Incorporating Conversion R&D and Testing Adaptation in an Existing Facility

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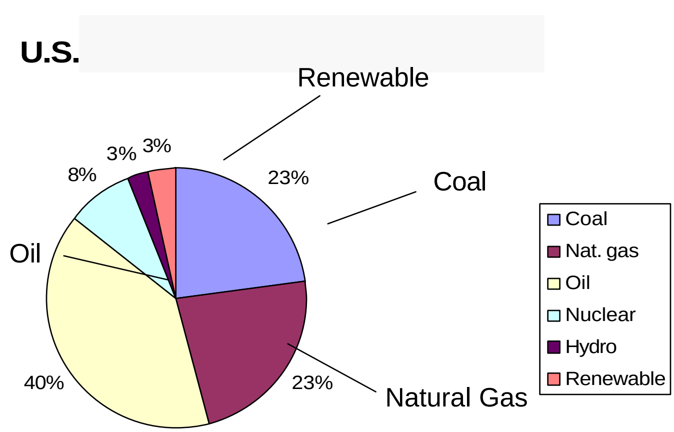
Energy Consumption in US



Ethanol - Renewable Fuel Standard

On August 8, 2005, President Bush signed the Energy Policy Act of 2005 (H.R. 6) into law. Includes national renewable fuels standard (RFS) that doubles use of ethanol and biodiesel by 2012 to 7.5 billion gallons in 2012.

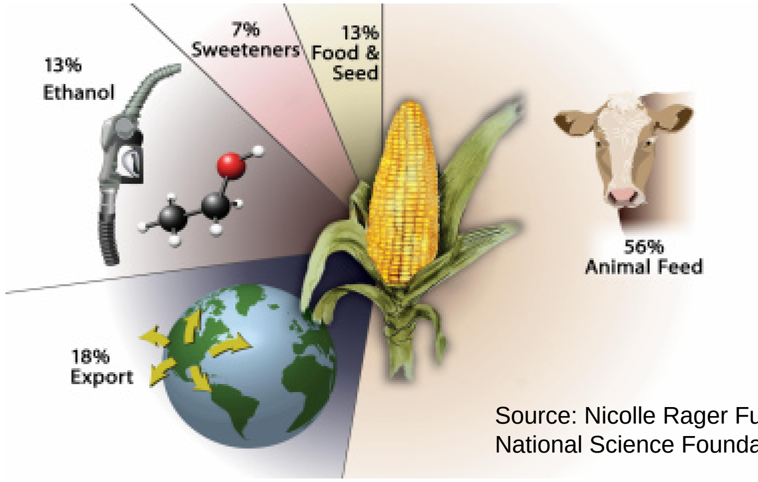
Beginning in 2013, a minimum of 250 million gallons a year of cellulose derived ethanol will be included in the RFS.

Source: RFA, http://www.ethanolrfa.org

Projections: US Ethanol Production

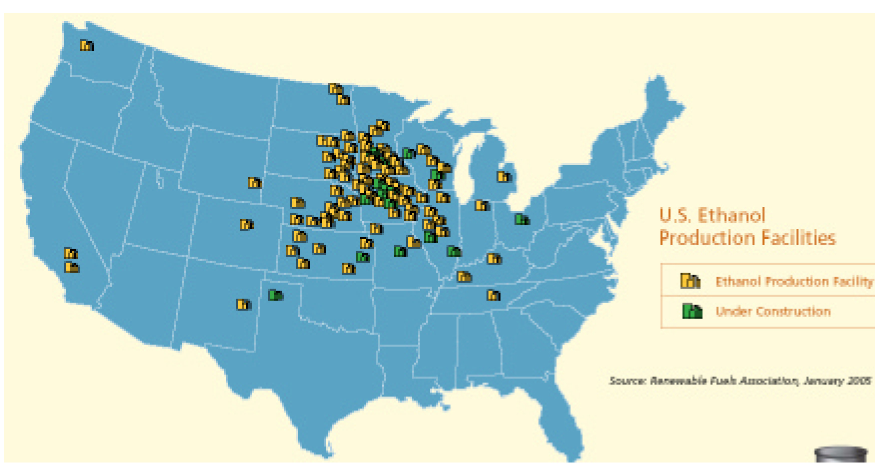
2006	4.8	(corn)
2008	7.5	(corn + cellulose)
2015	12.0	(corn + more cellulose)
2030	60.0	(a lot of cellulose + corn)

Corn (2004)

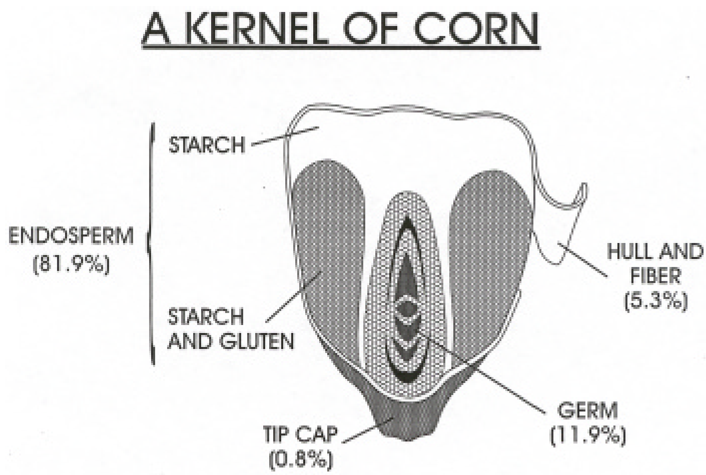


Source: Nicolle Rager Fuller,
National Science Foundation

Corn Ethanol Plant Locations

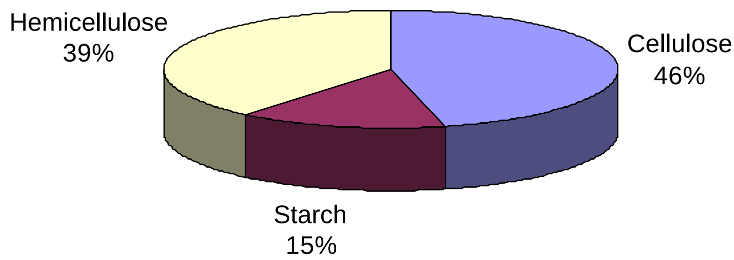


Corn Hull and Fiber Contain Cellulose



Corn Hull and Fiber

Cellulose and Pentosans in Corn Hull



Relative Amounts of Carbohydrates that make up 30% of total. Other components include protein, lignin, oil

Dien, Cotta, 2006

Typical Compositions for Corn Fiber from Wet Milling

Glucan (cellulose)	14.3%
Glucan (starch)	23.7
Xylan	16.8
Arabinan	10.8
Protein	11.8
Lignin	8.4
Acetyl	NA
Ash	0.4

Utilization of Fiber from Existing Processes: Challenges

Limited markets as animal feed

Increased US bioenergy production will generate more fiber:

about 6.5 lbs per bushel corn or

2.5 lbs per gal ethanol

1 billion gal ethanol = 1.25 million tons fiber

Corn Fiber Utilization Opportunities

Increase annual ethanol production by 100 million gal/ yr or more

Introduce cellulose conversion technologies into existing corn to ethanol facilities

Catalyze industry use of other cellulosics (for example, corn stover)

Utilization of Fiber

Benefits of existing industrial infrastructure

Fiber already collected:

fiber packaged with corn

Existing ethanol plants:

handle and manage fiber streams

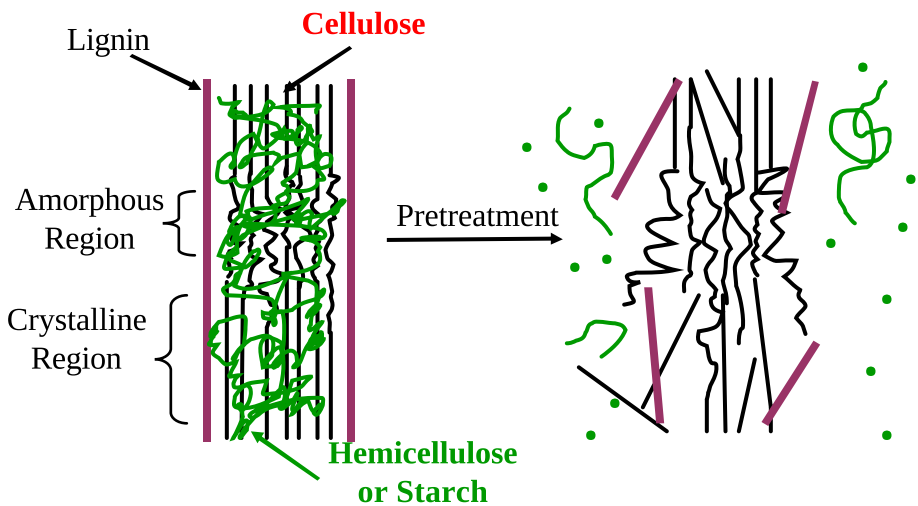
provide utilities

process fermentation ethanol

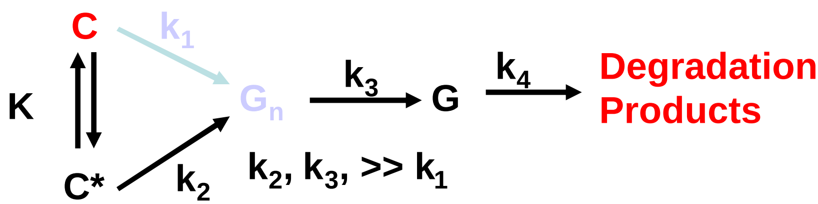
market ethanol and co-products

Effect of Pretreatment

Representation of Physical Changes



Autohydrolysis and Sugar Degradation during Pretreatment



$k_2, k_3, >> k_1$

at high temperatures $\mathbf{k_4} = \mathbf{k_3}$

Degradation products:

organic acids that catalyze further hydrolysis and degradation

aldehydes that inhibit both bacterial and yeast fermentations

Water acts as Acid

Liquid water dissociation constants

$k_w = 0.01 \times 10^{-12}$ (at 20 °C)

to 6.0×10^{-12} (at 230 °C)

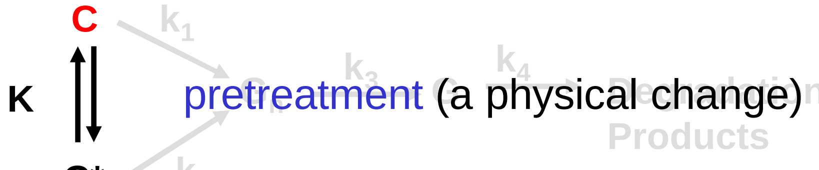
Principles of Liquid Water Pretreatment

a. Control (maintain) pH
   (protein in fiber is an effective buffer)

b. Use high temperature

c. Maintain water in liquid state (under pressure) to minimize degradation

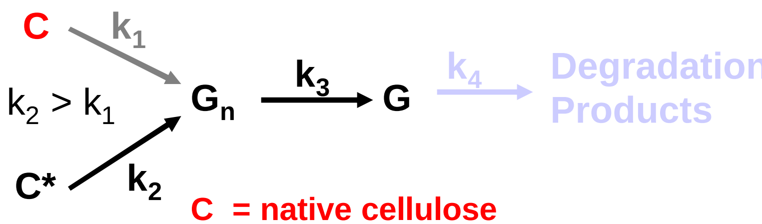
1. Pretreatment (carry out at high temperature)



pretreatment (a physical change)

C = native cellulose
C* = hydrated cellulose

2. Hydrolysis
(at low temperature, using enzymes)



C = native cellulose

C* = hydrated cellulose

G_n = glucans (oligosaccharides)

G = glucose (monomer)

Pretreatment Model:
Goal for this work

separate

pretreatment (a physical change)

from hydrolysis (a chemical change)

Rationale

Avoid hydrolysis, degradation products

Pretreatment Conditions

Fiber : Stillage Ratio

wet basis = 0.39 : 1 (390 g/ L)

Fiber : Water Ratio

dry basis = 0.16 : 1 (160 g / L)

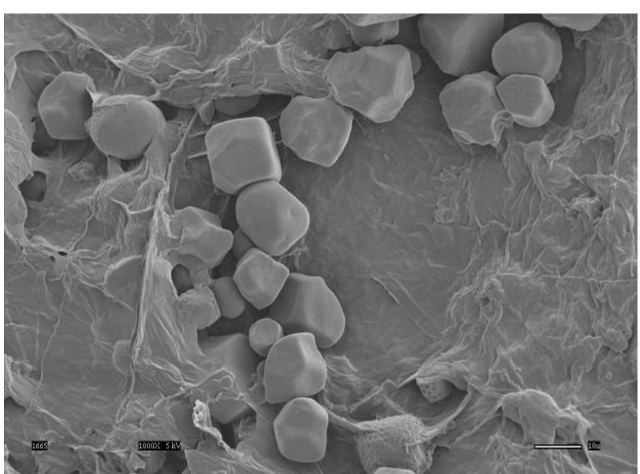
Temperature, pH, pressure, and Hold Time

160 C, pH > 4, 150 psig, 15 -20 min

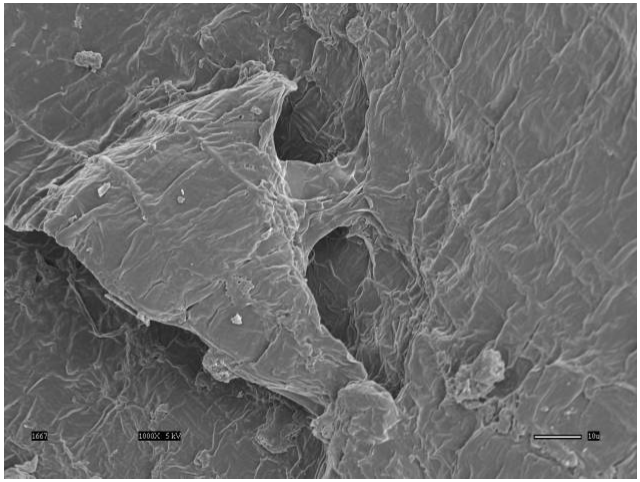
Separate liquid from solid (centrifuge)

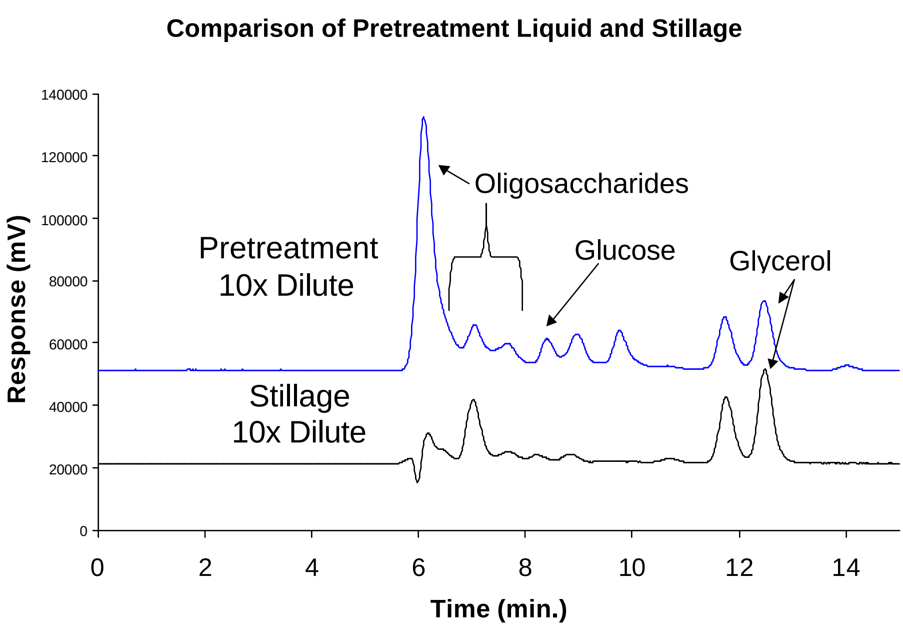
Liquid to fermentor, solid to feed drier

SEM of Fiber before Pretreatment



SEM of Pretreated Fiber





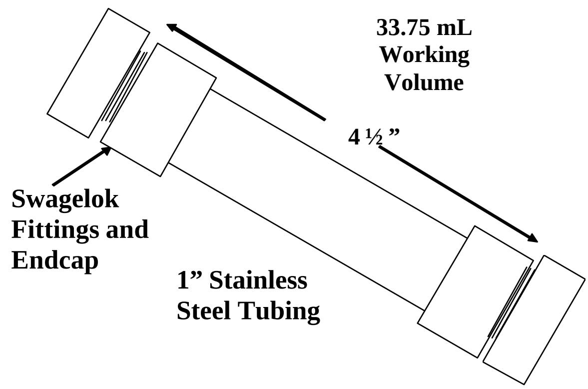
Controlled pH Liquid Hot Water Pretreatment

Conditions 160 C, 20 min

pH control through buffer capacity of liquid

Minimal fermentation inhibitors, no wash stream

Minimize hydrolysis to monosaccharides thereby minimizing degradation



Pretreated Corn Fiber
(Enzyme Hydrolysis)

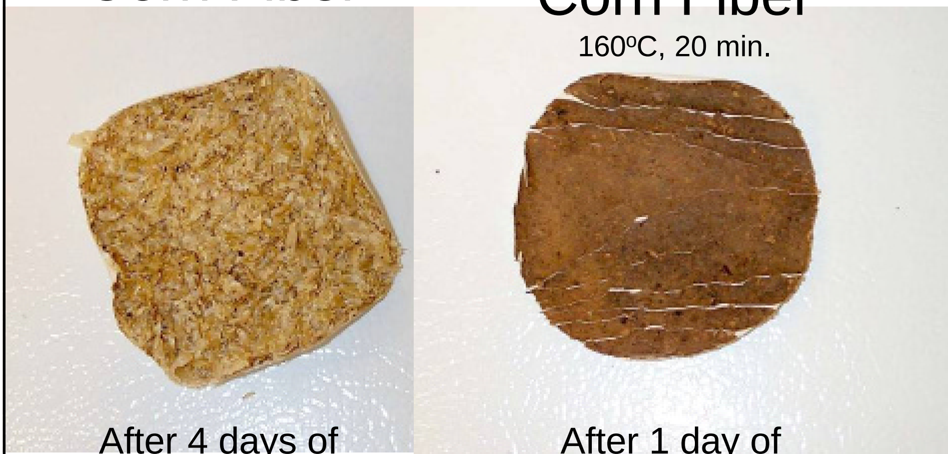
	Amylase 80 U α Amylase + 6.3 kU Amyloglucosidase per g biomass	Cellulase 10 FPU/g biomass (Celluclast + Novozyme 188)
Glucose[1] (g/g fiber)	0.0043	0.42
Yield[2] (%)	1.3%	100%

1 – grams of free glucose per gram of pretreated fiber

2 – based on analysis of pretreated fiber by 4% acid hydrolysis

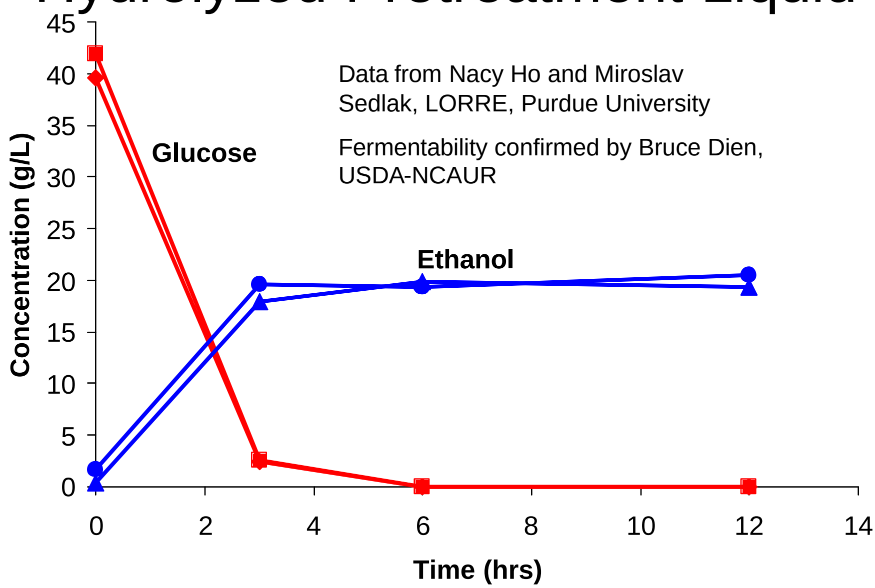
Corn Fiber | Pretreated Corn Fiber

160ºC, 20 min.



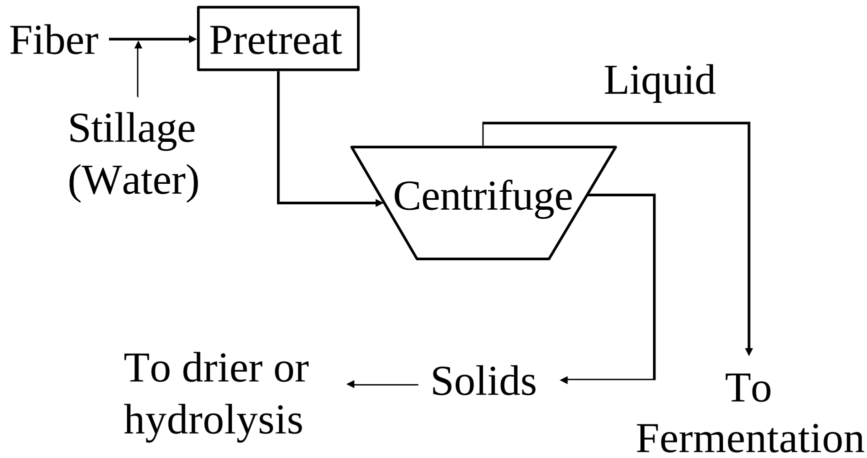
After 4 days of enzyme treatment (20 FPU/gram dry fiber) | After 1 day of enzyme treatment (20 FPU/gram dry fiber)

Fermentability
Hydrolyzed Pretreatment Liquid

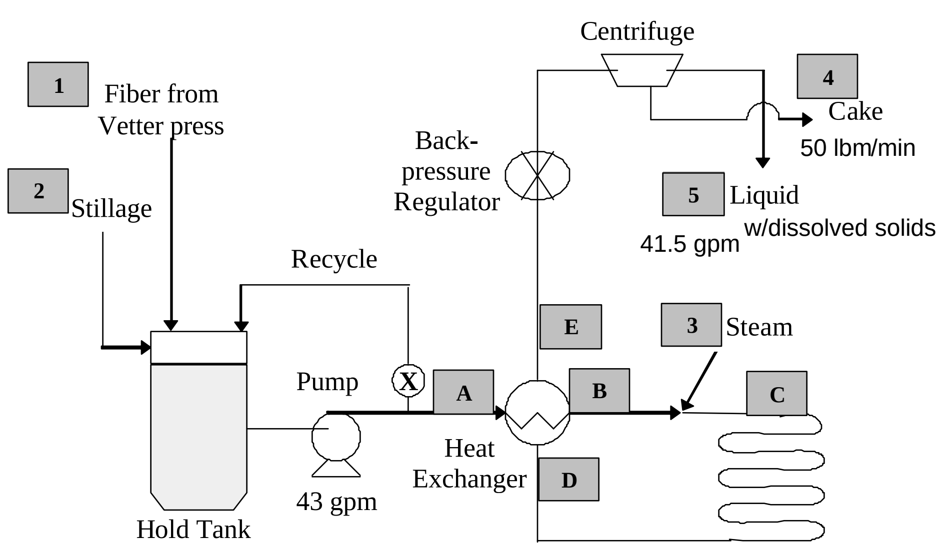


Process Description

Pretreat Fiber and Liquid/Solid Separation



Pretreatment Flow Diagram



Process Steps After Pretreatment

1. Separate **liquid** from **solids** with centrifuge
2. Process **liquid** stream
    - Add cellulase, other enzymes.
    - Combine with liquified starch stream.
    - Add yeast.
    - Hydrolyze, ferment in the same tank.
3. Process **solids** from pretreatment
    - Dry and sell as co-product feed.

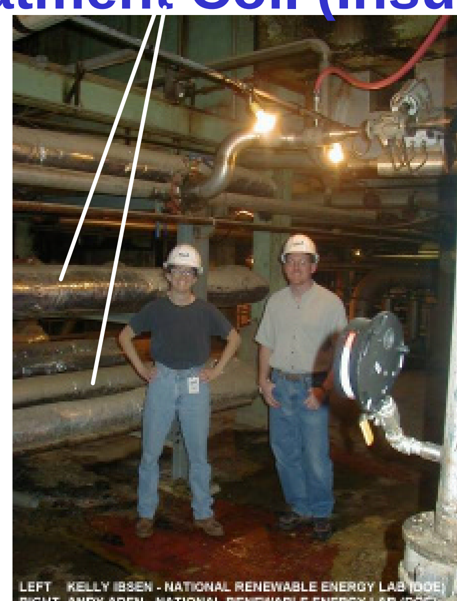
Pump

"Snake-coil" Plug Flow Pretreatment Coil

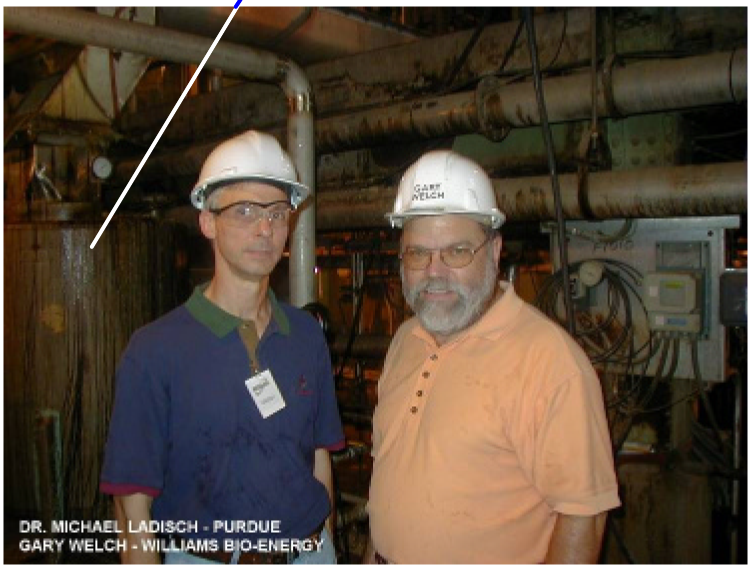
Williams Bioenergy

Pekin, IL

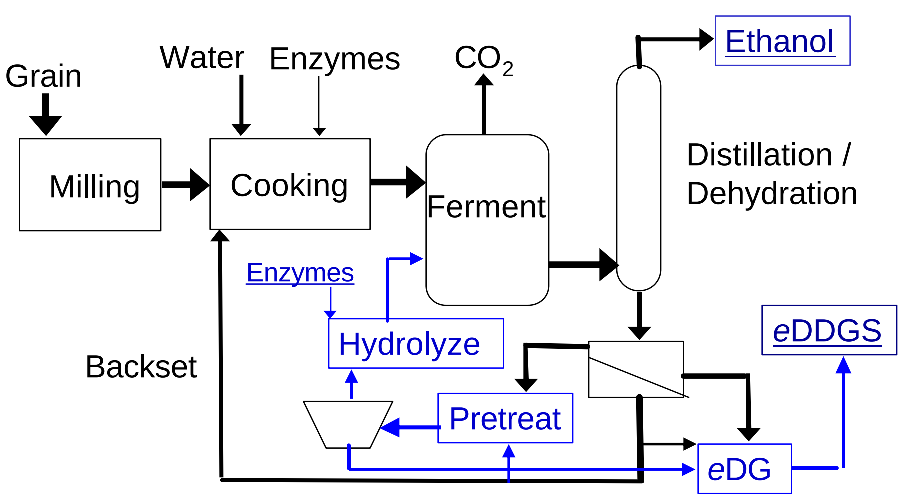
Pretreatment Coil (Insulated)



Hold Tank



Dry Mill (Dry Grind) Process with Cellulose Conversion



Processing Experiments Show

Conversion of Corn Fiber and Corn Stover gives fermentable sugars

Pretreatment required

- Water is an effective pretreating agent
- pH control minimizes monosaccharide formation

Industrial pretreatment development and pilot research being underway

Next Steps

Complete evaluation of process modifications

Continuous processing run

Tighten material and energy balances

Obtain operational data and test:

- equipment operation
- materials handling
- process robustness

Potential Impacts

Introduce existing corn to ethanol plants to conditions and equipment required for cellulose processing,

Enable cellulose conversion processes to derive economic benefits from existing fermentation, ethanol distillation, waste treatment, and power generation facilities.

This technology, while specific for existing ethanol plants, is also cross-cutting in that it could introduce ethanol producers to various types of cellulosic biomass for ethanol conversion.