Biorefineries of 2030: Assessing the Potential

Mark Laser

Thayer School of Engineering
Dartmouth College
mark.laser@dartmouth.edu

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Next Generation Biorefineries
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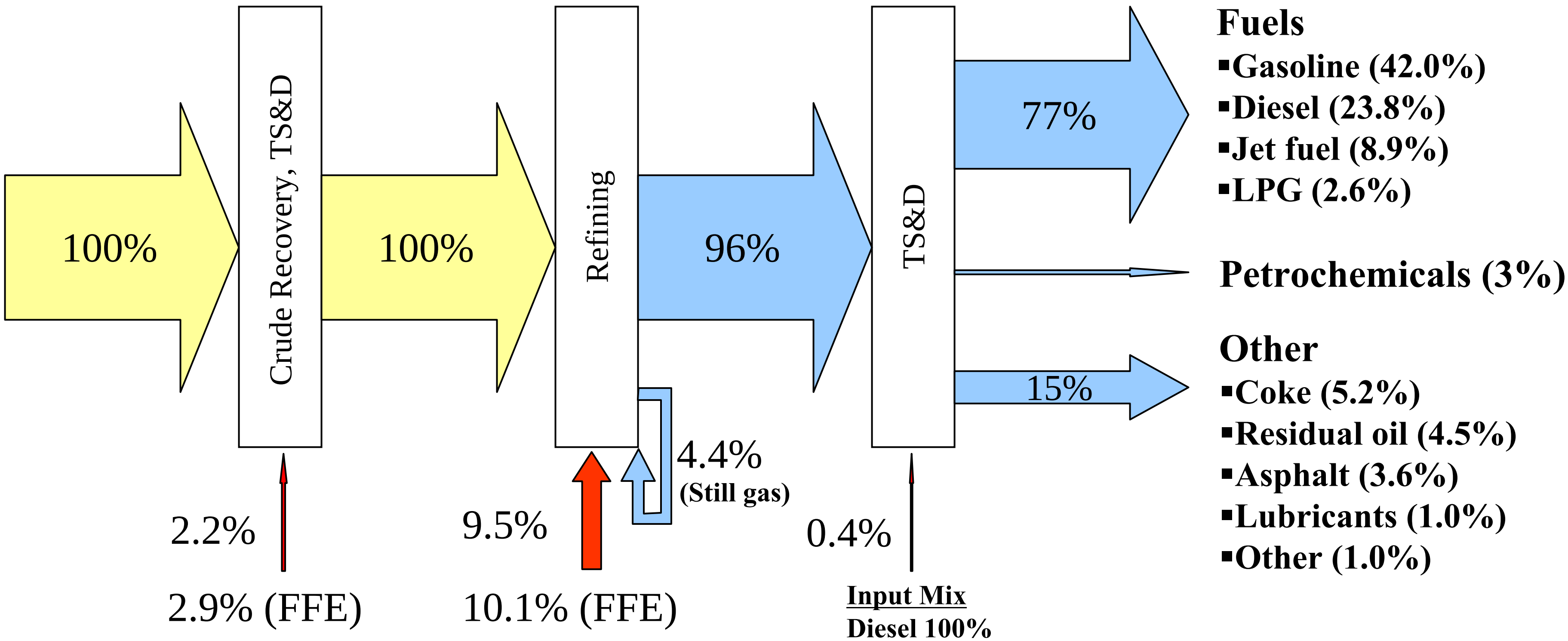
Oil Refining Energy Flows



Input Mix

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

Input Mix

Coal	19%
Residual oil	4%
Natural gas	71%
Electricity	6%

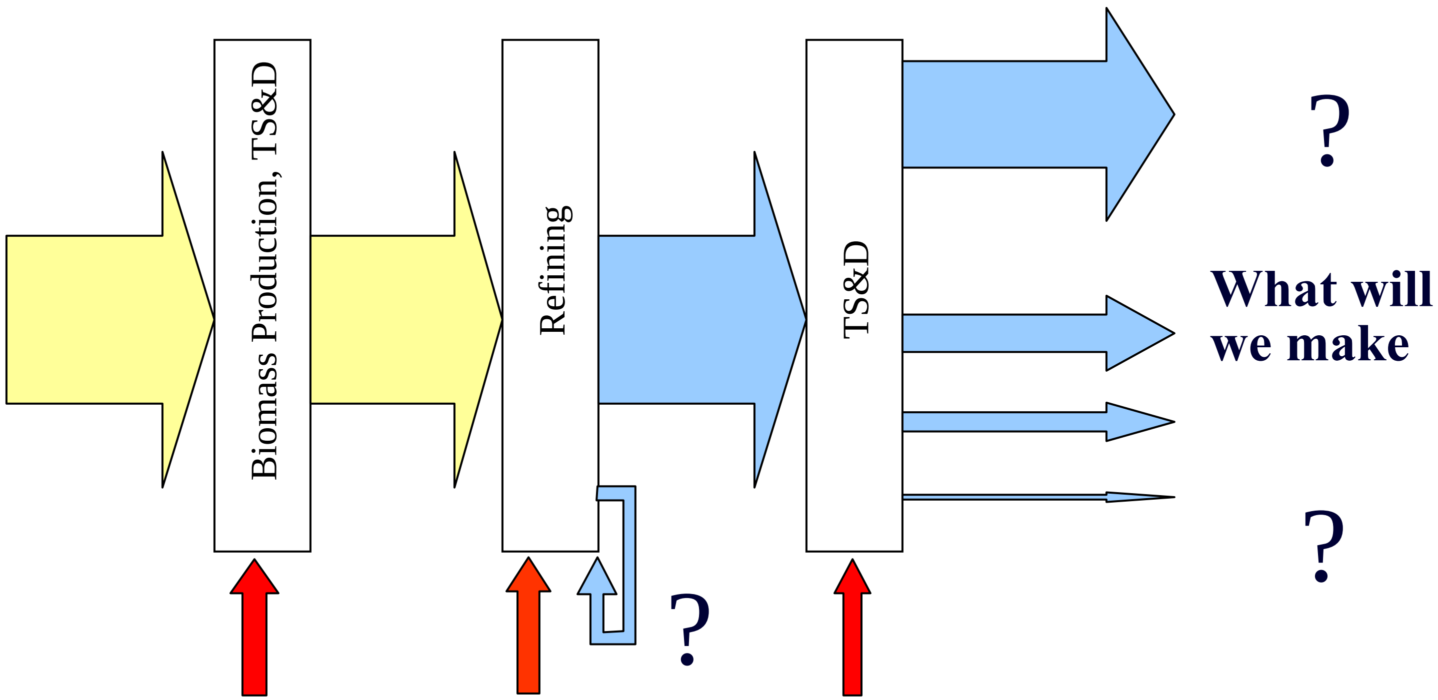
Sources:
External energy inputs/efficiencies: GREET, 2005
Refinery outputs: Energy Information Administration, 2005

Well-to-Pump Efficiency

All products: $$100 \times \frac{77+3+15}{100+2.2+9.5+0.4} = 85\%$$

Fuels: $$100 \times \frac{77}{100+2.2+9.5+0.4} = 69\%$$

Biomass Refining



What inputs will be required?

What will it cost?

How big can biorefining be: Niche player or major industry?

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

Multi-institutional

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

Multi-sponsor

- U.S. Department of Energy
- The Energy Foundation
- National Commission on Energy Policy

Objectives

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

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

Framing the Analysis

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

Emphasis on *mature technology*

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

e.g. Total expended effort to improve technology is similar to that done for petroleum refining

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.

RBAEF Process Analysis

Material & Energy Balance Models

Implemented using Aspen Plus

Built on extensive prior work

Princeton (thermochemical fuels & power)

NREL & Dartmouth (ethanol)

Basis for

Thermodynamic analysis "energy balance"

Material flows for environmental analysis

Economic analysis

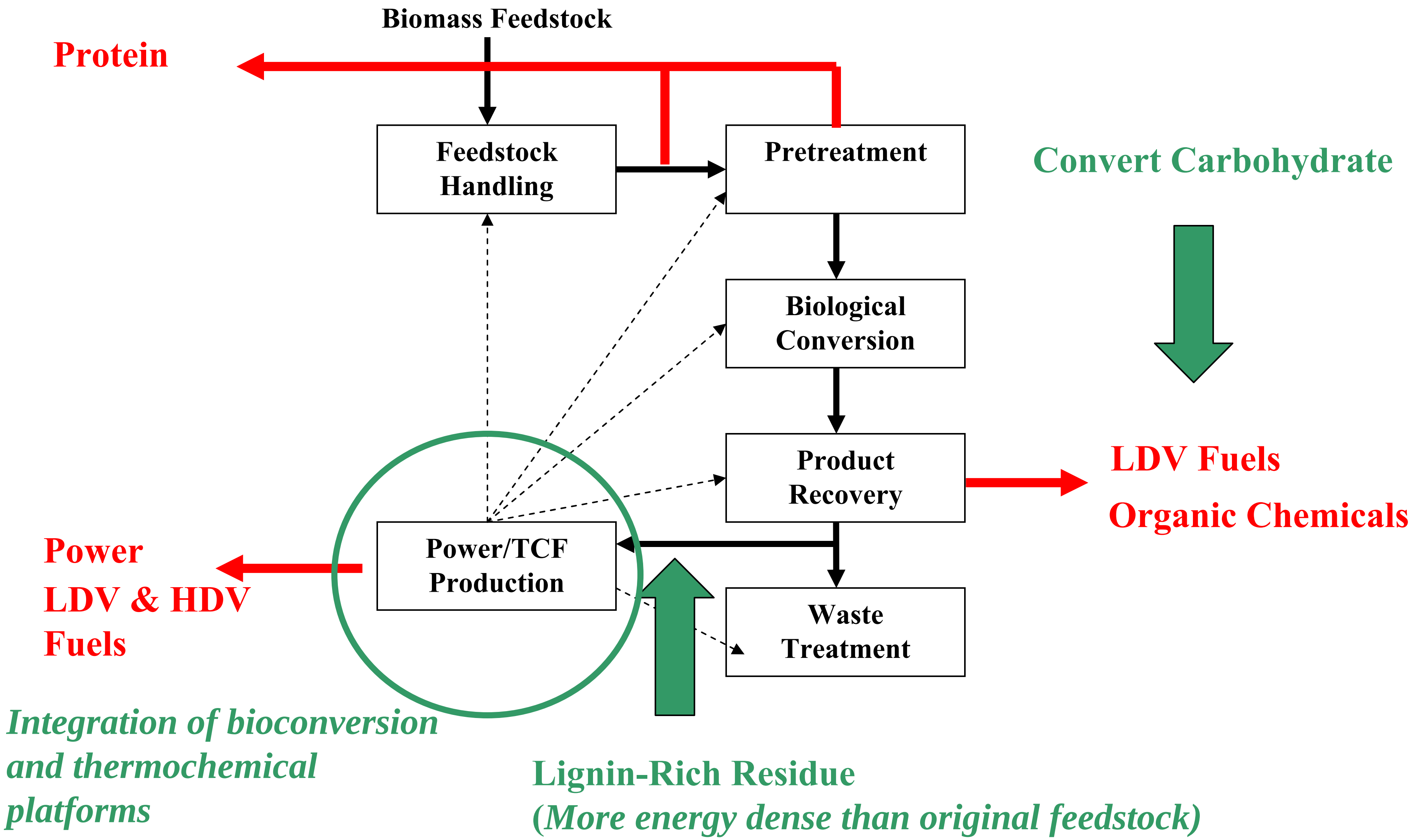
~7 person-year effort undertaken jointly by Dartmouth, Princeton

24 different scenarios including many product combinations

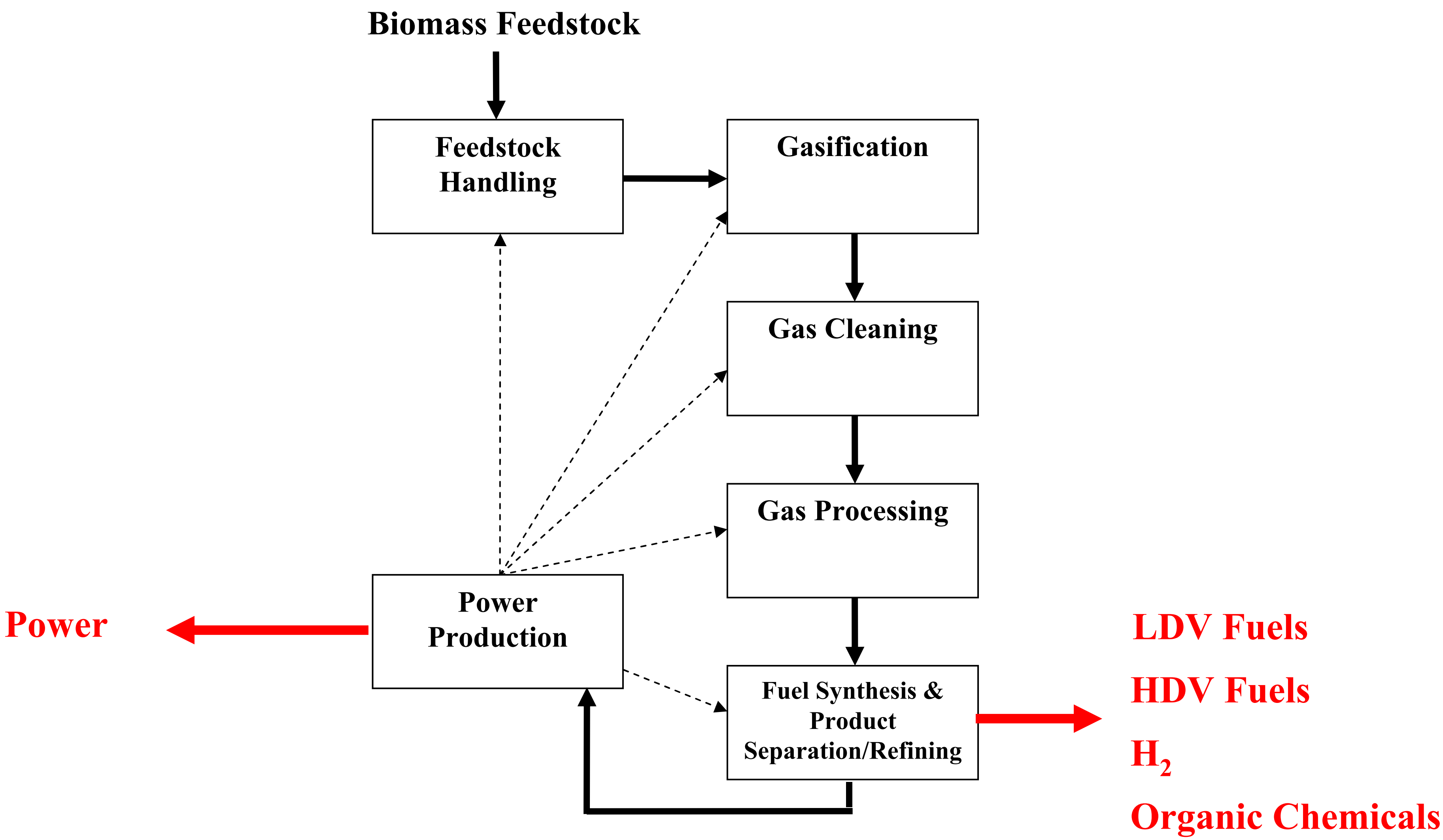
- **Electrical power**
- **Fischer-Tropsch Fuels**
- **Ethanol**
- **Hydrogen**
- **Dimethyl ether**
- **Light gases**
- **Animal feed**

Unprecedented for mature biomass conversion technologies

Bioconversion Platform



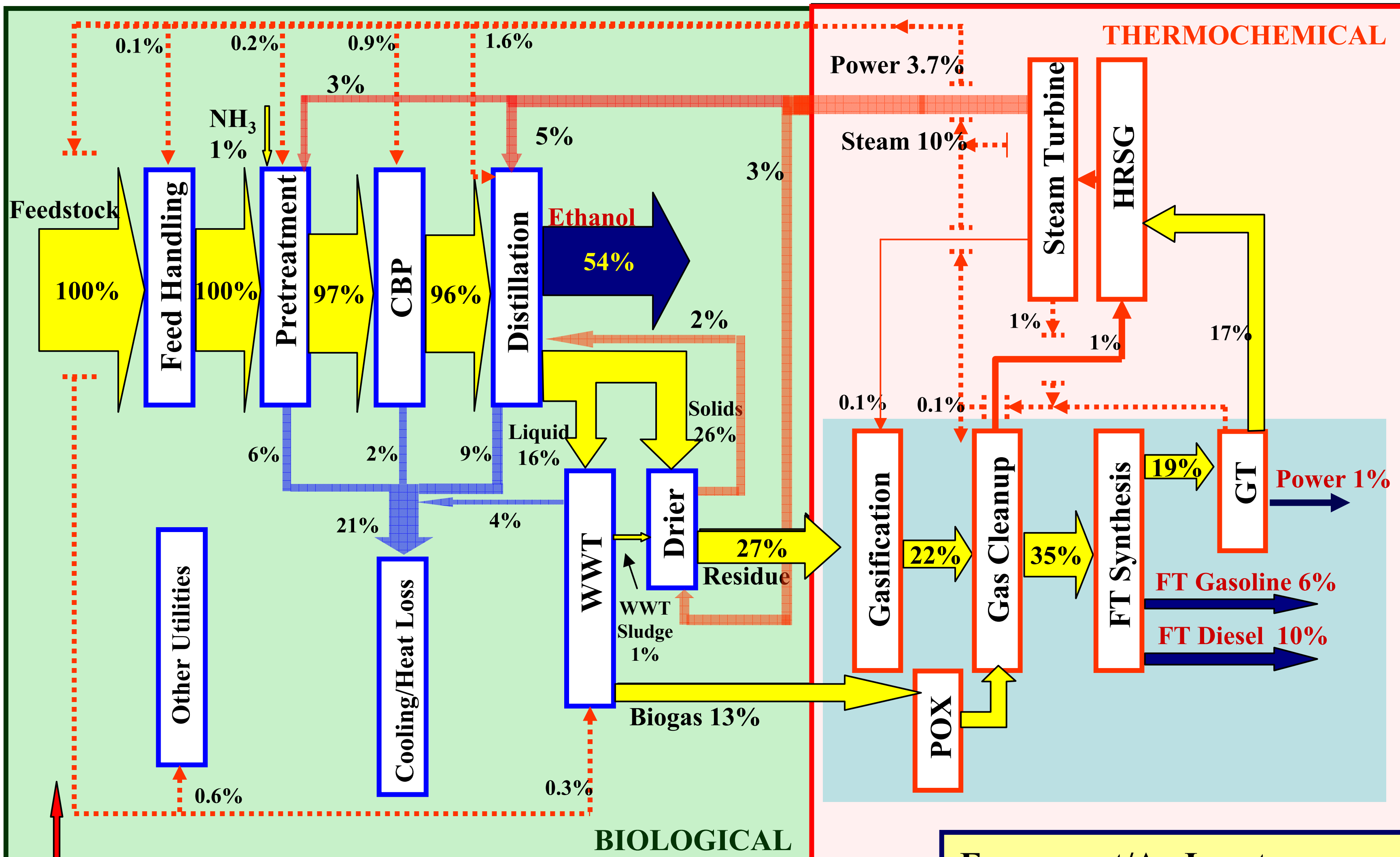
Thermochemical Conversion Platform



Key Mature Technology Features

Biological Processing	
▪Ammonia Fiber Explosion pretreatment	*no feedstock degradation and downstream inhibition*
▪Consolidated bioprocessing	*no dedicated cellulase production*
▪Energy efficient distillation	*intermediate vapor recompression heat pumps*
▪Extensive water recycle	*no evaporation of distillation bottoms liquid*
Thermochemical Processing	
▪Pressurized O_2-blown gasifier	*smaller gasifier sizes*
▪Warm gas clean-up	*reduced thermal losses*
▪Integrated tar cracking	*fewer pieces of equipment*
▪Combined cycle gas turbine	*increased generation efficiency*
Feedstock	
▪Switchgrass	*extensive growth area & environ. benefits*
▪Large scale	*5,000 – 20,000 dry ton/day*
▪High yield	e.g. *10 dry ton/acre/year (2X current yield)*

Mature Biomass Refining Energy Flows (example scenario)



Ag Inputs (Farming, feedstock transport) ~ 7 %

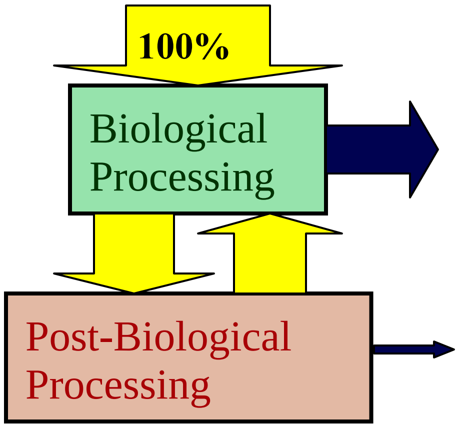
Energy out/Ag Inputs =

71/7 ≈ 10X

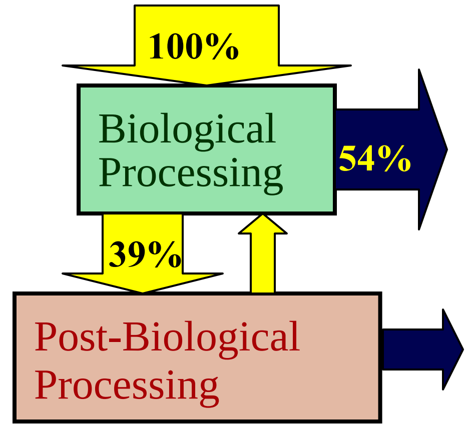
Thermochemical Processing of Residues Offers Lots of Value

Maturation of biological conversion → much larger opportunities

Current

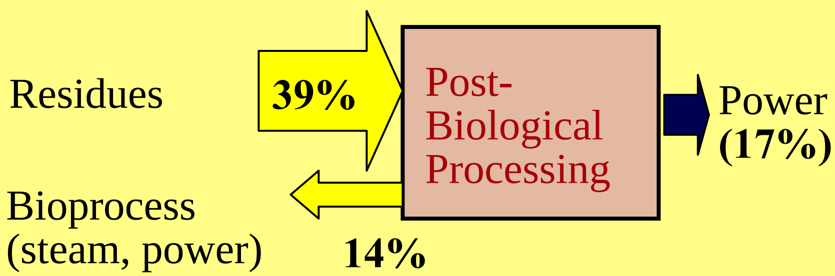


Mature



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

Power



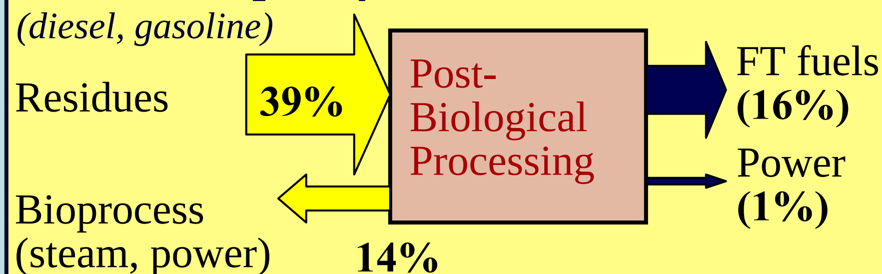
$$\eta_{power} = 17/(39 - 14) = 0.68$$

(19% more efficient than stand-alone)

***Large* baseload power contribution, compliments intermittent sources**

Fischer-Tropsch fuels

(diesel, gasoline)

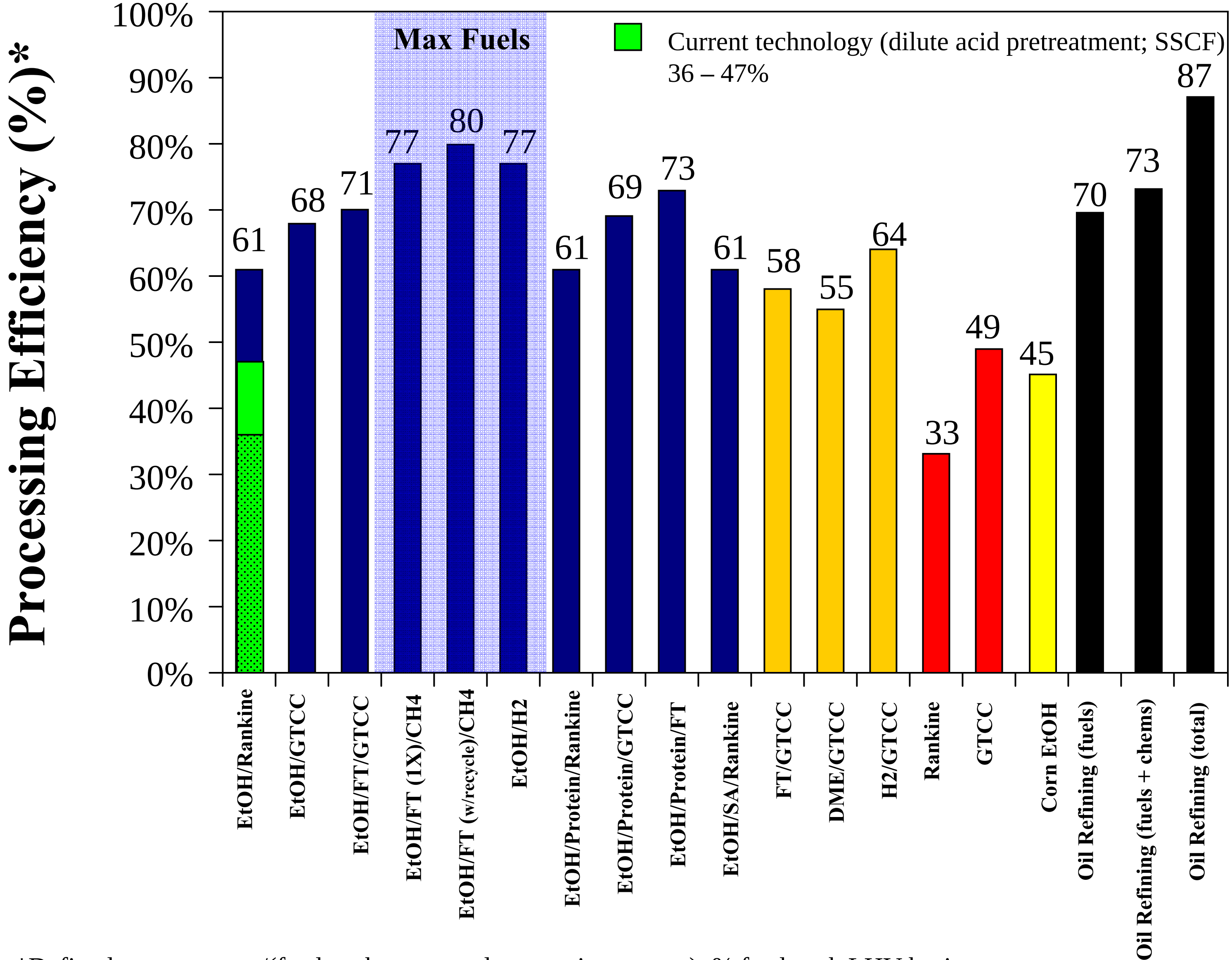


$$\eta_{FTfuels} = 17/(39 - 14) = 0.68$$

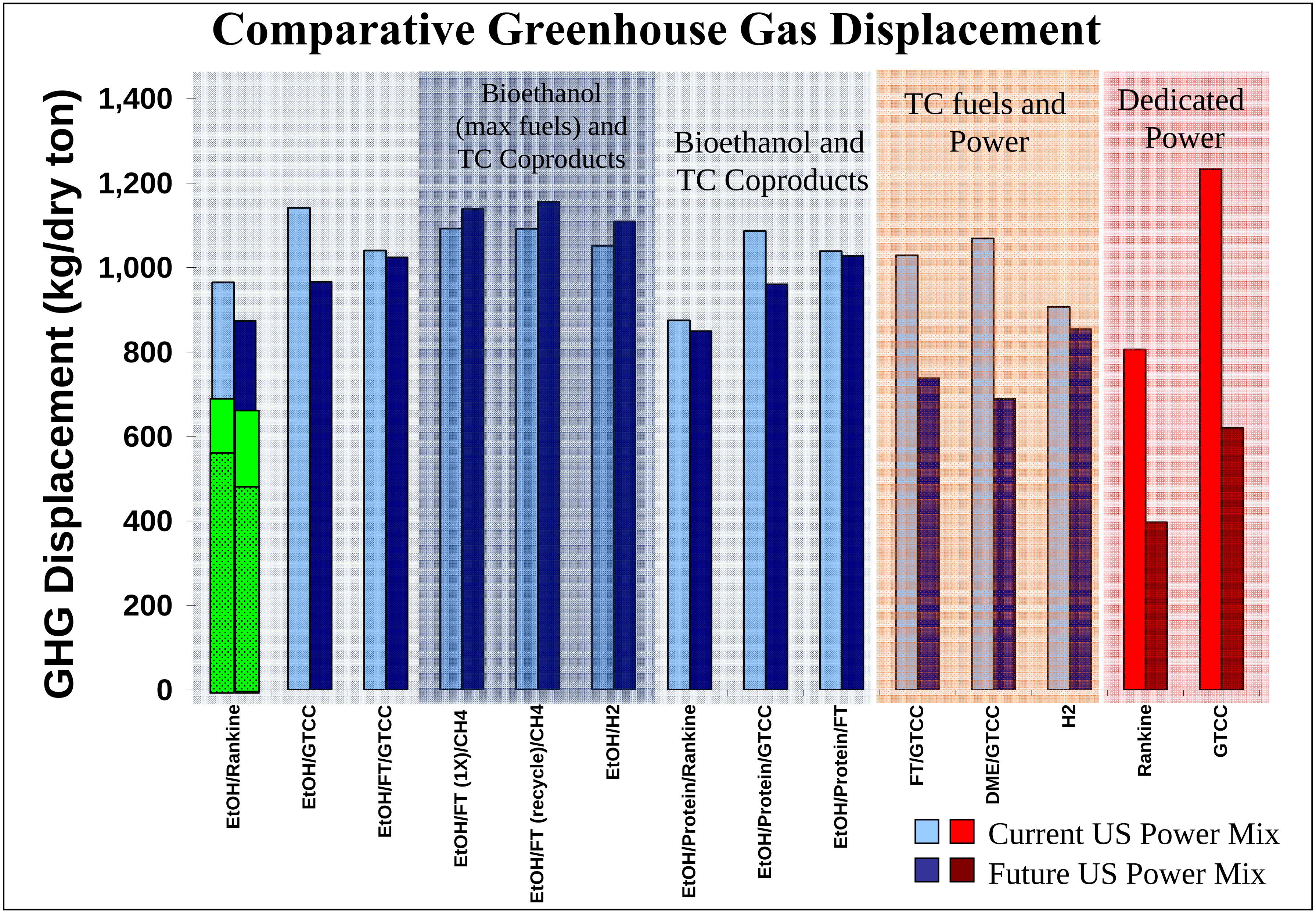
(10% more efficient than stand-alone)

E90 entirely from renewables

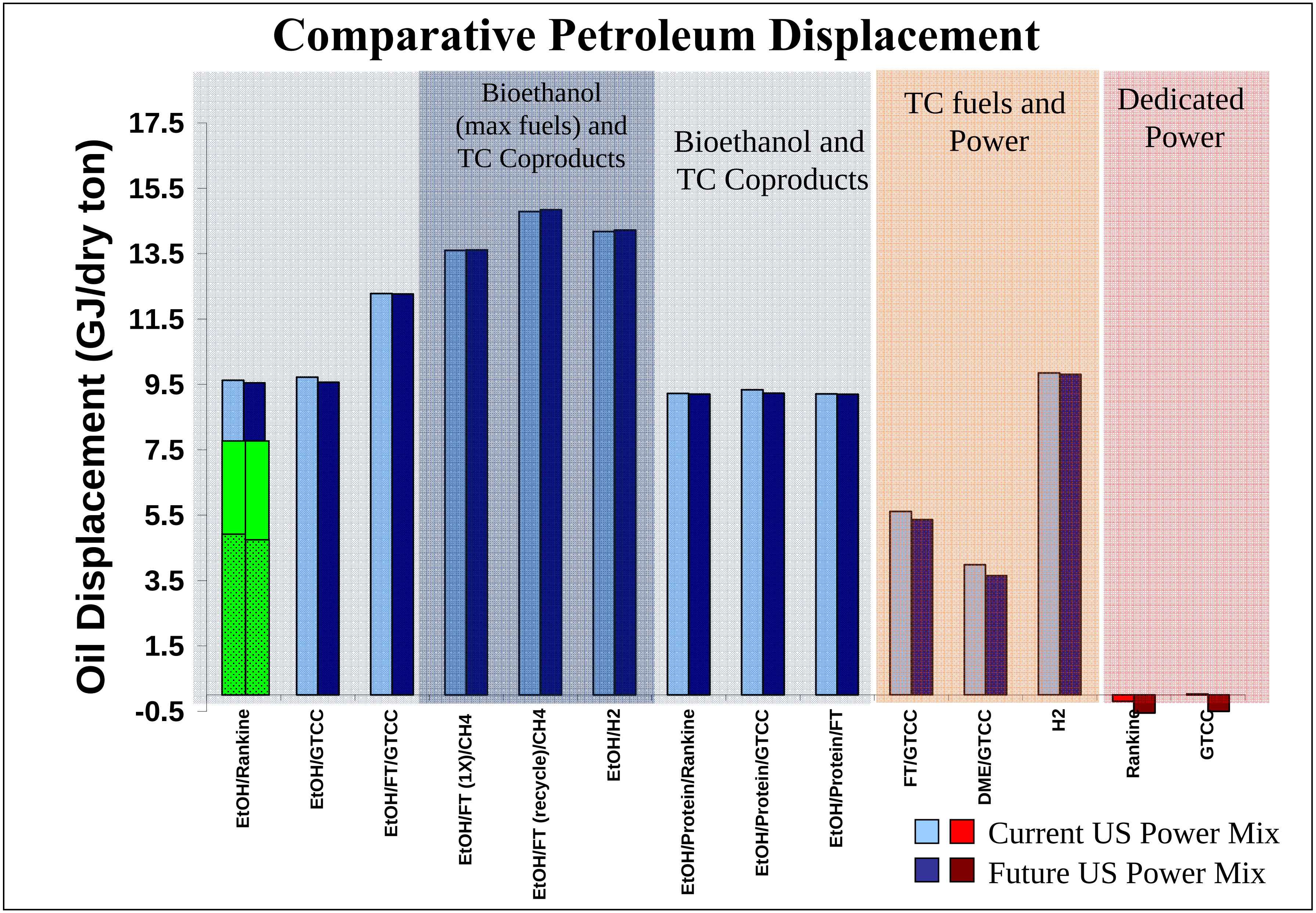
Processing Efficiencies



*Defined as energy out/(feedstock + external processing energy); % feedstock LHV basis



Current technology (dilute acid pretreatment; SSCF)



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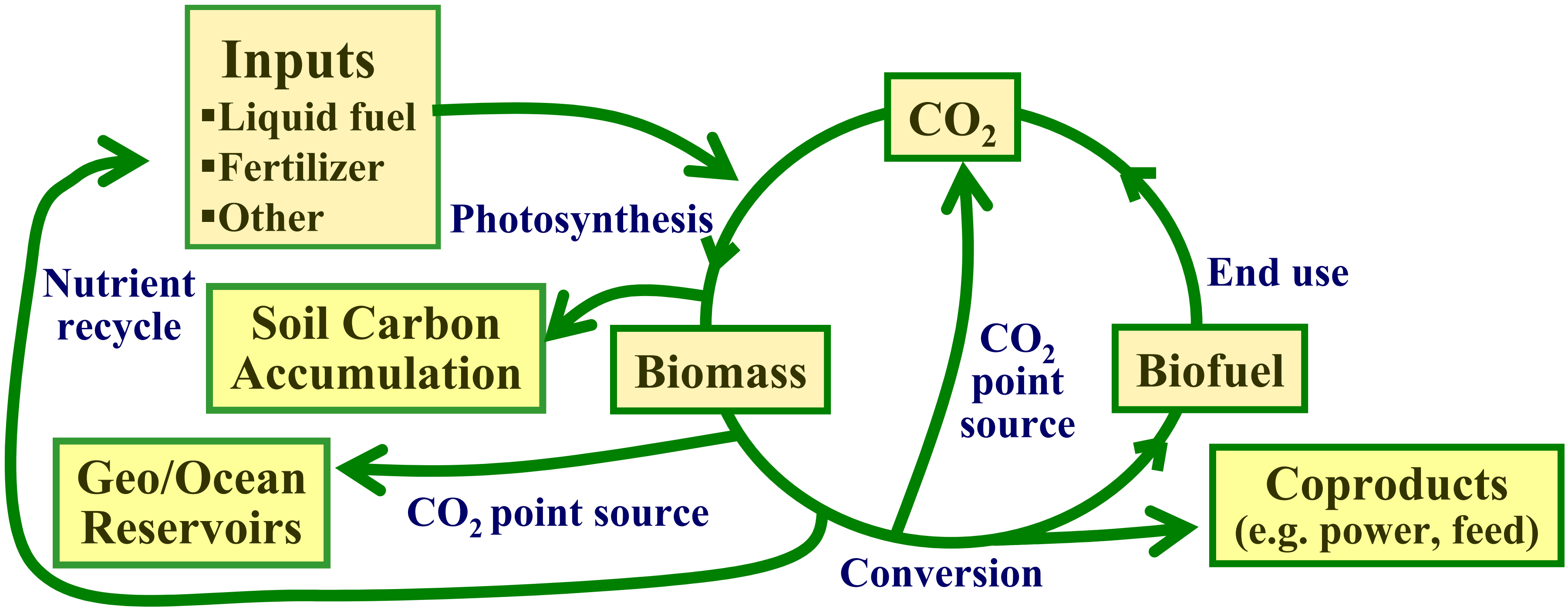


CO_2 Equivalent Emission
(% Gasoline base case, per mile, not cumulative)

	EtOH & Power	EtOH & FT Fuels & Power
Primary Cycle	0	0
Inputs	+10	+8
Coproducts	-56	-4
N recycle	-3	-2
Soil carbon accumulation	-43 to -159	-33 to -48
CO_2 capture, sequestration	-128	-48

Biofuels as Part of Broader Greenhouse Gas Mitigation Strategy

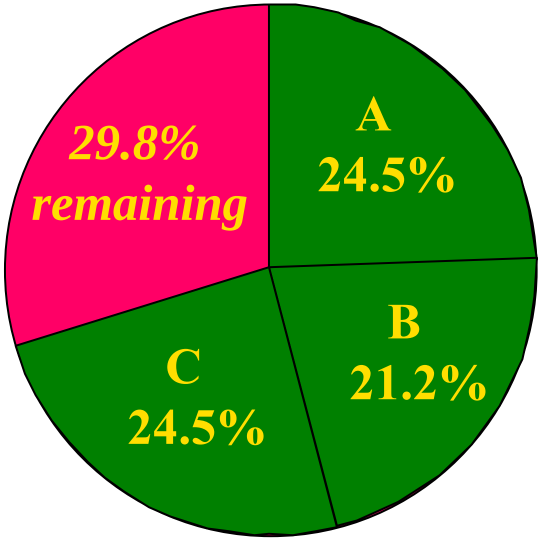
An Illustrative Example

CO_2 Emission Reduction Strategies

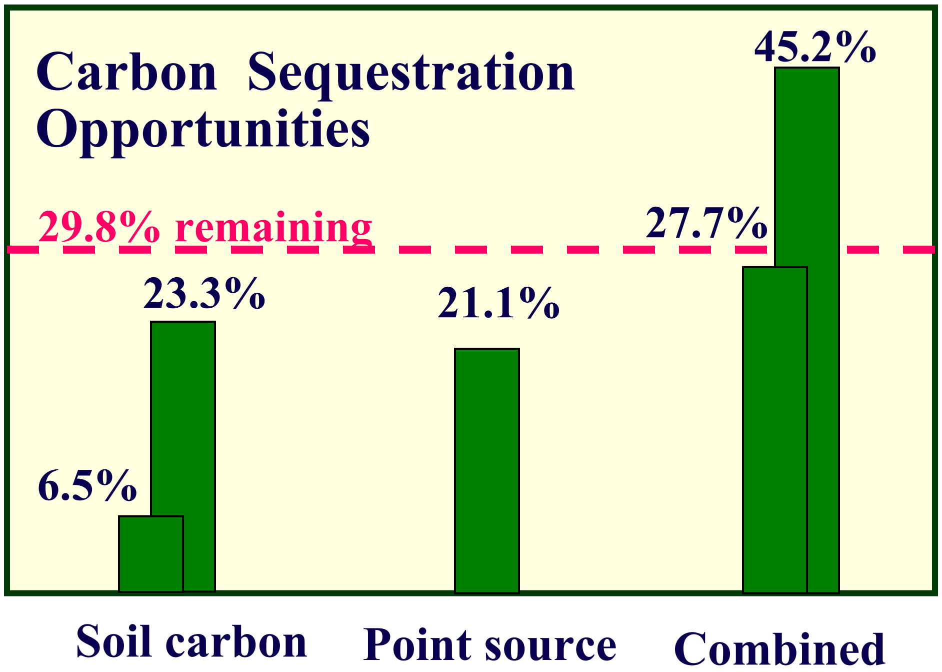
A. 1/3 current transport fuel from cellulosic biofuels, coproduce power

B. 40% electrical power from carbon-neutral sources

C. Triple transportation sector efficiency



Total CO_2 Emissions
Transport & Power Generation



Aggressive but possible CO_2 emission reduction combined with carbon sequestration accompanying biomass production & conversion:

-15.4 to 2.1% current emissions

Economics

Salient Observation:

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

Analytical Approach:

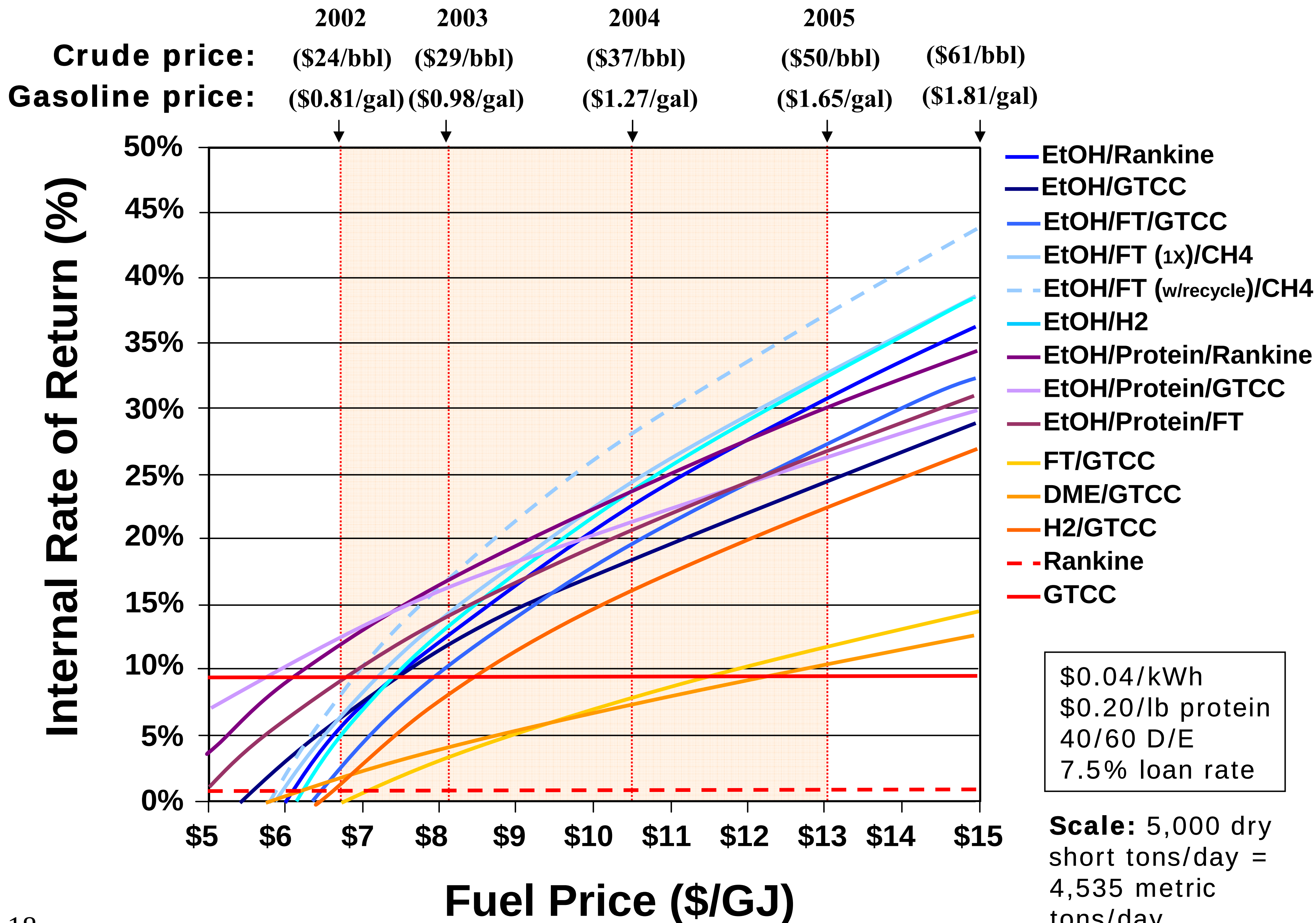
1. Estimate capital (NREL, Princeton, vendors, literature) and operating costs

2. Calculate internal rate of return using discounted cash flow analysis, as a function of:

   a) **Fuel & power prices**
   b) **Scale**
   c) **Debt-equity ratio and other financial parameters**

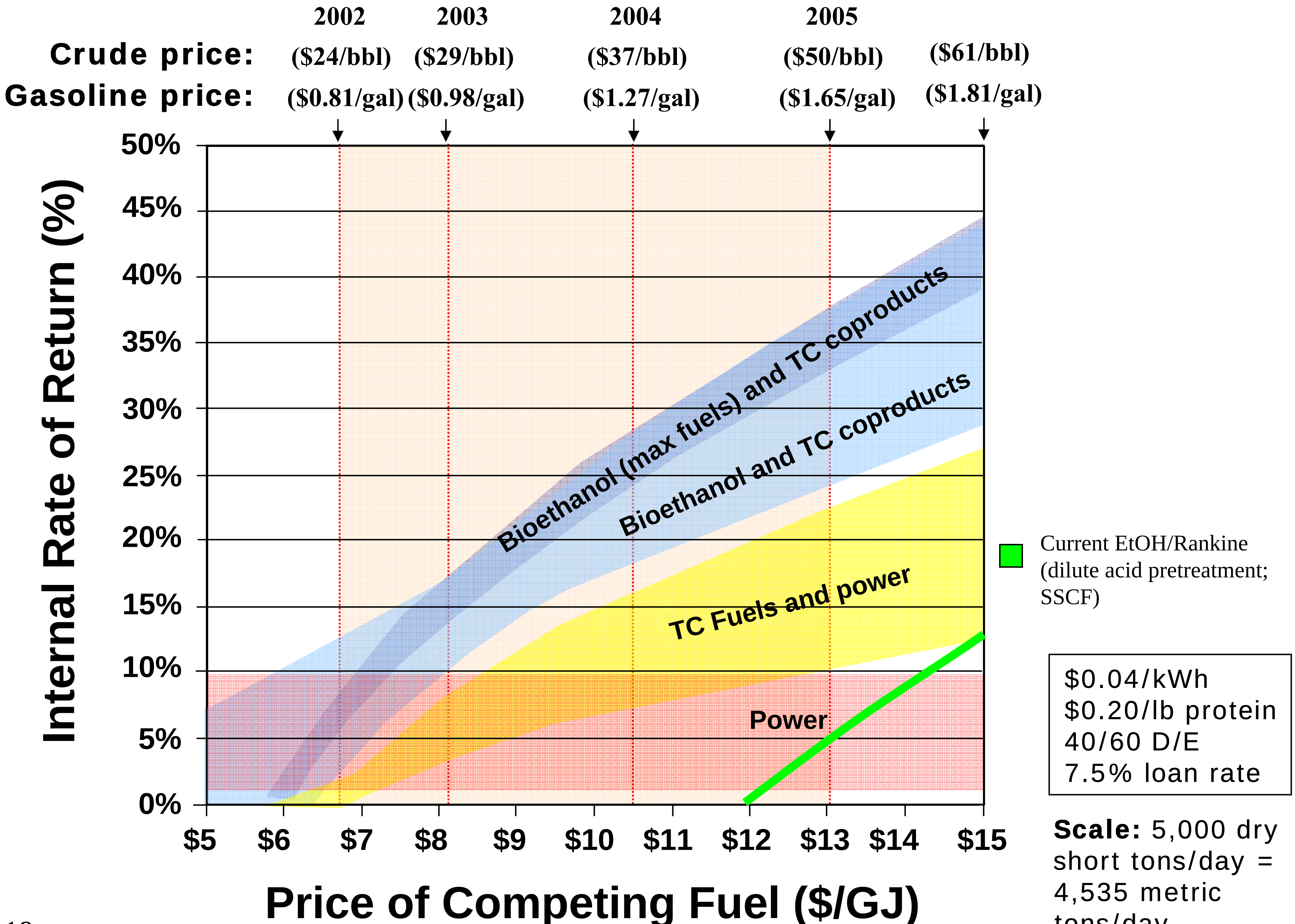
(Can also fix fuel & power prices and calculate IRR)

Scenario Comparison



Scale: 5,000 dry short tons/day = 4,535 metric tons/day

Scenario Comparison: 5,000 dry tons/day



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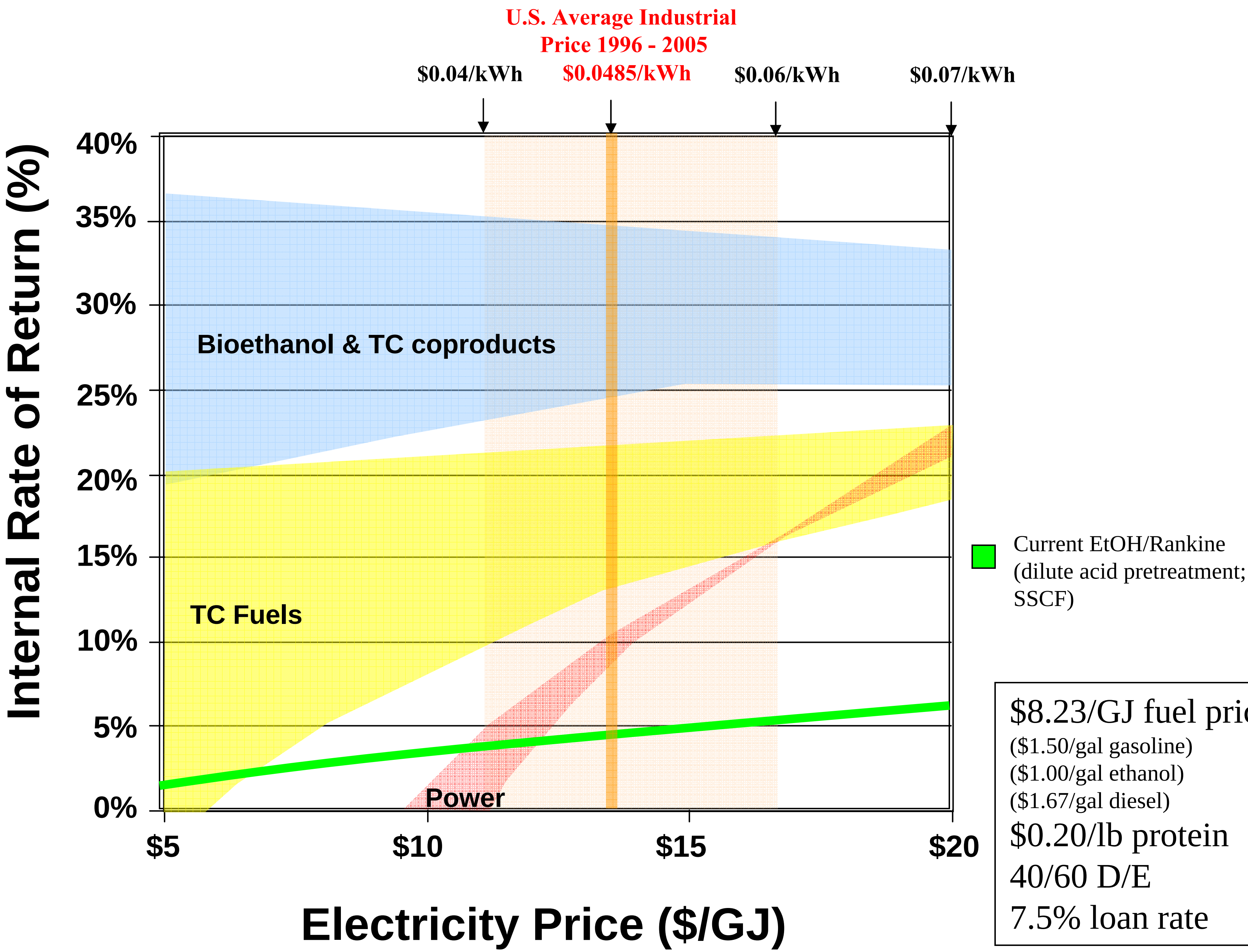
Scenario Comparison: 5,000 dry tons/day



$8.23/GJ fuel price
($1.50/gal gasoline)
($1.00/gal ethanol)
($1.67/gal diesel)
$0.20/lb protein
40/60 D/E
7.5% loan rate

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

- **≥ 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**

New Land Required to Satisfy Current U.S. Mobility Demand