

Biomass Conversion to Biofuel and Biobased Product

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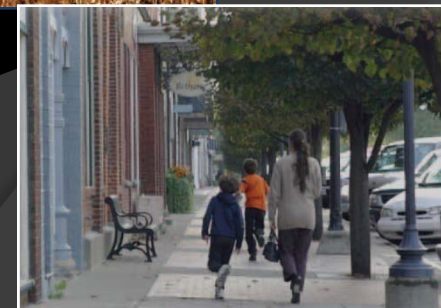
October 22, 2009

Presentation Outline

- ❑ Background
- ❑ Cellulosic-ethanol with ultrasound pretreatment
- ❑ Fungal fermentation of biomass to ethanol
- ❑ Biofuel residues for fish feed production
- ❑ Syngas fermentation to ethanol

Why is “Biorenewables” so Important?

- Provide biofuels and biobased chemicals
- Improve environmental quality
- Improve national security
- Contribute to sustainable development



What is Biomass?

- Agricultural crops and residues, forestry residues, energy crops, municipal wastes and other organic waste materials.
- Bana grass and guinea is a high yield energy crop readily available in Hawaii.
(Yield: 45 to 100 Mg/ha-yr)



Cellulosic Biomass to Ethanol

Total

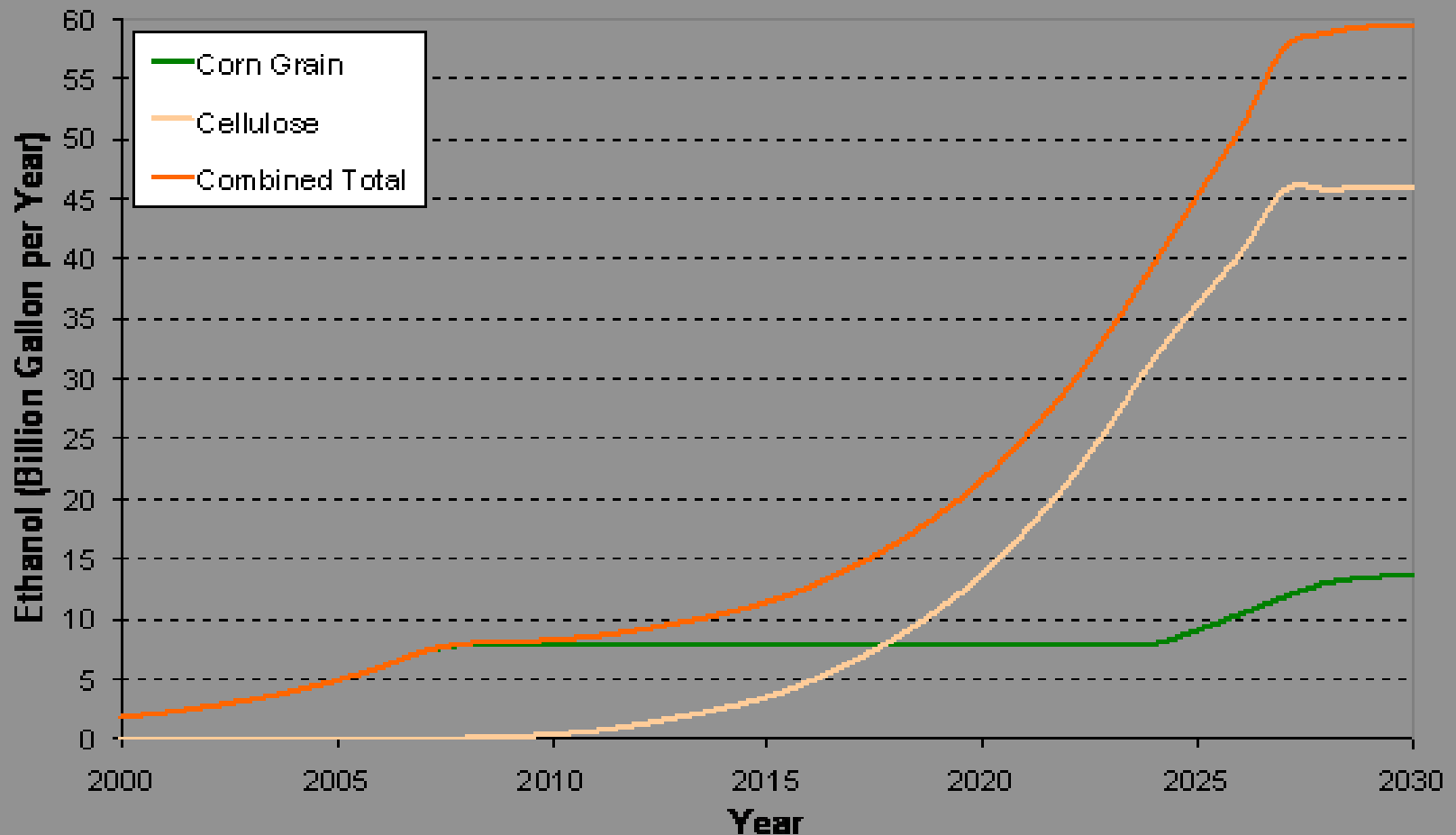


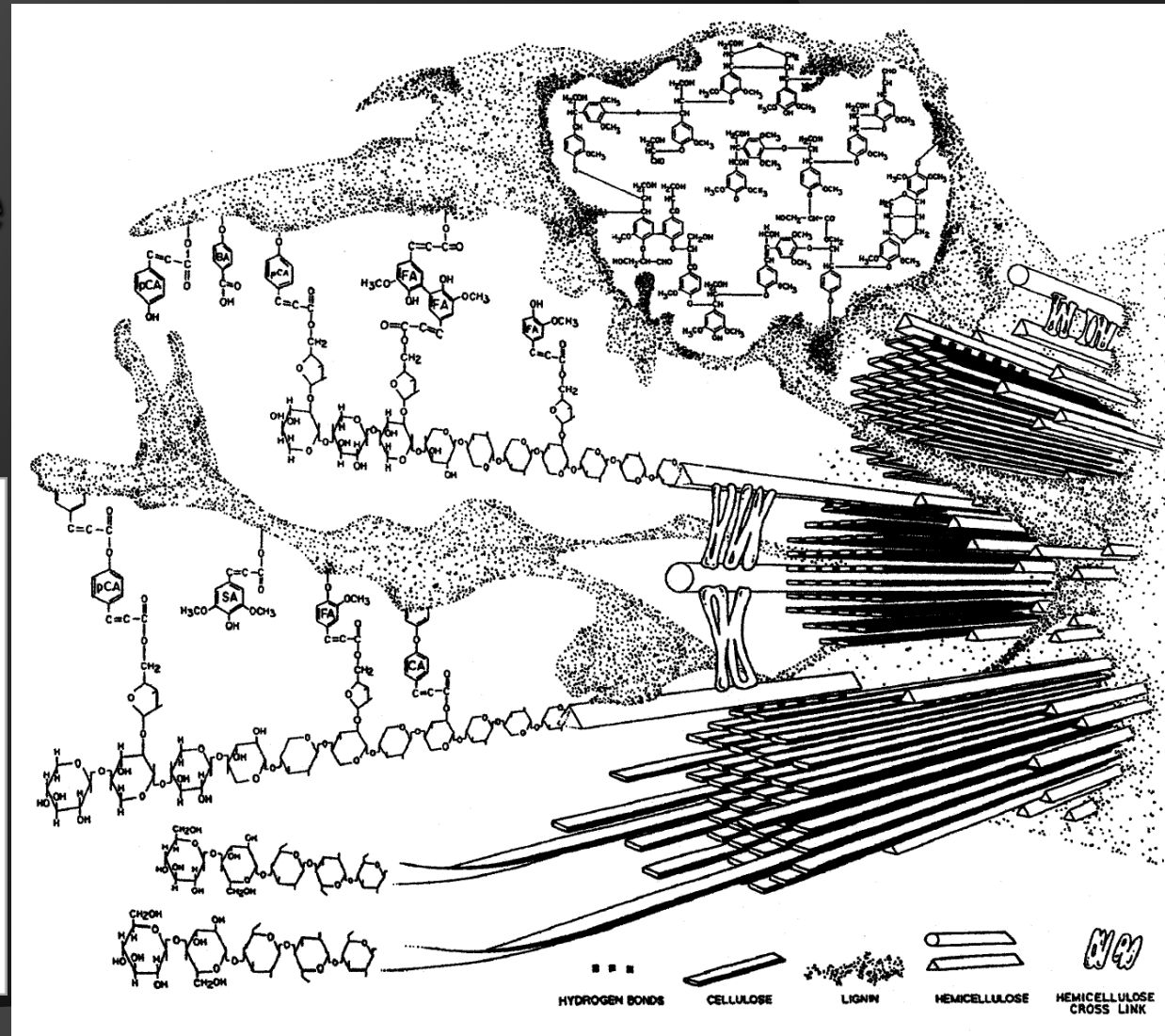
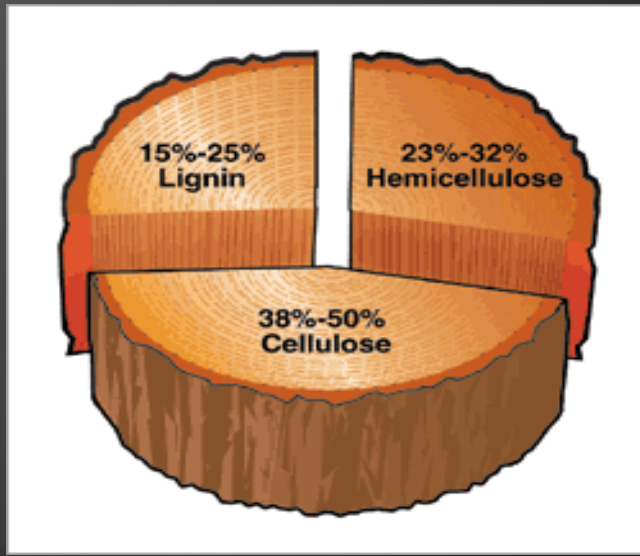
Chart representing ethanol volumes predicted from the high oil case using the transition model for the 30x30 NREL report. Date: 09/05/06, contact – Bob Wooley, National Renewable Energy Laboratory

Cellulosic Biomass to Ethanol

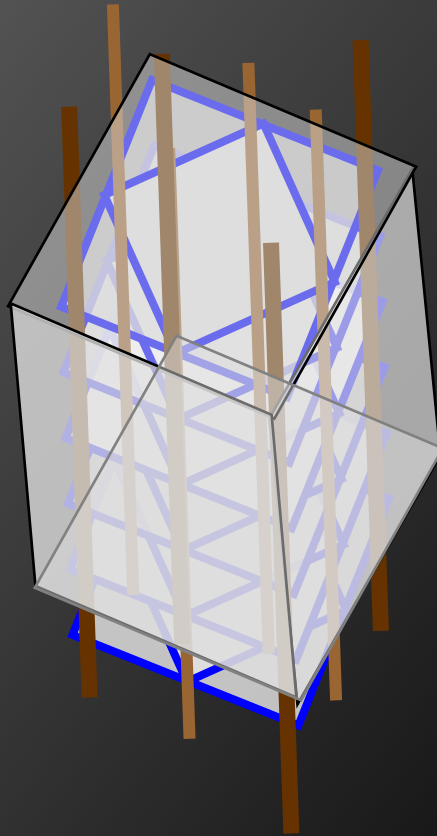
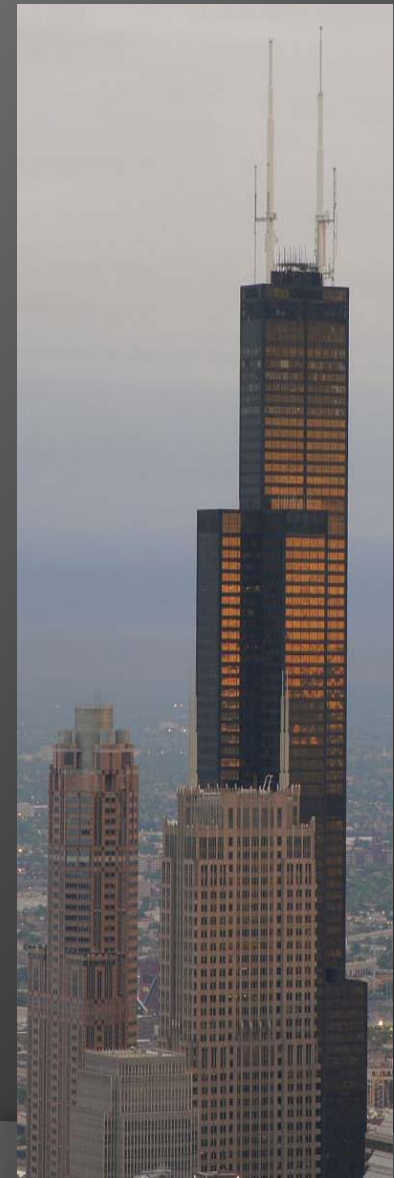
| | Gasoline (B gals) | Ethanol equivalent (B gals) |
|--------------------------------|-------------------|--|
| US consumption, 2004 | 139 | 200 |
| 60% from imports | 83 | 120 |
| 30% displacemnt | 42 | 60 |
| Biomass need at 80 gal/ton | | 750Mton |
| Land requirement @ 10 ton/acre | | 75 Macre |
| 100 MGY biorefinery | | 600 each @ 160 mile ² (125 K acr) |

Lignocellulosic Biomass Structure

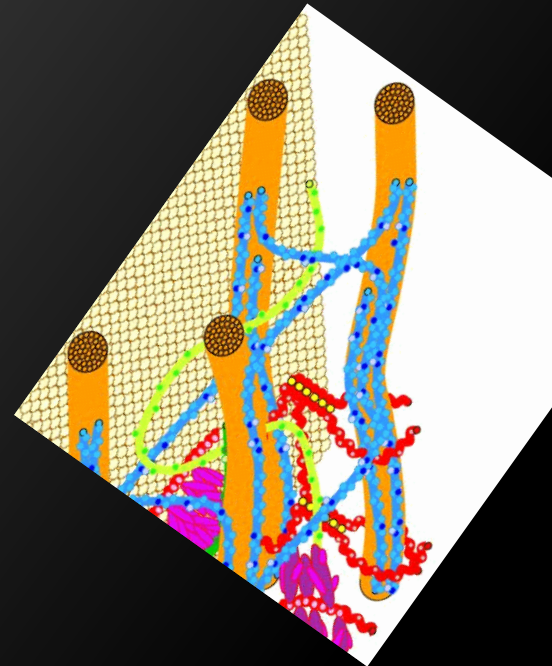
- Cellulose
- Hemicellulose
- Lignin



How an Engineer can Visualize!



Reinforced concrete



Plant cell wall material



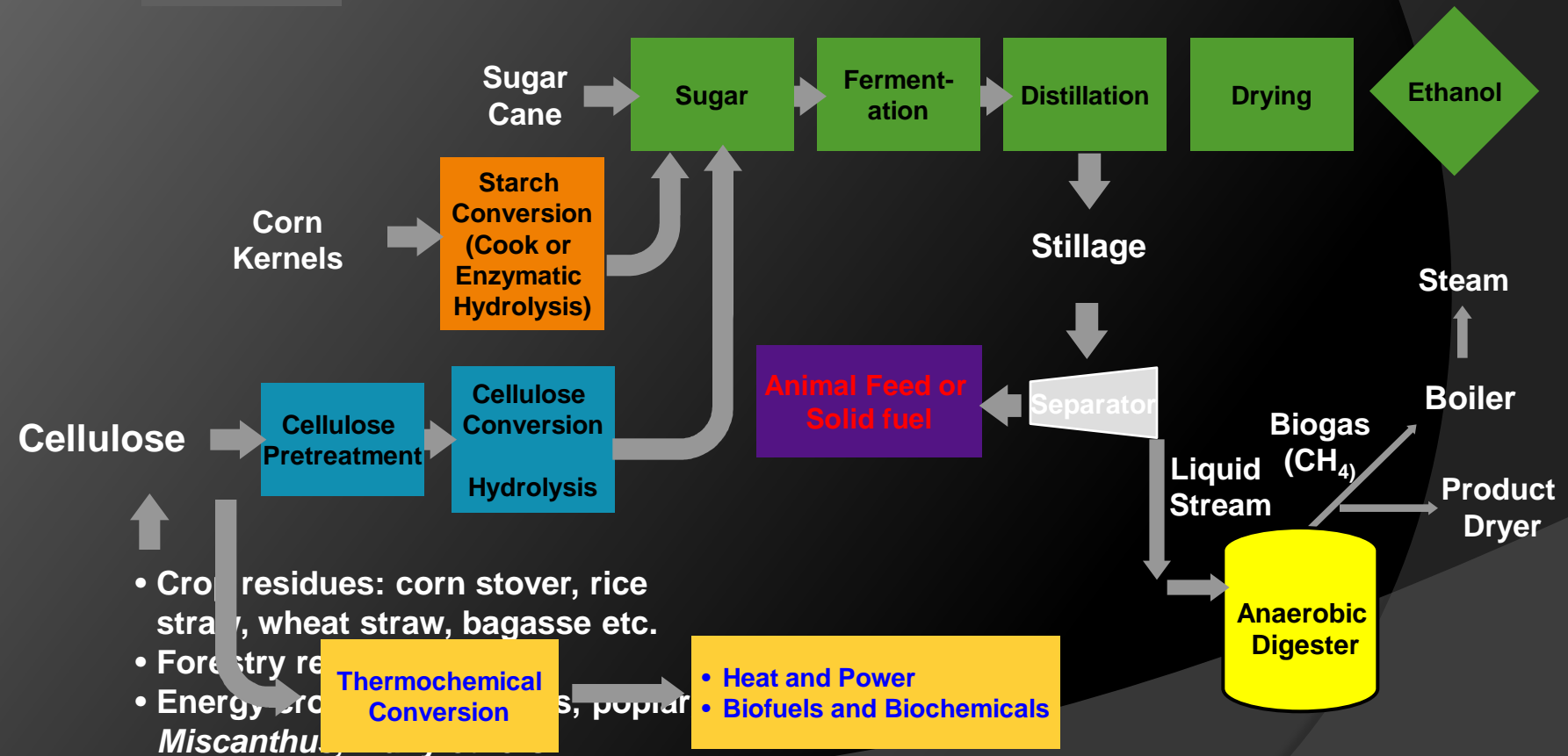
Biochemical Pathway for Biofuel Production

Cellulose-based ethanol

Starch-based ethanol

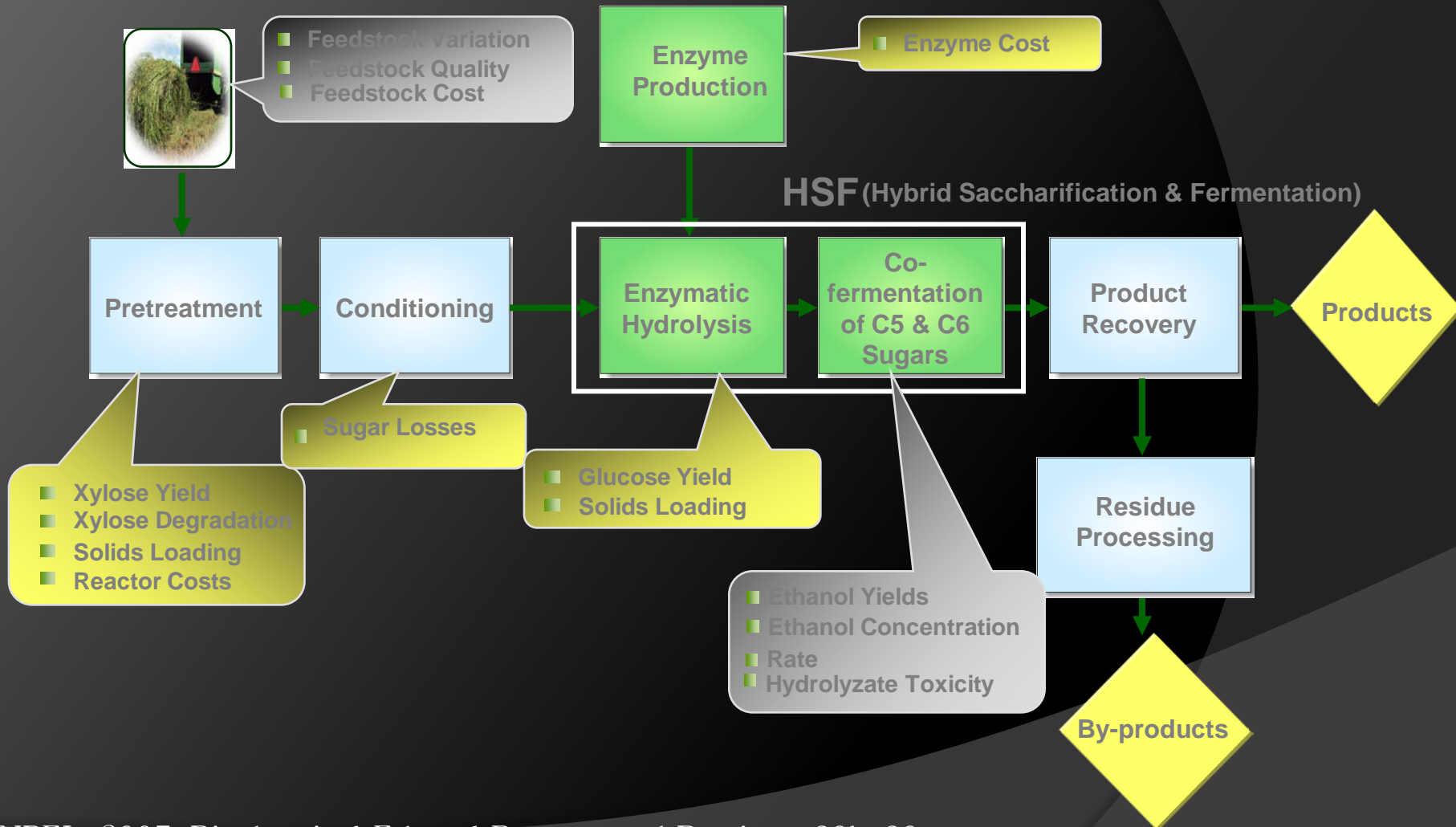
Sugarcane-based ethanol

VIDEO



- Crop residues: corn stover, rice straw, wheat straw, bagasse etc.
- Forestry residues: wood chips, sawdust, bark, etc.
- Energy crops: Miscanthus, sorghum, poplar, etc.

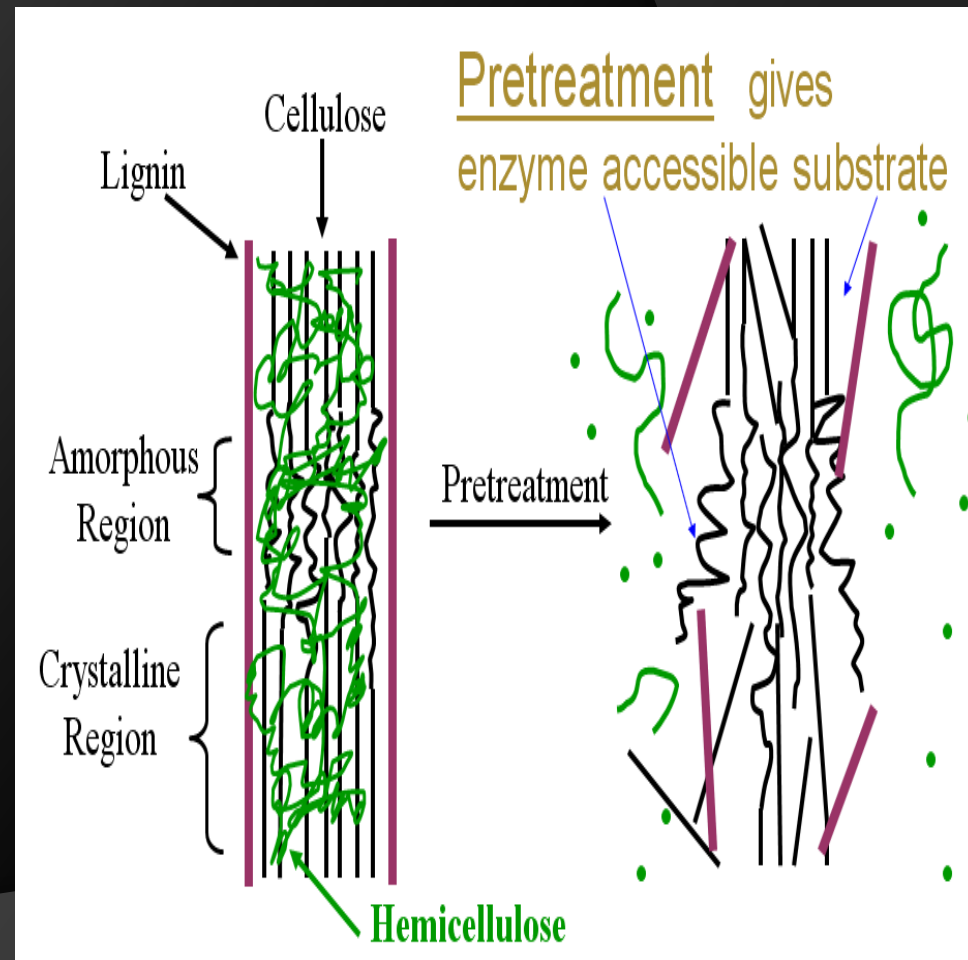
Biochemical Conversion



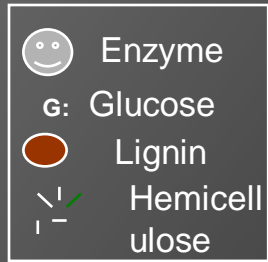
Why Pretreatment is Needed?

Pretreatment is essential to facilitate easy access of enzymes to cellulose/hemi-cellulose:

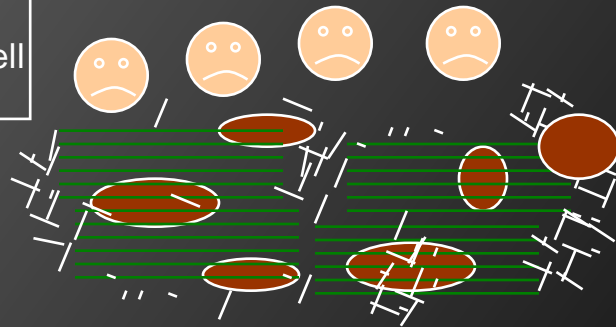
1. To solubilize lignin.
2. To dissolve hemi-cellulose.
3. To disrupt a cellulose-hemi-cellulose-lignin interaction.



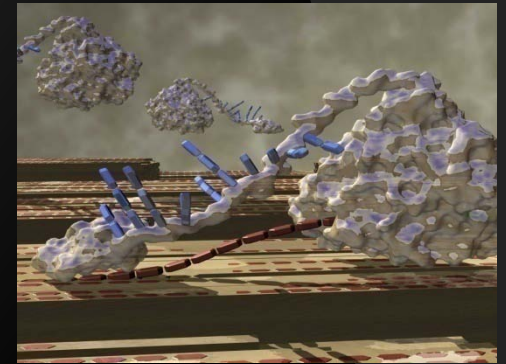
Enzyme hydrolysis of pretreated lignocellulosic biomass (animation)



Lignocellulosic biomass

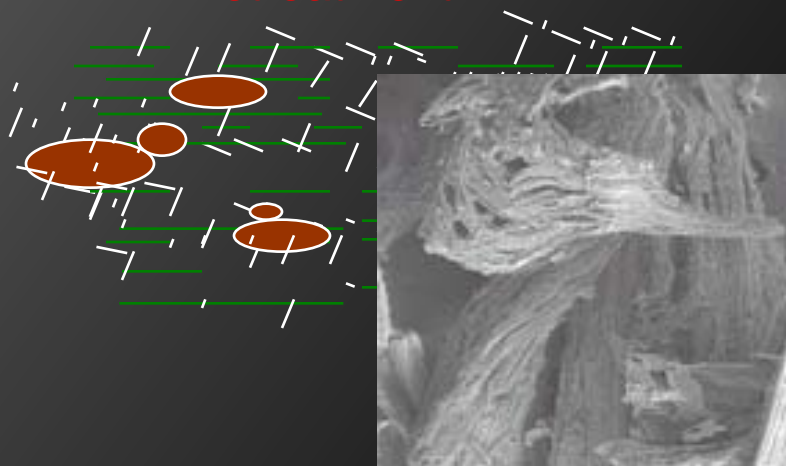


SEM (corn stover)

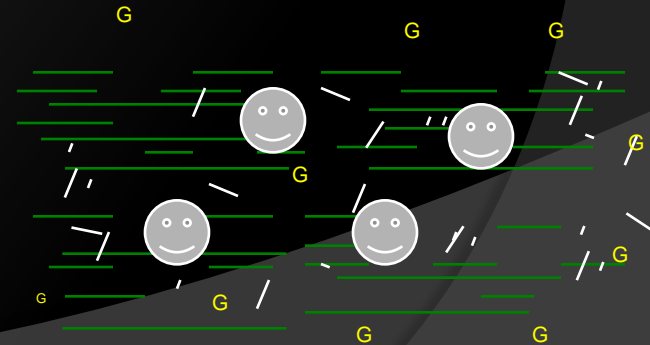


CBH1 from *T. reesei* (from NREL)

Pretreatment



Hydrolysis



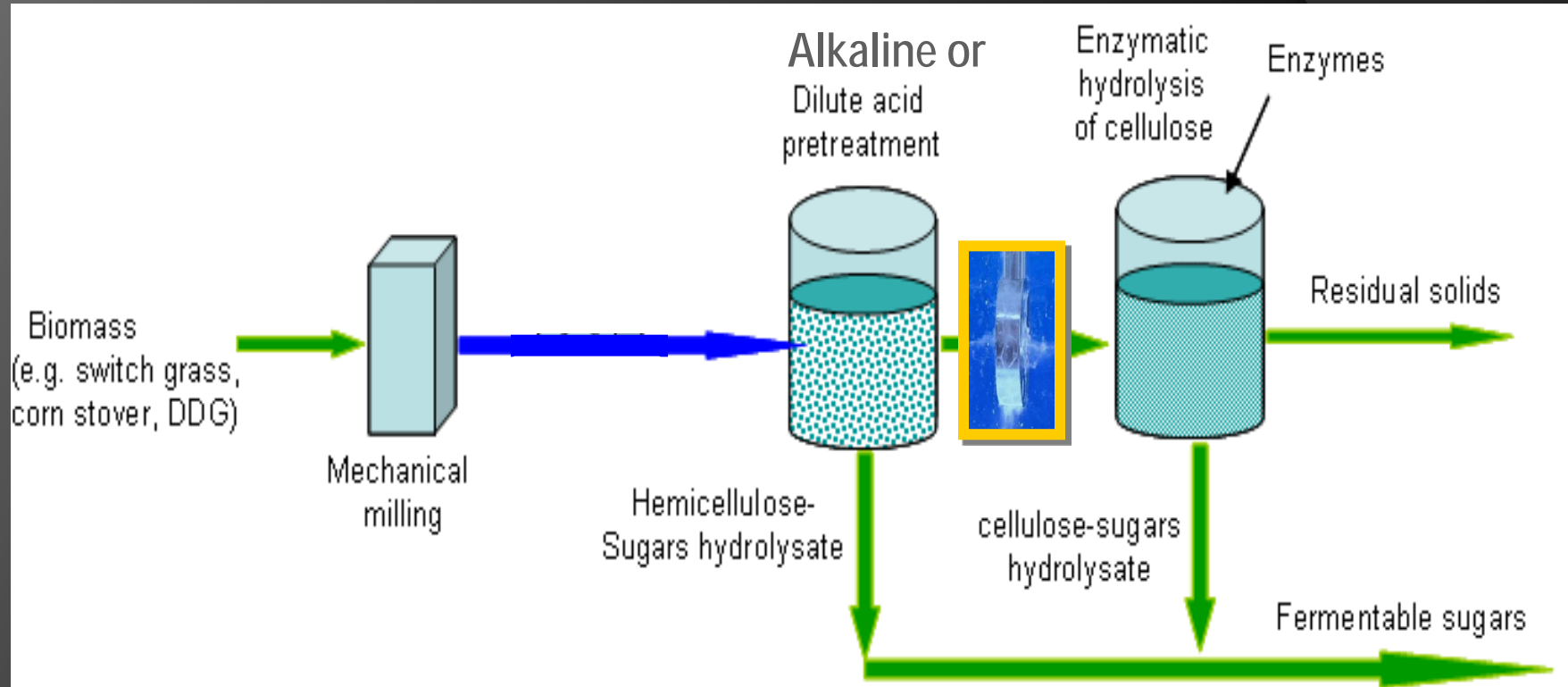


$\times 300$

120 Pa

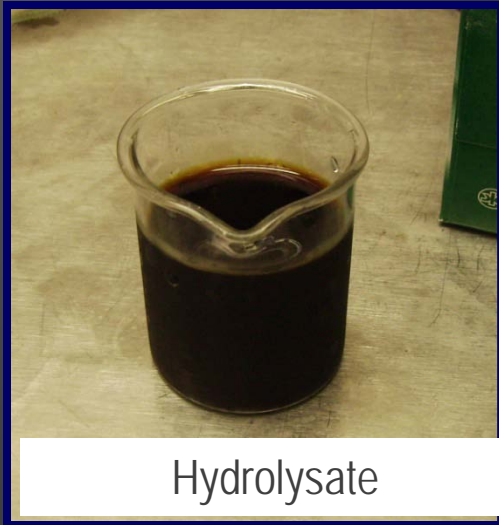
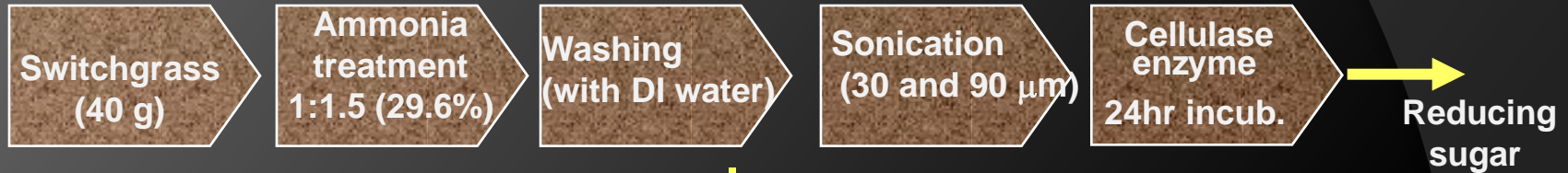
100 μm

Biomass Pretreatment



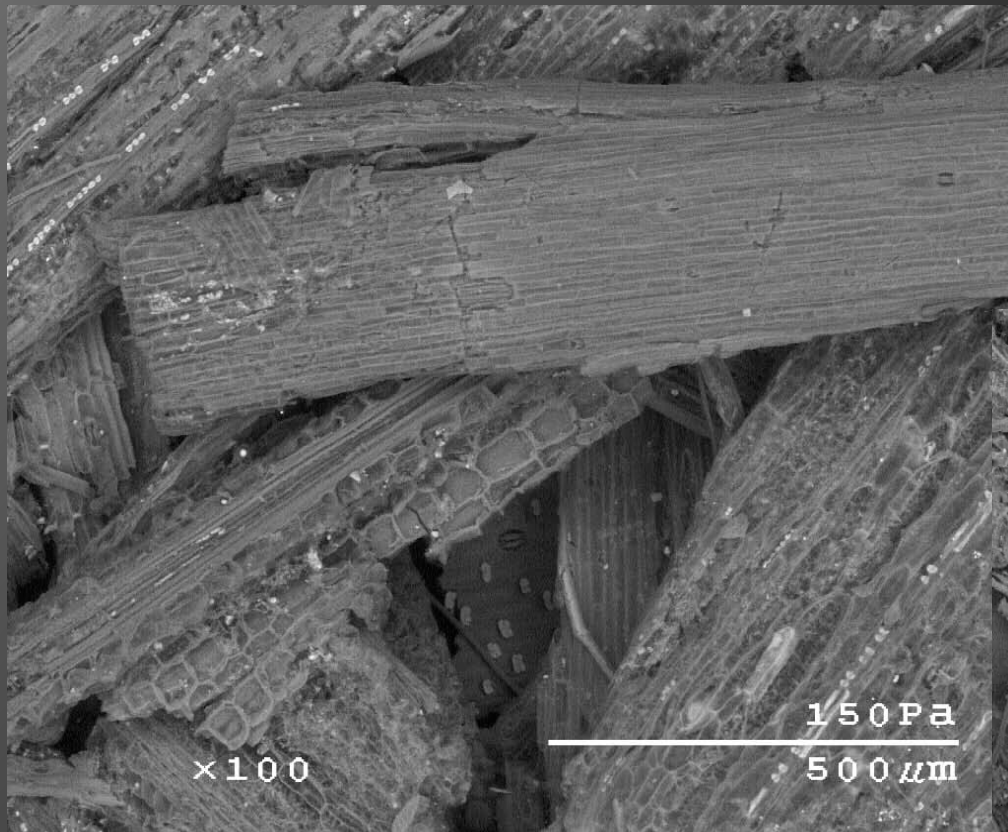
- ❑ Ultrasound pretreatment → increase in pore volume → 30 to 500°A
- ❑ Reduce crystalline structure of cellulose
- ❑ Reduce the enzyme loading and improve the rate of reaction
- ❑ Enhance sugar release → subsequent ethanol yield/ton of biomass

Ammonia Pretreatment of Switchgrass

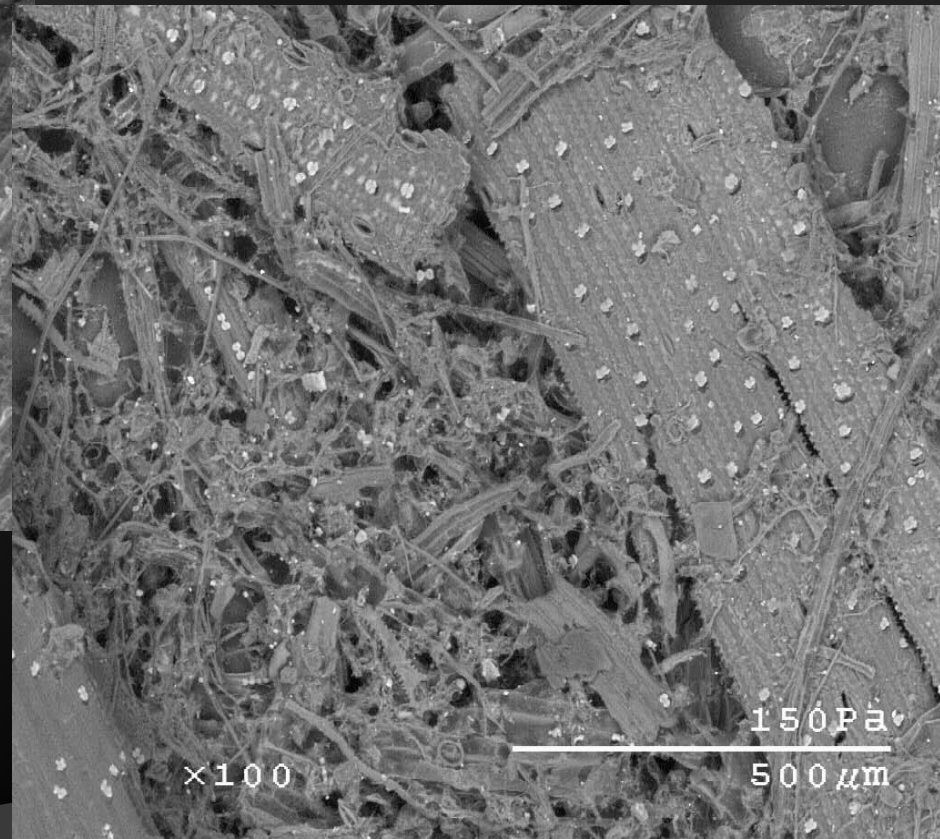


Cellulose: 45%
Hemicellulose: 31.4%
Lignin: 12%

Effect of Sonication on Microstructure

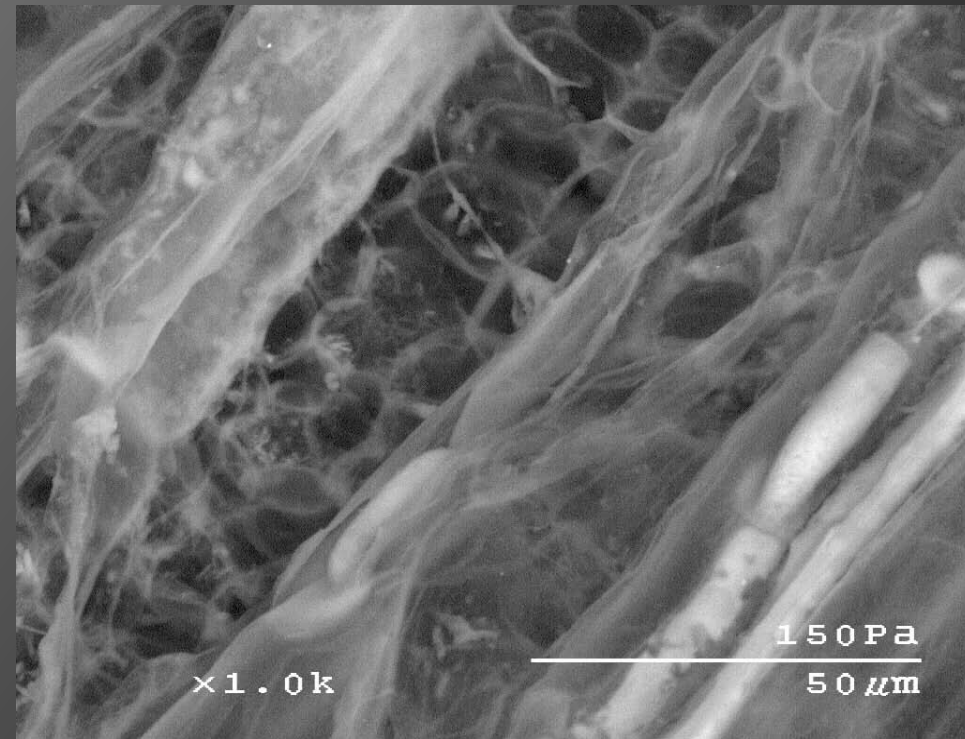


Control

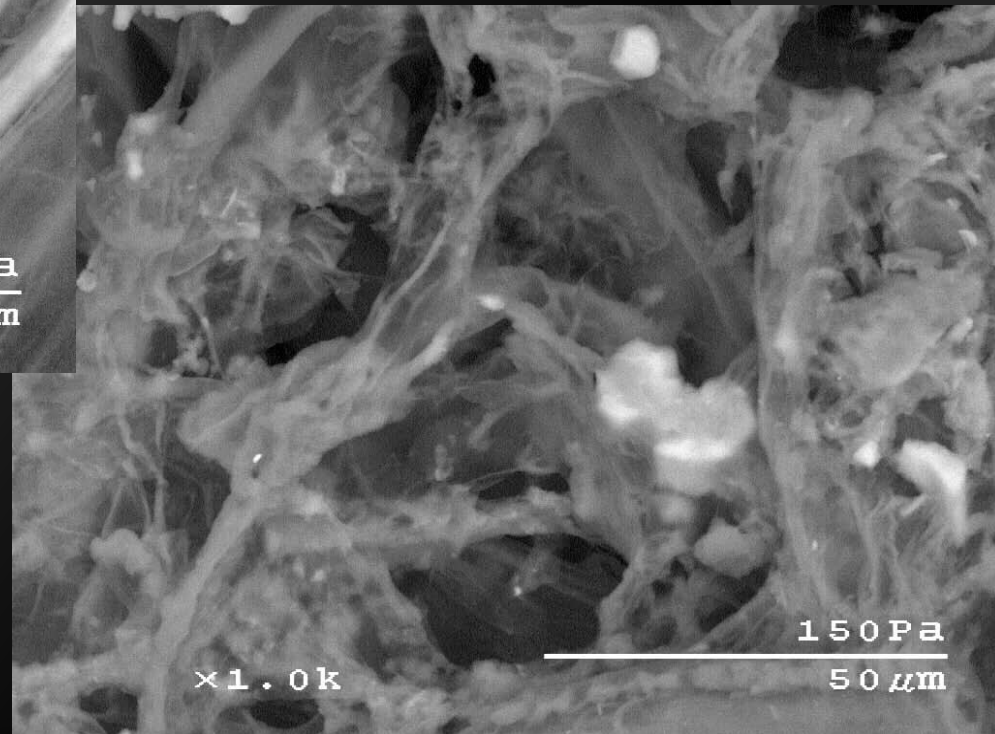


Ultrasound treatment: 40 sec

Change in Microstructure



Control

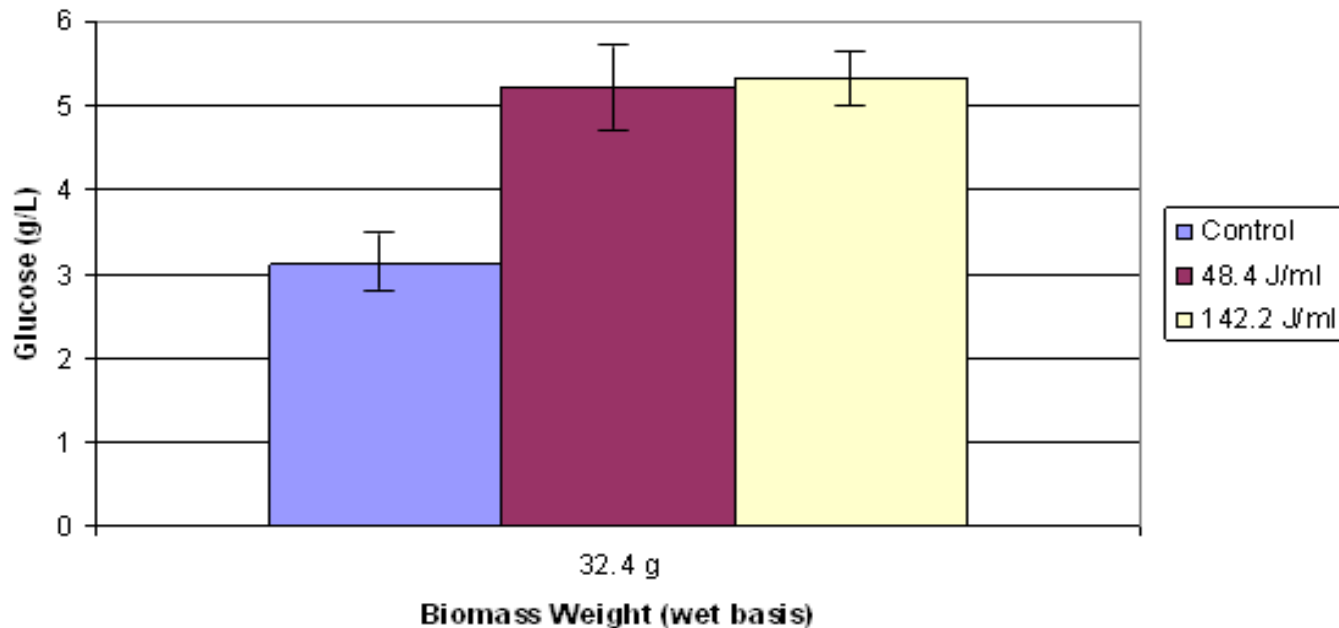


Ultrasound treatment: 40 sec

Reducing Sugar Release

| Exp | Energy density (J/ml) | Specific Energy (J/g wet biomass) | Glucose (g/L) |
|-----|--------------------------|--------------------------------------|------------------|
| 1 | 48.4 | 448.15 | 5.24 ±0.32 |
| 2 | 142.2 | 1316.67 | 5.34 ±0.5 |
| 3 | 0 | 0 | 3.1±0.35 |

Glucose Yield at Varying Energy Density



Fungal Fermentation of Biomass to Ethanol

Brown rot fungi

Yeast

Lignocellulose

**Wood
Rot
Fungi**



Brown Rot Fungi

e.g. *Gloeophyllum trabeum*

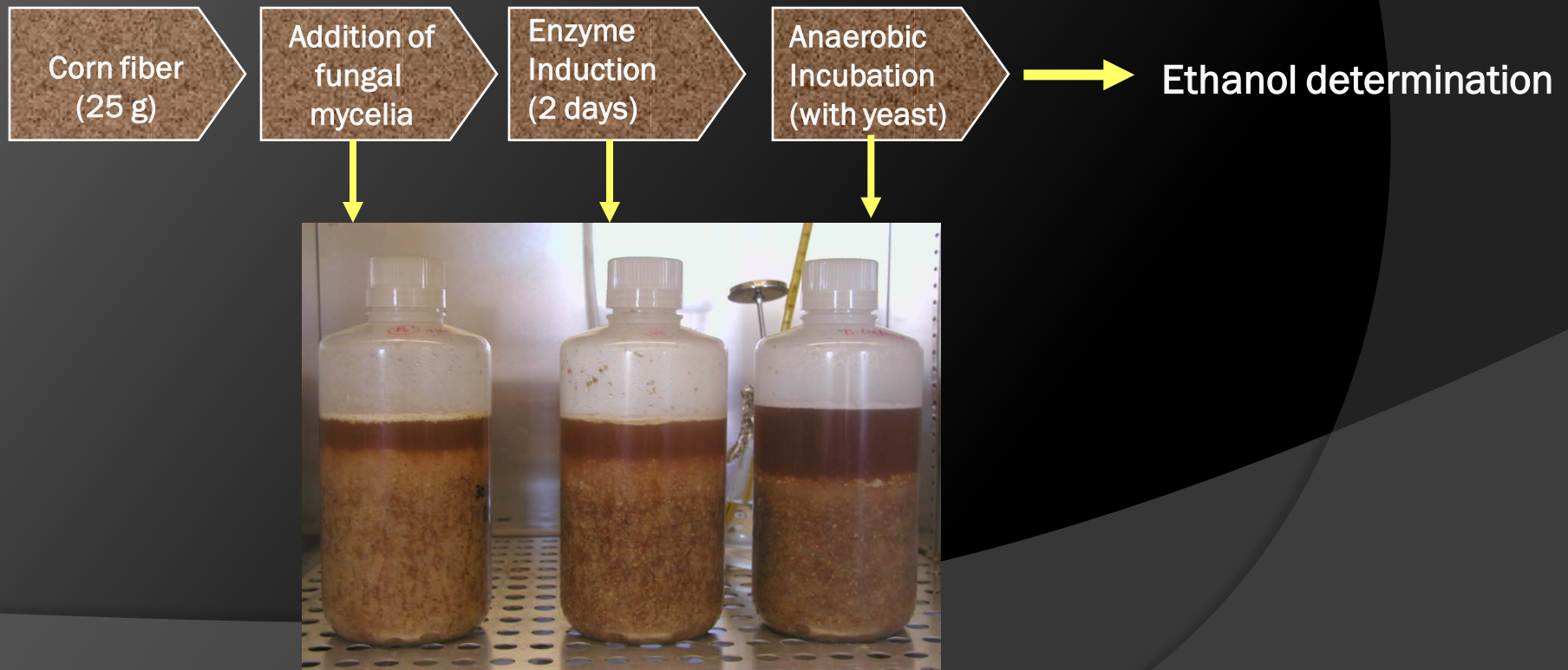
White Rot Fungi

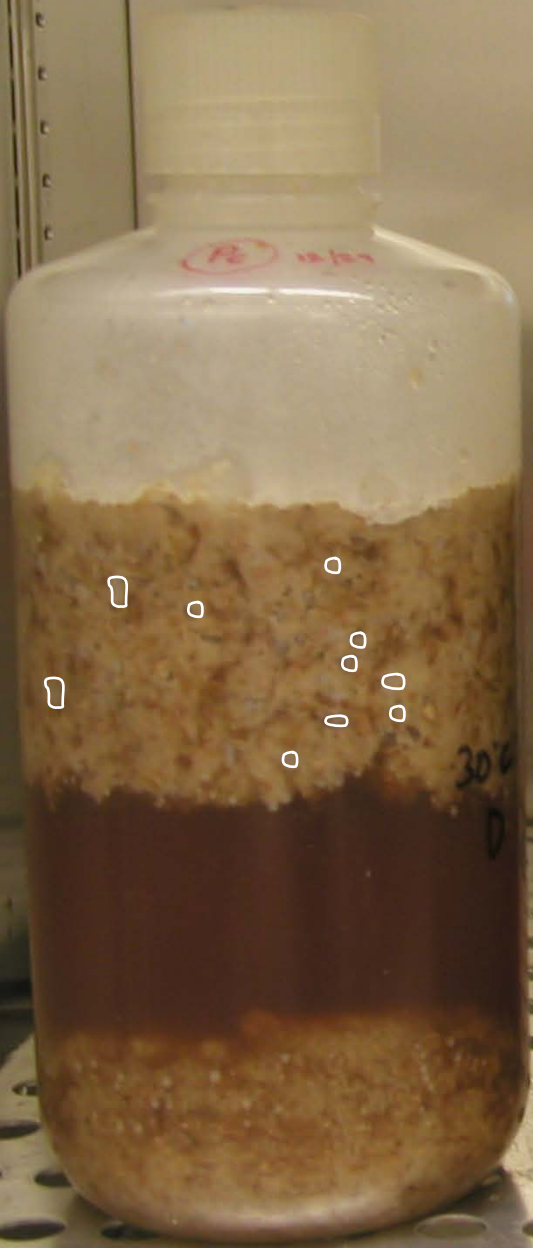
e.g. *Phanerochaete chrysosporium*

White rot fungi

Experimental Steps

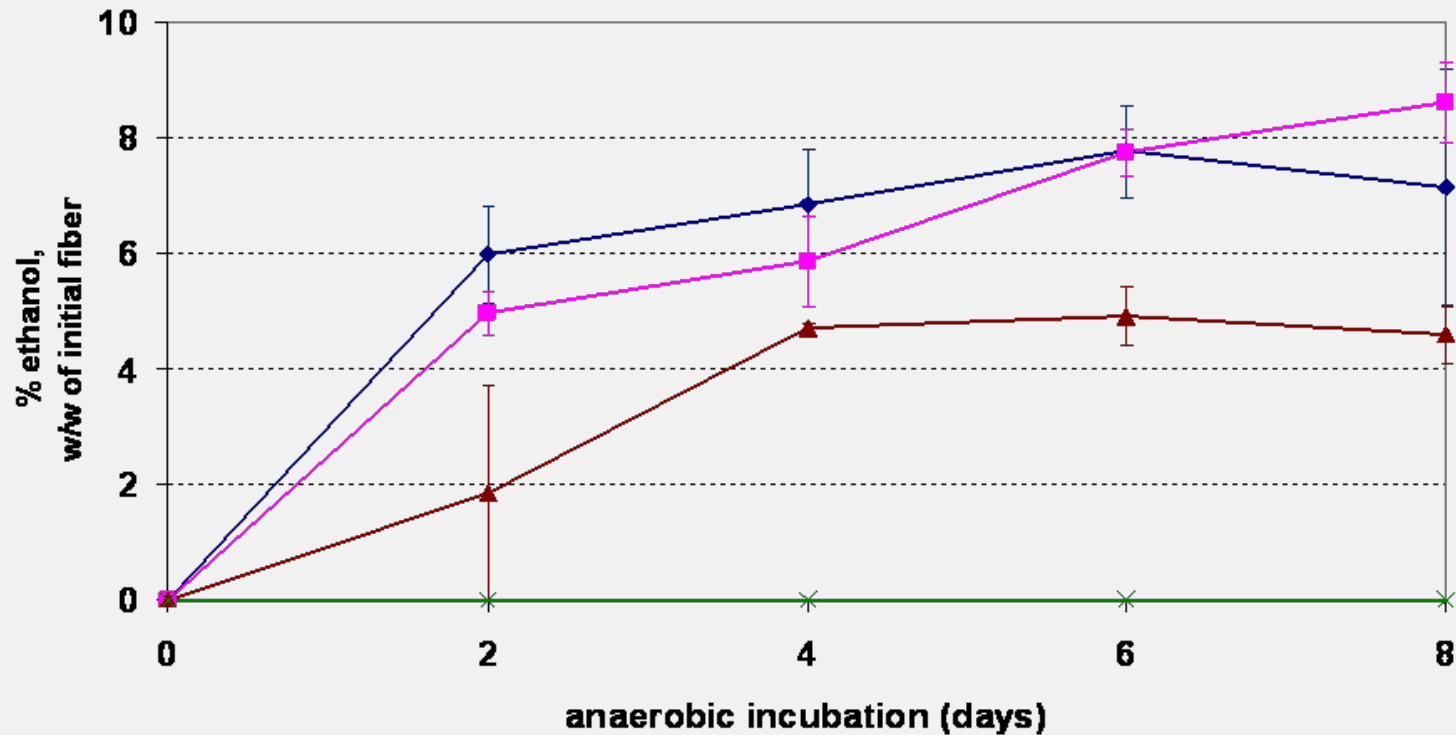
- Corn fiber (cellulose 16.5%, hemicellulose 45%, lignin ~ 1.5%, 37% others – protein, oil, ash etc.)





**Trained cormorants
with neckrings led
to the submergence
of the culture idea**

Ethanol profile during Simultaneous saccharification and fermentation of corn fiber



—◆— *P. chrysosporium* —■— *G. trabeum* —▲— *T. reesei* —×— Control

SSF with white and brown rot fungi converted ~ 9 % of fiber to ethanol on weight basis
SSF with *T. reesei* converted only ~ 5 % of fiber to ethanol on weight basis

Summary

- **Ultrasound pretreatment resulted a significant disintegration of cellulosic micro-fibrils**
- **Following sonication of switchgrass, reducing sugar yield improved by 70% with respect to control**
- **Fungal process was able to hydrolyze cellulosic biomass**
- **Over 10% of the corn fiber was converted to ethanol through fungal fermentation alone**

Fungal Fermentation



- ❑ Source of protein for animals, even for humans.
- ❑ Fungi prefer acidic condition (pH 4.0).
- ❑ High in lysine, 5.5% (DDGS 0.62%, soybean meal 3.0%) → co-fed with DDG to non-ruminants.
- ❑ Source of valuable fungal byproducts such as enzymes, chitin/chitosan, and lactic acids.
- ❑ Easy recovery of fungal biomass with high quality water for reuse.

Fungal Species of Interest

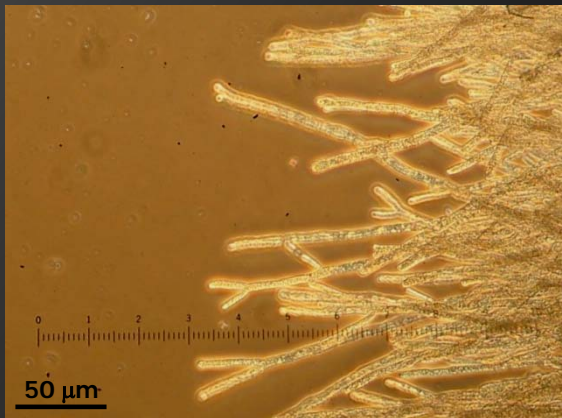


The focus: microfungi

Selection of Fungi

Kingdom: Fungi
Phylum: Zygomycota
Order: Mucorales
Family: Mucoraceae

Genus: *Rhizopus*
Species: *microsporus*



Vinasse Characteristics

| Parameters | Molasses vinasse | Sugarcane juice vinasse |
|--------------------------------------|------------------|-------------------------|
| pH | 3.85 ± 0.00 | 3.88 ± 0.01 |
| Chemical oxygen demand (g/l) | 86.52 ± 5.32 | 86.79 ± 7.38 |
| Soluble chemical oxygen demand (g/l) | 63.95 ± 4.84 | 68.35 ± 1.48 |
| Total solids (%) | 5.12 ± 0.00 | 2.46 ± 0.04 |
| Suspended solids (%) | 1.25 ± 0.10 | 0.59 ± 0.02 |
| Volatile solids (%) | 3.55 ± 0.00 | 1.77 ± 0.02 |
| Volatile suspended solids (%) | 1.07 ± 0.06 | 0.53 ± 0.02 |
| Total Kjeldahl nitrogen (mg/l) | 1088.36 ± 10.65 | 336.72 ± 4.61 |
| Potassium (mg/l) | 5598.00 ± 48.65 | 1533.33 ± 152.75 |

Some Findings

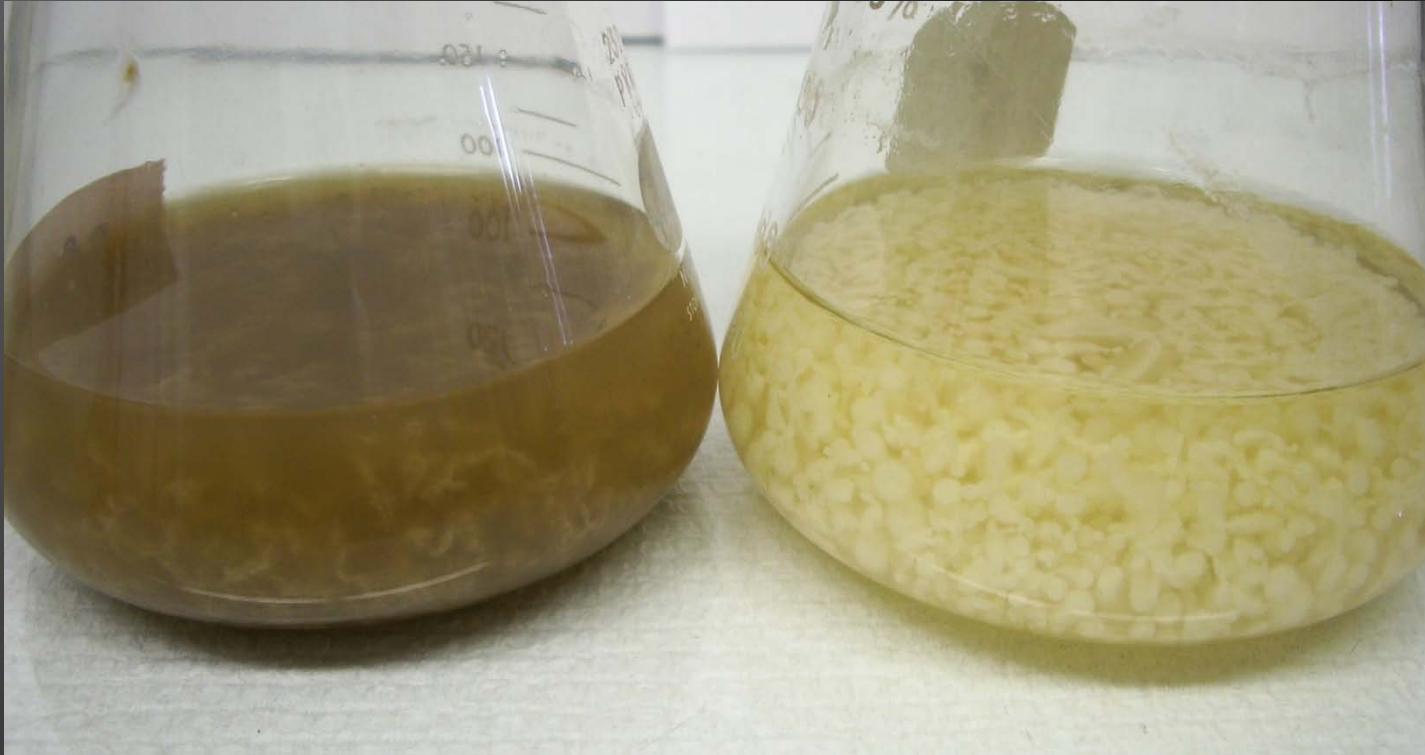
Rhizopus oligosporus could directly utilize vinasses from both molasses and sugarcane juice fermentations as substrates for its growth without any treatment or nutrient supplementation.

The optimal pH for fungal biomass production is 5.

Fungal biomass yields of 0.61 and 0.60 (g fungal biomass increase/g fungal biomass initial) were obtained from growing fungus on molasses vinasse and sugarcane juice vinasse, respectively.

SCOD removal of about 20 and 50% were obtained from effluents after harvesting fungal biomass from molasses vinasse and sugarcane juice vinasse, respectively.

Fungal Pellets



Draft-tube Batch Experiments



Aeration on



Aeration off → Floating mycelial pellets

Dried Fungal Biomass



YM medium



Sugarcane juice vinasse



Molasses vinasse

Cellulose -Ethanol: Syngas Fermentation

Lignocellulosic biomass

- 40–50% cellulose, 20–40% hemicellulose and 10–20% lignin
- can yield 60 billion gallons of fuel-grade ethanol per year in the US

Direct Fermentation

- ***Acid/enzyme hydrolysis of cellulose/hemicellulose to hexose/pentose***
- ***Ethanol fermentation from hexose/pentose***

- ***High cost of pretreatment and enzyme***
- ***Leaving lignin for disposal***

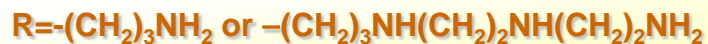
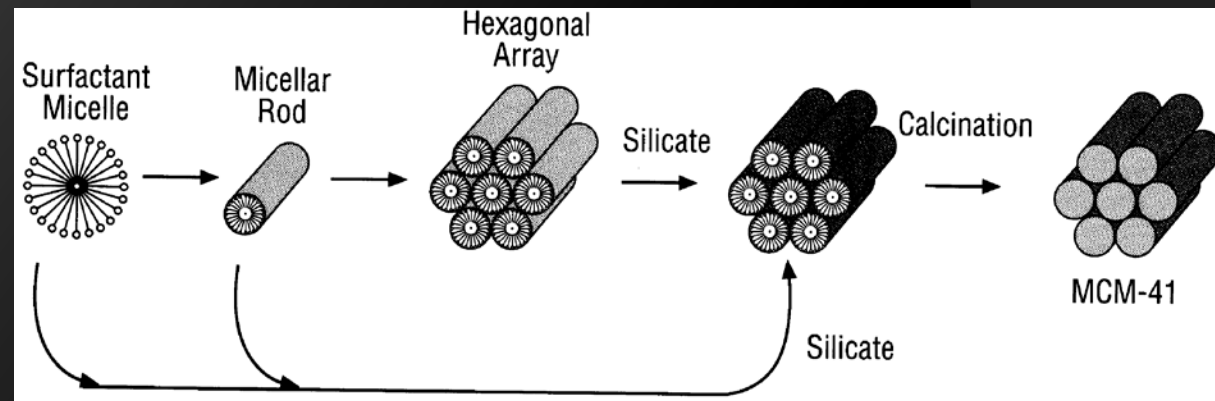
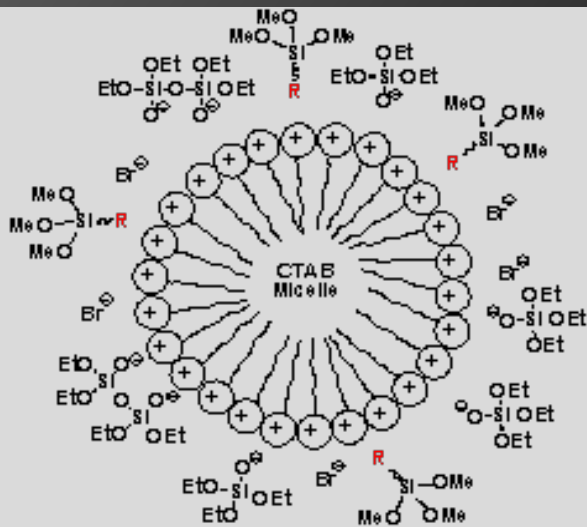
Gasification followed by Syngas fermentation

- ***Convert all the biomass to syngas (H_2+CO)***
- ***Ethanol fermentation from syngas***

- ***Gas/liquid mass transfer limitation due to poor solubility of CO and H_2***
- ***Inhibitory acetic acid as by-product***

Mesoporous Silica (MPS) functionalized by amine group

- **Parallel structure of silica having homogenous mesoporous (2-50 nm) pores**
 - **high area-to-mass ratio and accessibility**
- **Permanent bonding of amine on the silica structure**
 - **Selective adsorption of acetic acid ($-\text{NH}_3^+ \dots \text{Ac}^-$)**
 - **Regenerable by pH control**



Some Issues with Biofuels

- Potential impact on food/feed supplies due to land use.
- Possible increase in agricultural products prices (due to biofuel feedstocks production).
- Likely to impact biodiversity.
- Degradation of soil quality/soil erosion.
- Increased use of fertilizer and pesticides.
- May impact water quality and quantity.

Acknowledgements

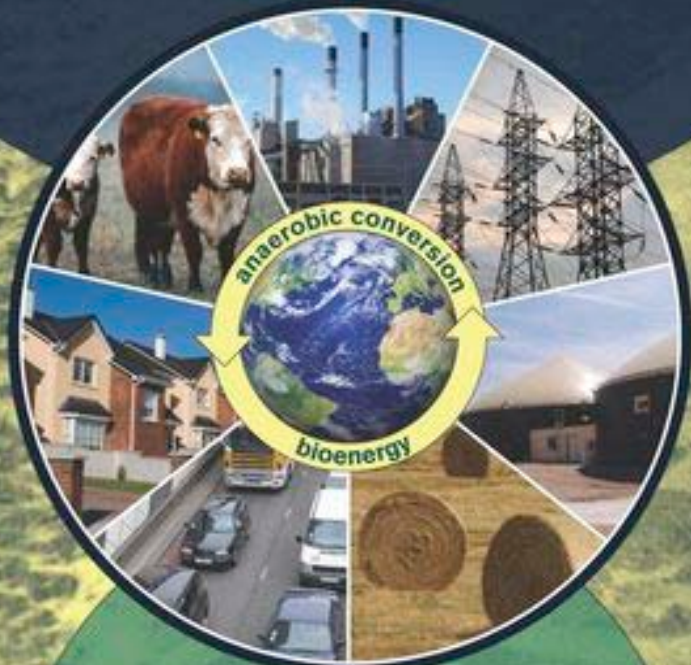
- ❖ Graduate students: Prachand Shrestha, Mary Rasmussen
- ❖ ConocoPhillips
- ❖ USDA and UDDOE
- ❖ ADM
- ❖ P&G

Books

Anaerobic Biotechnology for Bioenergy Production

PRINCIPLES AND APPLICATIONS

Samir Kumar Khanal



 Blackwell
Publishing

Biofuel and Bioenergy from Biowastes and Biomass



Samir K. Khanal (lead editor)

American Society of Civil Engineers

THANK YOU