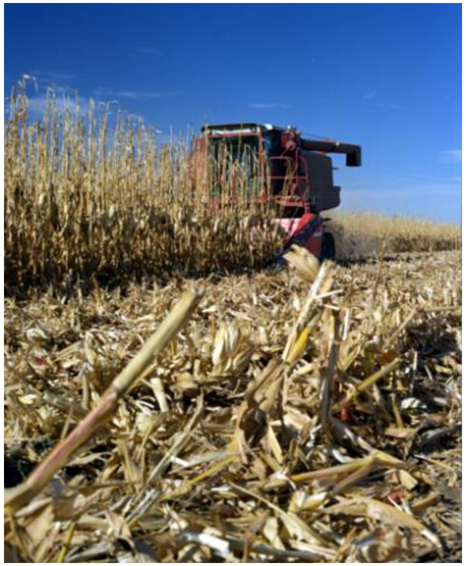

Deploying Enzymatic Biomass Conversion Technology: Challenges and Prospects

James D. McMillan
National Bioenergy Center
National Renewable Energy Laboratory

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Outline

- Enzymatic conversion technology overview
- Challenges: Issues hindering commercialization
- Prospects: Opportunities and progress
- Conclusions

Main Elements in an Enzymatic Process for a Sugars Platform

Feedstock collection and delivery

Pre-processing

Pretreatment (hemicellulose extraction)

Conditioning

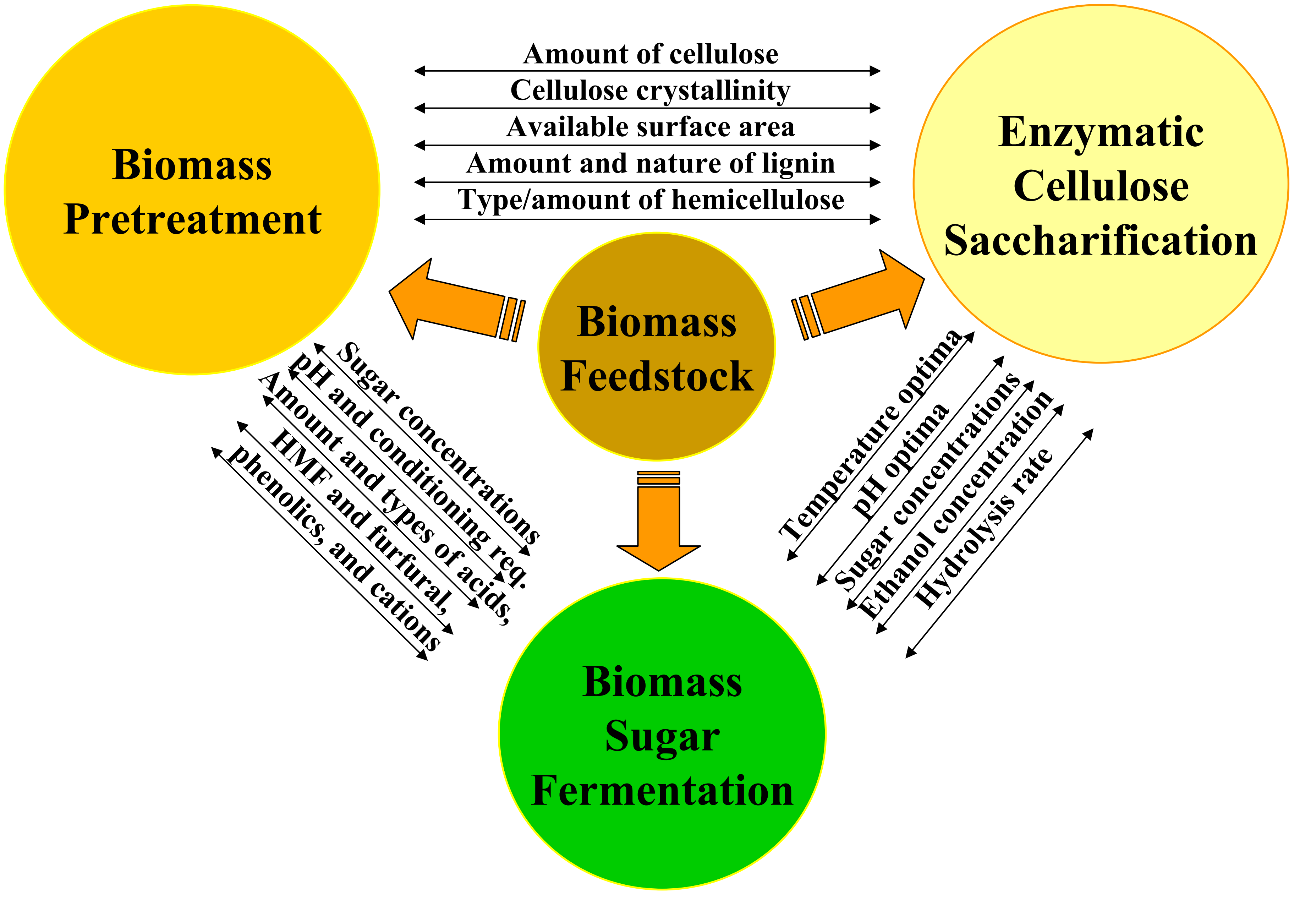
Enzymatic cellulose saccharification

Biomass sugar fermentation

Beer Slurry to Product (Ethanol) and Solids Recovery

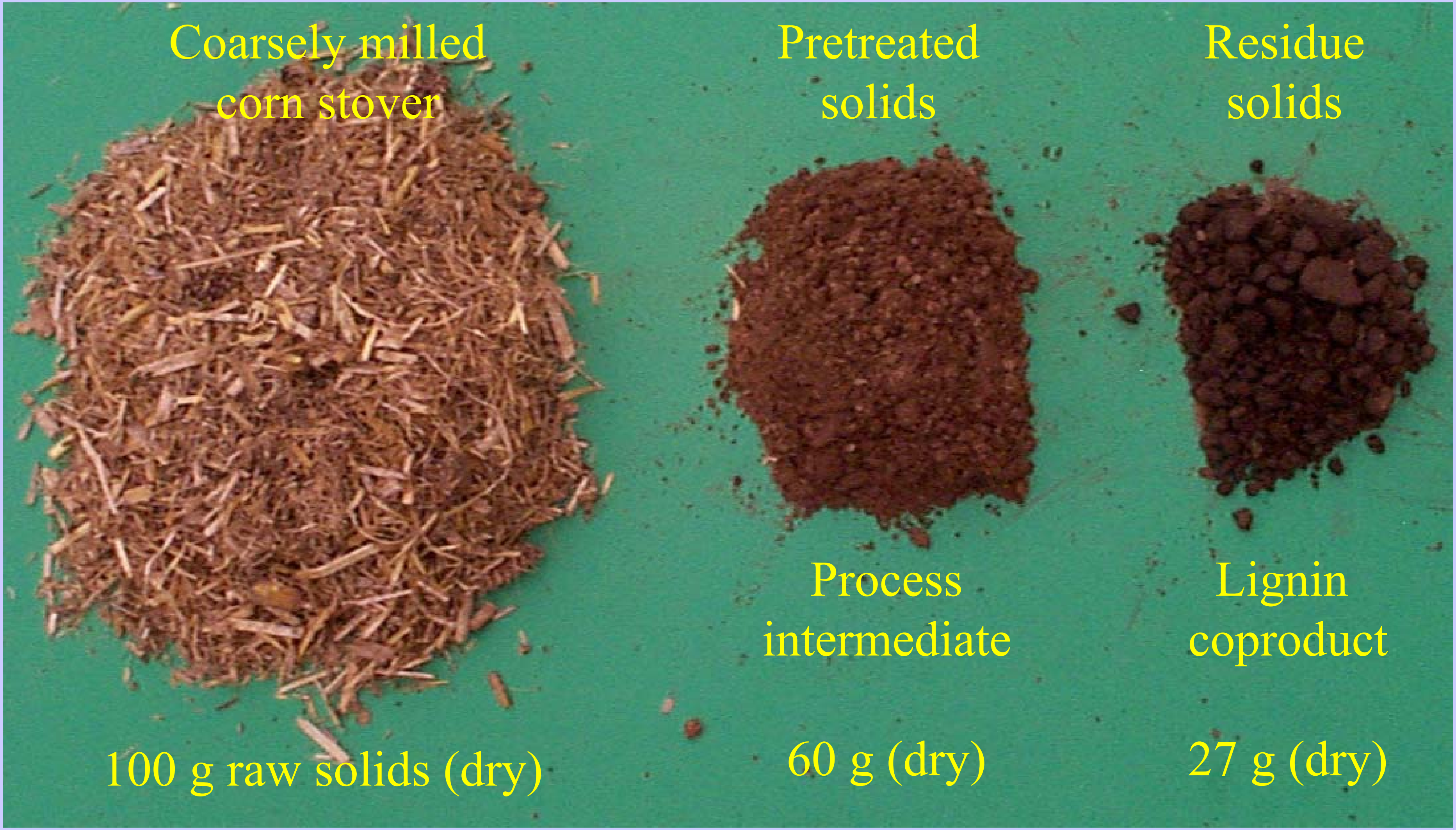
Many options exist for each of these steps….
….and there are many interactions to consider

Key Process Interactions



Technical Feasibility of Conversion

Example: Corn Stover Lignocellulose



Challenges to Deployment
Issues Hindering Commercialization

- Demonstrated market competitiveness
  - Compelling economics with acceptable risk
- Established feedstock infrastructure
  - Collection, storage, delivery & valuation methods
- Proven societal & environmental benefits
  - Sustainable
  - Supportive policies

Critical Success Factor for Pioneer Processing Plants

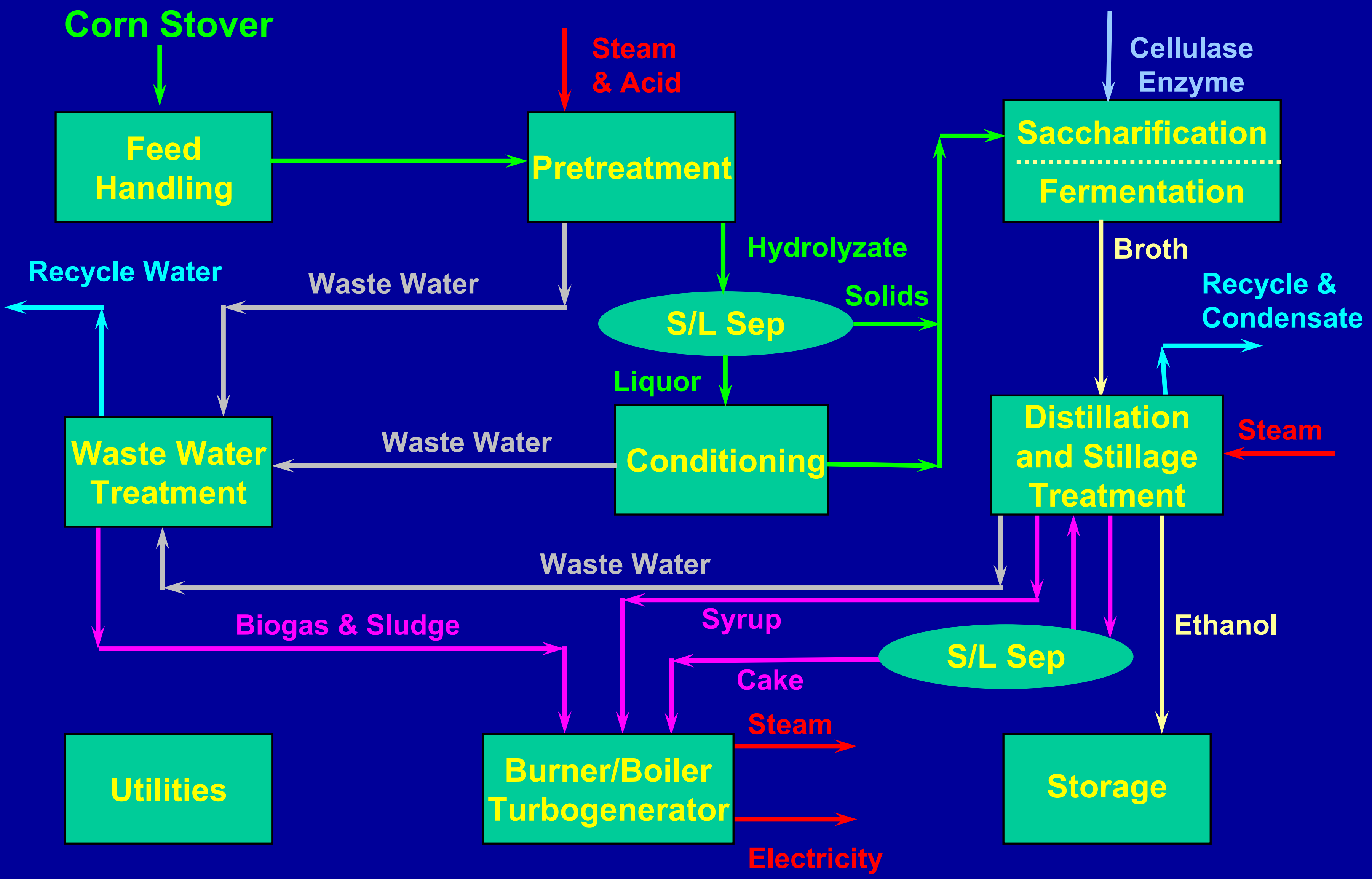
⇒***Accurately estimate cost and performance!****

- Plant cost growth strongly correlated with:
  - Process understanding (***integration issues***)
  - Project definition (***estimate inclusiveness***)

- Plant performance strongly correlated with:
  - Number of new steps
  - % of heat and mass balance equations based on data
  - Waste handling difficulties
  - Plant processes primarily solid feedstock

* "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants", a study by the Rand Corp. for DOE (1981)

Simplified Process Schematic



Projected Economics – Example

Plant Size Basis: 2000 MT Dry Corn Stover/Day
Assumed Corn Stover Cost: $35/dry ton
Assumed Enzyme Cost: $0.11/gallon of produced ethanol

Economic Parameter (Units, $1999)	Value
Min. Ethanol Selling Price ($/gal)	$1.30
Ethanol Production (MM gal/yr)	60
Ethanol Yield (gal/dry ton stover)	77.5
Total Project Investment ($ MM)	$200
TPI per Annual Gallon ($/gal)	$3.34
Net Operating Costs ($/gal)	$0.73

* Assuming 100% equity financing and 10% Internal Rate of Return (IRR)

Process Economics Findings

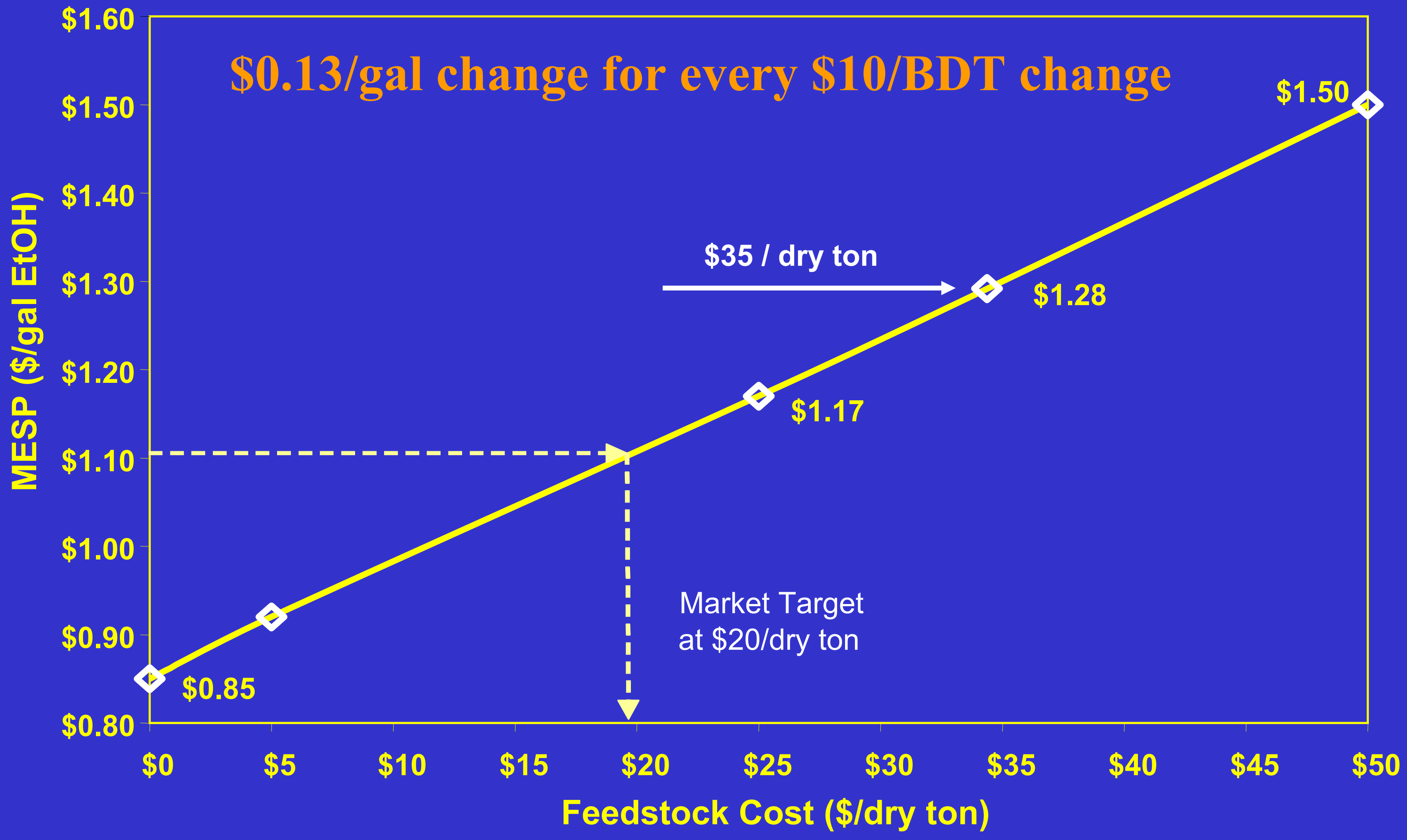
- Production costs dominated by
  - Feedstock
  - Enzymes - cellulases
  - Capital equipment throughout the plant

- Current USDOE, NREL, and ORNL efforts focus on decreasing these key cost centers.

⇒ *Today's focus: feedstock and pretreatment cost reduction opportunities and progress*

Impact of Reducing Feedstock Cost

Corn Stover Case Example

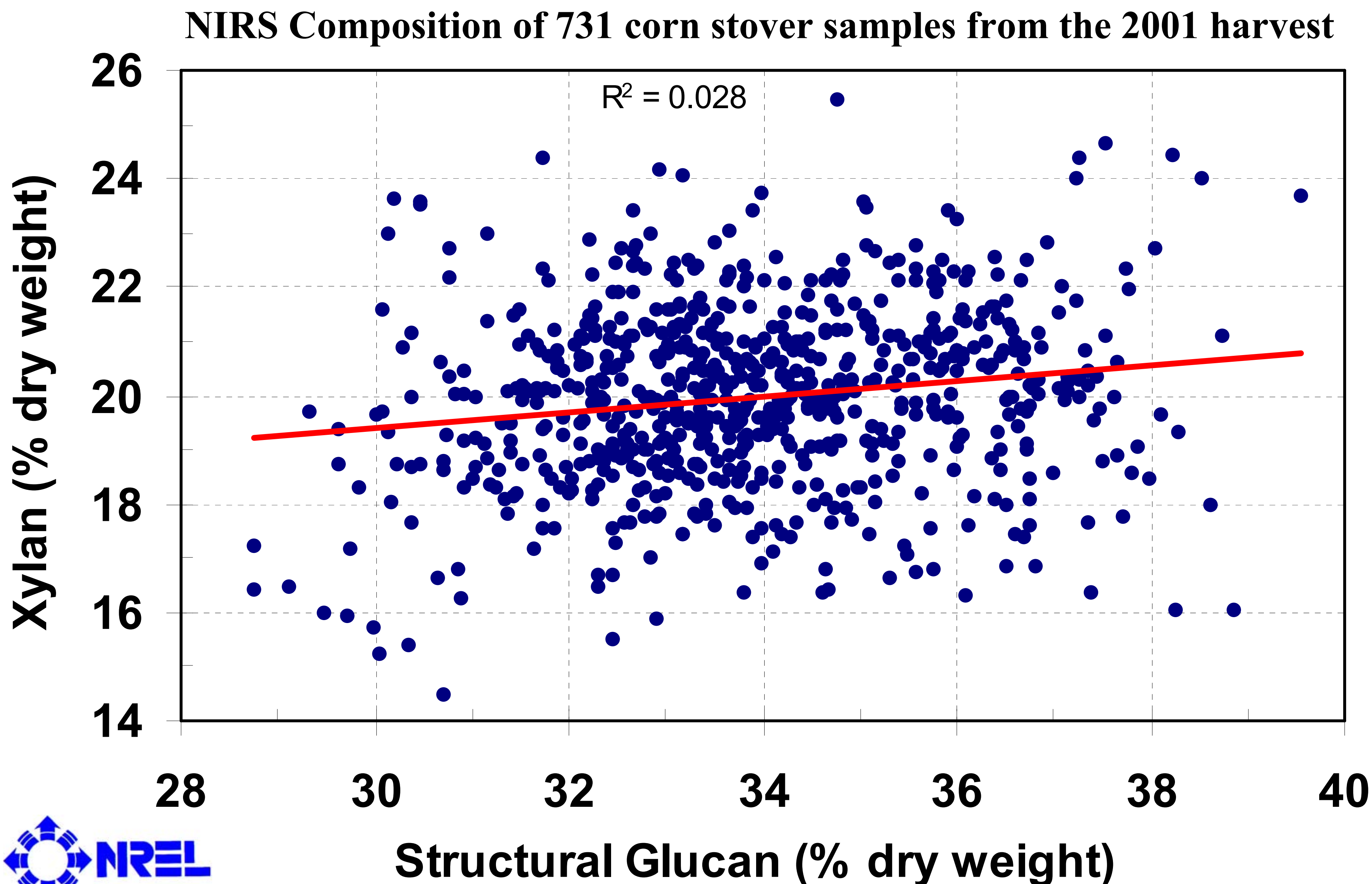


Towards a Low Cost Feedstock Infrastructure

- Apply innovative harvesting & storage methods
  - Whole stalk harvest?
  - Dry or wet densification?
- Value the feedstock based on its composition
  - In-field or point-of-delivery rapid compositional analysis, e.g., using calibrated Near InfraRed Spectroscopy (NIRS)

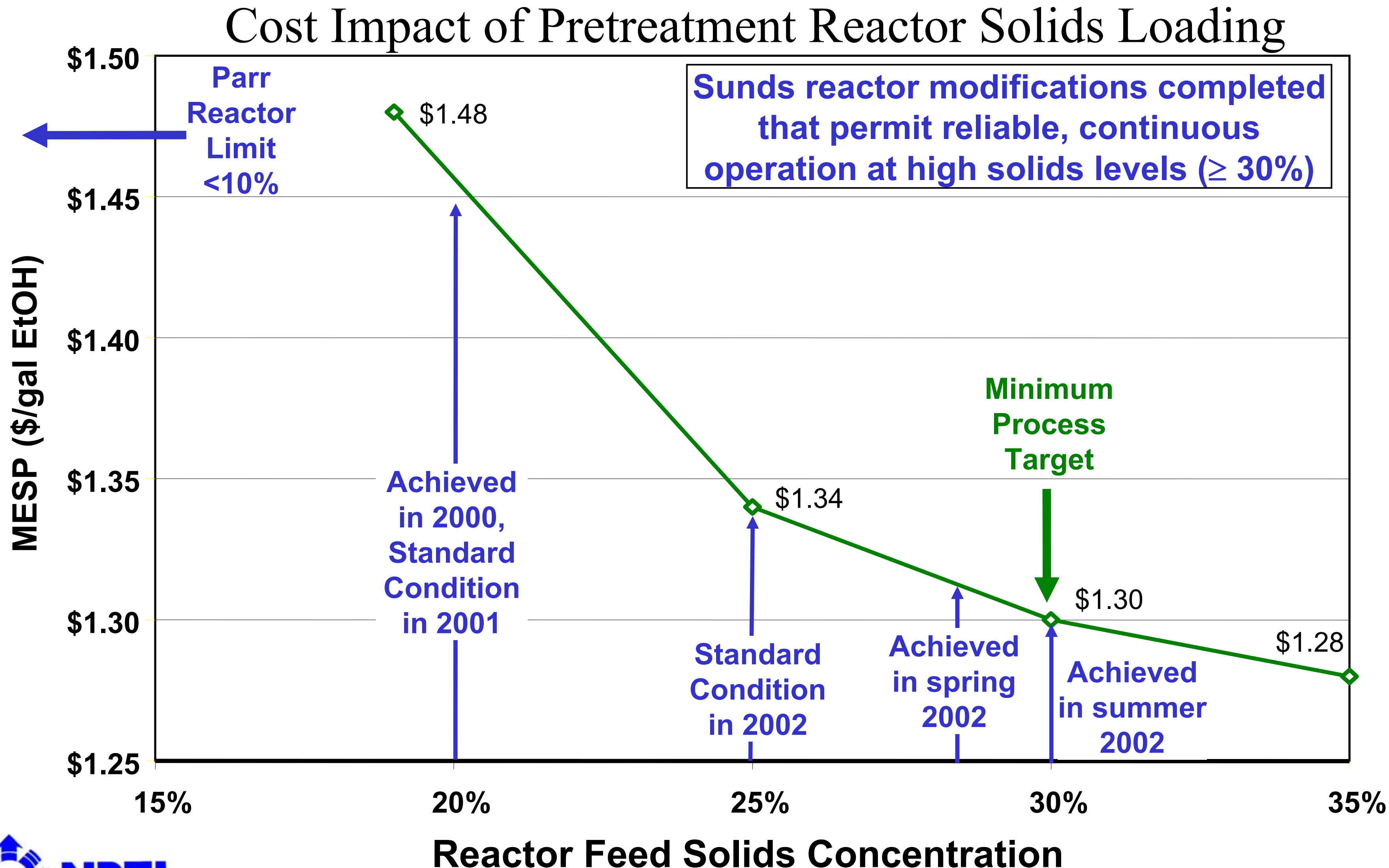
⇒*Application of NIRS has identified a previously under appreciated knowledge gap concerning the magnitude and sources of feedstock compositional variability*

Substantial Compositional Variability



Reducing Performance Risk

Demonstrating High-solids Processing



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Reducing Deployment Risk

Demonstrating Base-line Engineering Feasibility

- Dilute-acid pretreatment showstoppers overcome
  - some performance levels remain below targets

Minimum Pretreatment Performance Targets

Parameter	*Achieved*	*Target*
Catalyst Type	Dilute Acid	Dilute Acid
Reactor Solids Conc.	30 %	30 %
Residence Time	0.75-1.25 min	2 min
Acid Concentration	1.5 %	1.1 %
Temperature	190 °C	190 °C
Xylose Yield	80%	85%
Reactor Metallurgy	-----	Incoloy 825-clad

- Process samples produced for evaluation
  - Pretreated solids and hemicellulose hydrolyzate liquors
  - Lignin-rich process residues

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Comparative Liquor Concentrations

Corn Stover Dilute-acid Hemicellulose Hydrolyzate

Component	Concentration (g/L) (20% solids)	Concentration (g/L) (30% solids)
Glucose	9.24	17.7
Xylose	**59.68**	**93.6**
Arabinose	8.81	13.5
Galactose	4.55	7.1
Mannose	2.69	4.1
Oligomers	10.93	9.4
Furfural	1.51	2.4
Hydroxymethyl Furfural	0.25	0.5
Acetic Acid	7.06	11.49

Conclusions

- Good progress being made to reduce process costs and risks, but substantial technical challenges remain
- Critical knowledge gaps need to be overcome
  - Analytical and process chemistry
  - Sources of feedstock compositional variability
  - Controlling interactions in fully integrated processes
  - Life Cycle Analysis and overall sustainability
- Integrated process must be demonstrated
  - Expensive, high-risk activity likely to occur via industry-led bioenergy solicitation awards

⇒*It's a big task ahead, but we're on the right path!*

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