

***“RESEARCH AND DEVELOPMENT CHALLENGES
OF BIOETHANOL FROM CELLULOSIC BIOMASS”***

Presented by:

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Presented at:

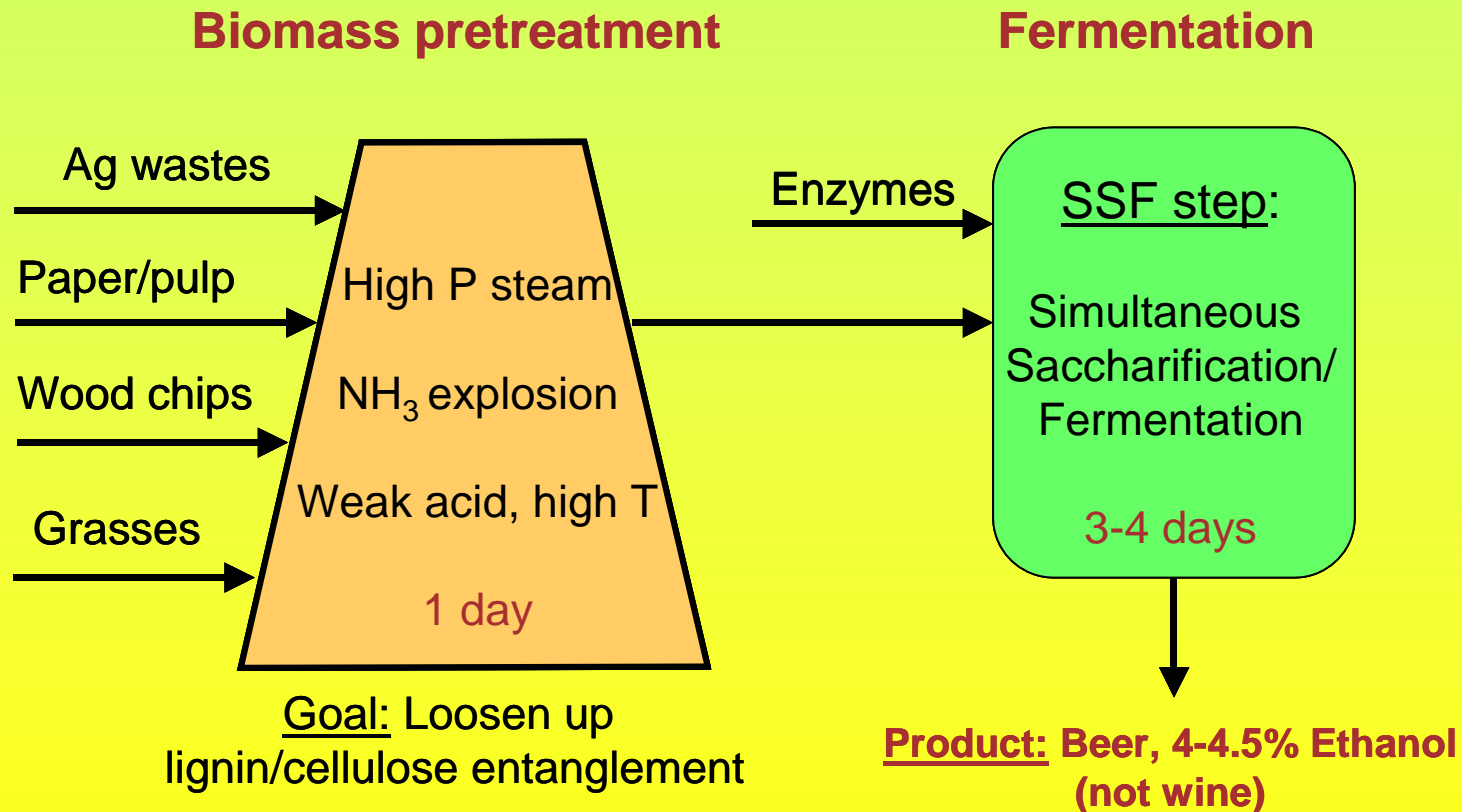
“Second Generation Ethanol-A Real Possibility”

Tortona, Italy

February 5, 2008

Key Challenges for Bioethanol from Cellulosic Biomass

We can make biofuels from biomass today...

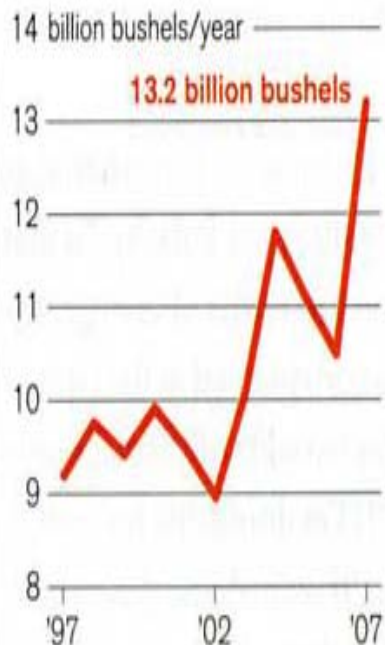


... but we must do so in a *sustainable* manner and *economically*

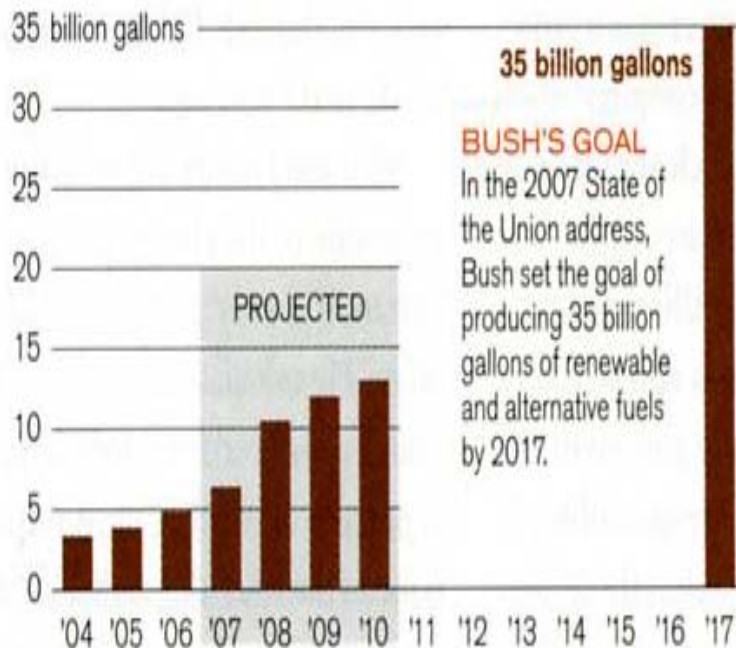
CORN GROWTH

The increase in the production of ethanol has prompted farmers to grow record amounts of corn. In 2006, about 17 percent of the U.S. corn crop went into production of the biofuel.

Corn production rises ...

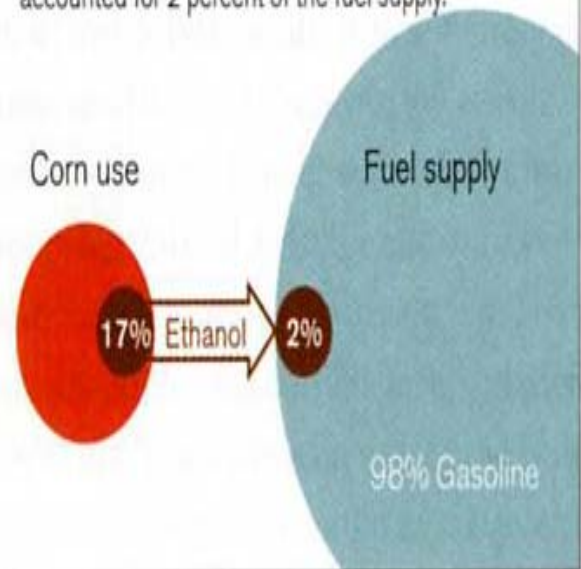


... as ethanol production increases to meet lofty goals ...



... though the impact is small.

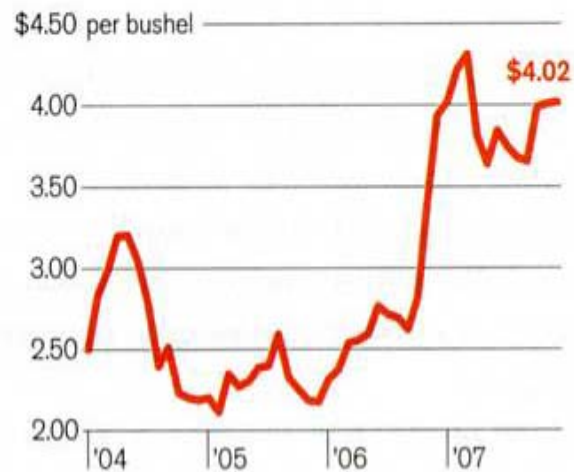
In 2006, 17 percent of the corn crop was processed into ethanol. That ethanol accounted for 2 percent of the fuel supply.



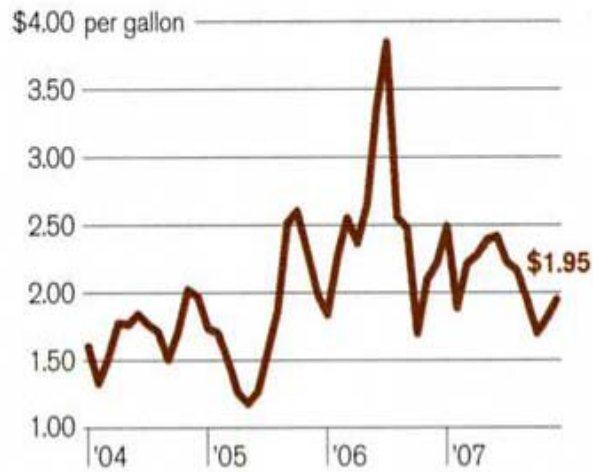
TIGHT MARGINS

The combination of rising corn prices and falling ethanol prices means producers of corn-derived biofuels are facing tight margins and an uncertain economic future.

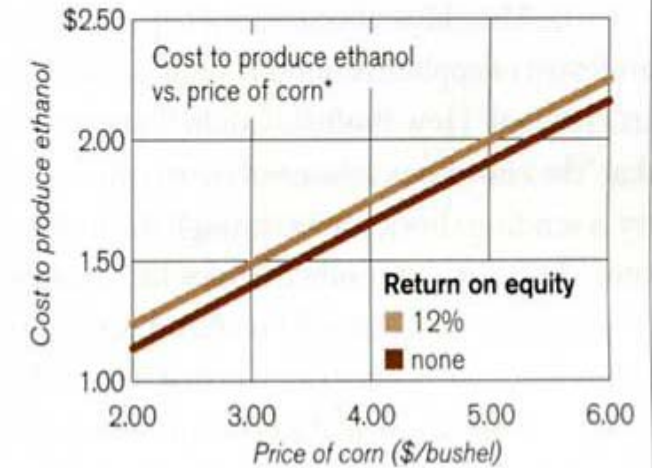
Corn prices are up ...



... but ethanol prices remain low ...



... making it difficult to produce profitably.



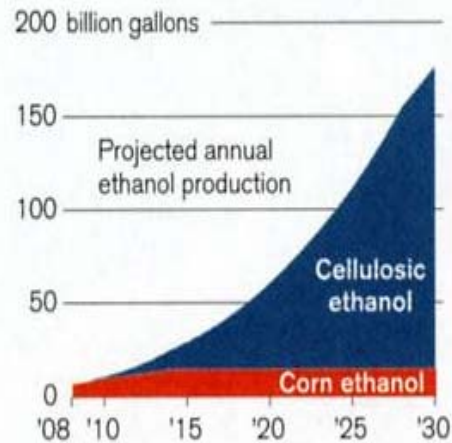
BIOFUEL FUTURE

Commercial production of biofuels from cellulosic biomass is at least four to five years away. But the technology has economic and environmental advantages over corn ethanol.

Commercial cellulosic facilities are being built ...

Company/Location	Technology used	
	Thermochemical	Biochemical
Abengoa Bioenergy/KS	●	●
Alico/FL	●	
BlueFire Ethanol/CA		●
Broin/IA		●
Iogen/ID		●
Range Fuels/GA	●	

... and may be the primary source ...



... of cleaner, more efficient ethanol.

Ethanol from:	Corn	Cellulose
Fossil energy used in production	●	●
Energy produced	1.3 times	10 times
Greenhouse-gas reduction**	12% to 26%	82% to 85%

Cost of producing 120 million gallons of ethanol in a newly constructed plant **Versus gasoline

Sources from upper left to bottom right: USDA; Vernon Eidman; Stephan Polasky/Jason Hill; Bloomberg (as of 11/13); Bloomberg (as of 11/12); Eidman; DOE; Khosla Ventures; Eidman

CELLULOSIC BIOMASS CONVERSION TO ETHANOL: *PRESENT STATUS*

- **Only Small Players in This Arena at This Time:**
 - ❖ Capacity: Less or ~ 20 Million Gallons/Year
 - ❖ Developers:
 - *Arkenol: Agricultural Residue, Cellulosic Biomass*
 - *Collins Pine, BCI: Wood Wastes*
 - *BCI: Rice Straw/Wood Waste*
 - *Masada: Cellulosic Biomass*
 - *IOGEN: Corn Stover*
 - *Others*
- **Big Players Have Entered!**
 - ❖ British Petroleum
 - ❖ Shell Oil
 - ❖ Others

TECHNOLOGY CHALLENGES IN BIOMASS TO ETHANOL: *IN THIS PRESENTATION*

- **Improved Pretreatment of Cellulosic Biomass**
- **Enhanced Hydrolysis of Cellulosic Biomass**
 - ❖ **New Enzymes Through Genetic Engineering**
 - ❖ **Abilities to Affect Degradation of Multiple Substrates**
- **Developments in Fermentation Processes**
 - ❖ **Heterogeneous Substrates in Cellulosic Biomass**
 - **Different Hexoses**
 - **Different Pentoses**
 - **Lignins**
 - ❖ **Catabolite Repressions Must be Anticipated**
 - ❖ ***Will Present One Example***
- ***Novel New Separation Technologies of Biofuels***
 - ❖ ***Will Present One Example***

BIOTECHNOLOGY PROCESS CHALLENGES IN CELLULOSIC BIOMASS PRODUCTION OF LIQUID FUEL: *DESIRABLE TARGETS*

- High Ethanol Productivity (> 20 Kg/M³-Hour)
- High Raw Material Conversion (~0.5 Kg ETOH/ Kg of Sugar): No Chemical By-Products
- Minimal or No Pretreatment: Direct ETOH Fermentation
- Capable of Converting 5-Carbon and 6-Carbon Sugars Simultaneously
- High Ethanol Concentration (~ 200 Gm/Liter)
- Thermophilic Organism for Ethanol Fermentation (> 65° C) and Low pH (~ pH 3)
- Continuous Fermentation Meeting All of the Above

TECHNOLOGY CHALLENGES IN CELLOSIC BIOMASS *PRETREATMENT*

- **Technically and Economically Pretreatment**
 - ❖ **Large-Scale Particle Size Reduction**
 - **Any New Technologies From Coal Processing?**
 - ☐ **Reduce Biomass Particle-Size Thus Avoiding Subsequent Pretreatment**
 - ❖ **Novel and New Pretreatment:**
 - **Acid and Solvent Pretreatments Questionable Economic Viability**
 - **Solvent (Organics or Ammonia Explosion) Pretreatment Questionable Economic Viability**
 - ❖ **On-Site Pretreatment: Avoid Biomass Transportation and Pipe-Line to Biorefinery**
- ***I Would Invest My Dollars to This Area as Priority: Pretreatment Technology***

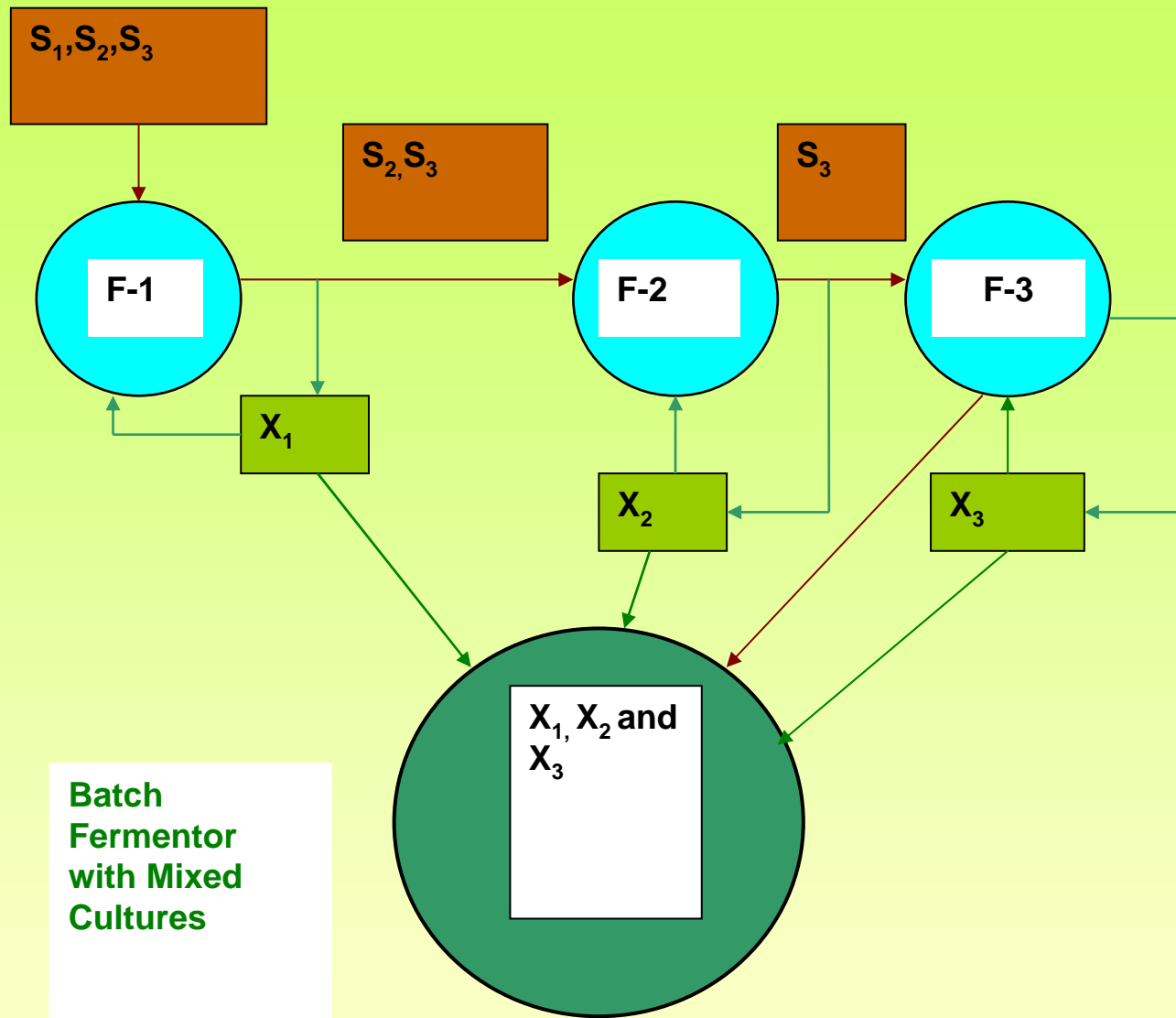
GOOD NEWS IN CELLULOSIC BIOMASS

***ENZYME* ACHIEVEMENTS**

- **Genetic Engineering Achievements: Enzyme Production**
 - ❖ **Cellulose and Hemicellulose Degradation Enzymes Can be Probably be Produced at Economic Costs**
 - **Will Require Large Volume Needs (Similar to Starch Degradation Requirements)**
- **Genetic Engineering Achievements: Fermentation**
 - ❖ **Five and Six Carbon Sugars Can be Fermented**
 - ❖ **Metabolic Pathway Manipulations: A Real Possibility**

POSSIBLE DEVELOPMENT CHALLENGES IN *FERMENTATION PROCESSES*

- **Improving Volumetric Productivity (*Reducing Capital Investment*) and Raw Material Conversion (*Reducing Variable Cost*)**
 - ❖ ***Continuous Mixed Substrates Fermentations Feeding to Batch Mixed-Culture Fermentation (Overcoming Catabolite Repression)***
 - ❖ ***Continuous and Staged Fermentations (Overcome Catabolite Repression) and Feeding to Batch Mixed-Culture Fermentation***
 - ❖ ***New Concept (Nanotechnology) in Cell Aggregation to Affect Cell Recycle Fermentations (Increasing Productivity)***
 - ❖ ***In situ Extractive Fermentation Systems (Increasing Productivity and Reducing Cost for Separation)***
 - ***In Collaboration from New Separation Technologies***
- **Note: Microbial Strains to be Employed will be From Existing Culture Collections and Newly Genetically Engineered Strains from *Metabolic Engineering***



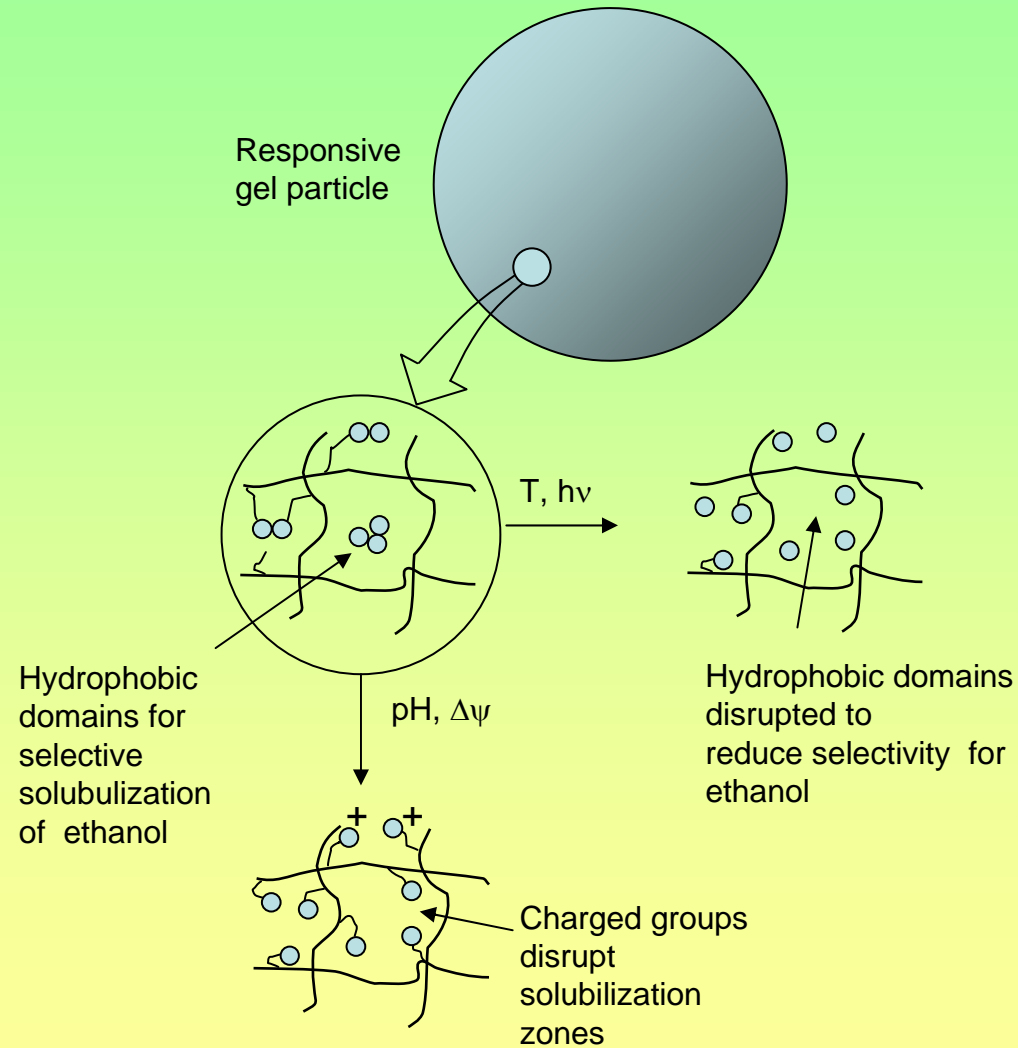
Batch
Fermentor
with Mixed
Cultures

Continuous Staged Fermentors for More Effective Multiple Substrate Utilization with Final Stage as Batch Fermentor and Increased Productivity

Novel New *Separation* Technologies for Biofuels

- **Basic Premise: Avoid Energy Intensive Separation Technology (e.g. Distillation)**
- **New Concepts (Ethanol Separation as Example)**
 - ❖ **Tailored, Stimuli-Responsive Adsorbents**
 - *Polymer Gels for Selective Adsorption*
 - *Reponsive to Stimuli for Desorption (e.g. pH, Temp., Light)*
 - ❖ **Supermagnetic Adsorbents**
 - *Nano-Magnetic Particles (HGMS for Separation)*
 - *Gel Coated Nano Particles Containing High Distribution Coefficient Extractants for Alcohols*
 - *Desorption of Alcohols with Minimal Content of Water*
 - ❖ **Structured Packings and Absorbents**
 - *Polymer Coating with Reactive Functionalized Surface for Alcohol Absorption*
 - *Responsive to Stimuli for Desorption*

Principle of Stimuli-Responsive Gels



CONCLUDING COMMENTS

- **Bioethanol from Cellulosic Biomass can Become a Commercial Reality**
- **Many Research and Development Challenges Lie Ahead Such as:**
 - **Cellulosic Biomass Pretreatment**
 - **Fermentation Processes to Improve Productivity and Raw Material Conversion**
 - **New Concepts in Ethanol Recovery**
- **An Ideal Challenge for R&D in Bioprocess Engineering**