Outline

- Needs
- Objective
- Curriculum development
  - Class room
  - Laboratories
- Deliverables
Need

- **Ethanol plants**
  - 189 in operation
  - 16 planned/construction
  - 10.75 billion gallons of ethanol fuel in 2009

- **Biodiesel plants**
  - 144 plants in operation
  - 51 plants idle +9 plants under construction
  - 2.69 billions gallons/year

- 163,000 workers are in jobs related to the biofuels industry

- **Cellulosic /advanced biofuel plants**
Need

- The complexity and interactions within systems such as biorefineries are difficult to demonstrate, much less simulate in a traditional classroom.
- The innovation of the “the development of new teaching strategies based in virtual reality technology” which will give students hands-on experience and knowledge not otherwise available.
- Virtual reality simulation software package that “looks and feels” like a real biofuel facility.
The deliverables of this project include:

- A simulation software package for biorefineries.
- A course package that can be used either in the classroom or a Web-based environment.
- A training course and package for those teaching this course in the future.

The outcomes/impacts will include:

- Improved student readiness for jobs in the biofuels industry.
- Accelerated biofuel facility operator independence.
- Improved optimization of biofuel production.
### Course outline

**Biorenewable Resources and Technology program designed to teach biofuel plant operations**

<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
<th>Laboratory Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review of conversion of biomass to fuels</td>
<td>Lab safety/simulator introduction</td>
</tr>
<tr>
<td>2</td>
<td>Biofuels, ecology, biomass, environmental issues</td>
<td>Enzymatic reaction kinetics, fermentations, esterification, distillation</td>
</tr>
<tr>
<td>3</td>
<td>Heat transfer (Convection and conduction)</td>
<td>Plant tour/dry grinding</td>
</tr>
<tr>
<td>4</td>
<td>Mass transfer (Newtonian and Non-Newtonian)</td>
<td>Biofuel characterization</td>
</tr>
<tr>
<td>5</td>
<td>Biofuel plant operation 1 (start up)</td>
<td>Group simulation exercises</td>
</tr>
<tr>
<td>6</td>
<td>Biofuel plant operation 2 (optimization)</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>7</td>
<td>Biofuel plant operation 2 (crash recovery)</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>8</td>
<td>Coupled heat and mass transfer</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>9</td>
<td>Unit operations 1</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>10</td>
<td>Unit operations 2</td>
<td>Simulation exercises</td>
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<tr>
<td>11</td>
<td>Unit operations 3</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>12</td>
<td>Energy balance</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>13</td>
<td>Biofuel plant design and staff, location and requirements, safety</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>14</td>
<td>Regulations 1</td>
<td>Simulation exercises</td>
</tr>
<tr>
<td>15</td>
<td>Regulations 2 and public relations</td>
<td>Quality Management Systems</td>
</tr>
</tbody>
</table>
\[ \begin{align*}
q_x^{cd}(dzdy) - q_{x+dx}^{cd}(dzdy) \\
+q_z^{cd}(dxdy) - q_{z+dz}^{cd}(dxdy) + q_y^{cd}(dxdz) - q_{y+dy}^{cd}(dxdz) = \rho C_d \theta / dtd(xdxdydz) \\
+Q(dx dy dz)
\end{align*} \]
Continuity Equation

\[ \text{dx} \times \text{dz} \]

\[ \rho \nu_{z+dz} \]

\[ \rho \nu_{y+dy} \]

\[ \rho \nu_{x+dx} \]

\[ \rho \nu_x \]

\[ \rho \nu_y \]

\[ \rho \nu_z \]

\[ \frac{d\rho}{dt} = \frac{\partial}{\partial x} (\rho \nu_x) + \frac{\partial}{\partial y} (\rho \nu_y) + \frac{\partial}{\partial z} (\rho \nu_z) = 0 \]
Simulator

- Labview environment
- Two packages
  - Corn to ethanol
  - Plant oil OR animal fat to biodiesel
- Two operators
- Three computers
  - Two simulators
  - One master (video and I/O)
- Text message enabled
- 42” flat panel security loop
- Alarms
I-BOS room
I-BOS room (Interactive Biorefinery Operations Simulation (I-Bos))
Simulator algorithms

- Mass and energy balance
- 1 kg elements
  - Composition
  - Energy
- Outcomes and measurables
  - Biofuel production
  - Energy
  - Efficiency
  - Recovery
Fermentation Transfer Functions

**Biomass, X**

\[
\frac{dX}{dt} = -F(X) + \left[ \frac{\left( \mu_{max} \right) (S)}{K_S + S} \right] \left( 1 - \frac{P}{P^*} \right)^n (X)
\]

**Glucose, S**

\[
\frac{dS}{dt} = F(S_f) - \frac{1}{Y_X} \left[ \frac{\left( \mu_{max} \right) (S)}{K_S + S} \right] \left( 1 - \frac{P}{P^*} \right)^n (X)
\]

\[
+ \frac{1}{Y_S} \left[ \frac{ \left( R_{DP_4} \right) (DP_4) }{ K_{DP_4} + DP_4 } \right] + \frac{1}{Y_S} \left[ \frac{ \left( R_{DP_3} \right) (DP_3) }{ K_{DP_3} + DP_3 } \right]
\]

\[
+ \frac{1}{Y_S} \left[ \frac{ \left( R_{DP_2} \right) (DP_2) }{ K_{DP_2} + DP_2 } \right]
\]

**Ethanol, P**

\[
\frac{dP}{dt} = -F(P) + \frac{Y_P}{X} \left[ \frac{\left( \mu_{max} \right) (S)}{K_S + S} \right] \left( 1 - \frac{P}{P^*} \right)^n (X)
\]

**Starch Intermediates, DP_4**

\[
\frac{dDP_4}{dt} = F(DP_4)_f - \frac{1}{Y_S} \left[ \frac{ \left( R_{DP_4} \right) (DP_4) }{ K_{DP_4} + DP_4 } \right]
\]

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Biomass</td>
<td>Concentration</td>
</tr>
<tr>
<td>F</td>
<td>Feed rate</td>
<td>1/time</td>
</tr>
<tr>
<td>(\mu_{max})</td>
<td>Maximum specific growth rate</td>
<td>1/time</td>
</tr>
<tr>
<td>S</td>
<td>Substrate (glucose)</td>
<td>Concentration</td>
</tr>
<tr>
<td>(K_S)</td>
<td>Monod coefficient</td>
<td>Concentration</td>
</tr>
<tr>
<td>P</td>
<td>Product (ethanol)</td>
<td>Concentration</td>
</tr>
<tr>
<td>(P^*)</td>
<td>Maximum product (ethanol)</td>
<td>Concentration</td>
</tr>
<tr>
<td>n</td>
<td>Exponent</td>
<td>unitless</td>
</tr>
<tr>
<td>(S_f)</td>
<td>Substrate (glucose)</td>
<td>Concentration</td>
</tr>
<tr>
<td>((DP_4)_f)</td>
<td>DP_4 concentration in the feed</td>
<td>Concentration</td>
</tr>
<tr>
<td>(Y_{X/S})</td>
<td>Yield ratio of biomass to glucose</td>
<td>Concentration/concentration</td>
</tr>
<tr>
<td>(Y_{S/DP_4})</td>
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<tr>
<td>(R_{DP_4})</td>
<td>Reaction rates of DP4</td>
<td>Concentration/time</td>
</tr>
<tr>
<td>(K_{DP_4})</td>
<td>Michaelis Menten Constants of DP4</td>
<td>Concentration</td>
</tr>
</tbody>
</table>
**Fermentation Transfer Functions**

**Starch Intermediates, DP₃, DP₂**

\[
\frac{dDP_3}{dt} = F (DP_3)_f - \frac{1}{Y_{S/DP3}} \frac{S}{K_{DP3} + DP_3} \left[ \frac{R_{DP3}(DP_3)}{K_{DP3} + DP_3} \right]
\]

\[
\frac{dDP_2}{dt} = F (DP_2)_f - \frac{1}{Y_{S/DP2}} \frac{S}{K_{DP2} + DP_2} \left[ \frac{R_{DP2}(DP_2)}{K_{DP2} + DP_2} \right]
\]

**Lactic Acid, LA**

\[
\frac{d(LA)}{dt} = -F(LA) + Y_{LA/X} \left( \frac{\mu_{max}(S)}{K_s + S} \right)
\]

**Acetic Acid, AA**

\[
\frac{d(AA)}{dt} = -F(AA) + Y_{AA/X} \left( \frac{\mu_{max}(S)}{K_s + S} \right)
\]

**Glycerol Acid, Gly**

\[
\frac{d(Gly)}{dt} = -F(Gly) + Y_{Gly/X} \left( \frac{\mu_{max}(S)}{K_s + S} \right)
\]

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<td>Monod coefficient</td>
<td>Concentration</td>
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<tr>
<td>((DP₃)_f)</td>
<td>DP₃ concentration in the feed</td>
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</tr>
<tr>
<td>((DP₂)_f)</td>
<td>DP₂ concentration in the feed</td>
<td>Concentration</td>
</tr>
<tr>
<td>(Y_{S/DP3})</td>
<td>Yield ratio of glucose to DP₃</td>
<td>Concentration/concentration</td>
</tr>
<tr>
<td>(Y_{S/DP2})</td>
<td>Yield ratio of glucose to DP₂</td>
<td>Concentration/concentration</td>
</tr>
<tr>
<td>(Y_{LA/X})</td>
<td>Yield ratio of lactic acid to biomass</td>
<td>Concentration/concentration</td>
</tr>
<tr>
<td>(Y_{AA/X})</td>
<td>Yield ratio of acetic acid to biomass</td>
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</tr>
<tr>
<td>(Y_{Gly/X})</td>
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<tr>
<td>(R_{DP3})</td>
<td>Reaction rates of DP₃</td>
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</tr>
<tr>
<td>(R_{DP2})</td>
<td>Reaction rates of DP₂</td>
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</tr>
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<td>(K_{DP3})</td>
<td>Michealis Menten Constants of DP₃</td>
<td>Concentration</td>
</tr>
<tr>
<td>(K_{DP2})</td>
<td>Michealis Menten Constants of DP₂</td>
<td>Concentration</td>
</tr>
</tbody>
</table>
Code for fermentation (high level)
Code for fermentation (low level)

\[ \varepsilon = \left( \frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1} \right)^n - 1 \left( \frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1} \right) \]

\[ \varepsilon_1 = 2 \left( 1 + C_r + (1 + C_r^2)^{1/2} \right) \times \frac{1 + \exp \left[ -\left( NTU_1 (1 + C_r^2)^{1/2} \right) \right]}{1 - \exp \left[ -\left( NTU_1 (1 + C_r^2)^{1/2} \right) \right]} \]

where \( NTU_1 = \frac{NTU}{n} \)
Code for milling (front panel)
Code for milling (front panel)
Status

- Ethanol is 90% complete
- Biodiesel is 80% complete
- Need to validate software
- 1st class planned spring 2011
- Online summer of 2011
Questions/Discussions

- Thanks
- USDA Higher Education Challenge Grant
- Crown Iron
- Emerson Electric
- Lincoln Way Energy
- CCUR
- Fastek