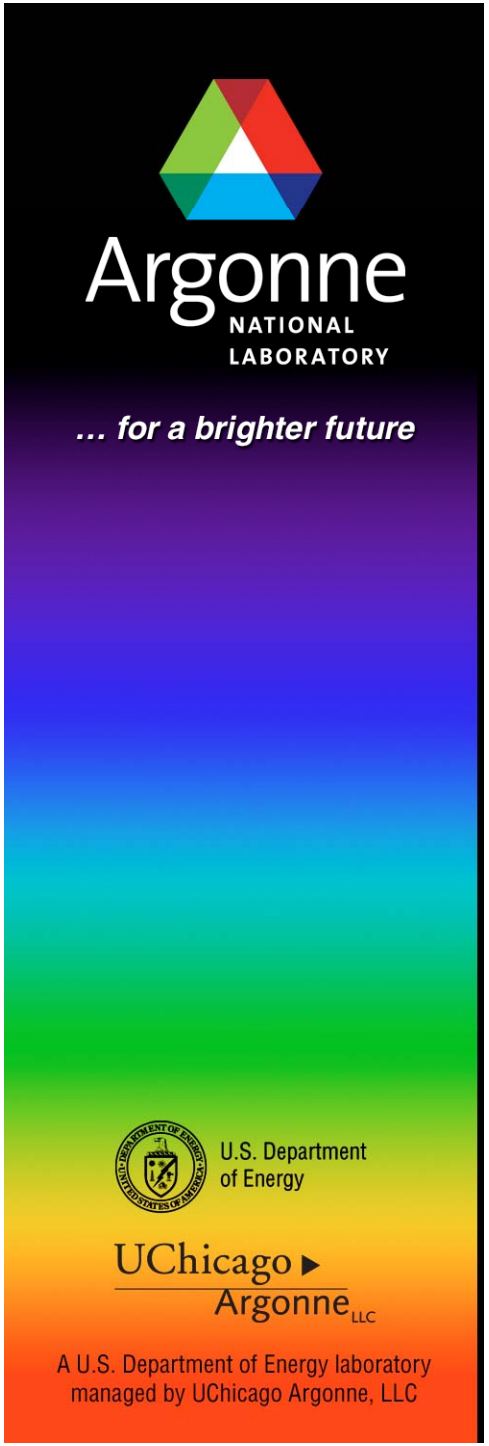


Biofuels R&D

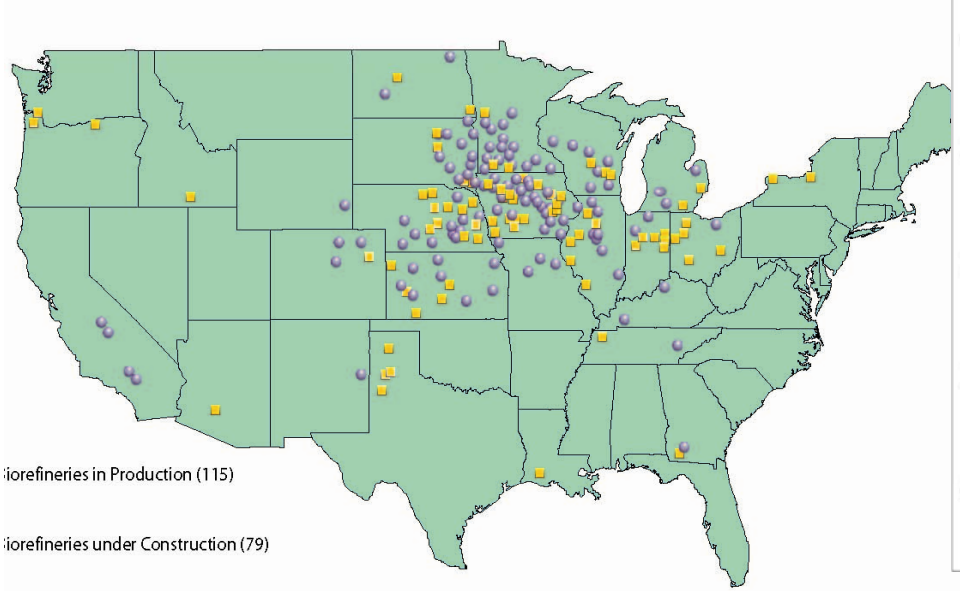
The Role of R&D in Agriculture and Related Industries: Today and Tomorrow

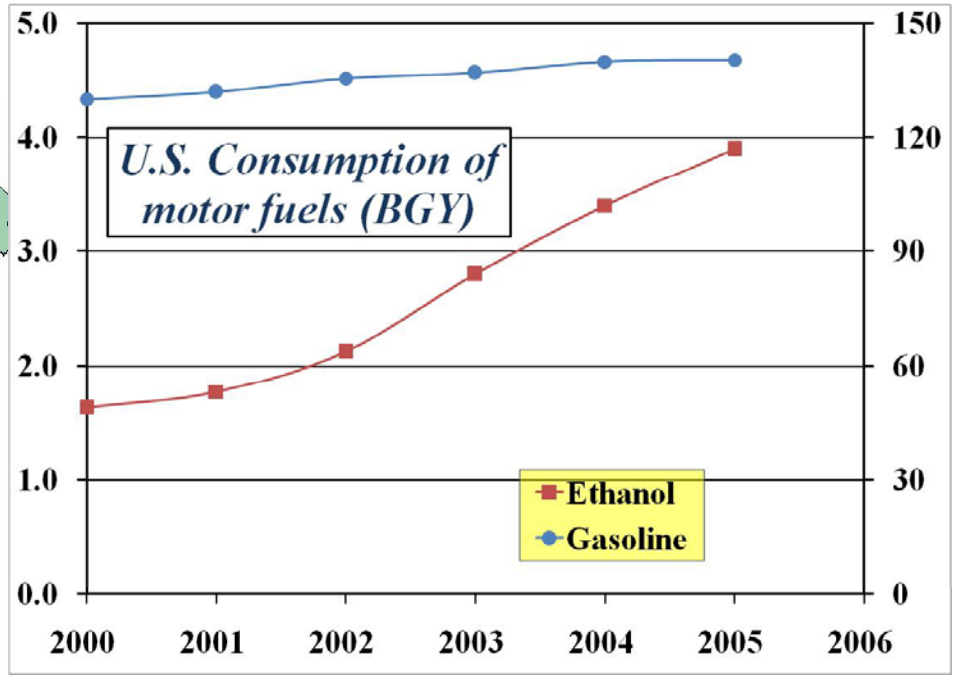
Federal Reserve Bank of Chicago

Seth Snyder, Ph.D.
Chemical and Biological Technology
Argonne National Laboratory

2007 September 24

Ethanol production





Detailed Biofuels Market Report: 9/17/07

Ethanol Plants and Production Capacity [1]	*Units*	*Current* 9/17/07
Current number of Ethanol Production Facilities	Facilities	129
New Ethanol Production Facilities	Facilities	76
Ethanol Production Facility Expansions	Facilities	9
Current ethanol production capacity	MGY	6,843
Planned ethanol production capacity	MGY	6,586
Current & Planned ethanol production capacity	MGY	13,429

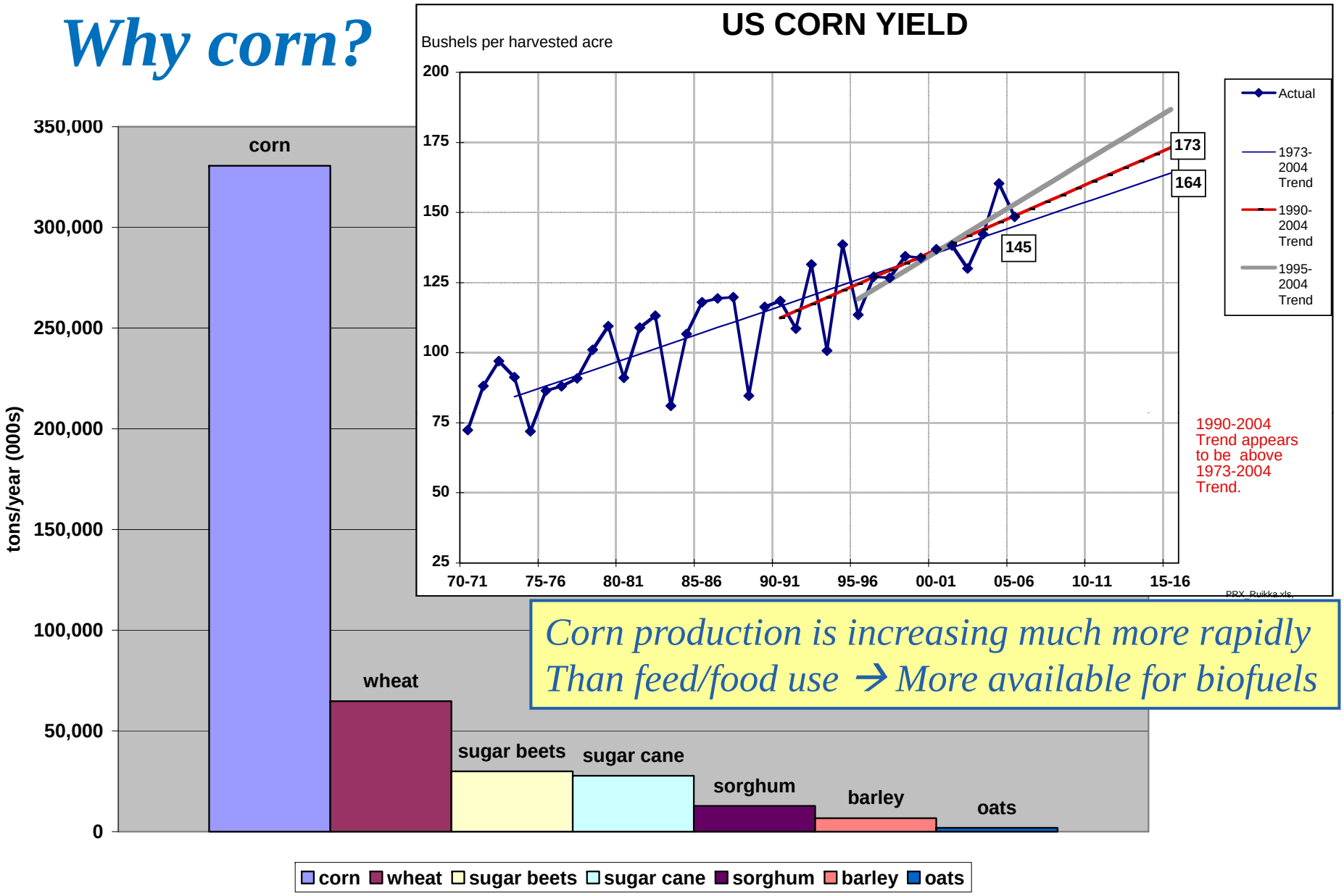
Biofuels Growth

- Current ethanol production = 6.8 BGY
- With expansions = 13.4 BGY
- EPACT 2005 calls for 7.5 BGY by 2012 (Energy Policy Act)
- Presidential and Congressional plans call for upwards of 35 BGY by 2017 “20-in-10”
- The 2006 State of the Union called for “30-in-30”, which is 60 BGY in 2030

- DOE/USDA predict maximum production from corn is 12-16 BGY
- Corn growers predict ~20 BGY with slow growth from there
- Monsanto has reported that corn hybrids we will achieve 33 BGY

- ***Strong need for R&D to achieve national goals!***

Why corn?



Corn production is increasing much more rapidly Than feed/food use → More available for biofuels

The real cost of oil!

- At $60 / barrel crude oil:
- Hydrocarbons are $0.20 /lb or $10 / MM BTU

- Natural gas is has ranged from ~$5 - $15 MM BTU

- At $0.07 captured dextrose costs:
- Hydrocarbons are $0.07 / lb or ~$9 / MM BTU

- If consumers paid the environmental costs of crude oil directly, prices would be $7 - $27/barrel higher. Source: Governor's Ethanol Coalition

Approximate Current Economics

Process	CAPEX ($/annual gal)
CTL (w/CO_2 sequestration) (1)	$4.25-$6.50
Starch ethanol(2)	$1.00-$1.75
Biochemical ethanol(2)	$1.85-$3.00
Thermochemical ethanol(2)	$2.00-$3.00

(1) L. Scully "The Business Case for Coal Gasification with Co-Production, July 2006

(2) 30x30 Vision document and references therein

* Prepared by Dave Dayton (NREL)

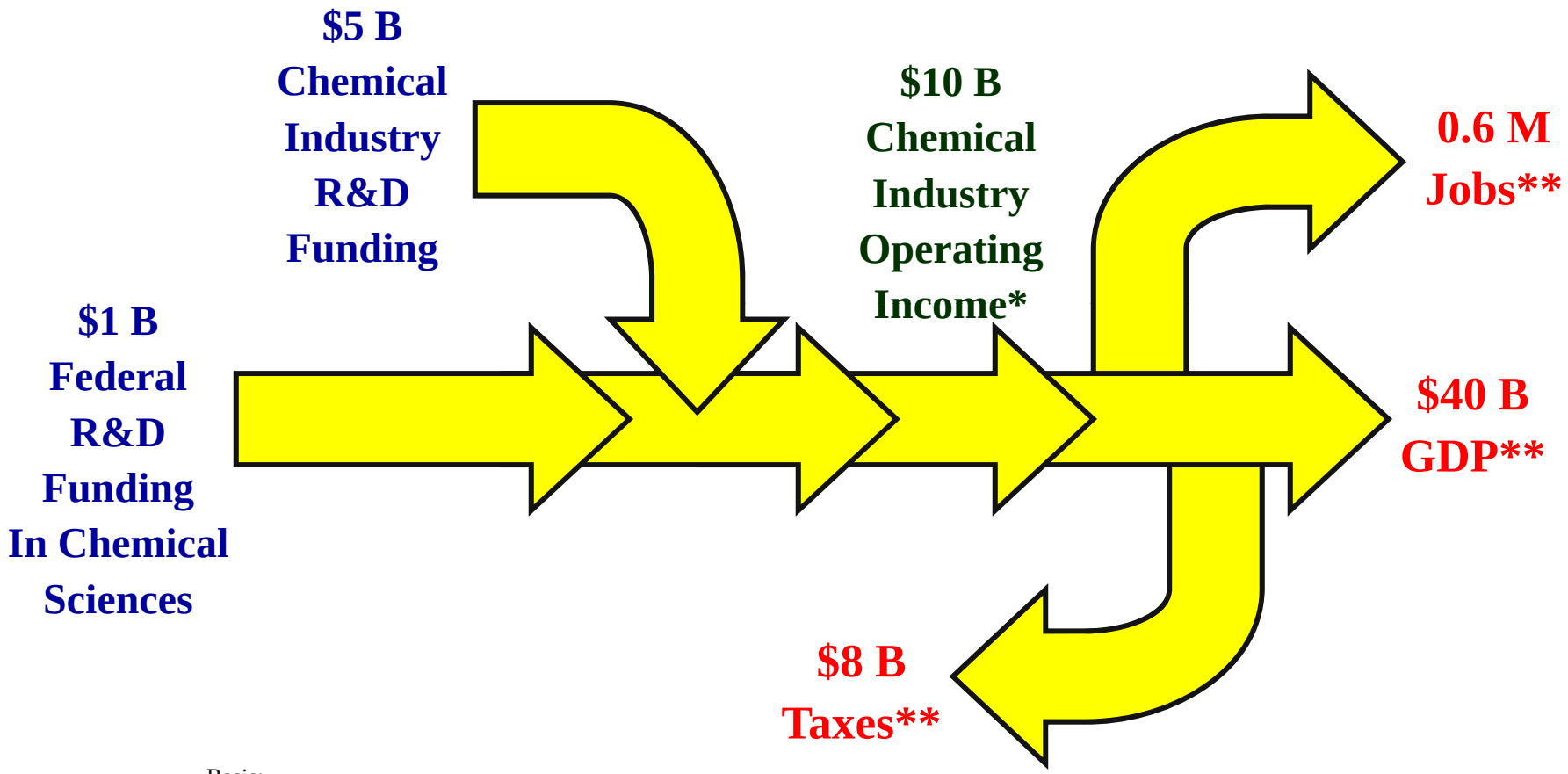
Products: Petroleum vs. Biobased?

- Biobased feedstocks are cheaper than petroleum.
- In petroleum, feedstocks ~75 % of manufacturing costs
- In biobased, feedstocks ~25 % of manufacturing costs
- ***Why?***

Biofuels and biobased products must compete on a cost basis!

- ***What do we need to do?***
  - Better conversions (enzymes, organisms, catalysts)
  - Better separations/product recovery
  - Better process integration (engineering)
  - Large volumes of affordable feedstocks (energy crops)

The Role of R&D: Macroeconomic Implications

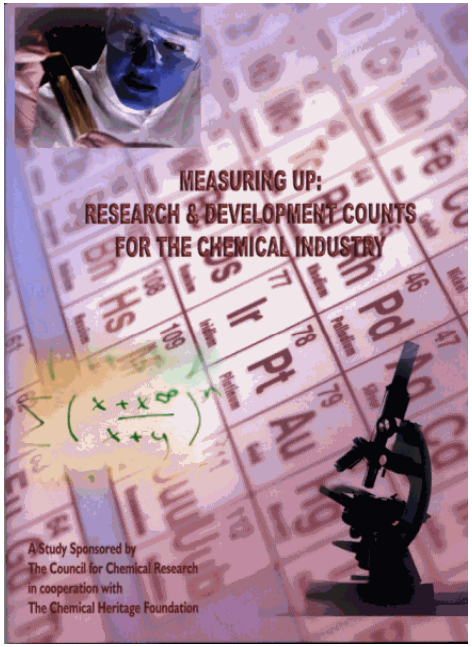


Basis:
*estimated from CCR study
**extrapolated from LANL study by Thayer, et al., April 2005 using REMI economic model

The Council for Chemical Research (www.ccrhq.org)

"Measuring Up: R&D Counts for the Chemical Industry

- $2 Operating income per $1 R&D invested
  - 17% after tax return
- Publicly funded science links highly to chemical patents, 6 citations per patent
- Basic research to patented invention typically takes 13-16 years
- Lag to commercialization from patent is 5+ years
- Overall cycle time of 18-21+ years.



The Council for Chemical Research

Biofuels, Biobased Products, Chemicals

- Commodities that ultimately compete on a cost basis
  - *Lower margins*
- Product differentiation is difficult
- Incentives are required for R&D investment and growth of the industry

- Many of the tools of biotech/biomedical research are transferable to biofuels.
- The value equation is very different

The Federal Cost Share Model

- **Basic Research**
  - 100 % Public
  - NSF, DOE Office of Science, USDA
- **Applied Research**
  - 80 /20 % Public/Private
  - DOE EERE, USDA
- **Development**
  - 50/ 50 % Public/Private
  - DOE EERE
- **Deployment – First of a kind**
  - 20/80 % Public/Private
  - Loan guarantees
  - DOE EERE
- **"N" th plants**
  - 100 % Private

- EERE = Energy Efficiency and Renewable Energy
- EERE is the home of the Office of Biomass

Major funding announcements

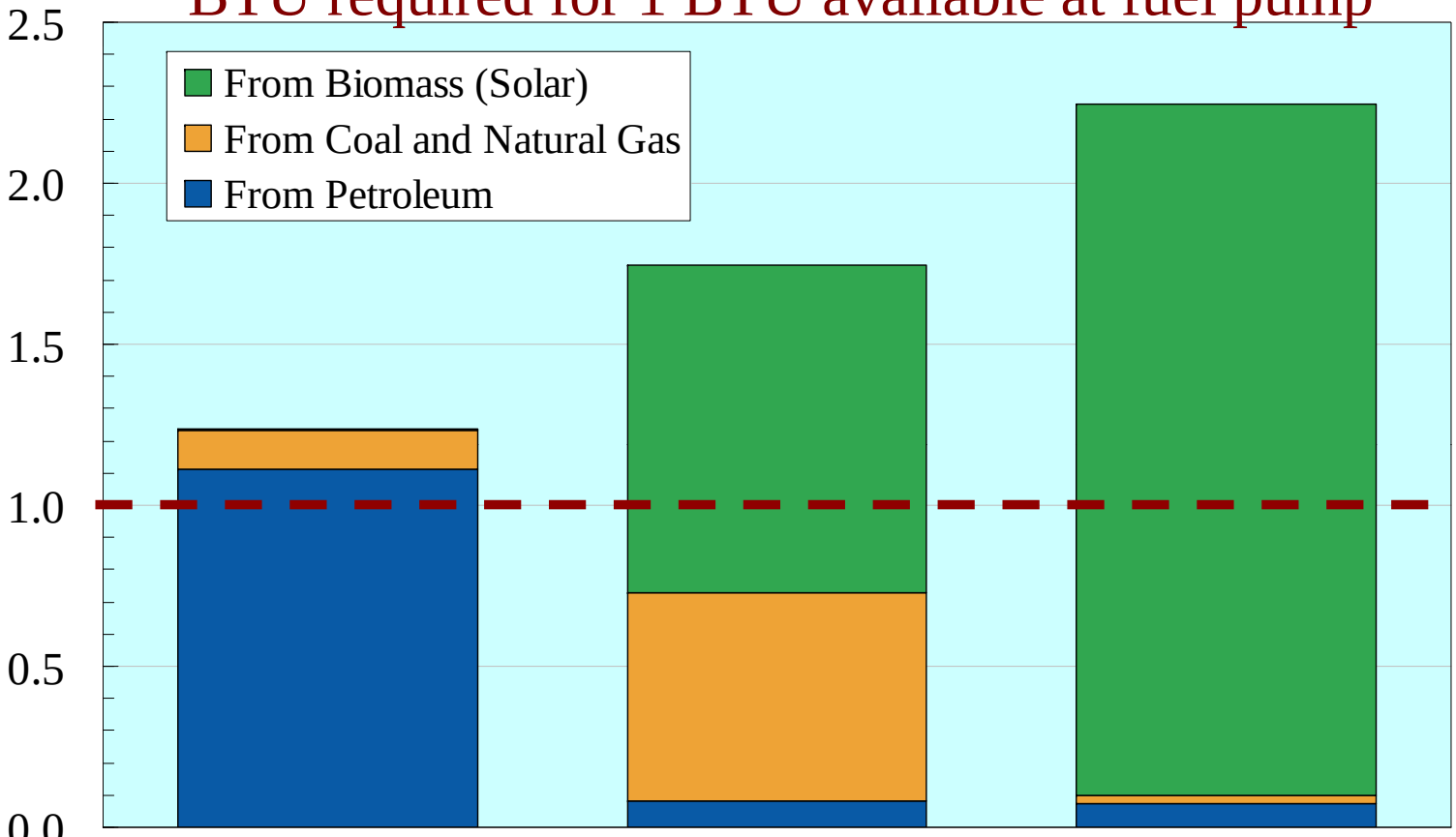
- **2002 DOE EERE – Biobased Products**
  - $20-50 M
  - DuPont (PDO – Serona), Cargill, NatureWorks (PLA), etc.
- **2007 GTL Bioenergy Centers**
  - $125 M - 100 % Federal – optional cost shares included
  - UC Berkeley, Oak Ridge National Lab, U Wisconsin
- **2007 Cellulosic ethanol – "commercial scale"**
  - Up to $385 M federal/ $1.2 B total
  - Abengoa, Alico, Blue Fire, Iogen, Poet (Broin), Range Fuels
  - 11-40 MGY
- **2007 Loan guarantees**
  - To be announced shortly
- **2008 10 % scale biorefineries**
  - Under review
- **Several privately funded centers**
  - BP $500 M Energy Bioenergy Institute
  - UC Berkeley/U Illinois

Biofuels funding issues and opportunities

- **VC Investment**
  - Khosla Ventures – invested in several companies
- **Incentives**
  - $0.51 cents/gallon
  - Extra credit for cellulosic
  - E85 Vehicles - CAFE requirements
- **Potential premiums**
  - CO_2
  - Domestic supply
- **Potential risks**
  - OPEC – price of crude oil
  - Infrastructure does not keep up with production
    - *Fuel distribution – rail, barge, pipeline*
    - *Exceed need for 10 % blends*
    - *E85 availability*

Energy Balances: The Type and Amount of Energy

BTU required for 1 BTU available at fuel pump



Energy in the Fuel

Gasoline	Corn Ethanol	Cellulosic Ethanol
Fossil BTU = 1.23	Fossil BTU = 0.74	Fossil BTU < 0.1
Petroleum BTU = 1.1	Petroleum BTU = 0.1	Petroleum BTU = 0.1
CO_2 reduction* = 0 %	CO_2 reduction*= 20 %	CO_2 reduction* = 85 %

* vs. gasoline

What will the feedstocks be?

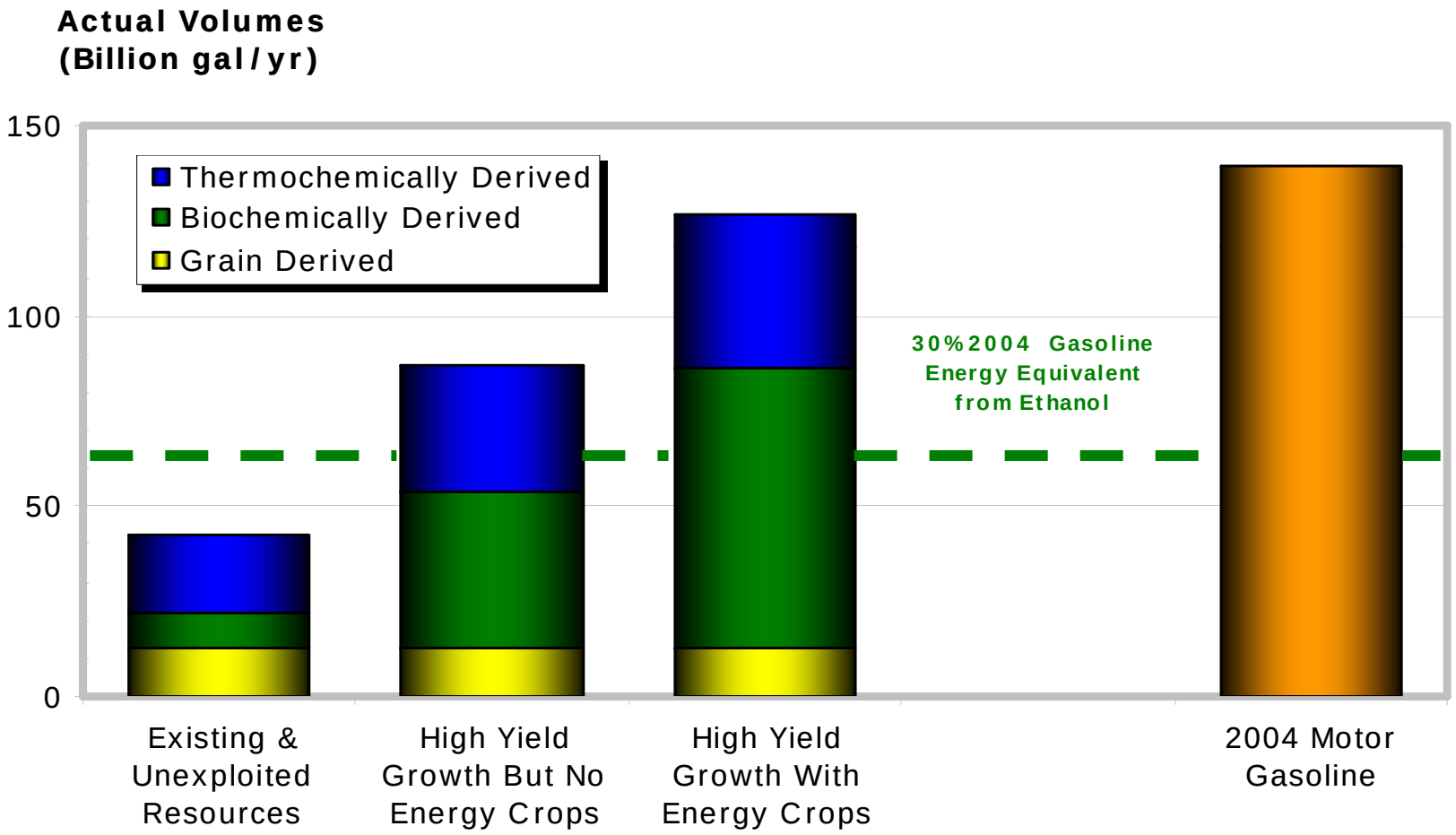
- **Now**
  - **Corn starch** → *ethanol (U.S.)*
  - **Sugar cane** → *ethanol (Brazil)*
  - **Rapeseed** (canola) → *biodiesel (Europe)*
  - **Forest residues** → *heat & power (No. America and Europe)*
- **Mid term**
  - **Corn starch** – *continued growth for 1-2 decades*
  - **Agricultural residues**: *Corn fiber, corn stover, etc.*
    - Cellulase R&D
  - **Forest Products**: *Paper and pulp mills, black liquor, forest residues → syngas*
  - **Oil crops**: *soybean, canola (upper Midwest), tropical oils*
- **Longer term**
  - **Energy crops** – *poplar trees, switch grass, etc.*
  - Growth on marginal lands → R&D opportunity
    - *See* "Billion-ton study": *http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf*

How does nature degrade biomass?

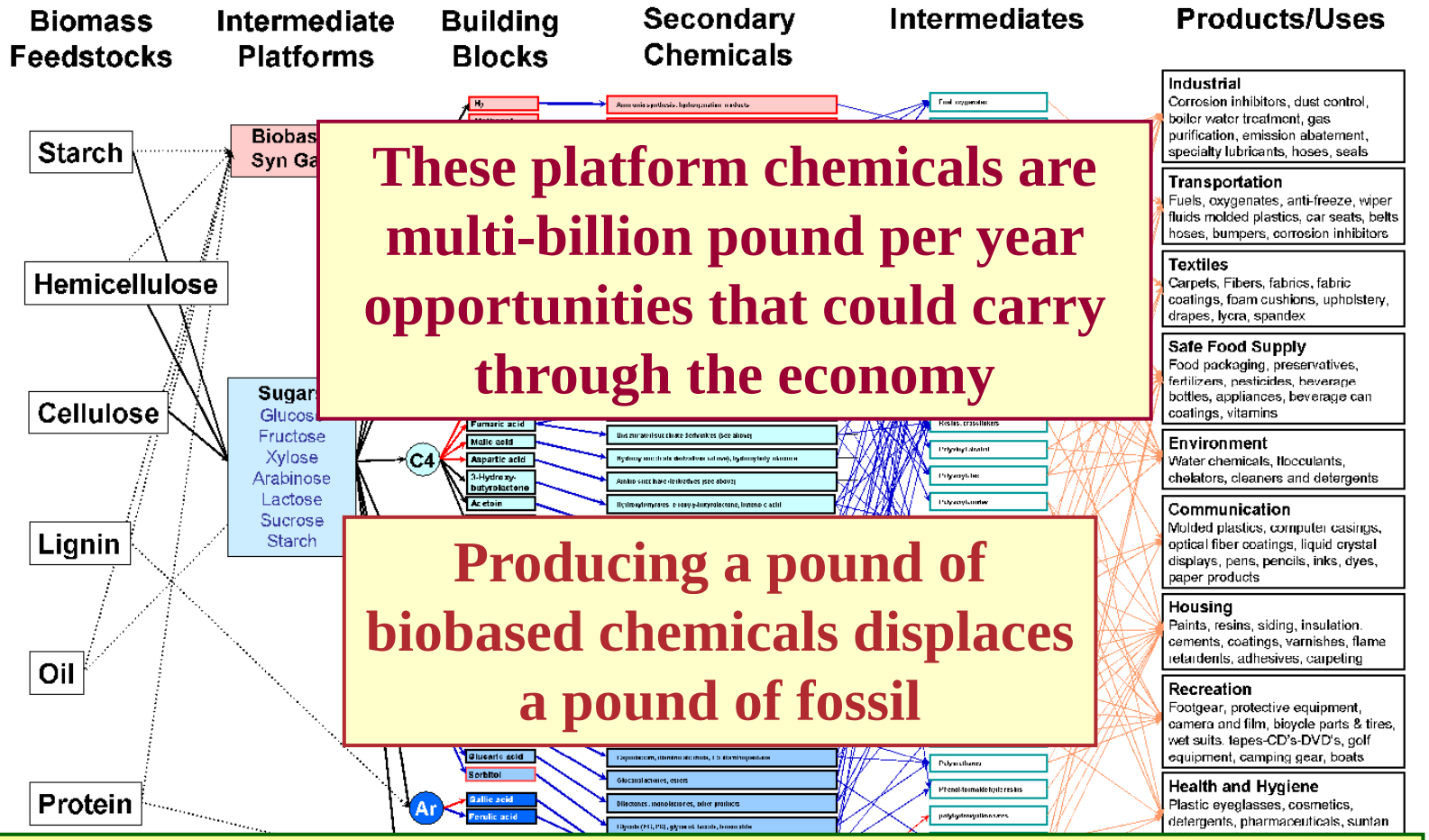
- Starch/sugars
  - ***Its food*** ← ***Glucose fermentations***
- Biomass – lignin/cellulose/hemicellulose
  - ***Fungal degradation – slow*** ← ***Biochemical conversion***
  - ***Combustion - fast*** ← ***Thermochemical conversion***

DOE EERE biomass model

- Biochemical & Thermochemical - *Need both*



DOE Office of Biomass - Products Analysis

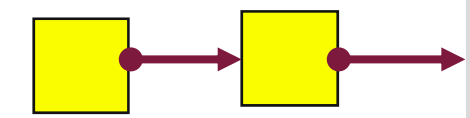


These platform chemicals are multi-billion pound per year opportunities that could carry through the economy

Producing a pound of biobased chemicals displaces a pound of fossil

- **3-6 Carbon organic acids (mono- and di-carboxylic acids)**
- **Neutral sugar alcohols (e.g., sorbitol)**

Opportunities for Succinic Acid Derivatives



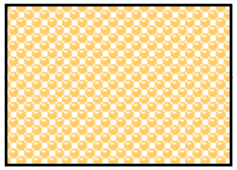
Sugars

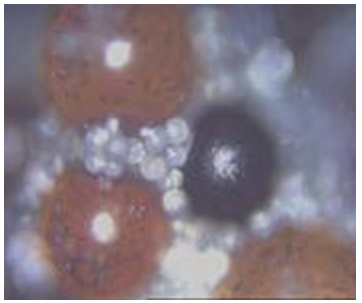
Succinic Acid - 6 MM lbs

- **Tetrahydrofuran (THF) - 255MM lbs**
- **Maleic Anhydride - 450MM lbs**
- **Fumaric Acid - 35MM lbs**
- **Malic Acid - 20MM lbs**
- **Dibasic Esters - 50MM lbs**
- **1,4-butanediol (BDO) - 150MM lbs**
- **Gamma-butyrolactone (GBL) - 105MM lbs**
- **Deicers – 10-100MM lbs**
- ***n*-methyl-2-pyrrolidinone (NMP) - 80MM lbs**
- **4,4-polyesters**

Separative Bioreactor

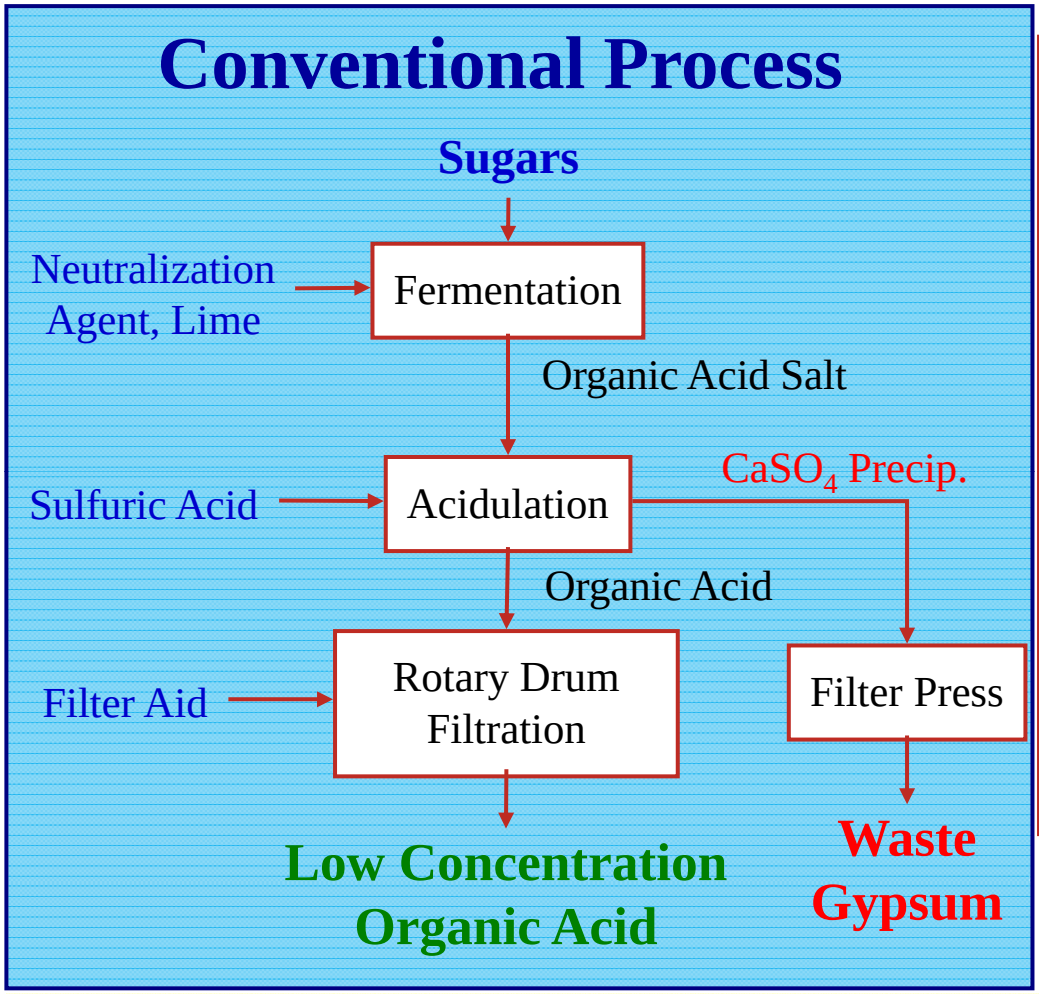
Cells or enzymes are immobilized in the porous resin wafer

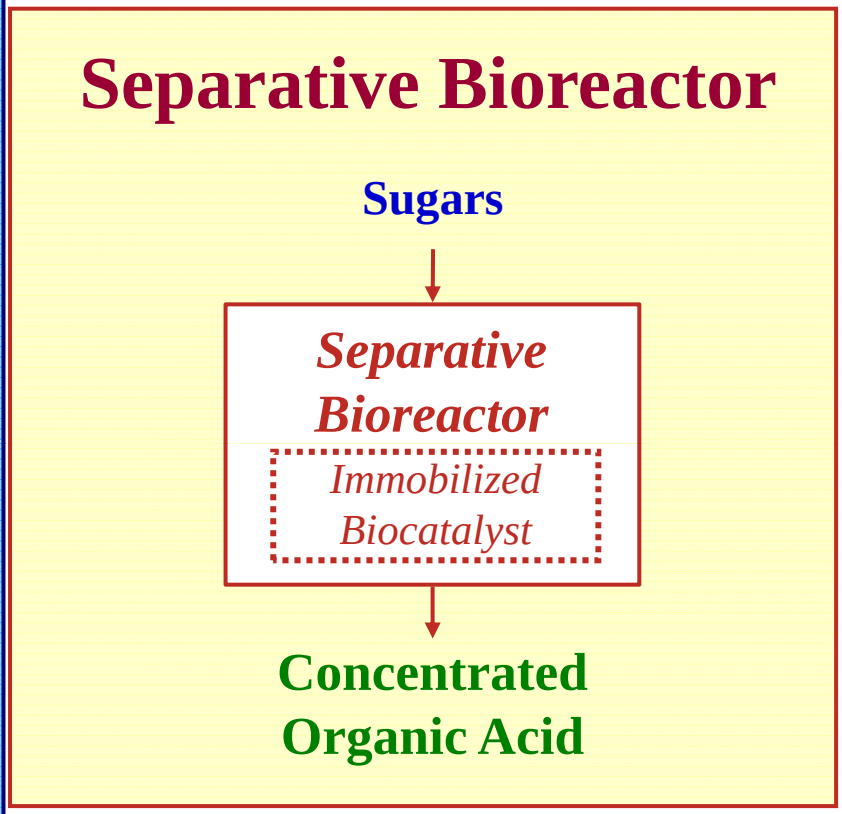




Argonne controls IP (key IP is in the background)

Biobased Chemicals



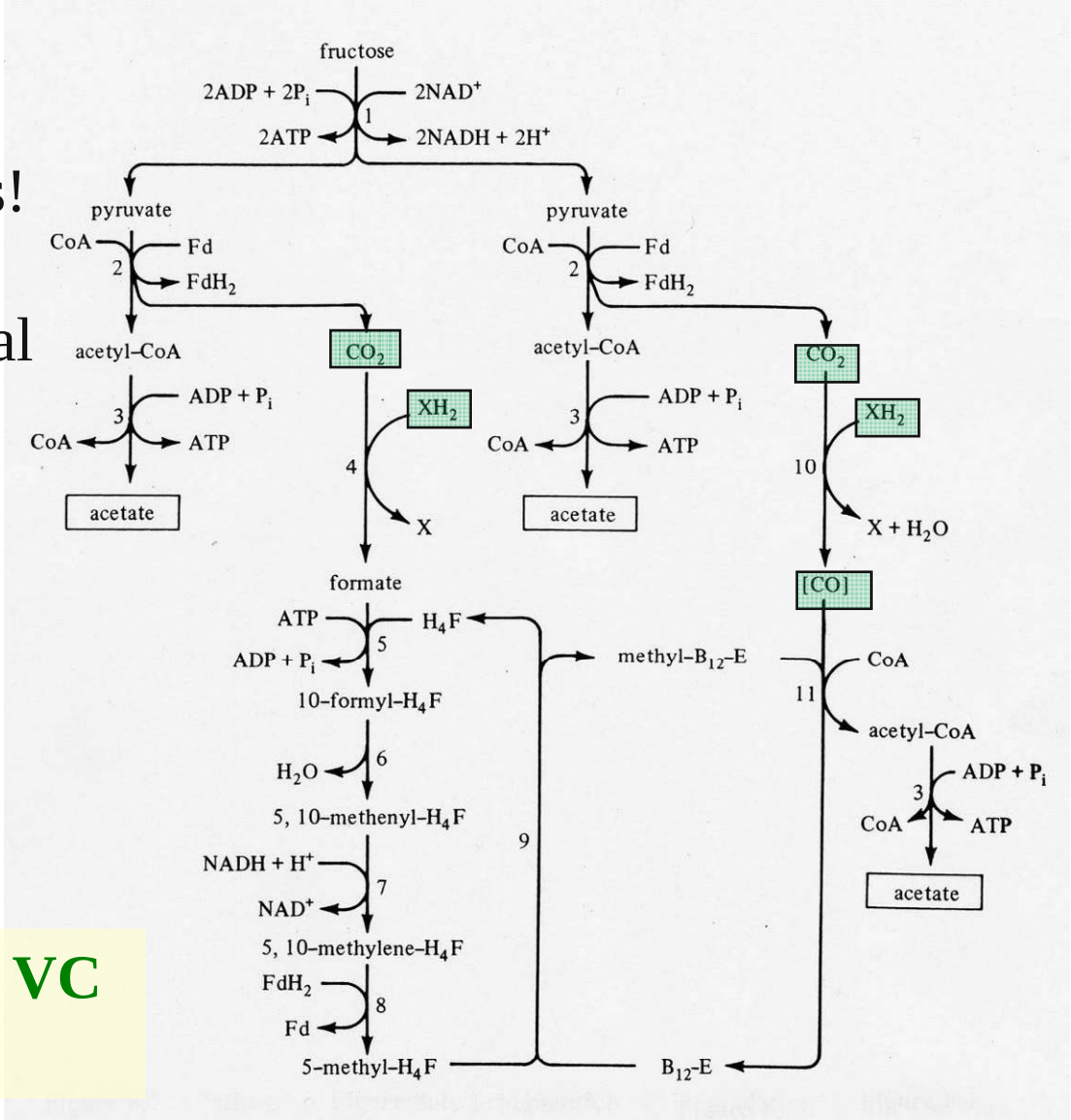


- ***Costs competitive with petrochemicals!***

- **Partnership with ADM**
- **Integrates bioprocessing and separations**

Syngas fermentations?

- $H_2/CO/CO_2$
- Yes you can ferment syngas!
- Anaerobic bacteria
- Some of the oldest biological mechanisms in existence



Technical barriers

Organism development

Gas/liquid mass transfer

Product titer

- **Partnerships with BP and VC funded companies**

Creating our Biobased Future

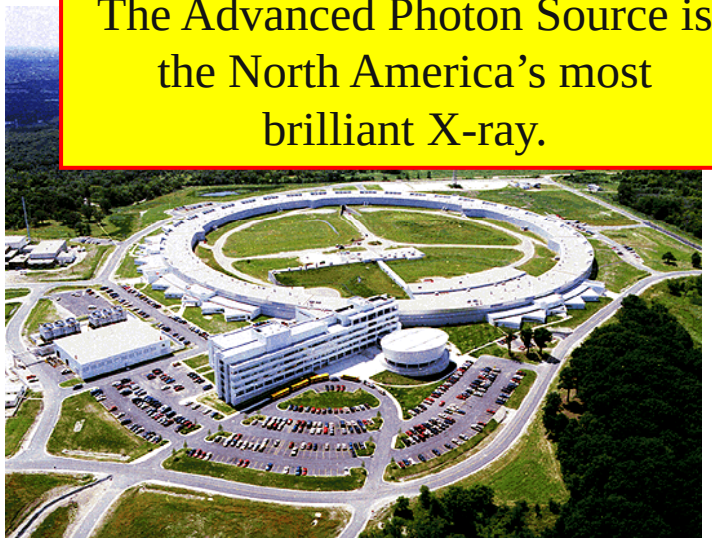
- **It will take the biochemical *and* thermochemical routes**
  - Feedstock and regional emphasis
  - Produce every available fuel, chemical, material
  - There will be multiple commercial opportunities
- **Maximize product output will minimizing impact/use**
  - ***Land***
  - ***Water***
  - ***Emissions***
  - ***Infrastructure***
  - ***Capital***
- **Don't overlook**
  - CO_2
  - Sustainability
- ***To create the biobased future will take biologists, chemists, and engineers!***

Argonne National Laboratory

America's first national laboratory

- Chartered in 1946 from Enrico Fermi's work on the Manhattan Project.
- Operating budget of ~$500 million
- As of 2006, Argonne is operated by the UChicago-Argonne LLC
- 25 miles southwest of the Loop

The Advanced Photon Source is the North America's most brilliant X-ray.



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The white deer are native to Northern Africa and Europe and were a gift to Gustav Freund, the estate owner in the 1930's.