




Resurgence of Industrial Biotechnology & Biocatalysis *via* Biorefinery

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Outline of the Presentation

- Biorefinery & Biocatalysis: The larger picture 
- Oil-based vs. Bio-based feedstocks & platform chemicals
- Biocatalysis: **Core technology** for Biorefinery
- **Center for Biocatalysis & Bioprocessing (CBB) @ The University of Iowa**: What are we doing in the area Biocatalysis & Biorefinery
- Summary/Conclusions

What is Biorefinery?

Biorefinery is the co-production of a spectrum of bio-based products (food, feed, materials, chemicals) and energy (fuels, power, heat) from biomass [definition IEA Bioenergy Task 42]

Bio-Refinery Concept

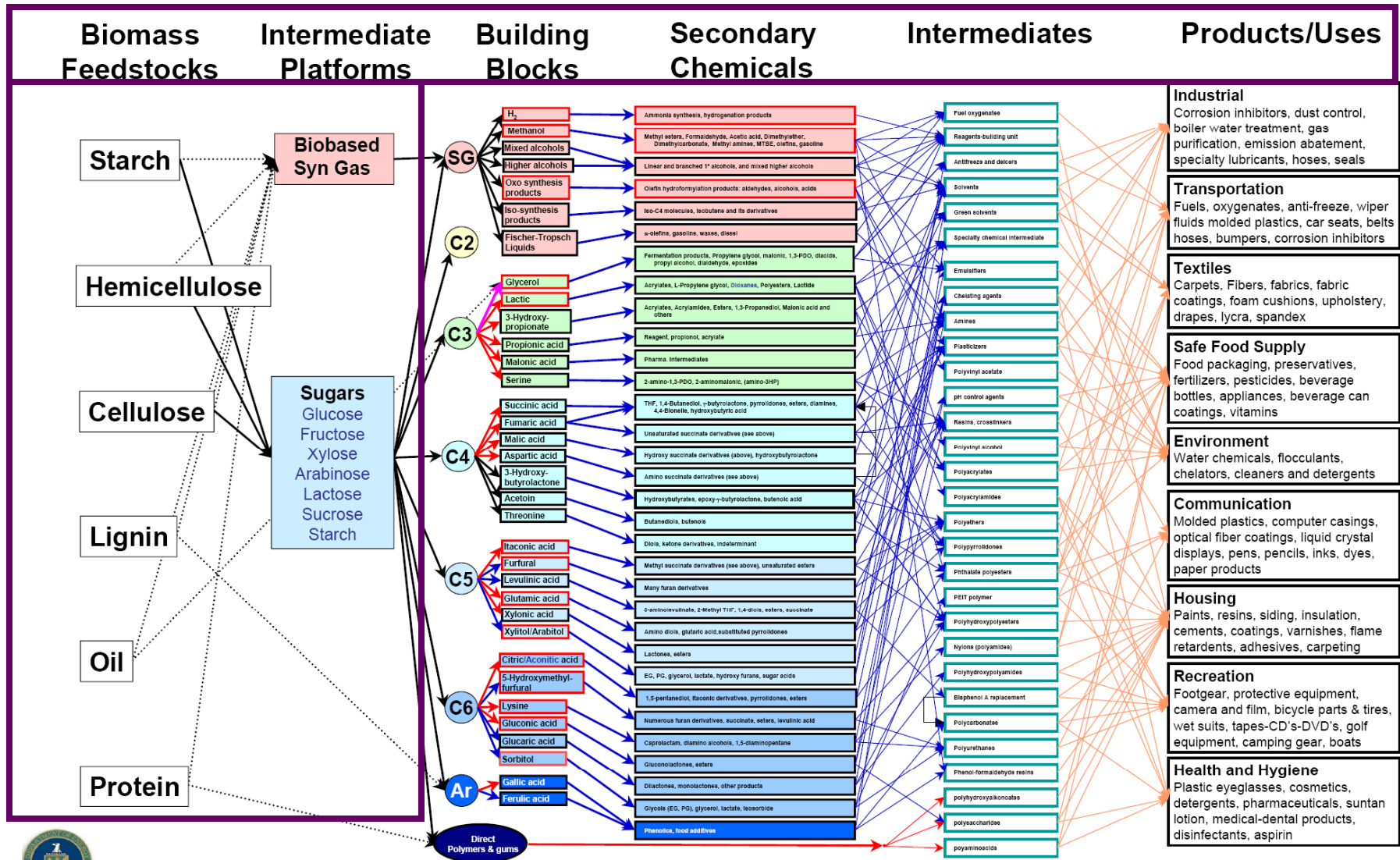
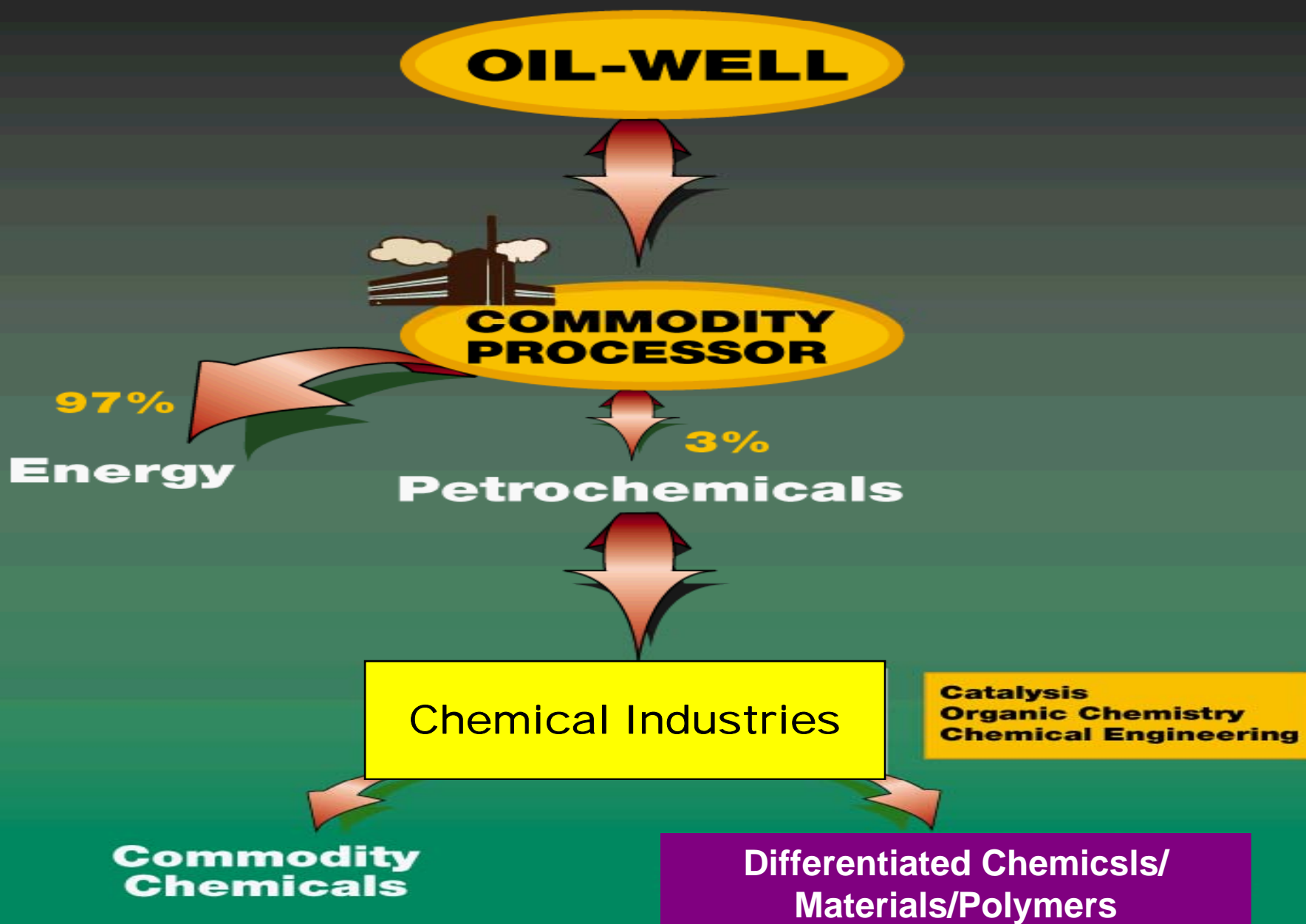


Figure 3 – Analogous Model of a Biobased Product Flow-chart for Biomass Feedstocks

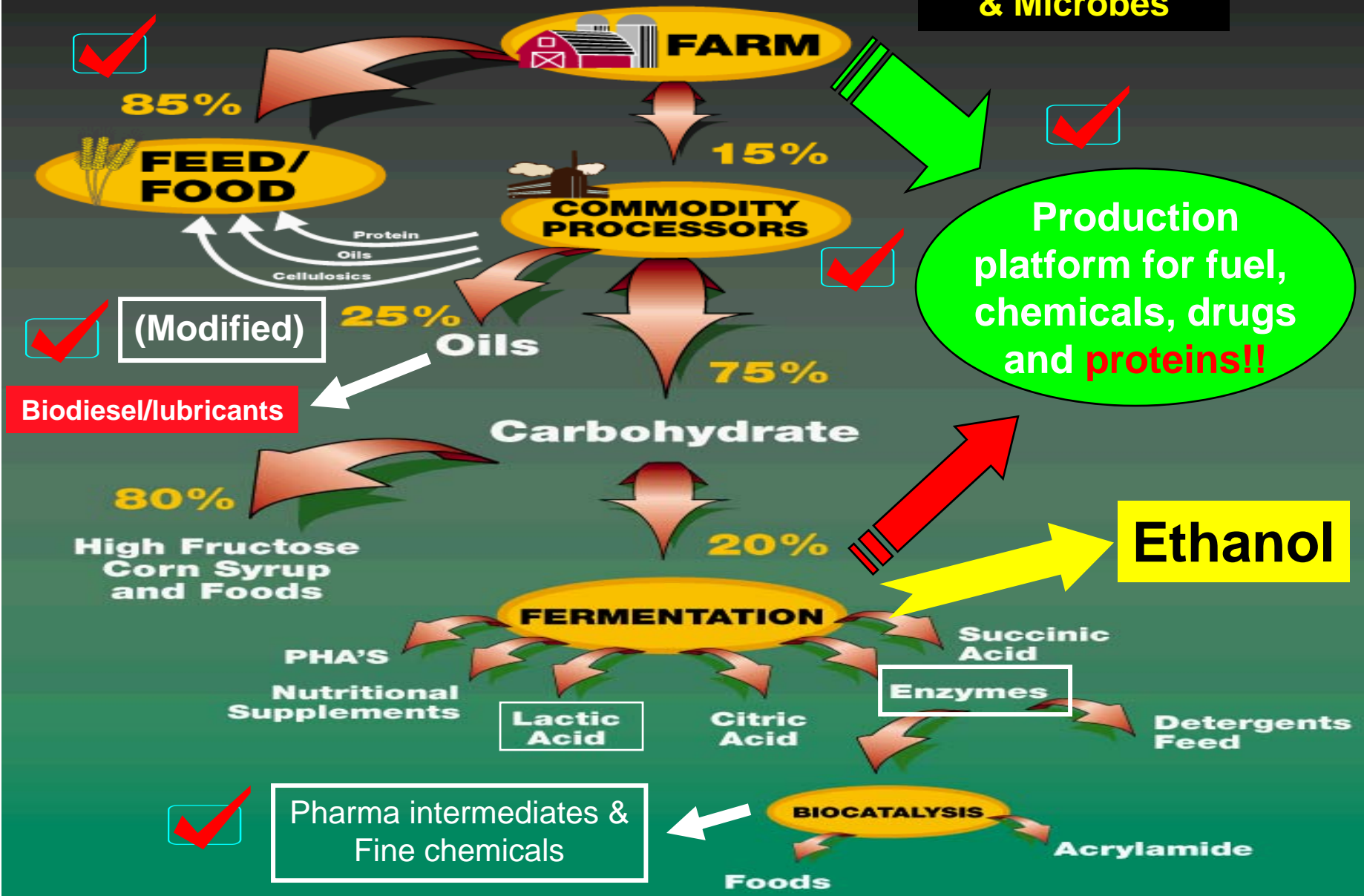


Oil-Based Chemical Industry



Agriculture/Biotech Based Chemical Industry

(Modified) Crops & Microbes



Human-Therapy

- Protein drugs
- DNA/RNA drugs
- Vaccines
- Stem cells

RED

Industrial (Biofeed-stock/energy)

- Bio ethanol/diesel
- Oils
- Corn starch
- Chemicals
- Enzymes

WHITE

Plant-Biotech

- Weedkiller/ insect resistant crops
- Healthy crops
- Plant-made medicines

GREEN

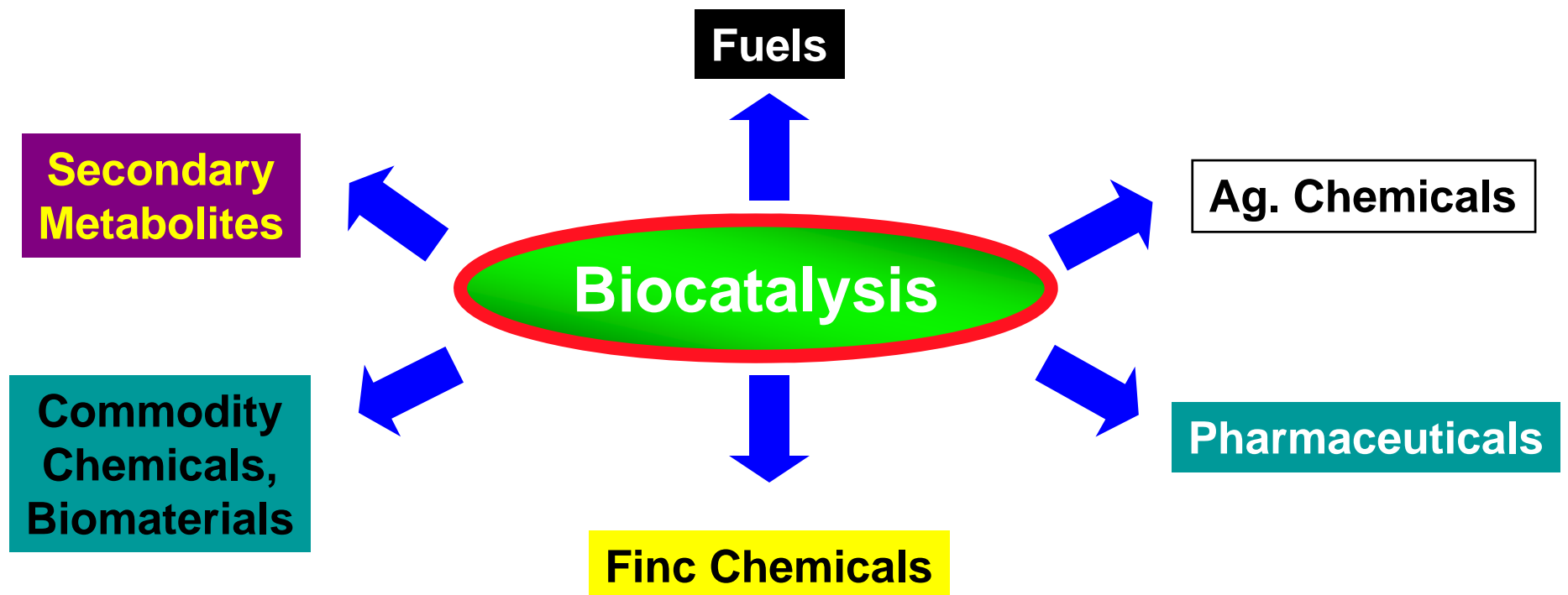
Genetically Modified

BIOTECHNOLOGY

Starch/Sugars
Ag. Residues
Energy Crops
Wood/Waste

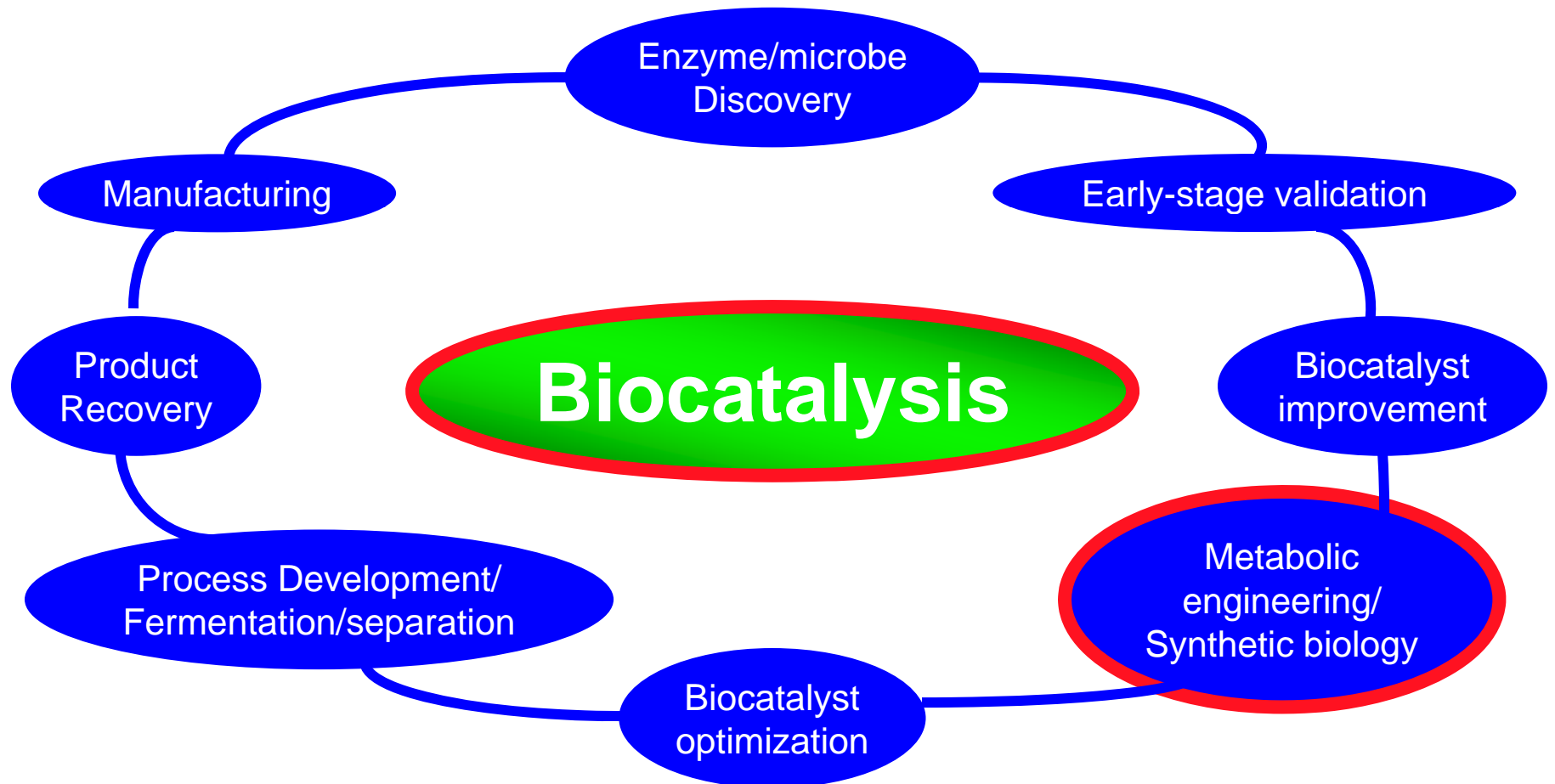
Core of Industrial Biotechnology is BIOCATALYSIS

“Biocatalysis* utilizes live/dead (recombinant/engineered) microbes or enzymes to generate products as well as environmental assessment of products”



*Including Fermentation

BIOCATALYSIS: Involves many technologies/disciplines



Value of White Biotech Products

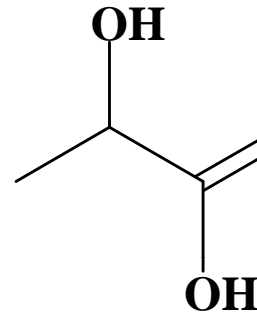
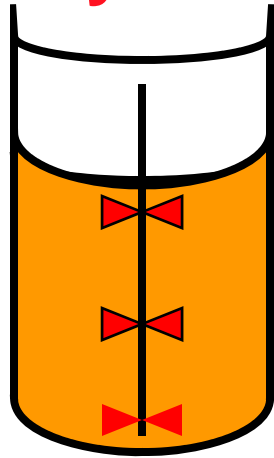
Product Group	Market Value (\$, 2003)	Applications
L-amino acids	>2 B	Nutrition, cattle feed, medicine
Nucleotides	>360 MM	Nutrition
Vitamin B12	75 MM	Nutrition, medicine
Citric/organic acids	1.5 B	Nutrition, chemistry, electronic, other technology
Antibiotics	35 B	Medicine
Cyclosporin A	1.5 B	Medicine
Statins	15 B	Medicine
Taxol*	1 B	Medicine
Avermectins	1 B	Veterinary medicine, Ag.
Industrial Enzymes	>2 B	Nutrition, chemistry, biocatalysis

***Mainly from plants/plant cultures**

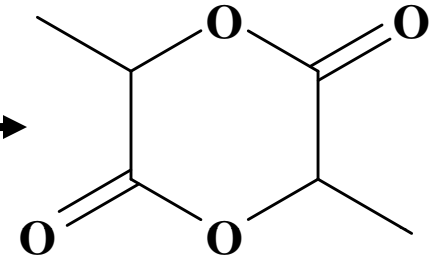
In terms of value, pharmaceuticals still dominate!!

Poly(lactic acid) (NatureWorks, LLC)

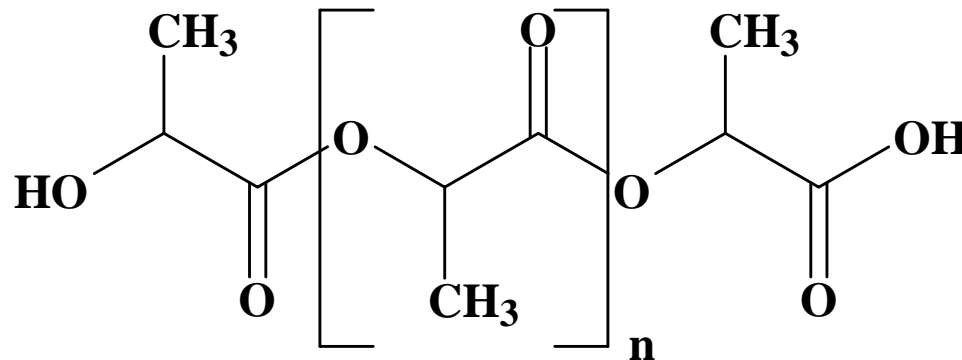
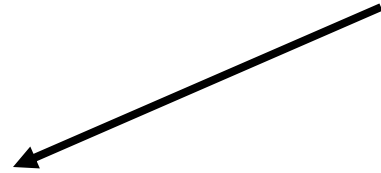
Sugars



L-lactic acid



L,L-lactide
D,L-lactide
D,D-lactide



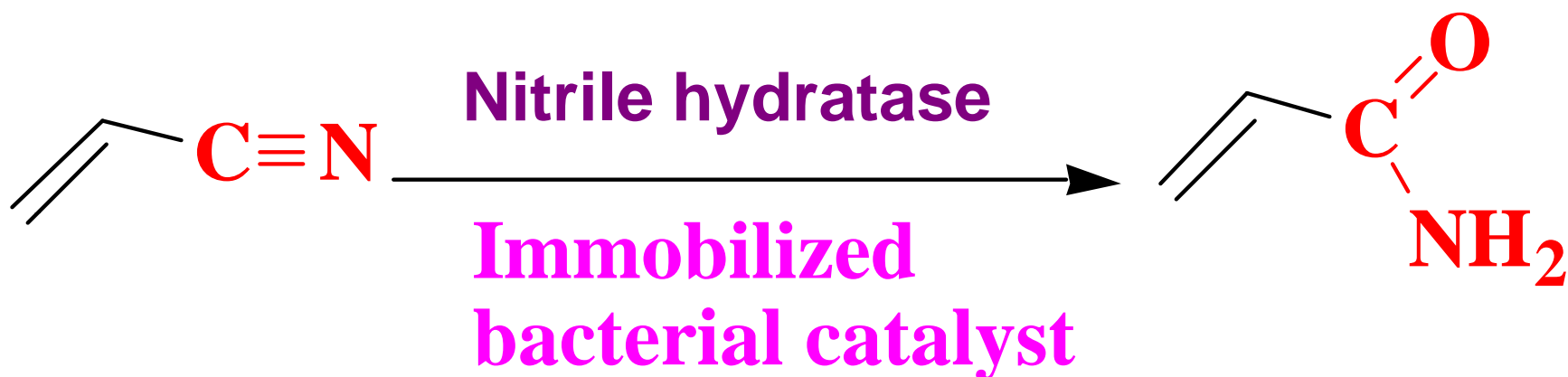
PLA



NatureWorks™
Cargill Dow Polymers LLC



Bio-Based Commodity Chemical



20,000 tons/year
(Nitto Chem Co., Japan)

J. Chem. Soc., Perkin Trans I, 1679 (94)

Industrial Lubricant from Soy

Continued
Oxidation from
Non-GMO soy

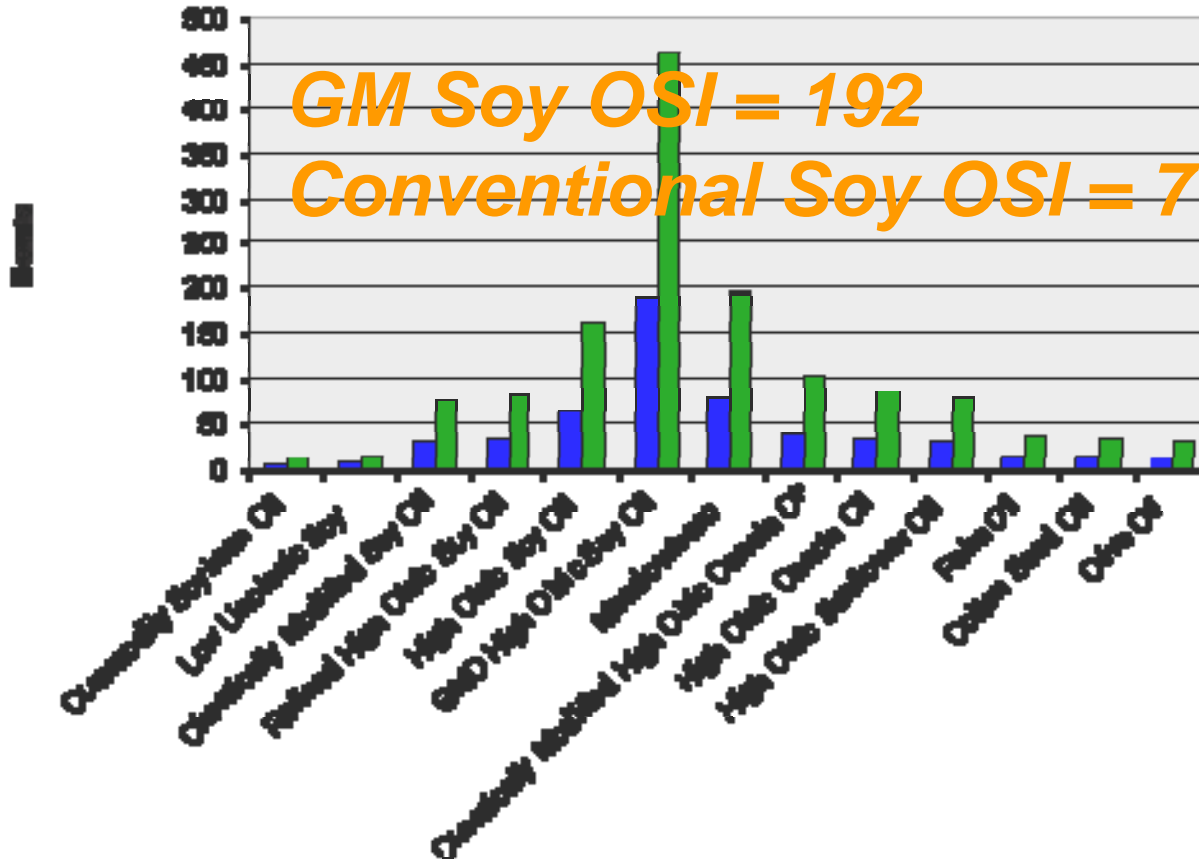




GM-Soybean Enabled the Product

Relative Stability Index and Active Oxygen Method

■ OSI Values (hours @ 110 C)
■ AOM Values (hours @ 97.8 C)




**Thanks to Dr. Lou Honary, Associate Professor,
U of Northern Iowa; CEO, Environmental Lubricants
Manufacturing, Inc. for the slides**



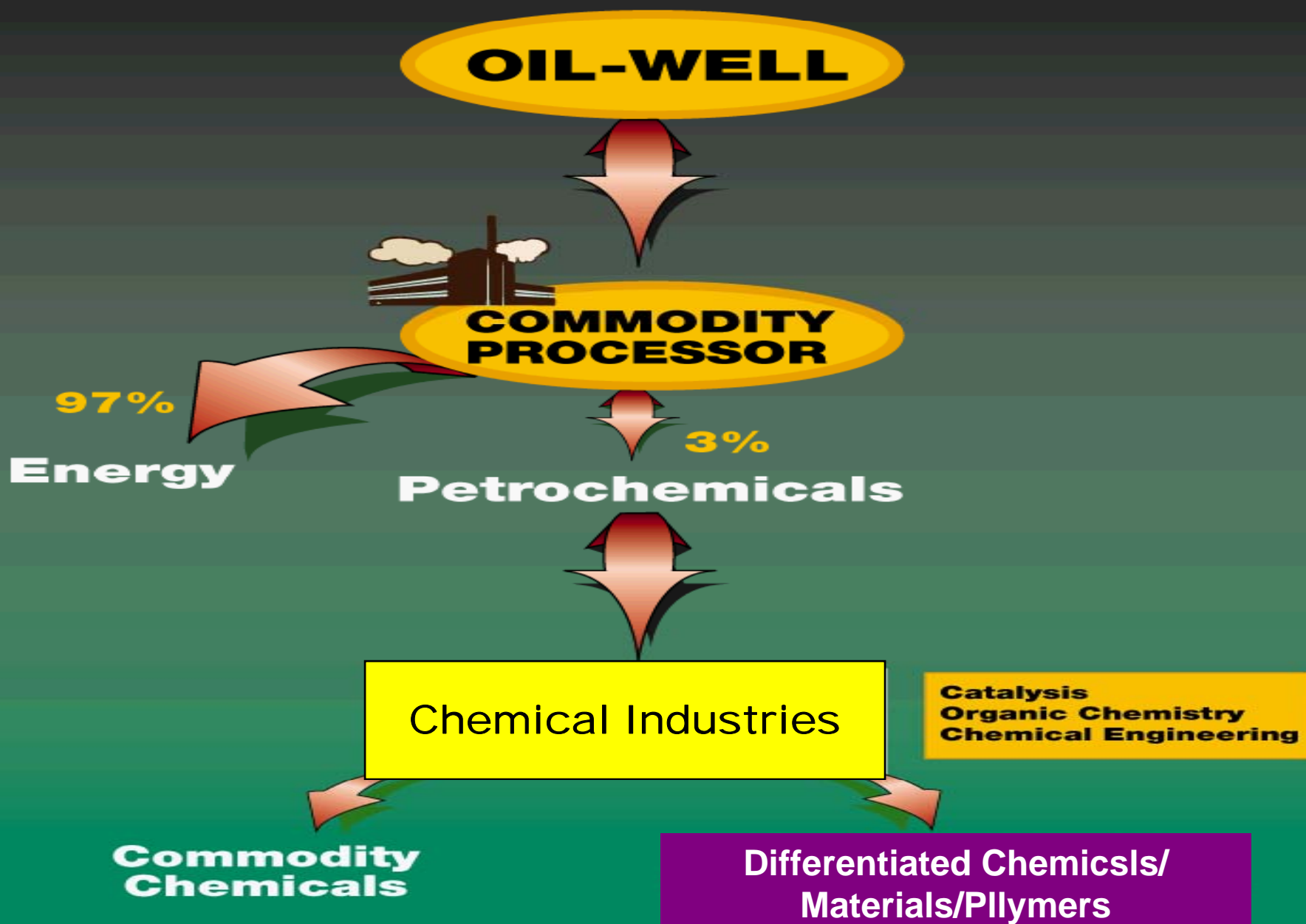
Chemicals from Corn & Soy

- **IOWA** is very rich in agriculture -
#1 in Corn and Soybean Production
in the United States
- **#1 in bioethanol & #2 in biodiesel**
- **Biorenewable chemicals from crops and crop residues is a “great fit”**

Outline of the Presentation

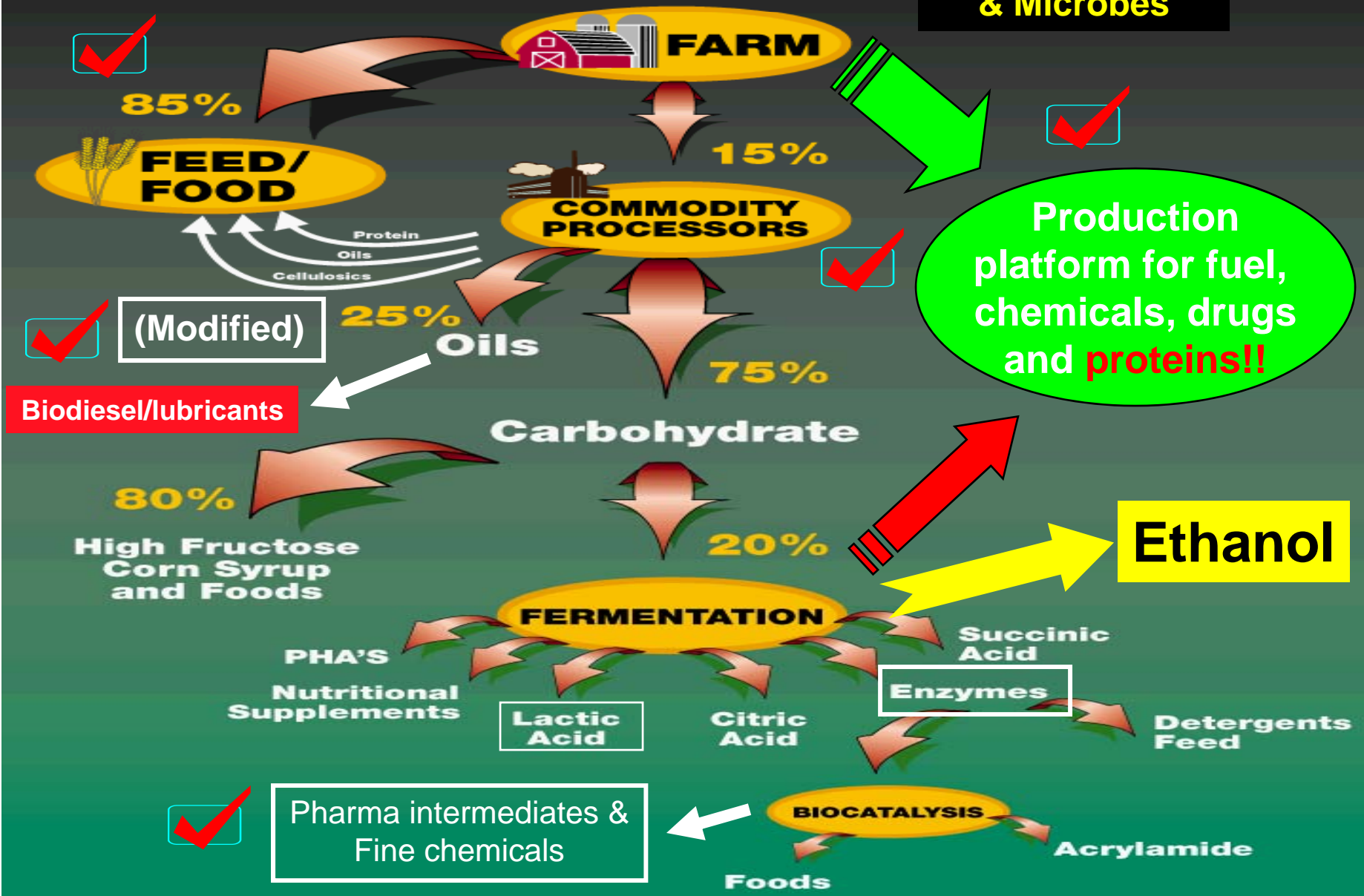
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Oil-Based Chemical Industry

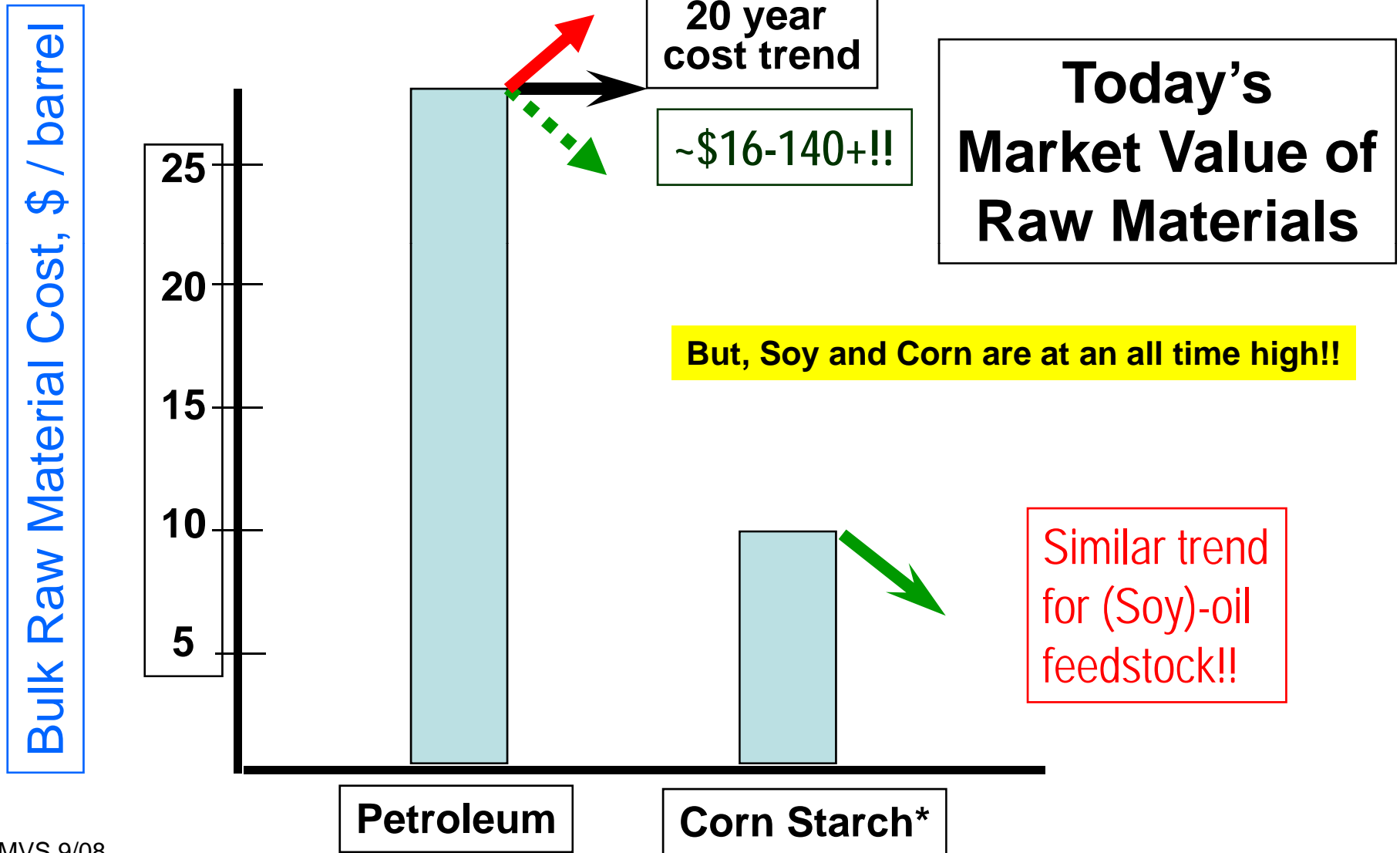


Agriculture/Biotech Based Chemical Industry

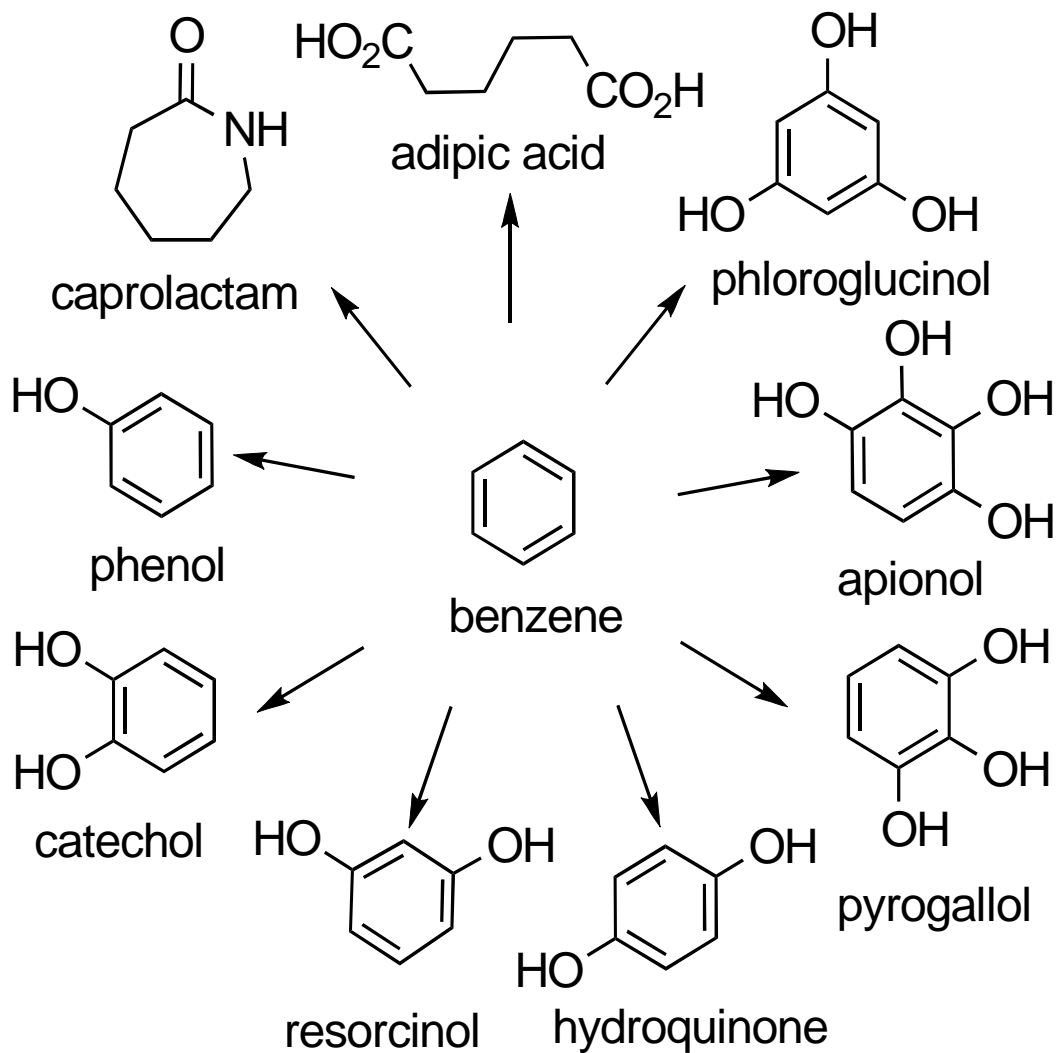
(Modified) Crops & Microbes



What is Driving Industrial Biotechnology Today?



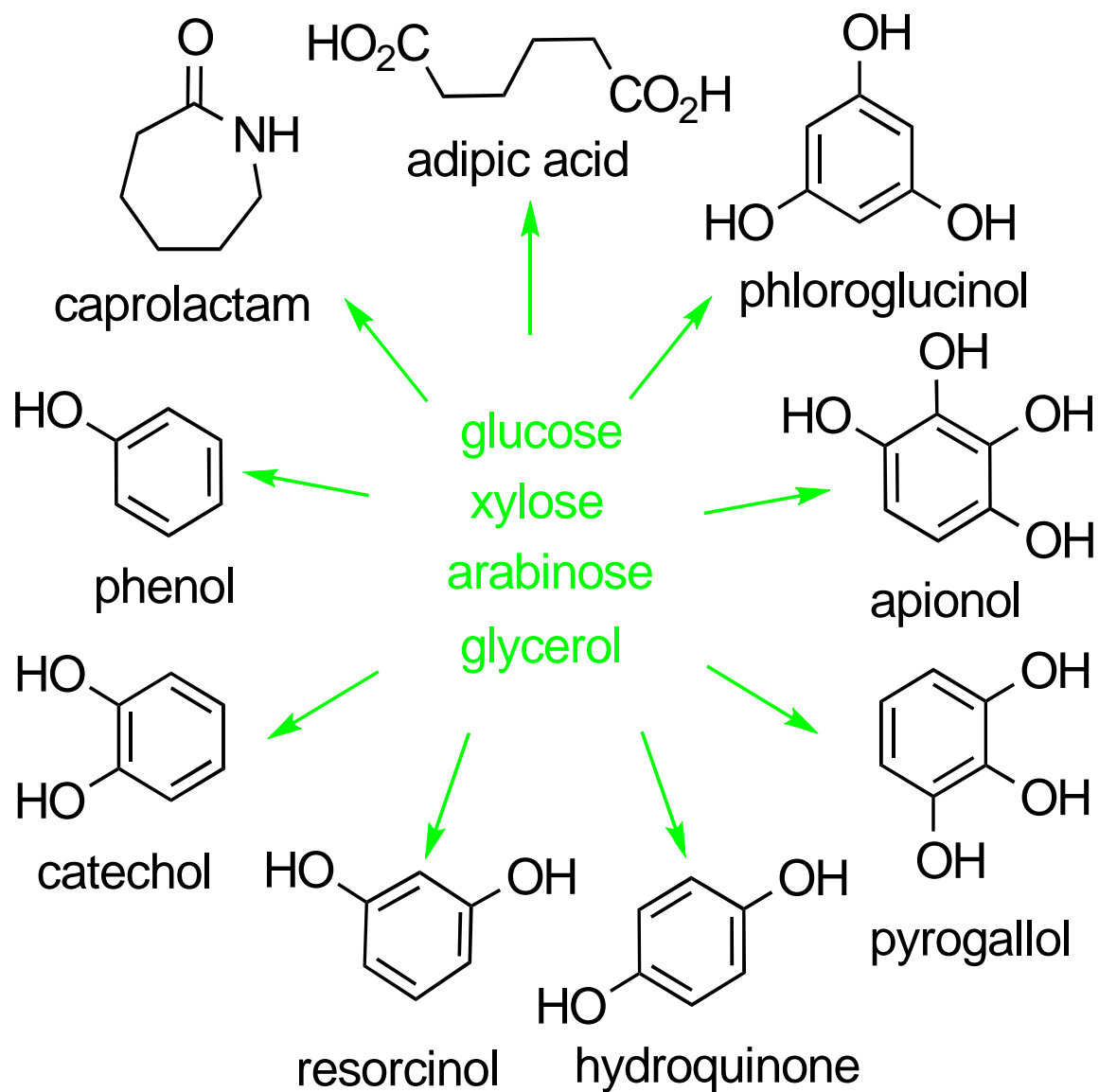
Aromatics from Petroleum



Courtesy:
Prof. John Frost
Draths Corp.



Aromatics from Sugars!!



Courtesy:
Prof. John Frost
Draths Corp.

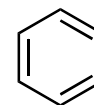


Aromatics from Renewables

- **New chemicals**
- **New chemistries**
- **Improved performance**

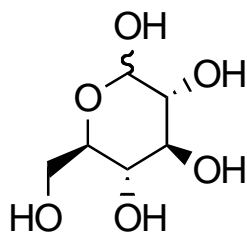
Aromatics from Renewables

Environmental Impact:

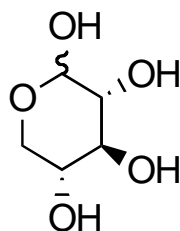


benzene

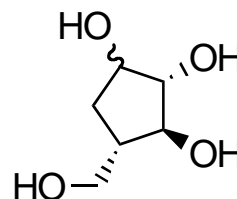
- Volatile
- Carcinogen (leukemia, non-Hodgkin's lymphoma)



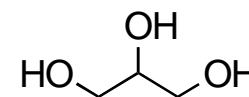
D-glucose



D-xylose



L-arabinose



glycerol

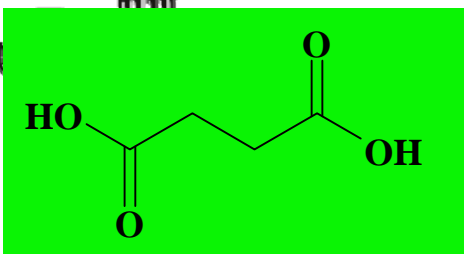
- Non-volatile
- Non toxic
- Carbon-di-oxide consumed

US Department of Energy (DOE) Goal

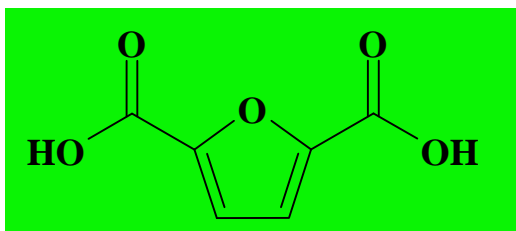
By 2025:

- **Replace 30% liquid transportation fuel with biofuels**
- **Replace 25% of industrial organic chemicals with biomass-derived chemicals**

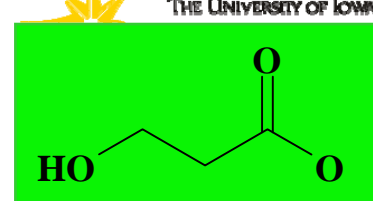
DOE "Top 10" Platform Chemicals from Carbohydrates



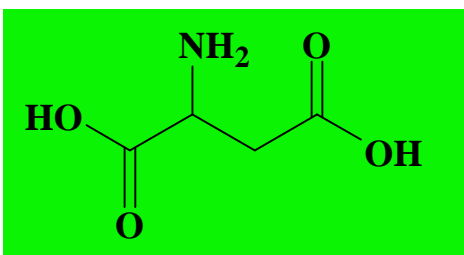
succinic acid



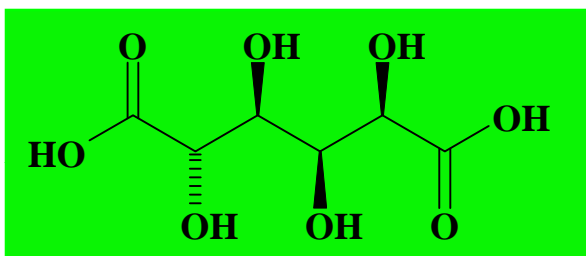
2,5-furandicarboxylic acid



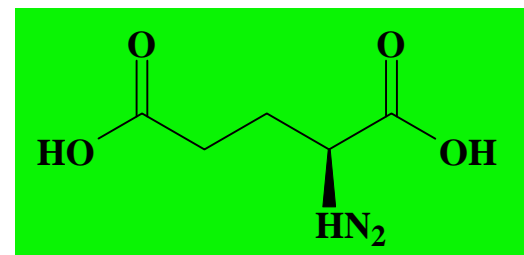
3-hydroxypropionic acid



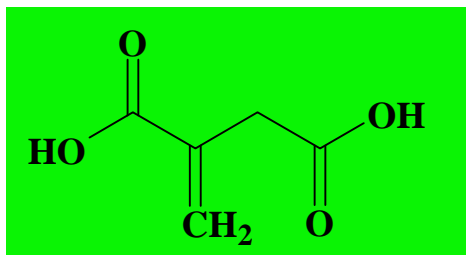
aspartic acid



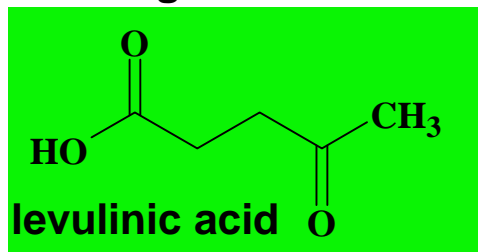
glucaric acid



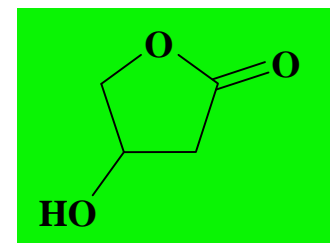
glutamic acid



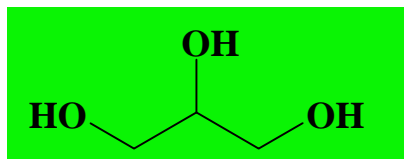
itaconic acid



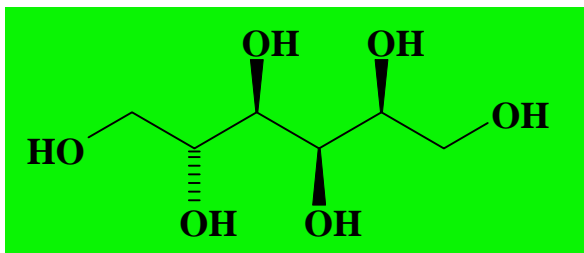
levulinic acid



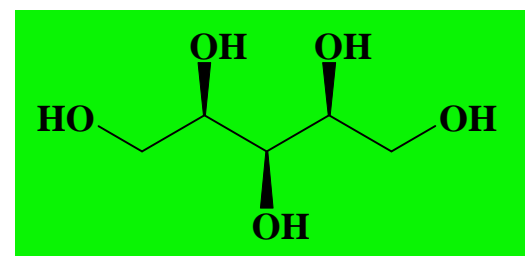
3-hydroxybutyrolactone



glycerol




sorbitol

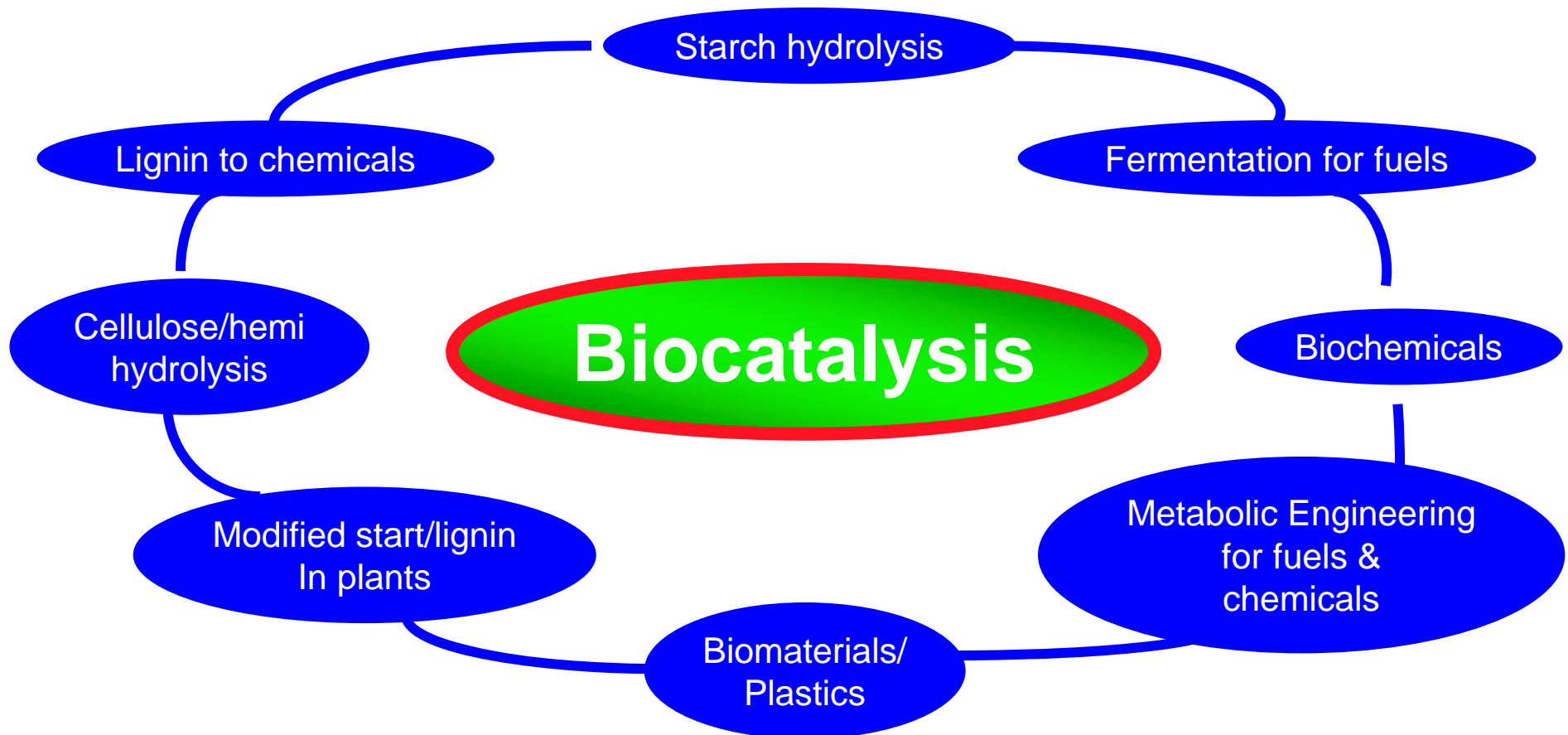


xylitol

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BIOCATALYSIS is Integral Part of Biorefinery



Enzymes are essential across the board, for processing renewable feedstocks

UNIVERSITY OF IOWA

Corn Stover



Energy Crops



Woody Biomass



Cellulosic Waste



MVS 9/08

BIOMASS

Thermochem
Chem/Bio*
Pyrolysis

*Biocatalysis

Oil

Starch
Sugar

C_6/C_5
Sugars*

$CO_2 + H_2$

Lignin*

Center for Biocatalysis
and Bioprocessing

Biocrude
Biodiesel*

Butanol*

Ethanol*

Chemicals*/
Materials*


Aromatics*
Biomaterials*



Cellulosic Ethanol: Enzymes are one of the barriers

- **Cost-effective pretreatment**
- **Reduction in cost of saccharification enzymes**
- **Saccharification efficiency of hemi-cellulose and cellulose sugars**
- **Ability to efficiently utilize both C5 and C6 sugars**
- **Economics of co-product streams**
- **Successful process scale-up**

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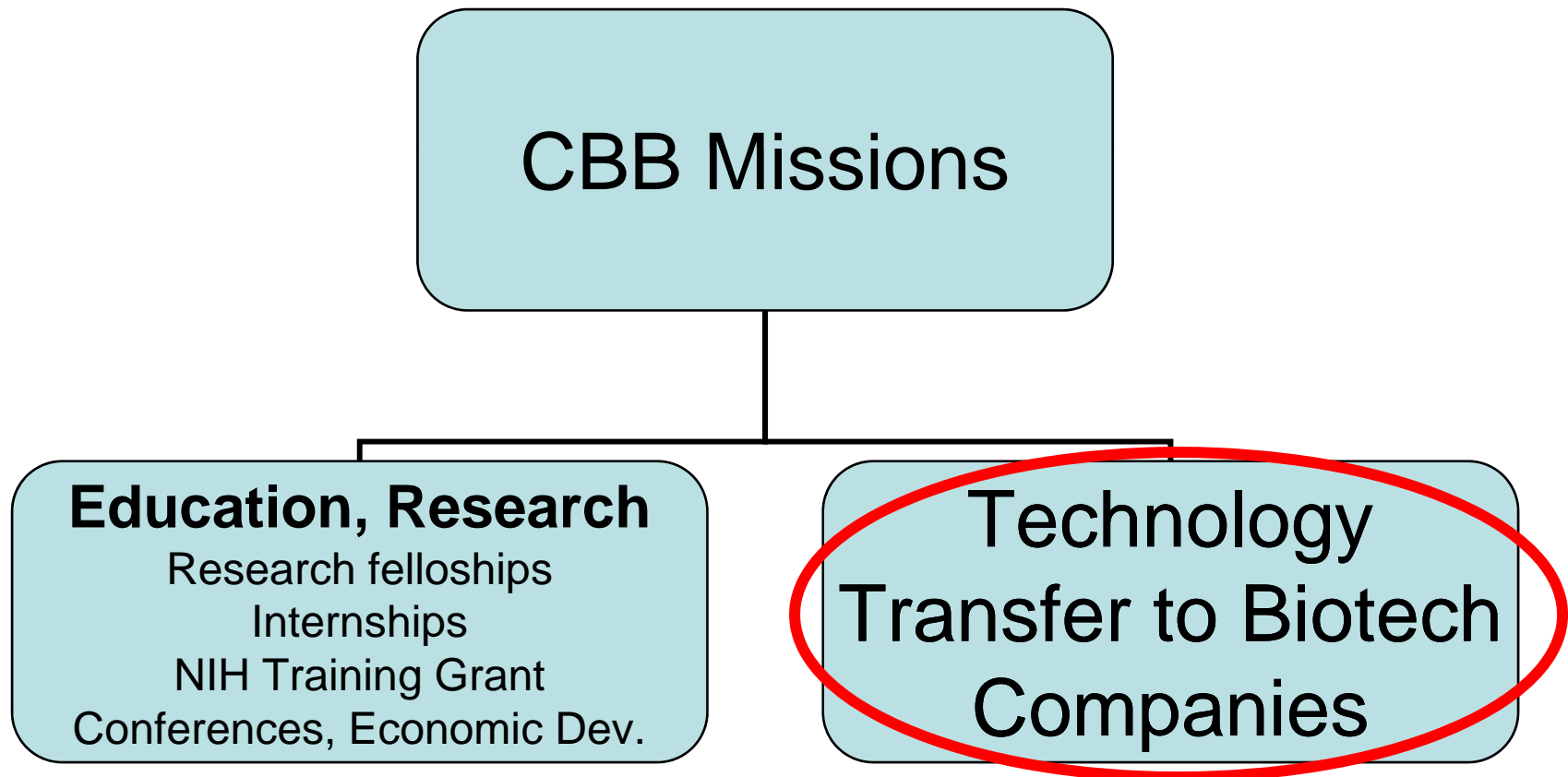
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University of Iowa

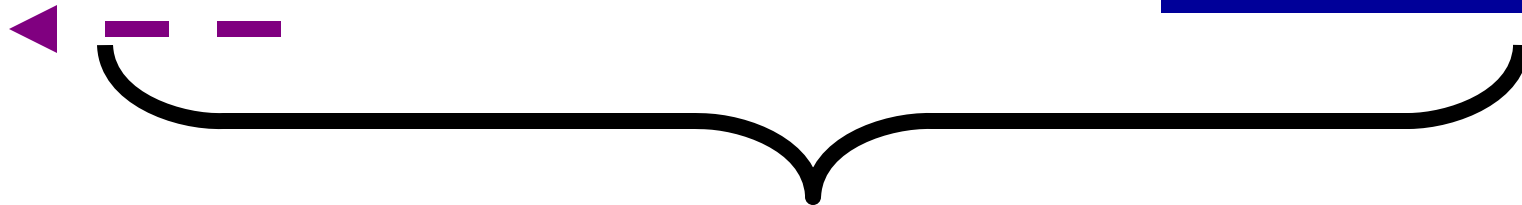
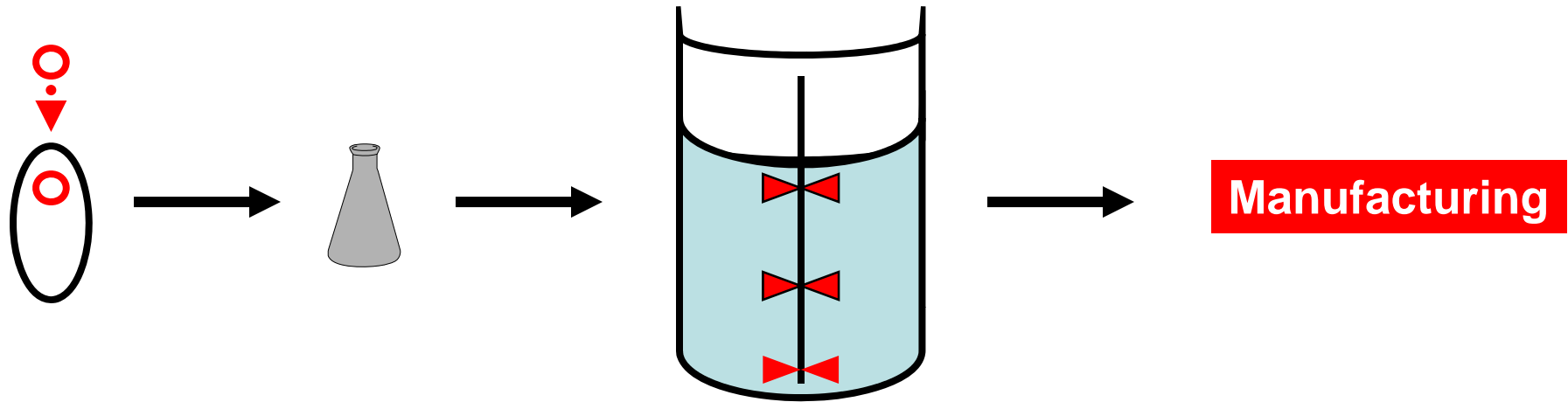
**Center for
Biocatalysis & Bioprocessing
(CBB) - Fermentation Pilot Plant for
Red and White Biotechnology**

University of Iowa, CBB





CBB: Biotechnology Capability



CBB-Expertise



**Protein Recovery
Hollow Fiber Filtration**

Model #: CF4-100
Type: 0.55 Mic
Area: 1.2 m²
Serial #: 60622018



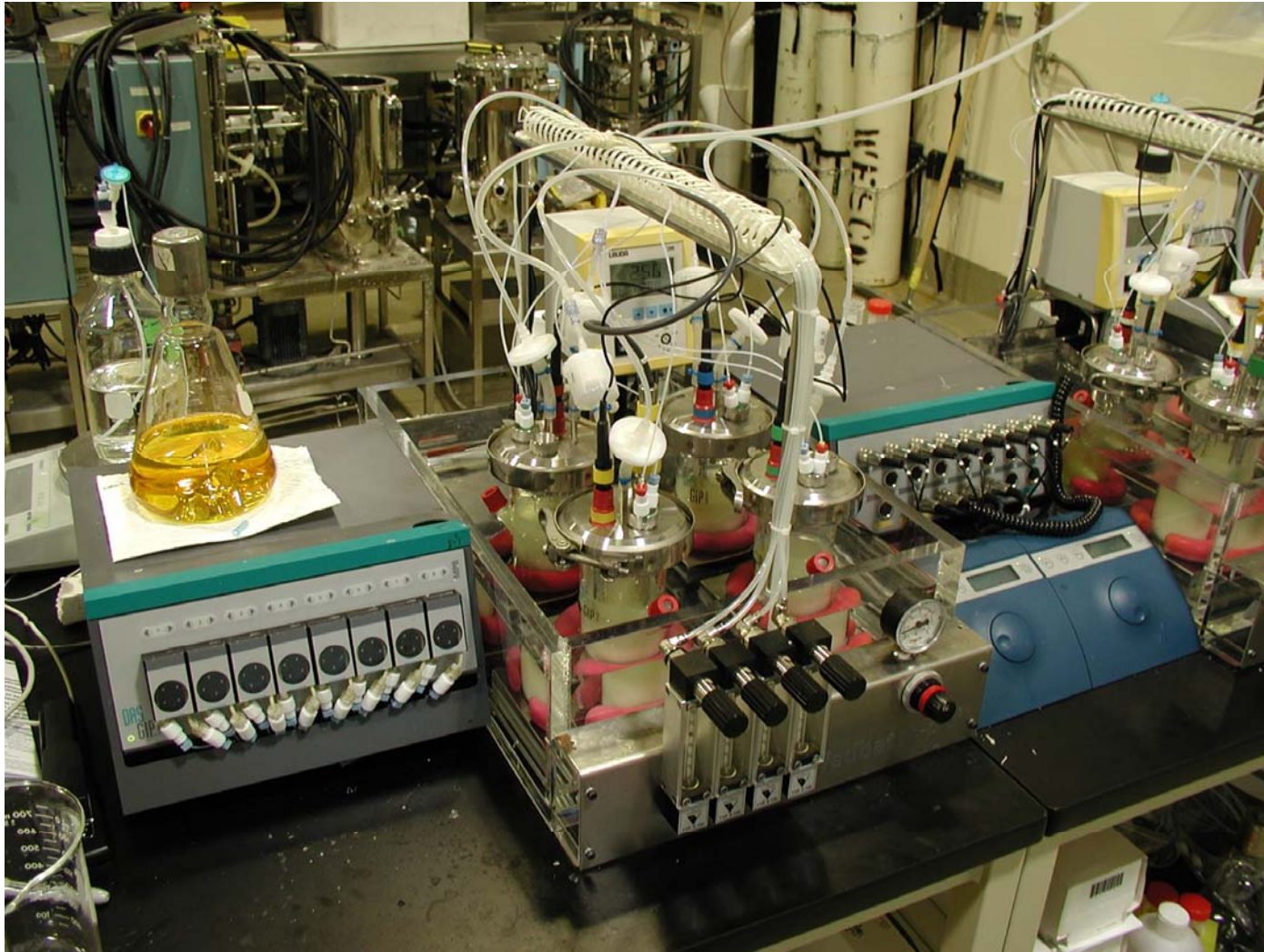
0.55



MADE IN USA

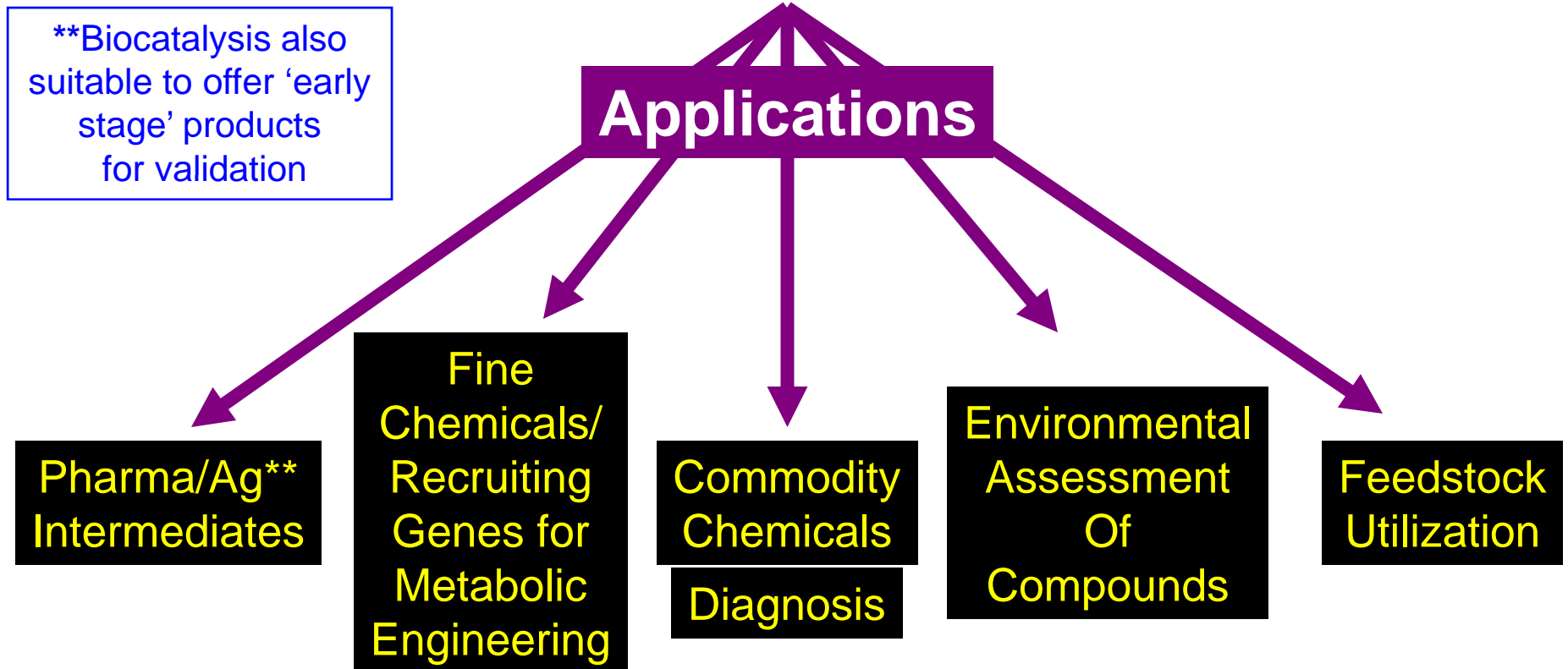


DASGIP System for Biomass/ Protein Optimization & Reaction Engineering



5-Year Vision - Biocatalysis Center

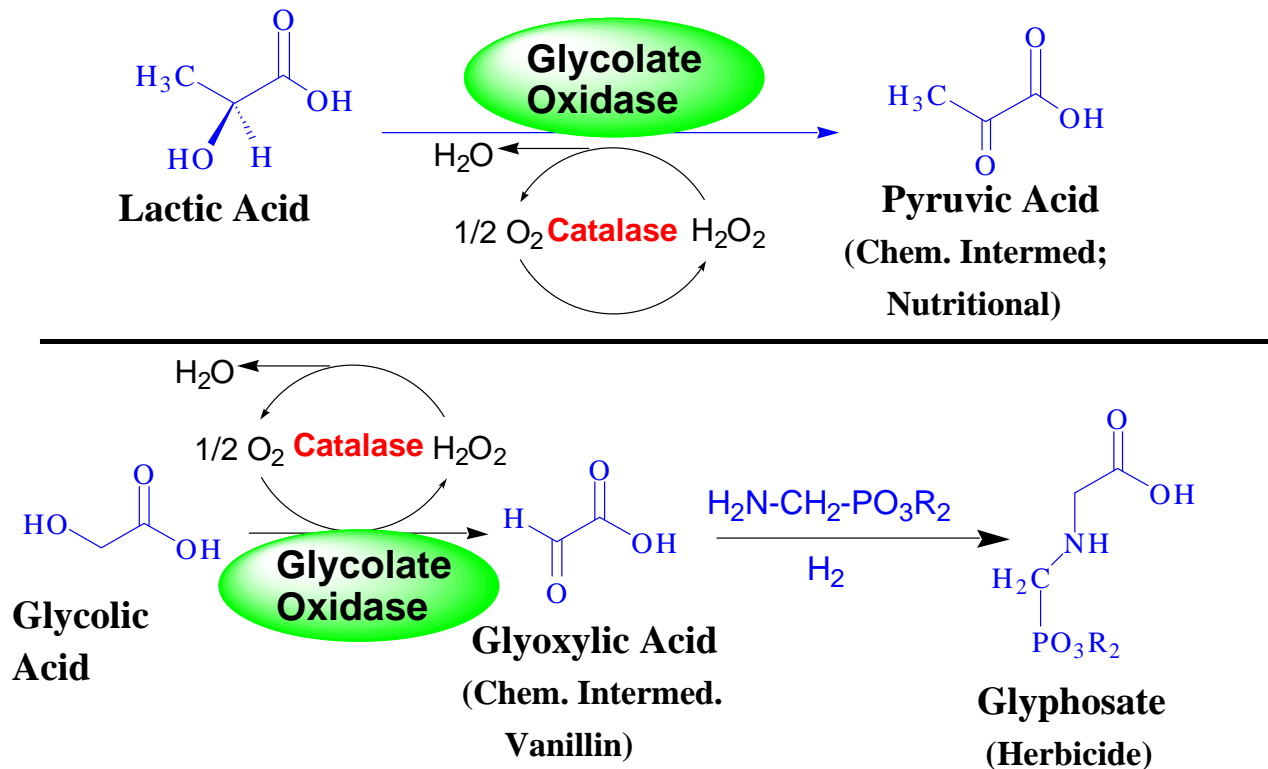
National Center for Microbe/Enzyme/Gene Resource for Biocatalyst Discovery & Screening





GO (Plant Enzyme) - UI Technology

Simplified Process for Production of Pyruvate -

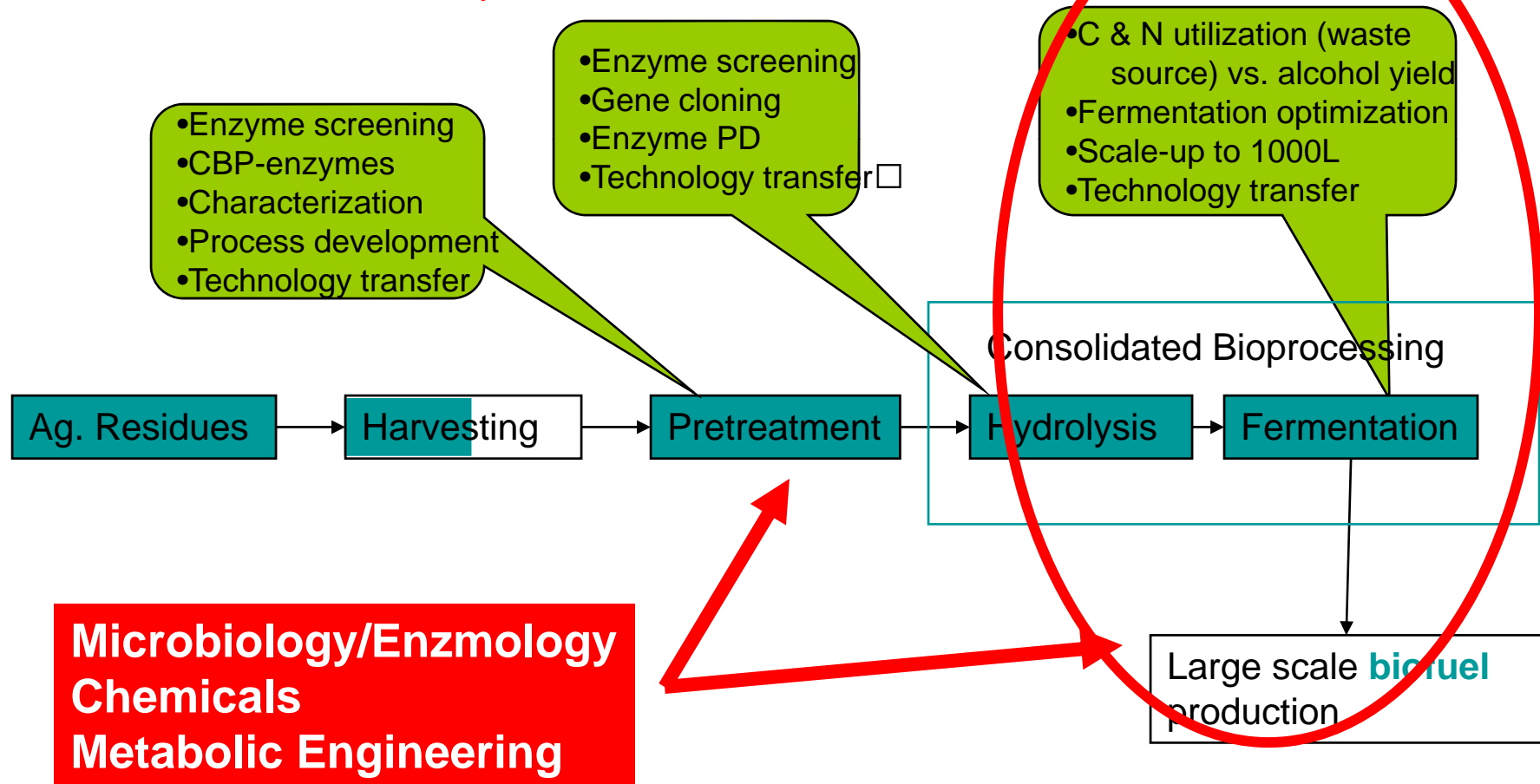


- GO-based production of pyruvate, Operations reduced from 7+ steps to 2!!
- GO-based production of glyoxylate (glyphosate, vanillate)
- GO-based production of other keto-acids
- GO-based resolution of racemic α -hydroxyacids
- GO-technology being patented; LO signed with a company + research funding

University of Iowa Strengths in a Bioeconomy Platform

Center for Biocatalysis & Bioprocessing (CBB) Capabilities

<http://www.uiowa.edu/~biocat/index.html>



Summary:

- Industrial Biotechnology (White Biotechnology) has lagged behind Biopharma (Red Biotechnology). However, the **timing is right for large growth in this area**
- From biofuels to chemicals to biomaterials, there is a **global resurgence (Biorefinery)**
- **Iowa is well positioned to lead in this area**
- US DOE has set clear **targets by 2025:**
 - 30% transportation via biofuels
 - 25% industrial chemicals from “Bio”
- **Biocatalysis is the “Core”** of Industrial Biotechnology and Biorefinery
- **CBB (U of Iowa) has an evolving “Biocatalysis” Platform**
 - Involved in biofuels and biochemicals