Converting Cellulose to Biofuels
Introduction

- **Renewable Cellulosic Biomass**’s Potential
  - Reduce dependence on **imported oil**
  - Enhance **energy security**
  - Reduce **greenhouse gas** emissions

Energy Future

- **Two major conversion approaches**
  - Biochemical Processing
  - Thermochemical Processing

20% Reduction in **oil** used for **light-duty** transportation
Thermochemical process

- Biomass
- Grinder
- Energy
- Oxygen or Air, Steam
- Ash
- Gasification Reactor
  - Biosyngas, Organics, Tar, Inorganics, Particles
- Tar Cracker
  - Oxygen
  - Biosyngas, Inorganics, Particles
- Filter
  - Particles, Inorganics
  - Syngas (CO, H₂, CO₂)
Figure 1. A typical thermochemical route to biofuel involves gasification of biomass to syngas followed by catalytic Fischer-Tropsch (FT) conversion to biodiesel. Source®17)
Figure 2. Bioprocessing of lignocellulose to ethanol involves pretreatment, hydrolysis, fermentation and separation. Source; (17).
To achieve economical processes,
Key Factors are
Catalyst Robustness And Costs
Feedstock availability and composition

• **Supply of feedstock** for use in biorefineries
  - **Low density of biomass**, **transportation costs** are high, such that **40-50 miles** is the maximum distance considered economically **feasible for biomass transport**
Pretreatment required to maximize ethanol yield: Various pretreatments (acids, bases, water, steam, heat in some combination).
Table 1. Compositions of different types of cellulosic biomass and the Maximum ethanol yields possible for each of the compositions.

<table>
<thead>
<tr>
<th>Feedstock Composition</th>
<th>Poplar</th>
<th>Red Maple</th>
<th>Corn Stover</th>
<th>Switchgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>43.8%</td>
<td>41.0%</td>
<td>34.6%</td>
<td>33.2%</td>
</tr>
<tr>
<td>Xylen</td>
<td>14.9%</td>
<td>15.0%</td>
<td>18.3%</td>
<td>21.0%</td>
</tr>
<tr>
<td>Arabinan, Mannan, Galactan</td>
<td>5.6%</td>
<td>0.0%</td>
<td>2.5%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Acetyl</td>
<td>3.6%</td>
<td>4.7%</td>
<td>Not Available</td>
<td>2.5%</td>
</tr>
<tr>
<td>Extractives</td>
<td>3.6%</td>
<td>3.0%</td>
<td>10.8%</td>
<td>10.2%</td>
</tr>
<tr>
<td>Protein</td>
<td>Not Available</td>
<td>Not Available</td>
<td>Not Available</td>
<td>5.7%</td>
</tr>
<tr>
<td>Lignin</td>
<td>29.1%</td>
<td>29.1%</td>
<td>17.7%</td>
<td>17.9%</td>
</tr>
<tr>
<td>Ash</td>
<td>1.1%</td>
<td>1.0%</td>
<td>10.2%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Total</td>
<td>101.7%</td>
<td>93.8%</td>
<td>94.1%</td>
<td>97.4%</td>
</tr>
</tbody>
</table>

Estimated Maximum Ethanol Yield, gal/dry ton biomass: 111, 97, 95, 99

Theoretical maximum yield (per short ton), assuming 100% hydrolysis and 100% fermentation

Data from Laboratory of Renewable Resources Engineering, Perdue Univ.
Biochemical processing

- The processing of cellulosic biomass requires five steps, as illustrated in Fig 3.
  1. Feedstock preparation
  2. Pretreatment
  3. Hydrolysis
  4. Fermentation
  5. Distillation

**Fig 3.** The basic unit operations in a biorefinery.
Consolidated bioprocessing (CBP)

- Feedstock Supply
- Pretreatment
- Consolidated Bioprocessing (CBP)
- Distillation And Storage

Fig 4. Consolidated bioprocessing combines hydrolysis and fermentation in a single vessel using a microorganism genetically engineered specifically for these dual purposes.
Microorganisms for ethanol fermentation

*Saccharomyces* is a genus in the kingdom of fungi that includes many species of yeast. Many members of this genus are considered very important in food production. One example is *Saccharomyces cerevisiae*, which is used in making wine, bread, and beer. Other members of this genus include *Saccharomyces bayanus*, used in making wine, and *Saccharomyces boulardii*, used in medicine.

**Why?**
- Produce ethanol at **high concentrations**
- Perform **reliably in commercial** starch-to-ethanol facilities
- Glucose into ethanol under **anaerobic conditions** (Embden-Meyerhof pathway)
- Making **CO₂** as a byproduct

**Characteristics**
- Tolerant of **inhavitors and products**
- **Consume** a wide range of **substrates** (both hexose and pentose sugars)
- High productivity to result in **high yield**
Fermentation inhibitors

- The major inhibitors present in biomass hydrolysates
  - Weak acids
  - Furan derivatives (Furfural and 5-hydroxymethylfurural)
    - Result from the degradation of the sugars found in the hemicellulose and cellulose fractions during processing
  - Phenolic
- Effects
  - Negatively affect product yield
  - Negatively Volumetric productivity (grams of product per liter per hour)

Enzyme inhibitors

- Constitue a major cost in the bioconversion of cellulose to ethanol
  - Nonproductive adsorption of enzyme onto lignocellulosic substrates prior to reaction
  - Intermediate and end-product inhibition
  - Mass-transfer limitations affecting the transport of the enzyme to and from insoluble substrates
  - The distribution of lignin in the cell wall
  - The presence of hemicellulose, phenolic compounds, proteins and fats
  - Lignocellulose particle size
  - And crystallinity and degree of polymerization of the cellulose substrate
Summary

- Ethanol is produced in large quantities, and an estimate 12 billion gal will be derived from corn in 2010.
- Since the cellulosic portion of the corn kernel is a potential source of an advanced biofuels as well Cellulosic ethanol is likely to be the first such fuel on the market.
- The technologies to process wood and other lignocellulosic feedstocks currently under development will enable the rapid expansion of cellulosic ethanol production from non-food feedstocks and lead the way for other advanced biofuels over the next ten years.