Sorghum for Biofuels:

Strategies for Developing Flexible, Integrated Biorefineries

William J. Orts

USDA-Agricultural Research Service
Western Regional Research Center
Albany, CA, USA

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Biofuels Trends

Generation 1: Food to Fuels

- Corn & soy as feedstocks

Generation 2: Cellulosics, etc

- Straw, wood, energy crops
- Sorghum ⇔ flexibility
- Municipal Solid Waste, MSW ??

We can invent our way toward energy flexibility.

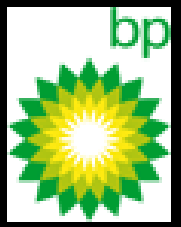
There likely won't be a single answer!

USDA Western Reg. Research Center (WRRC) Albany, California

Partnerships:

JBEI – Blake Simmons, Brad Holmes, et al.
Fractionation….

Prof. Peggy Lemaux
Plant biotech….



?

Prof. Dan Putnam
Cropping strategies….

Alternative energy….

Ethanol Yields (Source: Petroleum Club)

CROP	GAL/ ACRE	BIO-CONVERSION
Miscanthus	1800	2nd gen
Switchgrass	1700	2nd gen
Sweet potatoes	1069	1st gen
Hybrid poplar	1000	1st gen
Sweet sorghum	900	1st gen
Maize (starch & stover)	770	1st & 2nd gen
Sugar beet	714	1st gen
Sugar cane	702	1st gen
Maize (corn starch)	430	1st gen

Ethanol Yields (Source: Petroleum Club)

CROP	GAL/ ACRE	BIO-CONVERSION
Sorghum (w/ bagasse)	**2000+**	1st & 2nd gen
Miscanthus	1800	2nd gen
Switchgrass	1700	2nd gen
Sweet potatoes	1069	1st gen
Hybrid poplar	1000	1st gen
Maize (starch & stover)	770	1st & 2nd gen
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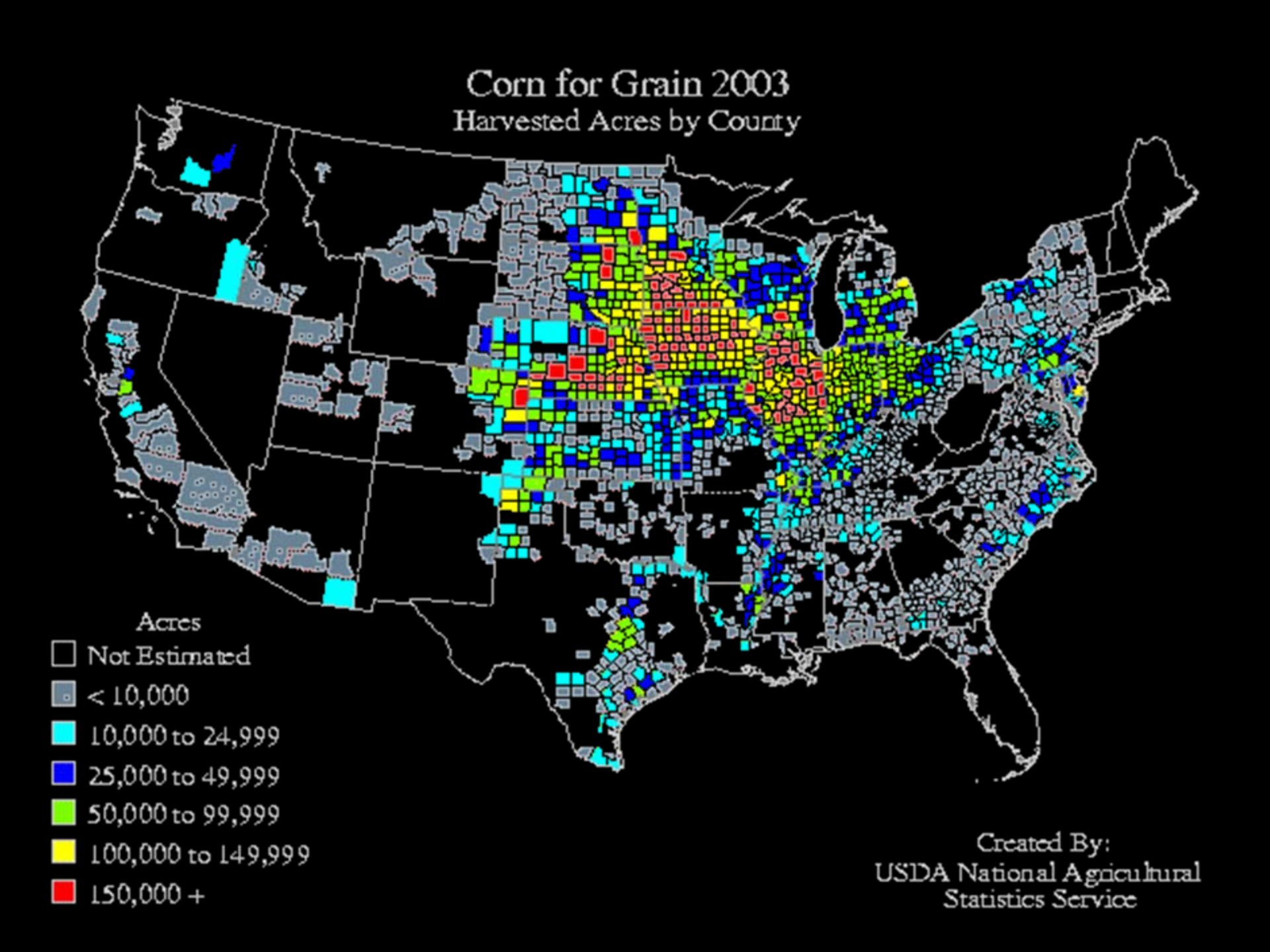
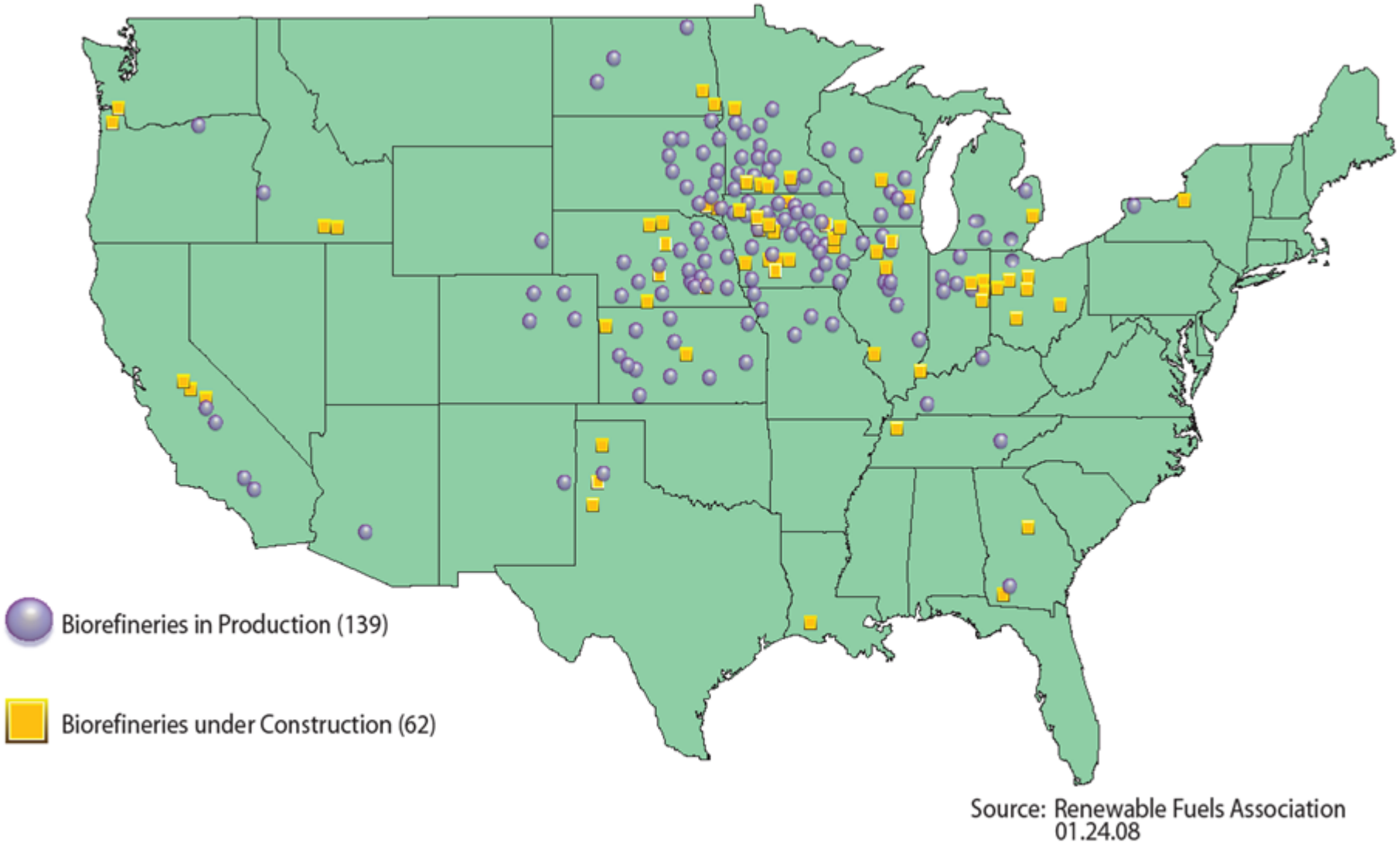
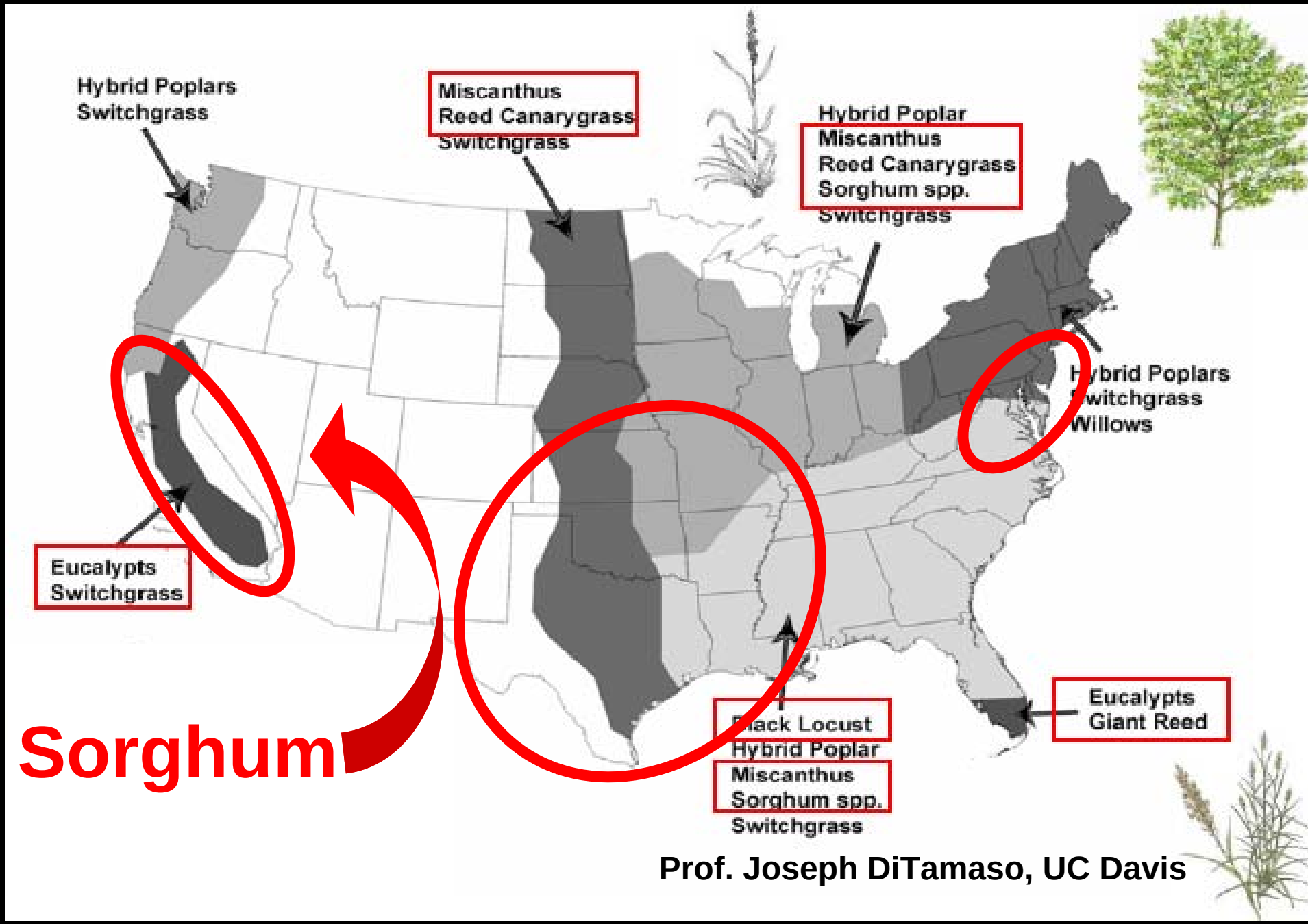
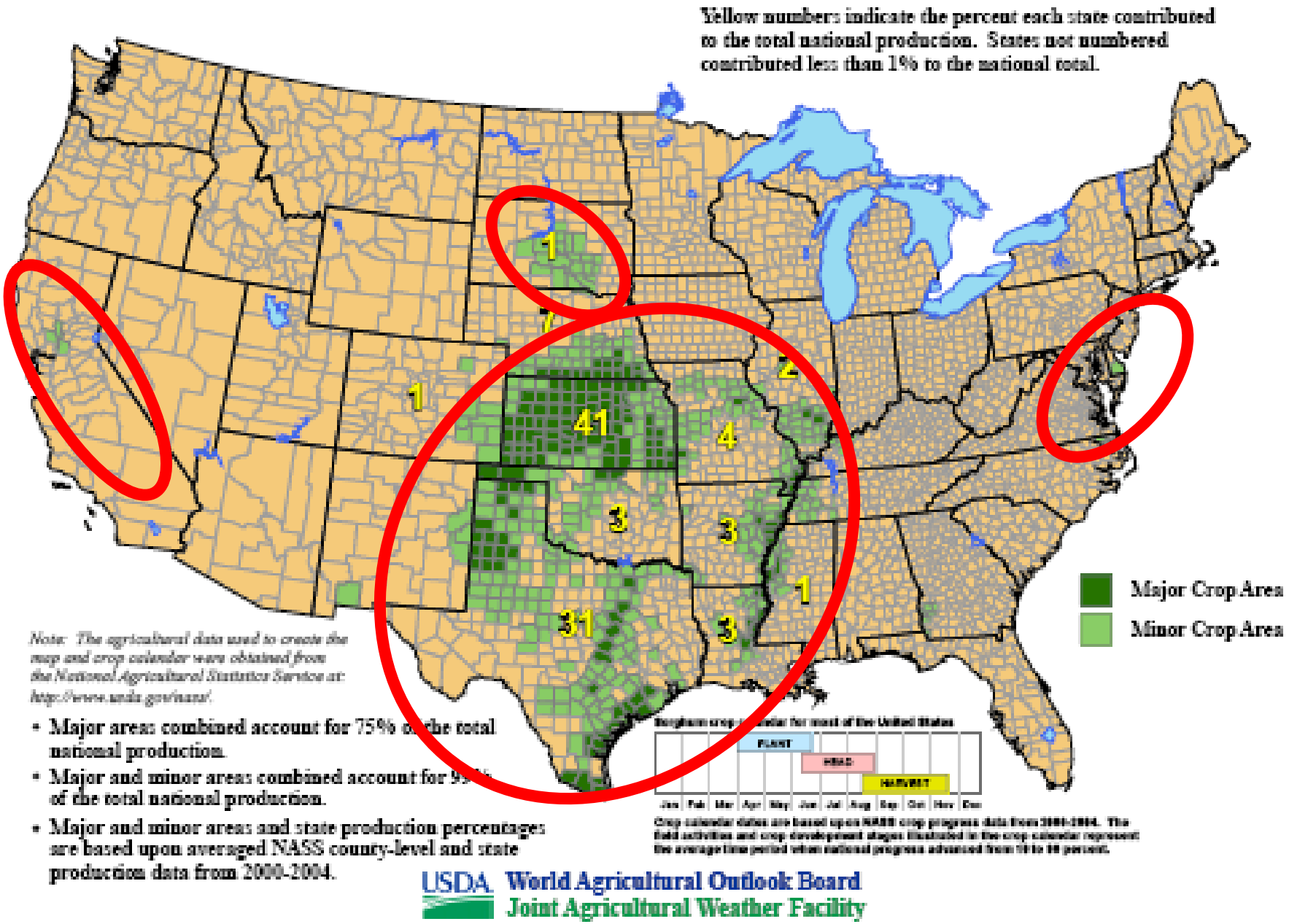

Corn for Grain 2003
Harvested Acres by County
Acres
Not Estimated
< 10,000
10,000 to 24,999
25,000 to 49,999
50,000 to 99,999
100,000 to 149,999
150,000 +
Created By:
USDA National Agricultural
Statistics Service


Biorefineries in Production (139)
Biorefineries under Construction (62)
Source: Renewable Fuels Association
01.24.08


Hybrid Poplars
Switchgrass
Miscanthus
Reed Canarygrass
Switchgrass
Hybrid Poplar
Miscanthus
Reed Canarygrass
Sorghum spp.
Switchgrass
Hybrid Poplars
Switchgrass
Willows
Eucalypts
Switchgrass
Sorghum
Black Locust
Hybrid Poplar
Miscanthus
Sorghum spp.
Switchgrass
Eucalypts
Giant Reed
Prof. Joseph DiTamaso, UC Davis

United States: Sorghum



Note: The agricultural data used to create the map and crop calendar were obtained from the National Agricultural Statistics Service at: http://www.usda.gov/nass/.

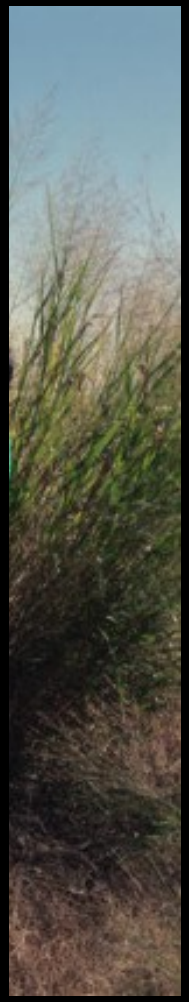
- Major areas combined account for 75% of the total national production.
- Major and minor areas combined account for 99% of the total national production.
- Major and minor areas and state production percentages are based upon averaged NASS county-level and state production data from 2000-2004.

Sorghum crop calendar for most of the United States

Crop calendar dates are based upon NASS crop progress data from 2000-2004. The field activities and crop development stages illustrated in the crop calendar represent the average time period when national progress advanced from 10 to 90 percent.

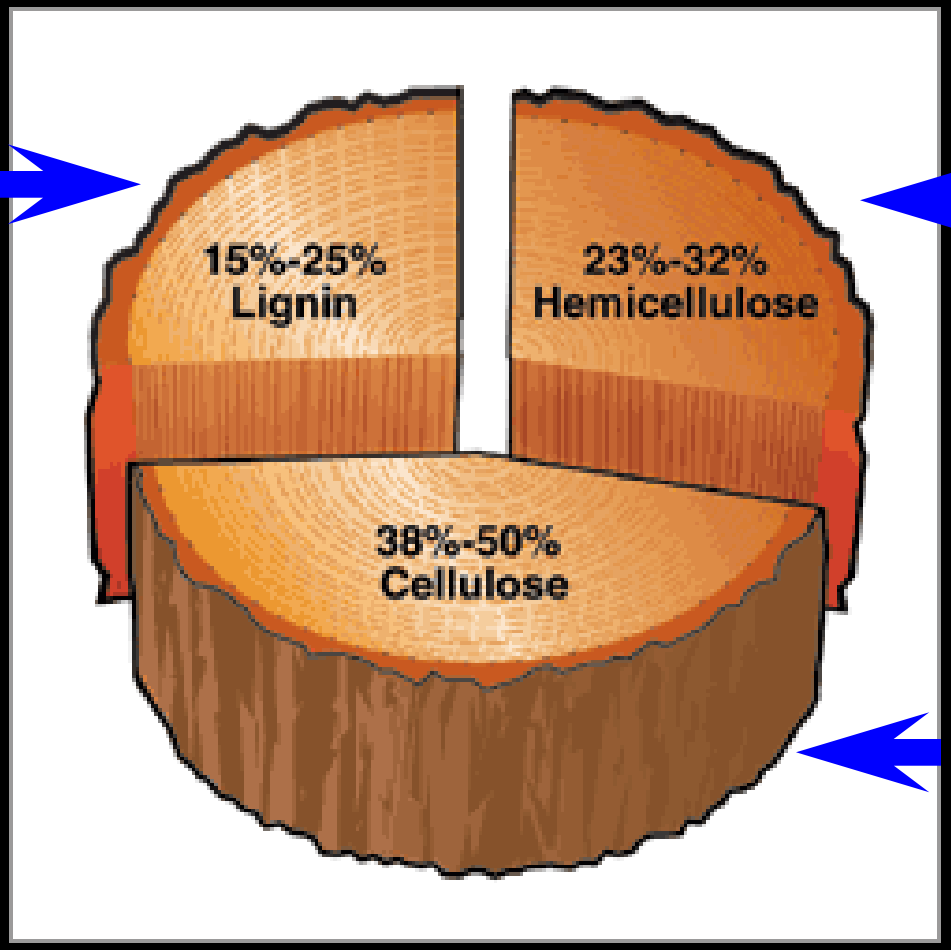
USDA World Agricultural Outlook Board
Joint Agricultural Weather Facility

Cellulosic Ethanol: Energy Crops



Biomass Composition

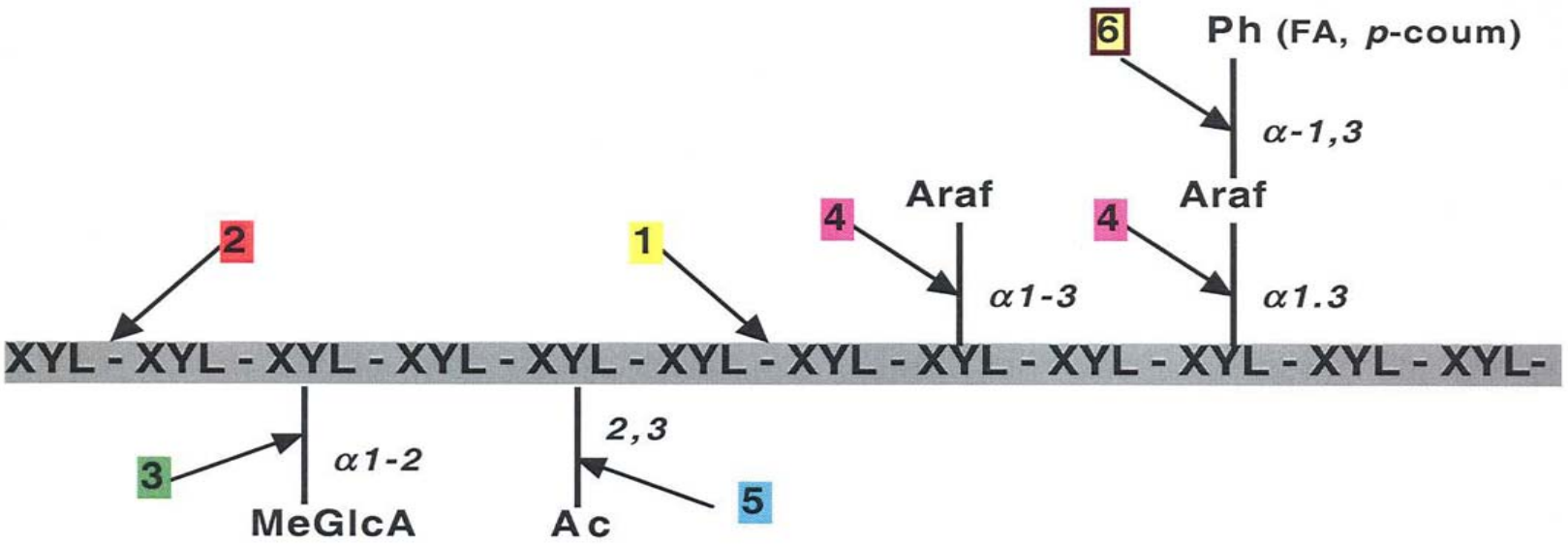
complex phenolic



5-carbon sugar

6-carbon sugar

Hemicellulose enzymes



1 endo-β-1,4-xylanase (EC 3..2.1.8)

2 β-xylosidase (EC 3.2.1.37) or exo-β-xylanase

3 α-glucuronidase (EC 3.2.1.139)

4 α-L-arabinofuranosidase (EC 3.2.1.55)

5 acetylxylan esterase (EC 3.1.1.72)

6 feruloyl esterase (EC 3.1.1.73)

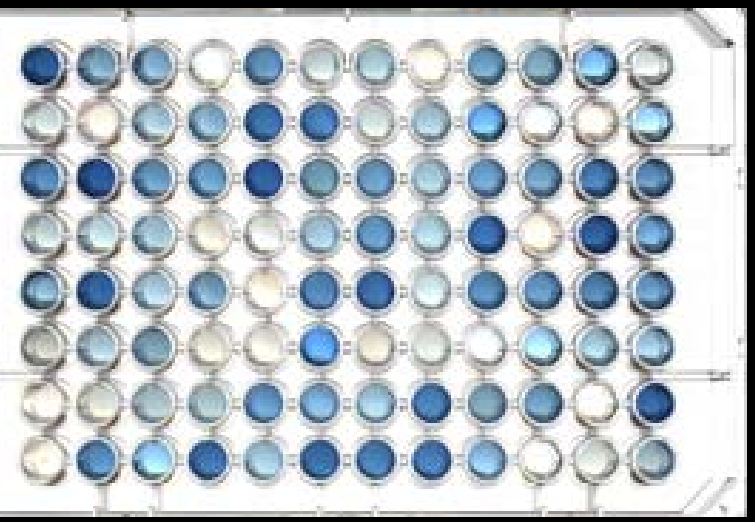
Dominic Wong, Charles Lee & Kurt Wagschal

Enzyme Sources

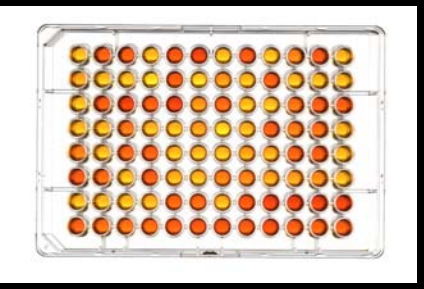
- Enzymes and microbes from
  - Fungi
  - Mushrooms
  - Rumen

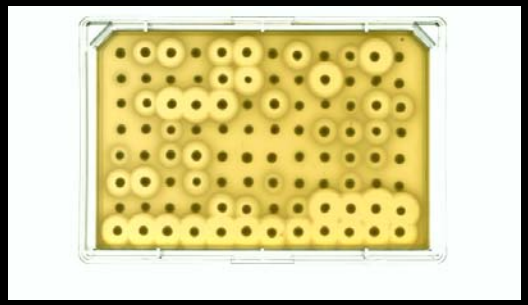
Gene Libraries

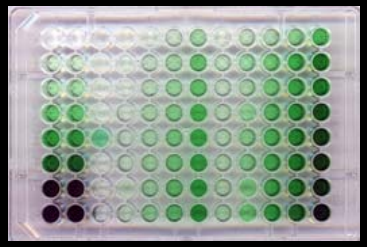
Charles Lee, Rena Accinelli

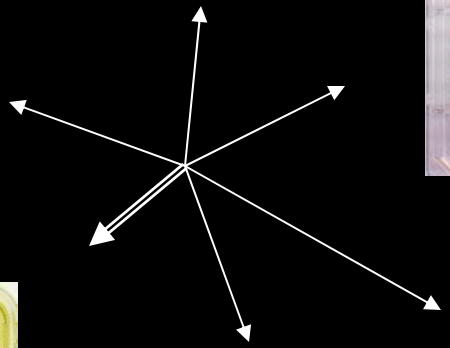


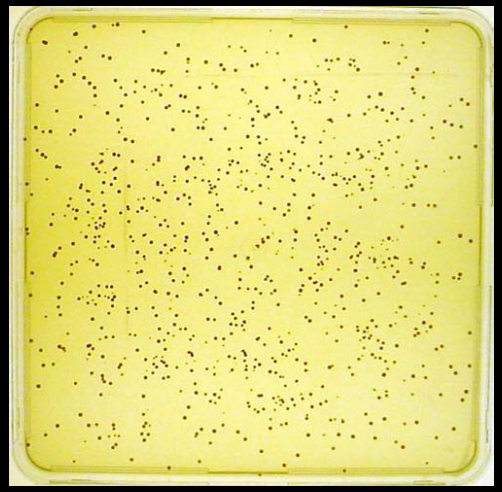
High-throughput Assay Screening

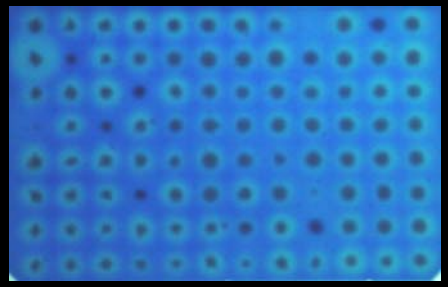


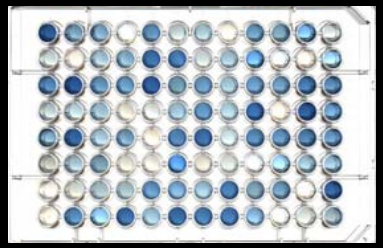








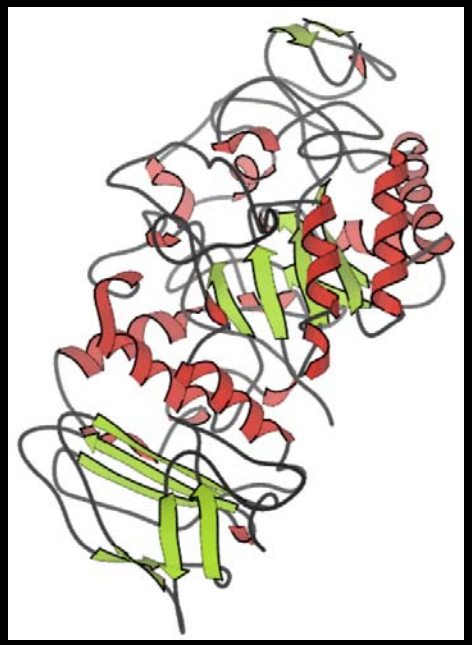




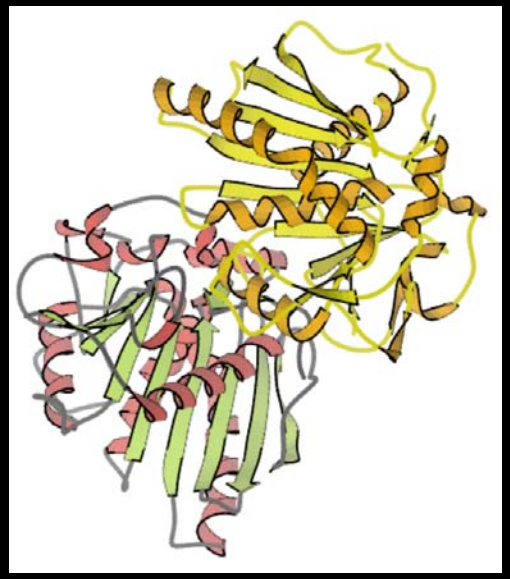
Q-tray

Kurt Wagschal, Chemrouen Heng

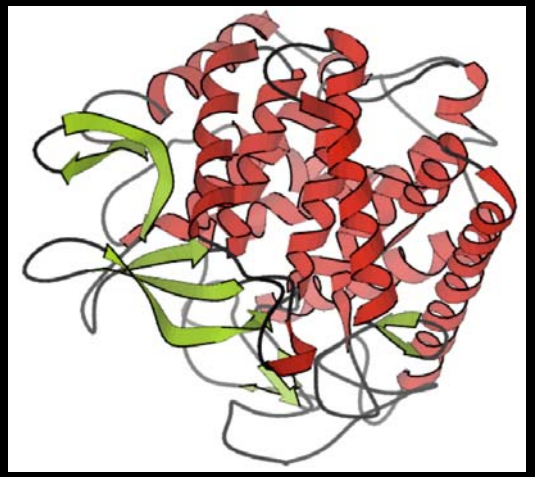
Signature Enzymes



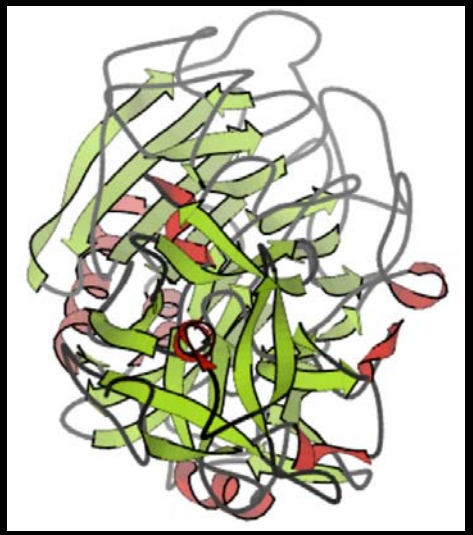
Mike Smith



Kurt Wagschal

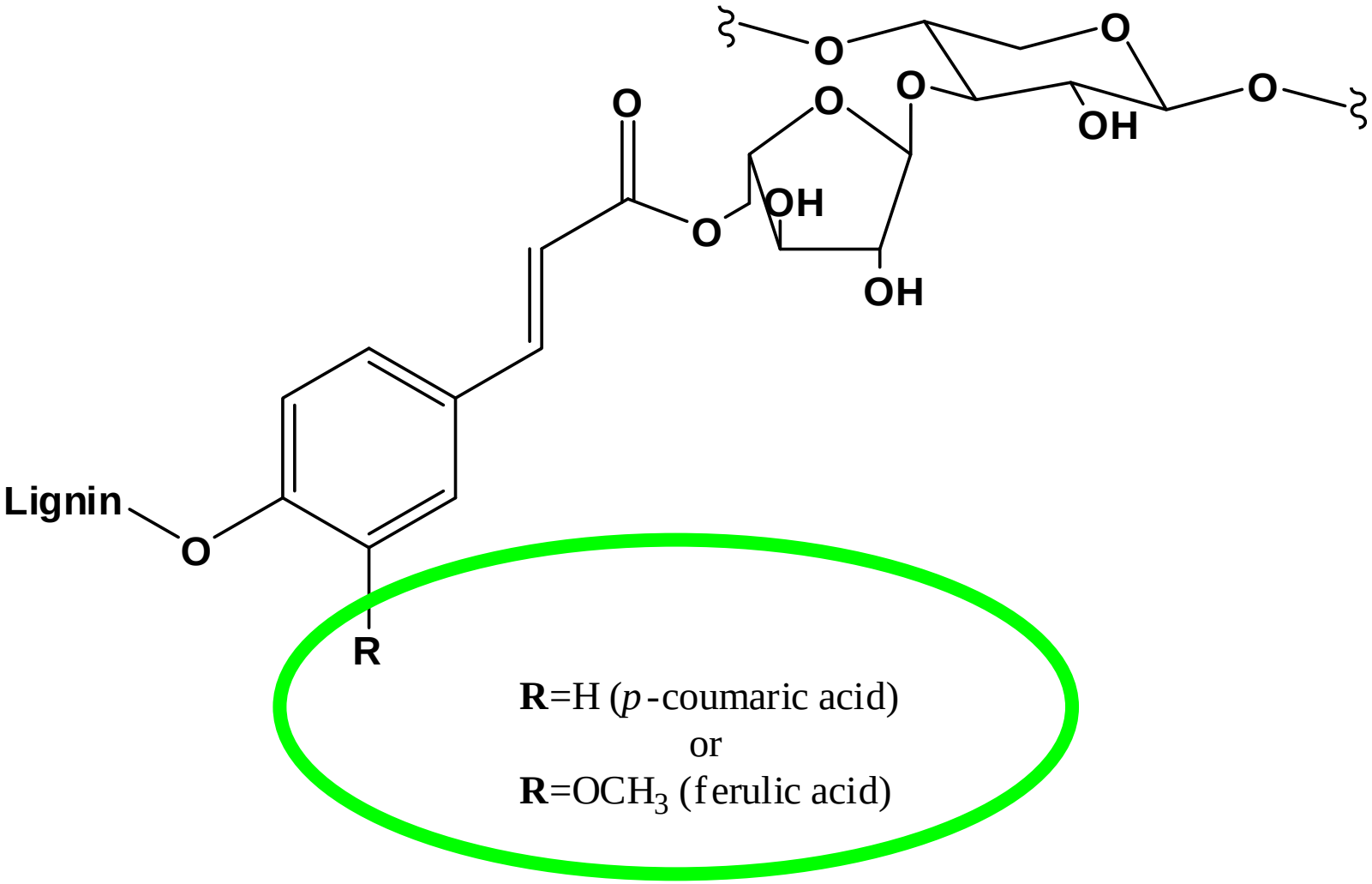


Charles Lee



Dominic Wong

Critical linkages: Ferulic acid esterase



Cinnamic acid linkage ⇔ hydrolyzed by

Ferulic Acid Esterase

Dominic Wong, Meiling Shang, Victor Chan

- 15 unique enzymes with genes
- Four patents – 1 being licensed

Partnerships:

Dr. Peggy G. Lemaux
Cooperative Extension Specialist

Project: Manipulating lignocellulosic material for improved bioenergy capability

Why sweet sorghum over grain sorghum?

- sweet sorghum stores much of its photosynthate as sugar in the stalks

Why sweet sorghum over sugarcane?

- Sweet sorghum needs much less water than sugarcane
- ¼ the inputs ⇔ ~ drought resistant

Reclaiming High Salinity Acreage

Dennis Falaschi - Panoche Drainage District

Jose Tall Wheatgrass

Sunflowers

Drainage Treatment

- **Ultimate disposal for salt**
- **Currently in development**
  - Reverse Osmosis (RO) treatment and salt crystallization that will produce a clean water stream and a dry waste product.
- **Pilot Plant planned for this spring**

Why not sorghum?

Straw for cellulose-to-ethanol

ISSUES:

- **Straw varies with seasons**
- **Aging ⇔ harvest time is once per year**
- **Moisture and storage are challenging**
- **Transportation ⇔ Low density**
- **Supply is not near highest demand.**

IOGEN CORPORATION

Optimal Biorefinery:

= 100 MM gal/yr

= 4000 tons biomass/day

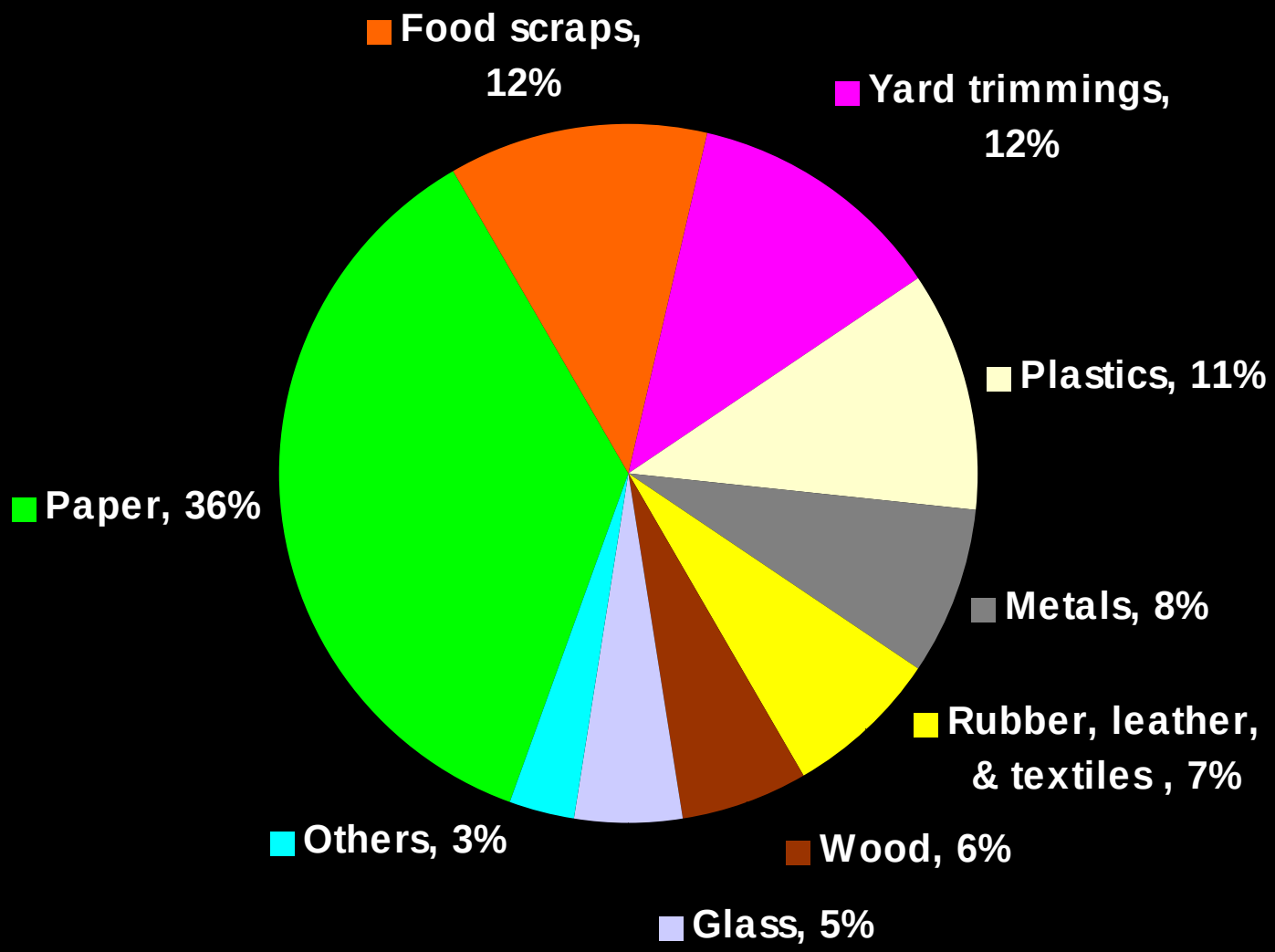
= 1000 acres wheat/day

= 365,000 acres/yr

= 570 sq. miles

= 15 mile radius

Composition of MSW



425 million tons per year of unsorted MSW produced in U.S. alone (BioCycle, 2006).

CR^3 Autoclaves:

- Pressurized hot water treatment.
- Reduces volume.
- Isolates recyclables
- Fractionates components

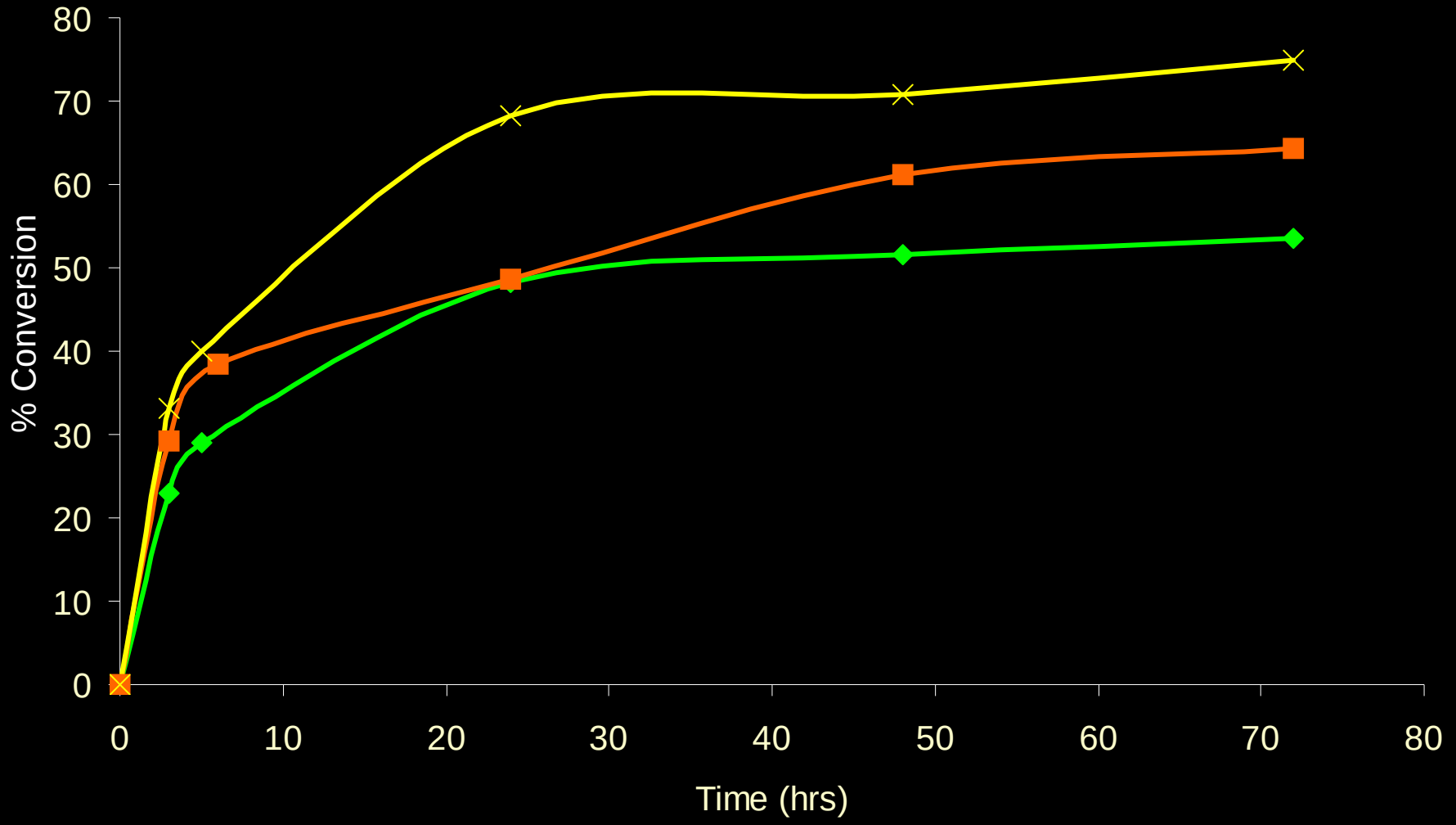
Conveyor loading MSW to autoclave

MSW inside the autoclave prior to steam treatment

MSW in the autoclave after steam treatment

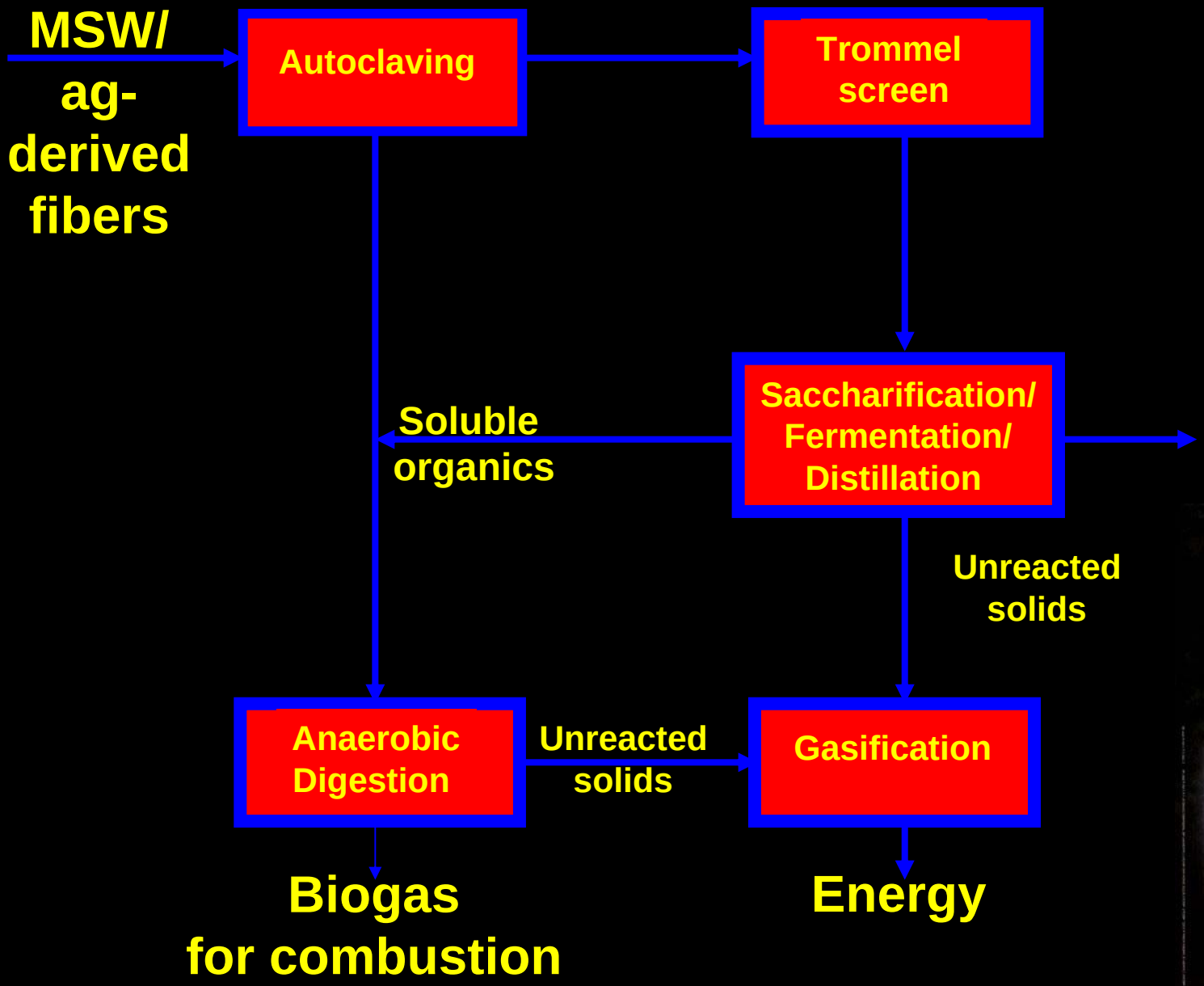
Clean fiber from MSW after centrifugal cleaners

Enzymatic hydrolysis of MSW



Ag-Derived biomass works about as well as MSW ⇔ Co-mingled waste….

Flow scheme for flexible biorefinery



Sorghum as Biofuel

Generation 1: Food to Fuels

- Sorghum spans categories

Generation 2: Cellulosics, etc

- Sorghum biomass competes with any US energy crop
- Co-mingled with other ag-residues…
- Municipal Solid Waste?

Sorghum ⇔ flexibility

International Partnerships:

Embrapa

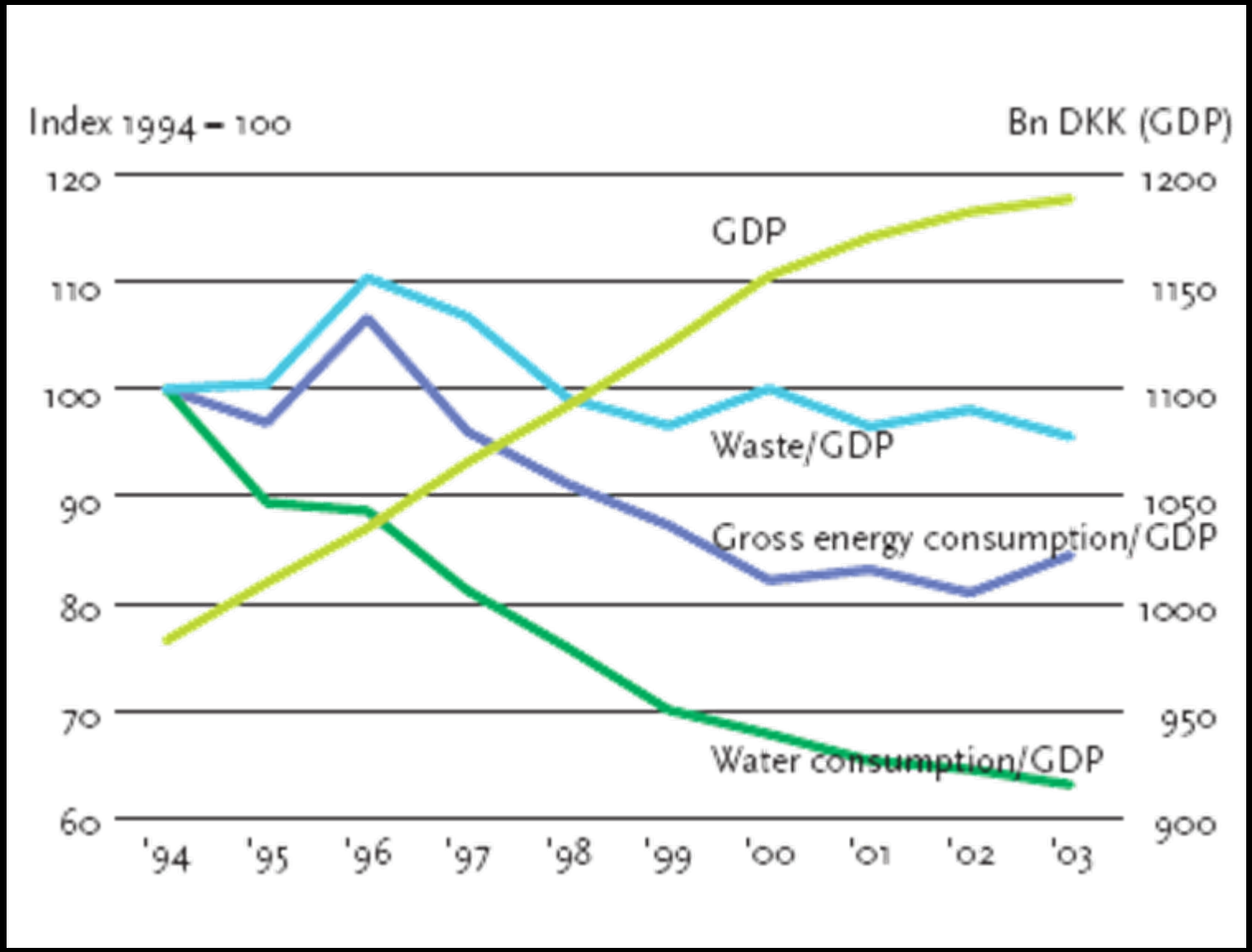
Recursos Genéticos e Biotecnologia

Active US-Brazil Exchange

Kazakh Former Bioweapons Lab

MacDiarmid Center for Renewable Fuels; Three Gorges China

In Denmark, economic growth and energy use are decoupled



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

Contacts

William Orts
510-559-5730
orts@pw.usda.gov