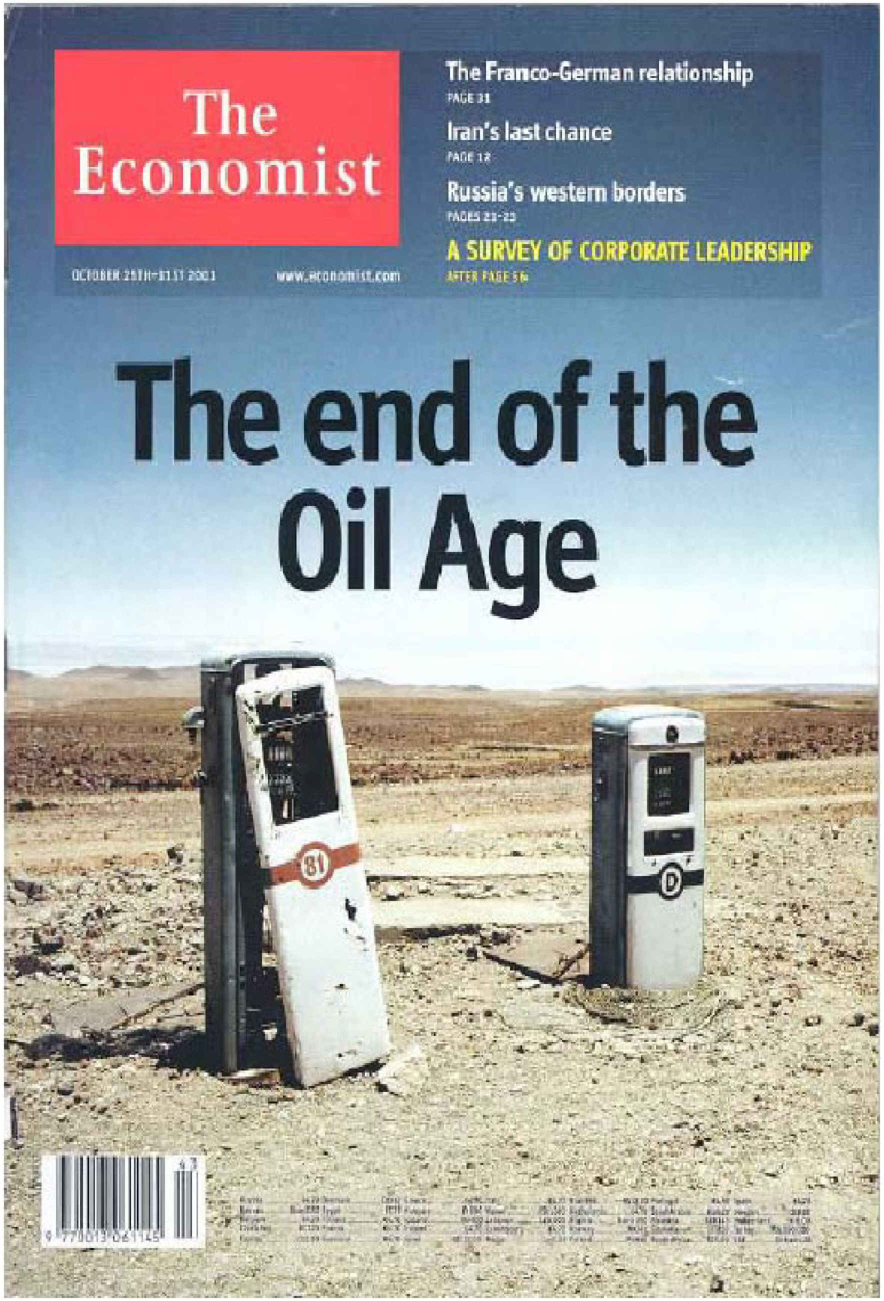
CELLULOSE ETHANOL

Opportunities & Challenges

XUEJUN PAN

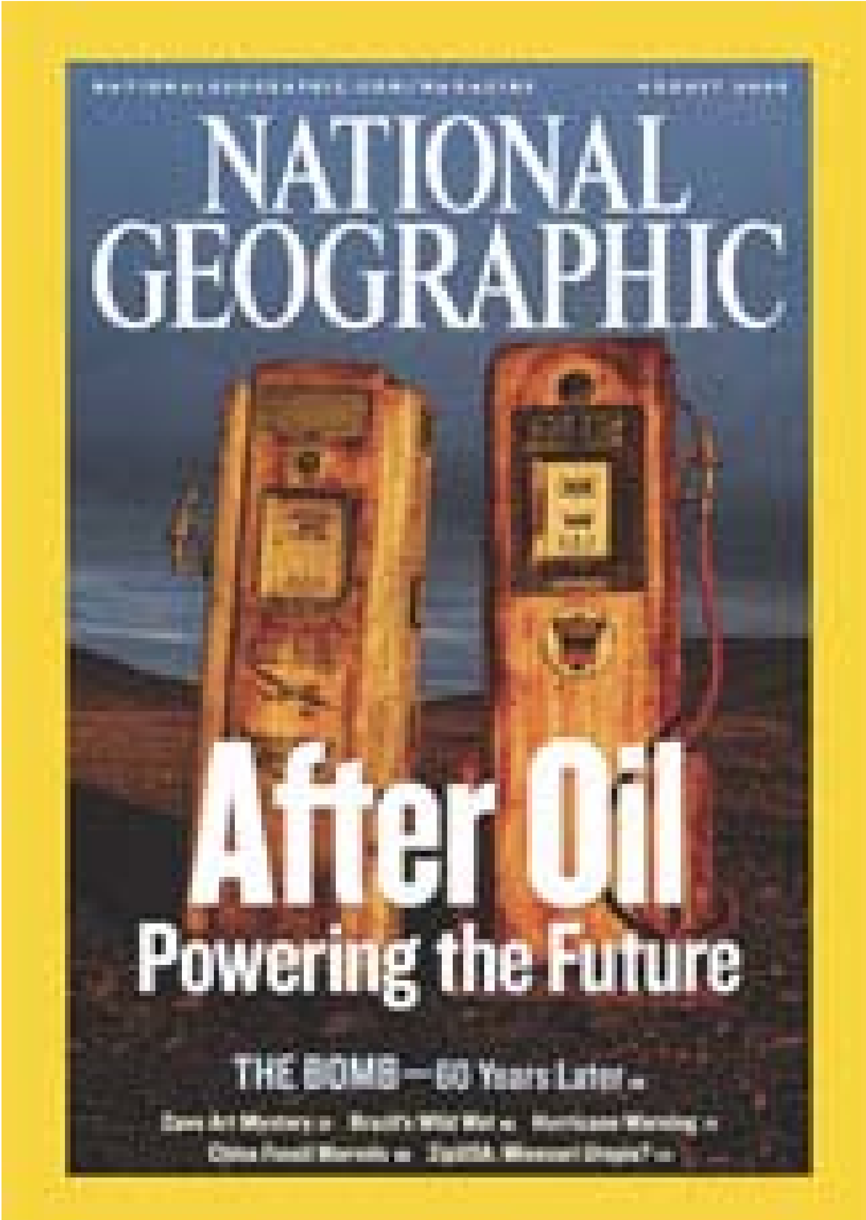
University of Wisconsin-Madison

Jan. 17, 2007



"The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil."

The Economist,
Vol.369, Issue 8347, Pg.12, Oct.25, 2003



ALTERNATIVE ENERGY

- *Nuclear energy*
- *Solar energy*
- *Wind power*
- *Hydro power*
- *Tide power*
- *Bioenergy*

BIOMASS FUELS

- *Bioethanol*
- *Biodiesel*
- *Biohydrogen*

National Geographic
August, 2005

NATURE|Vol 444|7 December 2006

BUSINESS FEATURE

BIOFUELLING THE FUTURE

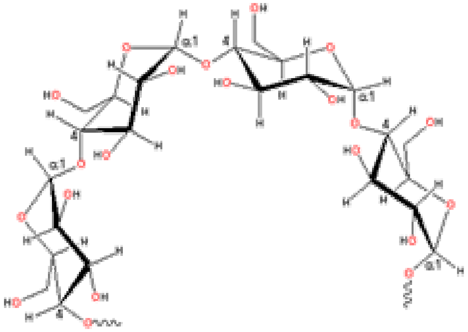
Why Ethanol – Driving Forces

- Rising gasoline and oil price
- Energy security and sustainable supply
- Concern about GHG emission
- 7.5 billion gallon (bioethanol + biodiesel) per year by 2012 required by RFS (Renewable Fuels Standard)
- DOE 30x30 goal: 60 BGY ethanol by 2030

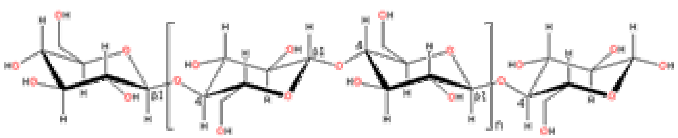
Why Ethanol – Advantages

- Renewable and sustainable fuel
- Reduces dependence on petroleum fuel
- Net energy gain: ethanol yields 1.64 units of energy for each unit of energy it took to produce, just 0.8 units from gasoline (USDA).
- Reduces CO_2 emissions (potentially CO_2 neutral, recycling carbon)
- Stimulates domestic economic development
  - Increase domestic jobs
  - Increase revenue particularly in rural areas
- Can be used in today's vehicles

BioEthanol

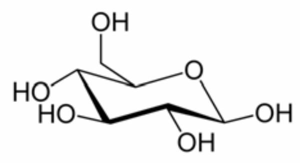


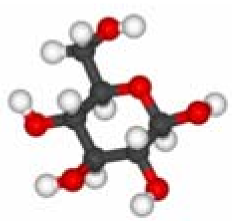
Starch



Cellulose

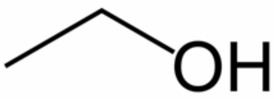
Enzymes →

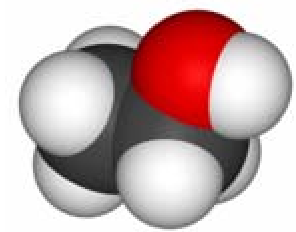




Glucose

Yeast →





Ethanol

$$(C_6H_{10}O_5)_n + nH_2O \longrightarrow nC_6H_{12}O_6 \longrightarrow 2nC_2H_5OH + 2nCO_2$$

World Ethanol Production

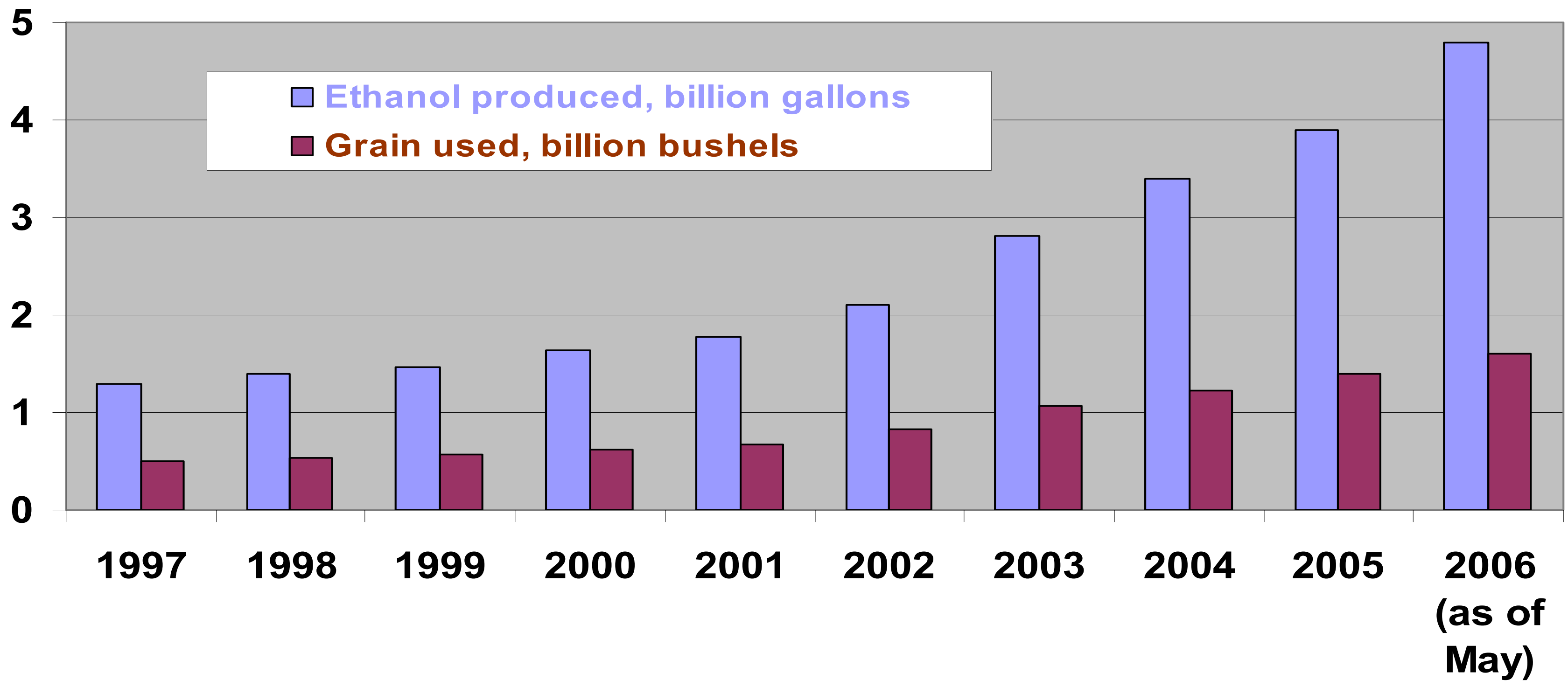
2005 World Ethanol Production – All grades, in millions of gallons

USA	4264	South Africa	103	Ukraine	65	Australia	33	Guatemala	17	Zimbabwe	5
Brazil	4227	UK	92	Canada	61	Japan	30	Cuba	12	Kenya	4
China	1004	Saudi Arabia	32	Poland	58	Pakistan	24	Ecuador	14	Swaziland	3
India	449	Spain	93	Indonesia	45	Sweden	29	Mexico	12	Others	710
France	240	Thailand	79	Argentina	44	Philippines	22	Nicaragua	7		
Russia	198	Germany	114	Italy	40	South Korea	17	Mauritius	3	Total	12150

Source: F.O. Licht

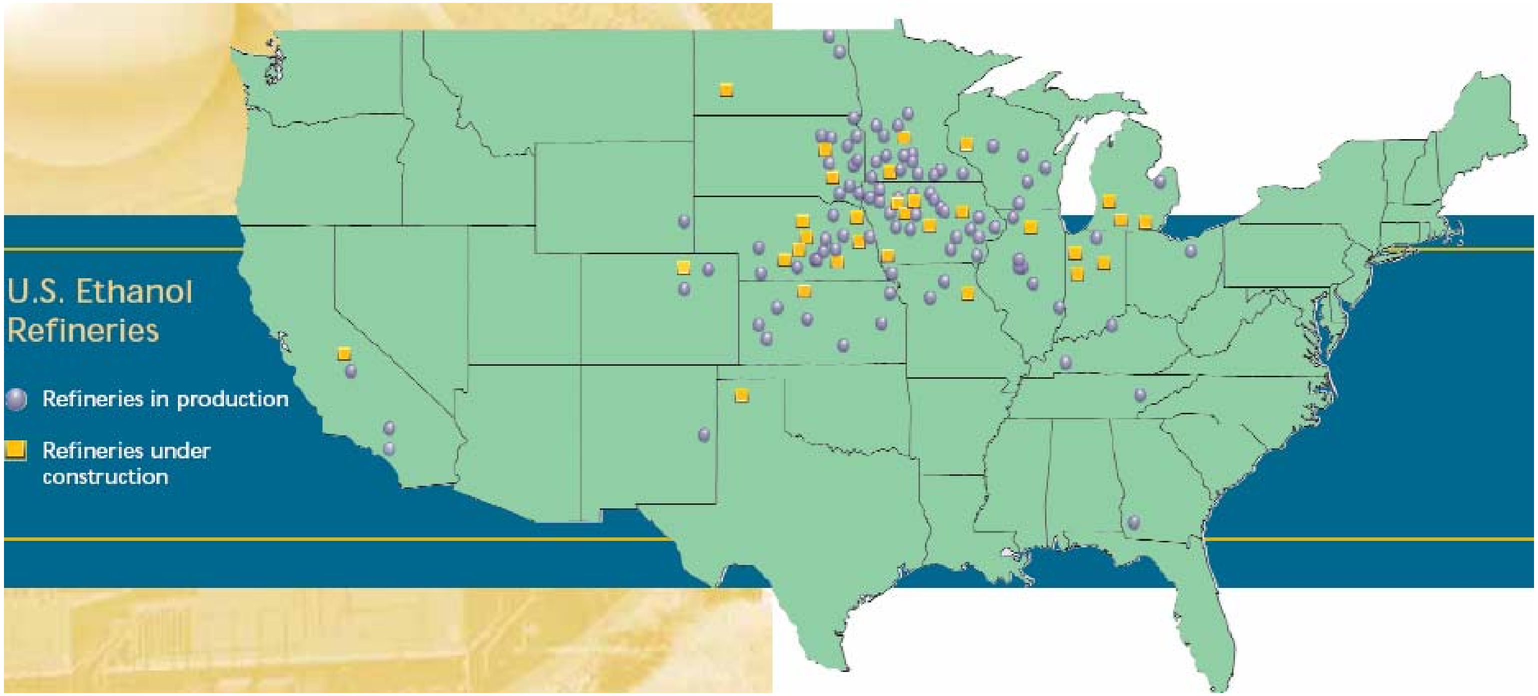
Top 3 countries: 78%

US Ethanol Production (Last ten years)



Source: RFA

US Ethanol Production Facilities



	In operation		Under construction/expansions		Total	
	Facilities	Capacity, BGY	Facilities	Capacity, BGY	Facilities	Capacity, BGY
US	110	5.39	81	6.00	191	11.39
WI	6	0.23	4	0.27	10	0.50

As of December, 2006. Source: RFA

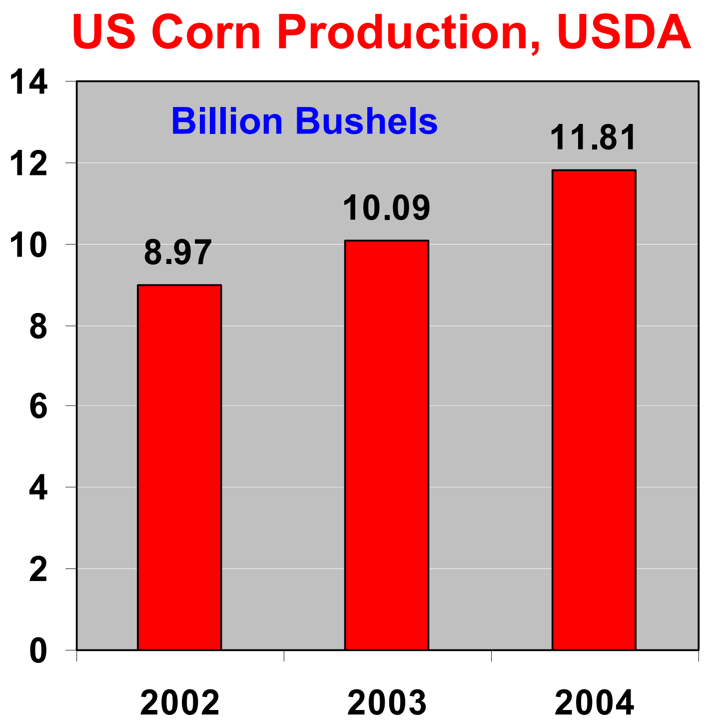
THE UNIVERSITY of WISCONSIN MADISON

Fuel Consumption in the US

- Approximately 140 billion gallons of gasoline each year
- To replace all 140 B gal with E15, 21 B gal of ethanol required, with E85, 119 B gal of ethanol required
- Current ethanol production: 5.4 B gal

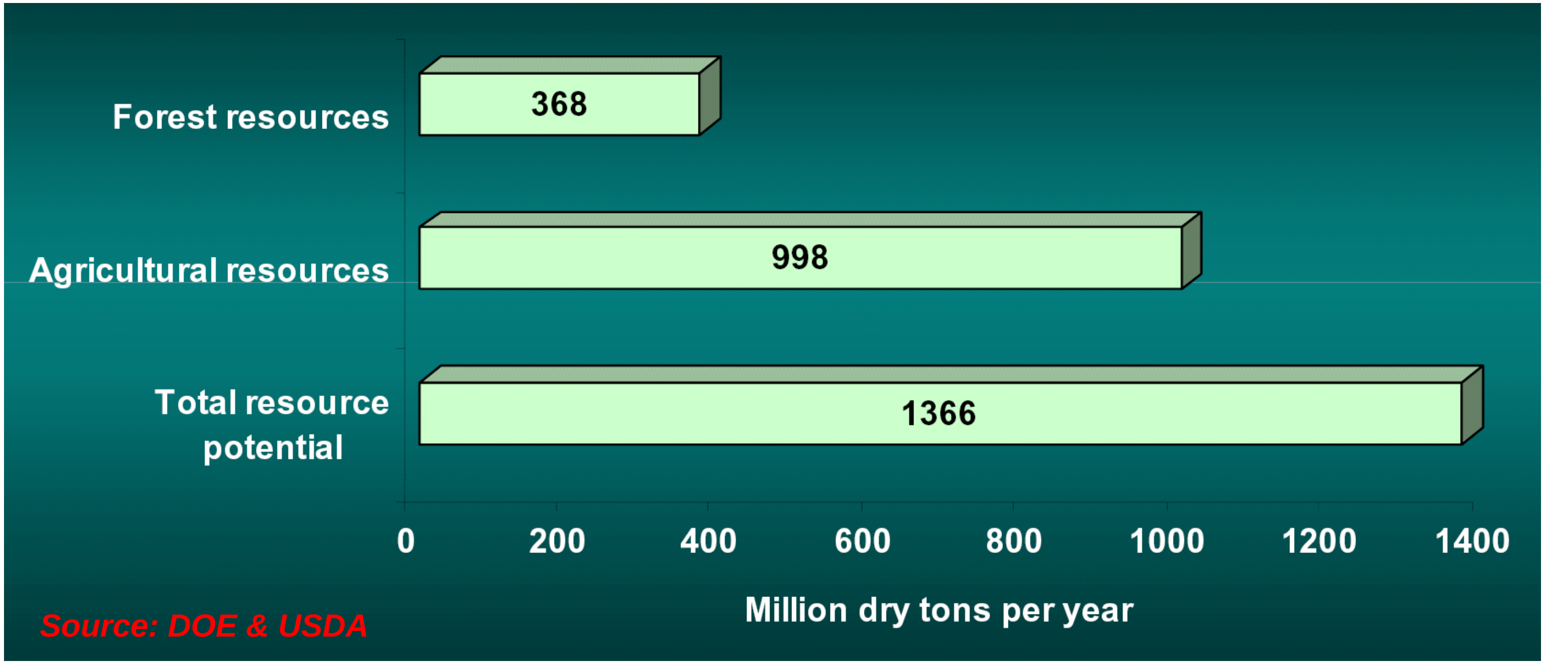
Maximum Ethanol from Corn

– The US produced 11.8 B bushels in 2004
– Each bushel of corn produces 2.6 - 2.8 gal of ethanol
– Therefore, ~32 B gal of ethanol could be produced if we used 100% of the corn produced
– Maximum ~15 B gal (5.6 B bushels of corn)



Estimated Ethanol from Cellulose

– **Approximately 1.4 B tons biomass available in the US**
– **60 (conservative) - 110 (optimistic) gal ethanol from per dry ton of lignocellulosic biomass**
– **Therefore, 80 - 150 B gal of potential cellulosic ethanol**



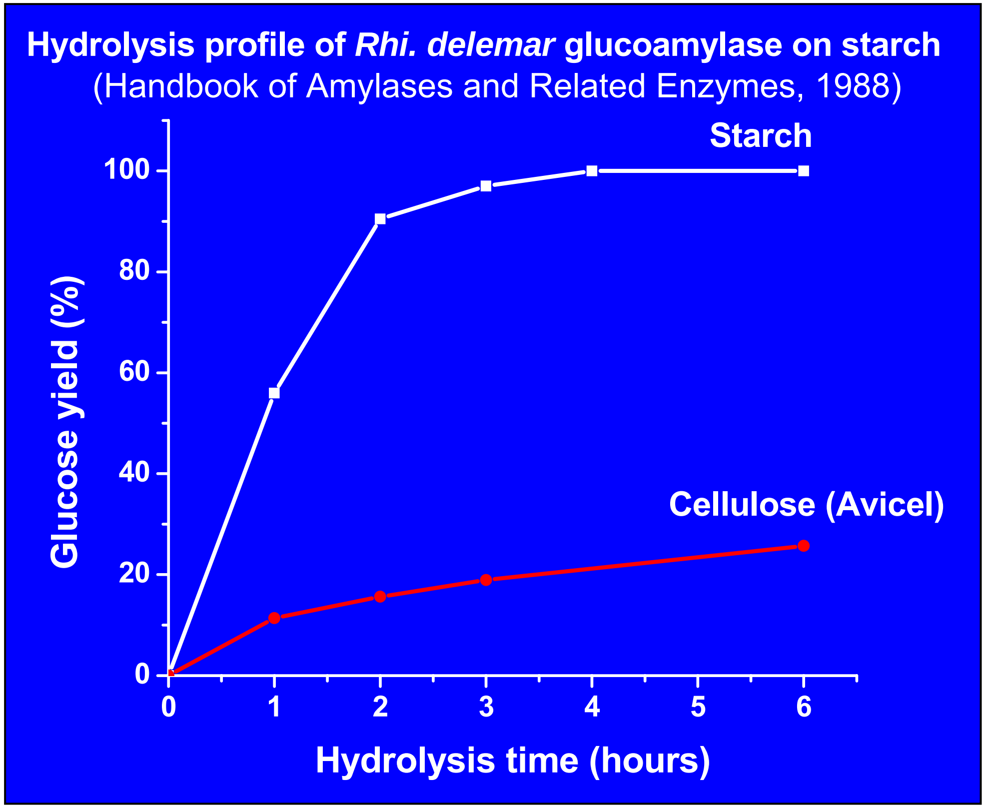
Cellulose vs. Starch - I

	Cellulose	Starch
Function	Structural material	Storage material
Structure	• β-glucosidic linkage • Crystalline	• α-glucosidic linkage • Amorphous
Accessibility	Blocked by lignin and hemicellulose, need expensive pretreatment	Directly accessible to amylase

Cellulose vs. Starch - II

	Cellulose	**Starch**
Enzymes	Cellulase • Expensive • Low activity	Amylase • Inexpensive • High activity
Conversion to ethanol	• Difficult • Expensive • Immature technology	• Easy • Inexpensive • Mature technology
Cost of production	Inexpensive	Expensive (inputs of energy, fertilizer, water, pesticide, and herbicide)

Cellulose vs. Starch - III

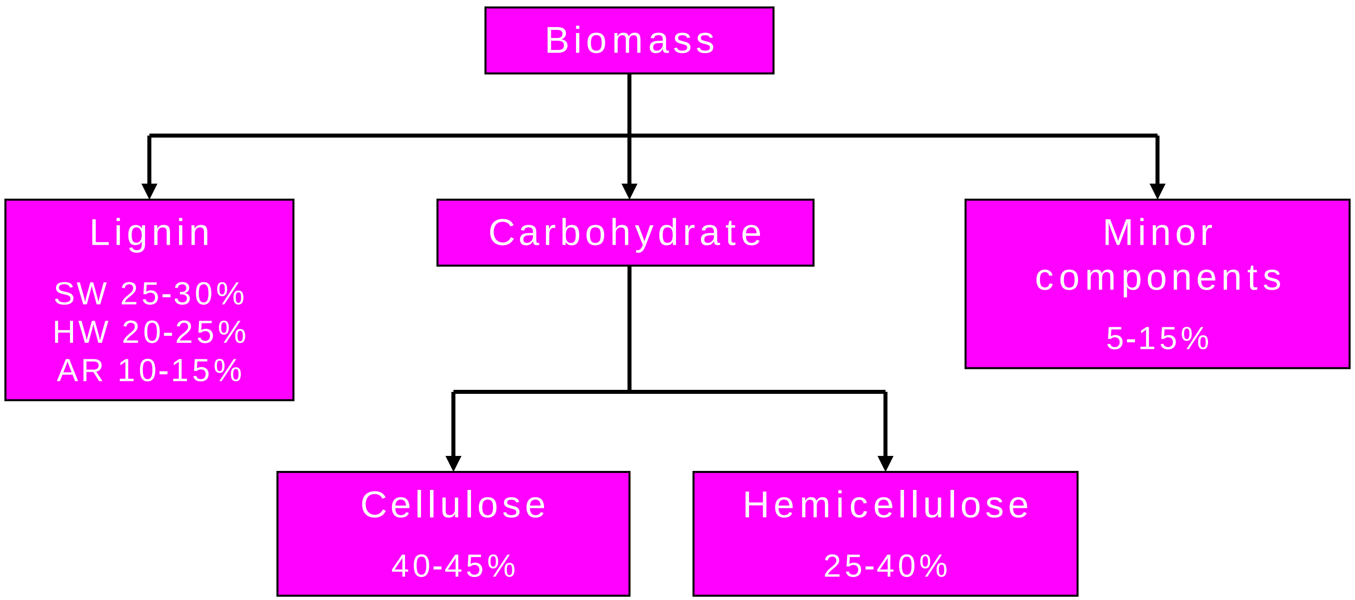


Enzymatic hydrolysability

Starch:

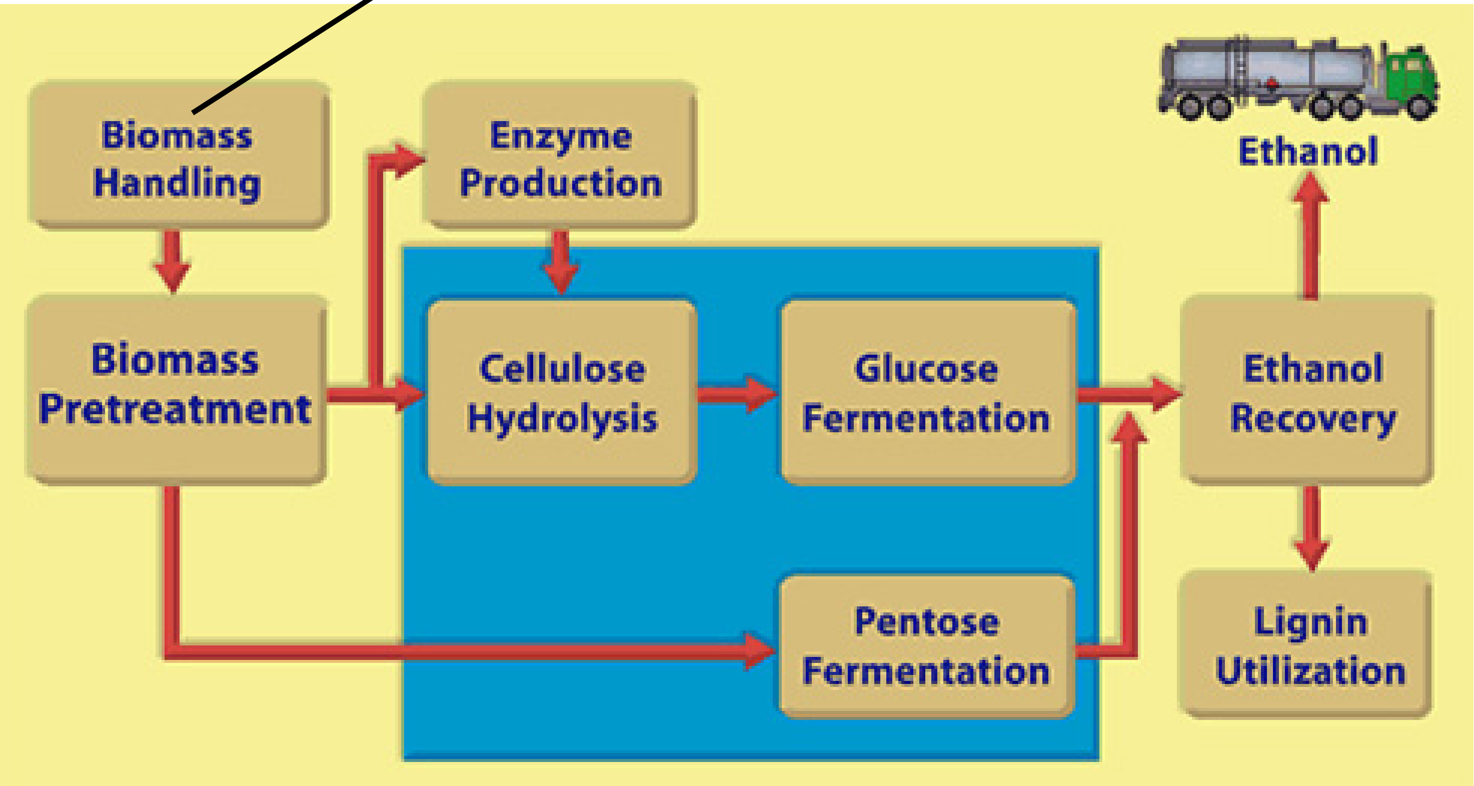
- few enzymes required
- fast and complete hydrolysis
- operation at high substrate consistency (up to 40%)

Chemical composition of biomass



Cellulose Ethanol Production

Forest and crop residues



http://www.ethanolrfa.org/resource/cellulosic

Pretreatment: bottleneck — expensive but cannot be skipped

Examples of intensively investigated pretreatments

- **Steam explosion**
- **Organosolv**
- **Hot water/dilute acid pretreatment**
- **Controlled pH**
- **Ammonia fibre explosion (AFEX)**
- **Ammonia recycled percolation (ARP)**
- **Flowthrough/percolation**
- **Lime pretreatment**

THE UNIVERSITY of WISCONSIN MADISON

Barrier of Cellulose Ethanol

- **High production cost**
- **How to reduce the cost from $2.30/g to $1.00/g?**

Breakthroughs Expected

- Low-cost and effective pretreatments
- Inexpensive and high-activity enzymes
- High-consistence hydrolysis
- Fermentation of pentose (5 carbon sugars) to ethanol
- High-value co-products from lignin and hemicellulose
- Development of biorefinery

Current Status of Cellulosic Ethanol

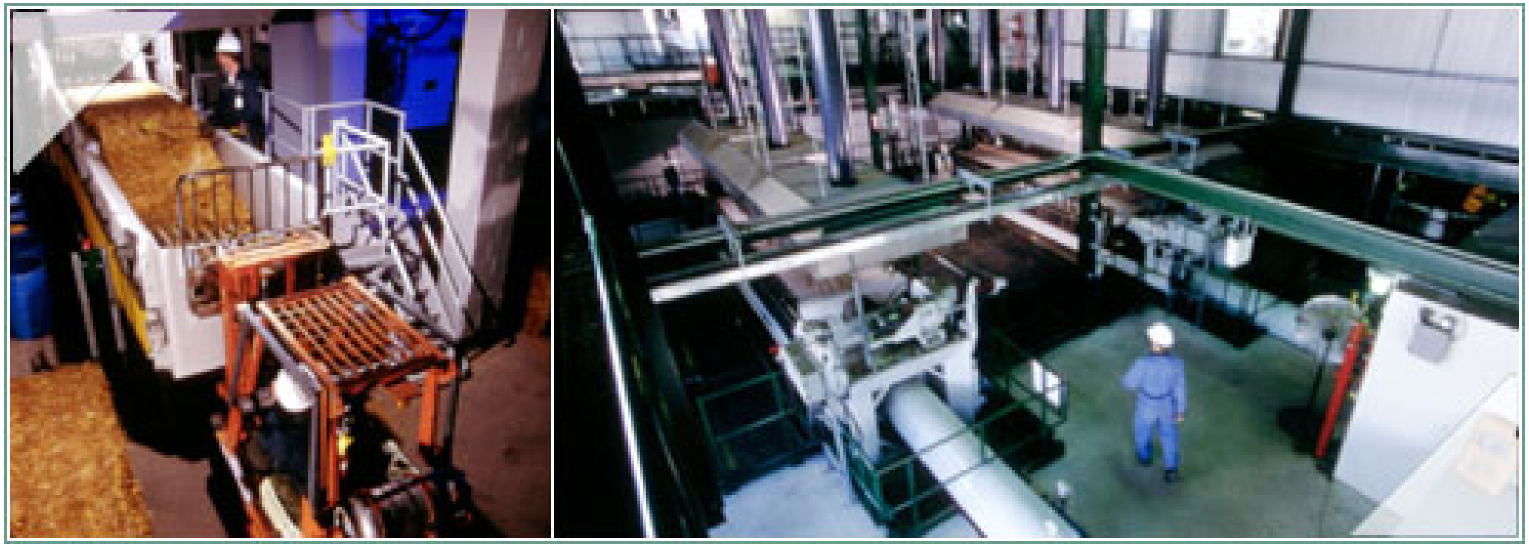
Iogen (Canada)

First cellulose ethanol facility (pilot scale) in the world

Feedstock: wheat, oat and barley straws

Capacity: 40 tonnes per day of feedstock

3 million liters of ethanol per year



http://www.iogen.ca/company/facilities/index.html

Canadian former Prime Minister Paul Martin at the launching ceremony, April 21, 2004

Abengoa Bioenergy

(St. Louis, MO, the 2nd largest ethanol producer in the world)

Will be the first commercial cellulose ethanol facility in the world at Babilafuente, Salamanca (Spain)

This new facility was scheduled to be operational in fall of 2006 and designed to produce 200 million liters (52.8 million gallons) of fuel-grade ethanol (FGE) per year. The plant will use wheat as feedstock for 87.5% of production and European wine alcohol as feedstock for 12.5% of production. The production of coproducts will be 480 t/day of Distillers Dried Grains and 416 t/day of CO_2.

http://www.abengoabioenergy.com/bioethanol/index.cfm?page=6&loc=2

Voyager Ethanol
Emmetsburg, IA

Broin companies
ETHANOL. BIOREFINING. LEADING THE REVOLUTION.

First commercial cellulose ethanol facility in the United States

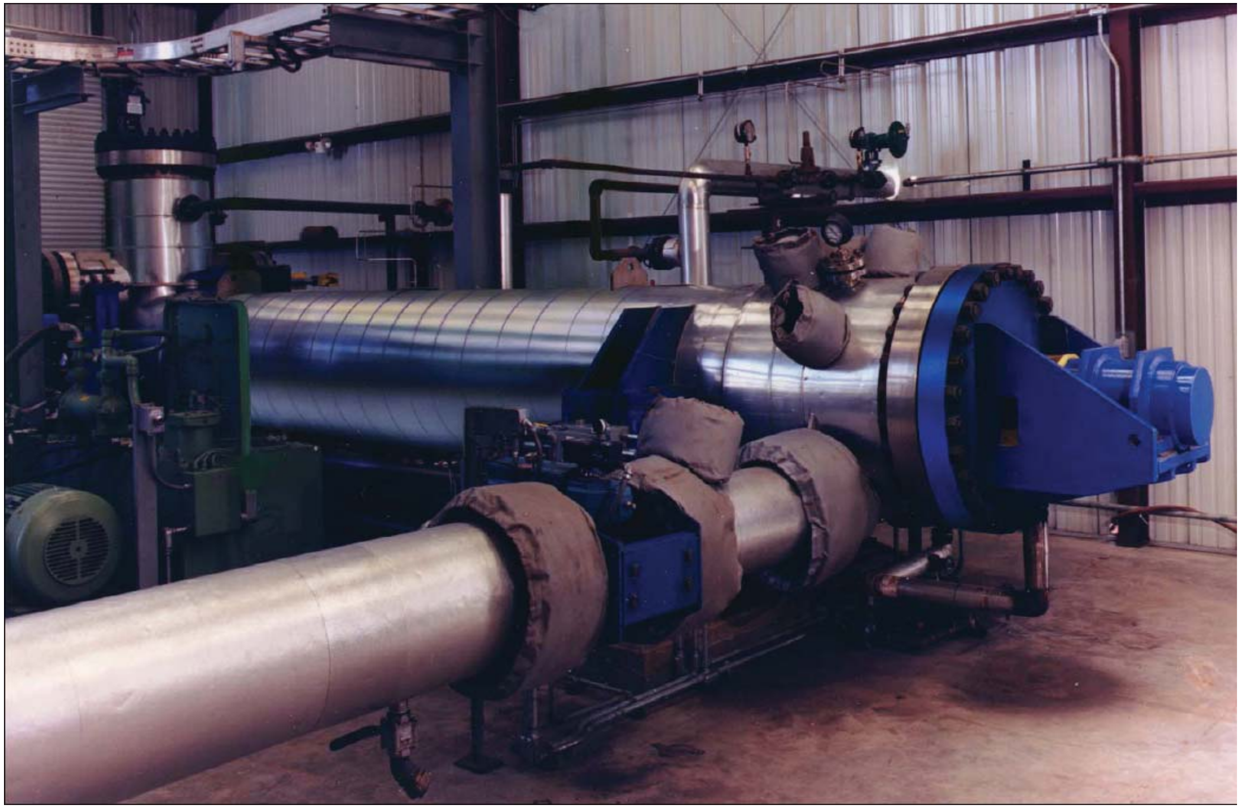
- **Feedstock: corn stover**
- **Technology: developed by Novozymes and DuPont**
- **Capacity: current 50 million gallons a year from corn, increased to 125 million gallons from corn and stover**
- **Schedule: completed by 2009**

http://www.voyagerethanol.com/index.asp

THE UNIVERSITY of WISCONSIN MADISON

SunOpta (Brampton, ON): Bioprocess Developer

(Continuous Steam Explosion Systems, formerly StakeTech)

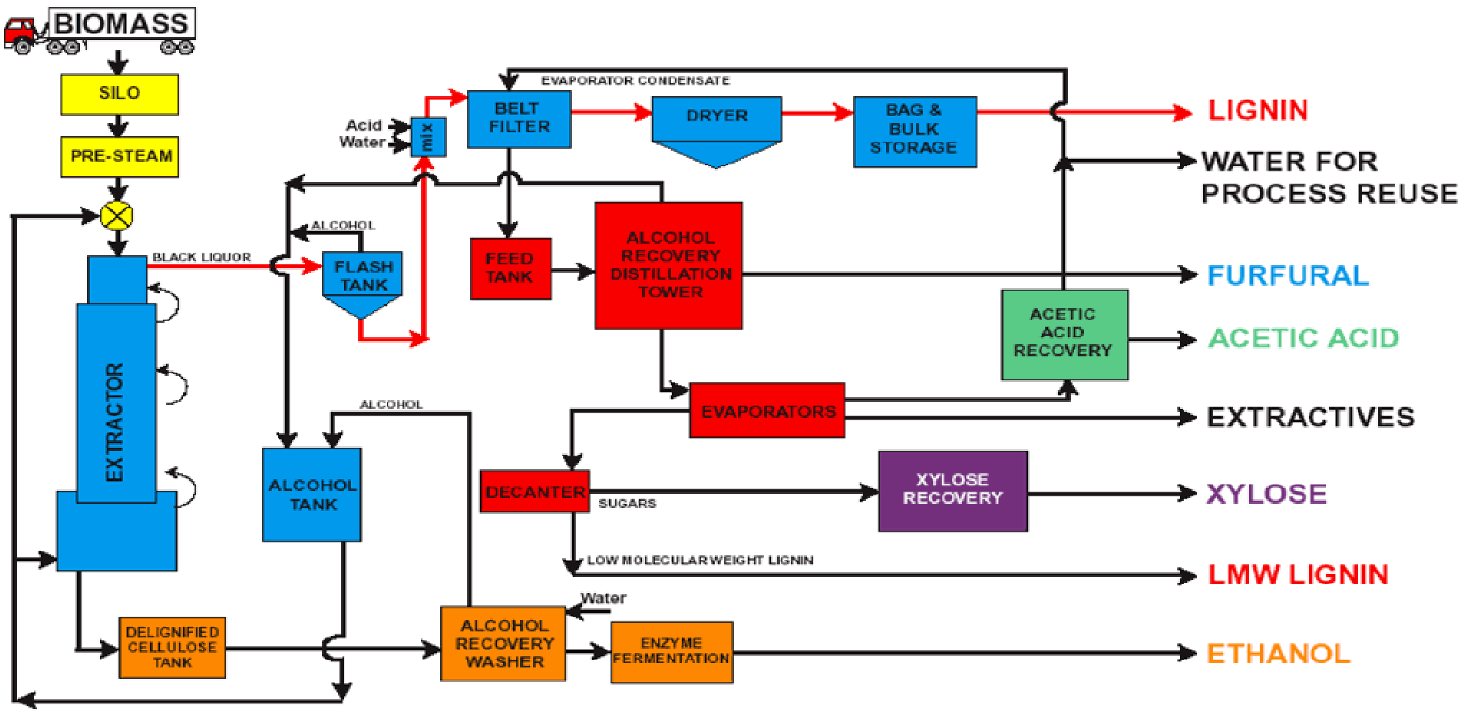


- **Aug. 2005, continuous steam explosion process for Abengoa, 4.7 million Euros, in Spain**
- **Aug. 2006, continuous process system for Celunol in Louisiana**

http://www.sunopta.com/bioprocess/index.aspx

An organosolv based biorefining process for lignocellulosic biomass: in addition to fuel ethanol, the process generates high-quality and high-value co-products from lignin and hemicellulose

Commercial Lignol Biofuel Biorefinery



Pan et al. 2005 *Biotechnology and Bioengineering*, 90, 473-481

http://www.lignol.ca

Summary

- Cellulose ethanol is the future of fuel ethanol.
- Technology is under development and modification.
- Breakthroughs are expected.
- More pioneers and investments are needed.

Thank you for your attention!