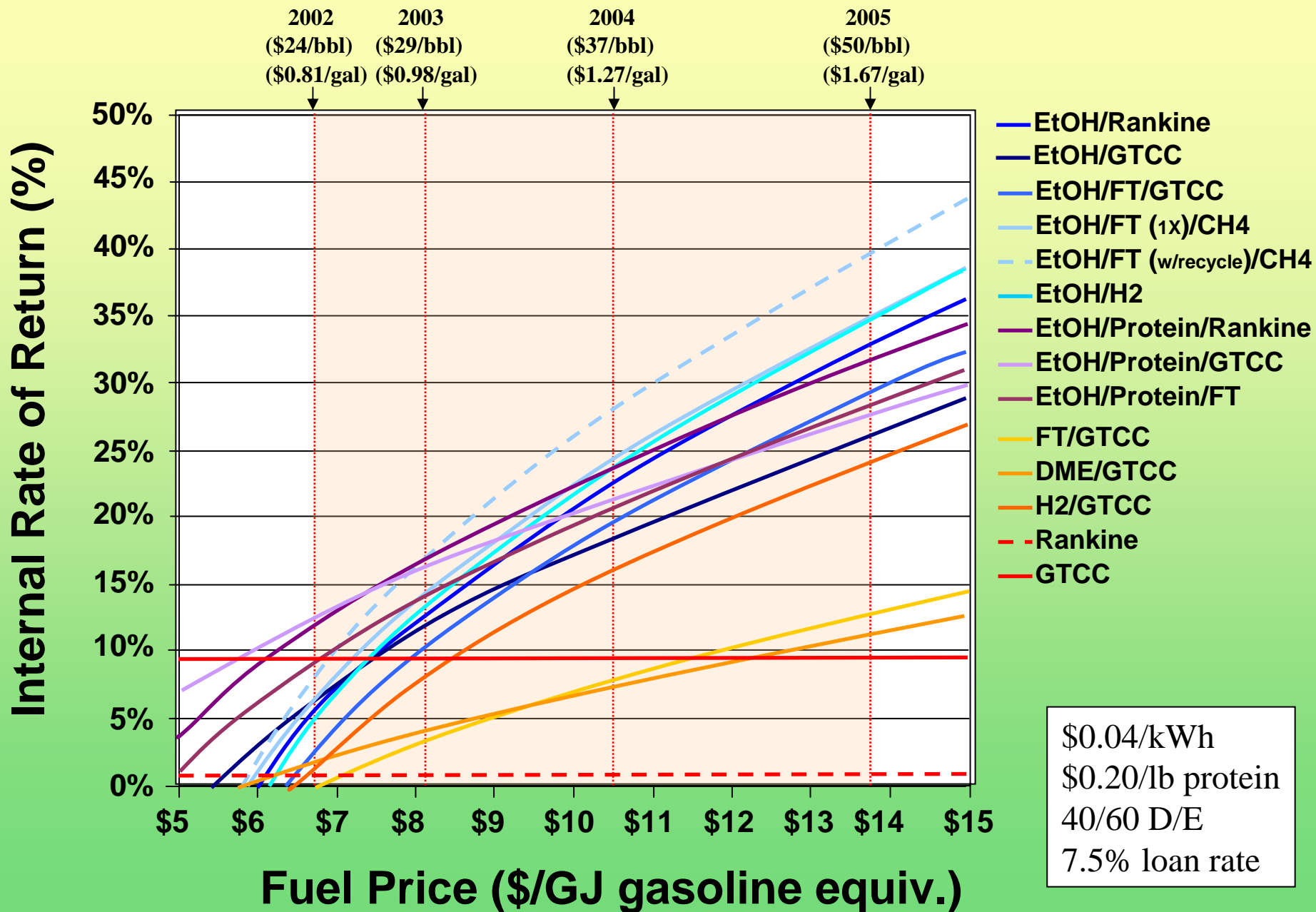


Mature Biomass Refining Energy Flows (example scenario)

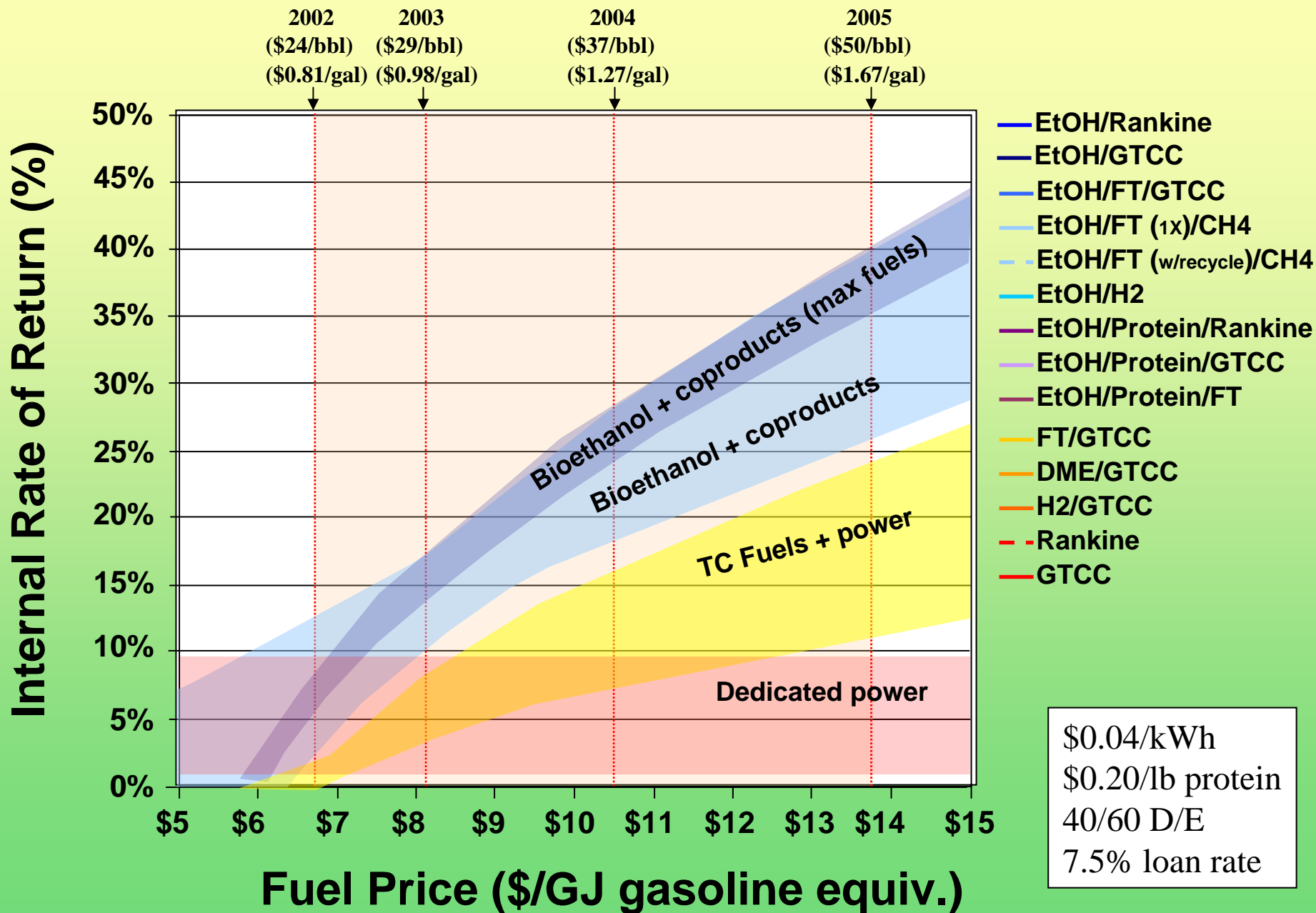


Ag Inputs (Farming, feedstock transport) ~ 5 %

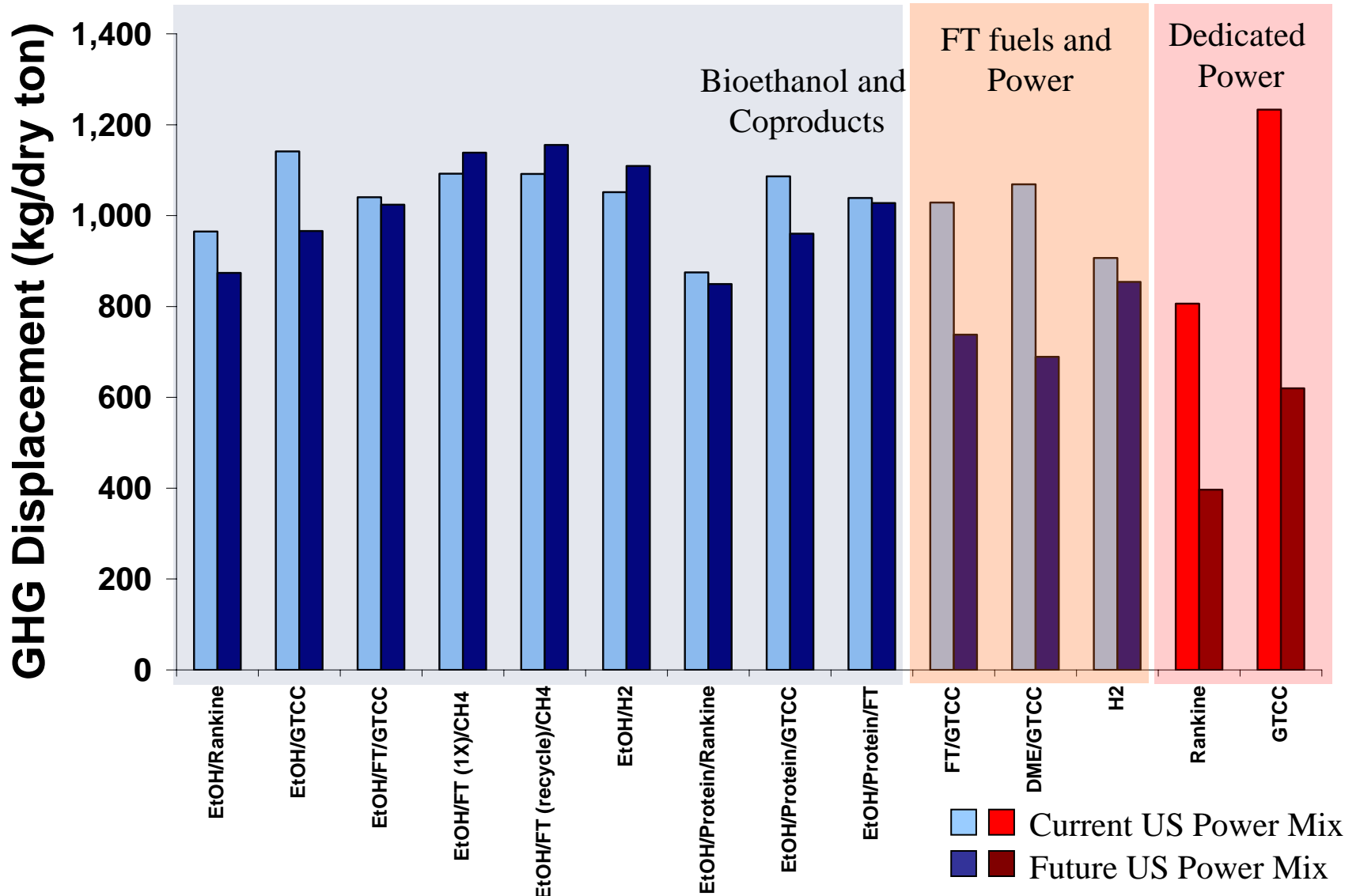
Scenario Comparison: Fuel price variable, power price constant, 5,000 tpd



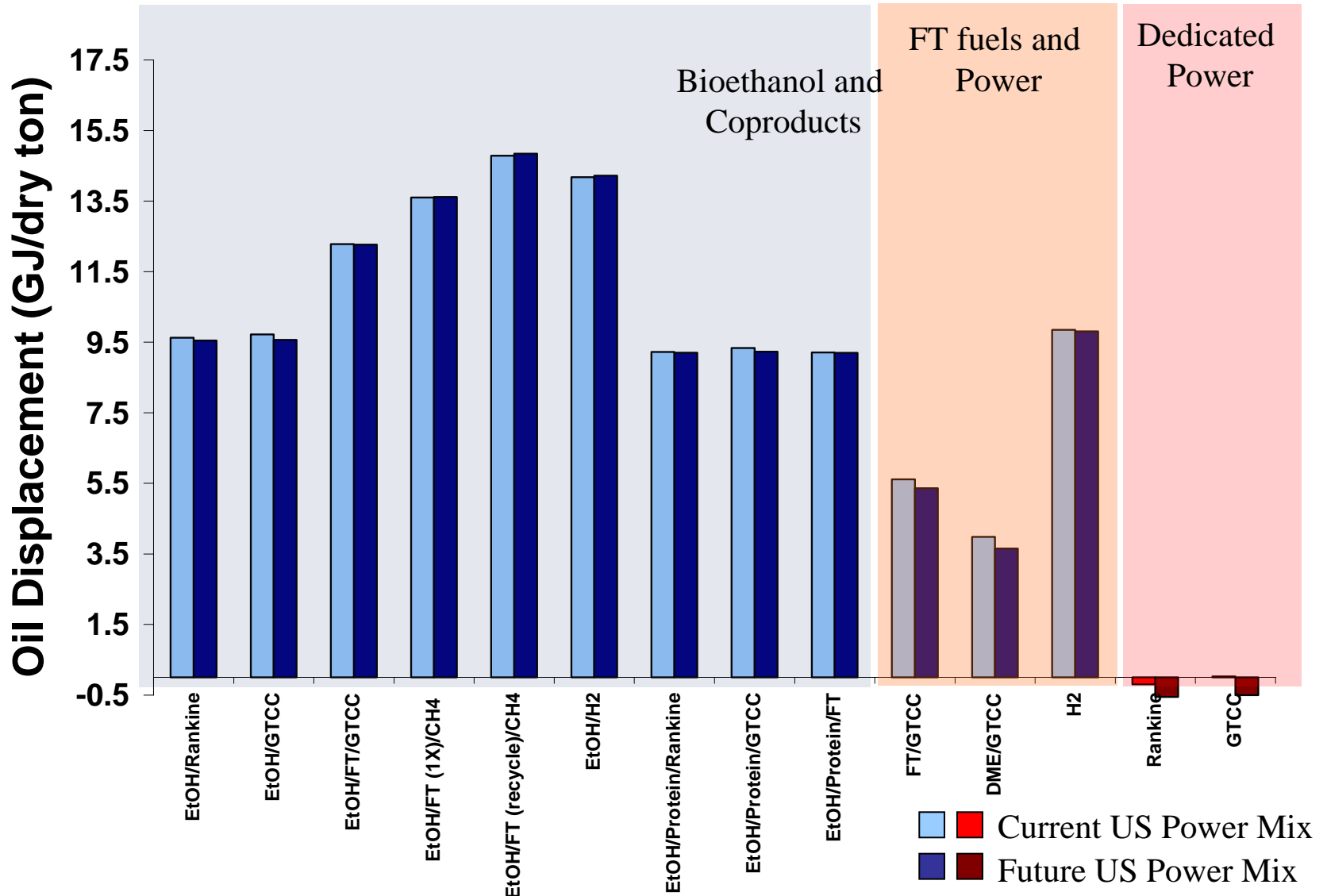
Scenario Comparison: Fuel price variable, power price constant, 5,000 tpd



Comparative Greenhouse Gas Displacement



Comparative Petroleum Displacement



Anticipated Features of Mature Biofuel Technology (RBAEF)

~ Two dozen cellulosic biomass processing scenarios developed based on performance & configurations anticipated for mature technology

- Ethanol, F-T fuels, dimethyl ether, hydrogen, electricity, feed protein
- Analyzed in a common framework
- Unprecedented

Efficient

$\geq 70\%$ feedstock energy --> fuels, power

Fossil fuel displacement ratio (out:in) > 10

Integrated biological & thermochemical processing key

Cost effective

Liquid fuel production cost-competitive with gasoline from oil @ \$30/barrel

Attractive production/utilization cycles

Near-zero net greenhouse gas emissions

High performance, clean-burning fuels

Large agricultural economy & soil fertility benefits

Life Cycle & Resource Issues

Life Cycle Issues

Usually considered on a per unit basis

e.g. Per ton, per gallon, per mile, per acre

In general, production & utilization of cellulosic biomass score very well

- Near-zero greenhouse gas emissions
- Substantial soil fertility benefits

NRDC: Several important potential benefits, no show-stoppers

Resource Issues

Even with positive effects per acre, an acre devoted to bioenergy production is not available exclusively for

Food production

Wildlife habitat/biodiversity

Recreation

A greater challenge

Resource Sufficiency: Radically Different Conclusions

Large contribution possible & desirable

United States

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*).

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

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

Goal of 100 billion gallons of ethanol by 2025 (Ewing & Woolsey, 2006, *A High Growth Strategy for Ethanol*)

Worldwide

Biomass becomes the largest energy source supporting humankind by a factor of 2 (Johanssen et al., 1993, *Renewables-Intensive Global Energy Scenario*).

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

Resource Sufficiency: Radically Different Conclusions

Large contribution not possible and/or not desirable

David Pimentel's group (8 papers, 1979 to 2002)

“Use of biomass energy as a primary fuel in the United States would be impossible while maintaining a high standard of living”

“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.”

Others

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

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

2030: Ethanol (corn and cellulose) 2.5% of transportation energy - 2% of this cellulosic (EIA, 2006)

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

Because of large land requirements, biofuels are not a long-term practical solution to our need for transportation fuels (Jordan and Powell, July 2006, *Washington Post*)

Understanding the Disparity of Resource Sufficiency Studies

The math is simple

$$NNL_{FP} = \left\{ \frac{VMT}{MPG \cdot Y_{P/F}} - I \right\} \frac{1}{P}$$

NNL_{FP} : Net new land, ignoring changed land for food production (acres)

VMT : Vehicle miles traveled (miles/yr)

MPG : Miles/gallon gasoline equivalent

$Y_{P/F}$: Process yield (gallons gasoline equivalent/ton dry biomass)

I : Feedstock produced from currently-managed lands (ton dry biomass)

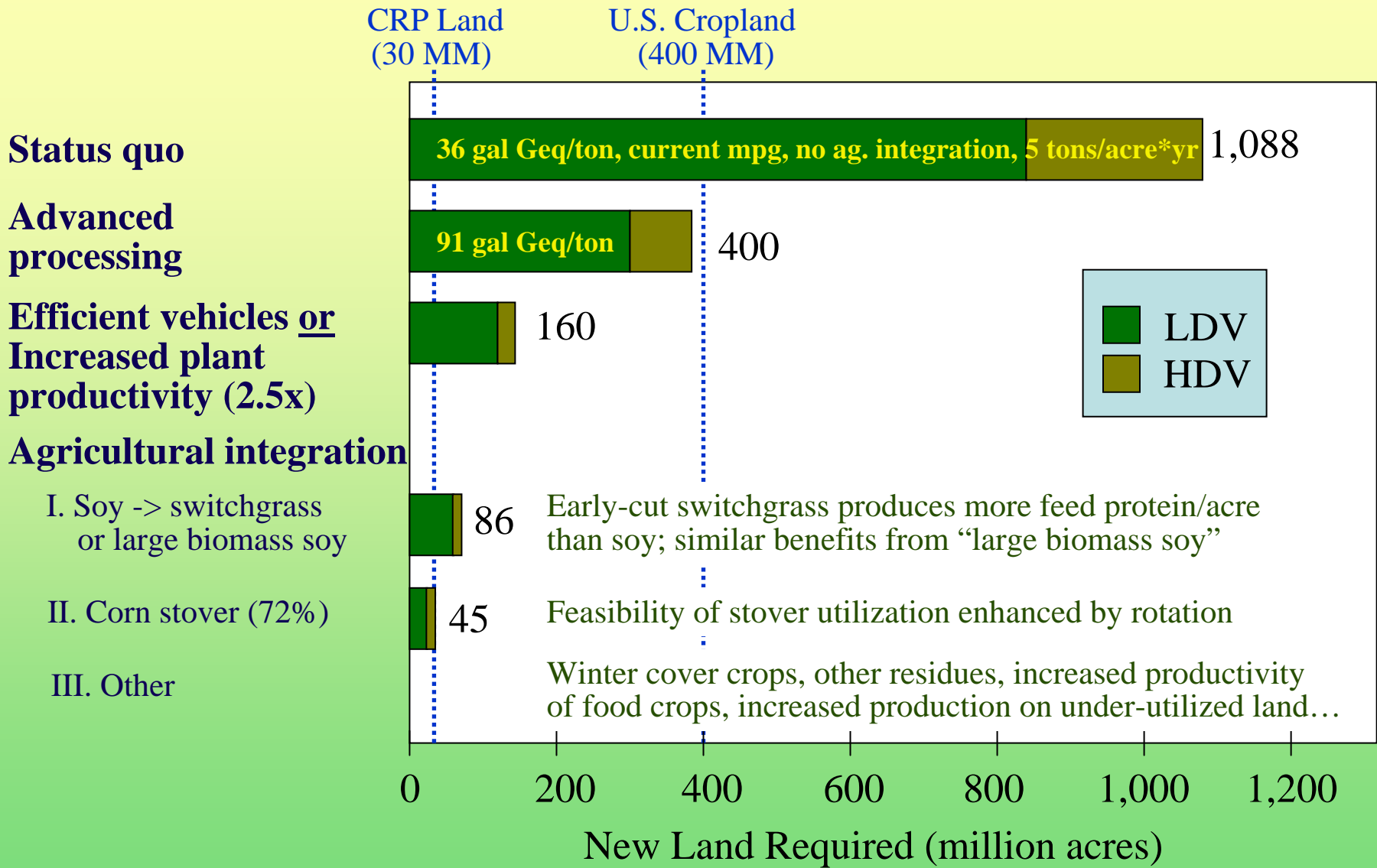
P : Productivity of biomass production (tons/acre/year)

Returning to that simple equation...

$$NNL_{FP} = \left\{ \frac{VMT}{MPG \cdot Y_{P/F}} - I \right\} \frac{1}{P}$$

Parameter	Least Efficient	Most Efficient	Ratio (Max/Min)	Source (High, Low)
<i>VMT</i> (billion miles, 2050)	6.1	4.5	1.4	“Car Talk” scenarios
<i>MPG</i> (LDV)	21	50	2.4	Current, D. Friedman
<i>Y_{P/F}</i> (gallons/ton)	36	91	2.5	Recent NREL, RBAEF
<i>I</i> (tons)	0	600	Infinite	Many, “Billion tons”
<i>P</i> (tons/acre/year)	1.3	24	12	D. Pimentel, V. Khosla
<i>NNL_{FP}</i> (million acres)	5,328	14	381	

New Land Required to Satisfy U.S. Mobility Demand



U.S. mobility demand, the largest per capita in the world, could be met from land now used for agriculture while maintaining food production

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.