BIO-FUELS UNIT OPERATIONS COURSE DEVELOPMENT

IOWA STATE UNIVERSITY

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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

John M. Urbanchuk CONTRIBUTION OF THE ETHANOL INDUSTRY TO THE ECONOMY OF THE UNITED STATES, Prepared for the Renewable Fuels Association, LECG LLC, February 19, 2007

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

Deliverables/impacts

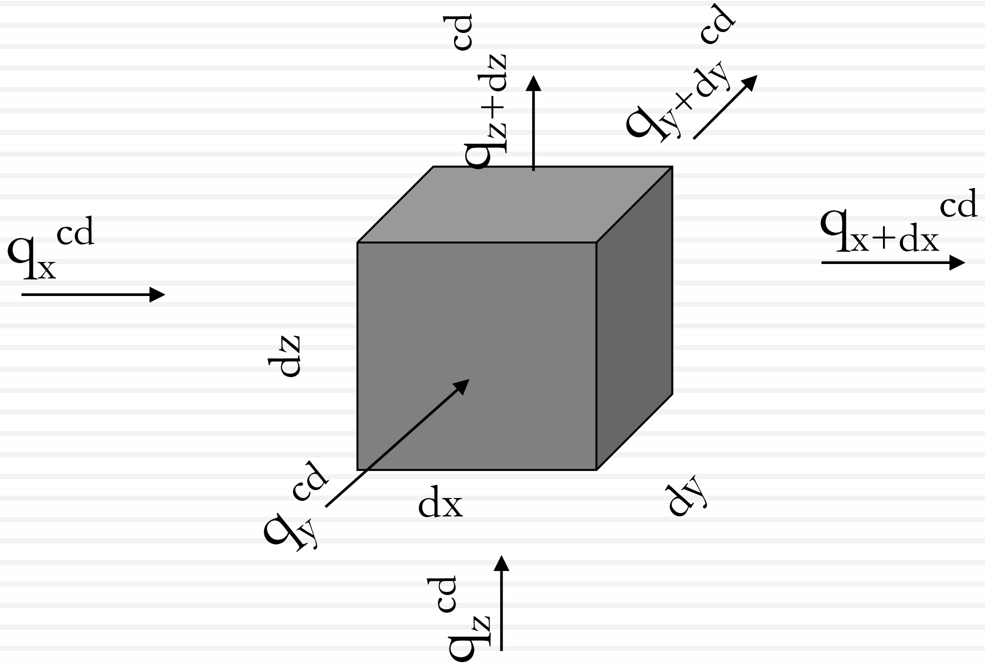
- The deliverables of this project include:
  - A simulation software package for biorefineries.
  - A course package that can be used either in the classroom or a Web-based environment.
  - A training course and package for those teaching this course in the future.
- The outcomes/impacts will include:
  - 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

Week	Topics	Laboratory Exercise
1	Review of conversion of biomass to fuels	Lab safety/simulator introduction
2	Biofuels, ecology, biomass, environmental issues	Enzymatic reaction kinetics, fermentations, esterfication, distillation
3	Heat transfer (Convection and conduction)	Plant tour/dry grinding
4	Mass transfer (Newtonian and Non-Newtonian)	Biofuel characterization
5	Biofuel plant operation 1 (start up)	Group simulation exercises
6	Biofuel plant operation 2 (optimization)	Simulation exercises
7	Biofuel plant operation 2 (crash recovery)	Simulation exercises
8	Coupled heat and mass transfer	Simulation exercises
9	Unit operations 1	Simulation exercises
10	Unit operations 2	Simulation exercises
11	Unit operations 3	Simulation exercises
12	Energy balance	Simulation exercises
13	Biofuel plant design and staff, location and requirements, safety	Simulation exercises
14	Regulations 1	Simulation exercises
15	Regulations 2 and public relations	Quality Management Systems

Lecture Slide



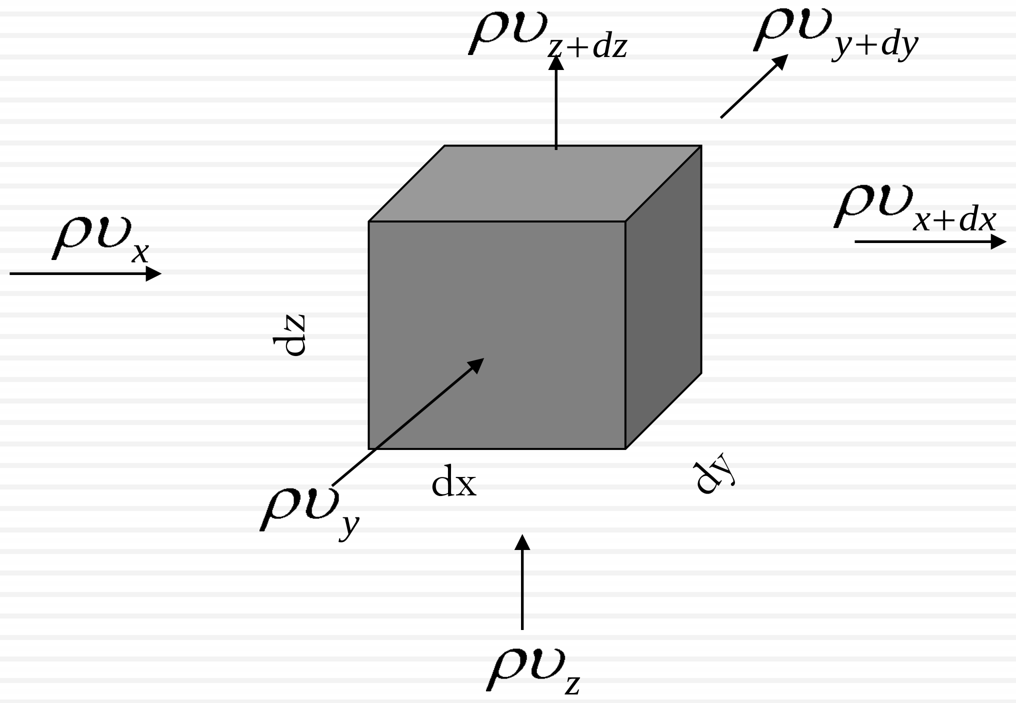
$$q_x^{cd}(dzdy) - q_{x+dx}^{cd}(dzdy)$$

$$+q_z^{cd}(dxdy) - q_{z+dz}^{cd}(dxdy) + q_y^{cd}(dxdz) - q_{y+dy}^{cd}(dxdz) = \rho C d\theta/dt(dxdydz)$$

$$+Q(dxdydz)$$

Lecture Slide

Continuity Equation



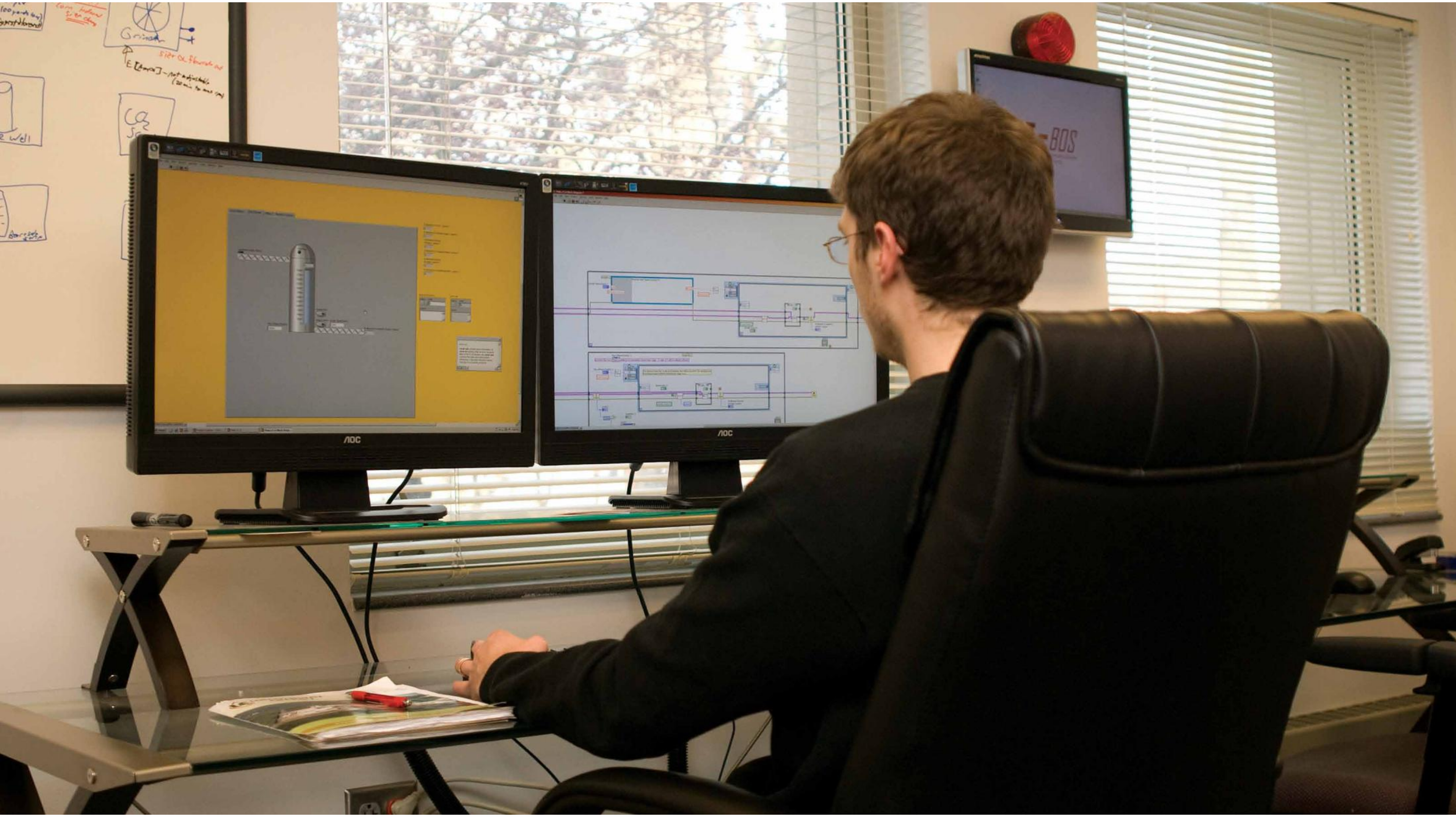
$$dxdydz\frac{d\rho}{dt} = dydz\upsilon_x\rho - dydz\upsilon_{x+dx}\rho + dxdz\upsilon_y\rho - dxdz\upsilon_{y+dy}\rho + dxdy\upsilon_z\rho - dxdy\upsilon_{z+dz}\rho$$

$$\frac{d\rho}{dt} + \frac{\partial}{\partial x}(\rho\upsilon_x) + \frac{\partial}{\partial y}(\rho\upsilon_y) + \frac{\partial}{\partial z}(\rho\upsilon_z) = 0$$

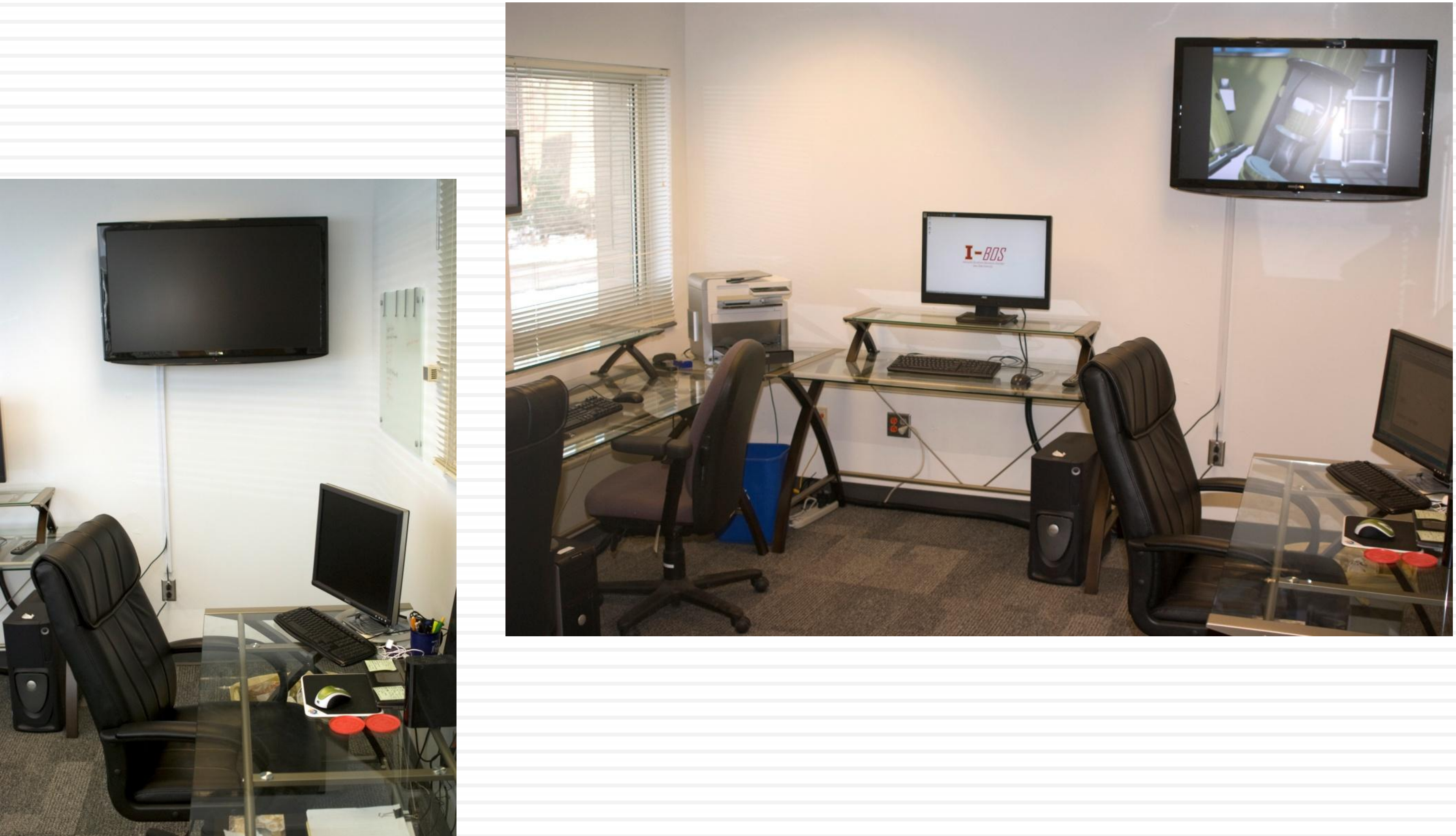
Simulator

- 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

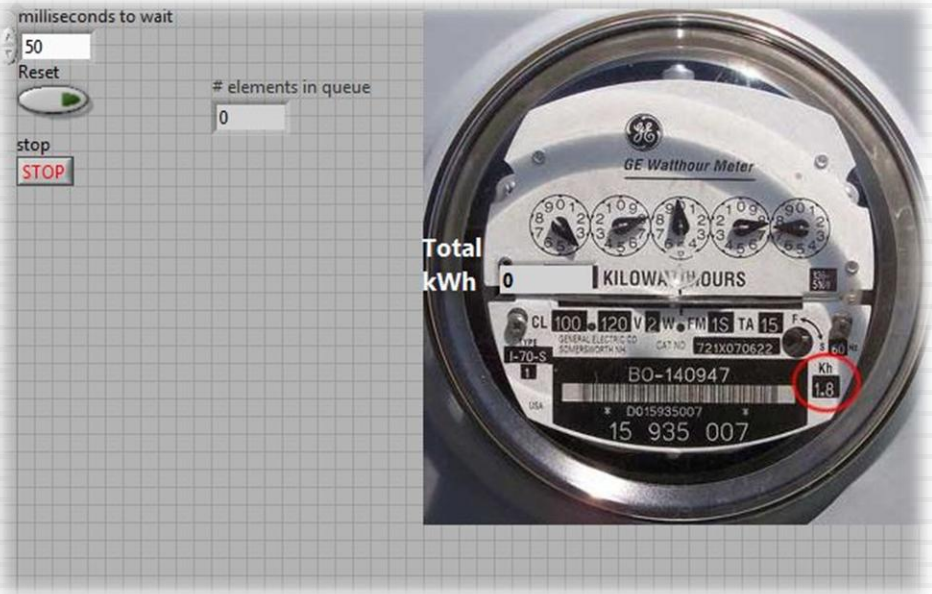


I-BOS room (Interactive Biorefinery Operations Simulation (I-Bos))



Simulator algorithms

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


milliseconds to wait: 50

elements in queue: 0

Total kWh: 0

Fermentation Transfer Functions

Biomass, X

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

Glucose, S

$$\frac{dS}{dt} = F(S_f) - \frac{1}{Y_{\frac{X}{S}}}\left[\frac{(\mu_{max})(S)}{K_s + S}\right]\left(1 - \frac{P}{P^*}\right)^n (X) + \frac{1}{Y_{\frac{S}{DP_4}}}\left[\frac{(R_{DP_4})(DP_4)}{K_{DP_4} + DP_4}\right] + \frac{1}{Y_{\frac{S}{DP_3}}}\left[\frac{(R_{DP_3})(DP_3)}{K_{DP_3} + DP_3}\right] + \frac{1}{Y_{\frac{S}{DP_2}}}\left[\frac{(R_{DP_2})(DP_2)}{K_{DP_2} + DP_2}\right]$$

Ethanol, P

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

Starch Intermediates, DP_4

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

Model	Description	Units
X	Biomass	Concentration
F	Feed rate	1/time
μ_{max}	Maximum specific growth rate	1/time
S	Substrate (glucose)	Concentration
K_s	Monod coefficient	Concentration
P	Product (ethanol)	Concentration
P*	Maximum product (ethanol)	Concentration
n	Exponent	unitless
S_f	Substrate (glucose) concentration in the feed	Concentration
$(DP_4)_f$	DP_4 concentration in the feed	Concentration
$Y_{X/S}$	Yield ratio of biomass to glucose	Concentration/ concentration
$Y_{S/DP4}$	Yield ratio of glucose to DP_4	Concentration/ concentration
$Y_{P/X}$	Yield ratio of ethanol to biomass	Concentration/ concentration
R_{DP4}	Reaction rates of DP4	Concentration/ time
K_{DP4}	Michaelis Menten Constants of DP4	Concentration

Fermentation Transfer Functions

Starch Intermediates, DP_3, DP_2

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

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

Lactic Acid, LA

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

Acetic Acid, AA

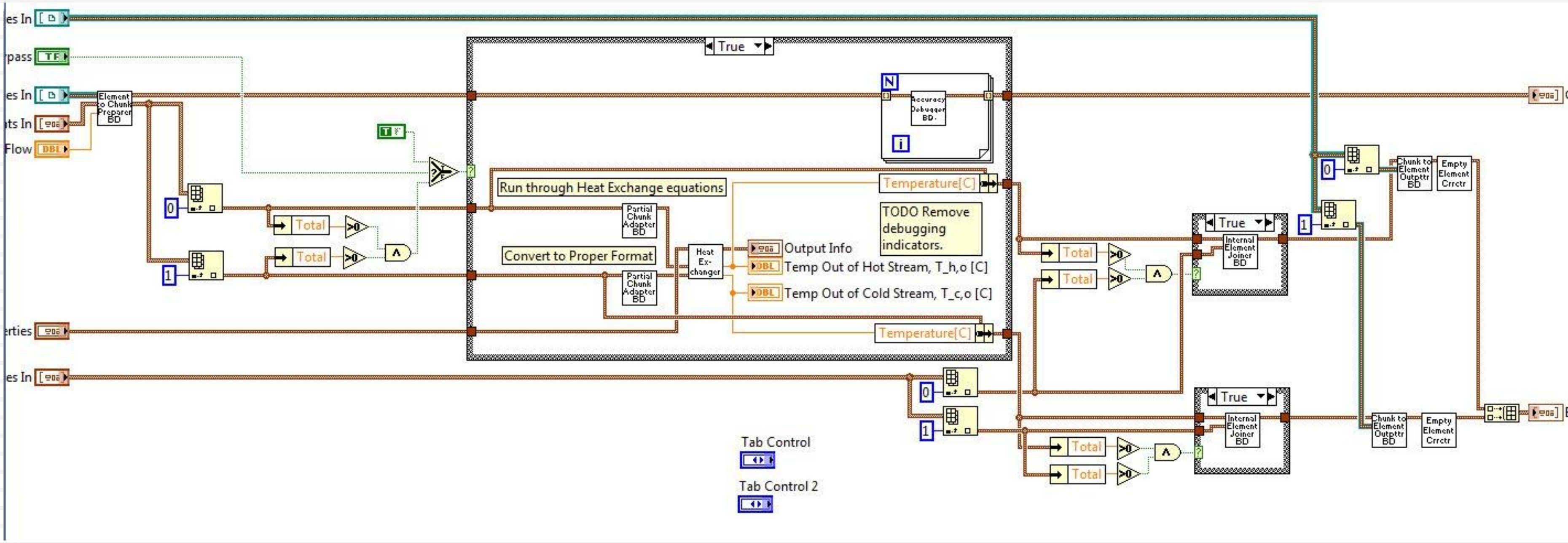
$$\frac{d(AA)}{dt} = -F(AA) + Y_{\frac{AA}{X}}\left[\frac{(\mu_{max})(S)}{K_s + S}\right]$$

Glycerol Acid, Gly

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

Model	Description	Units
F	Feed rate	1/time
μ_{max}	Maximum specific growth rate	1/time
S	Substrate (glucose)	Concentration
K_s	Monod coefficient	Concentration
$(DP_3)_f$	DP_3 concentration in the feed	Concentration
$(DP_2)_f$	DP_2 concentration in the feed	Concentration
$Y_{S/DP3}$	Yield ratio of glucose to DP_3	Concentration/concentration
$Y_{S/DP3}$	Yield ratio of glucose to DP_2	Concentration/concentration
$Y_{LA/X}$	Yield ratio of lactic acid to biomass	Concentration/concentration
$Y_{AA/X}$	Yield ratio of acetic acid to biomass	Concentration/concentration
$Y_{Gly/X}$	Yield ratio of glycerol to biomass	Concentration/concentration
R_{DP3}	Reaction rates of DP3	Concentration/time
R_{DP2}	Reaction rates of DP2	Concentration/time
K_{DP3}	Michealis Menten Constants of DP3	Concentration
K_{DP2}	Michealis Menten Constants of DP2	Concentration

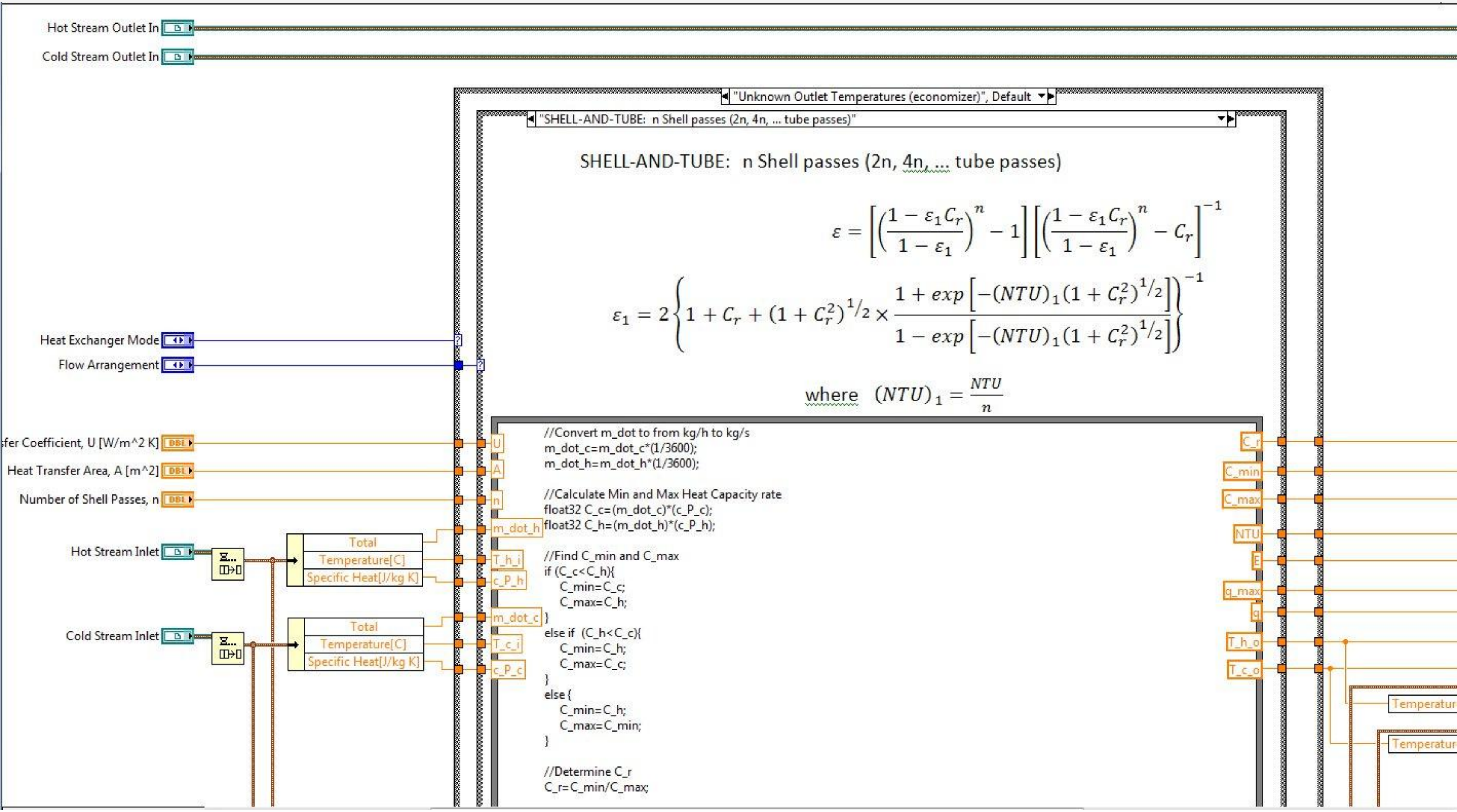
Code for fermentation (high level)


Run through Heat Exchange equations

Convert to Proper Format

TODO Remove debugging indicators.

Code for fermentation (low level)



SHELL-AND-TUBE: n Shell passes (2n, 4n, ... tube passes)

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

$$\varepsilon_1 = 2\left\{1 + C_r + (1 + C_r^2)^{1/2} \times \frac{1 + exp\left[-(NTU)_1(1 + C_r^2)^{1/2}\right]}{1 - exp\left[-(NTU)_1(1 + C_r^2)^{1/2}\right]}\right\}^{-1}$$

where $(NTU)_1 = \frac{NTU}{n}$

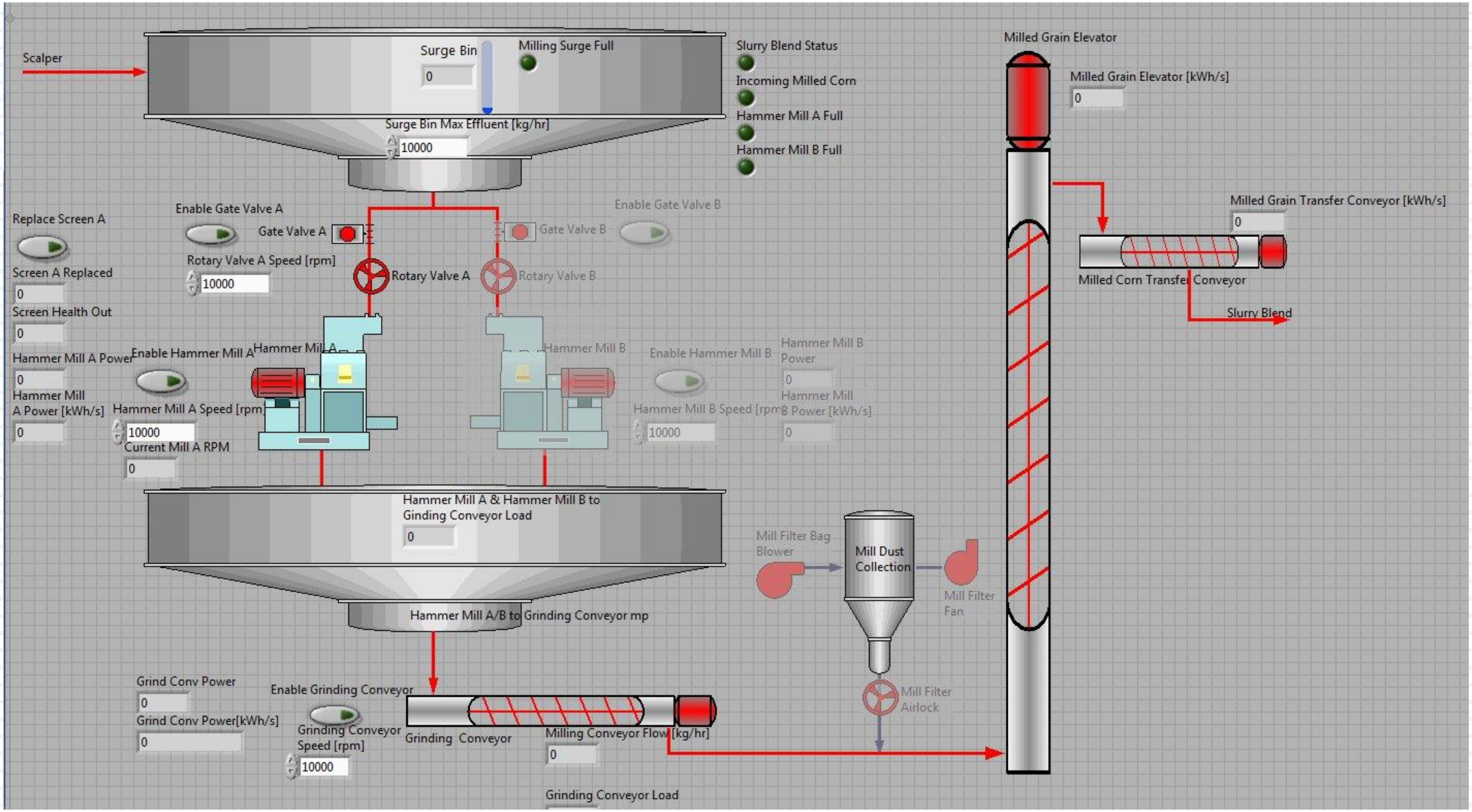
```
//Convert m_dot to from kg/h to kg/s
m_dot_c=m_dot_c*(1/3600);
m_dot_h=m_dot_h*(1/3600);

//Calculate Min and Max Heat Capacity rate
float32 C_c=(m_dot_c)*(c_P_c);
float32 C_h=(m_dot_h)*(c_P_h);

//Find C_min and C_max
if (C_c<C_h){
    C_min=C_c;
    C_max=C_h;
}
else if  (C_h<C_c){
    C_min=C_h;
    C_max=C_c;
}
else {
    C_min=C_h;
    C_max=C_min;
}

//Determine C_r
C_r=C_min/C_max;
```

Code for milling (front panel)



Surge Bin
0

Surge Bin Max Effluent [kg/hr]
10000

Milled Grain Elevator [kWh/s]
0

Milled Grain Transfer Conveyor [kWh/s]
0

Screen A Replaced
0

Screen Health Out
0

Rotary Valve A Speed [rpm]
10000

Hammer Mill A Power
0

Hammer Mill A Power [kWh/s]
0

Hammer Mill A Speed [rpm]
10000

Current Mill A RPM
0

Hammer Mill B Power
0

Hammer Mill B Speed [rpm]
10000

Hammer Mill B Power [kWh/s]
0

Hammer Mill A & Hammer Mill B to Ginding Conveyor Load
0

Grind Conv Power
0

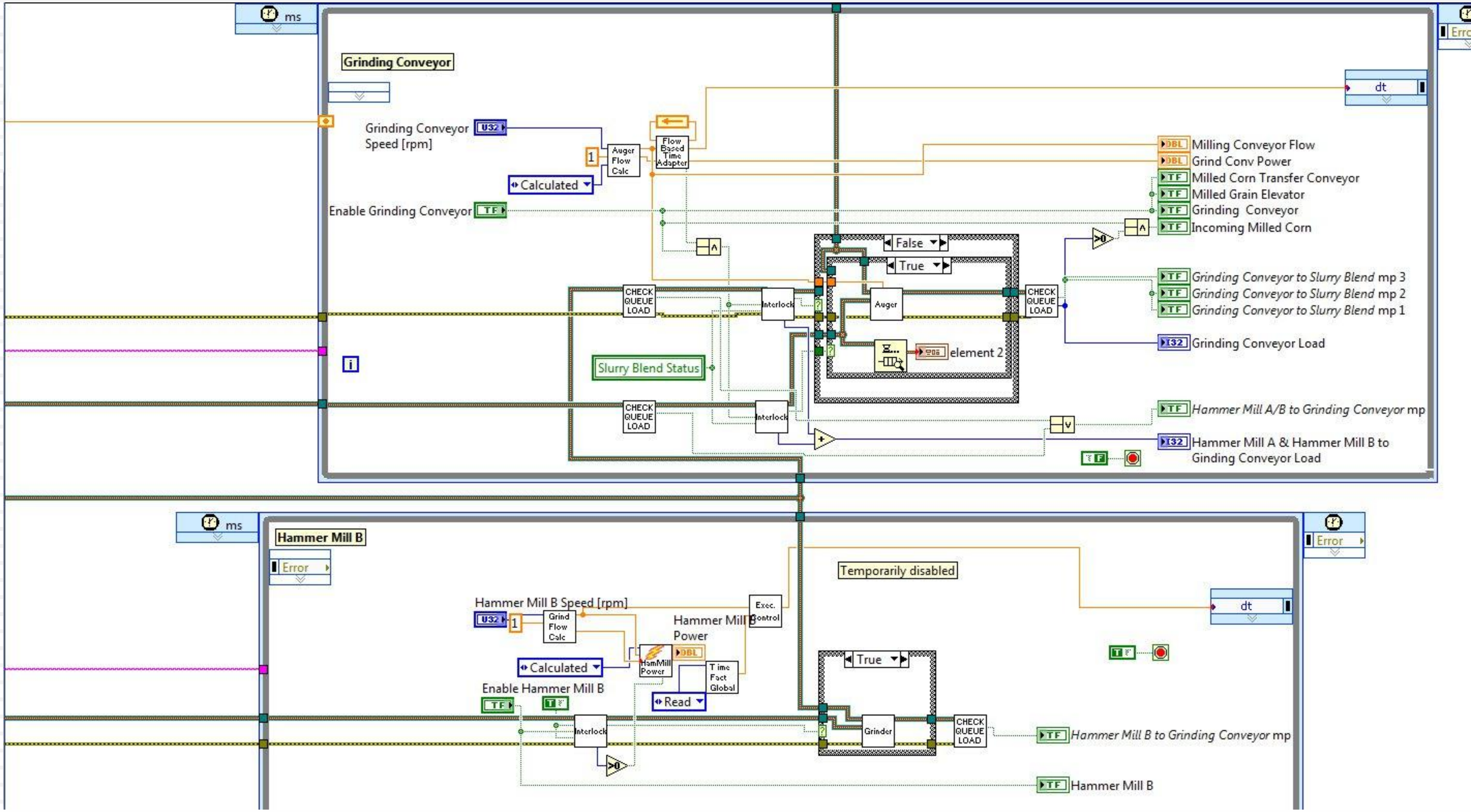
Grind Conv Power[kWh/s]
0

Grinding Conveyor Speed [rpm]
10000

Milling Conveyor Flow [kg/hr]
0

Grinding Conveyor Load

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