Review of Ethanol Production Process

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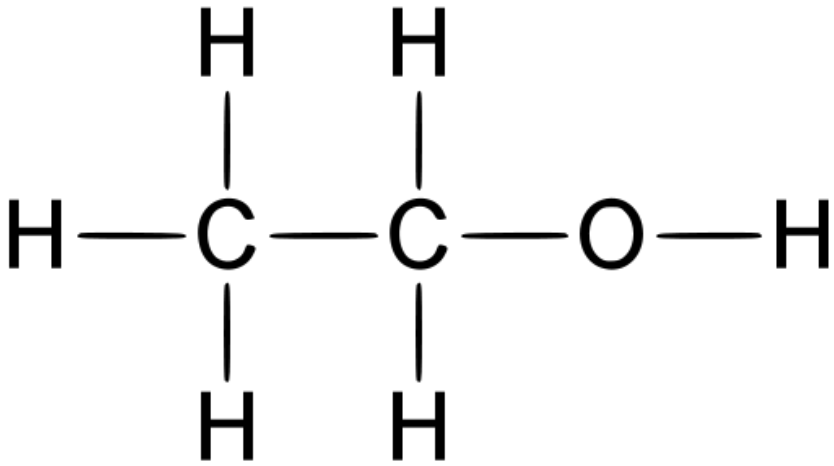
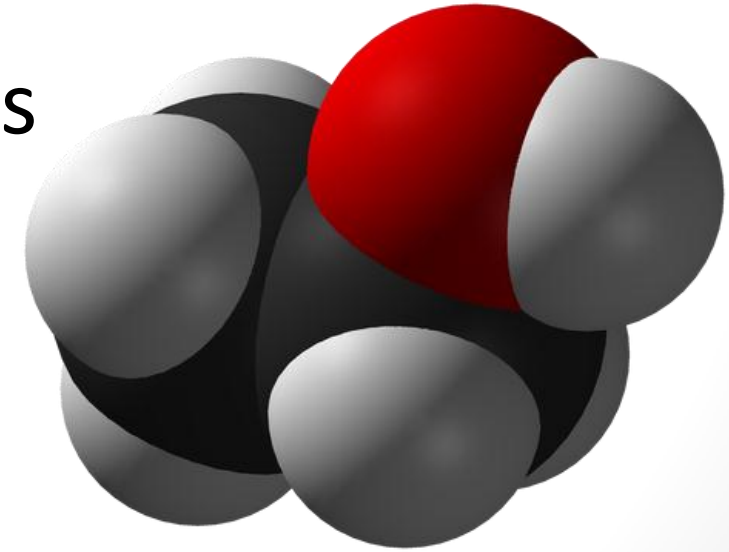


http://www.mrteverett.com/Chemistry/isomerism/isomers.asp

Overview

- Introduction
- Simple Flow Chart
- Complex Flow Chart
- Our Unit Operations
- Cost Analysis
- Conclusion
- References



http://0.tqn.com/d/chemistry/1/7/1/d/ethanol.jpg

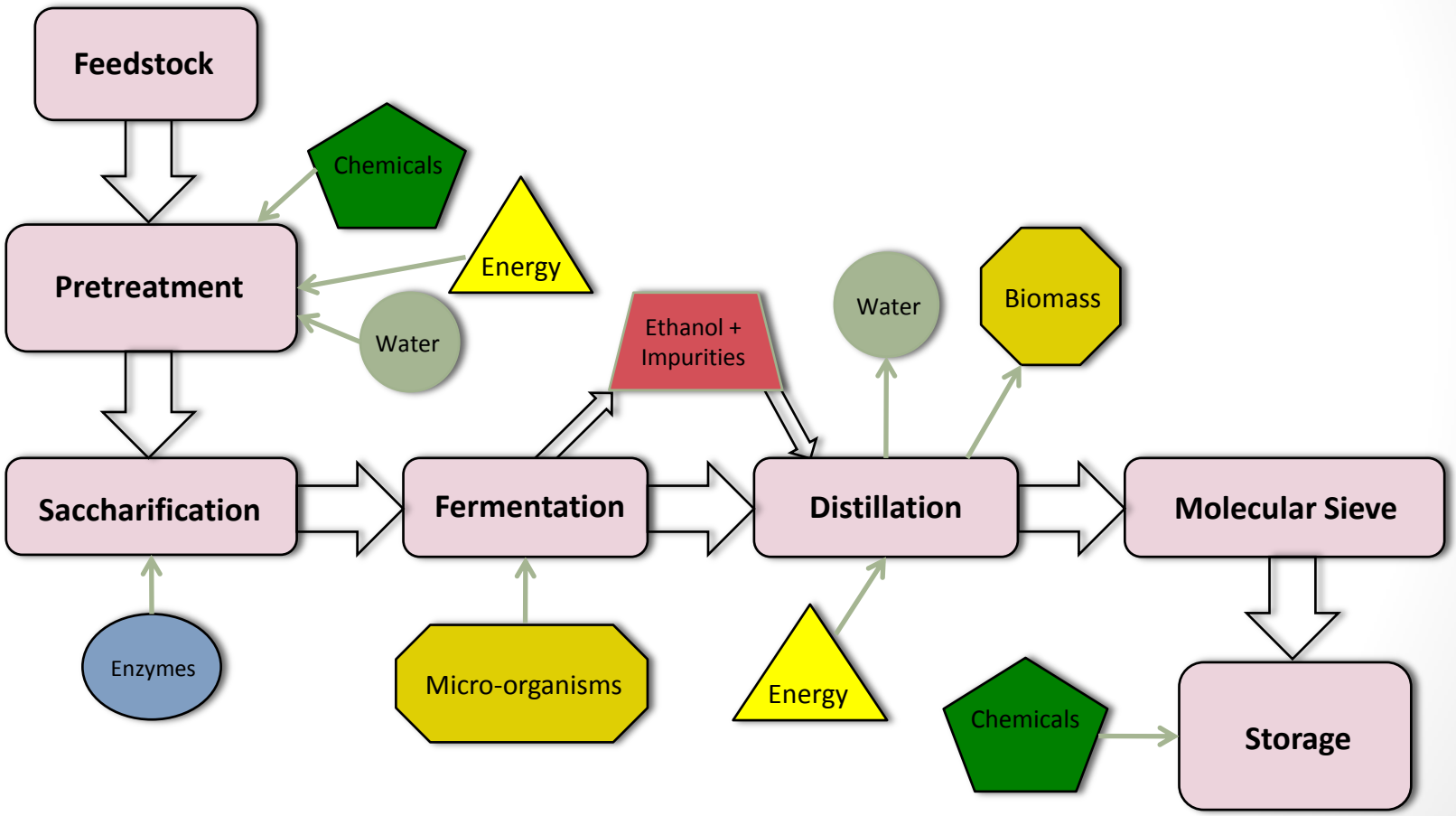
Introduction

- Ethanol has existed as a significant fuel for more than 100 years.
  - Model T
- Demand for ethanol increased during World War I as fuel needs increased.
- Ethanol is again gaining popularity as an alternative Automobile fuel.

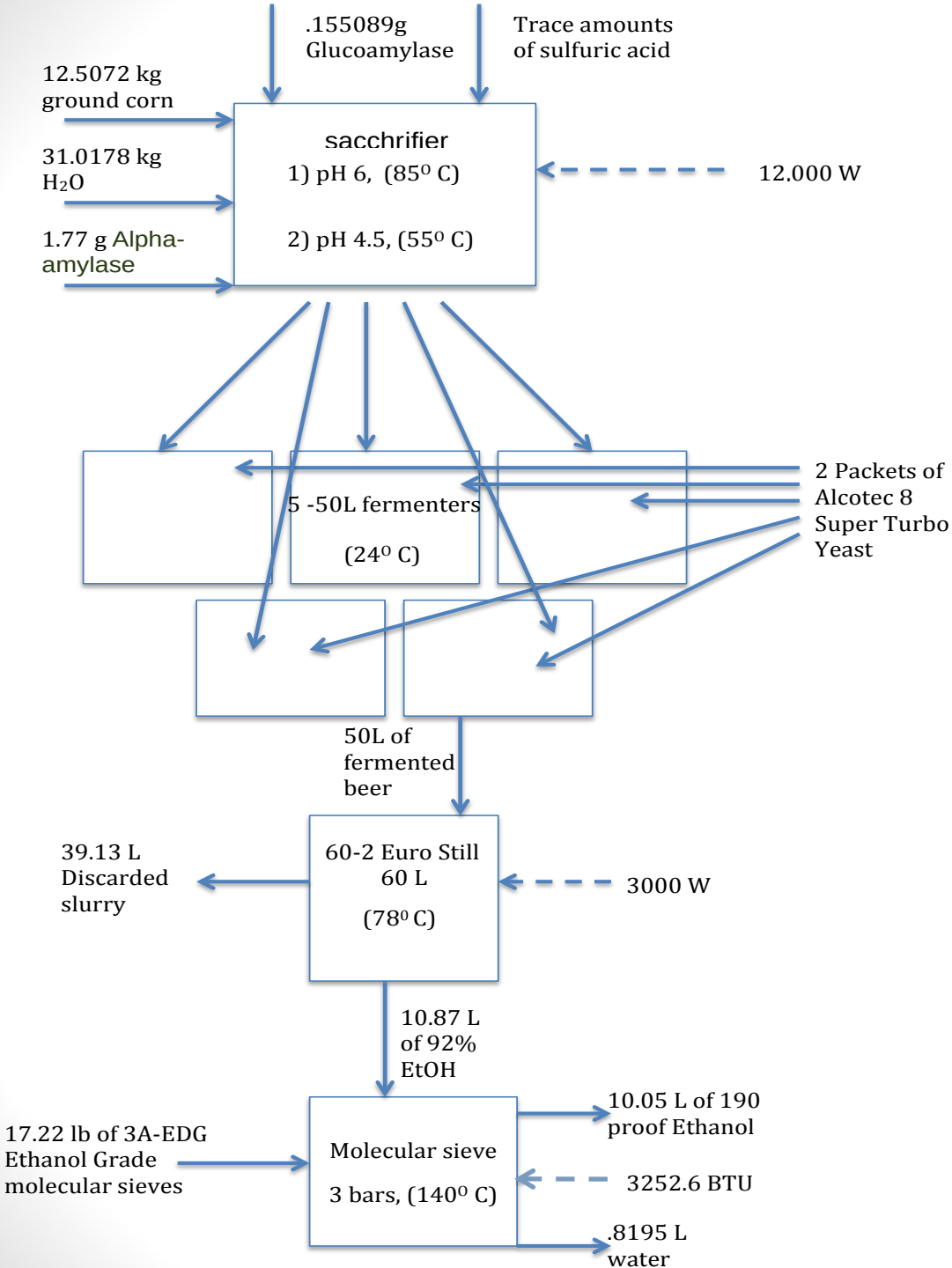
http://shakerlincolnmercury.blogspot.com/

- Objective: Produce enough 200 proof lab grade ethanol to supply the University Stores for one year.

Simple Flowchart Diagram



Complex Flowchart diagram



Feedstock Pretreatment

- Corn as a feedstock
  - Still the most economical
  - Readily available
  - Energy rich
    - 70-72% of kernel weight is starch (db)

http://www.bible411.com/newsletters/nb200810%20CORN%20ON%20THE%20COB.jpg

Feedstock Pretreatment

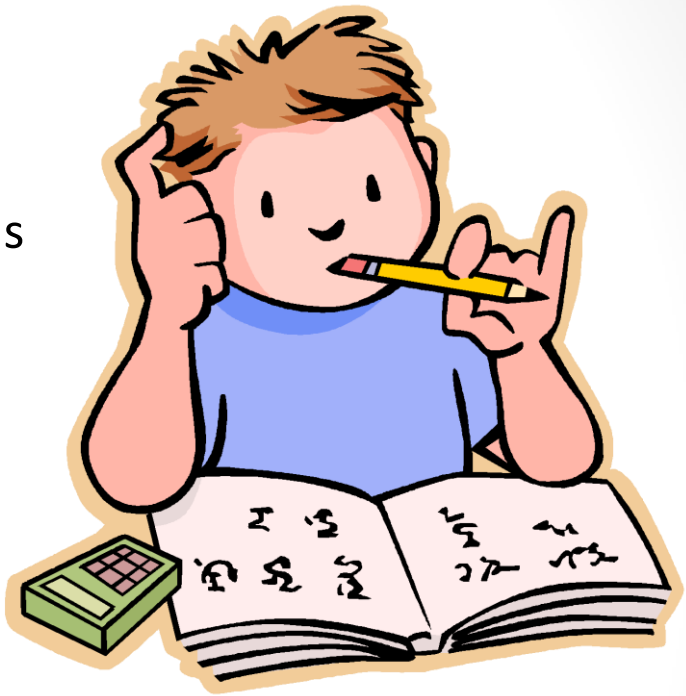
- Corn Feedstock
  - Ground Corn
    - No. 30 screen
    - 0.5mm particle size

http://www.mfgtrade.com/trade/clients/images/Photo_10548900.jpg

http://www.grainger.com/Grainger/USA-Standard-Sieve-5FXC8

Feedstock Pretreatment

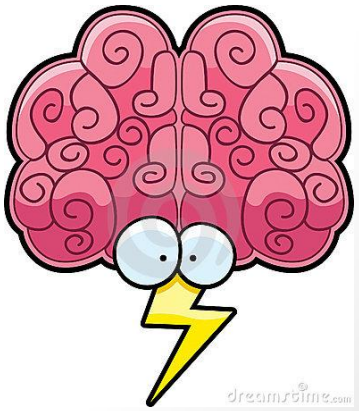
- Mash Composition
  - Consists of 75% water and 25% solids
  - Ground corn contains 13% moisture
  - Calculations:
    - $C = 0.87s + 0.13m$ Eq. 1
    - $M = 0.25s + 0.75m$ Eq. 2
    - $W = 0.00s + 1.00m$ Eq. 3
    - $M = xC + yW$ Eq. 4
  - Combine 1-4 and balance solid components:
    - $0.25s = x0.87s + y0.00s$ Eq. 5
    - $\mathbf{x = 0.287356}$ Eq. 6



http://www.lisle202.org/pages/uploaded_images/Thinking.gif

Feedstock Pretreatment

- Mash Composition Continued…
  - Again combine equations 1-4 and 6 and now balance moisture components:
  - $0.75m = (0.287356)(0.13) + y(1.00)$ Eq. 7
  - $\boldsymbol{y = 0.712644}$ Eq. 8
  - We now can combine equations 4, 6, and 8 to get our relationship between the mash, corn and water:
  - $\boldsymbol{M = (0.287356)C + (0.712644)W}$ Eq. 9
  - This equation shows that a mash with 25% solids is composed of 28.7% ground corn and 71.3% water.



http://thumbs.dreamstime.com/thumblarge_479/1266353842 5Q8j10.jpg

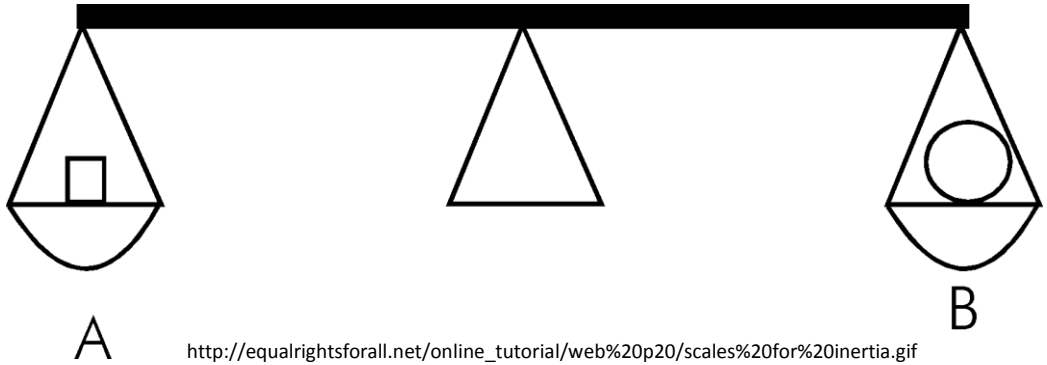
Feedstock Pretreatment

- Mash Density.
  - The density of the mash is needed to calculate the mass needed to fill our 50L fermenters.
  - Mash density can be represented by:
  - $\rho_M = x\rho_C + y\rho_W$ Eq. 10
  - x and y are the same variables as from equation 9.
  - Solving for ρ_M we find:
  - $\rho_M = 0.870499 g/cm^3$ *or* $\mathbf{870.499 kg/m^3}$ Eq. 11
  -

http://weworkforcheese.com/wp-content/uploads/2010/06/lightbulb.jpg

Feedstock Pretreatment

- Mash Mass
  - We can now calculate mash mass needed using:
  - $m_M = V\rho_M$ *Eq. 12*
  - Volume is 50L or $0.05m^3$; solving for m_M we get:
  - $\boldsymbol{m_M = 43.5249kg}$ *Eq. 13*
  - Using equation 9 we can find the mass of corn and water needed:
  - $m_C = (43.5249kg)(0.287356) = 12.5072kg =$ ***12507.2g*** Eq. 14
  - $m_W = (43.52549kg)(0.712644) = 31.0178kg =$ ***31017.8g*** Eq. 15

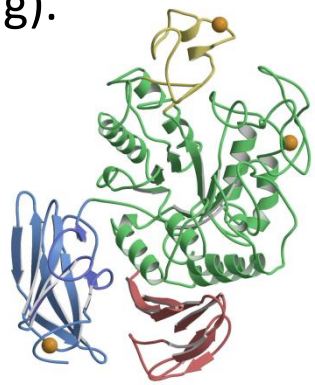


http://equalrightsforall.net/online_tutorial/web%20p20/scales%20for%20inertia.gif

Feedstock Pretreatment

- Enzyme Amounts
  - Enzymes are needed to break the starch down into simple sugars.
  - Amylase is needed at a rate of 42.8 U/g corn solids.
  - Glucoamylase is needed at a rate of 0.6 U/g corn solids.
  - $m_a = (m_C C_s a)/(v_a)$ *Eq. 16*
  - Where m_a is the mass of enzyme solution or powder needed.
  - m_C is the mass of corn in the mash.
  - C_s is the solid mass fraction in the corn.
  - a is the units per gram of corn solids needed (U/g).
  - v_a is the unit density of the enzyme solution (U/mg).
  - Solving this equation for the two enzymes gives:
  - $m_a=0.621g$ Eq. 17
  - $m_g=.0544g$ Eq. 18

Amylase



http://www.kms.ac.jp/~xraylab/research/image13.jpg

Feedstock Pretreatment

- Processing Steps
  - Mix water and ground corn.
  - Add amylase, heat to 85°C, maintain pH of about 6, hold there and mix continuously for 90 minutes. This is called liquefaction.
  - Cool mash to 55°C, drop pH to 4.1±0.5, add glucoamylase, hold and mix for 2 hours. This is called saccharification.
  - Send mash to the fermenters.

http://3.bp.blogspot.com/_ViFLVzjIPSk/TJVChswhF1I/AAAAAAAAAIU/Wf_1B51uFW0/s1600/au-revoir.jpg

Fermentation Theoretical

- Alcotec 8 Super Turbo Yeast

  Greater yeast inoculuum

  ⇩

  increased fermentation rate
- Claims to yield 20% ethanol by volume in 5 days.

http://www.turbo-yeast.biz/English/Alcotec8.htm

https://morebeer.com/view_product/19590

- 50L Volume Fermenter
- Quantity: 5
- Must run continuously everyday.

Fermentation Unit

- From Pretreatment:
  - Mass of corn = 12.5072 kg
- Knowing the composition of corn:
  - Mass of starch = .595(12.5072) = 7.4418 kg

- Then with the addition of water to starch and an enzymatic reaction:
  - 1.1111 Glucose = Starch + 0.1111 Water
  - 7.441 starch + (.1111)(7.441)water = 8.2669 kg = Mass of glucose
- Glucose breaks down to produce:
  - Glucose = 0.4589 Ethanol + 0.4641 CO2 + 0.05 other

- So we have:
  - 8.2669kg * 0.4589 = 3.7936 kg EthOH
  - 8.2669kg * 0.4641 = 3.83667 kg CO_2
  - 8.2669kg * 0.05 = 0.413345 kg other waste

Fermentation Unit

- total mass – CO_2 mass = Mass of slurry
  43.5249kg -3.83667kg = 39.6882kg = Mass of slurry
- % alcohol = mass of EthOH / mass of slurry
- 3.7936/39.6882 = .095585 = 9.56% Alcohol
- Mass Balance:
- IN: mash (from Pretreatment step) = 43.5749 kg
- OUT:
  - EthOH = 3.7936kg
  - CO_2 = 3.83667kg
  - All other wastes = 35.8946kg

Distillation

- Choosing a Still Size
  - (3000L/year) / (365 days/year)= 8.21 L/day
  - (8.21 L/day) x (1 / 20% ethanol in slurry)= 41.05 L of slurry/day

- 50L or greater still will be large enough to reach our goal

http://www.malts.com/var/plain_site/storage/images/choosing-whisky/a-simple-guide-to-the-world-of-whisky/the-art-of-making-whisky/distillation/196096-19-eng-ROW/Distillation.png

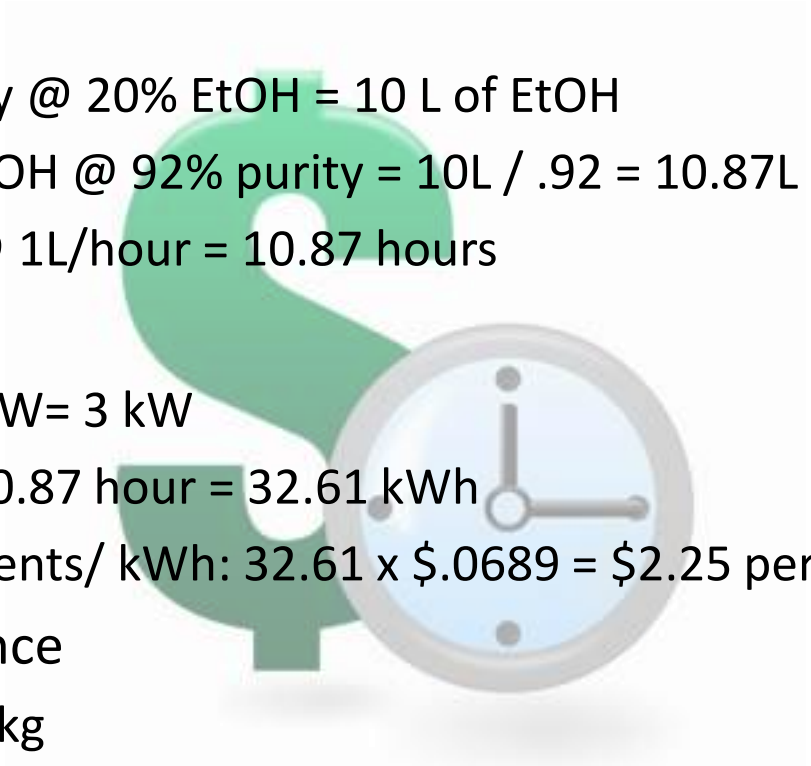
Distillation Still

- Euro 60-2 dual element still
  - 60L capacity
  - 1L distillate per hour
  - 92% purity of ethanol
  - 2- 1500W heating elements

http://homedistiller.org/photos-sold.htm

Distillation Calculations

- Time
  - 50L slurry @ 20% EtOH = 10 L of EtOH
  - 10L of EtOH @ 92% purity = 10L / .92 = 10.87L distillate
  - 10.87L @ 1L/hour = 10.87 hours
- Cost
  - 2 x 1500 W= 3 kW
  - 3 kW x 10.87 hour = 32.61 kWh
  - @ 6.89 cents/ kWh: 32.61 x $.0689 = $2.25 per batch
- Mass Balance
  - 50L = 50 kg
  - 50L in – 10.87L out = 39.13 L of slurry discarded after distillation



http://www.ratskey.com/images/time_money.jpg

Molecular Sieve

- Dehydration
- 3A-EDG Ethanol Grade
  - pore opening ~ 3 angstroms (0.3nm)
  - not absorbed 4.4 angstrom ethanol molecule
  - adsorb 2.8 angstrom water molecule
- Other parameters
  - bulk density = 47 lbs/cuft
  - equilibrium water capacity 21% wt
  - heat of adsorption = 1800 BTU/lb of H_2O
  - specific heat = 0.23 BTU/lb/ deg F

http://www.3angstrom.com/molecular_sieve.php

Molecular Sieve Dehydration Unit

- Vapor enters first column →water is adsorbed on the sieve → vapor continues through column → more water removed →dryer alcohol until fully dehydrated → vapors exit the column
- Once column reaches saturation limit → flow is diverted to second (dry) column → then first column is regenerated
- Recovery = 98%
- Purity = 99.5% dehydration alcohol as standard.
- Adsorption
  - 1.5-4 bar (20-60 psia)
  - 125-160°C (280-345°F)
- Water removal from the adsorbent
  - 0.1–0.5 bar (1.5-7 psia)

http://www.wintek-corp.com/biodiesel/molecular-sieve-dehydration-units-msdu.html

Molecular Sieve

- Dehydration unit has to run for ~ 4.34 minutes each day

$$0.5\ gpm \times \frac{3.785\ L}{1\ gal} = 1.89\ L/\min \times (x\ \min) = 8.21\ L \rightarrow x = 4.34\ min$$

- Mass Balance: amount of distillate (10.87 L), feed purity (92%), final ethanol purity (99.5%), and water vapor (8%).
  - E = 0.92e + 0.08w = mass of inflow (distillate) (kg)
  - P = y(0.995e + 0.005w) = mass of ethanol product (kg)
  - W = x(1w) = mass of water vapor (kg)
  - Solving for y: 0.92e = y(0.995e) → y = 0.9246
  - Solving for x: 0.08w = y(0.005w) +x(1w) → x = 0.0754
  - E = 0.9246P + 0.0754W.
- Mass of ethanol product = 10.05 kg
- Mass of water vapor = 0.8195 kg

Molecular Sieve

- Amount of molecular sieve needed:

$$\frac{Weight\ of\ water}{Weight\ of\ molecular\ sieve} = 0.21 \rightarrow \frac{0.8195\ kg \times 9.81 m/s^2}{x} = 0.21$$

$$\rightarrow \quad x = 38.28\ N = 8.61\ lbs$$

- Energy used by the molecular sieves = 3252.6 BTU
  - heat of adsorption (1800 BTU/lb of H_2O)
  - weight of the water vapor (1.807 lbs) in the molecular sieve dehydration unit

Cost Analysis

One Time Costs				
Item	Quantity	Unit Cost	Total Cost	Reference
75 L tank	1	$279.95	$279.95	Plasticmart.com 2011
Heating Element	4	$963.42	$3,853.68	Drillspot.com 2011
Agitator	1	$323.48	$323.48	Novatech-usa.com
Distillation Unit	1	$637.28	$637.28	Spirits 2011
Fermenter	5	$215.00	$1075.00	50L (13G) Variable Volume Fermenter 2011
Molecular sieve Dehydration Unit	1	$1,200.00 (assumption)	$1,200.00 (assumption)	Wintek 2010
TOTAL:			$7369.39	
Reoccurring Costs				
Item	Quantity per Batch	Unit Cost	Cost per Batch	Reference
Ground Corn	12.51kg	$385/1000kg	$4.82	Alibaba.com 2011
α-amylase	465718U	$288.50/5000000 U	$26.87	Sigma-Aldrich 2011
Glucoamylase	.054406g	$488.50/5g	$5.32	Sigma-Aldrich 2011
Distillation run	1 run	6.89 cents/ kWh	$2.25	EIA 2011
Alcotec Super Turbo Yeast	2	$5.95	$11.90	Alcotec 2005
Molecular Sieve	17.22 lbs	$99.25/25lbs	$68.36	3Angstrom 2009
Pretreatment Run	1 run	6.89 cents/ kWh	$0.55	EIA 2011
TOTAL:			$120.07	

Conclusion

- Ethanol is commonly used in many university and research labs.
- A variety of feedstocks and processes are available to make ethanol
- The process outlined in this presentation demonstrates a method to make the necessary amount ethanol to supply the University Stores for one year.

http://i.treehugger.com/files/th_images/blue_ethanol_flame.jpg

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Questions?