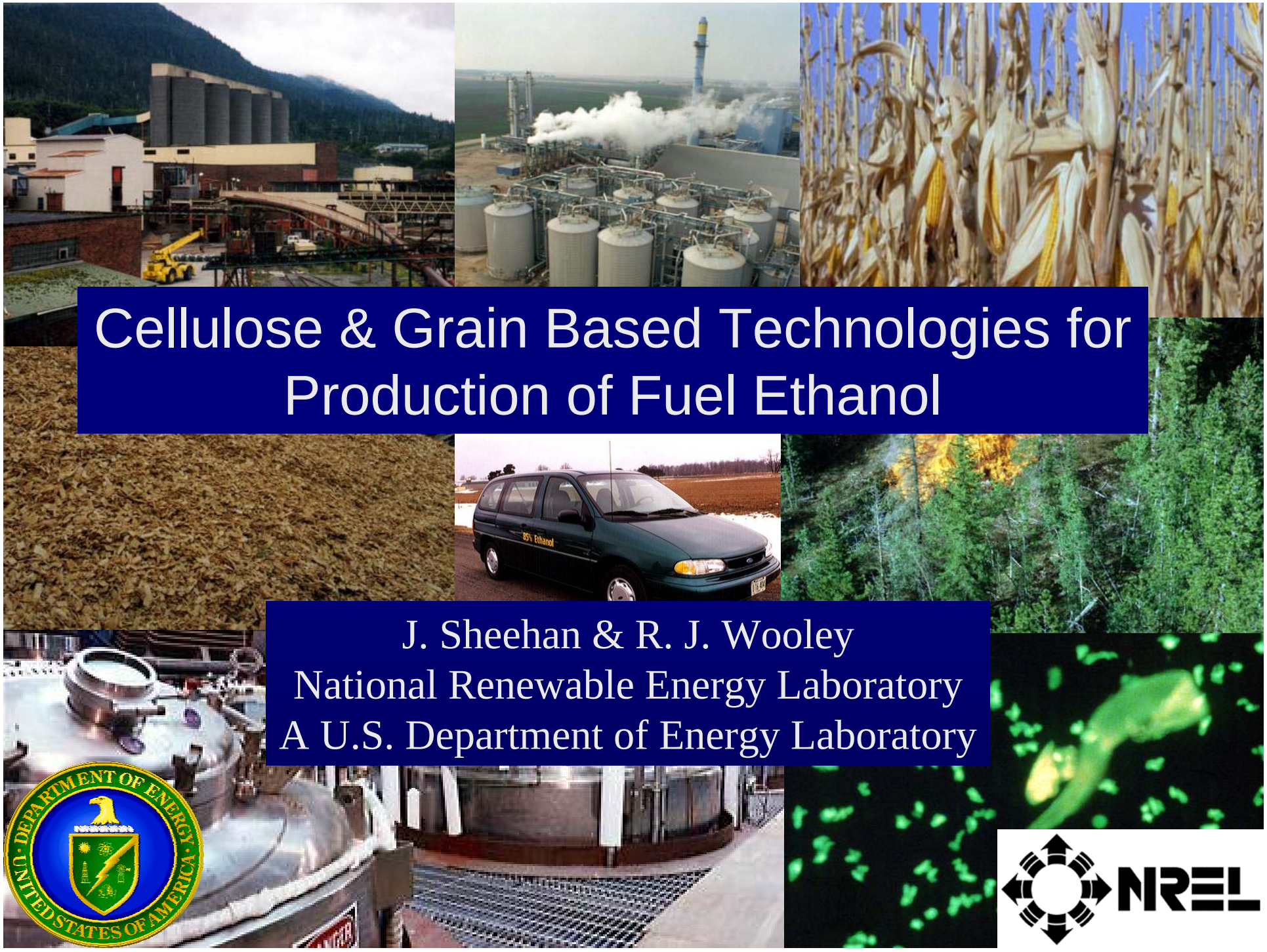


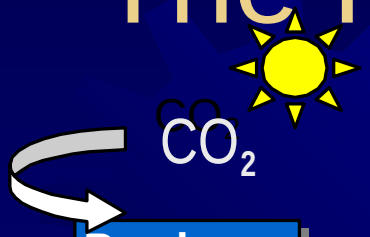
Cellulose & Grain Based Technologies for Production of Fuel Ethanol

J. Sheehan & R. J. Wooley
National Renewable Energy Laboratory
A U.S. Department of Energy Laboratory

Outline

- Sources of Ethanol
- Grain Based Dry Mill Process
- Cellulosic Based Processes
- Costs
- Conclusions

The Production of Ethanol



Produce biomass

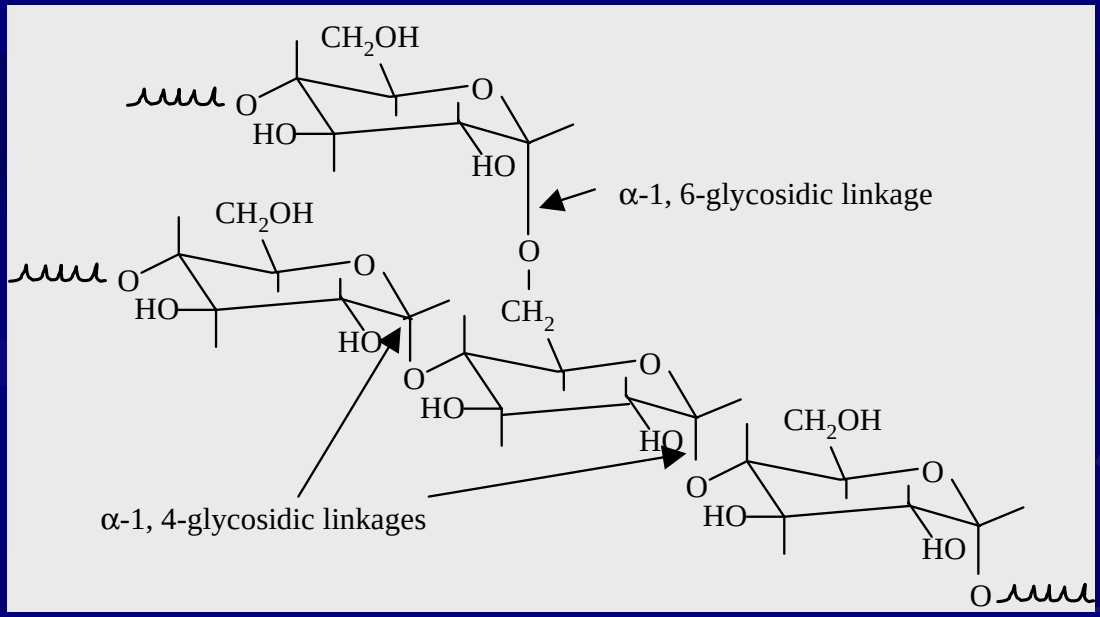
Convert and/or process biomass to fermentation feedstock

Ferment biomass intermediates to ethanol

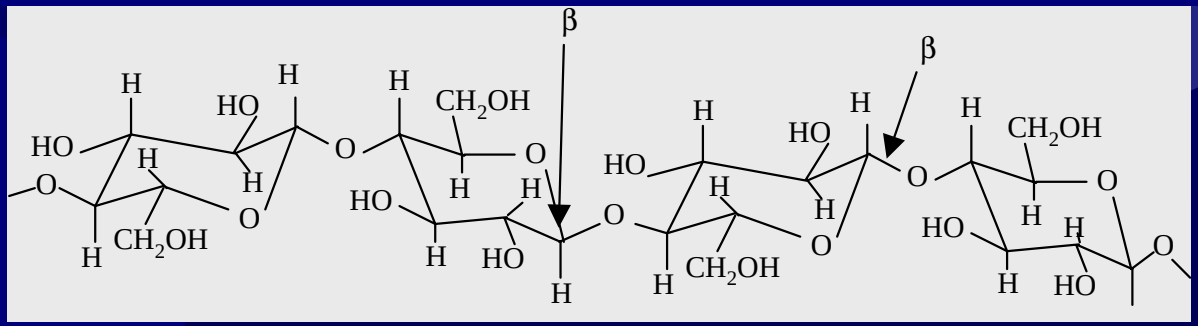
Recover ethanol and byproducts

Bioethanol – Starch & Cellulose

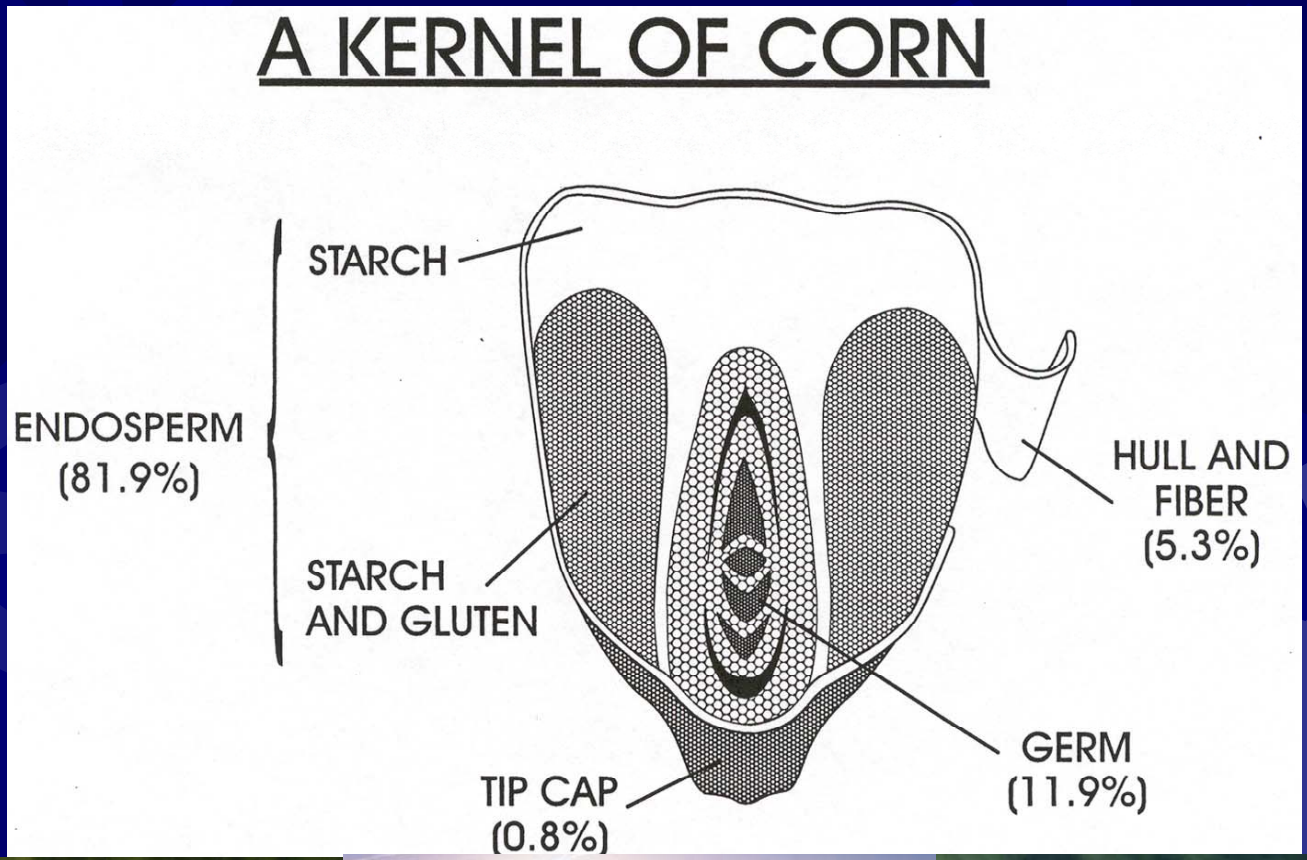
- Starch – Amorphous Glucose Polymer

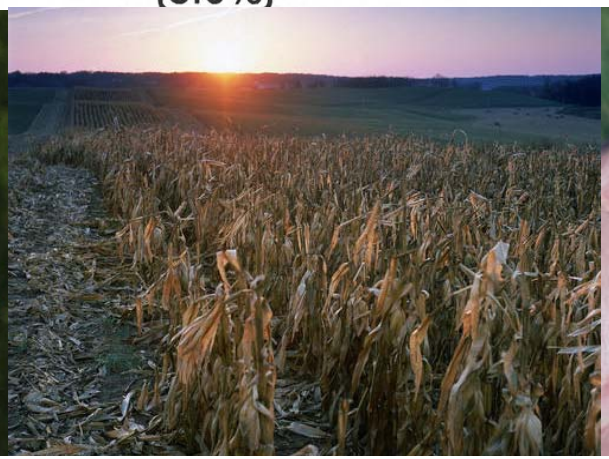


- Cellulose – Crystalline Glucose Polymer

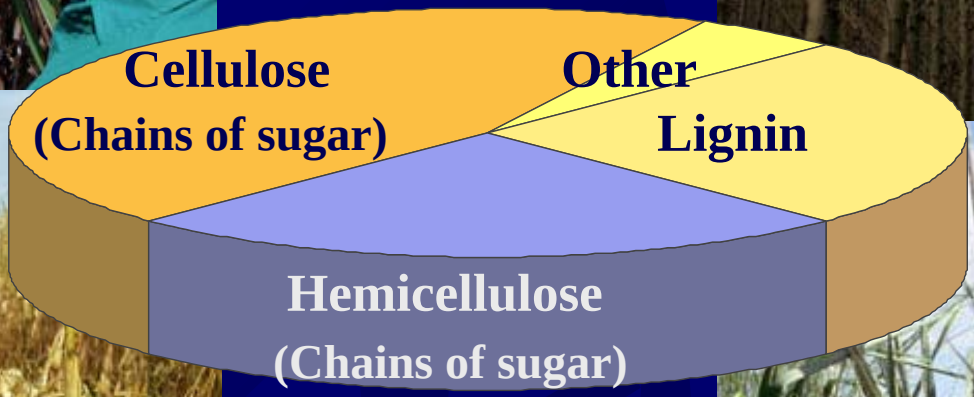


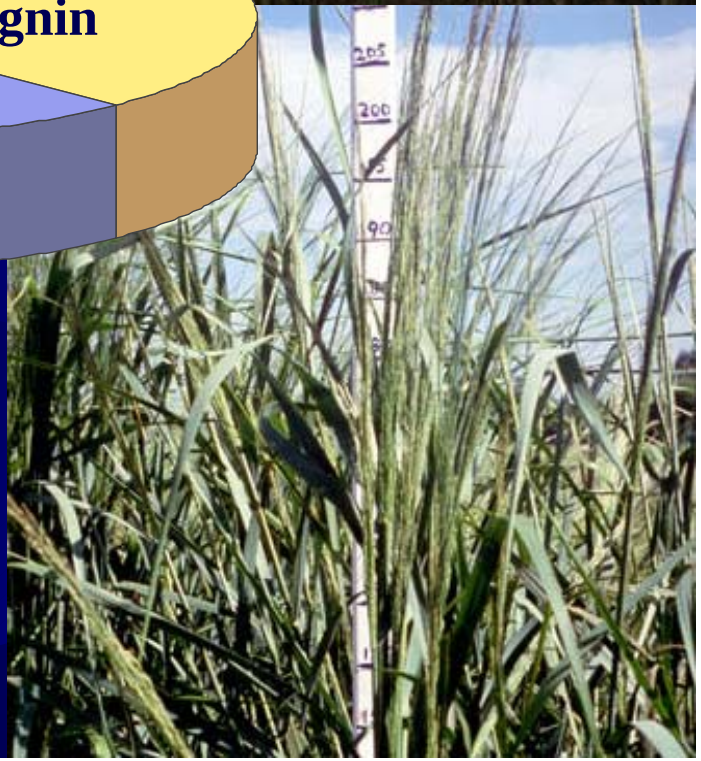
Grain – The Source of Starch





Sources of Cellulose

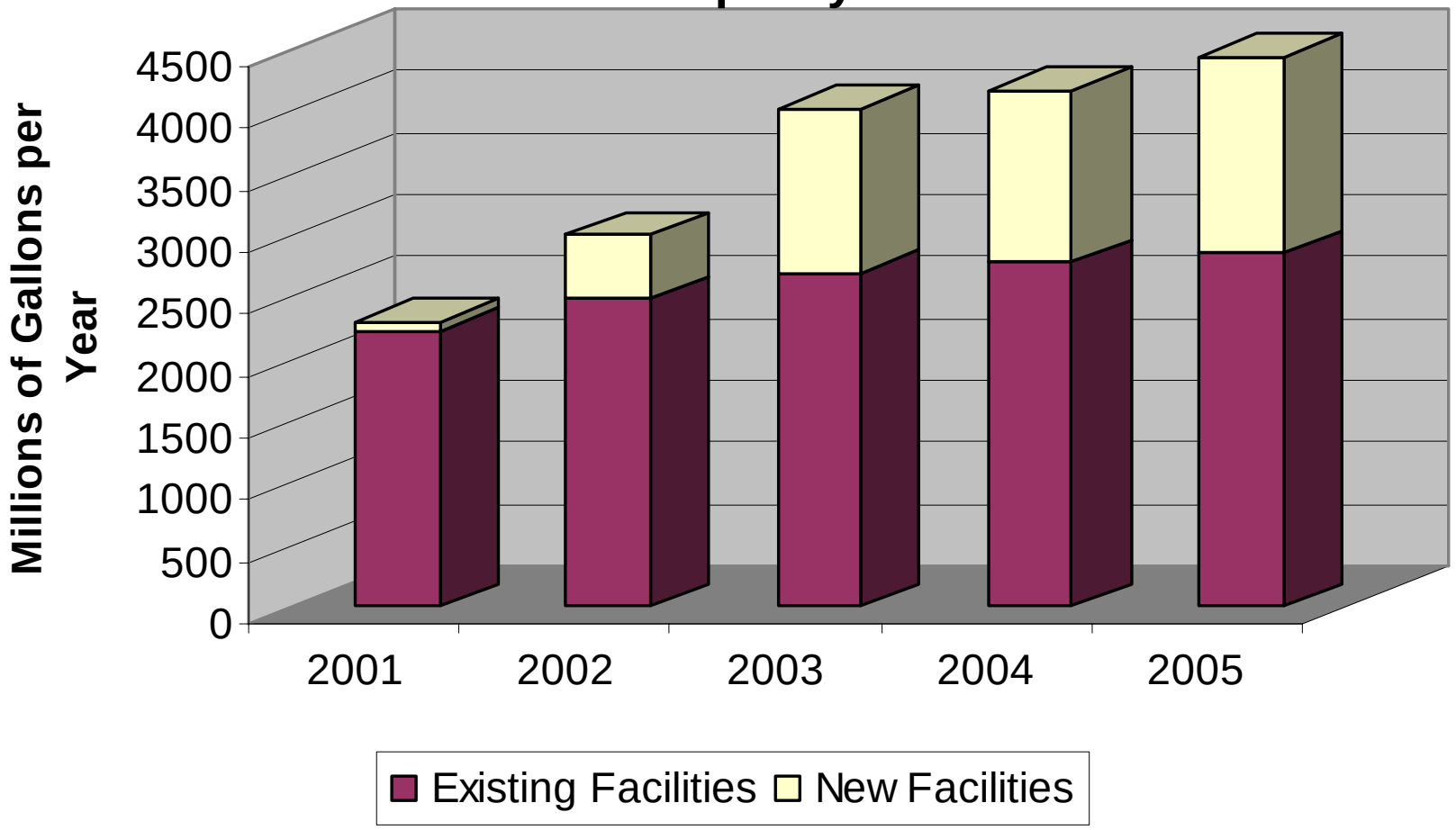




Dry Mill Ethanol Process

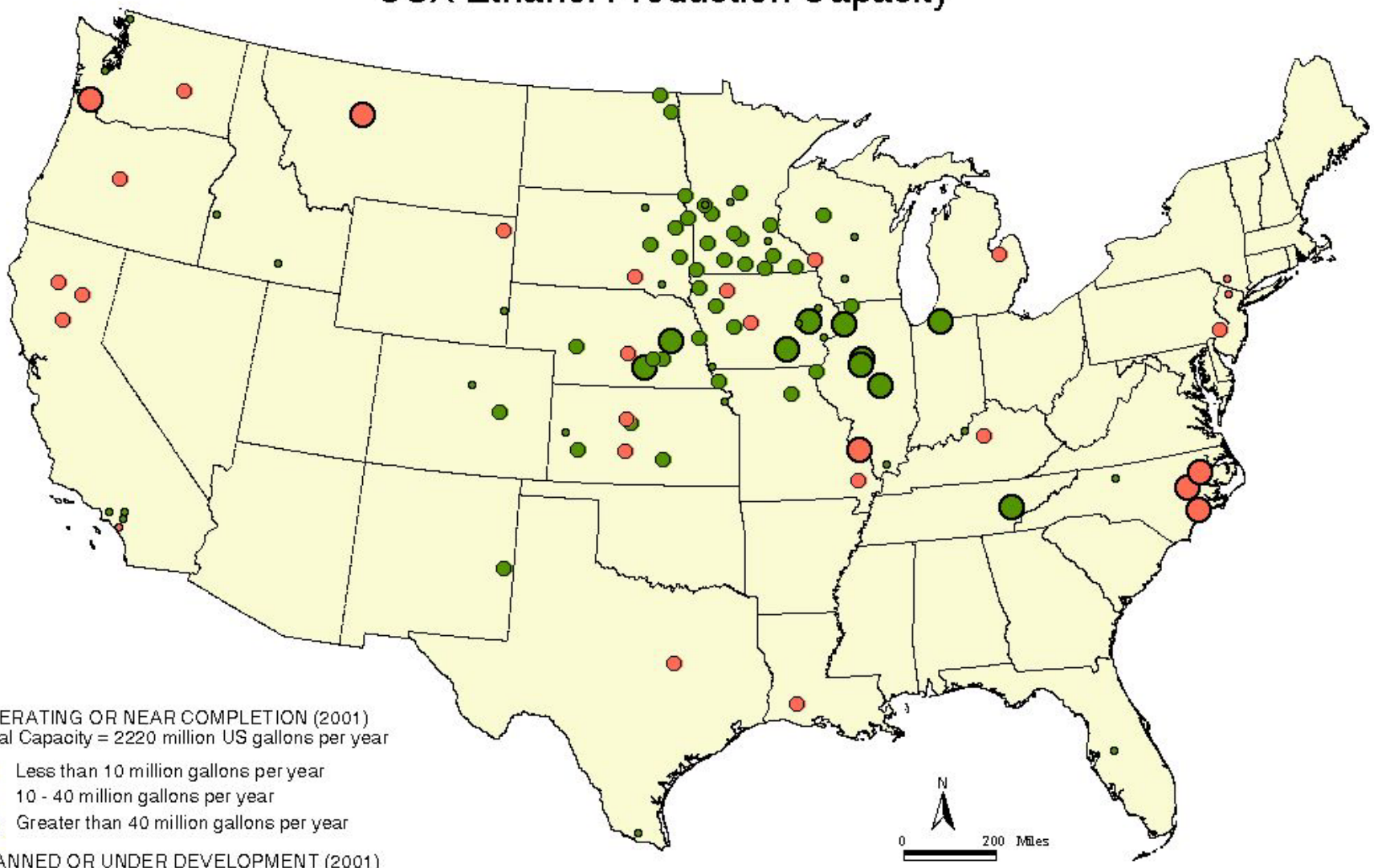
Corn kernels
Enzymes
Steam
Enzymes
Enzymes
Milling
Slurry
Jet Cooker
Liquefaction
Fermentation
Fresh water
Backset
Yeast
Condensate
Evaporation
Distillation/
Dehydration/
Scrubber
Centrifugation
Syrup
Drying
Steam
DDGS
Ethanol

Planned Growth of Starch Ethanol Production Capacity



Source: "U.S. Ethanol Industry, Production Capacity Outlook", CEC, August, 2001

USA Ethanol Production Capacity

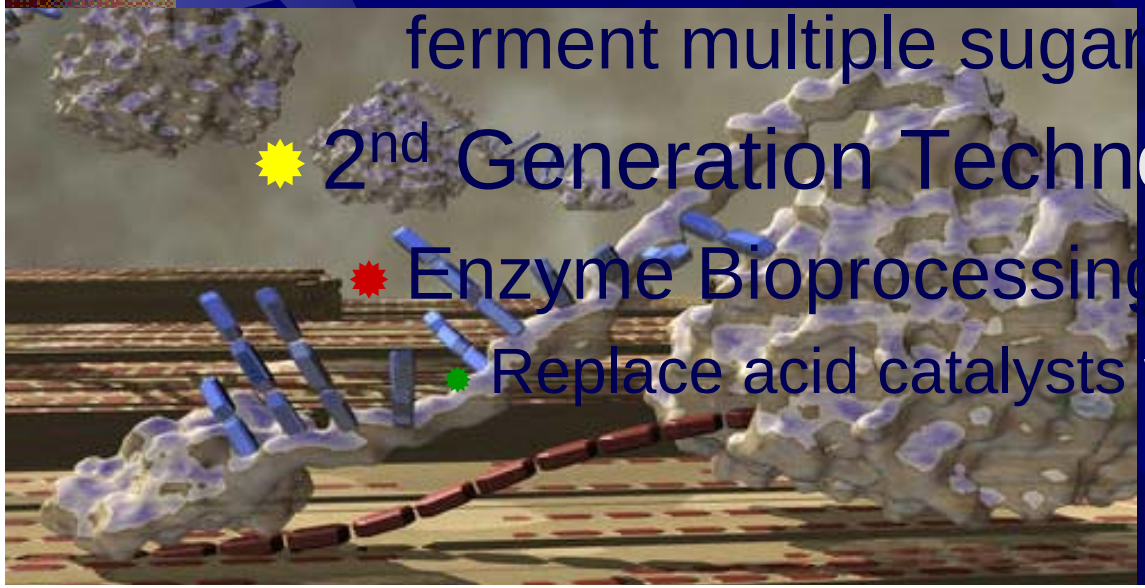


Cellulosic Conversion Today

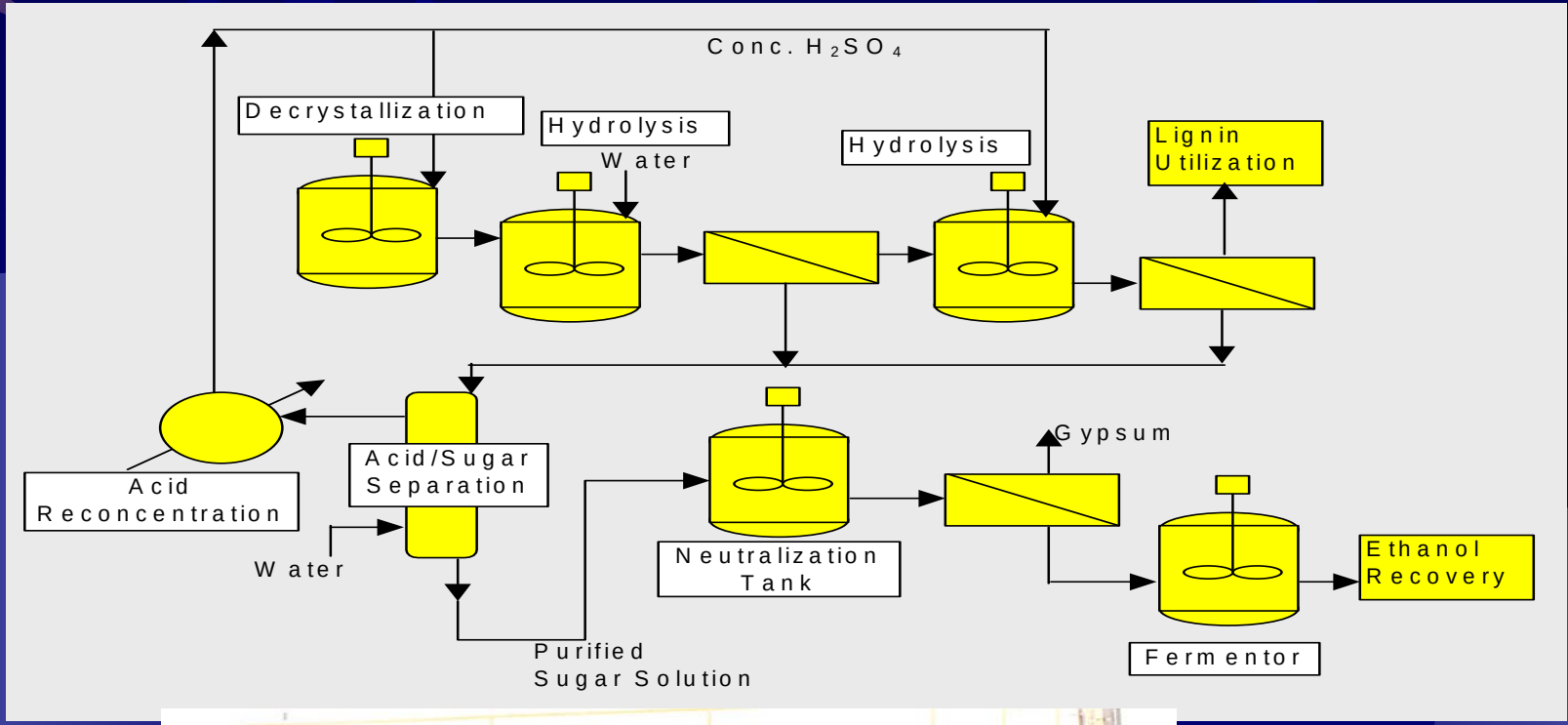
- First of a kind plants rely on “niche” sources related to environmental solutions
- The expanding industry will turn to higher volume supplies
  - Corn Stover
  - Energy Crops

Cellulosic Conversion Direction

- 1st Generation Technology
  - Concentrated Acid
  - Two Stage Dilute Acid
  - New genetically engineered microbes that ferment multiple sugars
- 2nd Generation Technology
  - Enzyme Bioprocessing
    - Replace acid catalysts with biological catalysts



1st Generation: Concentrated Acid



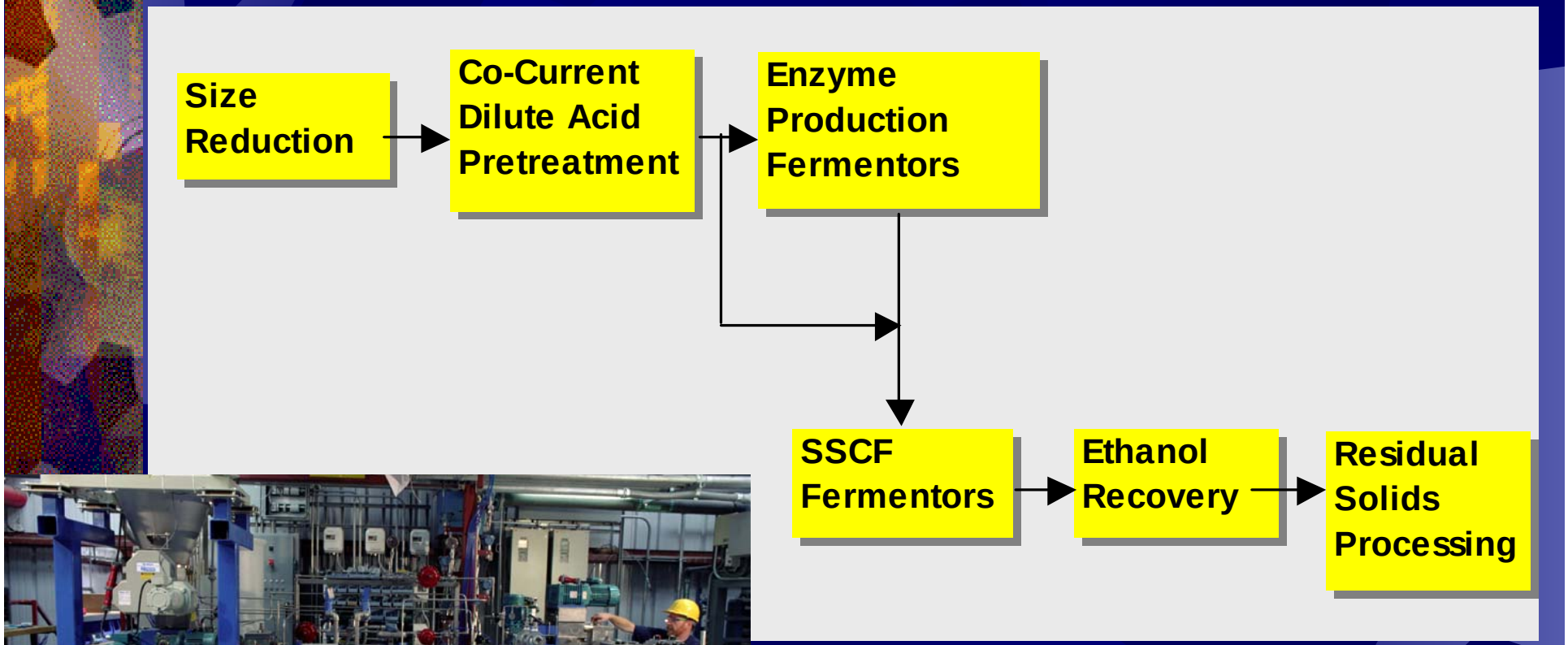
1st Generation: 2-stage Dilute Acid

Hydrolysis of wood chips

Technology Tradeoffs – Cellulosic Conversion

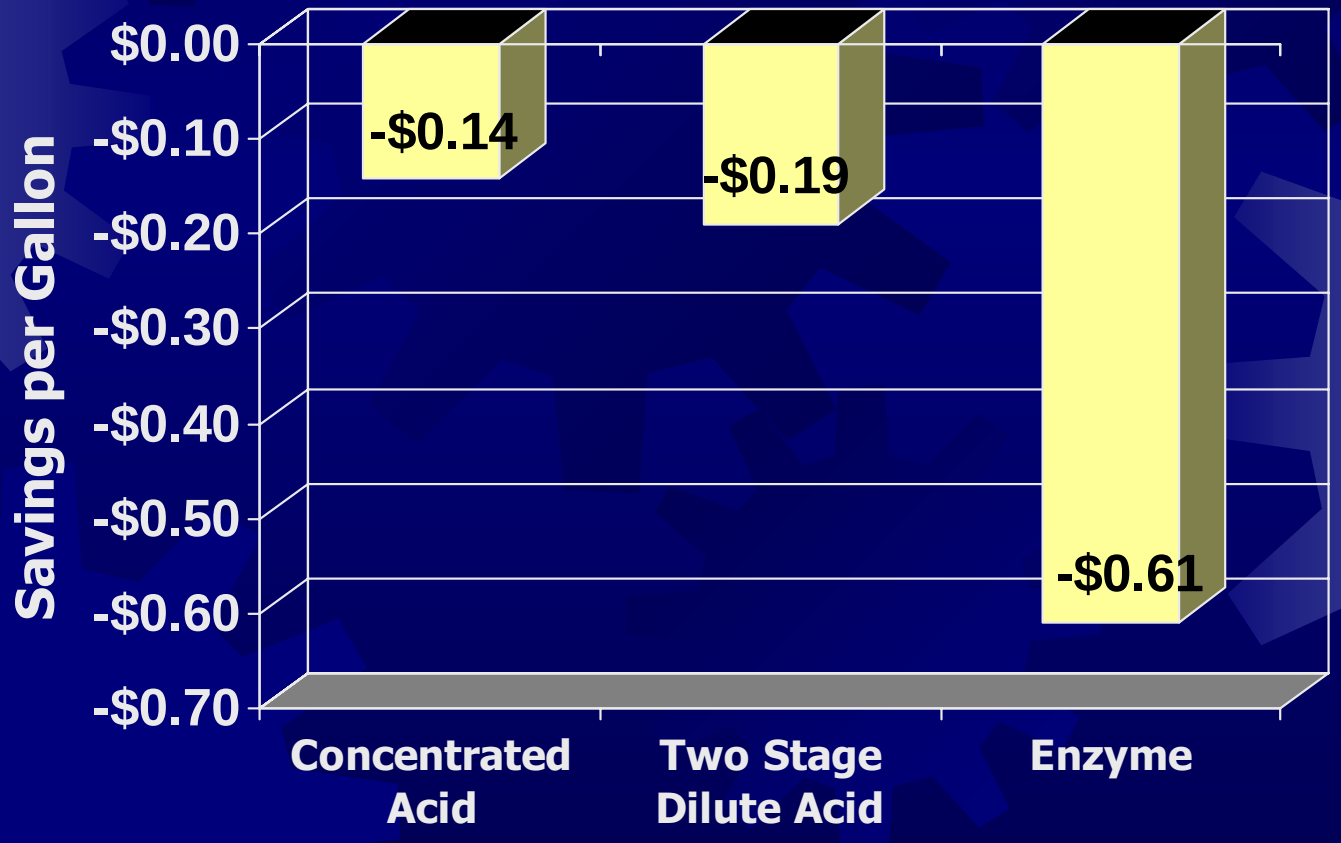
- Two-Stage Dilute Acid
  - low capital cost
  - low ethanol yields
- Concentrated Acid
  - high capital cost
  - high ethanol yields
- Enzymatic
  - greatest cost reduction potential
  - enzymes are currently too expensive

2nd Generation: The Enzyme Process...



2nd Generation—why the Enzyme Process?

Potential for Cost Reductions



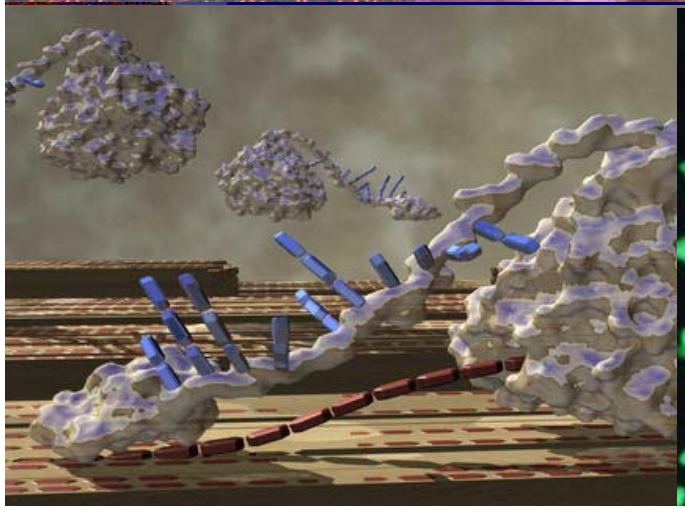
Technology Development Plan

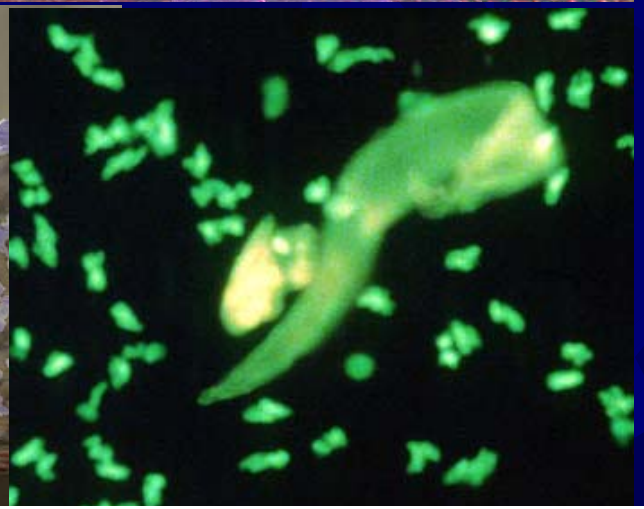
- We conclude that the enzyme process should be the focus of R&D, while the acid processes should be the focus of near-term deployment efforts
- Our economic analysis is consistent with the history of these processes

Technology Pathways for the Enzyme Process

Focus on Biotechnology

- Better enzymes
- Better fermenting organisms
- Better feedstocks

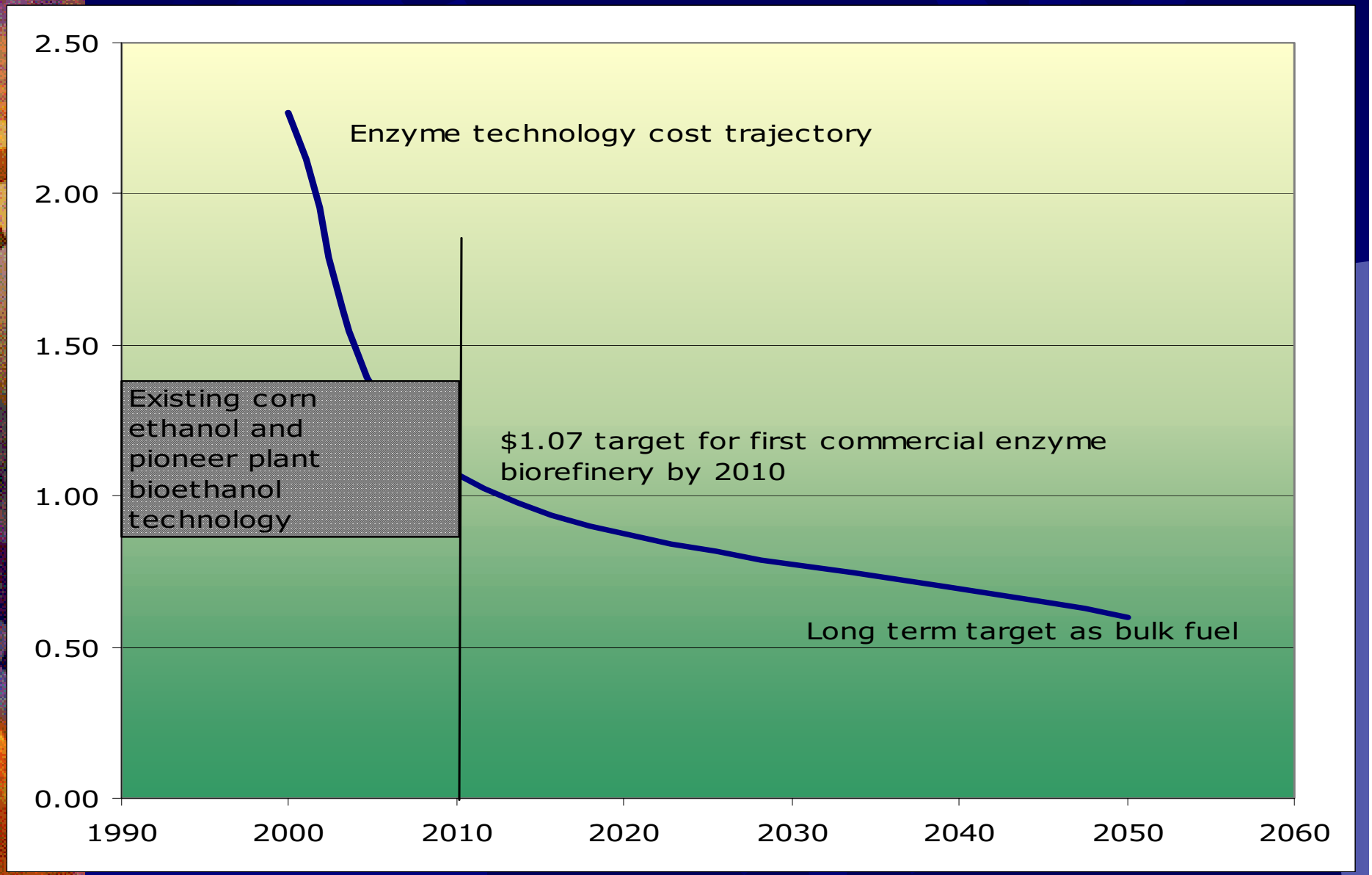




Technology Pathways: Biotechnology for Enzymes

- Use industry expertise in cellulase production
  - Industry tells us that enzyme production technology is substantially better than what we (NREL) have observed in the lab
  - Industry has committed themselves (with assistance from DOE) to a 10x reduction in cost of enzymes

Where are the costs of Cellulosic Conversion?



Operation Costs

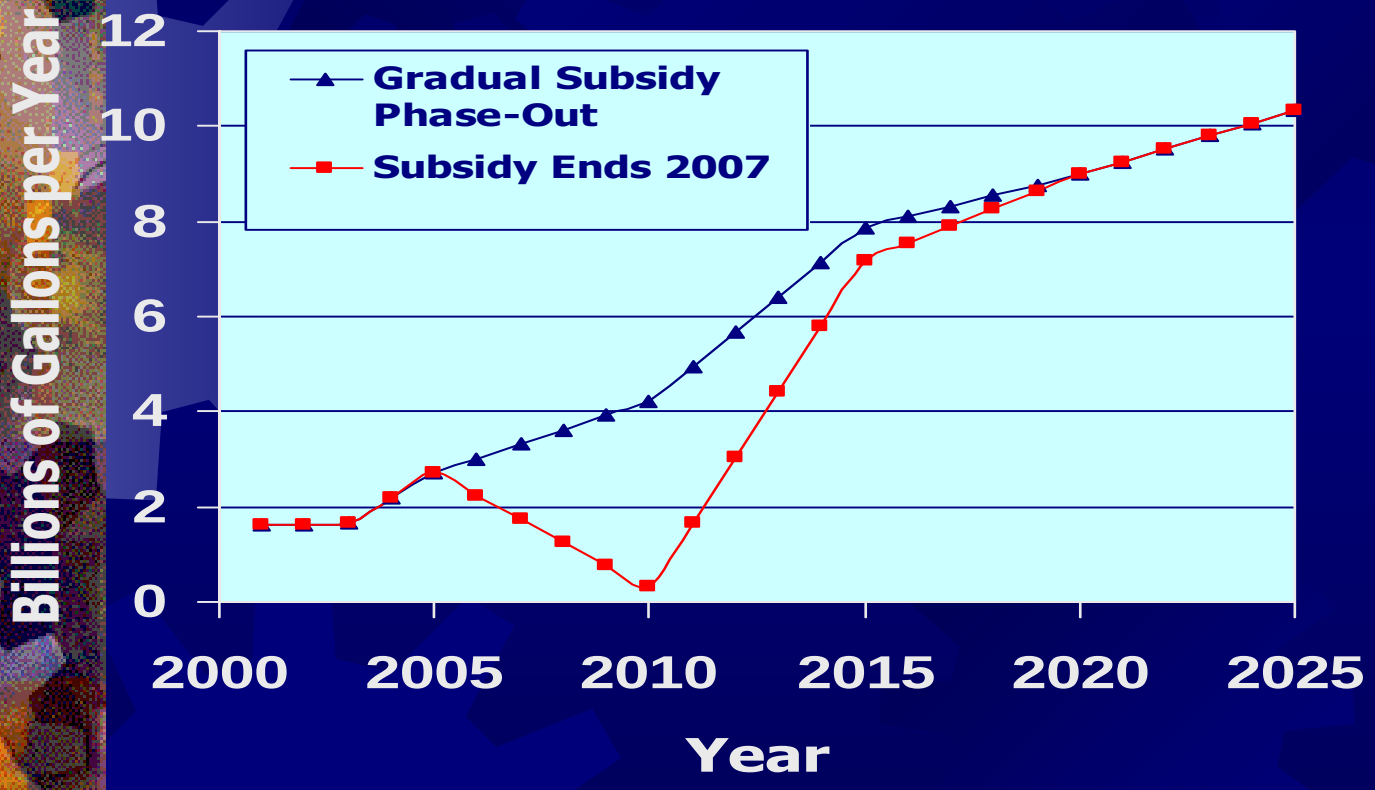
- Corn Dry Mill (Industry Averages)
  - Feedstock $0.82
  - By-Product - $0.28
  - Fuels $0.13
  - Waste & Water $0.01
  - Enz & Chem $0.09
  - Fixed $0.17
  - Operating $0.93
  - Capital $0.15
  - Total $1.08

Source: “1998 Ethanol Costs of Production”, H. Shapouri, USDA, Presented at the 6the National Ethanol Conference, Las Vegas, NV, Feb. 18-20, 2001

- Cellulosic (Projected)
  - Feedstock $0.37
  - By-Products -$0.07
  - Fuels $0.00
  - Waste & Water $0.01
  - Enz & Chem $0.27
  - Fixed $0.14
  - Operating $0.72
  - Capital $0.60
  - Total $1.32

Source: “”Lignocellulosic Biomass to Ethanol Process Design …”, Wooley, et al., NREL Report TP-580-26157, July, 1999

Possible future



Gradual phasing out of subsidies from now to 2020
The current 2007 sunset would disrupt the industry

DOE Supported Bioethanol Commercialization Projects

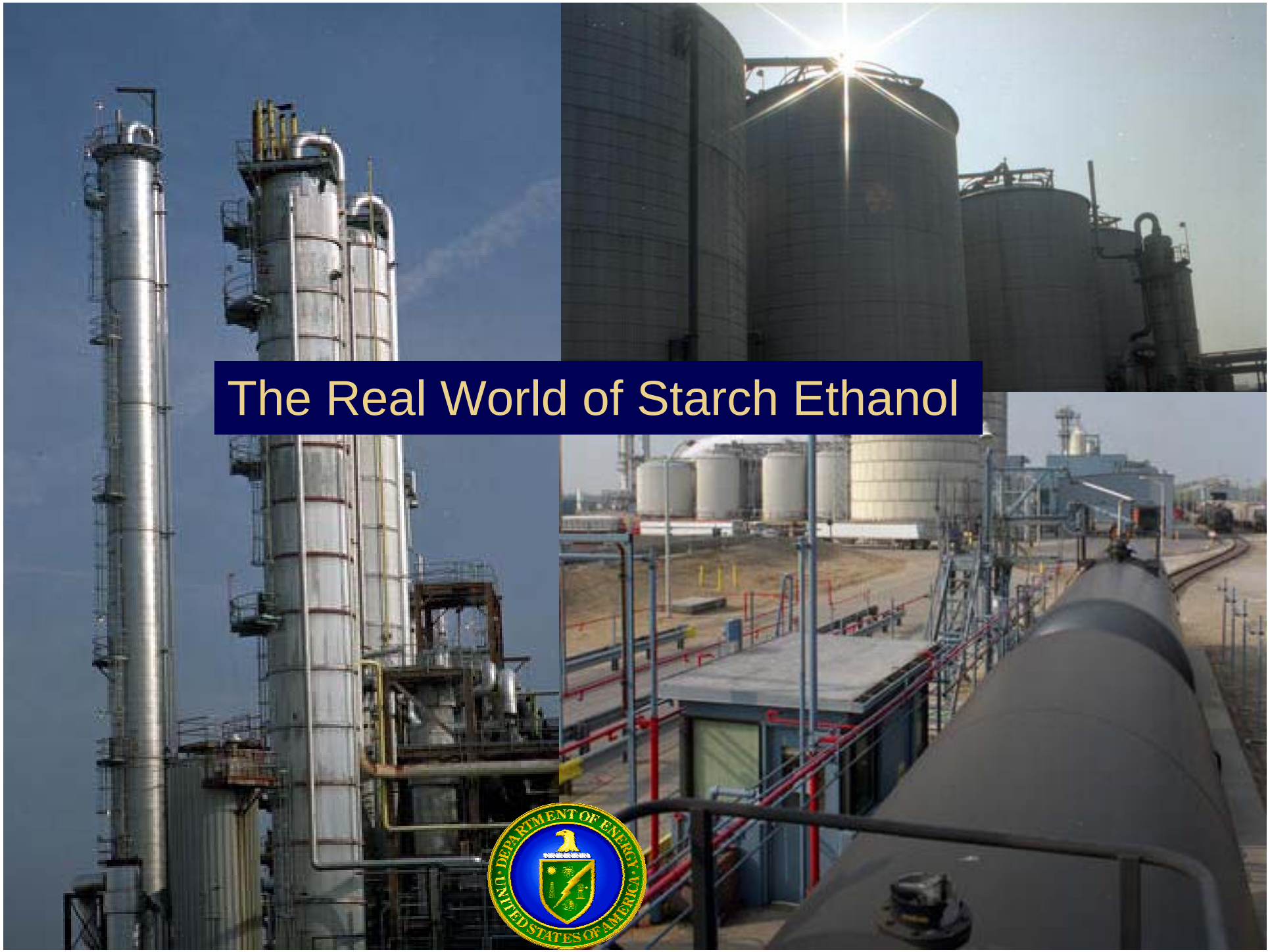
Company Project location	**Startup**	**Technology**	**Feedstock**	**Ethanol production**
BCI Jennings, LA	2003	Two-stage dilute acid	Bagasse	20 x 10^6 GPY (gallon/year)
Masada Middletown, NY	2003	Concentrated acid	MSW	10 x 10^6 GPY
BCI/Gridley LLC Gridley, CA	2004	Two-stage dilute acid	agricultural wastes and wood wastes	20 x 10^6 GPY
Sealaska Ketchikan, Alaska	2004	Two-stage Dilute acid	Timber harvest and mill residues	6 x 10^6 GPY
BCI/Collins Pine Chester, CA	2003	Enzymatic	Timber harvest and mill residues	20 x 10^6 GPY

Cellulosic Ethanol Commercialization Issues

- Biomass feedstock, availability and cost
- Suitable site
- Stable/secure ethanol market
- Ethanol production technology with process guarantee
- Qualified owner-operator
- Project financing

Conclusions

- Starch ethanol is a mature industry
- Existing ethanol industry will be a key player in the emerging biomass conversion
- Biomass to ethanol is emerging in niche situations
- Tremendous cost savings in conversion cost will be achieved in the future
- Improvement in core technology will facilitate development of ‘biorefineries’ that will allow ethanol to compete with petroleum based fuel


The Real World of Starch Ethanol
DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

The Emerging World of Cellulosic Ethanol