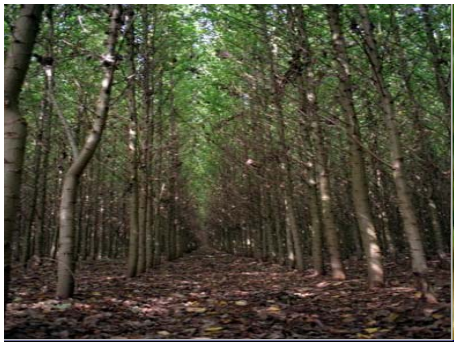


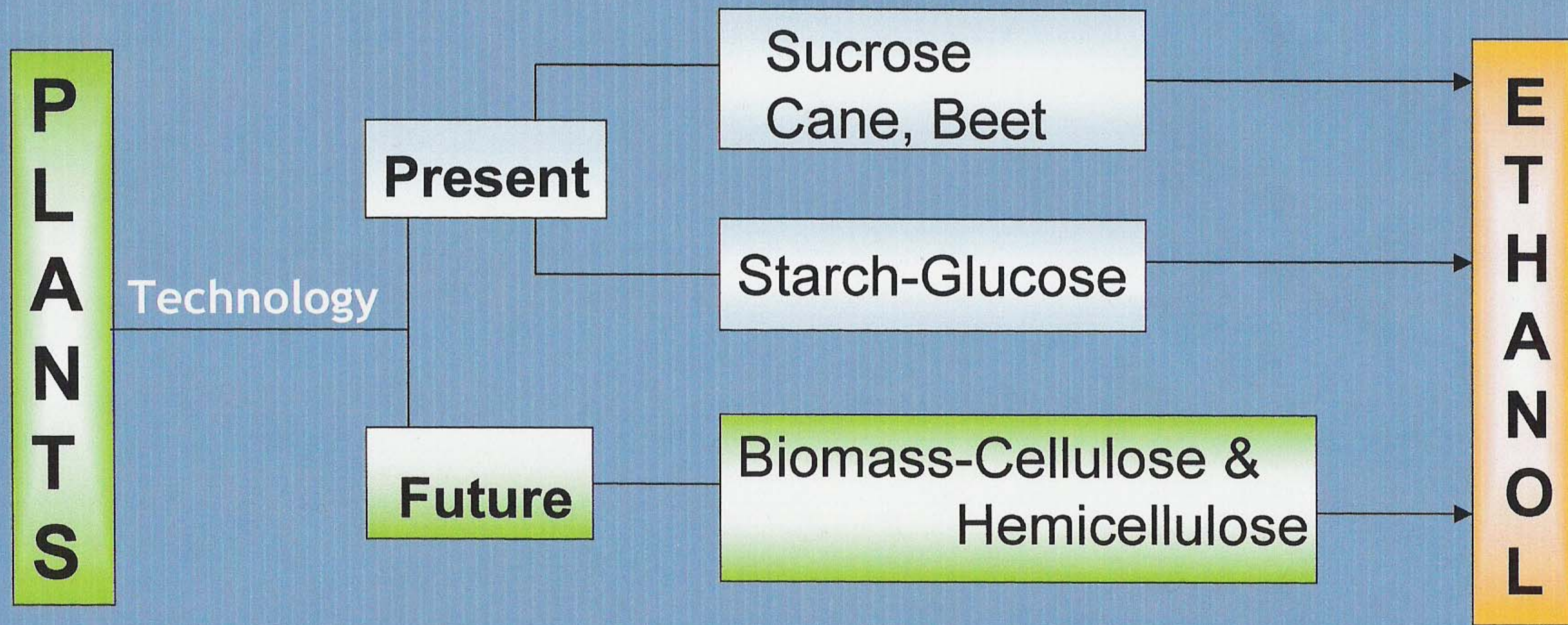

Cellulosic Ethanol Technology Assessment

Rod Bothast
National Corn-to-Ethanol Research Center
Southern Illinois University Edwardsville

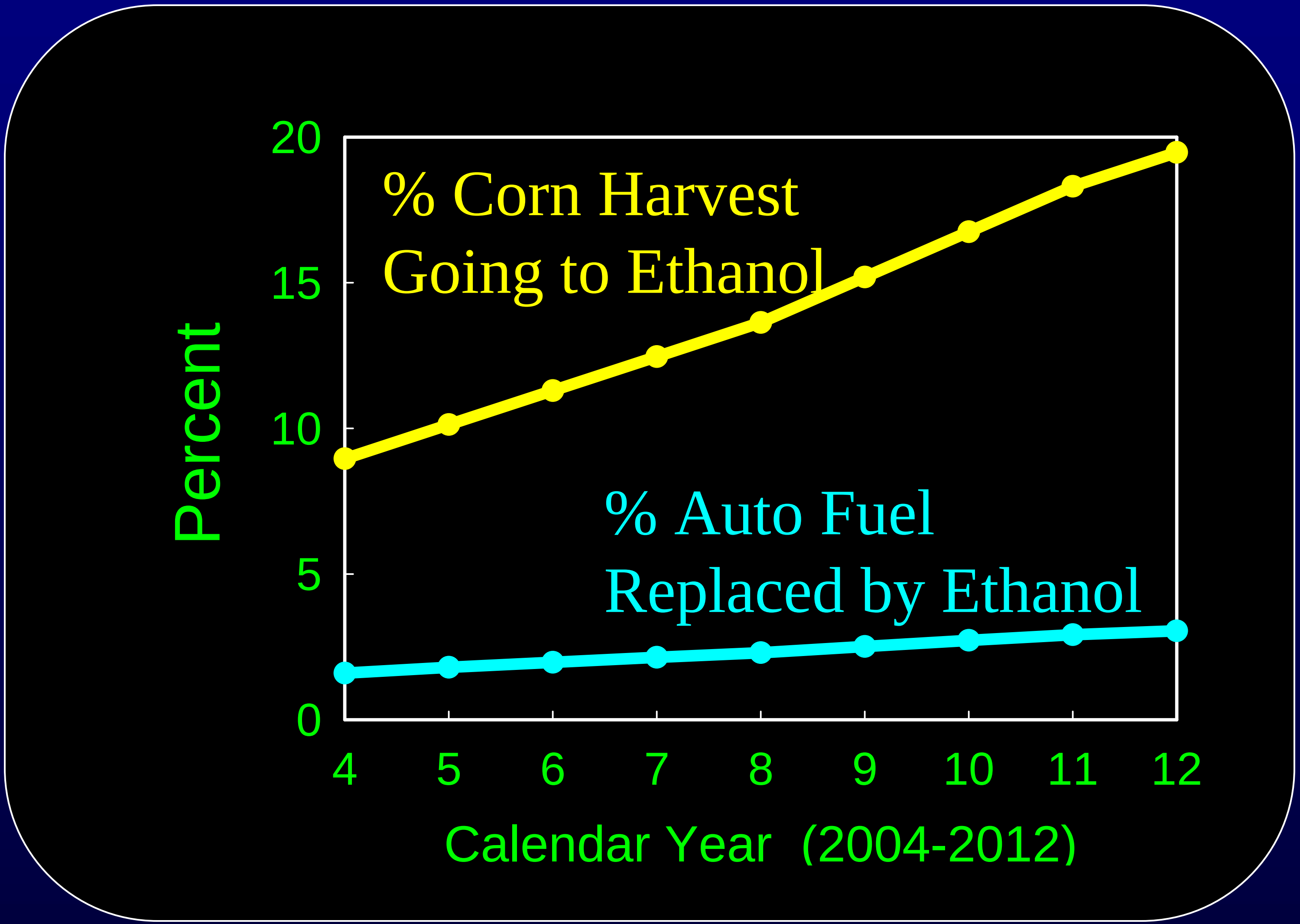



Renewable Carbon to Fuel Alcohol

Genencor International
Innovative by Nature



Impact of corn ethanol for replacing imported oil



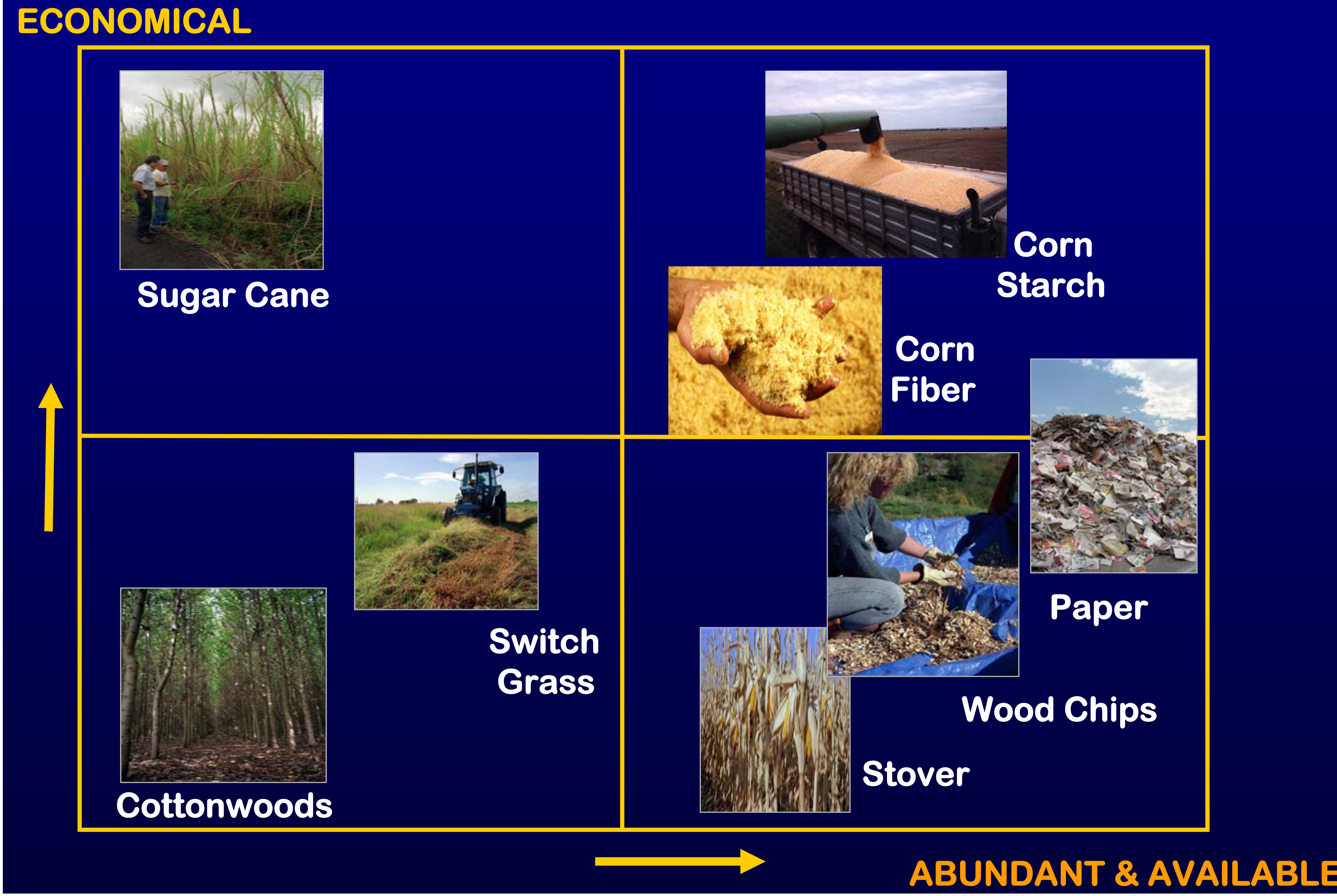
(RFA & CRA, 2002)

Biomass Feedstock Availability in the U.S.

	Estimated Qty.	Energy Use	Available New Energy
Urban Wood	0.59	0.08	0.51
Forest Residues	0.38	0.37	0.01
Mill Residues	0.66	0.65	0.01
Ag Residues	3.95	0	3.95
Energy Crops	1.07	0	1.07
Total (Quads)	6.65	1.1	5.55

M.E. Walsh, D.G. De La Torre Ugarte, et. al., Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Oak Ridge National Laboratory, Updated January **2000**

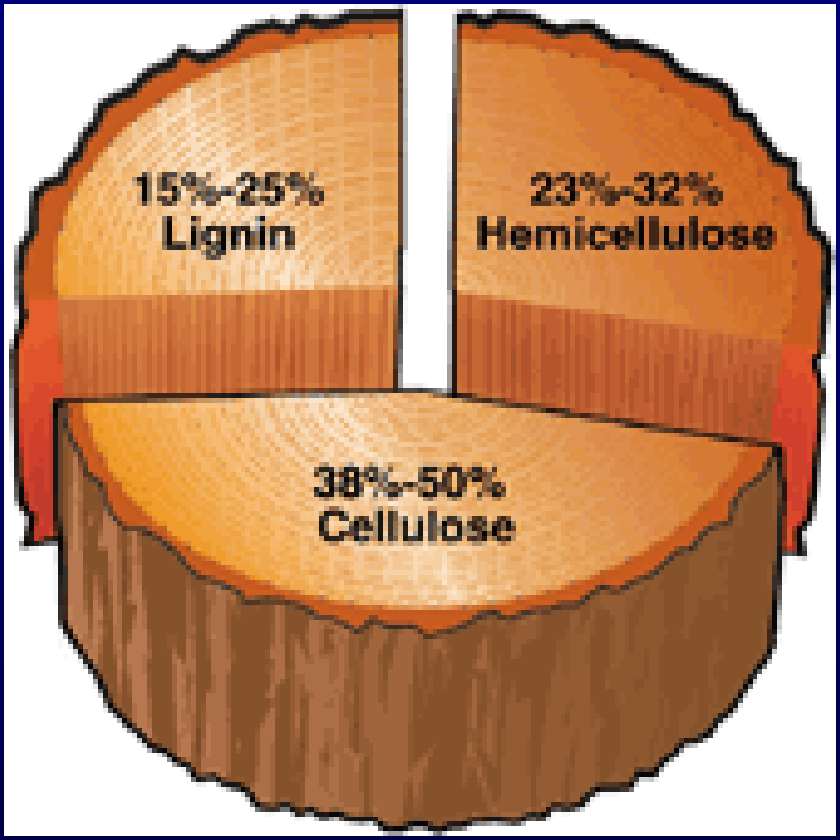
US Biomass Sources



Challenge

How Do You Put Low Cost Biomass in Your Automobile?

Composition of Biomass

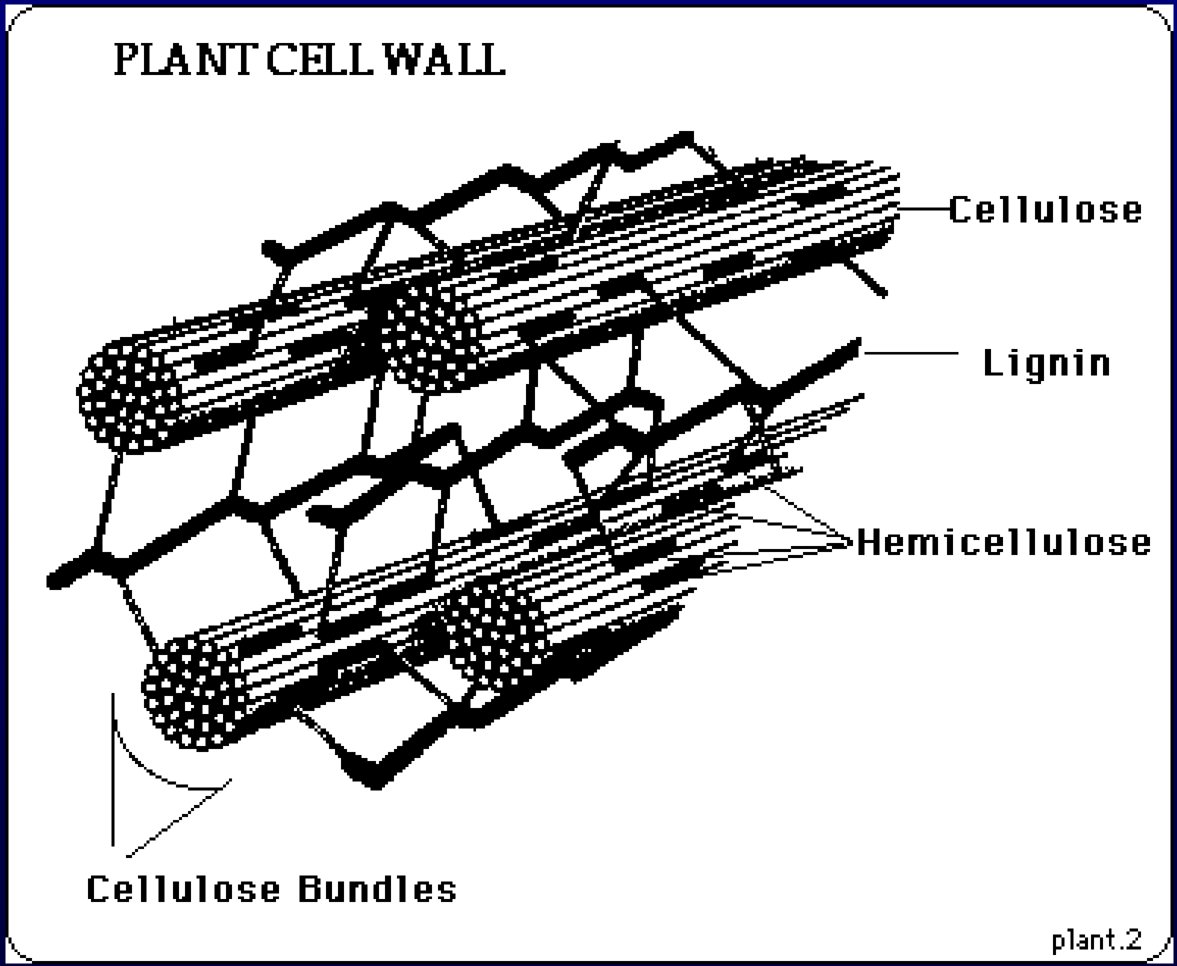


Cellulose & Hemicellulose are carbohydrates that can be broken down to free sugars and fermented to ethanol. Lignin has a high heating value.

Others: extractables, pectin, and ash.

Source: www.nrel.gov

Plant Cell Wall Structure



Robert Shleser , 1994

Utilization of Biomass for Production of Fuel Ethanol

Corn Fiber

↓

Pretreatment

↓

Enzymatic Saccharification

↓

Fermentation

↓

Ethanol Recovery

Amounts of feedstocks to produce 10 ml ethanol

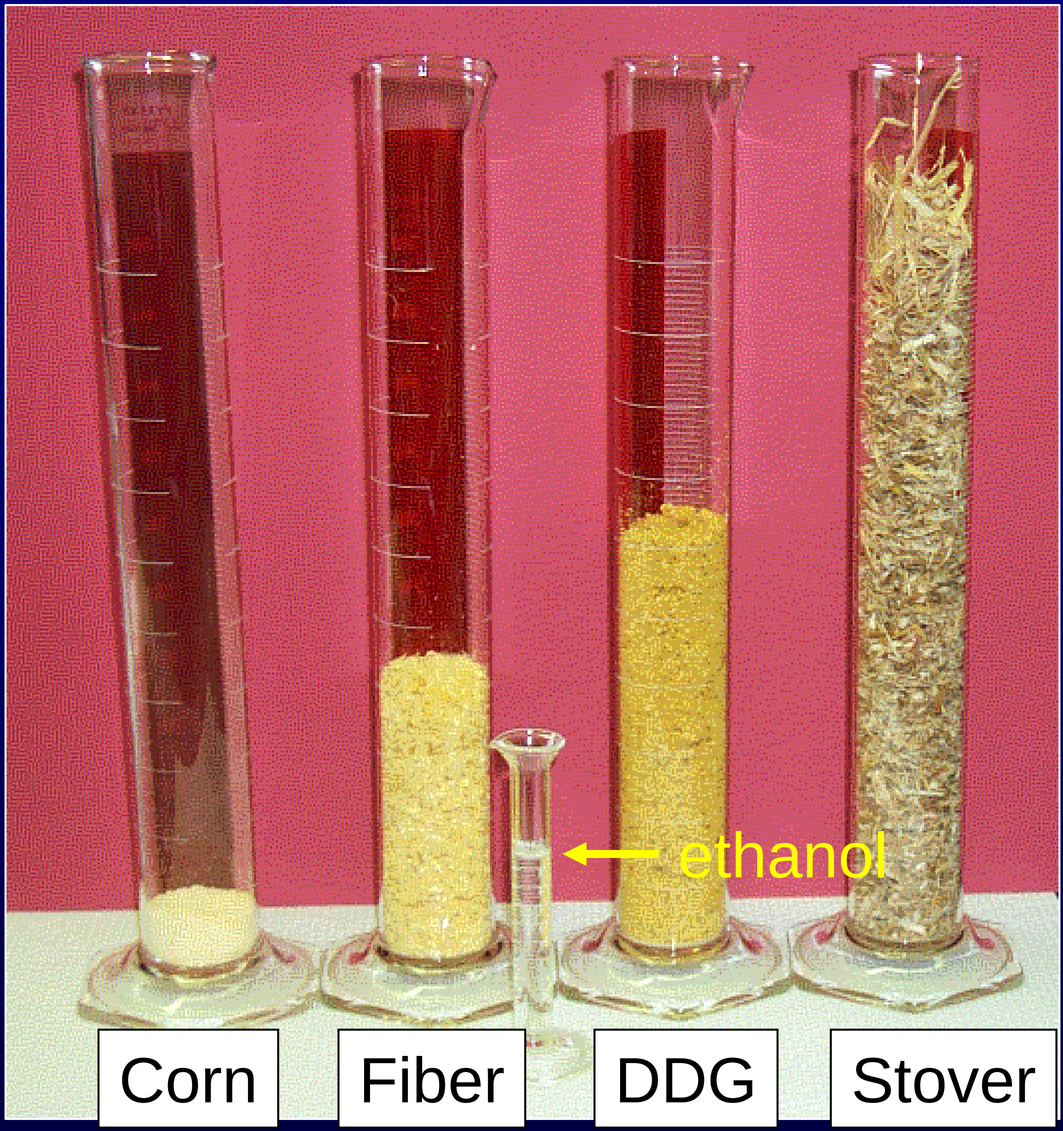
Moisture Content

Corn 15%

Fiber 46%

DDG 64%

Stover 5%



500 ml graduated cylinders used for comparisons

Corn Kernel Cellulosics

Near Term Technology Validation

No incremental supply chain Costs

Potential 10% Yield increase

4.5 M gal Ethanol per plant Annually

Minimal incremental capital

DDGS weight reduced 44%

No increase in corn acres

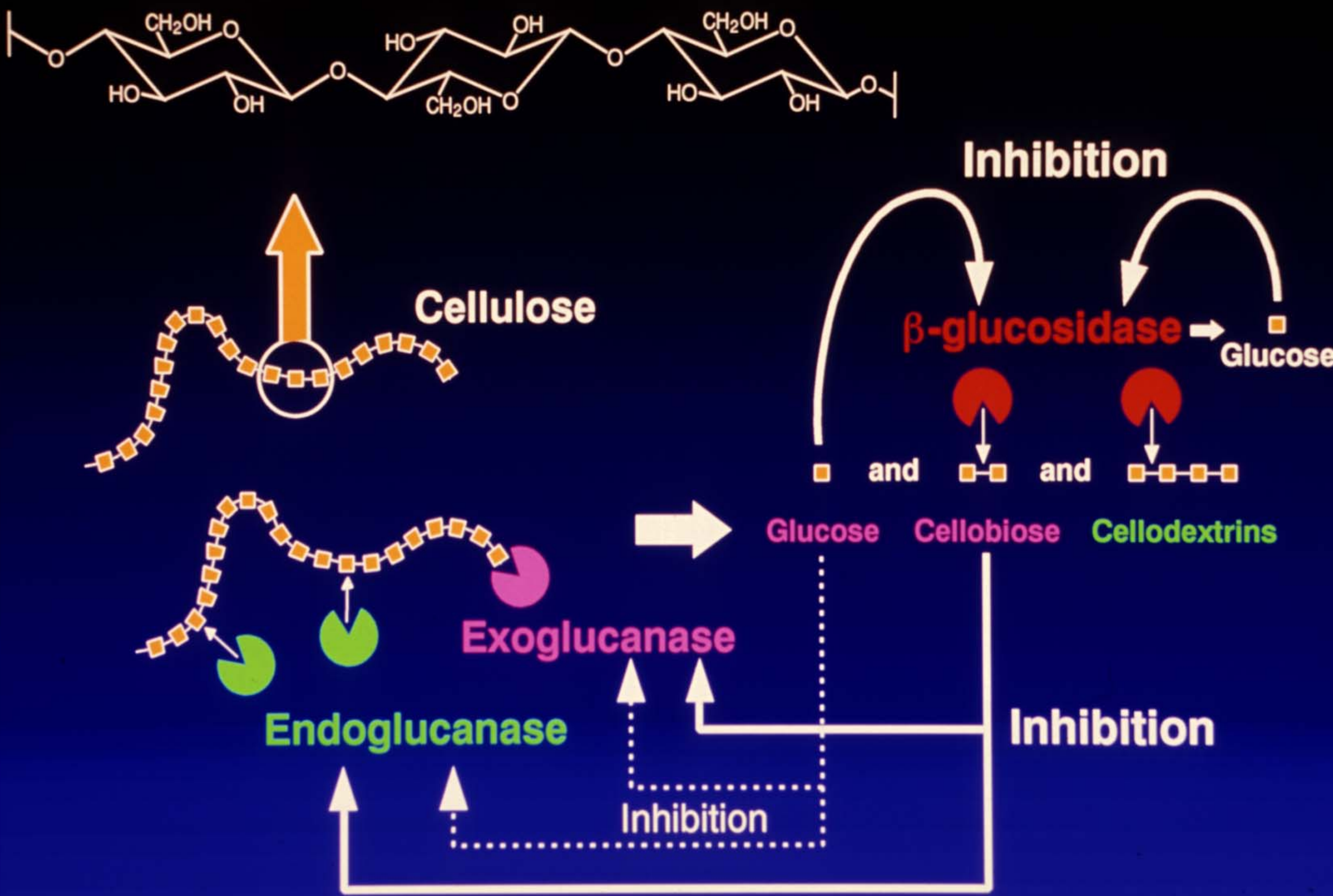
Selected Pretreatment Strategies

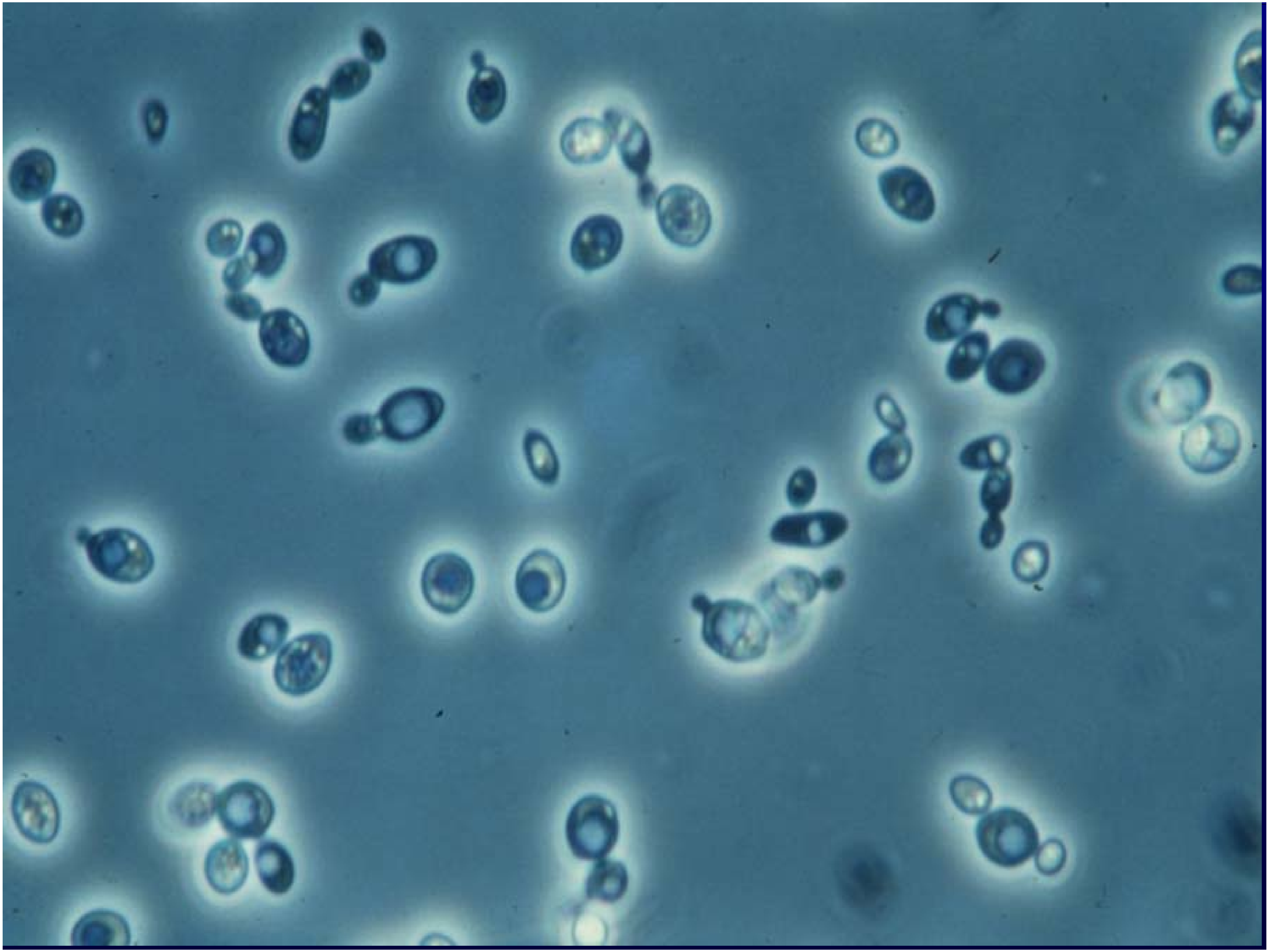
Acid

Base

Pretreatment	Pentoses	Inhibitors
Strong Acid	+	++
Dilute Acid	+	++
Hot Water	-	+
AFEX	-	-
Alkaline Peroxide	-	-

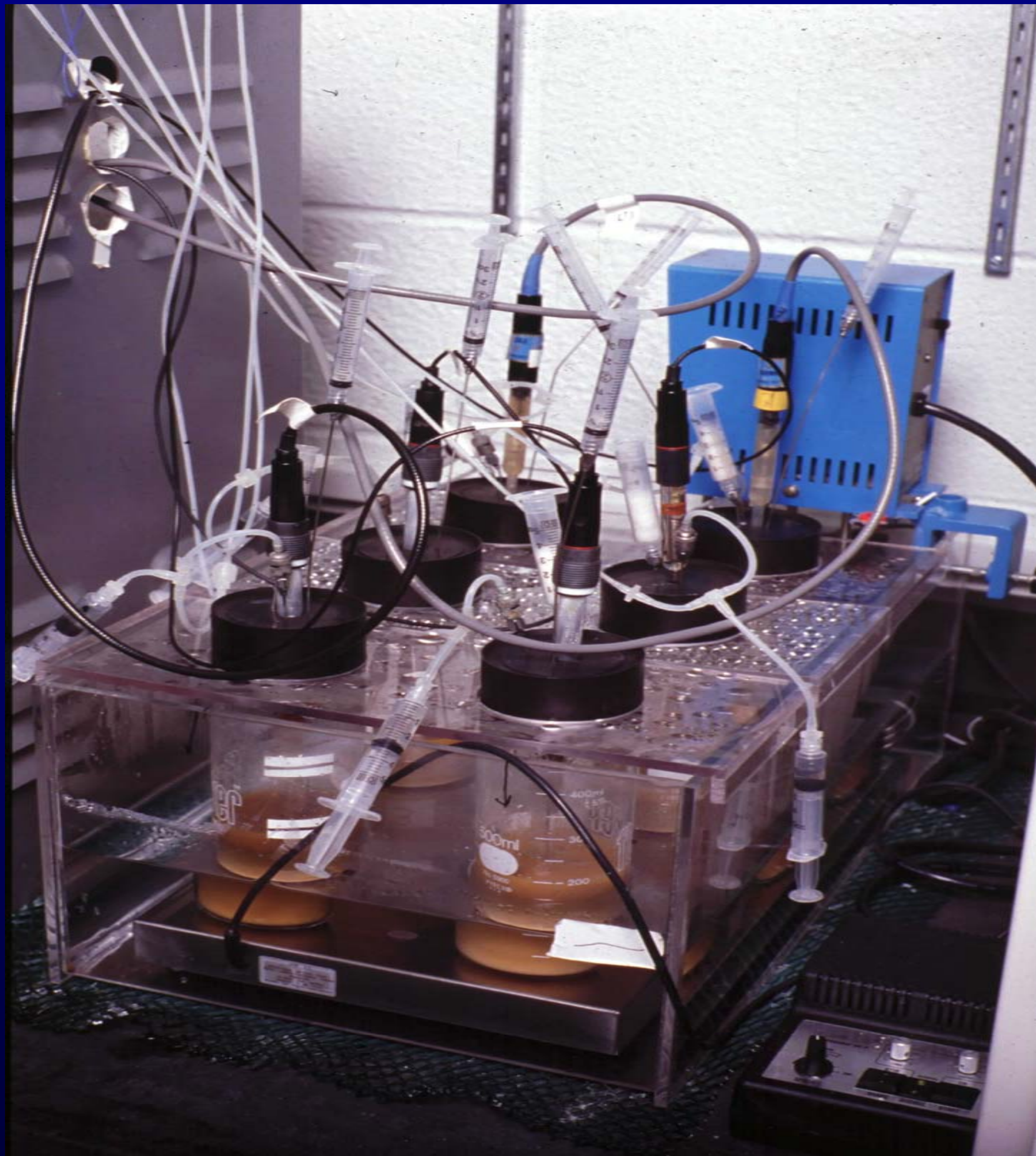
Enzymatic Hydrolysis of Cellulose



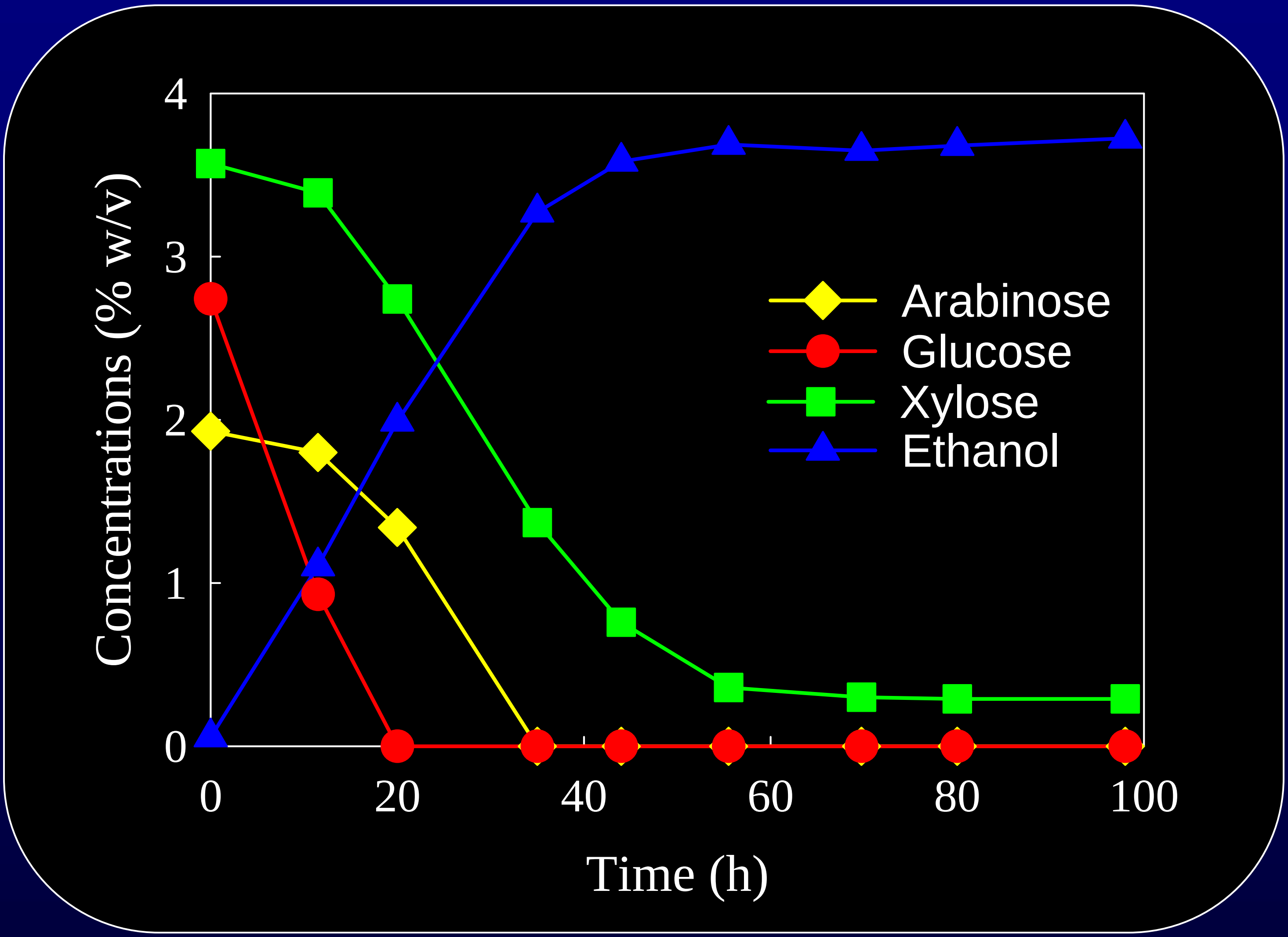


Recombinant Microorganisms for Fermentation of Mixed Sugars to Ethanol

- **Recombinant organisms are now available**
  - **Recombinant *Escherichia coli***
  - **Recombinant *Saccharomyces***
  - **Recombinant *Zymomonas***
  - **Recombinant *Klebsiella oxytoca***
- **Commercialization prospects**
  - **BCI with recombinant *E. coli***
  - **Iogen with recombinant *Saccharomyces***



Ethanol Fermentation Of Corn Fiber Hydrolysate by *E. coli* FBR5



Future Strains: Critical Traits

- **Pentose utilization**
- **High ethanol yield and productivity**
- **Genetic and phenotypic stability**
- **Hardiness (tolerance to ethanol and inhibitors)**
- **Efficient use of multiple sugars**
- **Growth at low pH/high temperature**
- **Ease of use with current production technology**

Ethanol cost derived from $50/ton corn stover versus equivalent corn prices in dry-grind processing

	Conversion Rate Gallons Per Ton	Enzyme Cost Per Gallon	Cost Per Denatured Gallon	Corn Equivalent Prices
Future	89.7	$0.10	$1.25	2.35
		$0.25	$1.40	2.98
Base	68.0[b]	$0.10	$1.65	4.02
		$0.25	$1.79	4.62

From Tiffany and Eidman, 2004

Cost Comparison for Corn & Stover

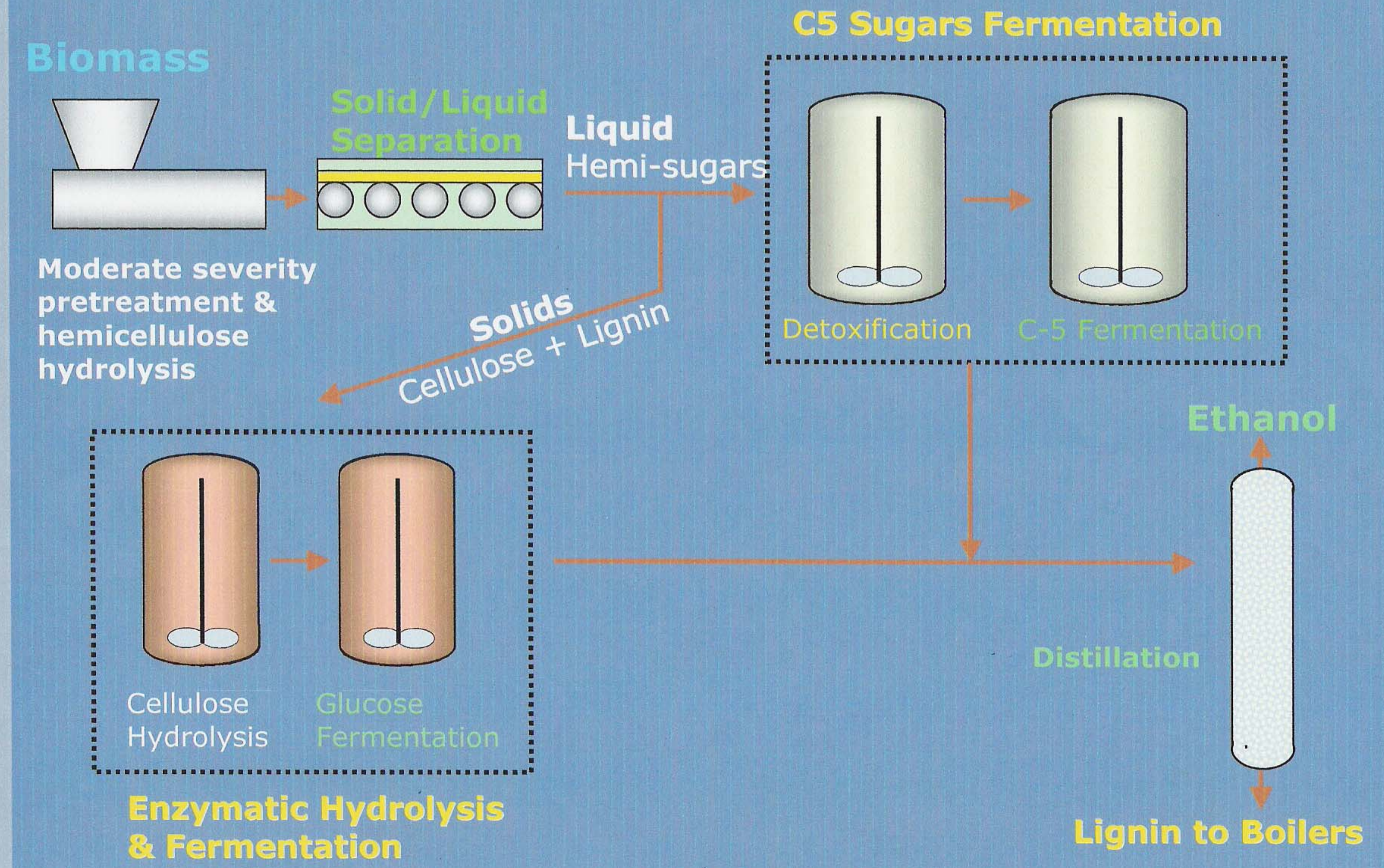
	Corn Starch	Corn Stover
Annual Ethanol (MMGal)	50	50
Ethanol Prod. Cost ($/gal)	0.96	1.45
Total Prod. Costs (MM$/yr)	47.8	72.0
Co-product Credit ($/gal)	0.26	0.13
Feedstock costs[1] ($/gal)	0.793	0.51
Capital Invest. (MM$)	48.0	193.7

Hope for future

[1]*Corn at $2.25/bu & stover at $40/ dry ton*

USDA, ERRC, March 2005

Biomass Processing: Example 1



Technological Constraints to Scale-UP

- Pretreatment- Substrate more reactive to enzymes
- Fermentation inhibitors
- Genetic stability, productivity and alcohol tolerance of recombinant microorganisms
- Recovery of dilute alcohol- Solids Loading