

**“Responsible Packaging”:
Renewable Materials
within the Context of the Biorefinery**

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S.F.



Silicon Valley

Introduction

Snapshot ⇔

Fuel ethanol & biorefineries

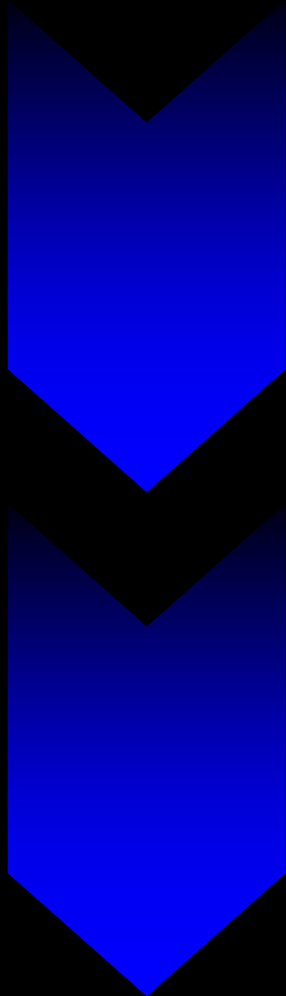
Snapshot ⇔

Renewable packaging

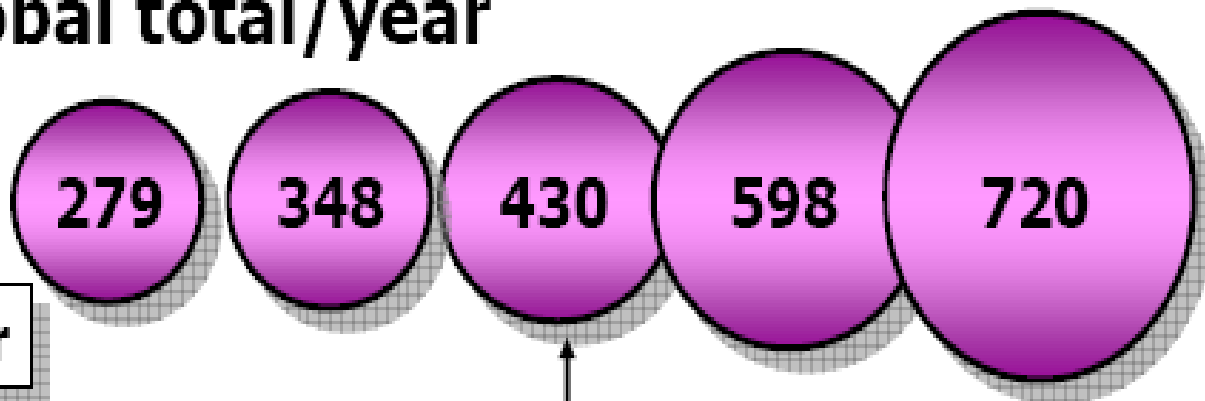
Their commonalities

New directions

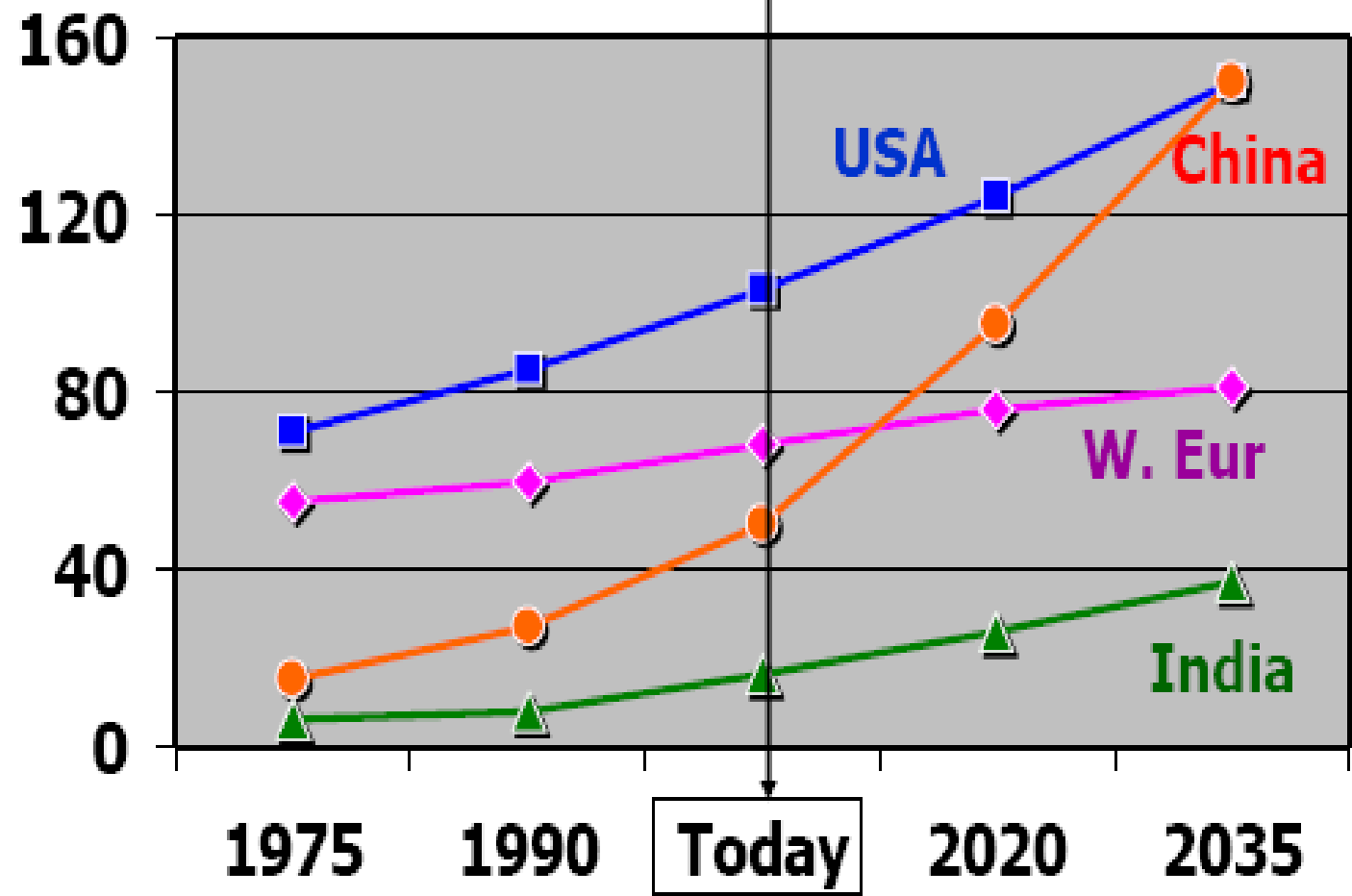
“Athletic” Biorefineries



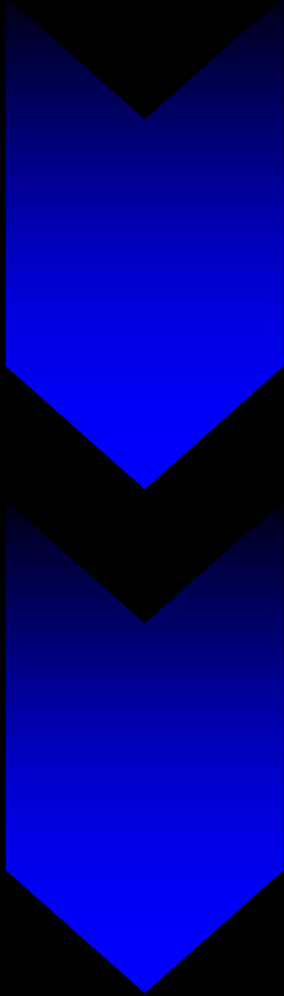
Global total/year



Quads/year

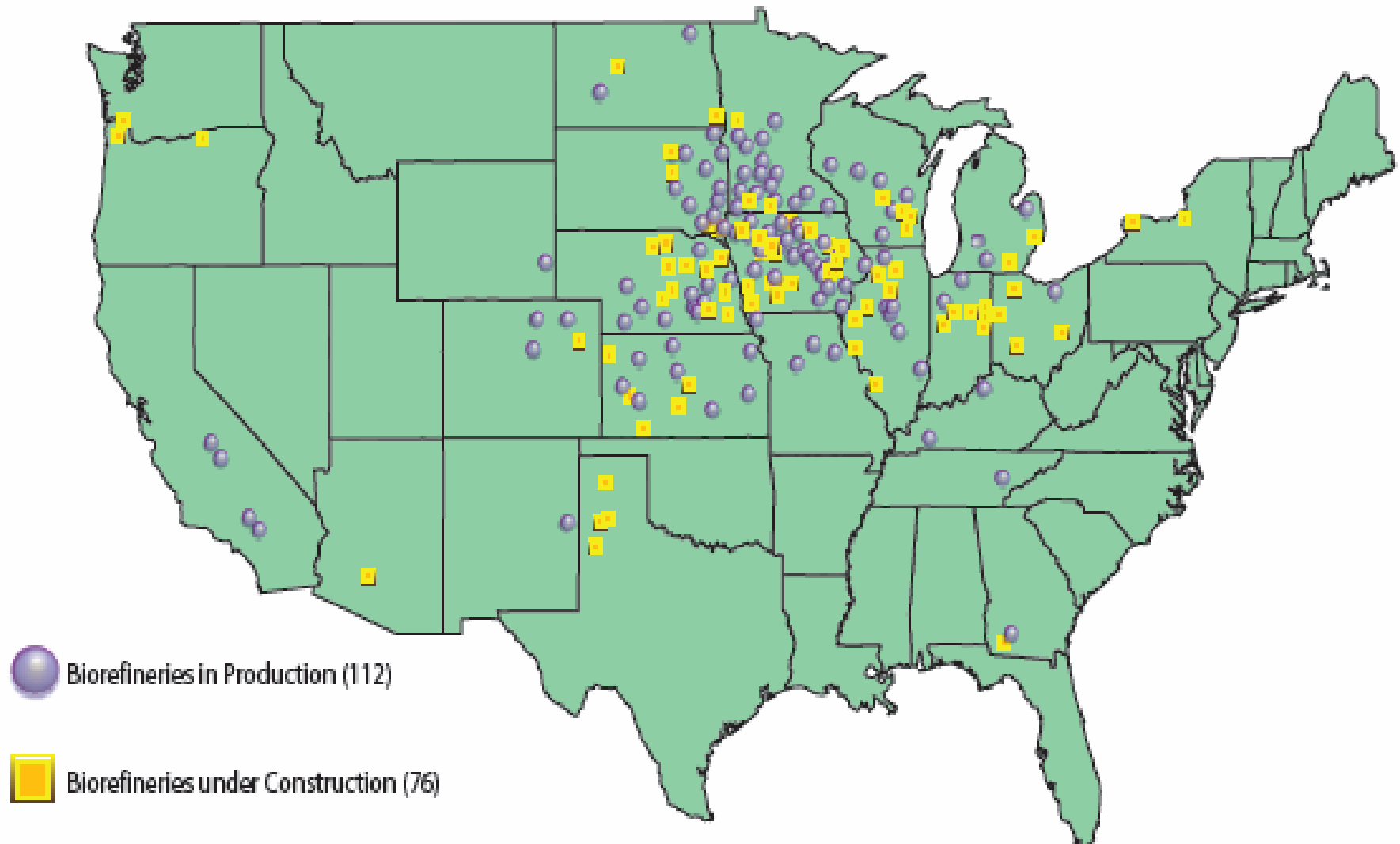


Corn-to-Ethanol: U.S trends



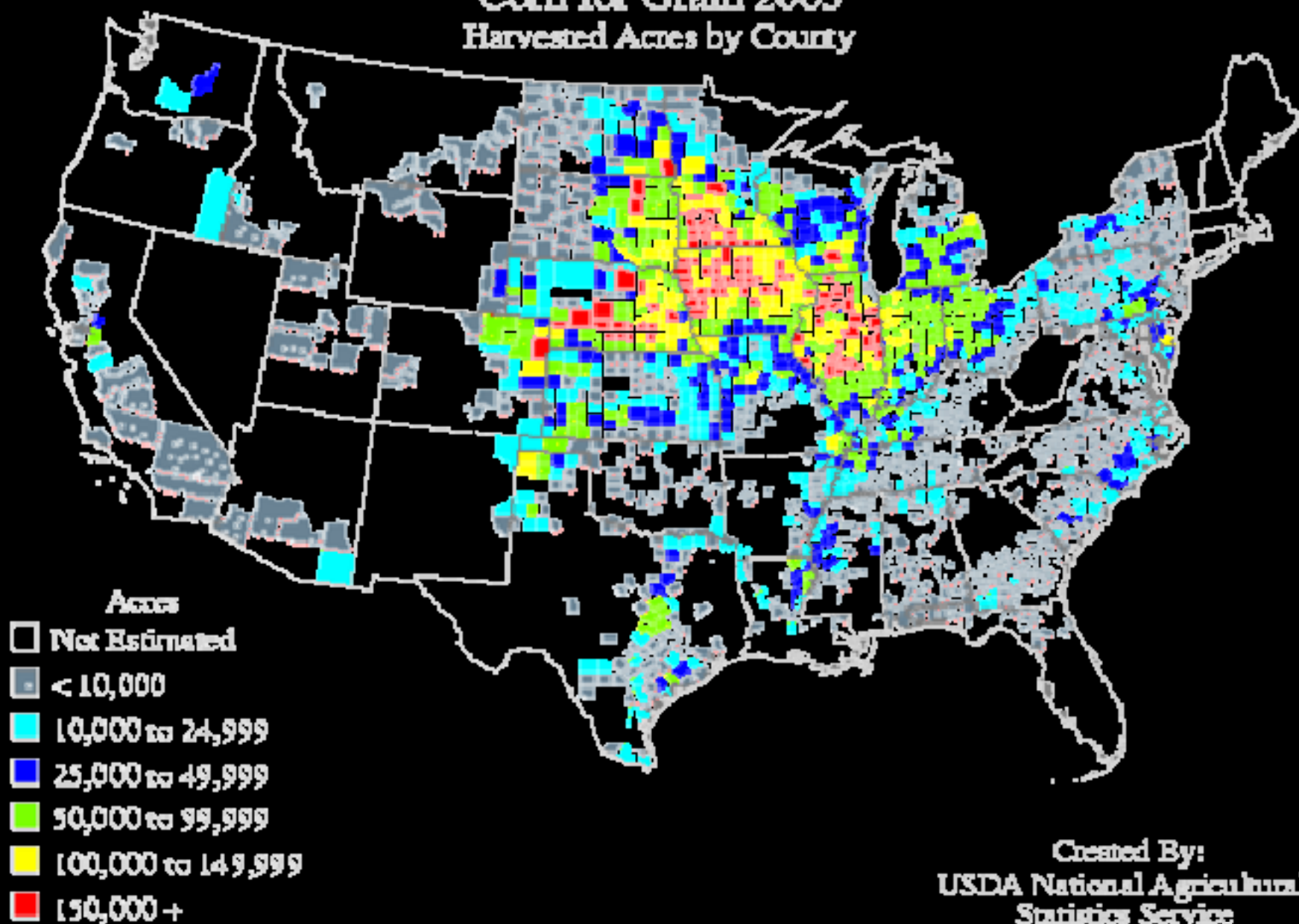
- **Production is at 5 billion gals/yr**
- **~2% of transportation fuel**
- **Ethanol uses ~20% of US corn**
 - **Food vs. fuel debate**
 - **Monoculture**
- **Most ethanol is not produced near refineries**
- **It is not widely produced in the most populated states.**

U.S. Ethanol Biorefinery Locations



Source: Renewable Fuels Association

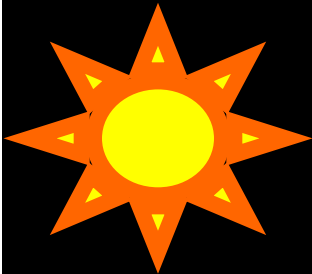
Corn for Grain 2003 Harvested Acres by County



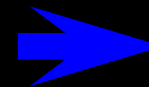
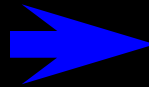
Corn Ethanol



H₂O



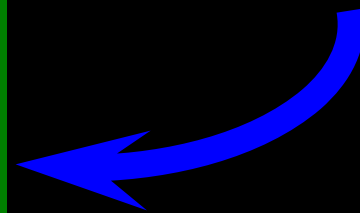
CO₂



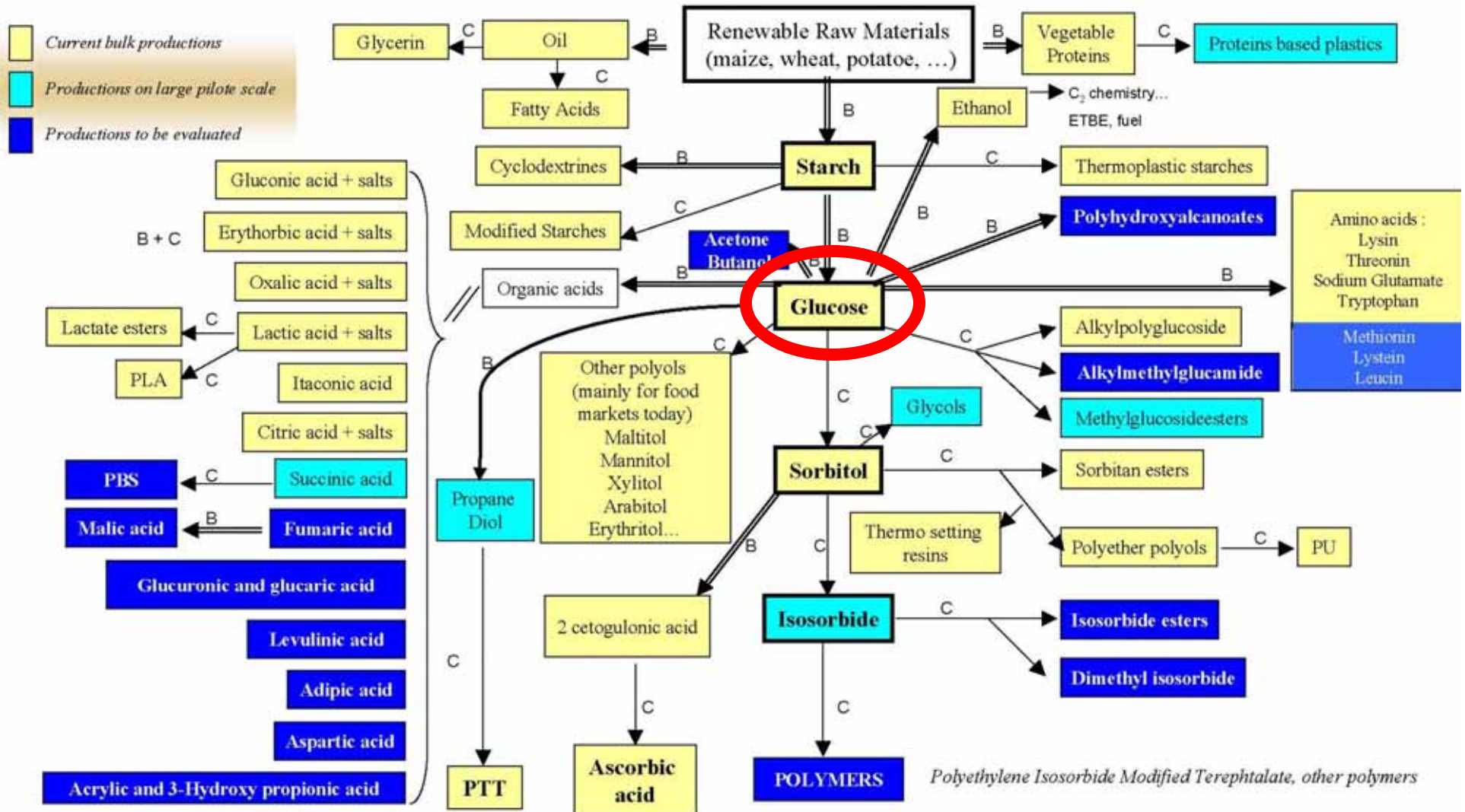
~~Starch~~
Fermentable
sugars

Polylactic acid
Polyhydroxyalkanoates
1-3-propane-diol
FEEDSTOCKS

*High Performance
Microbial
Fermentation*

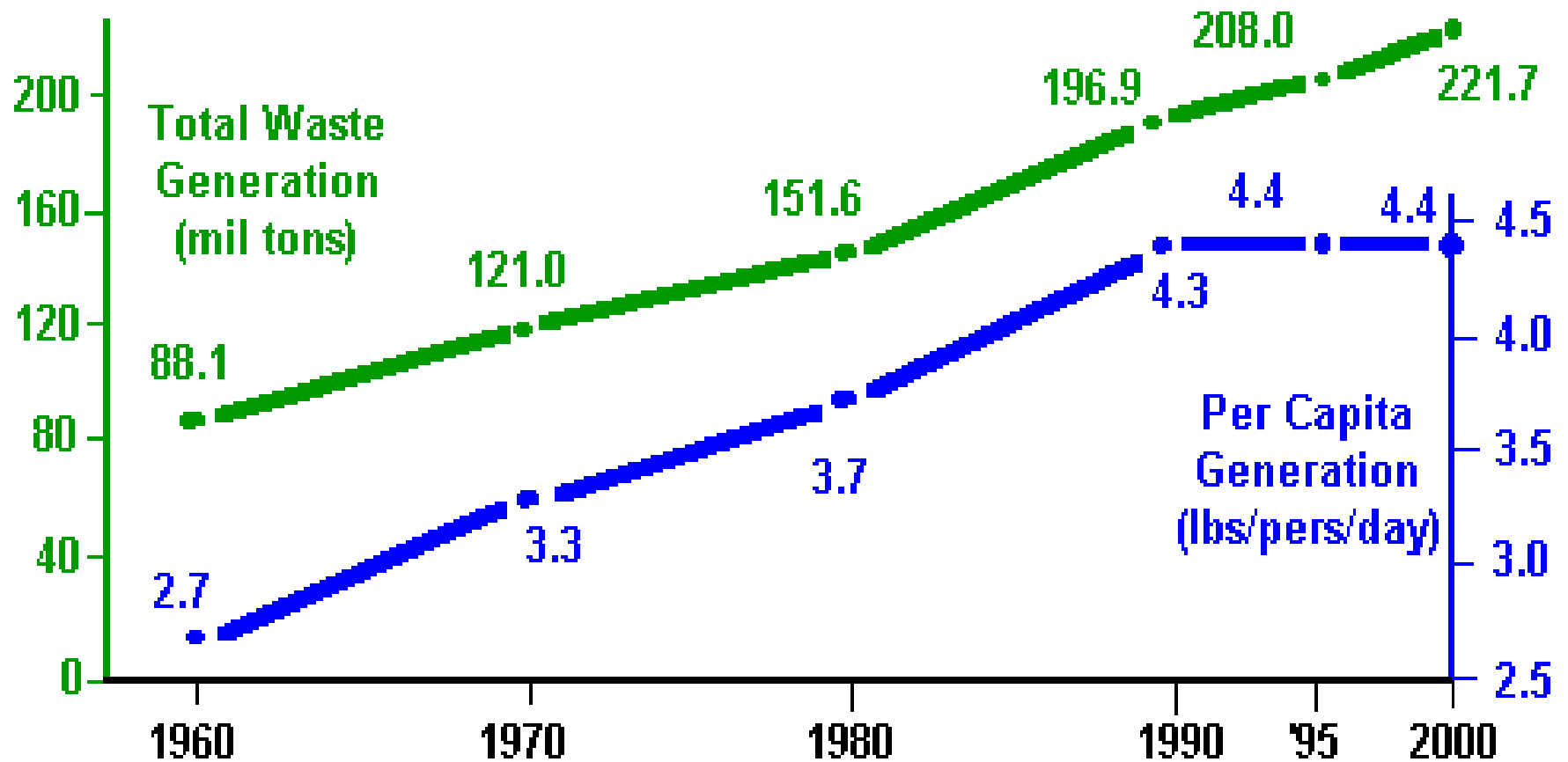


The Biorefinery ⇔ Sugar is key!



C = chemical process
B = biotechnological process

WASTE GENERATION RATES - 1960 TO 2000



Source: Characterization of MSW in the US: 1996 Update, US EPA, Washington, DC

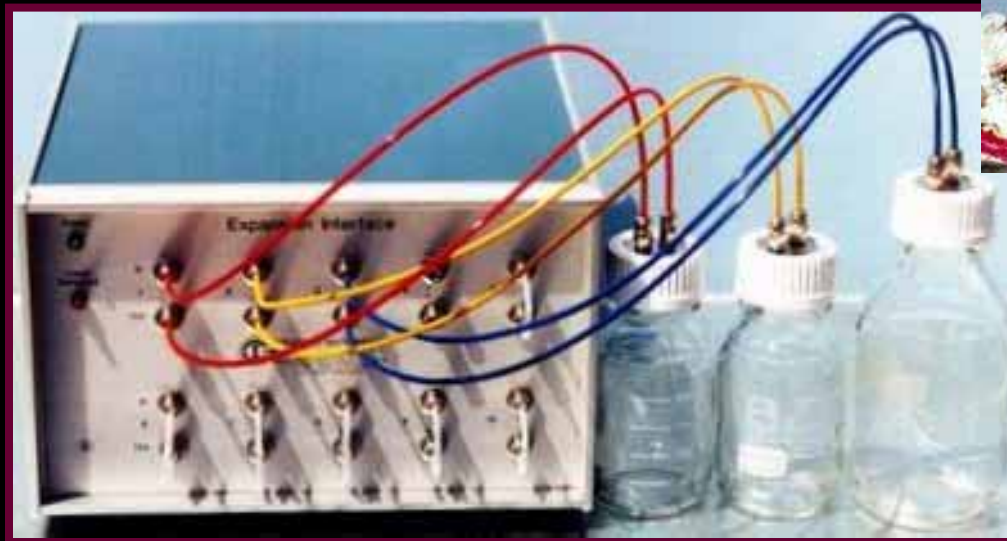
Responsible Packaging History

- **Biodegradable**
 - Starch blends ??
- **Compostable**

ASTM D6400



**Bill
Rathje**



O₂ consumption & CO₂ evolution

Responsible Packaging History

- Sustainable ↔ Biobased Content

ASTM D6852

Based on “age of the carbon”

ASTM D6866-04v

- isotopic ratios of $^{14}\text{C}/^{12}\text{C}$ and $^{13}\text{C}/^{12}\text{C}$ are different depending on whether the carbon is “old” (fossil fuel) or “new”
- Carbon Credits ↔
“carbon neutral substances”

Wheat-Based Composites

Gregory Glenn USDA-ARS-Albany

Paperboard



Wheat starch/fiber



Starch Packaging Plates and Bowls



Greg Glenn



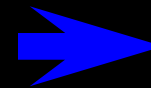
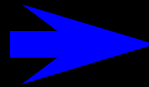
Smart & Final

Polyhydroxyalkanoate

H₂O



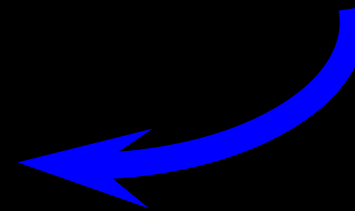
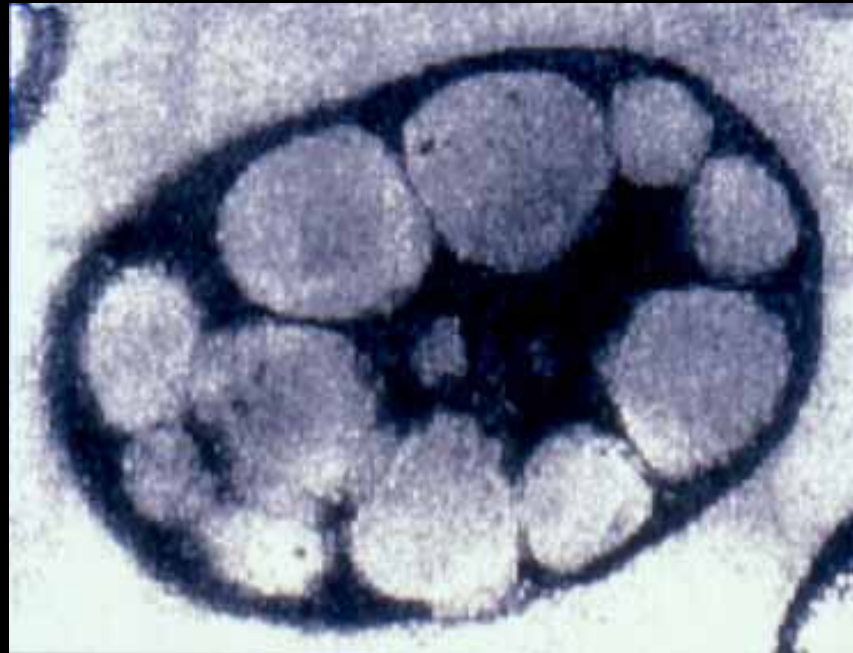
CO₂



Starch =
Fermentable
sugars

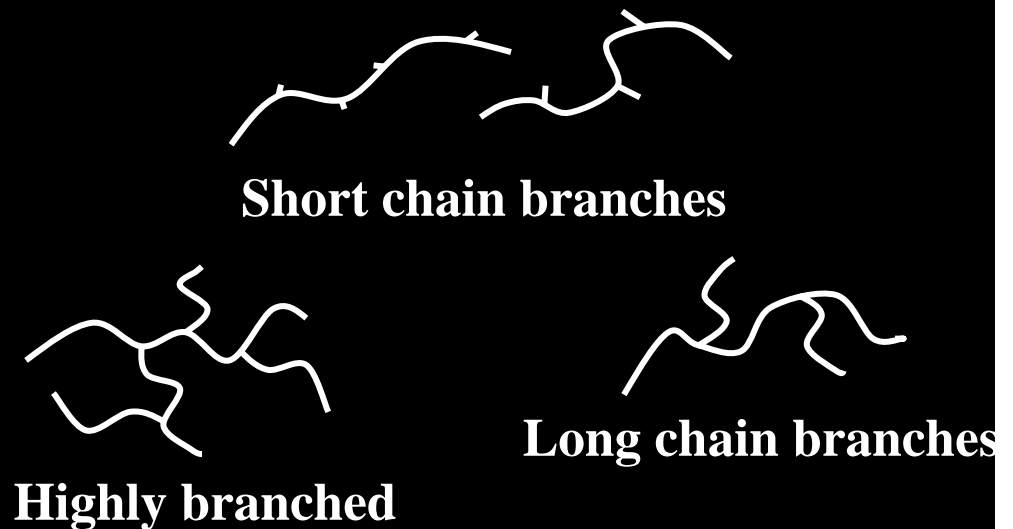
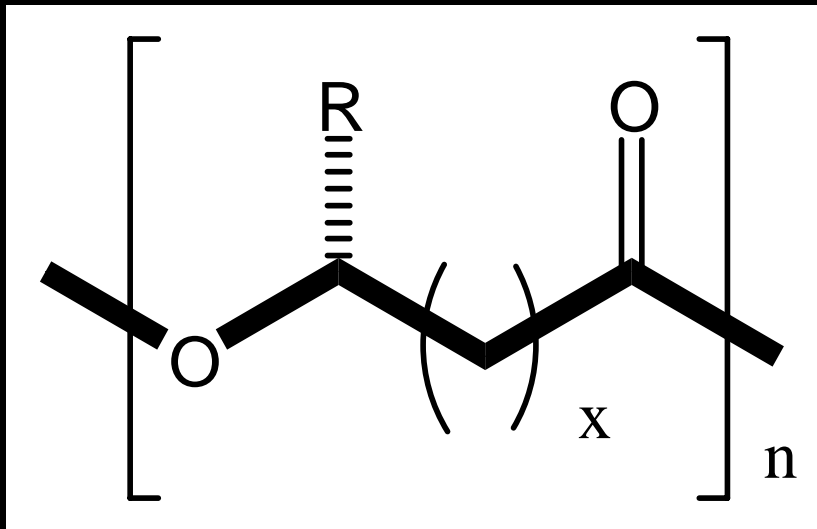
*High Performance
Microbial
Fermentation*

PHAs



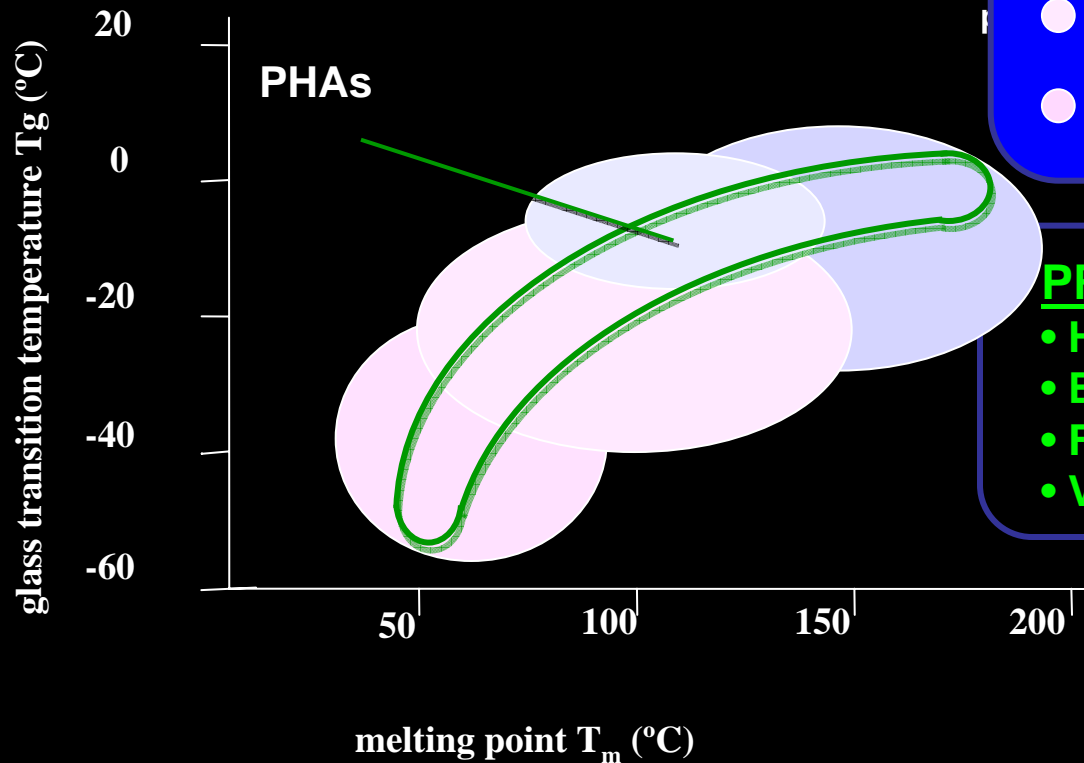
PHAs: Polymer Diversity

- ✓ Metabolix is the main American producer (BP & ADM)
- ✓ Of past interest to P&G (NODAX), ICI, Zeneca, & Monsanto



PHAs: BioPolyester Properties

THERMAL PROPERTIES



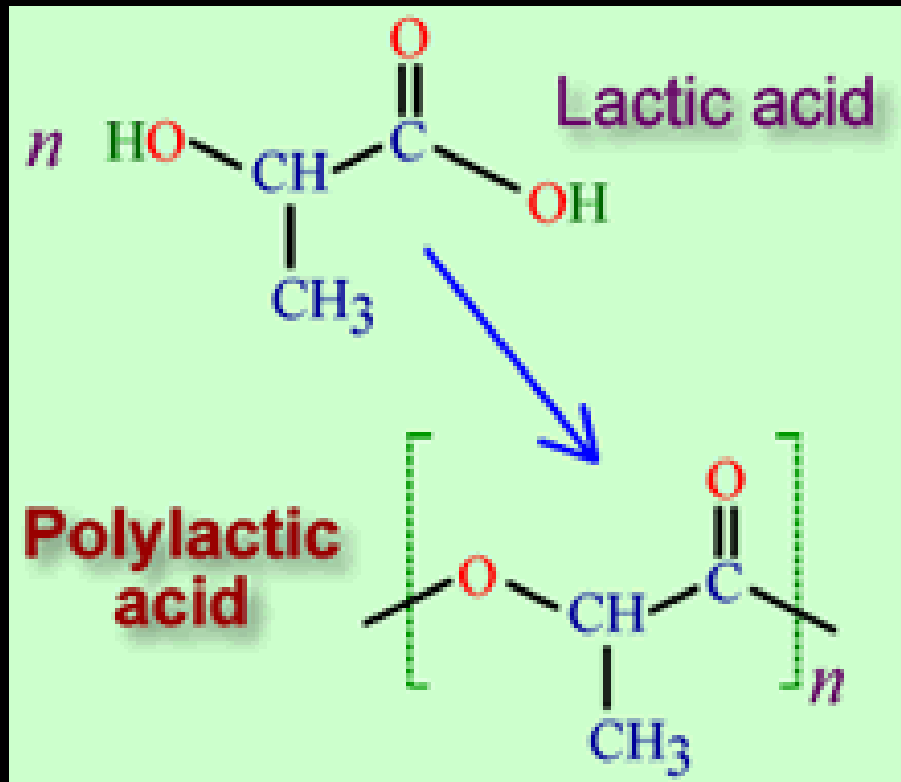
- thermoplastics
- hot melt adhesives
- coatings
- pressure sensitive adhesives

PROPERTIES

- Hydrolytically stable
- Biodegradable
- Form excellent films
- Very good UV stability

-- Jim Barber, Metabolix

Poly(lactic acid), PLA: Cargill



Biomass Cellulose-to-ethanol



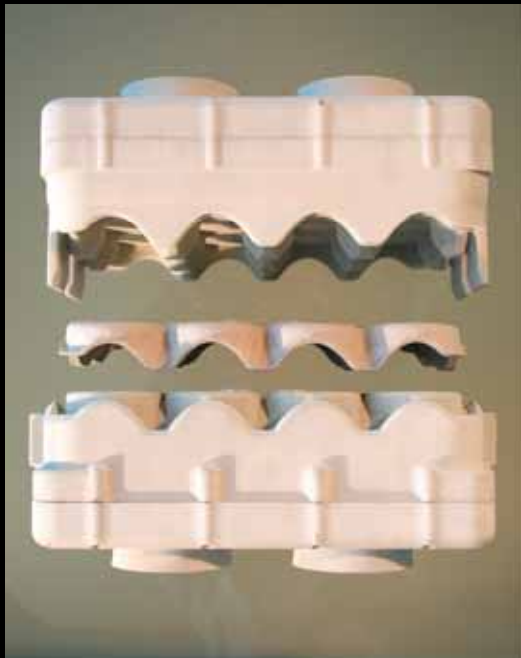
Farmers can no longer burn straw in California and many other states.

Cellulose from straw is a potential source of ethanol

Straw Biomass Utilization:



Straw-based
packaging



Straw for cellulose-to-ethanol



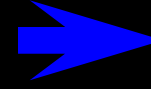
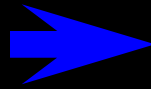
The Canadian company, Iogen, is converting wheat straw and corn stover to ethanol

The Athletic Biorefinery

H₂O

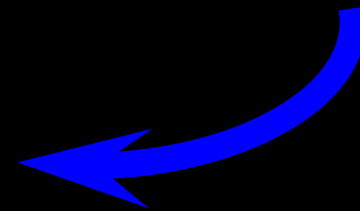


CO₂



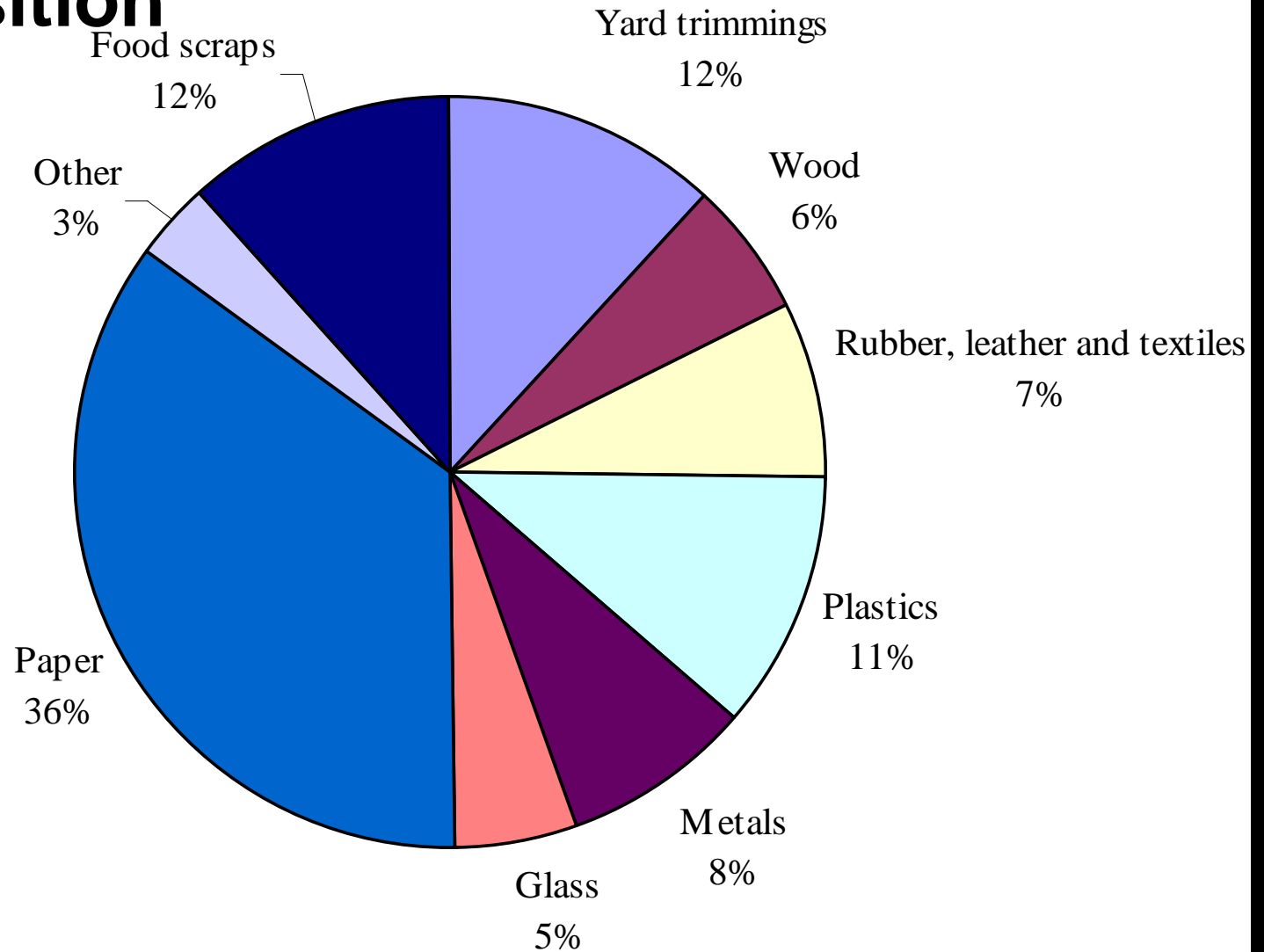
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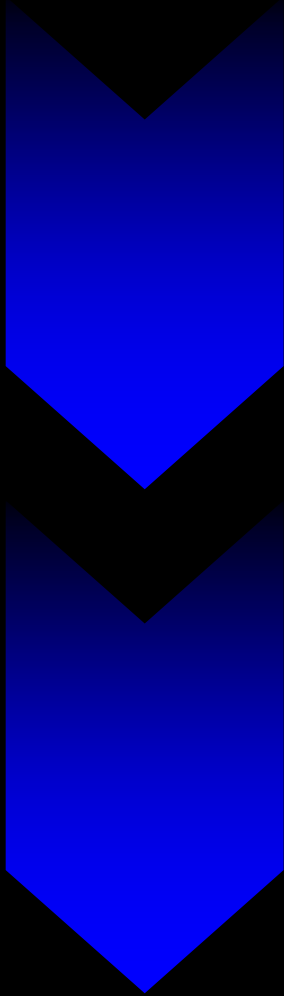


Convert Municipal Solid Waste (MSW) to Ethanol

Composition



MSW as a Platform for Biomass-to-Ethanol Biorefinery



- MSW ⇔ 236 million tons/year in U.S.
- 35 - 45% paper and paperboard products
- Will reduce landfill volume by >40%
- In MSW, paper is already fractionated
- Can produce other co-products
 - ⇔ Pulp
 - ⇔ Methane
 - ⇔ Syngas products

“Athletic Biorefinery”

Biomass Pretreatment:

A pressurized hot water treatment allows straw, co-mingled with MSW, to be hydrolyzed relatively easily.

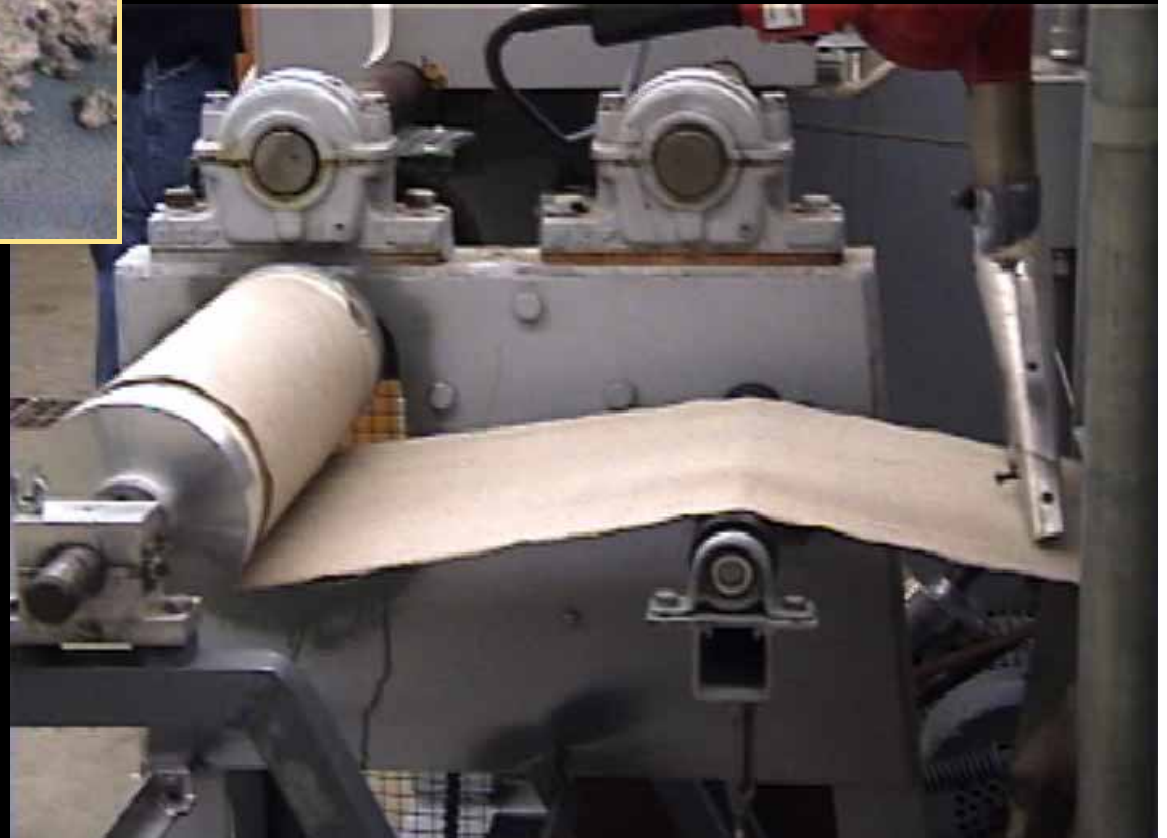


Cellulose-to-Ethanol Biorefinery \Leftrightarrow CR³

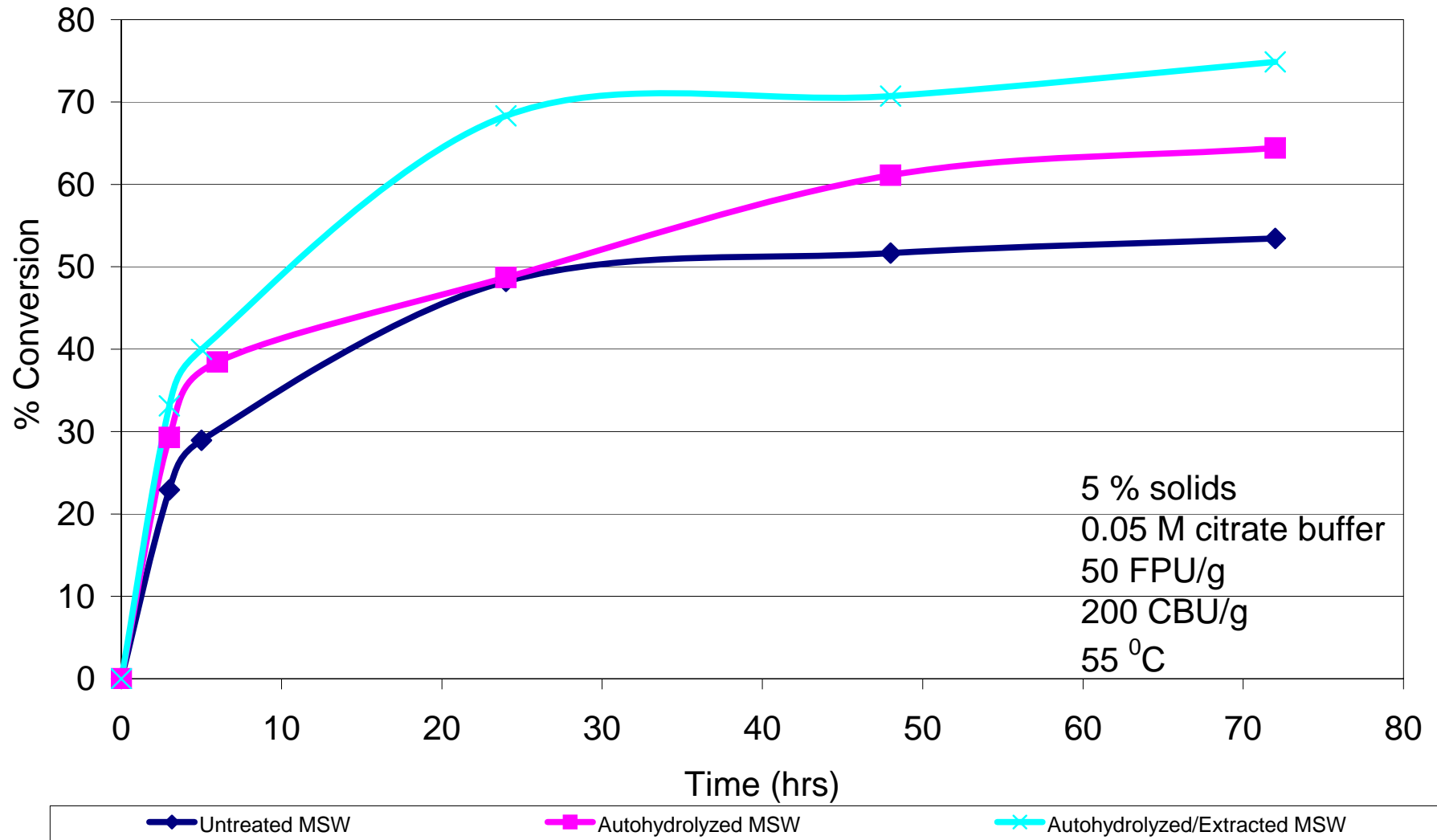


Processed paper from
recovered fiber

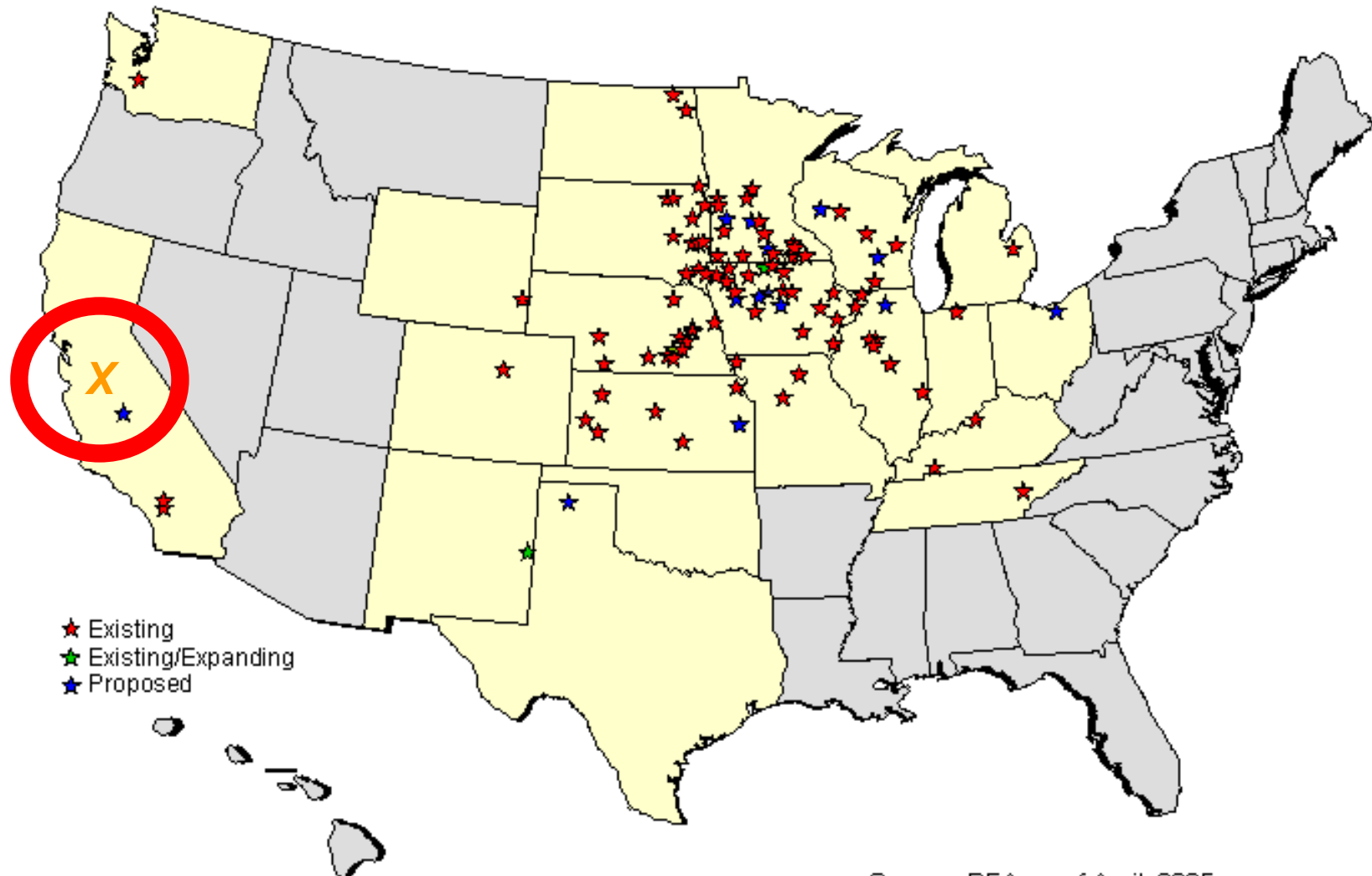
**Biomass \Leftrightarrow
MSW and ag-
waste processing
plant**



Enzymatic hydrolysis of MSW



U.S. ETHANOL MANUFACTURING LOCATIONS



Source: RFA as of April, 2005

Summary:

Many renewable packaging materials will result from biorefinery development

Strategies for biorefinery development must extend beyond corn

Flexible biorefineries will expand our scope ⇔ MSW ??

New research in enzymes and microbes should lower costs

BCE:

Bor-Sen Chiou
Gregory Glenn
Kevin Holtman
Syed Imam
Charles Lee
Rick Offeman
Bill Orts
George Robertson
Mike Smith
Kurt Wagschal
Dominic Wong
De Wood



Illustration by Y. Rook.

Thank you.



Oil Transport Routes (1994)

Crude oil seaborne trade

Main inter-area movements in million metric tonnes, 1994.

