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FUEL ETHANOL: THINKING CLEARLY ABOUT THE ISSUES

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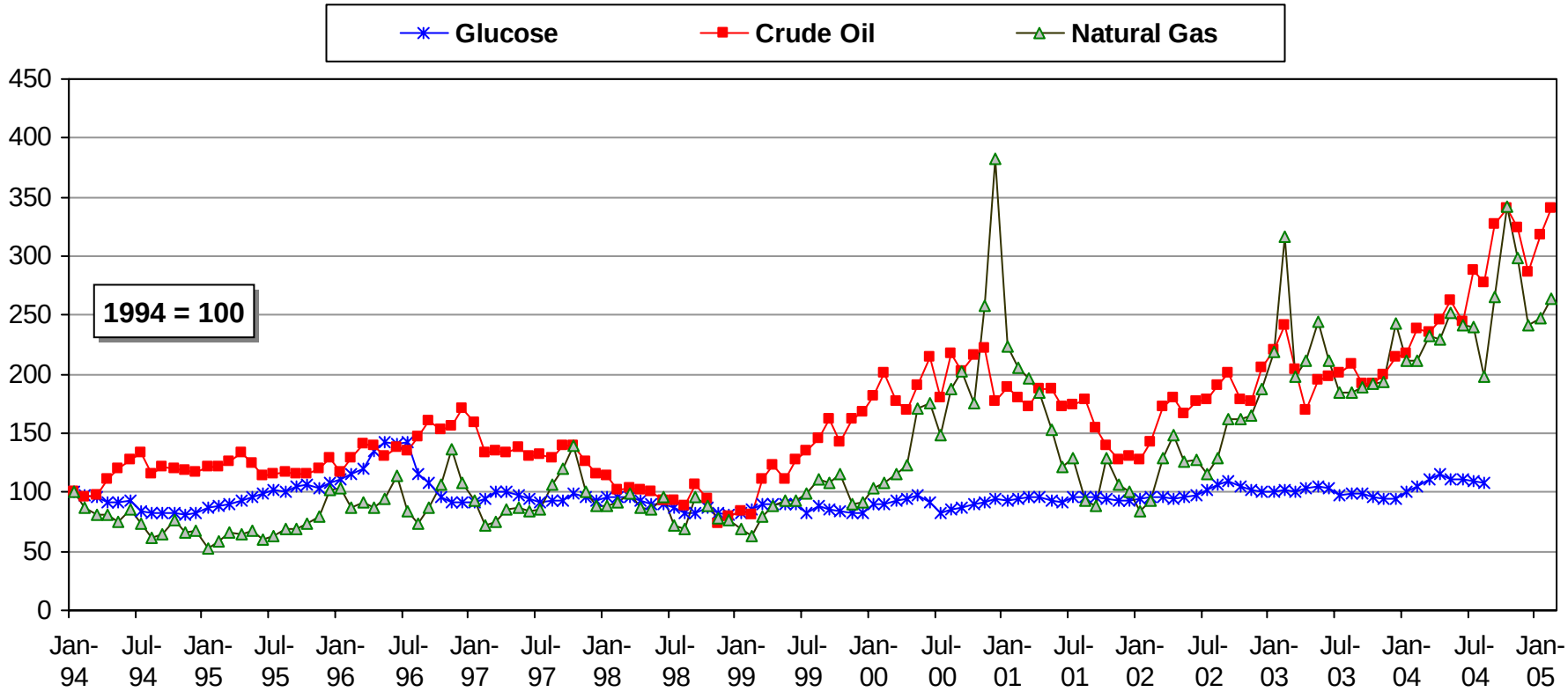
Glucose, Crude Oil & Natural Gas Price Index



Actual Jan 94	
SBO (cents/lb)	28.93
Crude ($/barrel)	15.19
Nat gas ($/mm btu)	2.55
Propylene (¢/lb)	11.25

Actual Feb 05	
SBO (cents/lb)	21.50
Crude ($/barrel)	51.76
Nat gas ($/mm btu)	8.73
Propylene (¢/lb)	43.00

From J. Stoppert, 2005

Presentation Overview

1. Thinking clearly about energy
   - We need energy services, not energy *per se*
   - Different energy carriers have different strategic importance & different *qualities*
   - Options for dealing with our petroleum problem
2. Biofuels (esp. ethanol): some issues
   - The irrelevant "net energy" argument
   - "Food vs. fuel?" No, that is <u>not</u> the question.
   - Environmental performance of biofuels
   - Economic competitiveness of biofuels

Some Basic Energy Facts

1. Services we need from energy (current sources or *carriers* of these services)
   - Heat (natural gas, coal)
   - Light (coal, natural gas, hydro/nuclear)
   - Mobility (petroleum—97%, ethanol)
2. Energy has fundamentally different *qualities*: carriers are not all interchangeable *"All BTU are not created equal"*
3. Our society literally stops without liquid fuels

All Energy Carriers do Not Have Equal Strategic Importance Either

1. Coal– we have huge domestic reserves
2. Natural gas—imports significant, mostly from Canada and Mexico
3. Petroleum– more than 60% imported and rising
   - "We are addicted to oil"
   - Imported from some of the worst places on earth
     - Some of our petrodollars shot back at us
     - Sustain oppressive regimes
     - Use oil as a political weapon against their neighbors & us
4. Petroleum dependence undermines climate security, economic security & national security
5. Bad for us, **terrible** for poor countries without oil

Options for Dealing with Petroleum Issue

1. Decrease demand
   - More efficient vehicles (implement available technology)
   - Fewer miles traveled (better planning)
2. Increase supply
   - Athabasca oil sands (Canada)
   - Oil shale (U.S.)
   - Super heavy oil (Venezuela)
   - Coal to liquid fuels (U.S. South Africa, China)
   - Biofuels
     - Biodiesel
     - Ethanol (from corn or cellulosics)

Ethanol: Some Myths and Realities

- Myth: Ethanol has a negative "net energy"

  Reality: Gasoline's "net energy" is worse than ethanol's and anyway this metric is irrelevant
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Most Recent Pimentel & Patzek Study*- Some Serious Deficiencies and Errors

- Define ethanol's % net energy as:
  - [(Ethanol Heating Value (LHV) – Fossil Energy Inputs) /Ethanol Heating Value (LHV)] x 100
- All BTU are treated as equivalent (1 BTU coal = 1 BTU petroleum = 1 BTU natural gas and so on)
- Confuse "fossil fuels" with "liquid fossil fuels"=petroleum
- They calculate net energy for ethanol from:
  - Corn - 29%
  - Switchgrass - 50%
  - Wood - 57%
- They make no comparisons with other liquid fuels
- I calculate net energy for:
  - Gasoline from petroleum - 45%
  - Electricity from coal - 240%
- **Natural Resources Research, vol. 14, No. 1, March 2005 pgs. 65-76*

Net Energy *Reductio Ad Absurdum:* the Accounting Analogy

- "Net energy" is an energy accounting tool: a terrible one
- Using the net energy approach of "All BTU are equal" an international company's accountants would calculate:
  - 100 U.S. $ + 100 Pounds Sterling + 100 French francs + 100 lira = $400 U. S.
  - The math is right; the idea is absurd!
- We cannot add up different forms of energy on a straight BTU basis any more than we can add up different currencies on a straight equivalency basis
- Different forms of energy have different qualities—just like different currencies do

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Are All Btu Created Equal: What Does "the Market" Say?

Energy Carrier	Energy Content* (Btu/X)	Typical Market Value ($/X)	Market Value ($/MM Btu)
Coal	20.4 MM Btu/short ton	$40.30/short ton	$2.00
Natural Gas	1,030 Btu/ cubic foot	$7.30 per 1000 cubic foot	$7.10
Petroleum	5.8 MM Btu/barrel	$55 per barrel	$9.50
Electricity	3413 Btu/ Kwhr	$0.082/Kwhr	$24.00
* EIA 2004 pg. 357-386			

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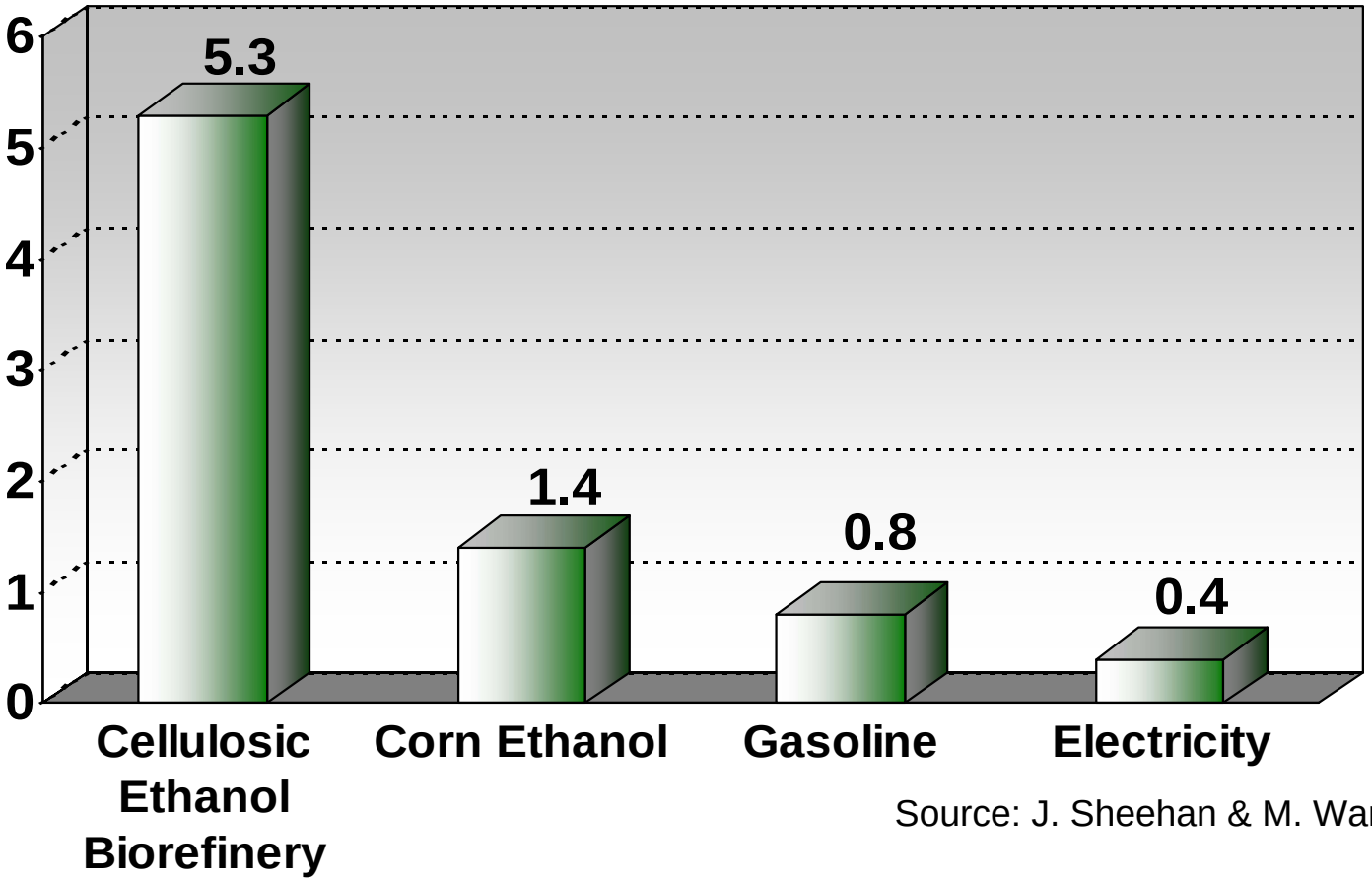
Fossil Energy Replacement Ratio:
the Primary Climate Security Driver

$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$



Source: J. Sheehan & M. Wang (2003)

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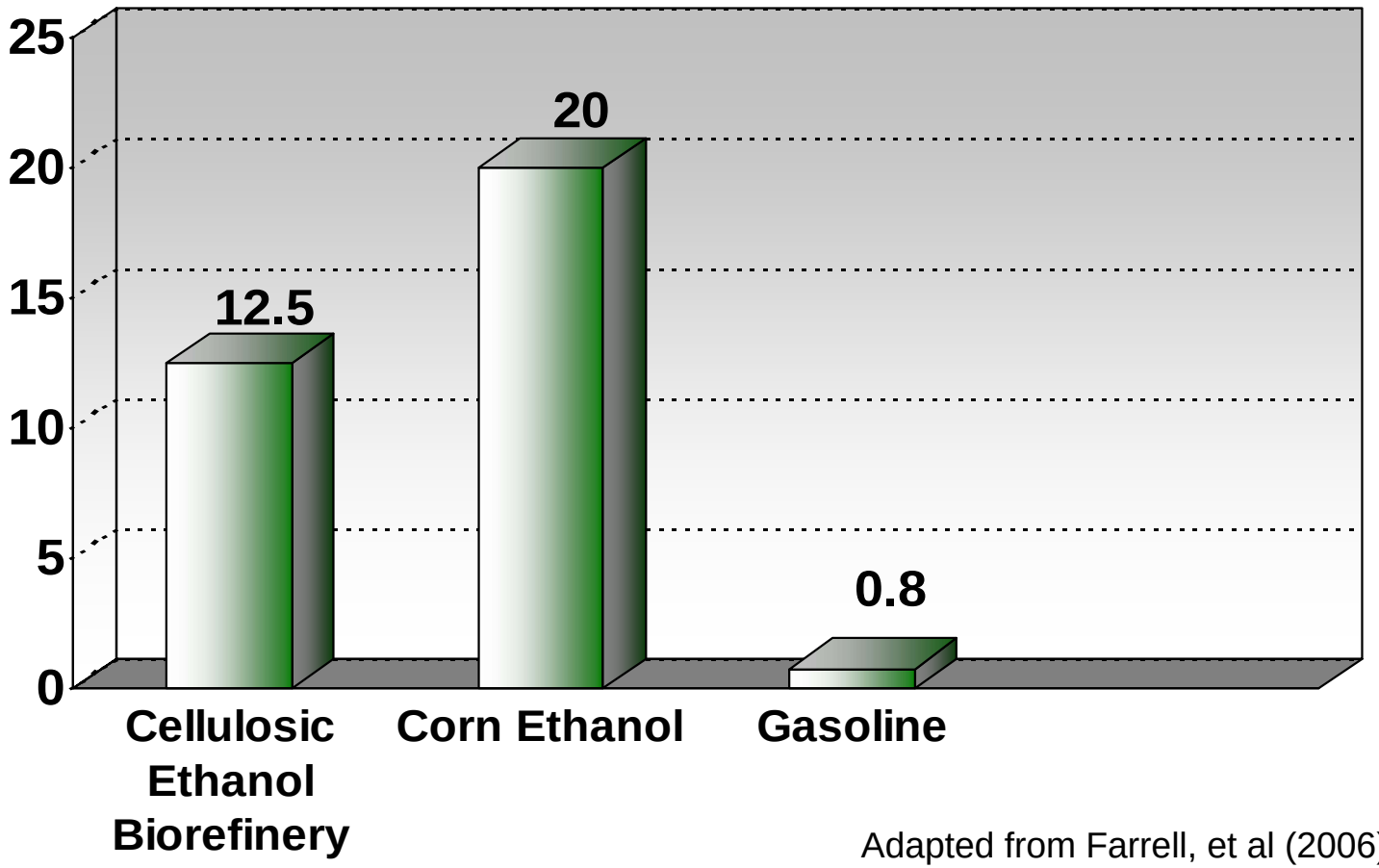
Petroleum Replacement Ratio:
the Primary Energy Security Driver

$$\text{Petroleum Replacement Ratio (PRR)} = \frac{\text{Liquid Fuels Delivered to User}}{\text{Petroleum Energy Used}}$$



Adapted from Farrell, et al (2006)

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Ethanol: A Few Environmental & Food Details

- Environmental facts
  1. 13% greenhouse gas reduction relative to gasoline for corn, much more for cellulosics
  2. Declining soil erosion, from 7.5 tons/acre in 1982 down to 4.7 tons/acre in 2003
  3. Declining fertilizer use per bushel, declining absolute use of pesticides, herbicides
  4. However, increased demand for ethanol may encourage less sustainable farming practices
  5. 95% reduction in petroleum use per mile driven
- Food facts
  1. Carbohydrates (starch) in corn are converted to ethanol, remaining protein is fed to animals
  2. More than 75% of all corn consumed is fed to animals, not people (<10% for human consumption)

Will People Go Hungry Because of Biofuels?

- Macronutrients: 2000 cal & 50 gm protein/person/day
- Total U.S. human demand: 205 trillion cal & 5.1 trillion grams protein/yr
- Three major U.S. crops *alone* (corn, soy, wheat) produce 1300 trillion kcal & 51 trillion grams protein/yr
- Could meet U.S. human demand for protein & calories with 25 million acres of corn
- *Most U. S. agricultural production (inc. exports) is fed to animals-- i.e., we are meeting <u>their</u> protein/calorie needs from our land resources. Their needs are:*
  - 1040 trillion kcal/yr (5 times human demand)
  - 56.6 trillion gm protein/yr (10 times human demand)
- Can address perceived "food vs. fuel" conflict by providing <u>animal feeds</u> more efficiently, on less land

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U.S. Livestock Consumption of Calories & Protein

ANIMAL CLASS	HERD SIZE (THOUSANDS)	TOTAL PROTEIN (MILLION KG/YR)	TOTAL ENERGY (TRILLION CAL/YR)
Dairy	15,350	10,400	184.8
Beef	72,645	25,100	525.3
Hogs	60,234	6,900	136.2
Sheep	10,006	461	10.6
Egg production	446,900	2,470	4.3
Broilers produced	8,542,000	9,540	150.3
Turkeys produced	269,500	1,760	28.6
Total consumed by U.S. livestock		**56,630**	**1,040.00**
Human requirements		**5,114**	**205**

Two Technical Prerequisites for Large Scale Biofuels

- Effective, economical pretreatment to increase accessibility/digestibility of cellulose and hemicellulose sugars (60-80% of grasses, crop residues, hay, etc)
- A successful pretreatment will likely make sugars in cellulosics available for *ruminant animal feeding* also.
- Complete utilization of all biomass components: carbohydrates, lignin, protein, lipids, minerals, pigments, pectin, organic acids, etc.

Ruminant Animals & Biorefineries

Mobile Cellulose Biorefinery
(a.k.a. Cow)

Stationary Cellulose Biorefinery

Ruminant Bioreactor:

Biomass Input ~ 26 Lb/Day*

Capacity ~ 40 Gal Fermentor

SSCF Bioreactor:

Biomass Input ~ 5,000 Dry Ton/Day
= 10 M Dry Lb/Day

Capacity ~ 45 M Gal Fermentor

Cow is 3x more efficient than bioreactor

*Rasby, Rick. "Estimating Daily Forage Intake of Cows". University of Nebraska-Lincoln Institute of Agriculture and Natural Resources, http://beef.unl.edu/stories/200608210.shtml, 10/02/06.

Coproducing Feeds and Fuels in Biorefineries

- *Unless human diets change significantly,* the "food vs. fuel" issue in the U. S. context is therefore to produce animal feeds, particularly ruminant animal feeds:
  - more efficiently (less land, other inputs) and
  - with less environmental impact
- Must supply animals (fish, poultry, swine, cattle) with:
  - *Calories (food energy), and*
  - *Protein*
- How can biorefineries coproduce protein and energy feeds along with fuels and chemicals?
- *In fact, they are already doing it! (both corn wet and dry mills do so)*
- Cellulose-based biorefineries will also be in the feed business, whether they like it or not

What Might the Future Look Like?

- Land available (million acres)
  - Cropland (430): corn, wheat, soy, sorghum, alfalfa, hay, CRP
  - Permanent pasture (570)- half suitable for mechanical harvest
  - Most of these acres suitable for perennial grasses
  - Does NOT include forests
- Assume a pretreated perennial grass yielding 10 tons/acre/yr with 10% protein, 75% cellulose + hemicellulose (90% digestible), 15% lignin and ash
- Supply ruminants 710 trillion cal/yr & 36 trillion grams protein/yr using ~40 million acres of productive grasses
- Leaves available >600 million acres for other feeds, human foods and biofuel production
- I simply do not agree that land for food is a limiting resource for biofuel production—animal feed is the issue

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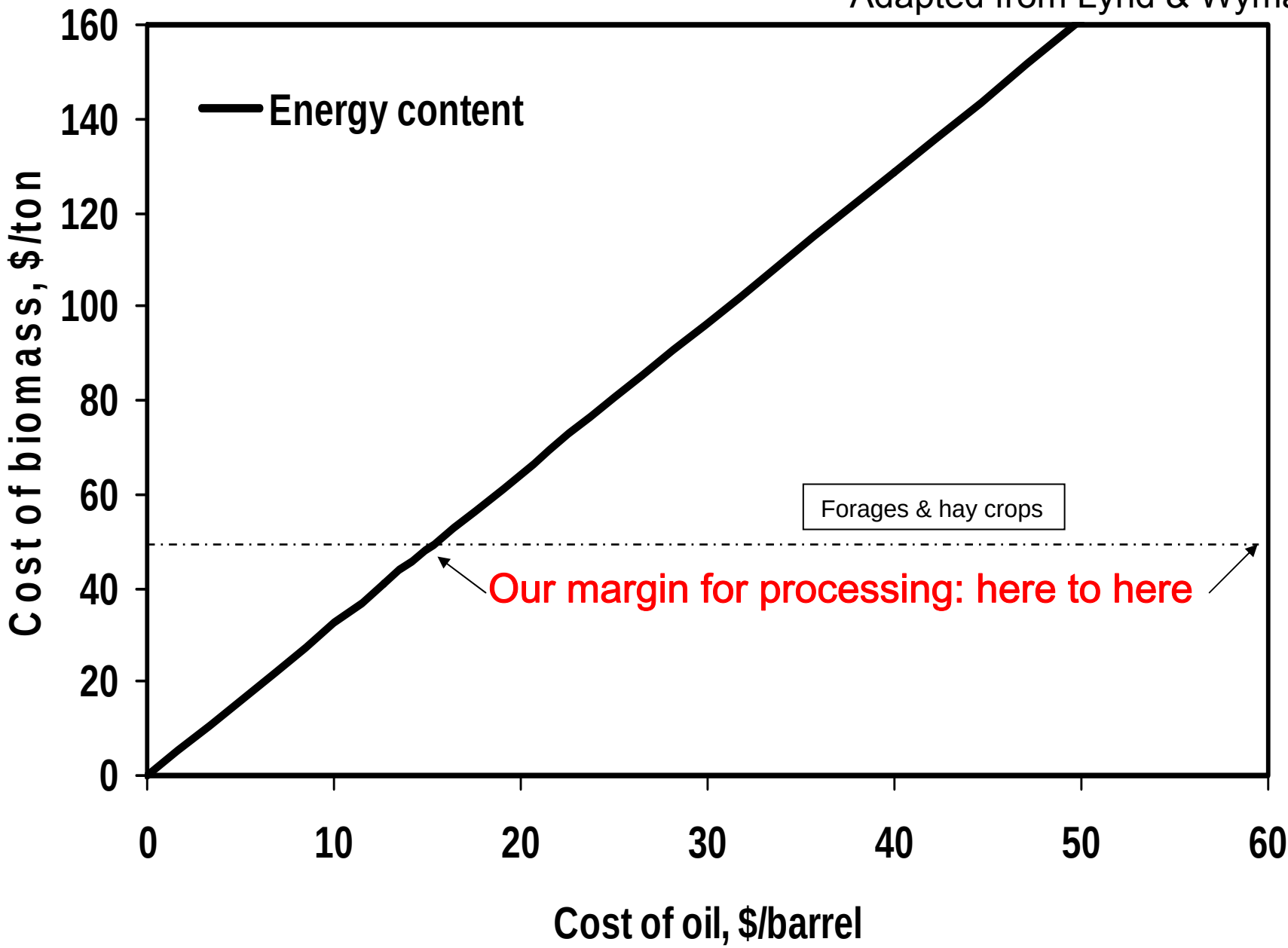
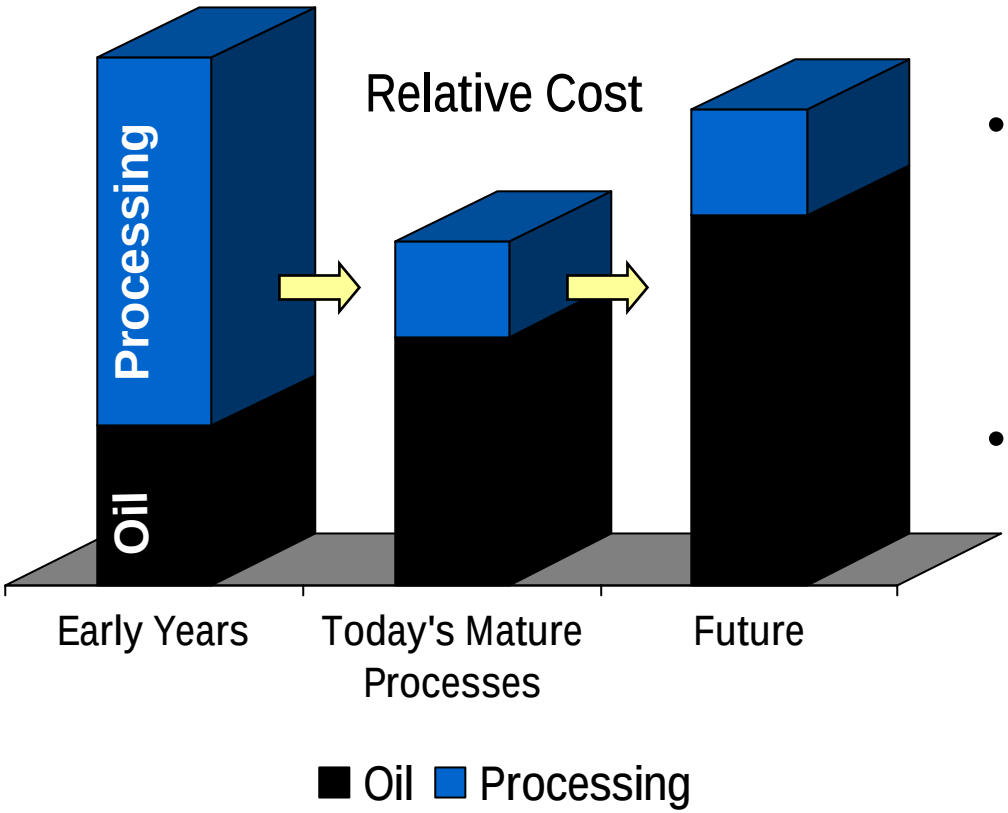
Adapted from Lynd & Wyman



Plant material is much, much cheaper than oil on both energy & mass basis

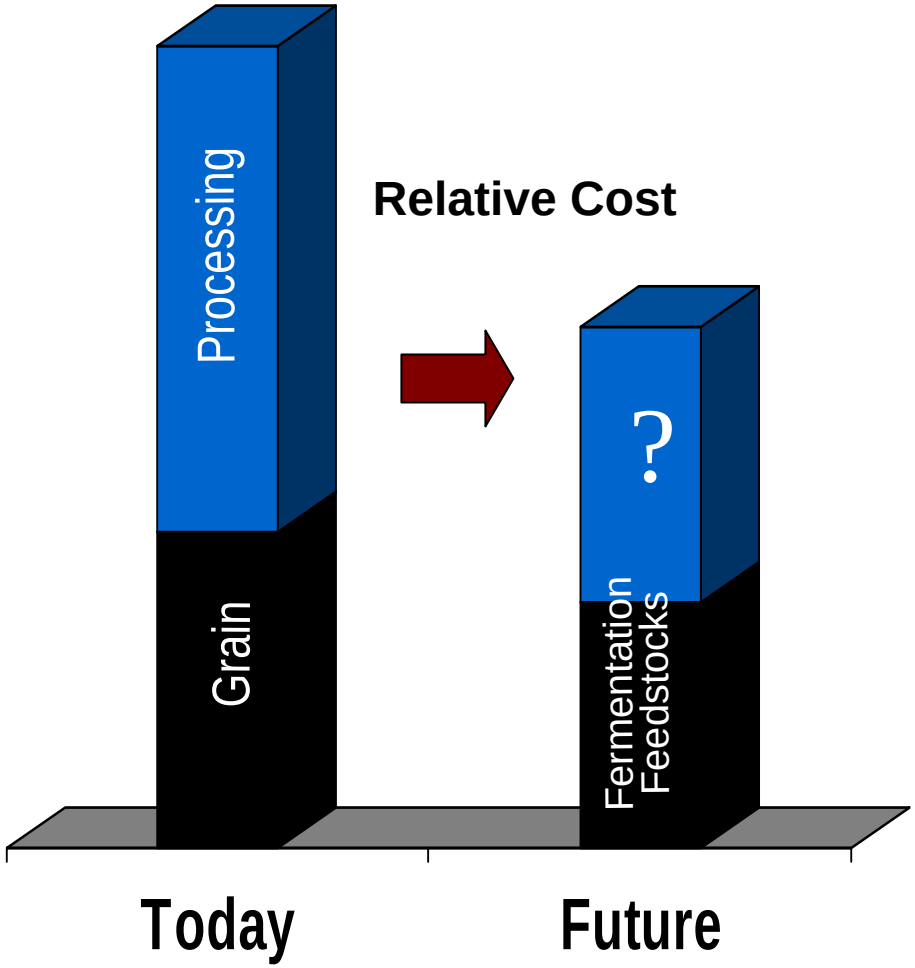
Impact of Processing Improvements: Oil's Past & Future



- Historically, petrochemical processing costs exceeded feedstock costs
- Petroleum processing efficiencies have increased and costs have decreased dramatically but reaching point of diminishing returns
- Petroleum raw materials have long-term issues
  - Costs will continue to increase as supplies tighten
  - High price variability
  - Impacts national security
  - Climate security concerns
  - Not renewable
- **Not a pretty picture for our petroleum dependent society**

From J. Stoppert, 2005

Impact of Processing Improvements: The Future of Biomass Conversion

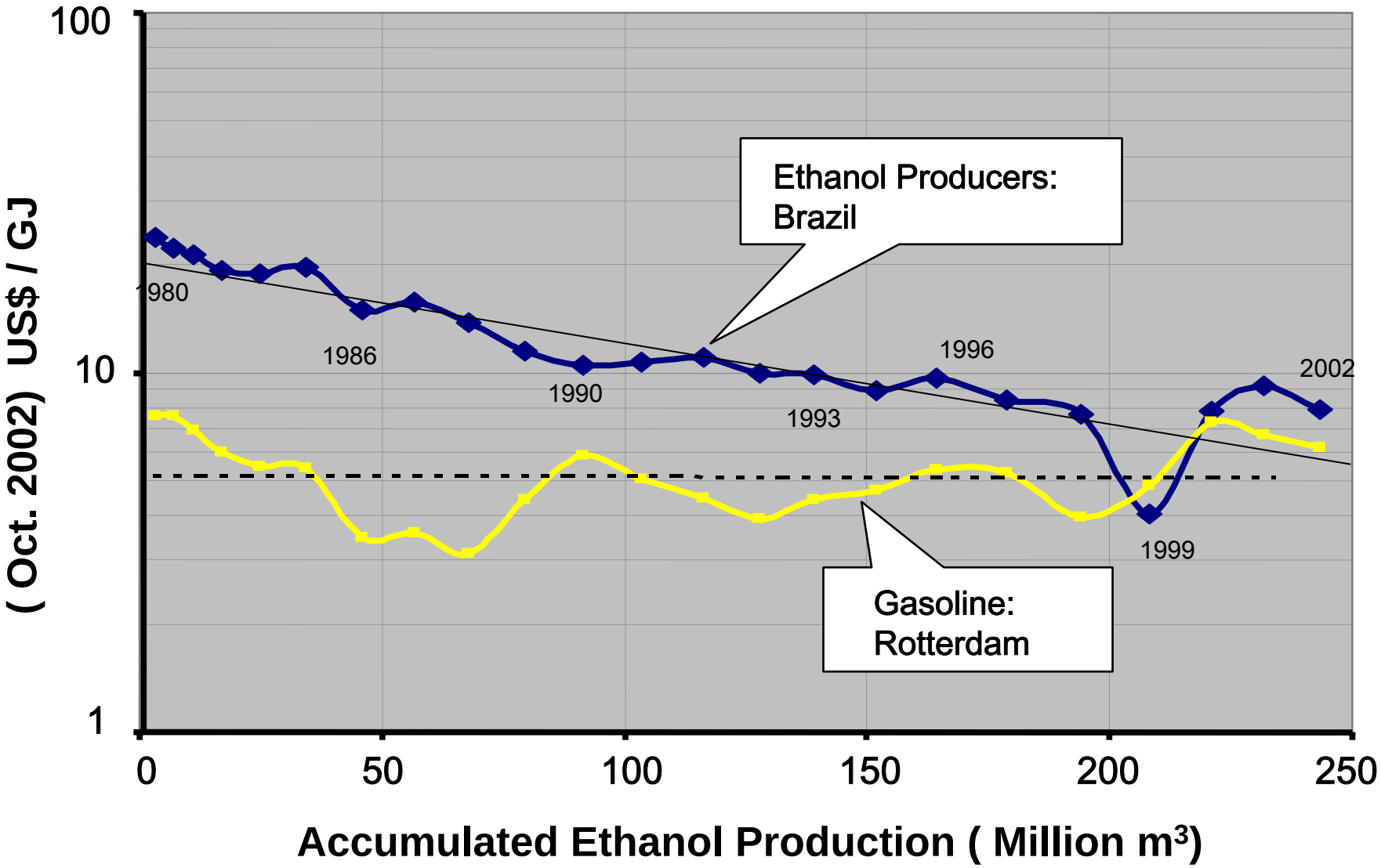


Adapted from J. Stoppert, 2005

- Processing is dominant cost of biofuels today
- Cellulosic raw material costs should be stable or decrease
- Processing costs dominated by pretreatment, enzymes & fermentation
- Biomass processing costs will decrease: deserves high priority to make it happen sooner rather than later
- Much more attractive future
  - Domestically produced fuels
  - Environmental improvements
  - Rural/regional economic development

Learning Curve: Sugar Ethanol Production Cost

(J. Goldemberg, 2003)



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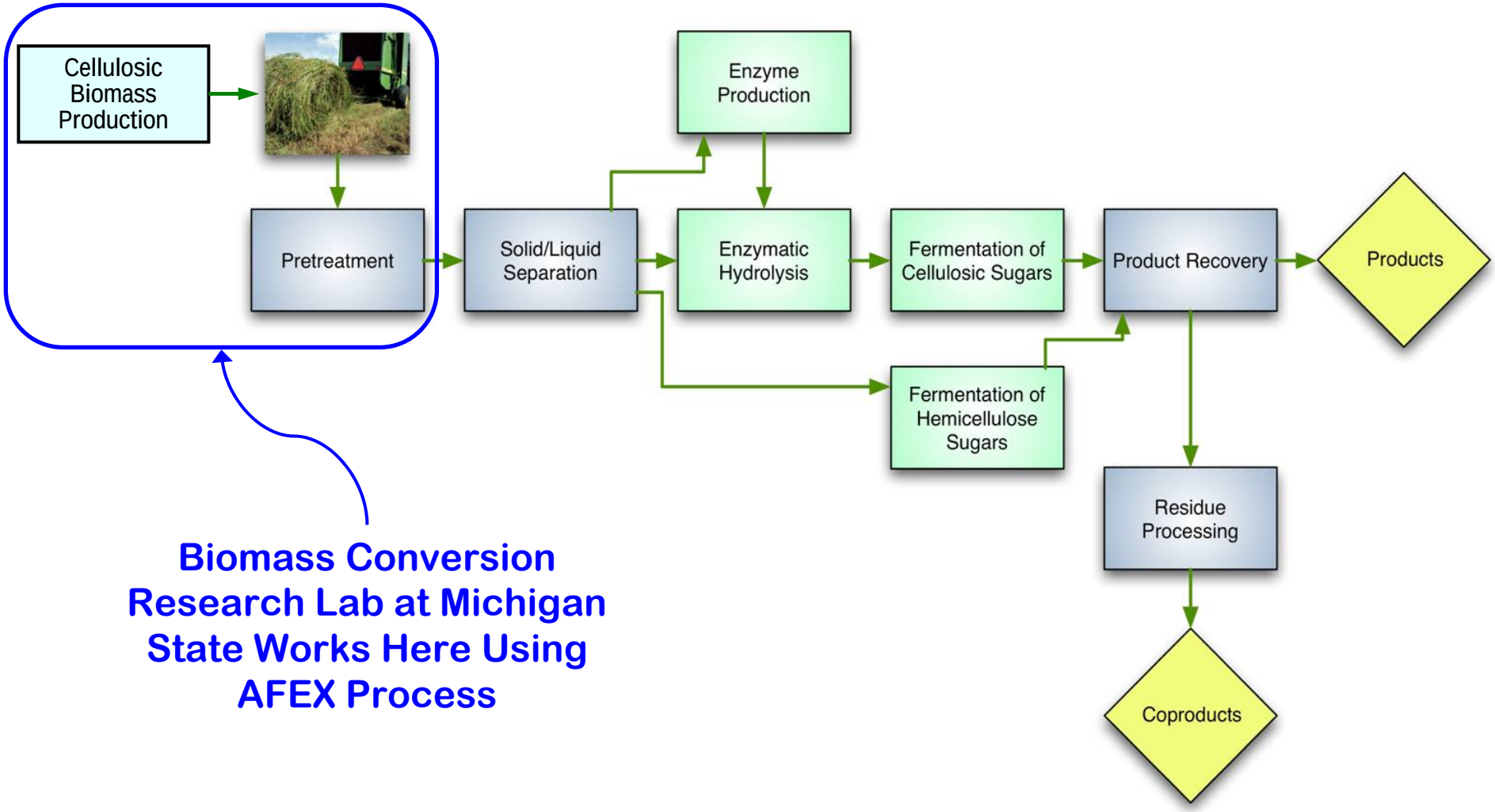
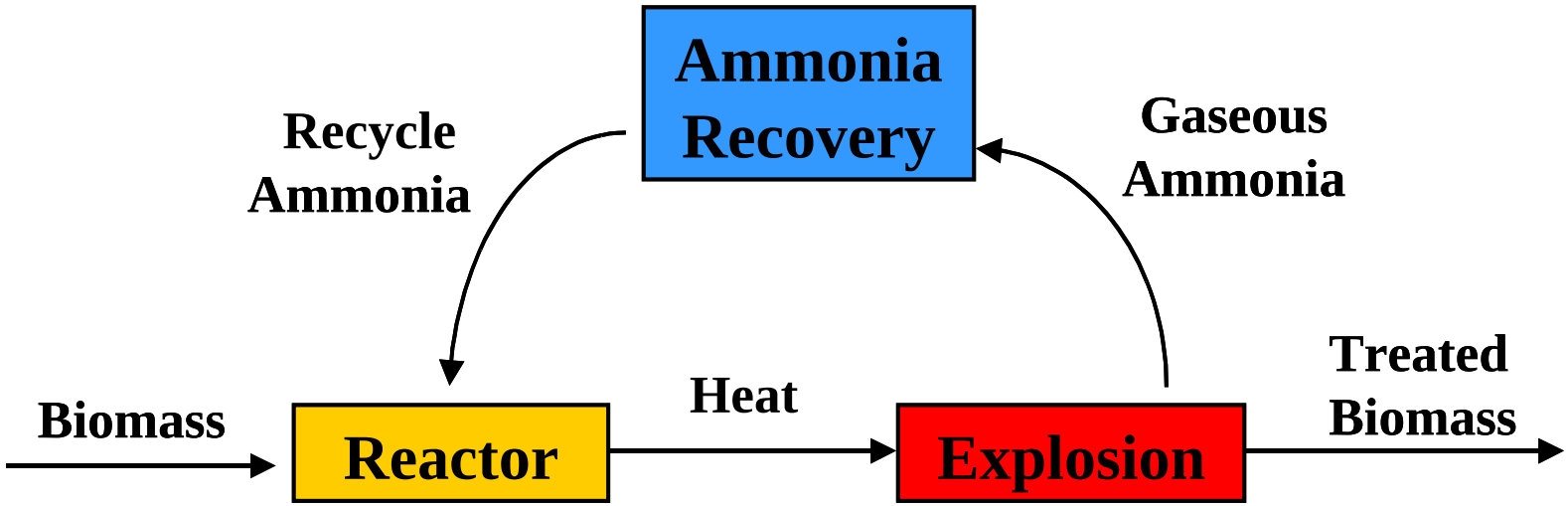


Biomass Conversion Research Lab at Michigan State Works Here Using AFEX Process

DOE 2005

How does AFEX work?



- Biomass heated (~100 C) with concentrated ammonia
- Rapid pressure release ends treatment
- 99% of ammonia is recovered & reused, remainder serves as N source downstream for fermentation
- No sugar degradation, relatively mild conditions
- No hydrolysis to sugar monomers, xylooligomers formed

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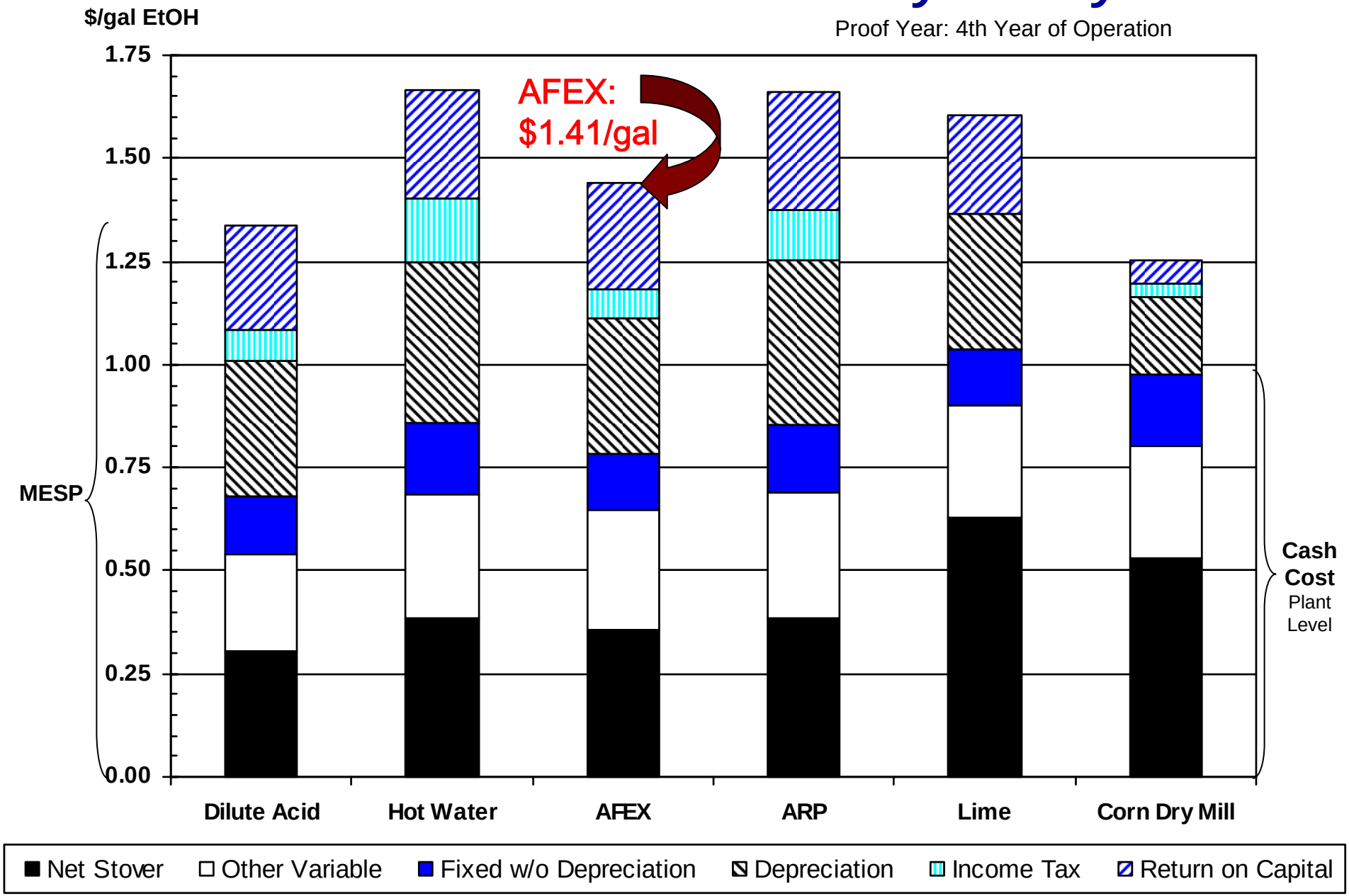
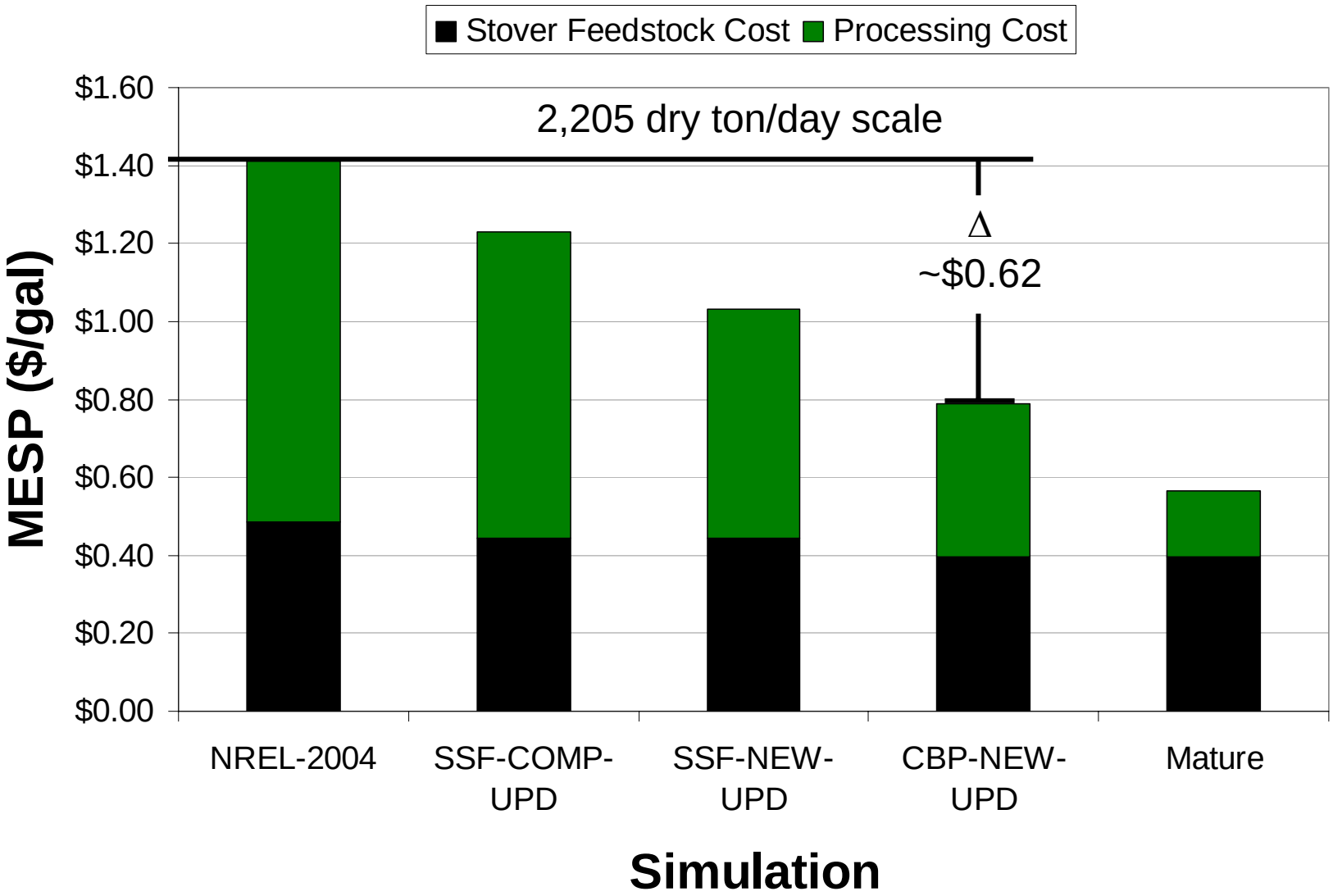
Pretreatment Economic Analysis by NREL



Results of AFEX Economic Analysis*

- Reduce ammonia loadings
- Reduce required ammonia recycle concentrations (manage system water)
- Reduce capital cost of AFEX
- **Analysis performed by Dr. Tim Eggeman of NREL*

Final Results



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  Reality: Ethanol from corn costs $1.20/gal; ethanol from cellulosics, when mature, will cost $0.60/gal
- **We don't have many liquid fuel options…we need to think clearly about these important issues**

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Questions ??