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Biofuel Feedstock Options and Conversion Platforms for Today and Tomorrow

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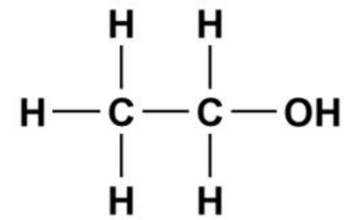
Part 1. Overview of Biofuels, Feedstocks, and Conversion Platforms

1st Generation Biofuels: Ethanol and Biodiesel

- Fuel Ethanol is the #1 Biofuel in the World Today
  - 13.5 billion gallons produced in 2006
  - ~70% produced in USA and Brazil



ethanol
Fuel For Clean Air

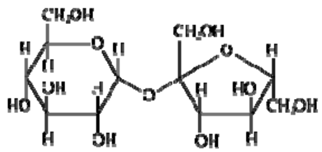
- Biodiesel is the #2 Biofuel in the World Today
  - 1 billion gallons produced in 2005
  - ~85% produced in Europe

BIODIESEL

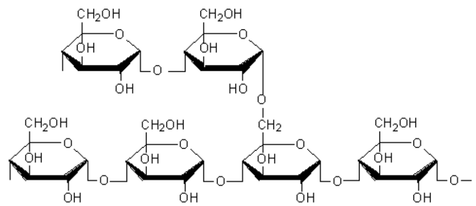
Source: F.O. Licht

1st Generation Feedstocks for Ethanol

- Mainly plant storage carbohydrates
  - Sucrose (sugar): from cane or beet



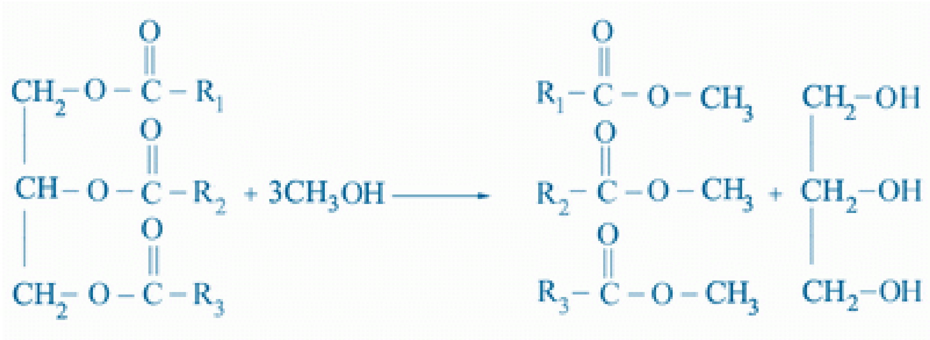
  - Starch: from corn, milo, wheat, cassava



- Storage carbohydrates are readily converted to simple sugars that can be fermented to ethanol by brewer’s yeast

1st Generation Feedstocks for Biodiesel

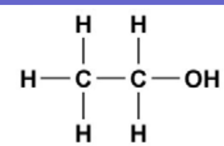
- Primarily plant storage lipids
  - Vegetable oils: from soy, canola/rape
  - Animal fats: from beef, poultry, etc.
- Vegetable oils contain triacylglycerols that can be readily converted to biodiesel (fame)



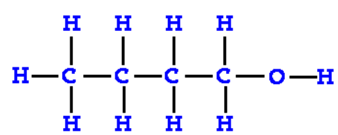
Picture from http://www.me.iastate.edu/biodiesel/pages/biodiesel3.html

2nd Generation Biofuels

- "Cellulosic Ethanol"



  - Ethanol made from lignocellulosic biomass
- Butanol



  - More btus/gallon; less problems blending and transporting than with ethanol
- Thermochemically-derived Fuels
  - Methanol, ethanol, hydrogen, F-T gasoline and diesel

Why Are 2nd Generation Biofuels Still in the Future and not "Here and Now"?

- We don't know how to make 2nd generation biofuels in an economical way.
- Much more research is still needed, both basic and applied to lower capital, operating, and production costs.

Conversion Platforms for Biofuels

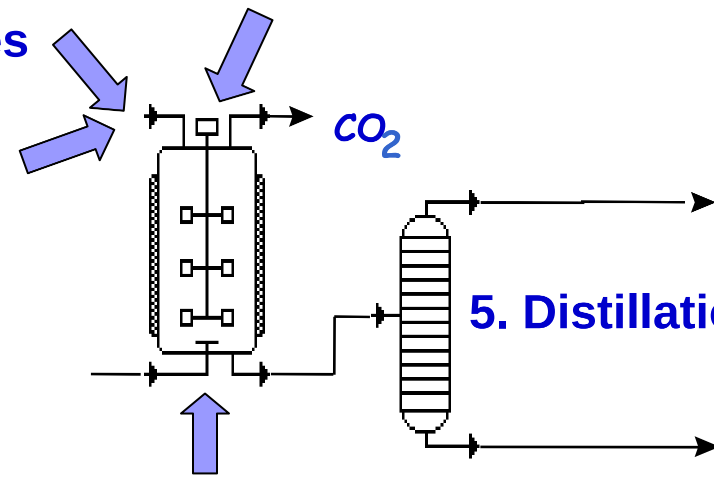
1st Generation Biofuels are Simple to Produce with a Biochemical Sugar Platform Technology

Biochemical Platform for Fuel Ethanol Production from Sugar

1. Add sugar or molasses

2. Add water and nutrients

3. Add Yeast



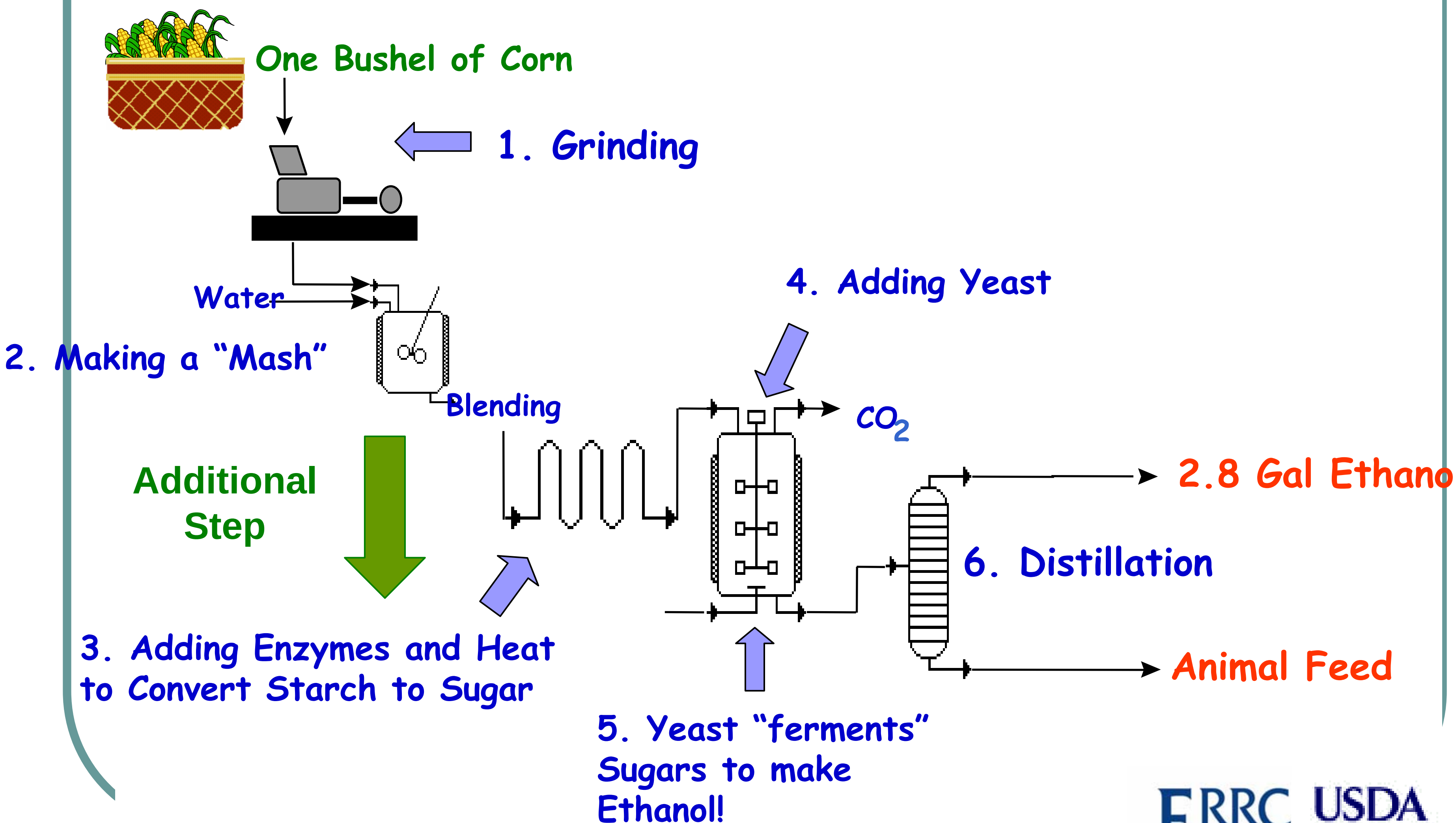
4. Yeast ferments sugar to make ethanol

5. Distillation

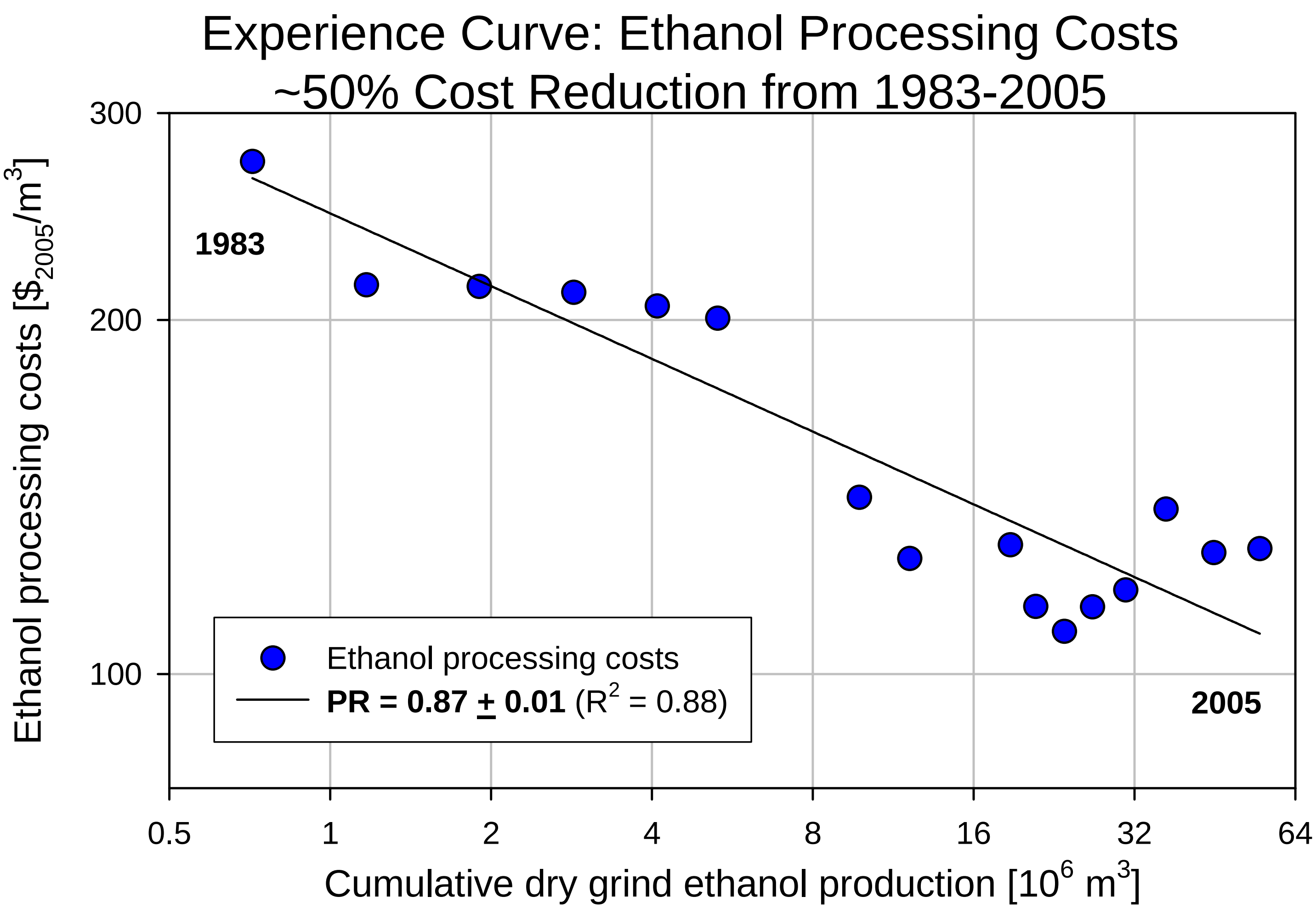
Ethanol

Byproducts

Making Ethanol from Starchy Crops is Slightly More Complex than from Sugar



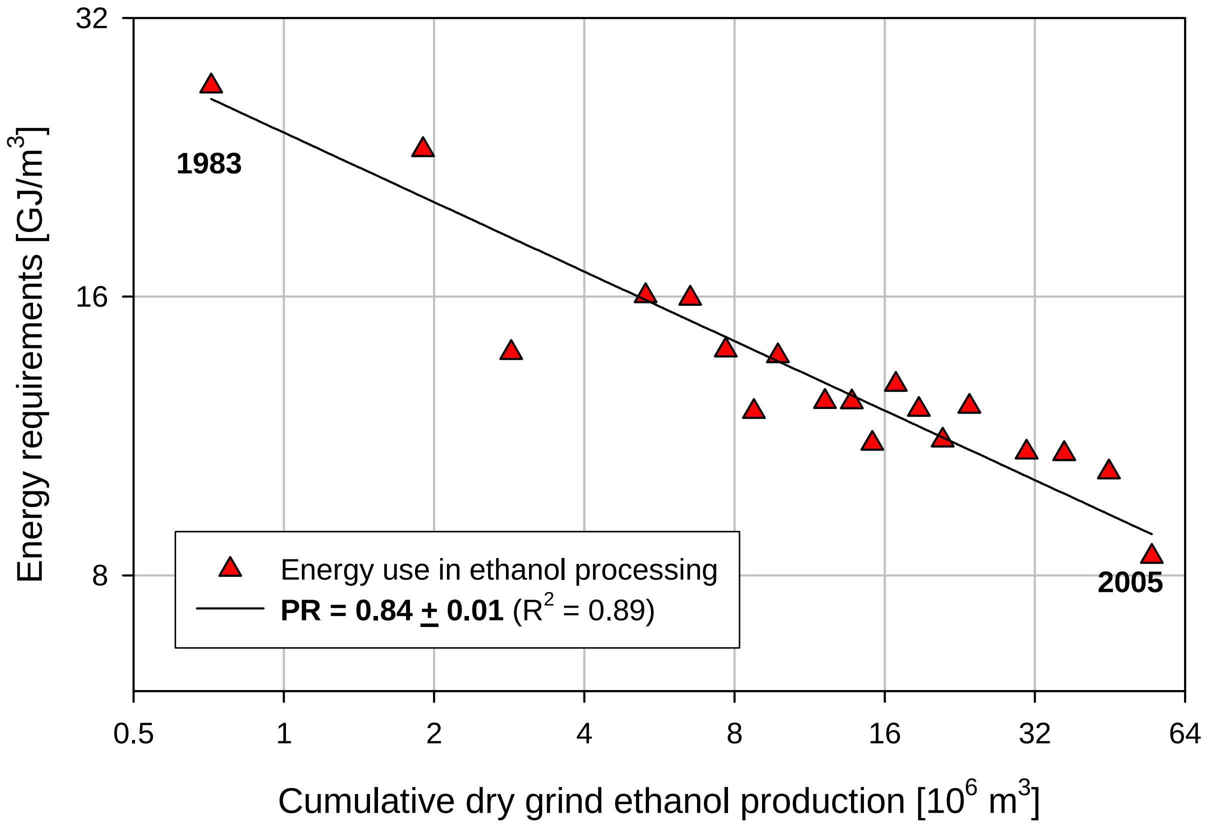
We Can Make Ethanol From Corn Economically Because of Years of R&D and Experience



Source: Willem Hettinga, 2007

We Can Make Ethanol From Corn Efficiently Because of Years of R&D and Experience

Experience Curve: Energy Use in Ethanol Processing
~63% Reduction in Energy Use from 1983-2005



Source: Willem Hettinga, 2007

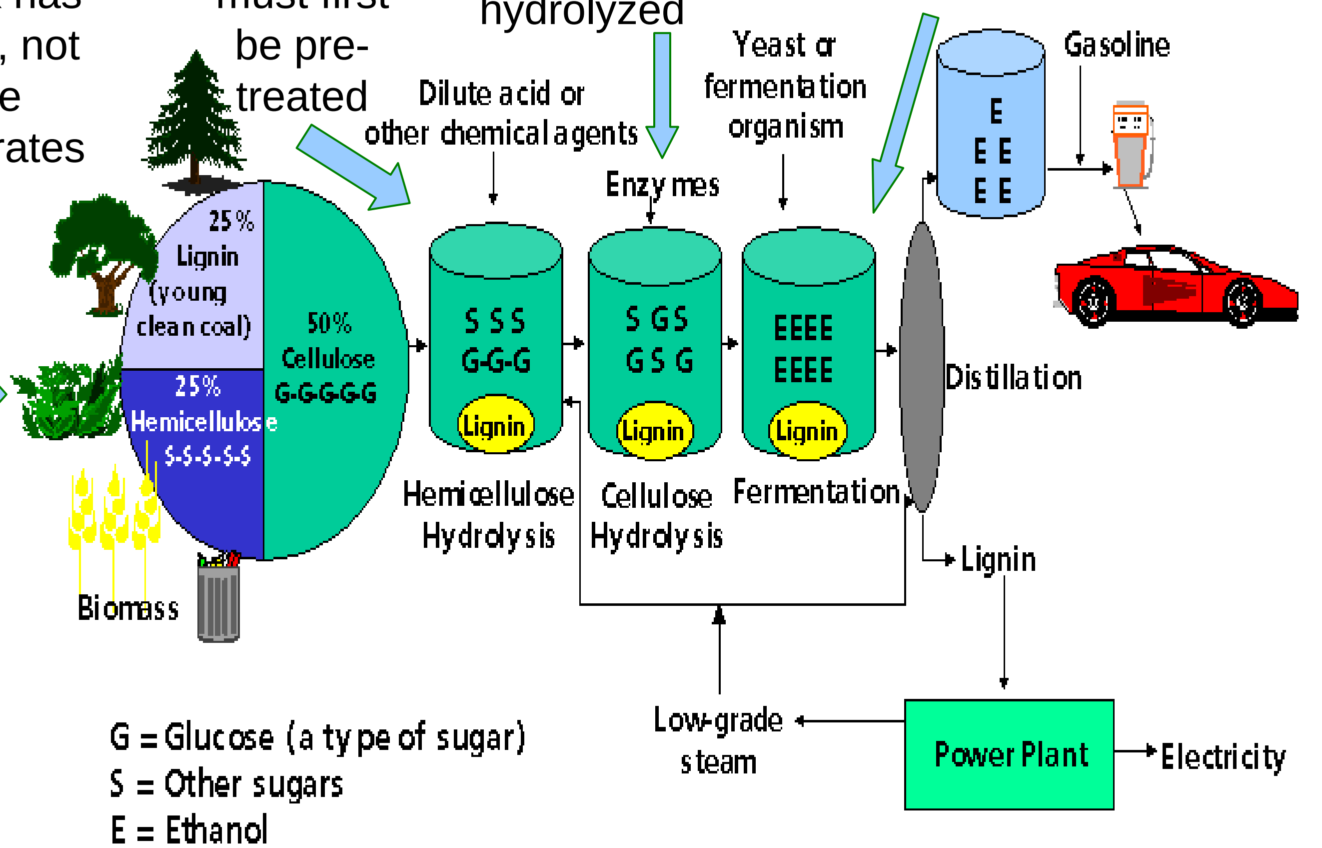
2nd Gen. Biofuels Can Be Produced by the Bio-Chemical (Sugar) Platform but Not Easily or Cheaply

1. Lignocellulosic biomass feedstock has structural, not storage carbohydrates

2. The feedstock must first be pre-treated

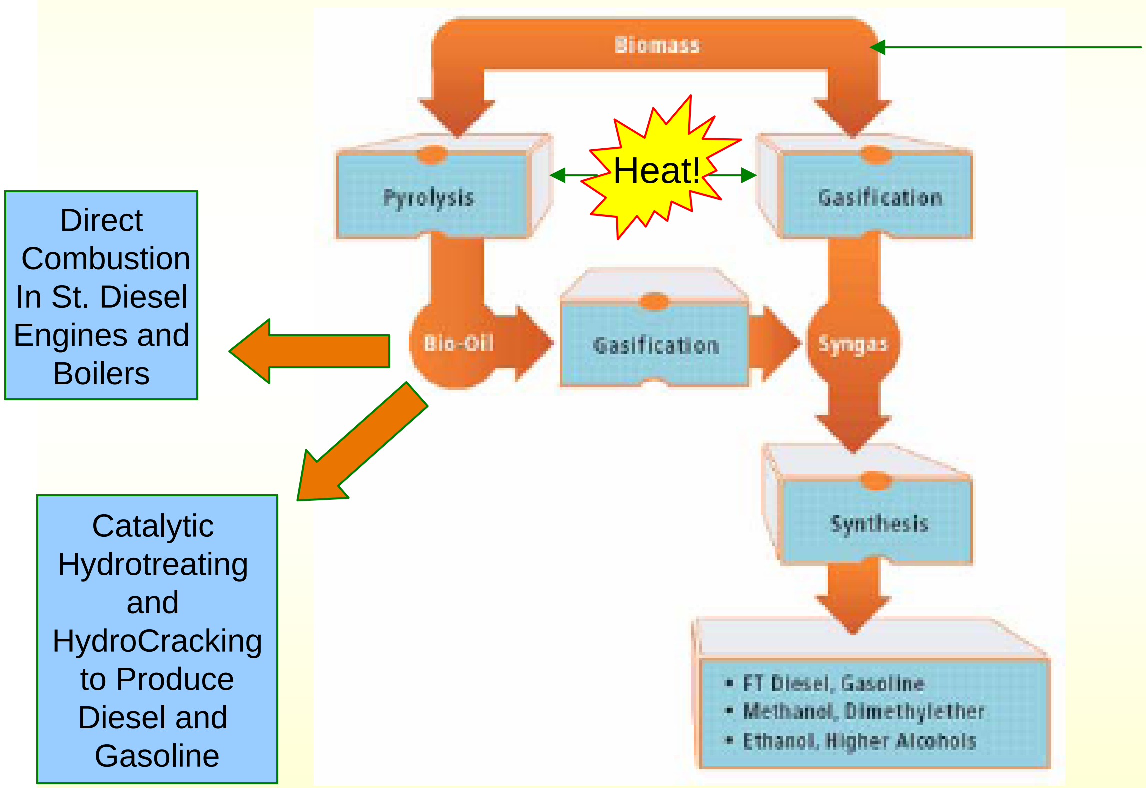
3. Then enzyme hydrolyzed

4. Then sugars are fermented using special organisms



2nd Generation Biofuels Can Also Be Produced By a Thermochemical Conversion Platform

Thermochemical Biomass Conversion



Uses Almost any Biomass, including Lignin Fraction!

Modified from Source: Abengoa Bioenergy - Viorel Duma
http://www.thermochem.biomass.govtools.us/documents/6ff05c7b-88c8-439d-af57-998b7c93e8ab.pdf

Which Is Better for Making Liquid Fuels from Biomass: BC or TC??

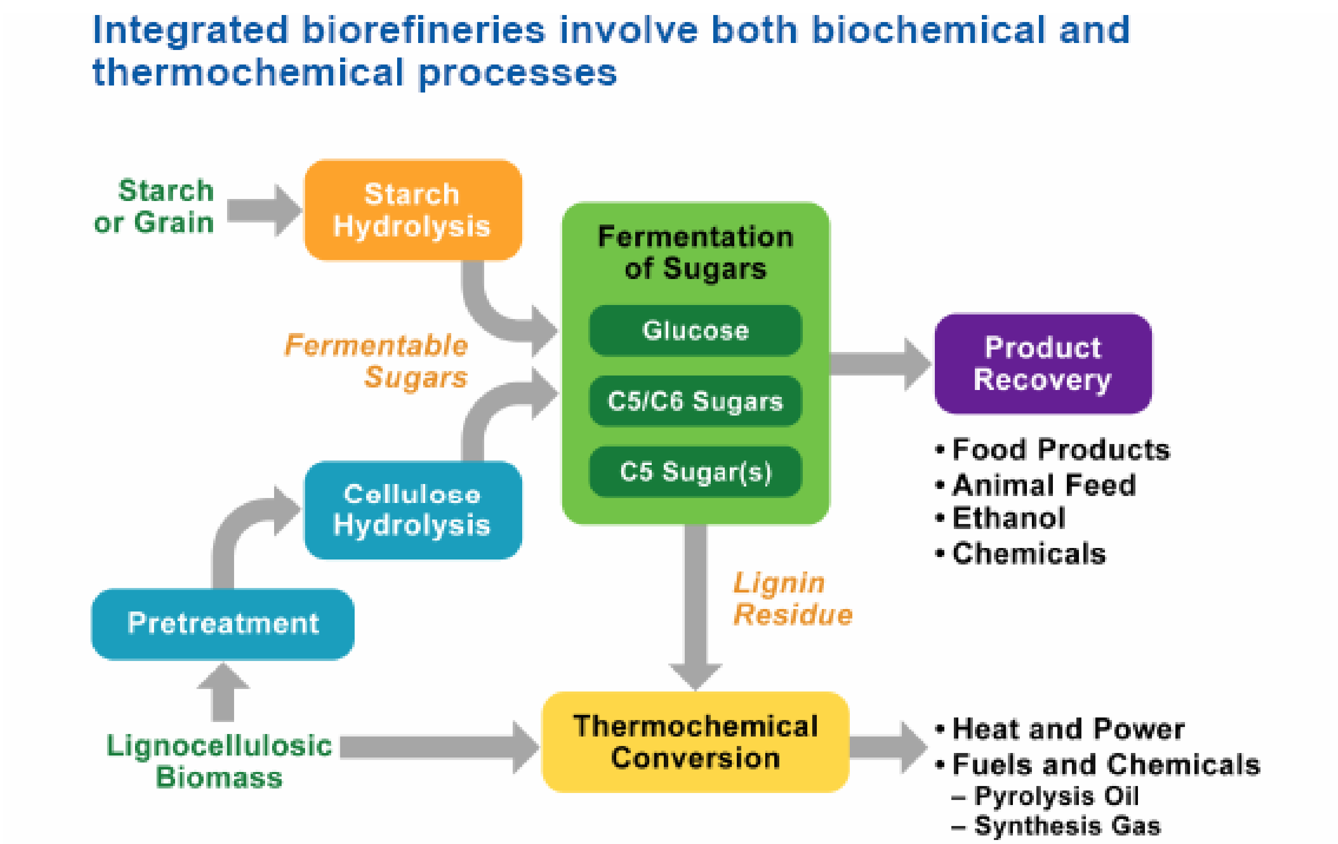
- No one knows yet!
- Each technology has pros and cons
- Both use biomass feedstocks
- Each has numerous researchable technical challenges to solve
- Each has great potential

Which Is Better for Making Liquid Fuels from Biomass: BC or TC??

- We recently helped fund a critical study: “Comparative Economics of Biorefineries Based on the Biochemical and Thermochemical Platforms”, Wright and Brown, Biofuels, Bioprod., Bioref. 1:49-56 (2007)

- The report concluded:
  - Capital costs for TC and BC biorefineries will be similar
  - These costs will be 4 to 5 times higher than same sized grain plants
  - If corn prices exceed certain levels, costs for some biomass-derived fuels will be competitive with grain derived ethanol.

The Technology of the Future May be a Hybrid



Source: DOE

But There are 3rd Generation Technologies Being Developed Too

- Consolidated bioprocessing
  - Development of organisms that break down biomass and produce biofuels with no added enzymes or pre-treatment
- Synthetic biology
  - Development of new organisms with new pathways to produce advanced fuels directly from multiple feedstocks

Part 2: Recommendations for the Future

The Need to Develop Economical Renewable Fuels is Critical and Urgent

- For all nations
- For the environment
- For the rural economies of the world

What Decisions Should Be Made Regarding Future R&D in Bioenergy?

- Research on bioenergy should be greatly increased in the public and private sectors
- Research is the key to the future of renewable biofuels
- Since we don’t know whether BC or TC processes will ultimately be most effective for biofuel production, each area should be strongly and equally funded

What Decisions Should Be Made Regarding Future R&D in Bioenergy?

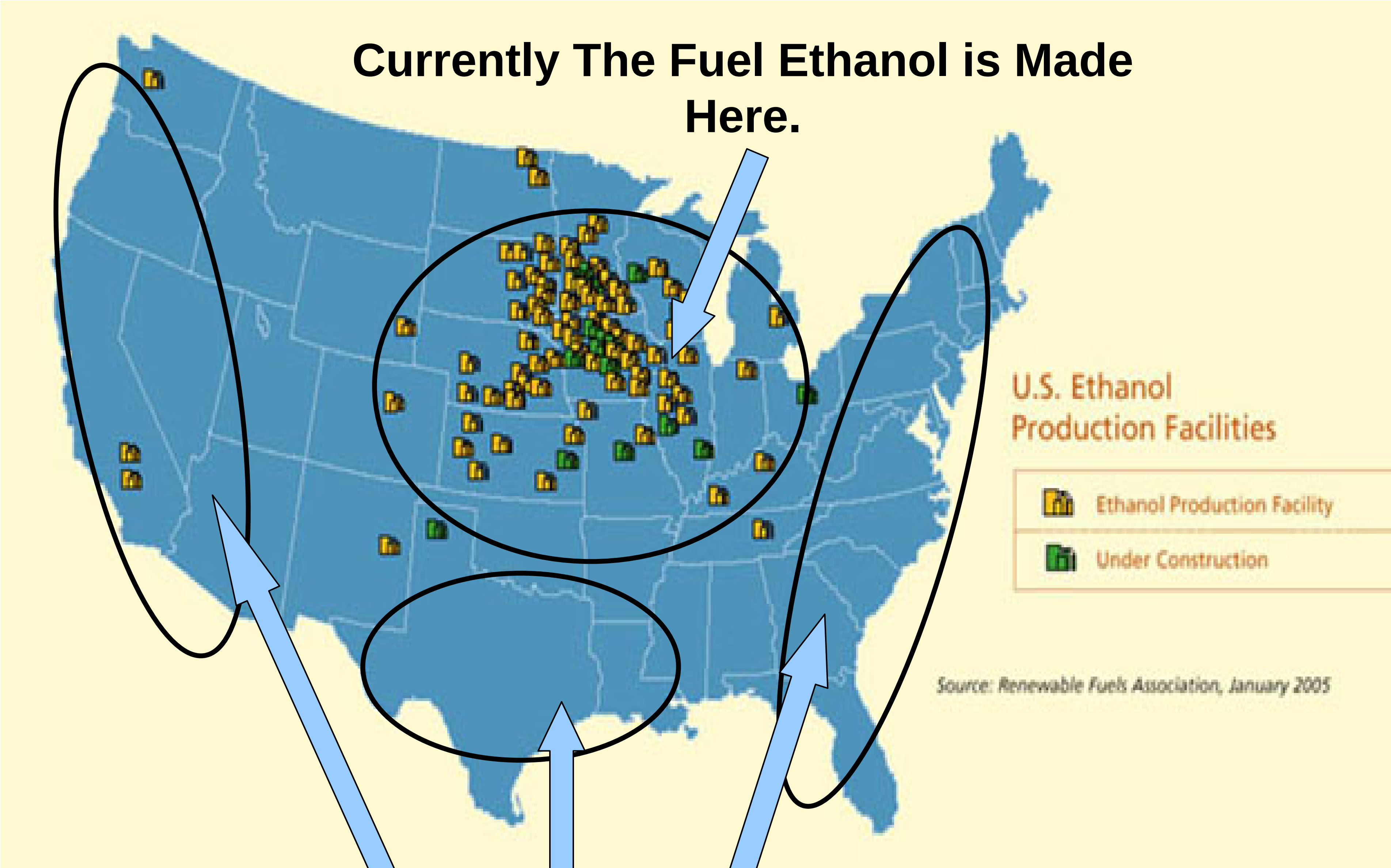
- In our rush to develop 2nd generation biofuels, let's not forget 1st generation technologies that remain unexploited!
  - Example: Dr. Reddy and sweet sorghum

- In ARS, in addition to working on cellulosic feedstocks, we are also investigating near-term energy crops:
  - Pearl millet
  - Field peas
  - Forage soybeans
  - Hull-less barley

The ARS-USDA is Committed to Sustainable Fuel Ethanol Production

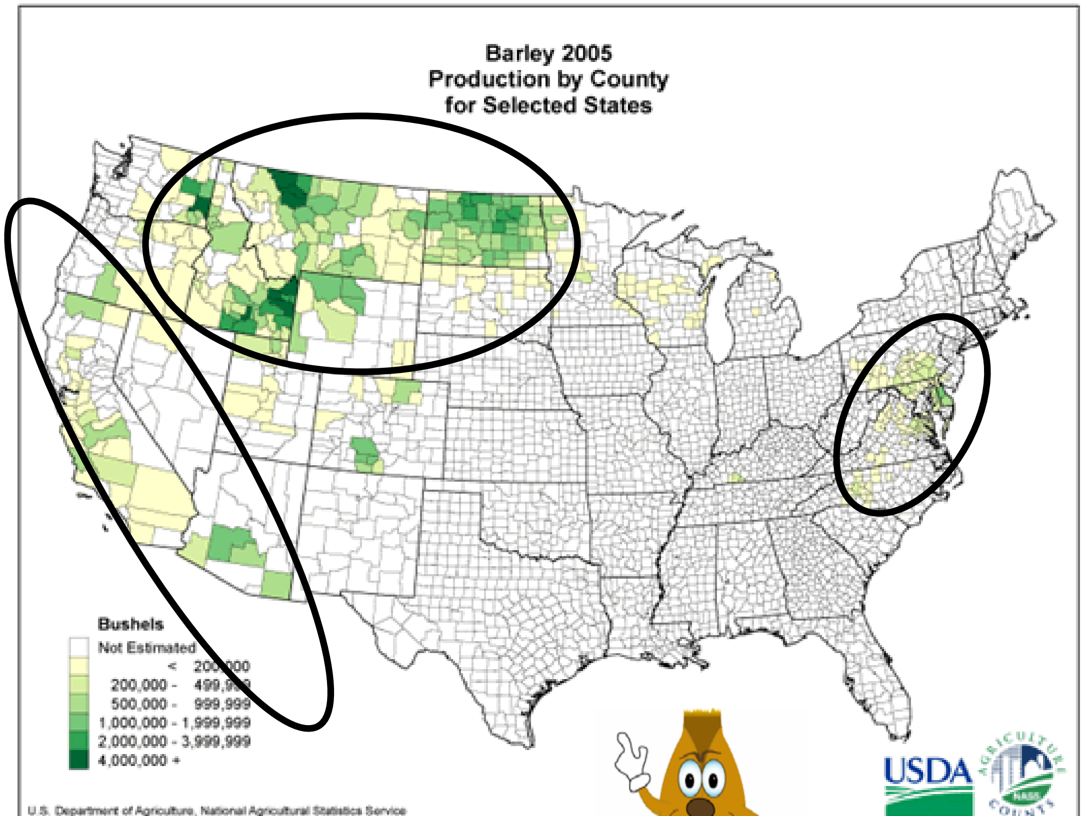
- To prevent “fuel versus food” issues
- To ensure livestock producers have enough feeds
- To avoid overuse of fragile farmland

Currently The Fuel Ethanol is Made Here.



But We Have the Major Markets for Fuels Here!!

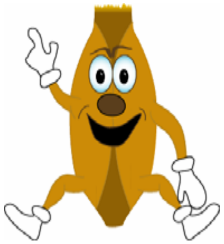
Barley is A Crop Grown Outside the Corn Belt



These “barley belts” can provide feedstock for ethanol plants outside the corn belt where transportation fuels are needed!

Technical Issues with Barley as a Fuel Ethanol Feedstock

- Abrasive hull – destroys milling equipment
- Low starch content (~50-55%) compared to corn's (~70%) – results in low ethanol yields
- High viscosity of mash due to **<u>β-glucans</u>** – makes processing difficult and expensive and limits the feed use of the ethanol co-products, DDGS.



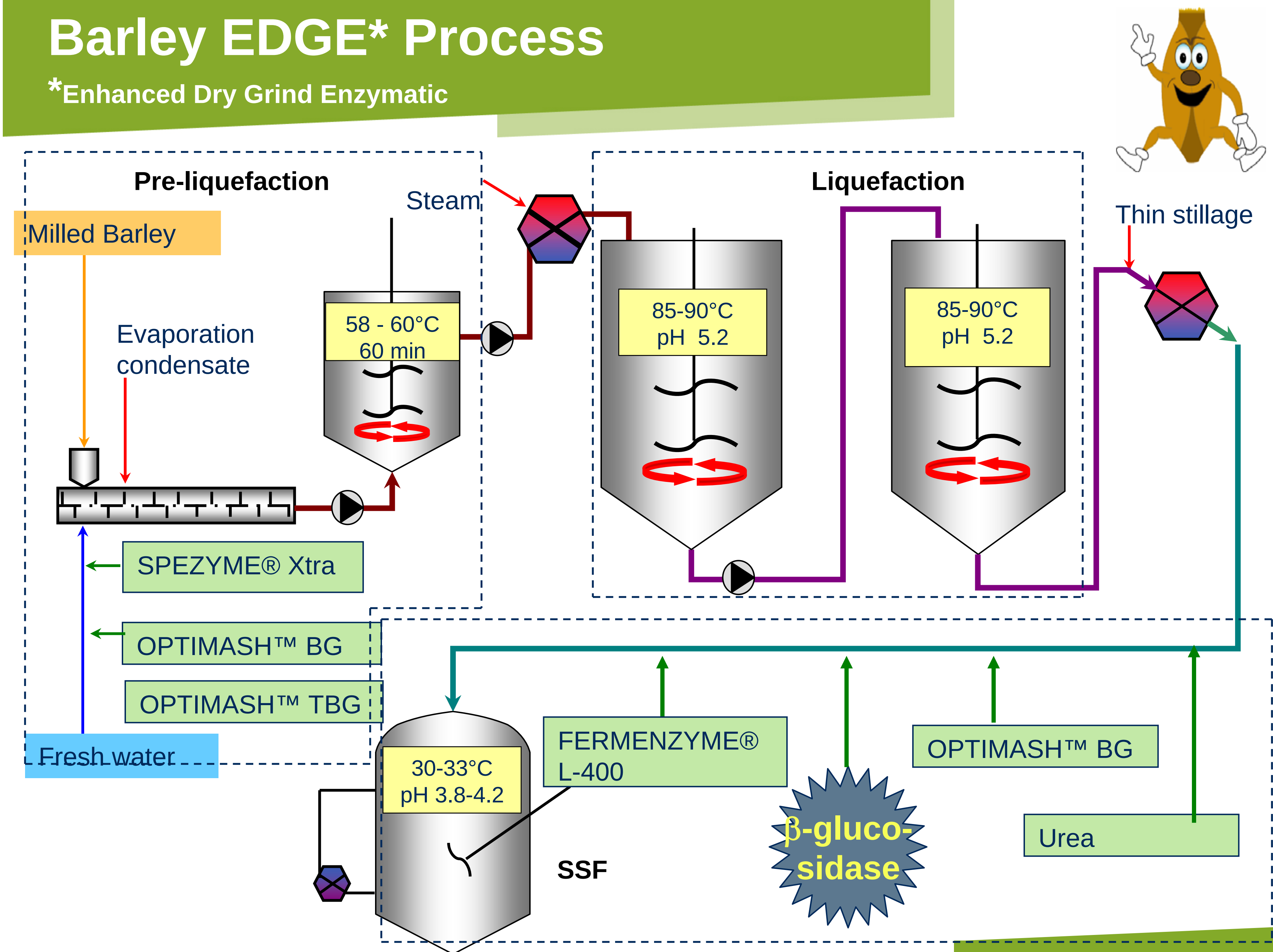
ERRC/ARS Has A Major Barley Research Program to Solve These Technical Issues

- Working with breeders to develop better hull-less and hulled barley for fuel ethanol production.
- Developing dry fractionation processes to separate barley grain into fermentable and non-fermentable fractions.
- Working with Genencor, A Danisco Division to use new enzymes to reduce viscosity, increase ethanol yield, and develop energy saving fuel ethanol processes

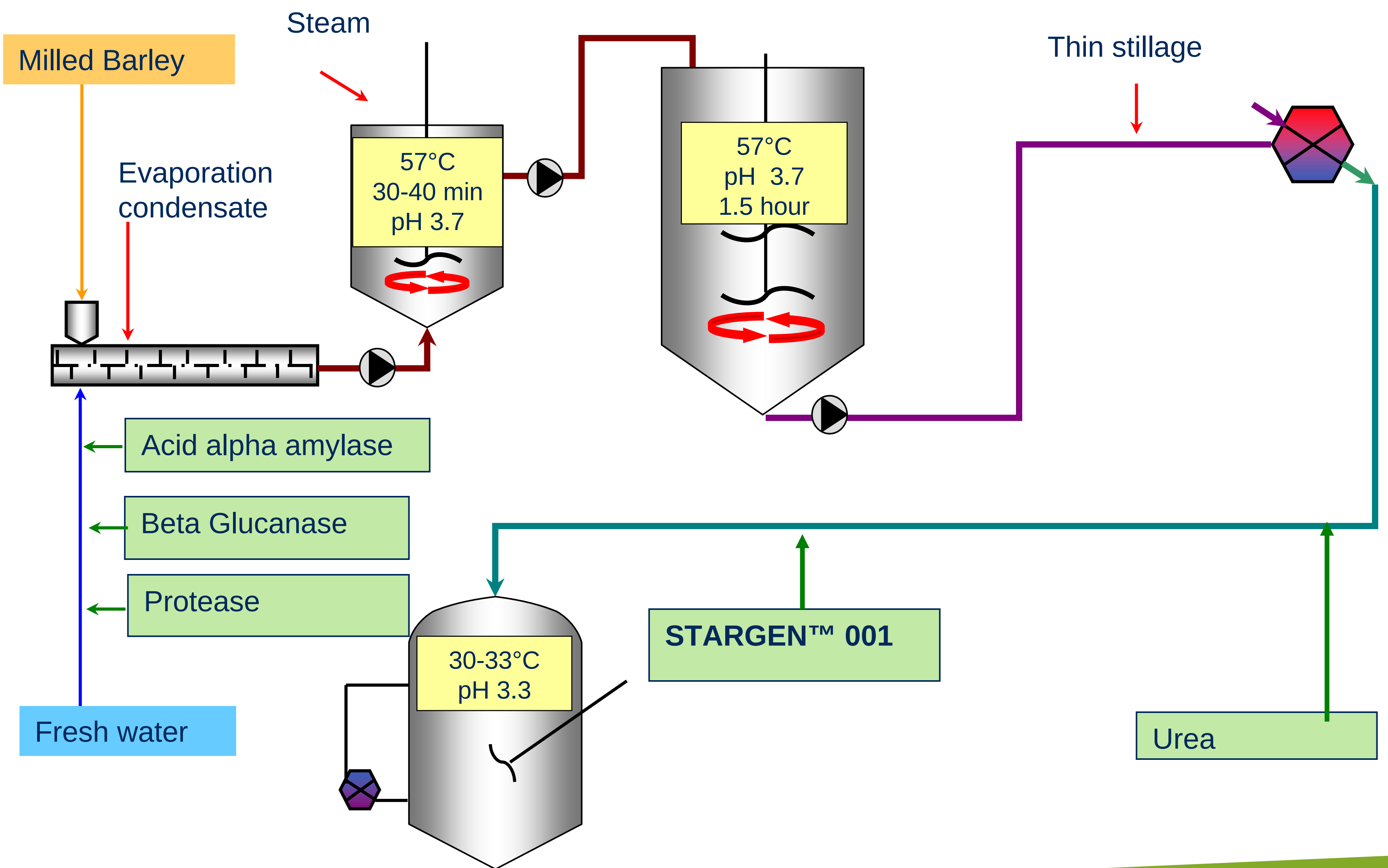
Barley Breeding at Virginia Tech

Barley EDGE* Process

*Enhanced Dry Grind Enzymatic



STARGEN™ Process



Bottom Line on Barley

- Production of fuel ethanol from barley can lead to another 1-2 billion gallons of ethanol from the grain ***plus*** another 1-2 billion gallons from the straw when cellulosic ethanol processes are commercial.
- Farmers and rural economy outside the corn belt will benefit.
- In many areas of the U.S., winter barley can be “double cropped” with soy, providing more grain from the same land.
- Barley as a cover crop prevents erosion and loss of nitrates/phosphates into watershed and improves the environment

Recommendations for Energy Crop Developers

- Develop energy crops that deliver more than just cellulose.
- Even pure cellulose (a structural carbohydrate) is difficult to convert to ethanol.
- Why not develop perennial grains and legumes that produce starch and oil, easily converted into biofuels, as well as straw/stems for BC or TC conversion?

Examples of Second Generation Energy Crops

- Perennial wheat (starch and biomass)
- Marama bean (*Tylosema esculentum (burch*.) (Perennial leguminous oilseed)
- Alfalfa (protein and biomass)
- Forage soybeans (high biomass yields and oilseeds)
- Others

Back to the Future?

- Rudolph Diesel ran his engine on peanut oil
- Henry Ford developed the Model T to run on ethanol
- Let’s work together to make the renewable fuels of the future using this inspiration from the past!

Thanks for your Attention!