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CREATING THE BIOFUELS FUTURE: DESIGNING "WIN-WIN" SOLUTIONS

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Biomass R&D Technical Advisory Committee
Detroit, MI
September 10, 2007

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Linked Sustainability Challenges of the Coming Decades

- Diversify transportation fuels & end strategic role of petroleum in the world
- Provide food for growing & wealthier population (which will consume more meat)
- Control greenhouse gases & limit other human emissions (for example, nitrogen & phosphorus discharge to ground & surface waters)
- Provide economic opportunities for rural people
- *These challenges & opportunities **intersect** at biofuels, particularly cellulosic biofuels*
- *Abundant opportunities for creative design, "win-win" and system level thinking*

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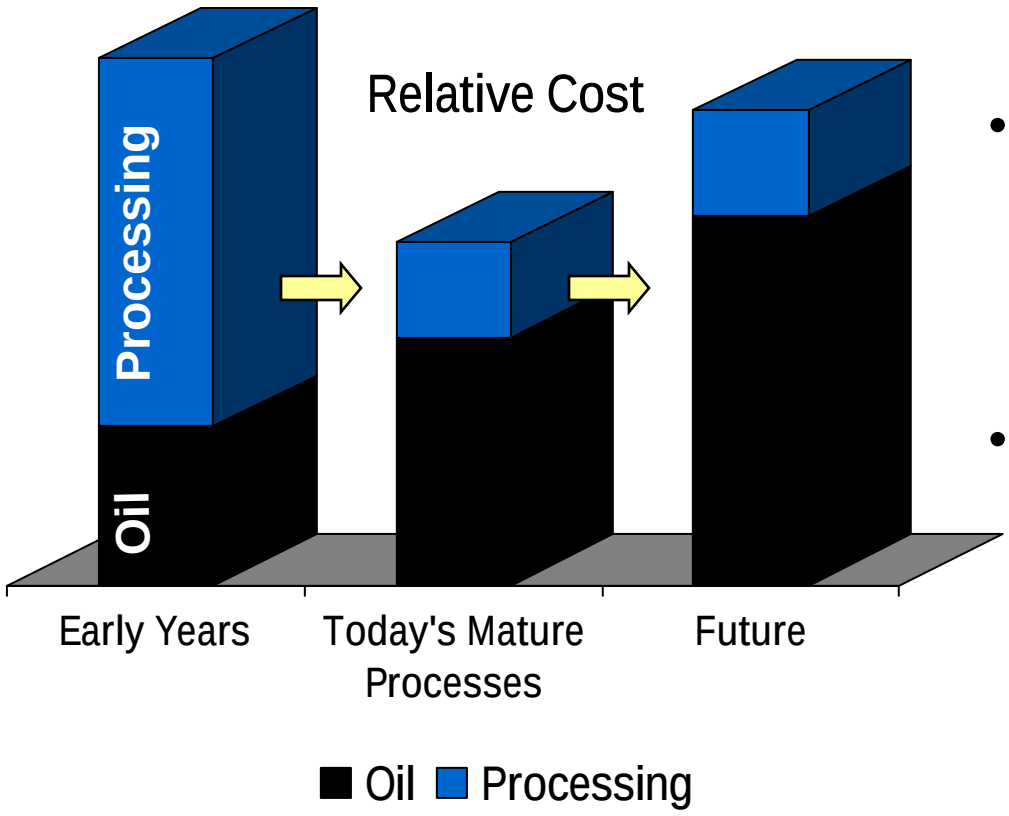
Impact of Processing Improvements: Oil's Past & Future



- 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

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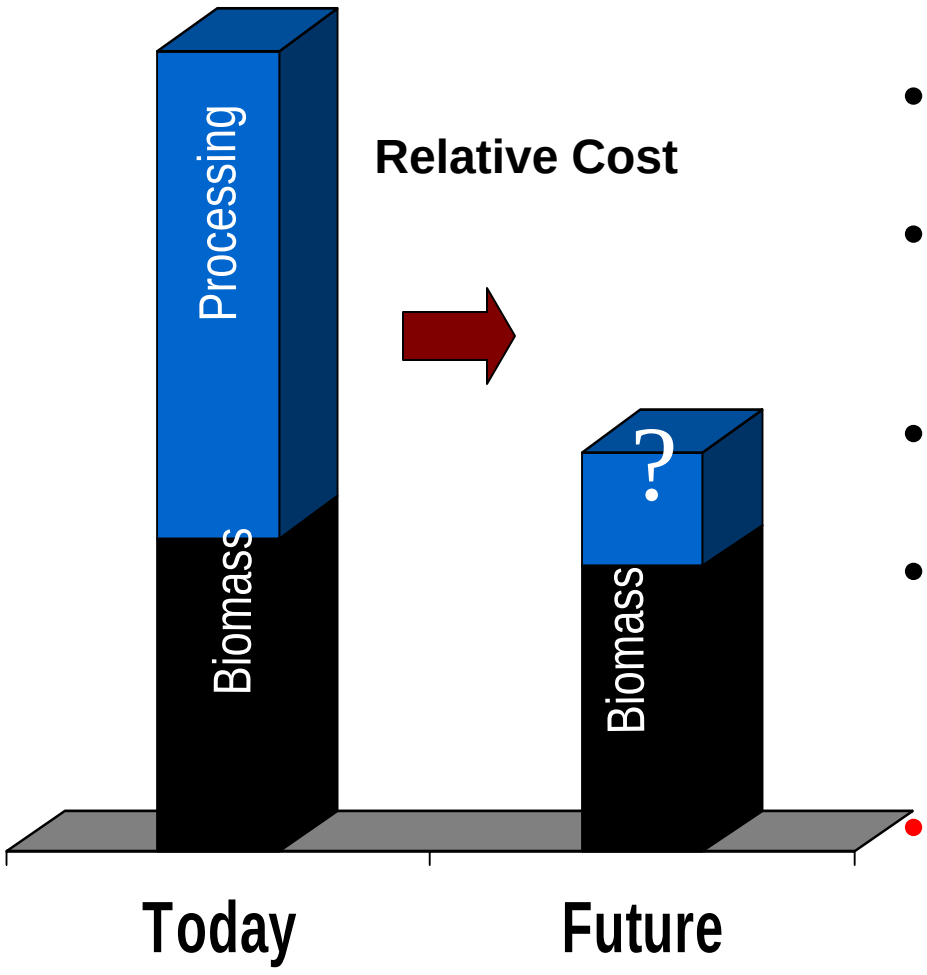
Impact of Processing Improvements: The Future of Cellulosic Biomass Conversion



Adapted from J. Stoppert, 2005

- Processing is dominant cost of cellulosic biofuels today
- Cellulosic biomass costs should be stable or decrease
- Processing costs dominated by pretreatment, enzymes & fermentation
- Biomass processing costs must (& will) decrease
- Two ways to do this:
  1. "Learning by doing" in large scale plants
  2. Applied (cost focused) research
- Much more attractive future
  - Domestically produced fuels
  - Environmental improvements
  - Rural/regional economic development

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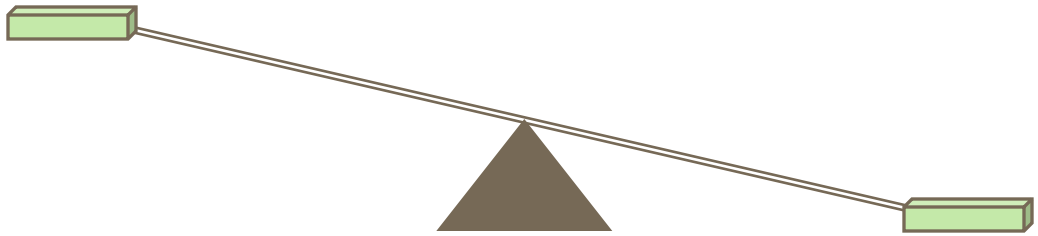
Biofuels: Changing Balance Between Processing and Feedstock

Today



Feedstock

Processing

- Pretreatment
- Enzymes
- Fermentation

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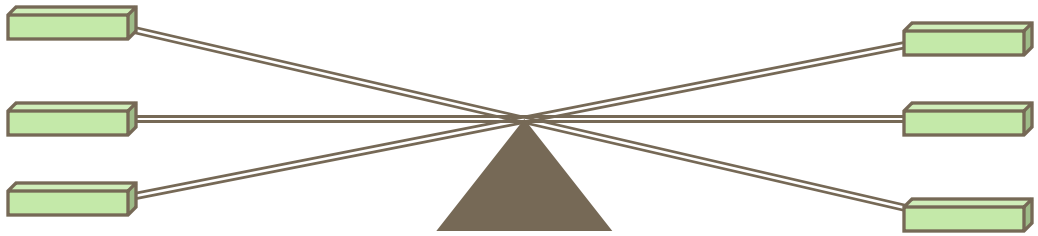
Biofuels: Changing Balance Between Processing and Feedstock

Near Future



Feedstock

- Biomass yield & properties
- Harvest/transport logistics
- Sustainability, eg. greenhouse gas certification
- Rural economic development
- Co-products (chemicals, materials
- …Many more!

Processing

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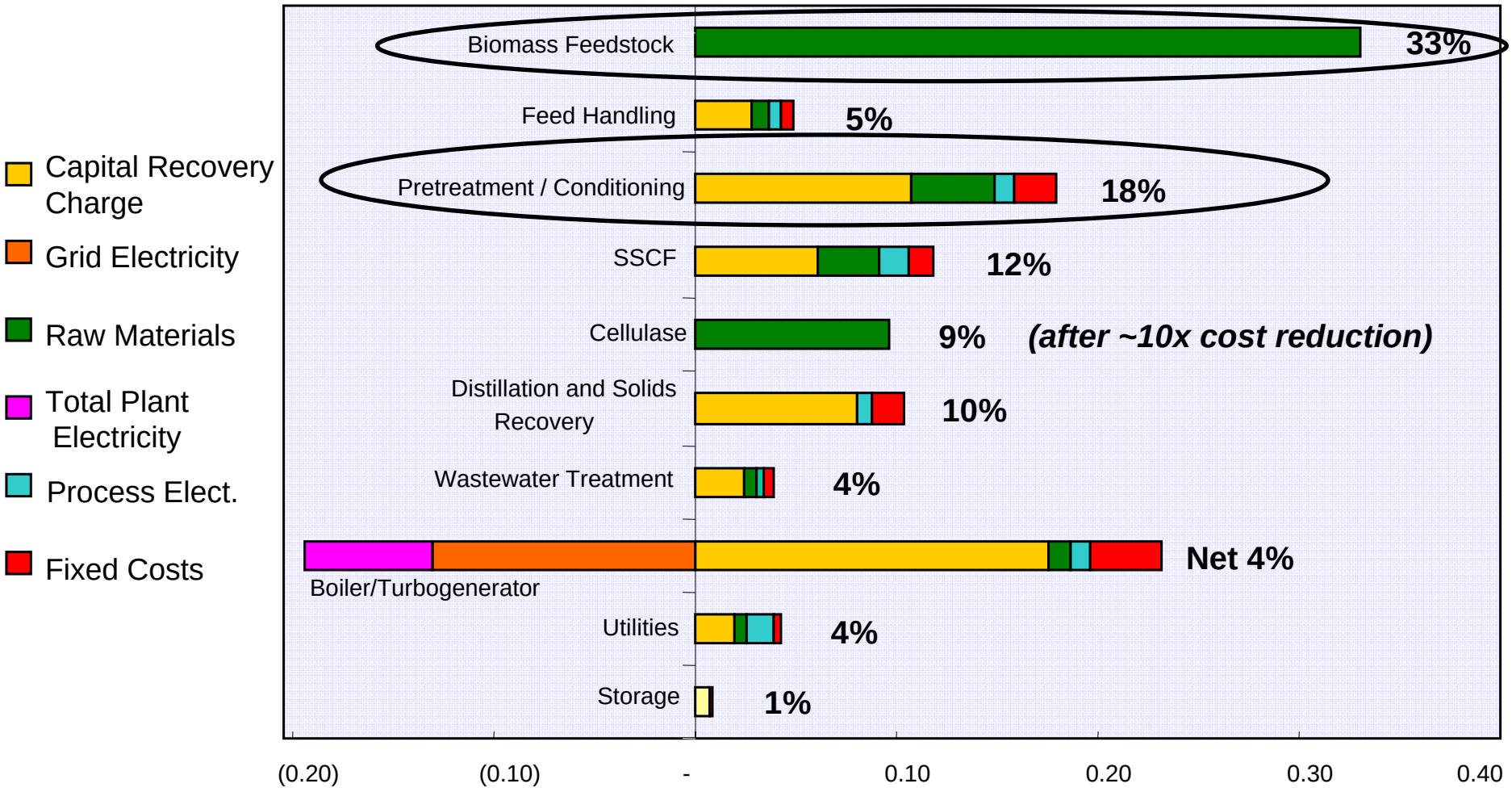
Key Processing Cost Elements



Biomass Refining CAFI

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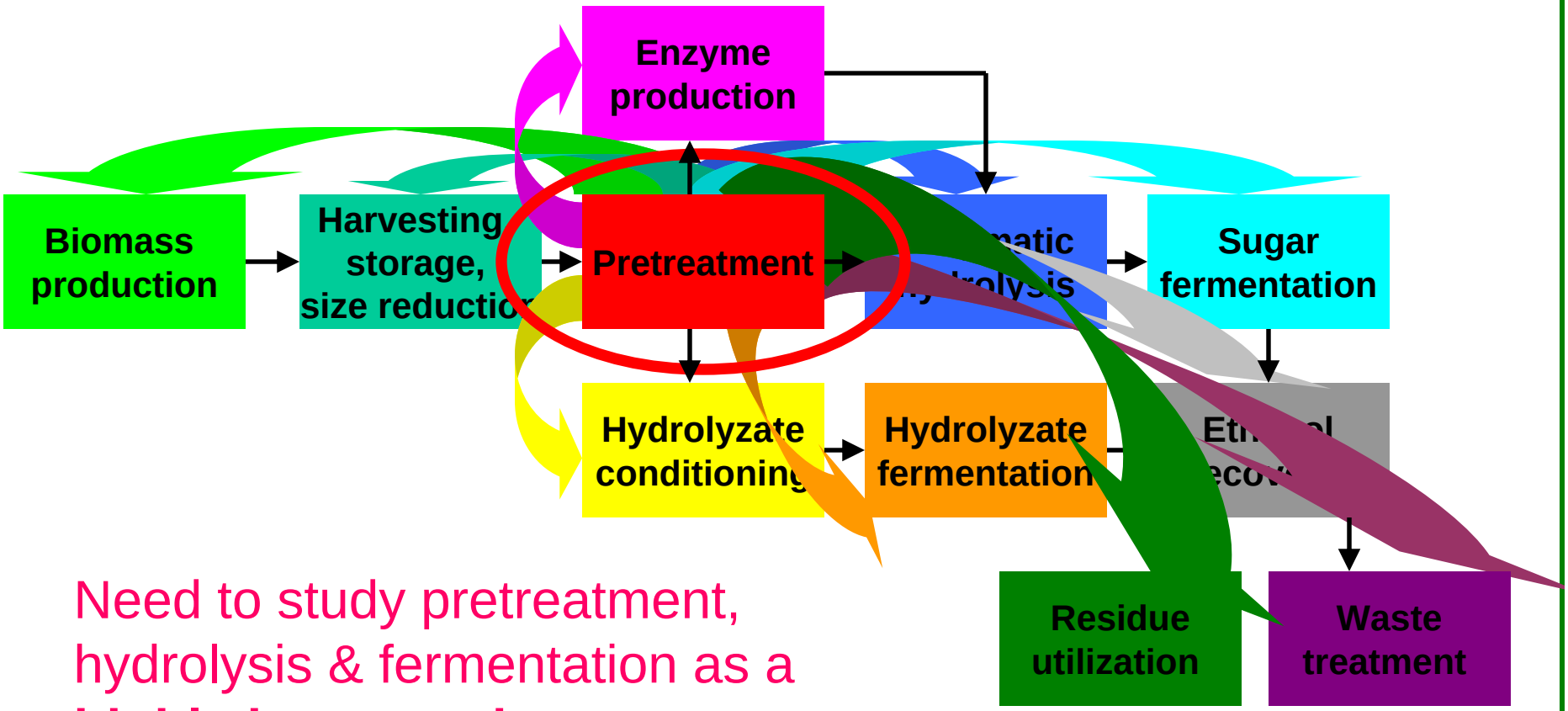
Central Role and Pervasive Impact of Pretreatment for Biological Processing



Need to study pretreatment, hydrolysis & fermentation as a **highly integrated system**

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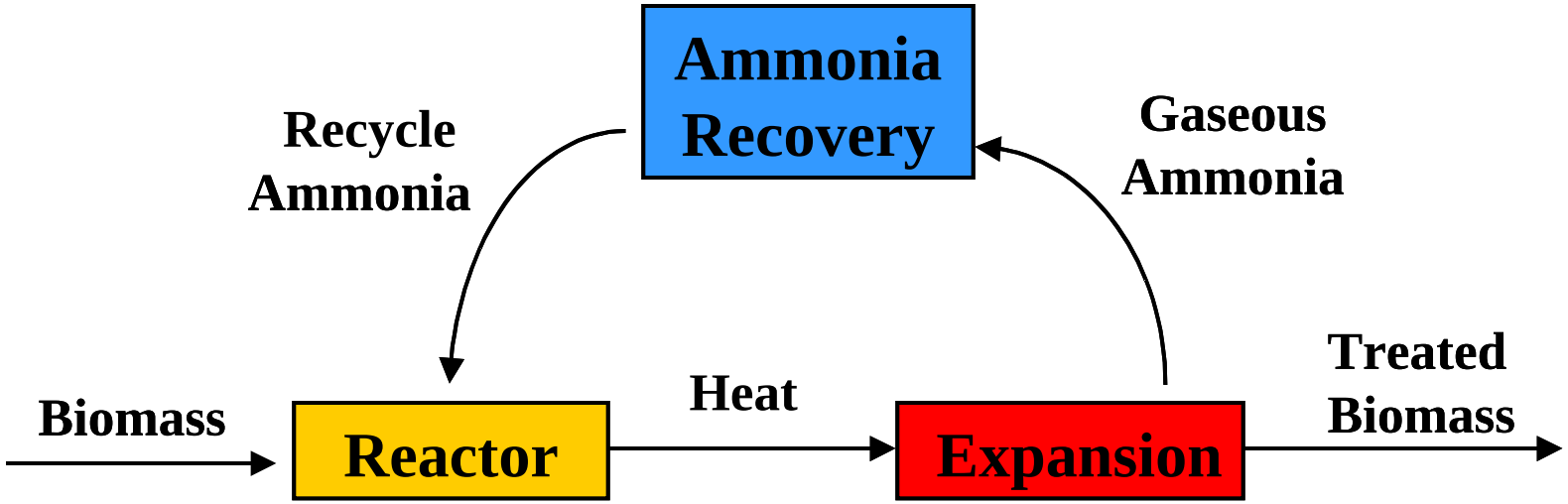
How does AFEX work?



- 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
- AFEX covered by multiple U. S. and international patents
- Fermentation inhibitors NOT produced

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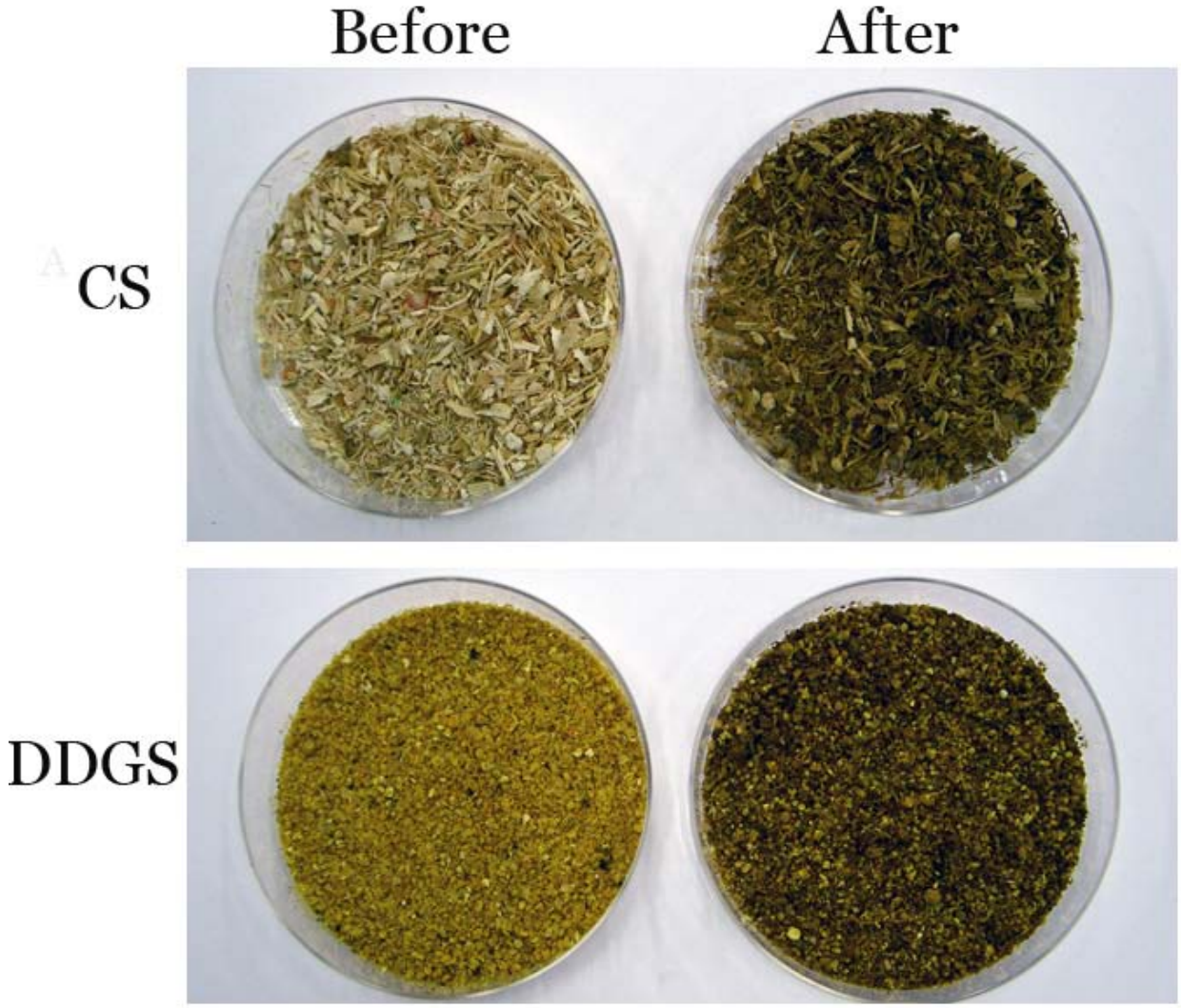
Before and After AFEX



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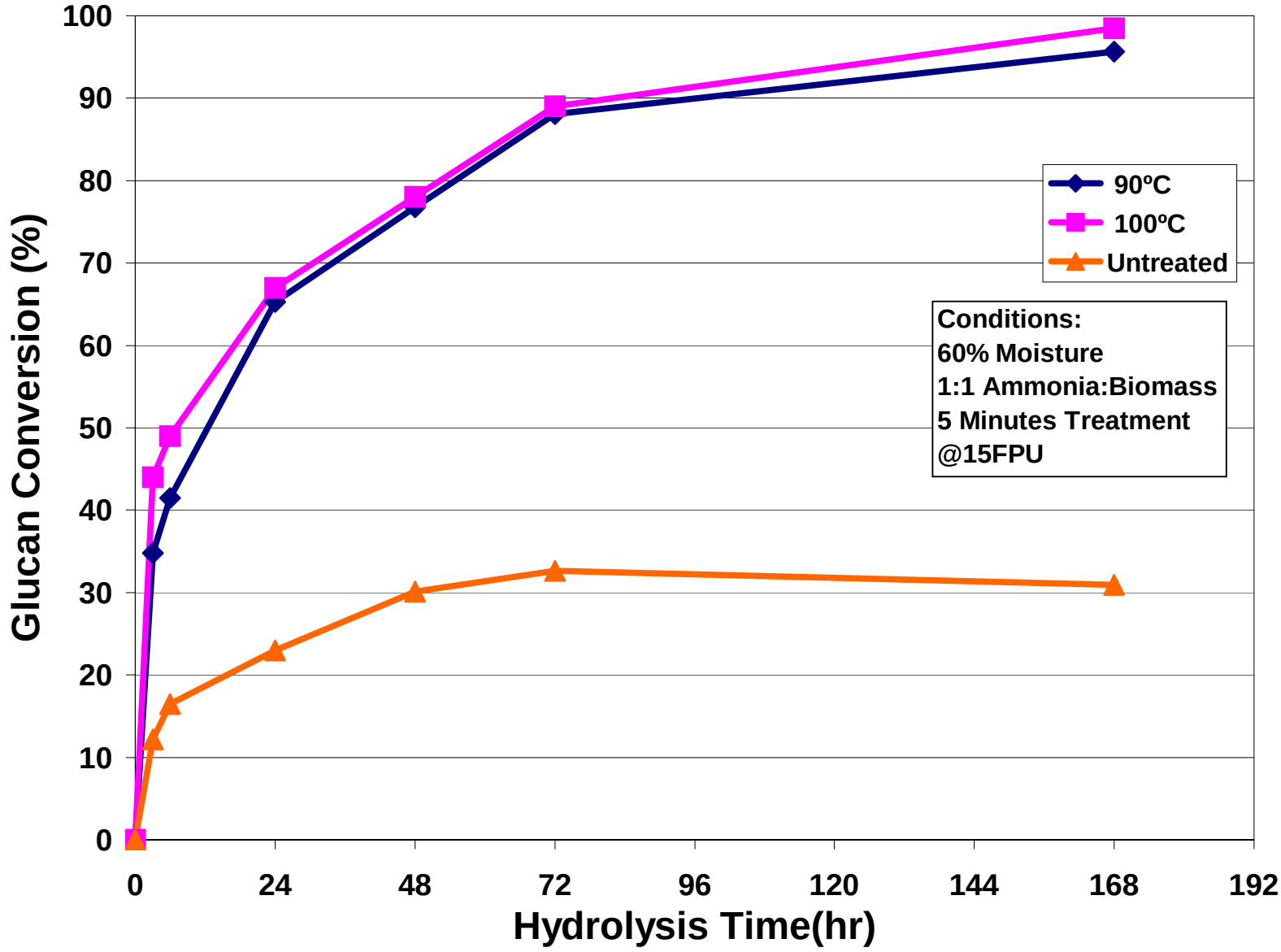
Kinetics of Glucan Hydrolysis



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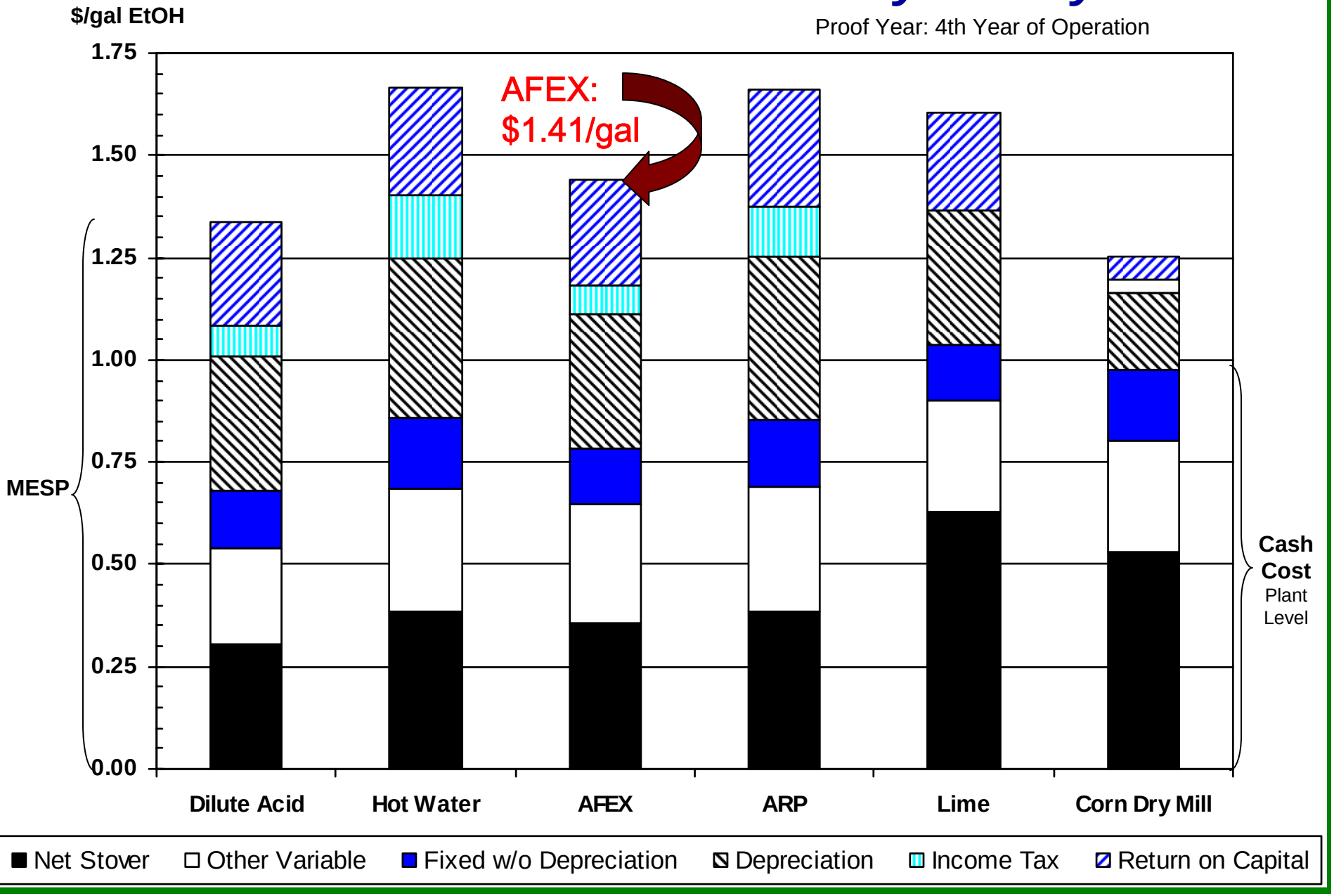
Pretreatment Economic Analysis by NREL



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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*

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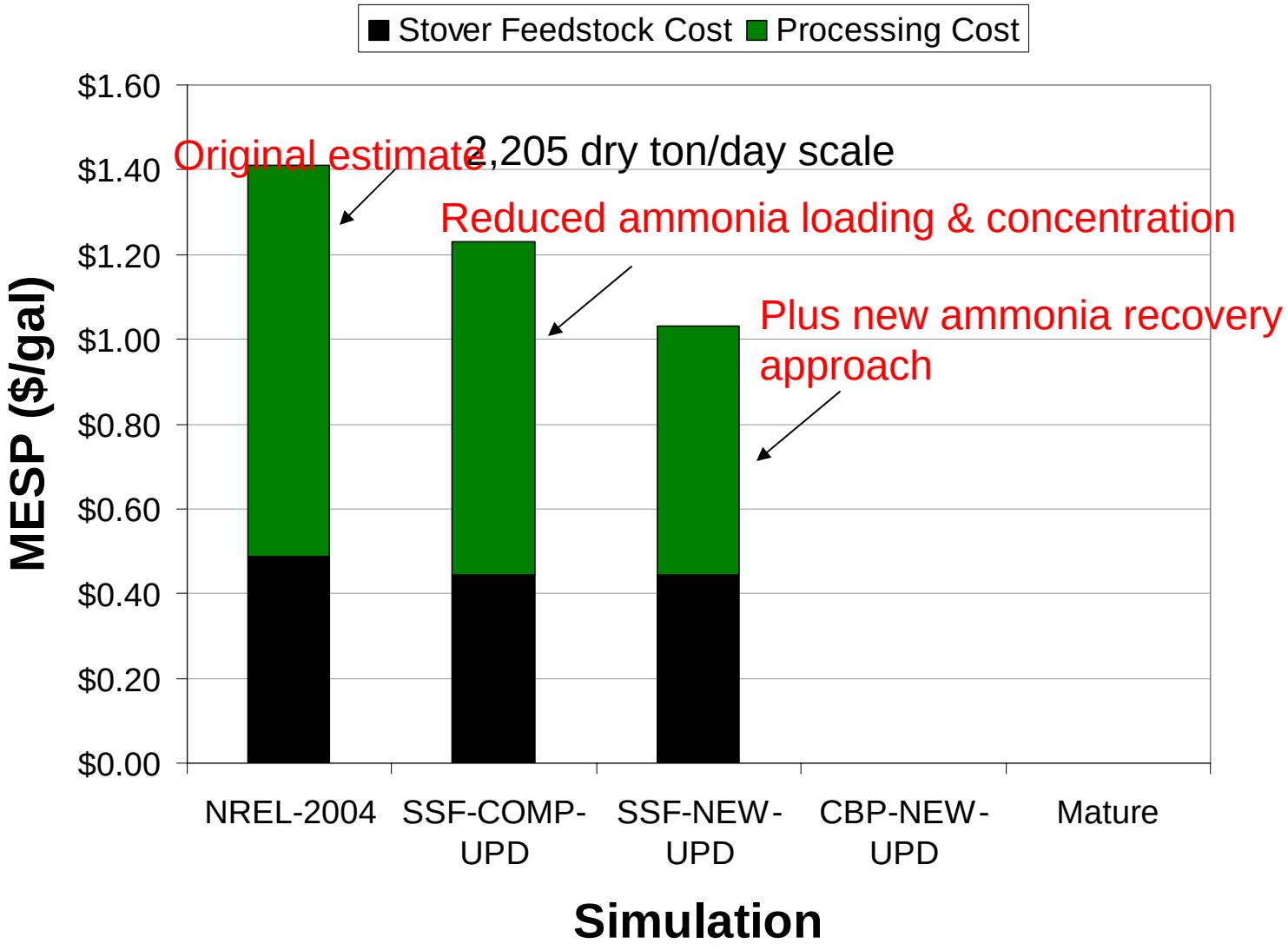
Improvements in AFEX Give Improved Ethanol Production Costs



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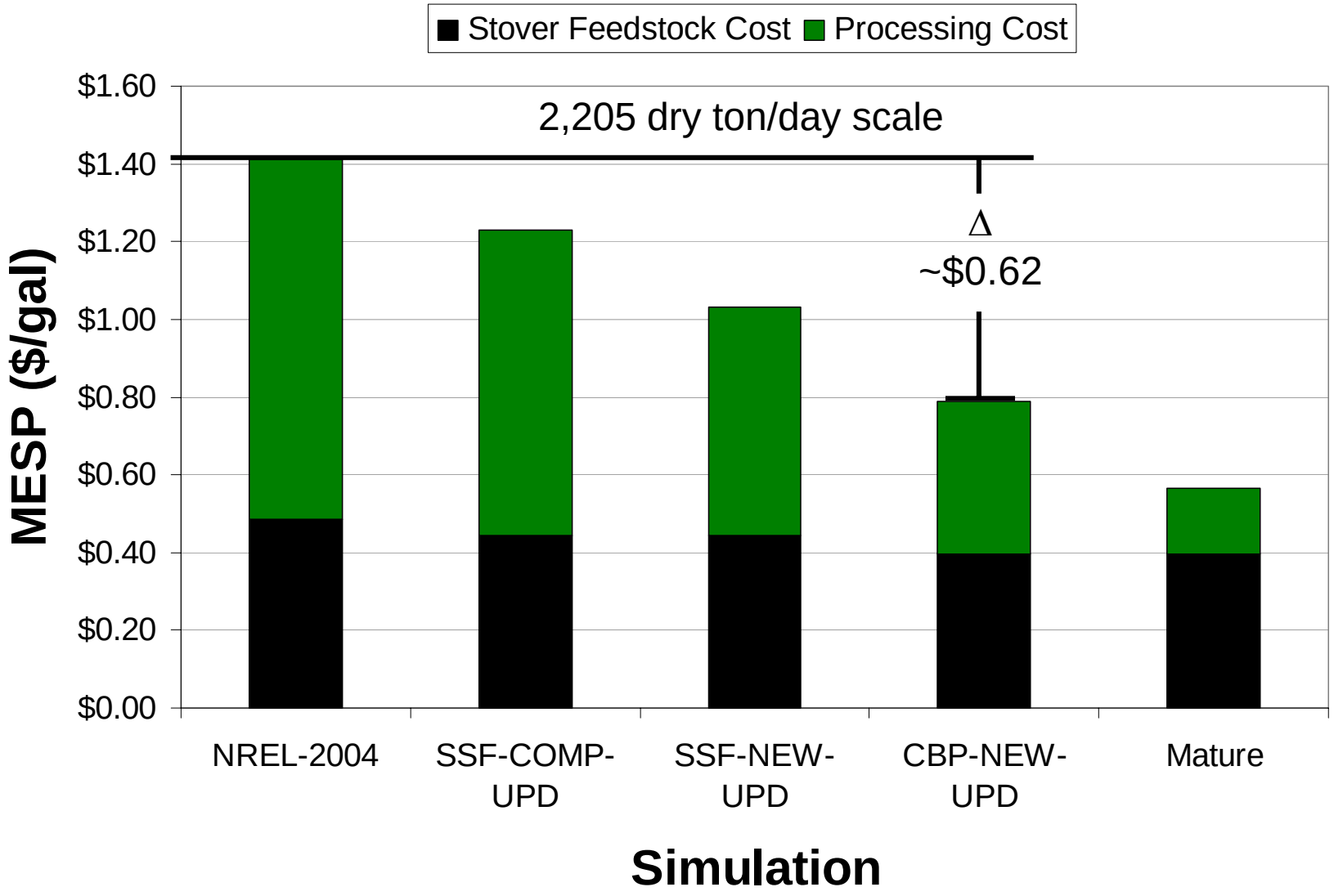
End Result of Process Improvement will be Very Low Cost Cellulosic Ethanol



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We Have Come a Long Way: But There is Much Left to Do

- Processing Cost Reduction
  - Large scale plants (~$400 million)
  - Strong public & private research investment (~$1 billion)
- Feedstock-related issues should become increasingly important
  - Cost & availability
  - Harvesting, logistics, transport
  - Sustainability, eg. greenhouse gas certification
  - Rural economic developmennt
  - Resolving “food vs. fuel” issues

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Anticipating the Biofuels Future

- Premise: *the cellulosic biofuels industry will grow rapidly in coming years.*
- Some resulting questions:
  - How will society/interest groups, etc. react?
  - How will related environmental issues (carbon sequestration, water, soil quality, landscape values, biodiversity, etc.) be addressed?
  - What will the implications be for food/feed/fiber markets?
  - Can we coproduce fuels (& foods/feeds)
  - How can farmers & local communities benefit?
  - How will the research enterprise respond?

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What Happens Because of Inexpensive Ethanol?

- Petroleum dominance declines
  - *Reduce petroleum's influence on prosperity & politics*
  - *Less chance for international conflict*
  - *Greater economic growth opportunities for poor nations*
- Environmental improvements possible
  - *Reduced greenhouse gases*
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  - *Local cellulosic biomass processing*
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- Less expensive food (animal feed) possible
  - *Improved animal feeds: protein & calories*
  - *Less expensive, more abundant human food*

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Will People Go Hungry Because of Biofuels?

- 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 (~5% of our cropland)
- *Most U. S. agricultural production (inc. exports) is fed to animals-- i.e., we are meeting their 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)
- Thus we can address perceived "food vs. fuel" conflict by providing animal feeds more efficiently, on less land
- Dairy & beef cattle consume more than 70% of all calories and protein fed to livestock
- As nations grow richer, they want more protein, especially more meat….

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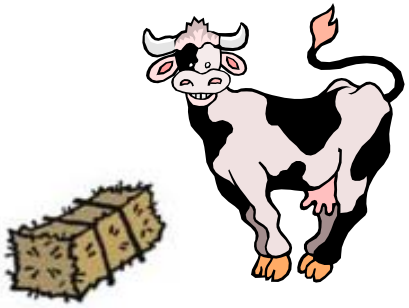
Ruminant Animals & Biorefineries:

Improve Cellulose Conversion for Biorefinery
= Improve Cellulose Digestibility for Cows

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 industrial 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.

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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**

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Grasses: Sustainable Sources of Protein & Calories for Cattle Feeding?

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Thinking Ahead: Farmers & Biofuels

"More than a century of bitter experience has taught farmers that when they simply sell a raw crop, they fall ever further behind."

David Morris "The American Prospect" April 2006

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Capturing Local Benefits from Biofuels

- Some issues for farmers/local interests
  - If farmers merely supply biomass, they will not benefit much from the biofuels revolution
  - Investment required for cellulosic ethanol biorefinery is huge ~ $250 million and up—difficult for farmers to participate
- Some issues for biofuel firms/larger society
  - Supply chain issues are enormous—need 5,000 ton/day from ~1,000 farmers: chemicals/fuels industries have zero experience with such large agricultural systems
  - Cellulosic biomass is bulky, difficult to transport
  - Need to resolve "food vs. fuel" problem: actually "animal feed and fuel opportunity"
- Is there a common solution?
  - Regional Biomass Processing Center– concept worthy of study
  - Pretreat biomass for biorefinery & ruminant (cattle) feeding
  - Much lower capital requirements—accessible to rural interests
  - Develop additional products over time—animal feed protein, enzymes, nutraceuticals, biobased composites, etc

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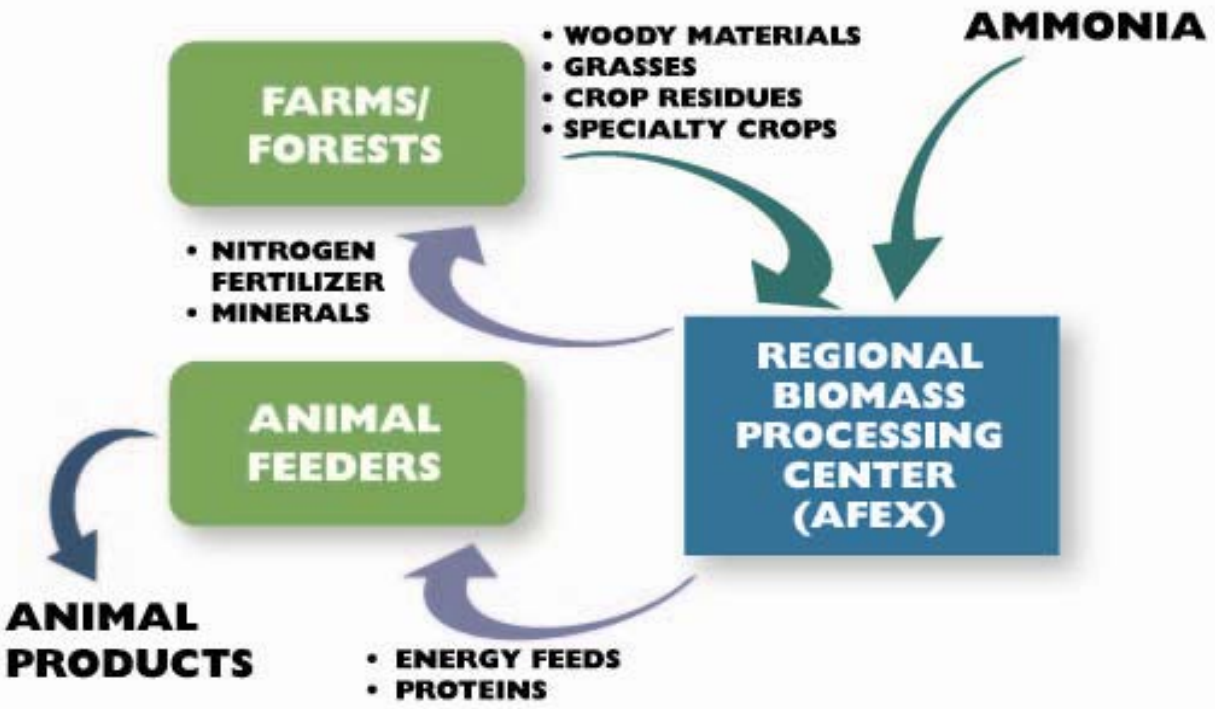
REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



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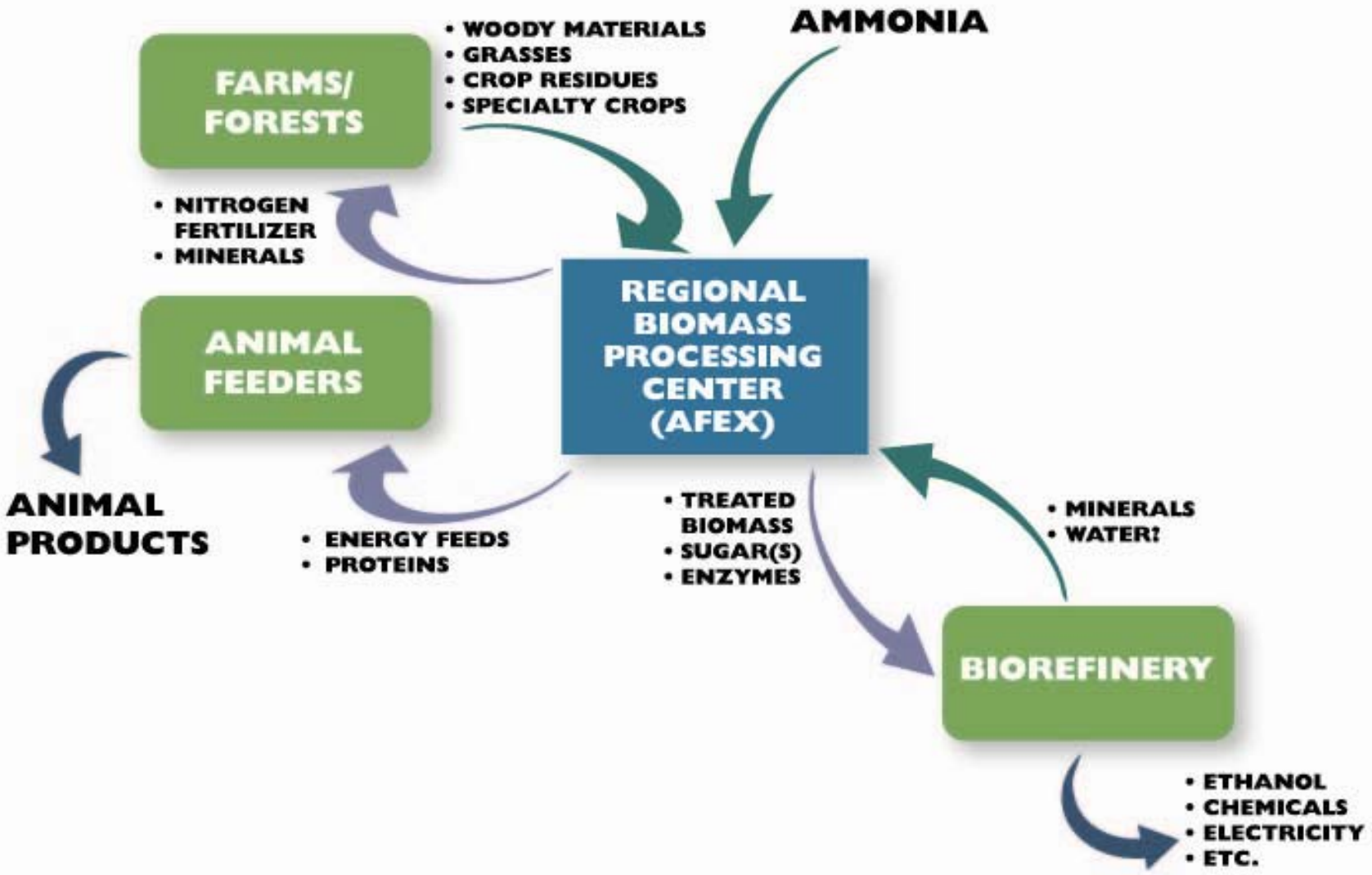

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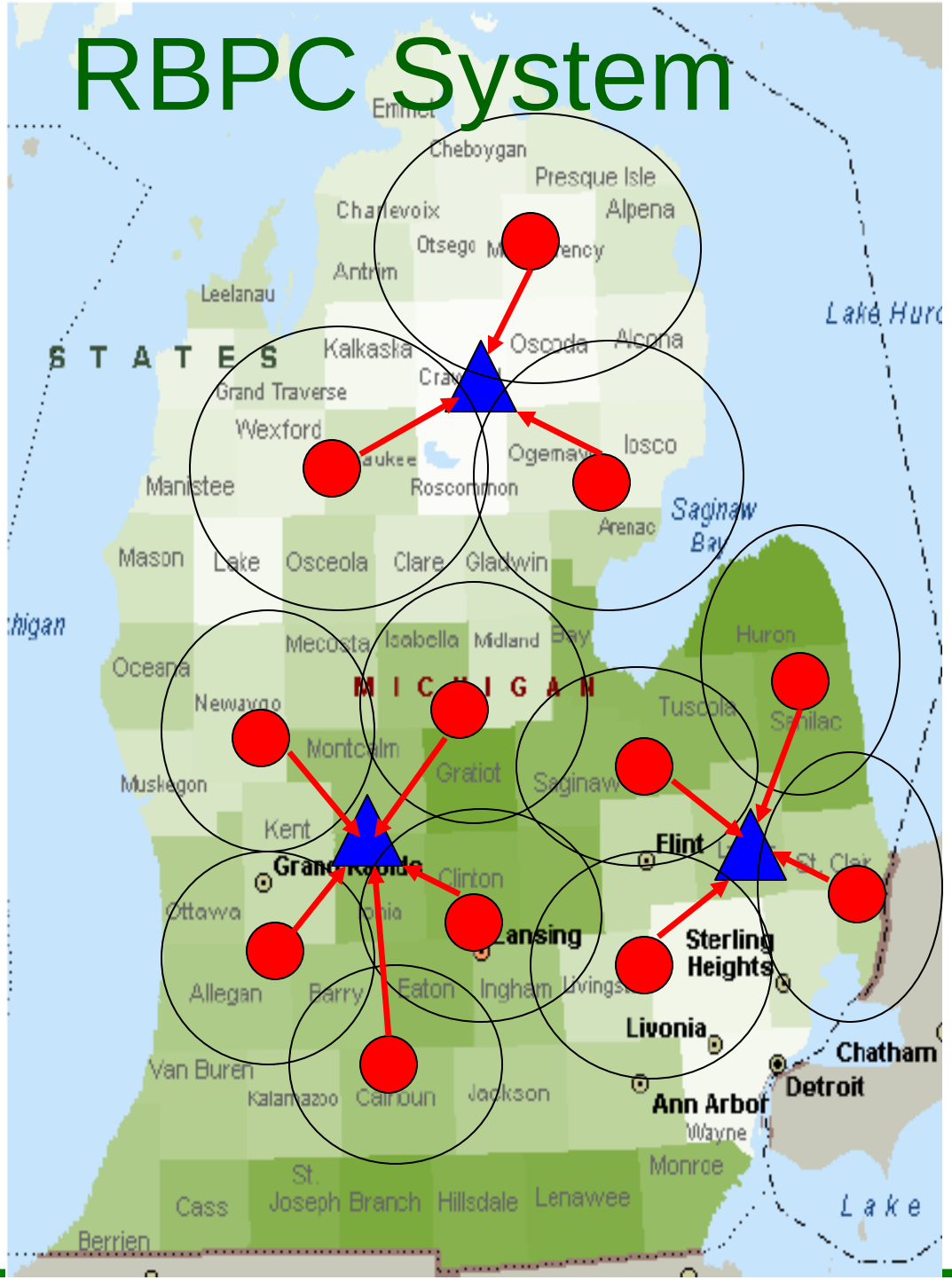
RBPC System

- Decentralized, spatially optimal pretreatment centers
- Multiple RBPCs supply single, larger biorefinery
- Greater geographic coverage
- Synergistic local relationship
- Fewer contracts to manage
- Uniform, already pretreated biomass for biorefinery



Sustainable rural economies + Sustainable biofuels

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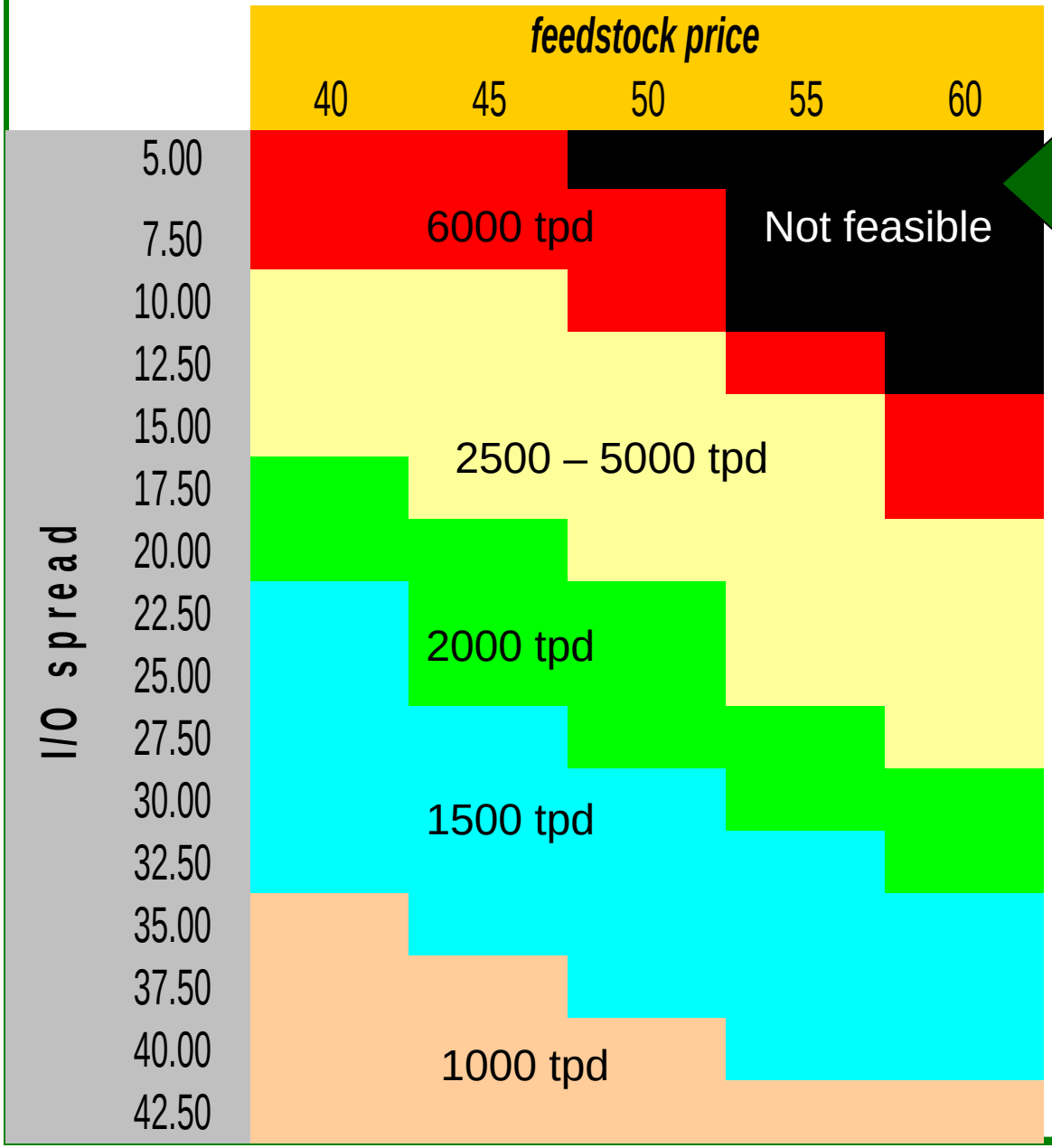
Economically Feasible Set



Minimum **scale plant that works (>12% ROI) under price combination**

- I/O spread = BIG driver
- As I/O spread grows; smaller facilities work
- @ LCB < $50, ***can*** achieve > 12% ROI;
- I/O Spread NOT sole determinant - LCB price plays a major role.
  - under $25, all feasible
  - over $65, only 7000 tpd +, with BR price > $82.50 feasible
  - Others?

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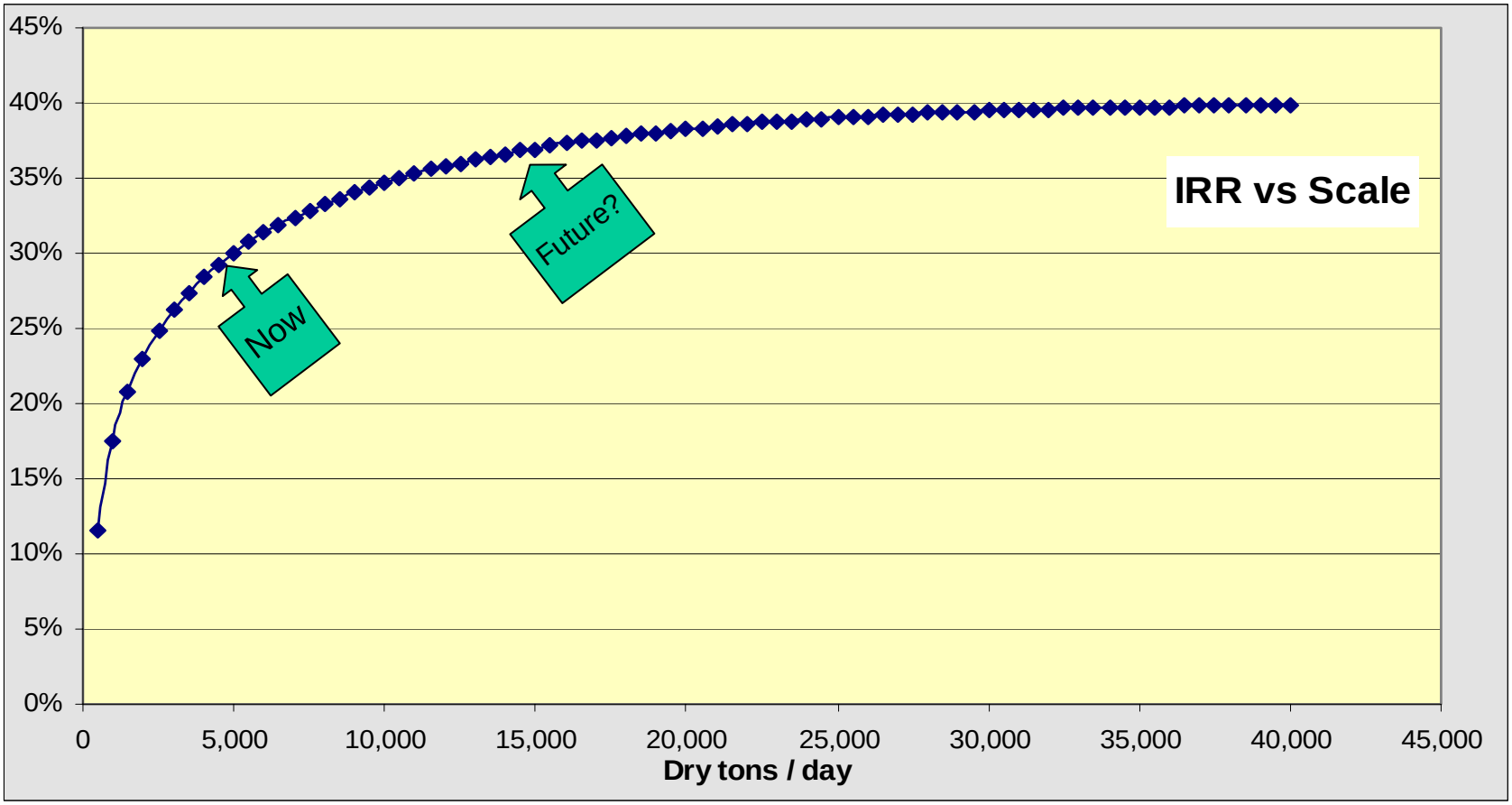
Impact to Biorefinery

- Lower capital costs
- Lower operating costs
- Add: more available LCB

- Larger, & /or more, facilities
- More economies of scale
- Move up return curve



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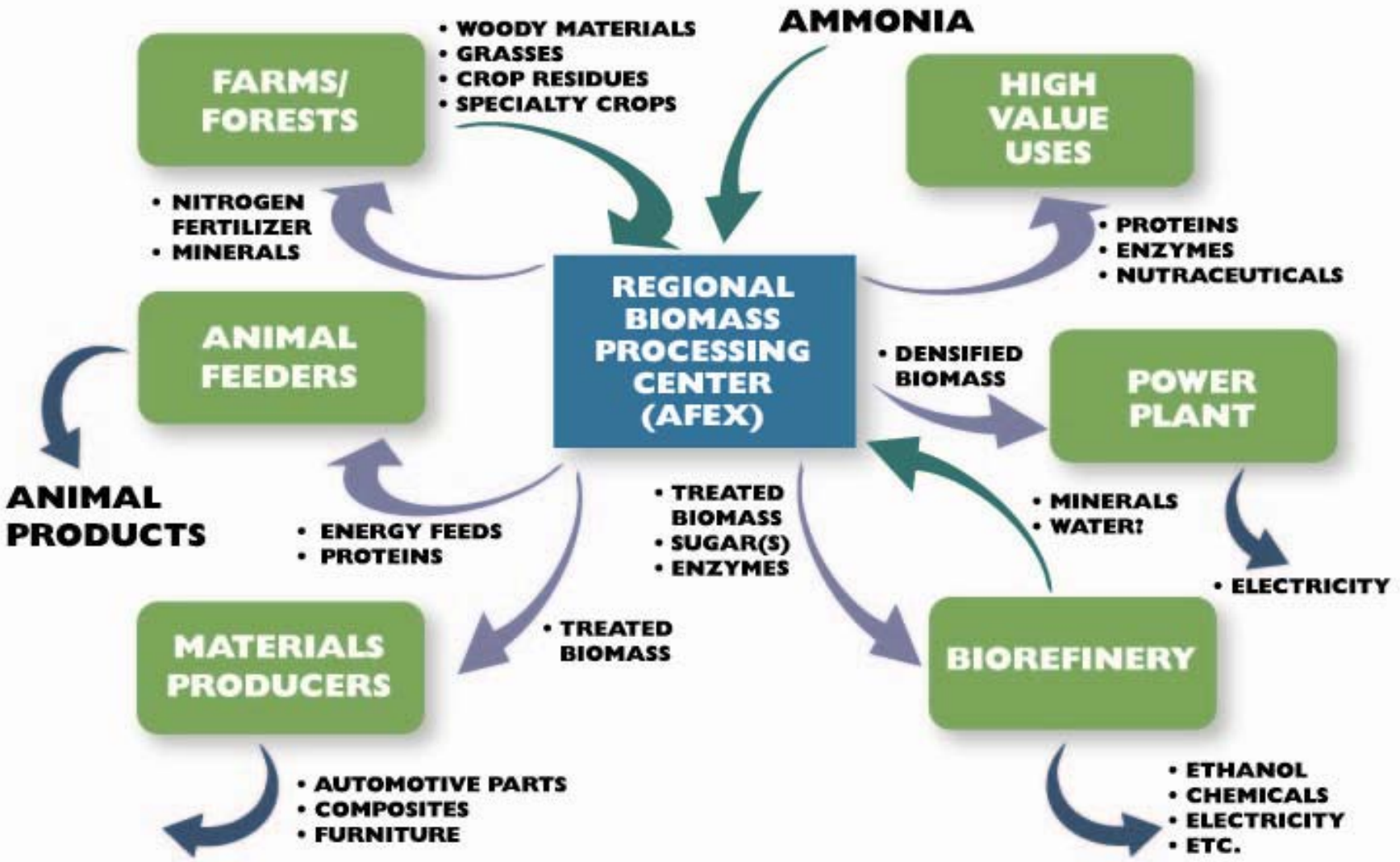

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What Happens Because of Inexpensive Ethanol?

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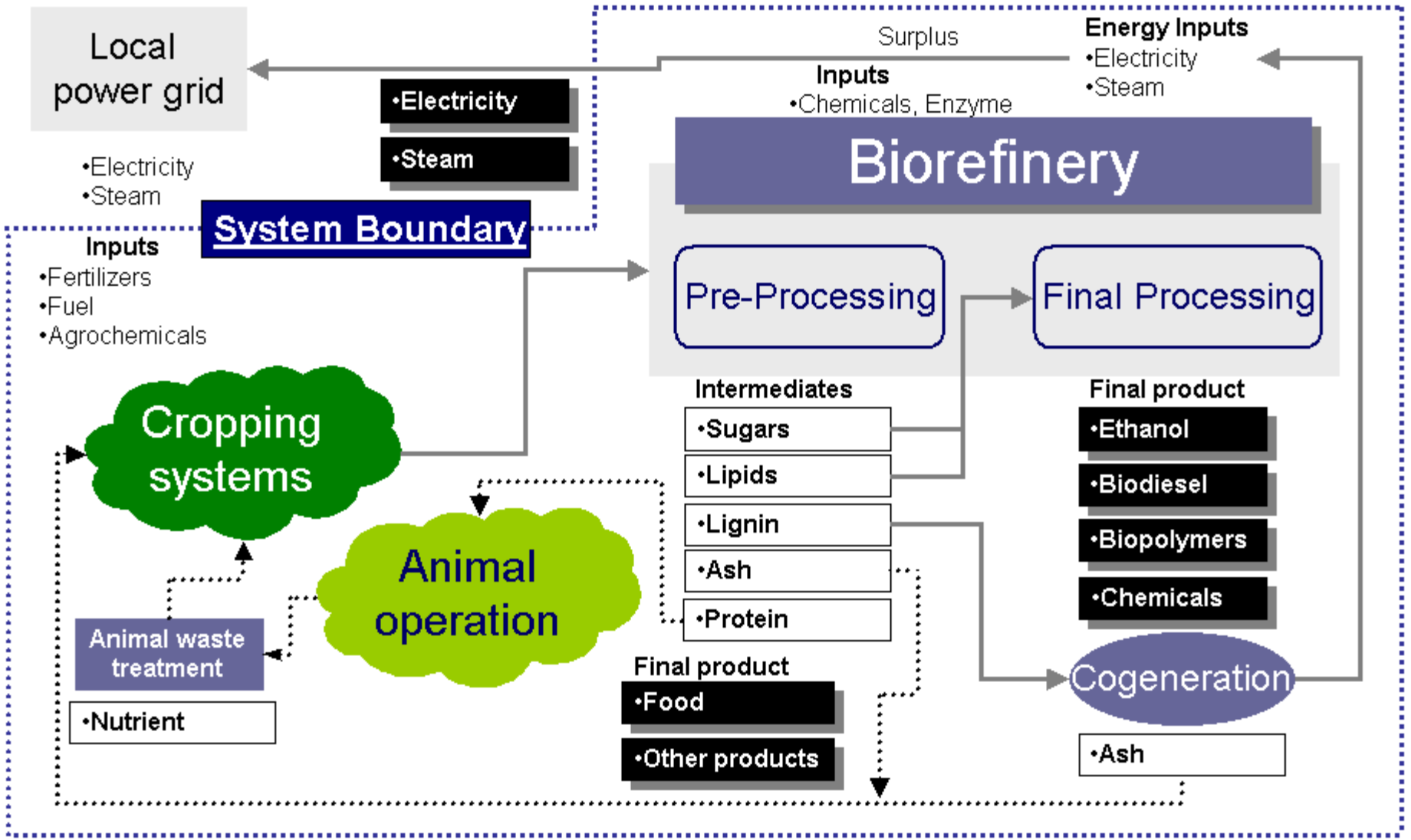
ALL BIOMASS IS LOCAL



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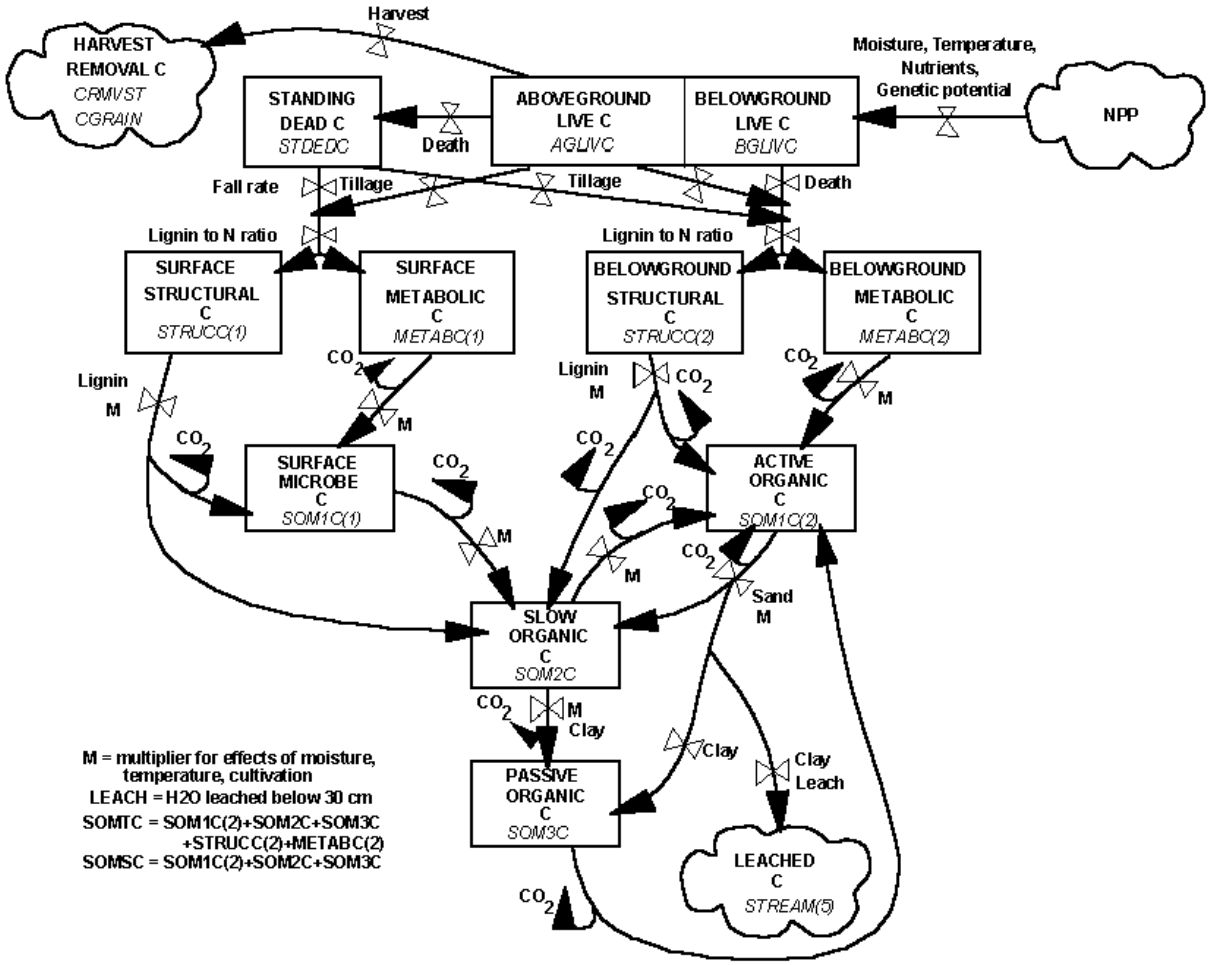
Soil Organic Carbon Dynamics in CENTURY



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Improving the Sustainability of Biofuels: Corn Stover Removal & Cover Crops

- We want to harvest corn residue (stover) to make cellulosic ethanol & improve farmer profits
- However, corn stover removal will tend to reduce soil organic matter (soil fertility) & increase soil erosion
- This is not the right direction…
- *Can we find a way to remove stover sustainably?*
- Use winter cover crop
  - Plant cover crop (cool season grass: wheat, rye, oats) after corn harvest
  - Cover crop grows rapidly in spring, takes up excess soil nitrogen & phosphorus
  - Kill or plow under cover crop before planting next corn crop
  - *Or* harvest cover crop as biofuel feedstock- we are now studying this option

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Grasses: Improve Soil Quality & Reduce Nitrogen & Phosphorus Losses

Winter wheat cover crop
May 5, 2005 Holt, MI

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Bare Corn Field- Holt, Michigan
May 5, 2005

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Improving the Sustainability of Biofuels: Corn Stover Removal & Cover Crops

- Basic cropping system
  - Corn (plow till) – soybean (no-till): CPSN (grain)
- Effect of winter cover crop under no-till corn continuous cultivation
  - 0 % of corn stover removed: CC (grain) (No cover crop)
  - Average 56 % corn stover removal: CC (56%) (No cover crop)
  - Wheat and oats as winter cover crops with 70 % corn stover removal : CwCo (70%)
- Effect of winter cover crop under no-till corn-soybean rotation
  - Wheat and oats as winter cover crops after corn cultivation with 70 % corn stover removal: CwSCo (70%)
  - Average 54 % of corn stover removed: CS (54%) (No winter cover crop)

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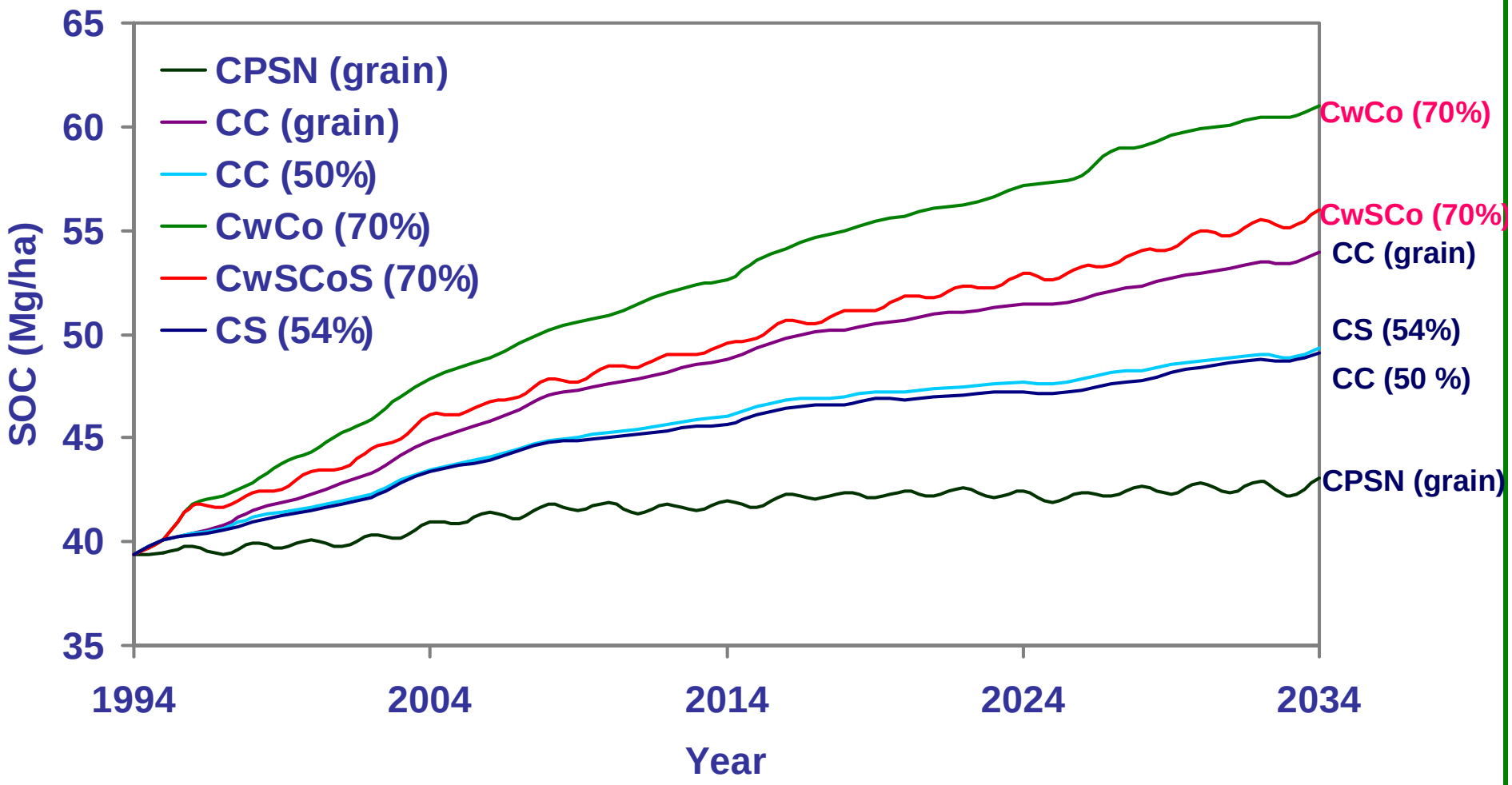
Cover Crop Increases Soil Fertility While Still Removing Lots of Stover



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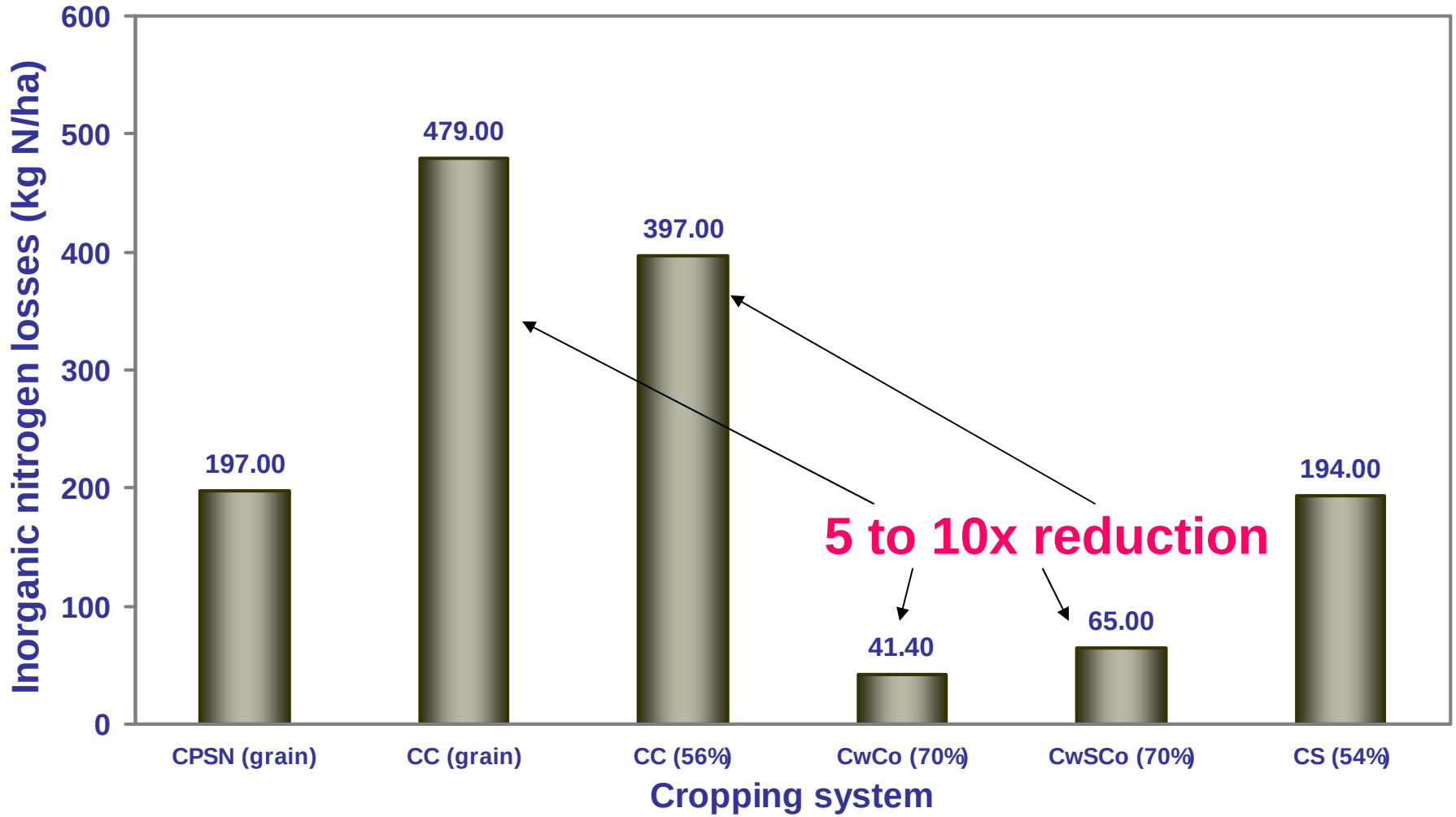
Cover Crops Reduce Nitrogen Losses Tenfold*



*40 year time scale, Washington County, Illinois

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  - *Less chance for international conflict*
  - *Greater economic growth opportunities for poor nations*
- Environmental improvements possible – if we make it so
- Rural economic development possible – if we make it so
- Less expensive food possible – if we make it so
- ***The future is ours to create***

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Questions ??

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My Assumptions/Points of Departure

- Inexpensive crop raw materials will catalyze the growth of new and existing biocommodity industries
- Life sciences will be critical to the development of biocommodity industries:
  - Modify properties of plant raw materials
  - Improve processing technology
  - Permit novel products
  - Enhance environmental performance of system
- *We have a unique opportunity to design these industries for better environmental performance*
- One important tool: life cycle analysis (LCA)

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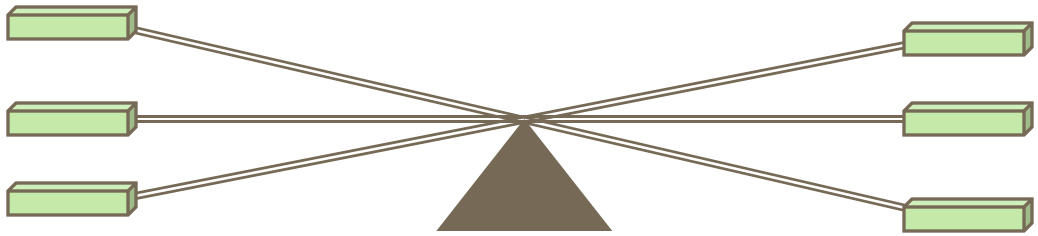
Biofuels: Changing Balance Between Processing and Feedstock

Near Future



Feedstock

- Biomass yield & properties
- Harvest/transport logistics
- Sustainability
- Rural economic development
- Co-products
- …Many more!

Processing

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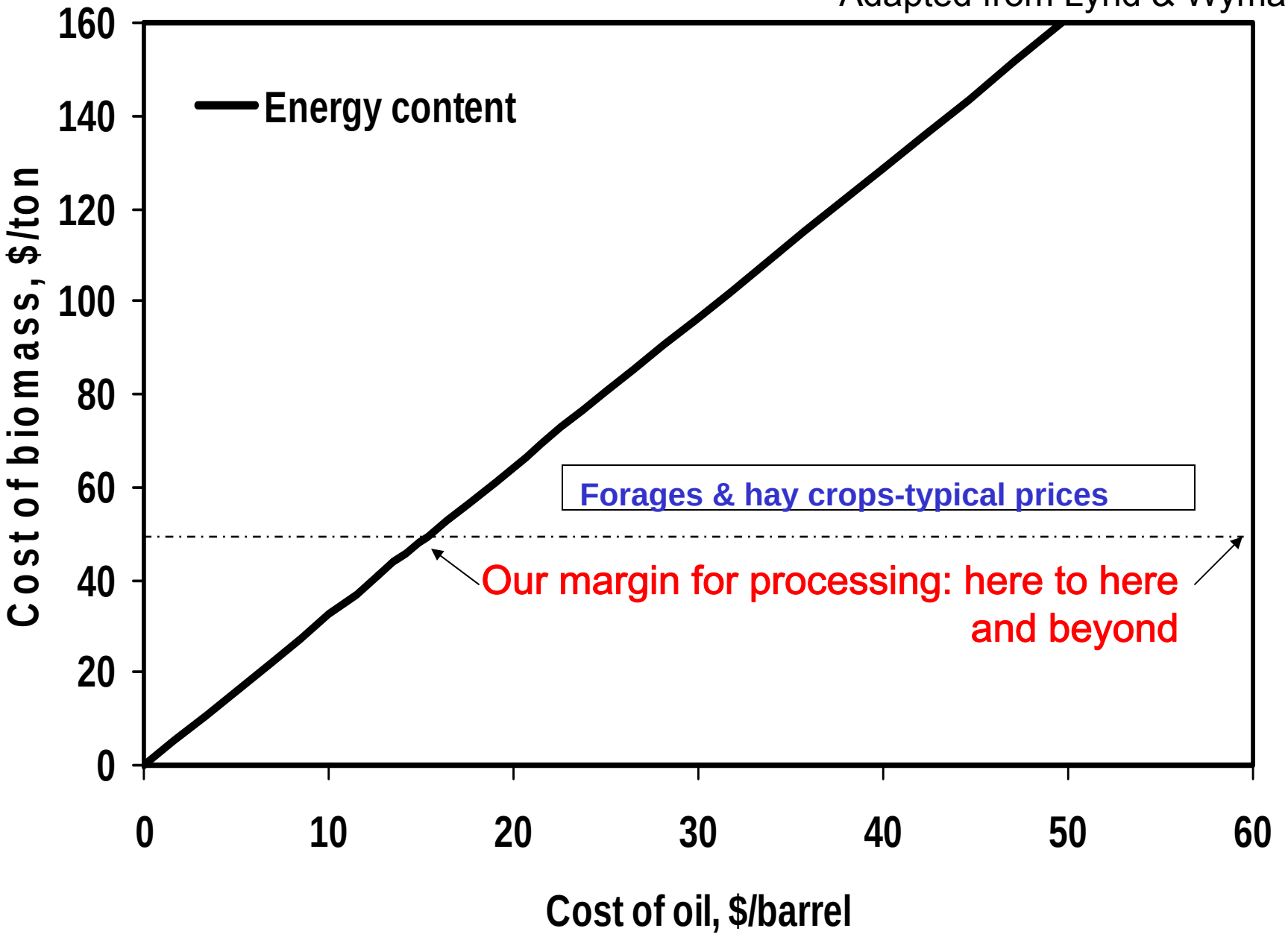
Adapted from Lynd & Wyman



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

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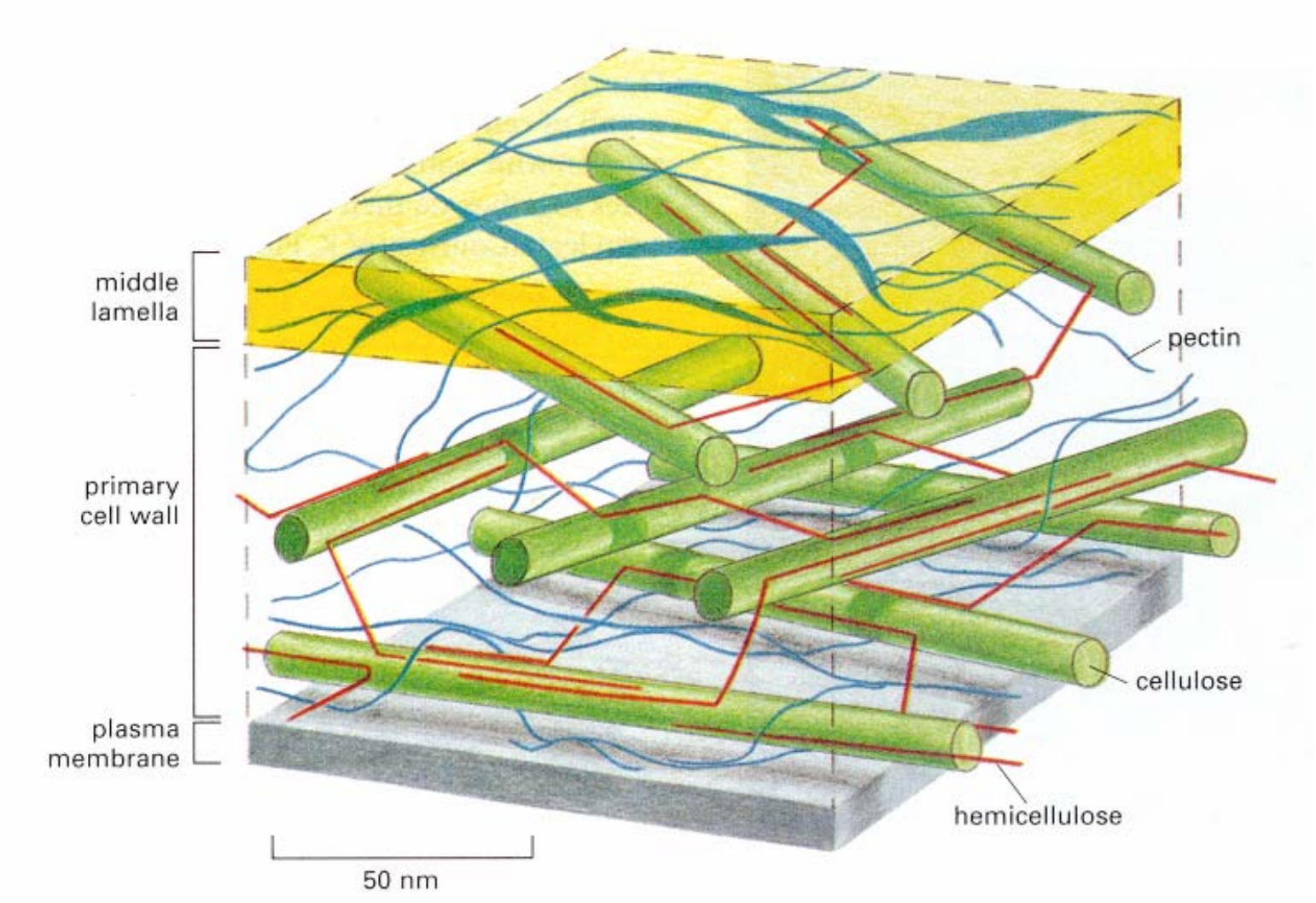
Why Is Pretreatment Necessary?



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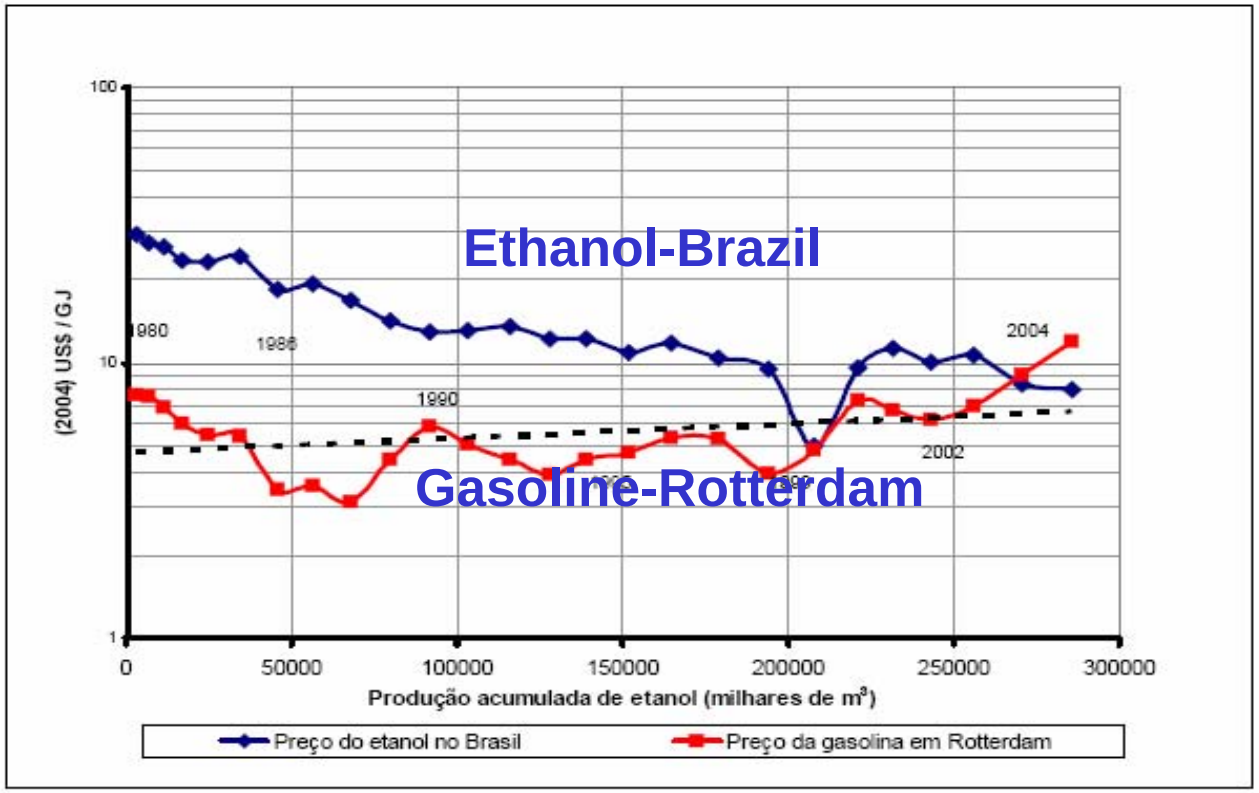
Brazil Has Been Reducing Sugar Ethanol Costs for 30 Years Cellulosic Ethanol Costs Have Declined and Will Decrease More!

Votorantim | Novos Negócios

.....WHILE THE COST HAS BEEN REDUCED THREE FOLD AND IS NOW LOWER THAN THE COST OF GASOLINE



Source: Goldenberg, 2005

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Water Loadings and Stover Solids Made Soluble by Pretreatments

Pretreatment	Water:Solids Ratio	% Solids Solubilized
Dilute acid	>5	36
Flowthrough	>10	29.3
Controlled pH	6.2	37.7
AFEX	0.6	12.0
ARP	>5	40.0
Lime	10.0	23.0

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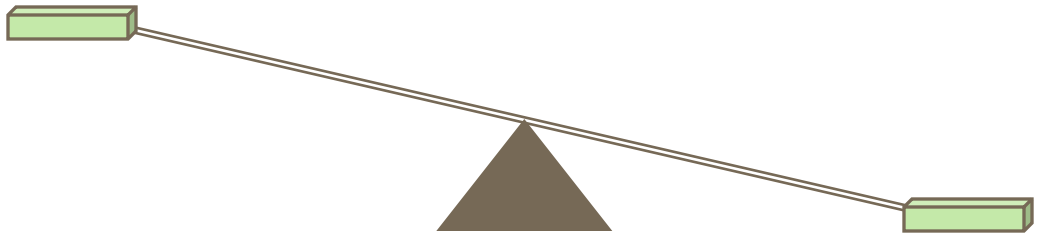
Biofuels: Changing Balance Between Processing and Feedstock

Today



Feedstock

Processing

- Pretreatment
- Enzymes
- Fermentation