

Commercializing A Major New Enzyme Market

Cellulase for Biomass

**Cellulase Enzyme Program
National Renewable Energy Laboratory**

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The Process: ACE²

- **A**ssessment
- **C**ommercialization
- **E**conomics
- **E**xpectations

Assessment

- Present Cellulase cost . .
50¢/gal ethanol
- Reduce to 5¢/gal ethanol
- Achieve 10 X Cost Reduction
with Proven Tools

Assessment

- Enzyme Cost 0.1X
- R & D 50 to 100 FTE
- Margin 50 to 70%
- Market Share 15 to 30%
- Market Size \$500 million
- Operating Income >\$10 million

Assessment:

Improve Enzyme Activity

Activity Effort	Gain	Multiplier	Difficulty	Effort, FTE
Thermal Stability	Exponential	3x to 5x	Medium	10 - 15
Specific Binding	Linear	0.3x - 0.5x	High	20 - 30
Recycle Enzyme	Non-Linear	3x to 5x	Higher	30 +
Limit Inhibition	Non-Linear	< 1x	Low	10 - 15
Increase K_{catalyst}	Non-Linear	2x to 4x	Low	5 - 25+
Decrystallize cellulose	Step Change	3x to 4x	High	15+

Assessment: *Lower Cost*

Base Case Protein Cost	\$5/kg		
Improvement Activity	Benefit \$/kg	Difficulty	Effort FTE
Larger Fermentors, 300 m³-- 500 m³	\$0.80 to \$1.10	Low	< 1
Use Hydrolyzate Substrate	\$1.00 to \$2.00	Low	5 - 10
Protein Expression, 80 gm/liter	~\$1.00	High	15+
Productivity, Fill Factor, Cycle time	< \$1.00	High	15+

Commercialization

- **Customers For Enzyme**
 - **Biomass Processors**
 - **Feedstocks**
 - **Benefits**
- **Corn Processors, Corn Stover, Corn Growers**
 - **Infrastructure**
 - **No More Land Use**
 - **Large, Sustainable Quantities**
- **Low Cost Sugars**

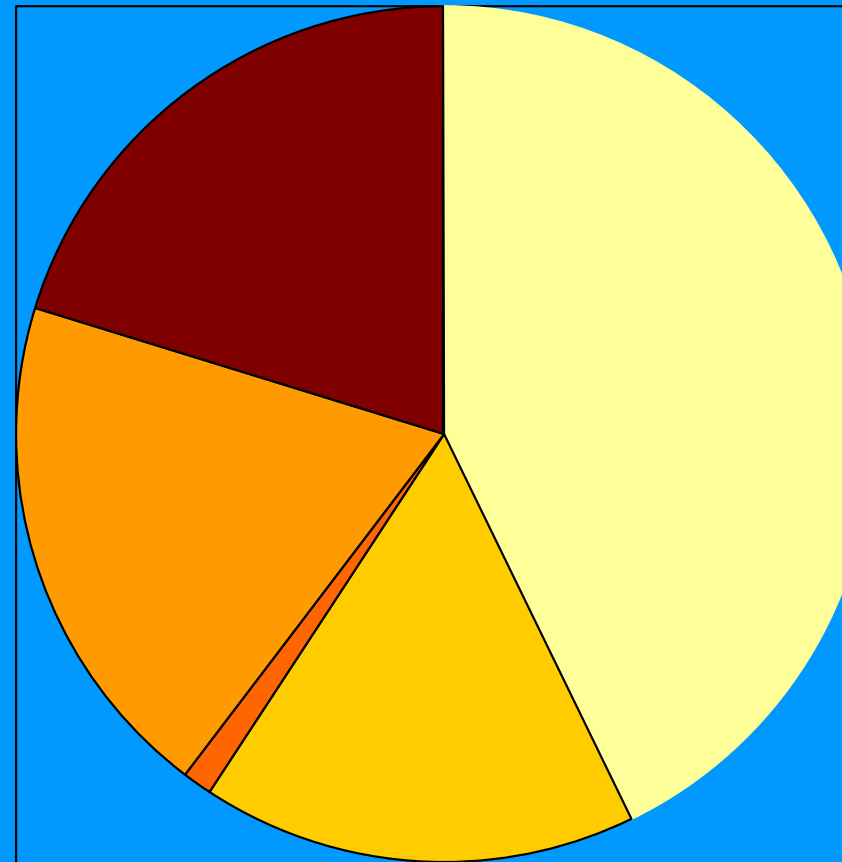
CORN STOVER

Largest Biomass Feedstock

Estimated Corn Stover available
is 153 MM dry tons, 60%
of 255 MM dry tons produced,
3% of Total Biomass

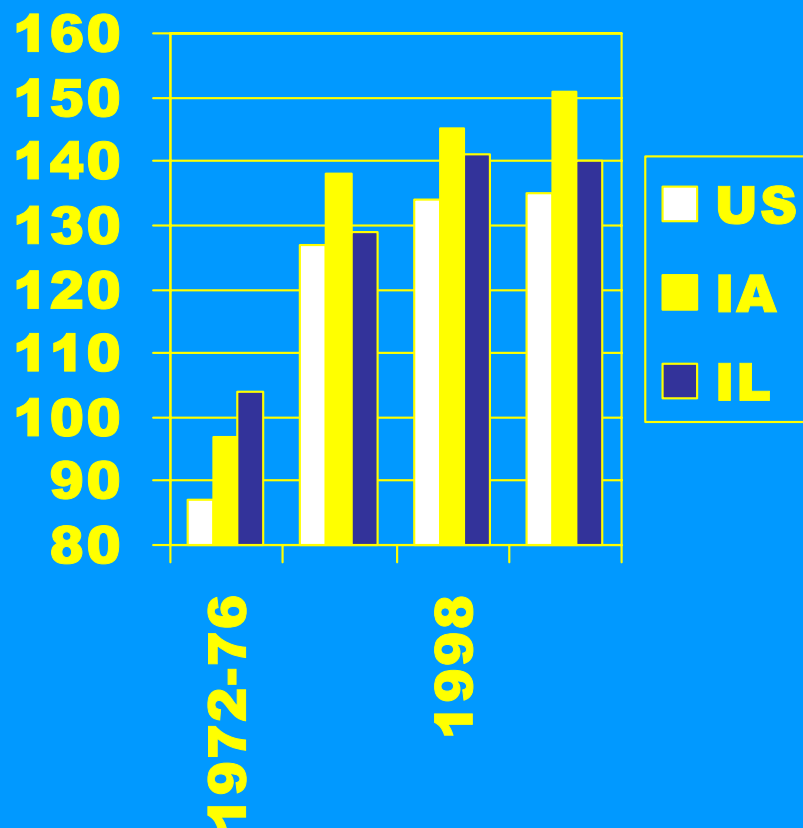
All less than \$50/ton

Corn Stover	153 MM dry tons
Other Ag Stover . . .	58
Corn Fiber	4
Energy Crops	70
Wood Co-Products. <u>72</u>	
TOTAL dry tons . .	357MM



More Stover !!

- YIELDS INCREASING
- 200 BU/AC COMMON
- 1:1 RATIO CORN/STOVER
- MORE TO COME
 - PRECISION FARMING
 - BIOTECHNOLOGY
 - GENETIC POTENTIAL IS 400 TO 600 BU/AC
- WHAT TO DO WITH IT?



Benefits

Processing 30% of Corn Stover

- 2nd largest WW enzyme market: \$440 MM at 5¢/gal EtOH
- Sugars less than \$4/cwt
- \$2.7 Billion Farm Income from Feedstock Sale, \$35/dry ton delivered: \$10 million per county
- Adds 5 to 8 billion gallons of Ethanol
- Replaces fiber for paper now supplied from hardwood trees
- Mitigates 8% - 15% US Kyoto GHG Commitment

ACE²

- **A**ssessment
- **C**ommercialization
- **E**conomics
- **E**xpectations

CELLULASE ENZYME POTENTIAL FROM ENZYME SUPPLIER PERSPECTIVE

- WHAT IS MY COST TO SUPPLY THE ENZYME?
- WHAT IS THE VALUE OF MY ENZYME IN THE CUSTOMER'S PROCESS?
- WHAT IS THE OPPORTUNITY CREATED BY THE DIFFERENCE BETWEEN THESE TWO VALUES?

DEVELOP REVERSE INCOME STATEMENT FOR SUPPLYING CELLULASE ENZYME FOR CORN STOVER HYDROLYSIS.

REVERSE INCOME STATEMENT

- *Begin with the required SALES.*
- *Work Backward to calculate REQUIRED MARGINS and allowable costs per unit and OPERATING INCOME.*
- *Check Market Share.*
- *Proceed? Yes or NO*

Recall Assessment

- Previously

- Enzyme Cost 50¢→5¢/gal EtOH
- R & D 50 to 100 FTE
- Margin 50 to 70%
- Market Share 15 to 30%
- Market Size \$500 million

Operating Income +\$10 million

- **Choose SALES to be \$70 million**

REVERSE INCOME STATEMENT

1. Target to add the equivalent of 10% to Company GoVen annual sales of \$700 Million.

10% of \$700 Million \$70 Million

2. Required Manufacturing Margin. 70%

3. Other Cost Assumptions

- R&D cost of 10%
- S&A cost of 14%

REVERSE INCOME STATEMENT

3. Revenue of \$70 Million generates \$33 Million Operating Income
4. Manufacturing Margin is 70%
5. Sales Price per Kg protein and its Specific Activity for \$70 Million Revenue
 - 5.1 Use an Enzyme Cost of \$3/kg of enzyme protein in the fermentation broth. The Sales Price with a 70% manufacturing margin is \$10/kg.
 - 5.2 Determine SAE for enzyme cost per gal EtOH

REVERSE INCOME STATEMENT

ASSUMPTIONS

- Enzyme usage is 10 FPU/gm of cellulose, the equivalent of 53,000 FPU/Gallon of EtOH
- \$10/Kg enzyme protein selling price
- SAE of 600 FPU/gm enzyme protein

e.g.

SAE = 53,000 FPU (\$10kg/ \$0.08 cost per gallon) is
6,360 FPU/gm and about 10x improvement

REVERSE INCOME STATEMENT

- A 10X IMPROVEMENT IN ACTIVITY RESULTS IN AN ENZYME COST OF 8¢ PER GALLON OF ETHANOL, on cellulose basis only
- "As Is" COST PER GALLON FROM TOTAL SUGARS IS 40%LESS
 - i.e. 10X IMPROVEMENT RESULTS IN 5¢ PER GALLON EtOH on cellulose (C) and hemicellulose (HC) basis
 - (38% C x 90% yield + 32% HC x 80% yield is 1.75 gallon ethanol total/gallon from cellulose)

ENZYME MARKET FOR MIDWEST CORN BELT

SIZE: \$440 Million, Required Share, 16%

- **Corn Stover Collected: 70 Million dry metric tons**

One dry US ton left per acre, 50% farm participation
(Source: Union of Concerned Scientists)

- **Enzyme Required, 44 Million Kg**

$(70 \text{ Million dry metric Tons} \times 38\% \text{ C})(10 \text{ FPU/gm C})$
 $\div (6,000 \text{ FPU/gm ENZ})$ is 44 Million Kg ENZ

- **Market Share for \$70 Million is 16%**

$\$70 \text{ Million} \div \440 Million is 16%

SUMMARY

5¢ /gal EtOH enzyme cost

	<u>MILLION</u>
Annual Sales	\$70
Less COGS at \$3/KG	<u>21</u>
Manufacturing Income	\$49
Mfg Margin, 70%	
S&A expenses, 14% of Sales	10
R&D expenses, 10% of Sales	<u>7</u>
Operating Income	\$33

Operating Margin, 47%

Market Share is 16% of 70 Million MT Corn Stover

Producers Perspective

Major Differences Today

- More stover
- More knowledge
- More grower benefits

ACE²

- **Assessment**
- **Commercialization**
- **Economics**
- **Expectations**

Expectations

Corn Stover Potential

- **Major positive impact**
 - Enzyme business
 - Rural farm economy
 - Related industries
 - Environment
- **Many envision this becomes reality in 2 to 5 years.**
- **For all to Win depends on**
 - Sustainable harvest in large quantities.
 - Attain conversion technology targets
 - Market for the products