Cellulosic Fuels Development

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The Energy Bioscience Institute

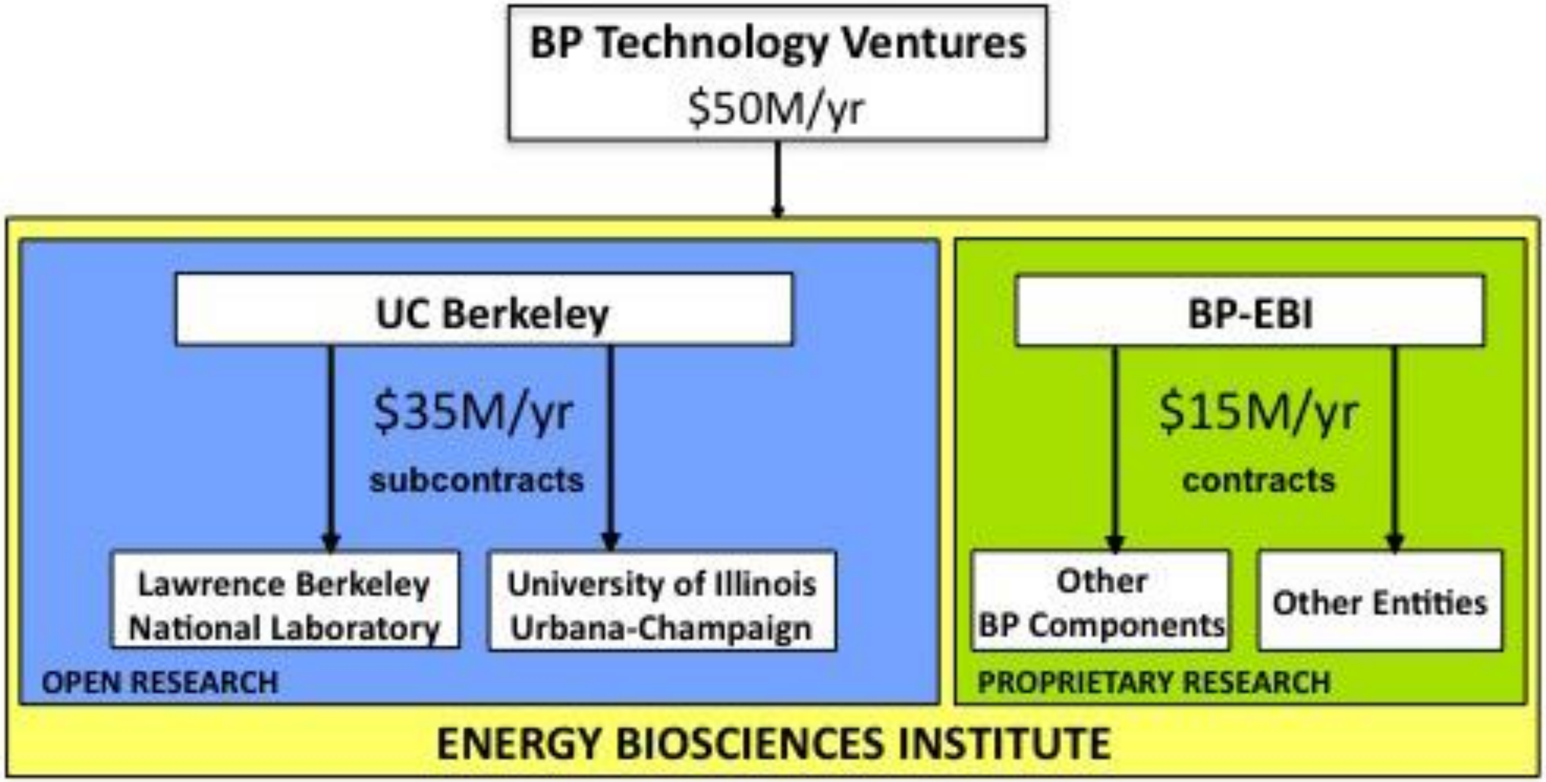
- **Partnership between UCB, UIUC, LBNL, and BP**
- **BP committed $500M over 10 years**
- **Motivations**
  - Climate change mitigation
  - Security of energy supply
  - Increasing energy demands in future decades
  - Renewable Fuel Standard (Energy Independence and Security Act of 2007) – 16 billion gallons/year by 2022 from cellulosics
- **Mission**
  - Apply biological knowledge to the energy sector
  - Find total system solutions to biofuels that are cost effective and sustainable
  - Educate scientists and engineers across the relevant disciplines

Facilities

UC Berkeley

UI Urbana-Champaign

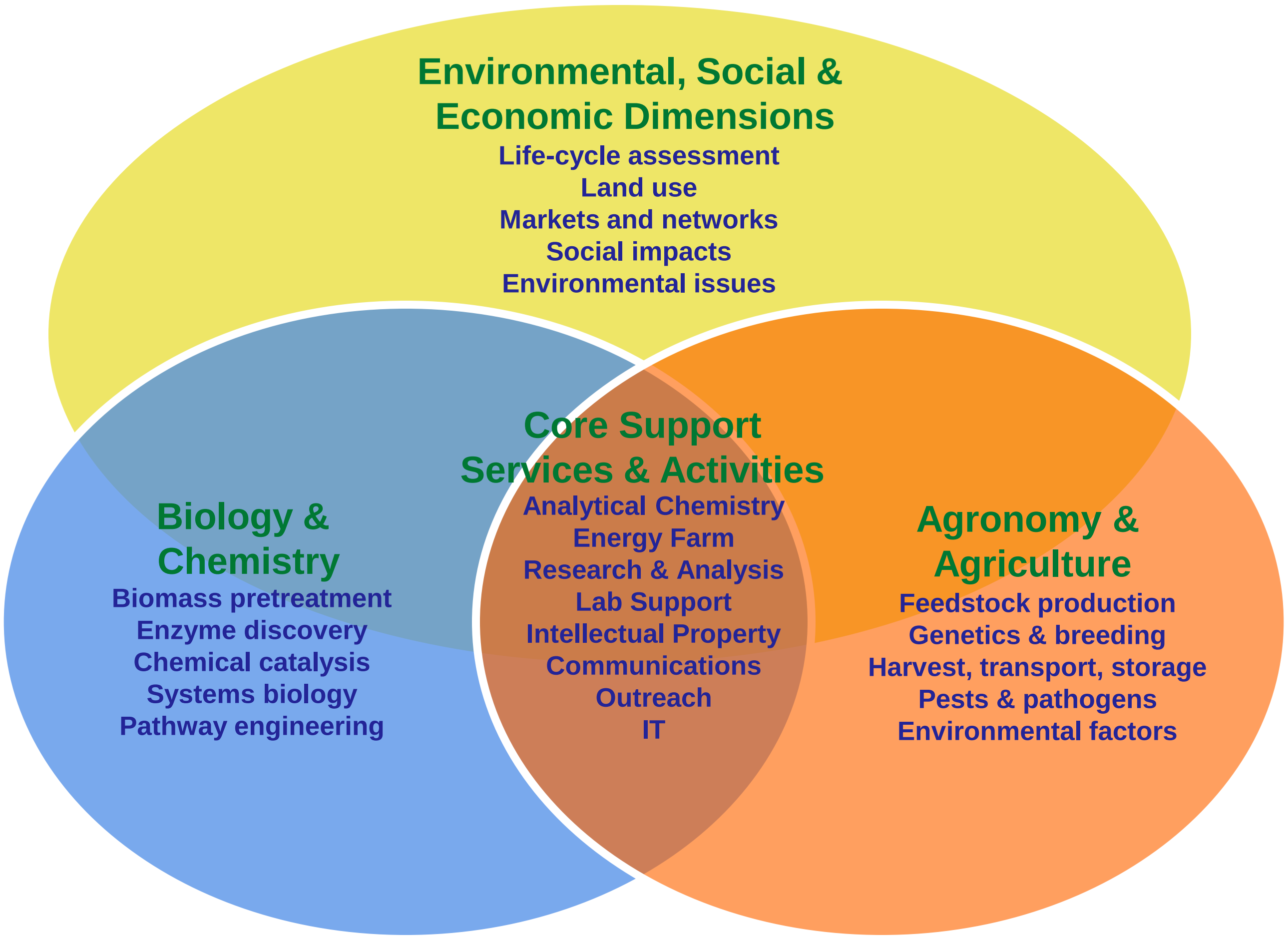
EBI Funding


BP Technology Ventures
$50M/yr
UC Berkeley
$35M/yr
subcontracts
Lawrence Berkeley National Laboratory
University of Illinois Urbana-Champaign
OPEN RESEARCH
BP-EBI
$15M/yr
contracts
Other BP Components
Other Entities
PROPRIETARY RESEARCH
ENERGY BIOSCIENCES INSTITUTE

Strategic Initiatives for Research

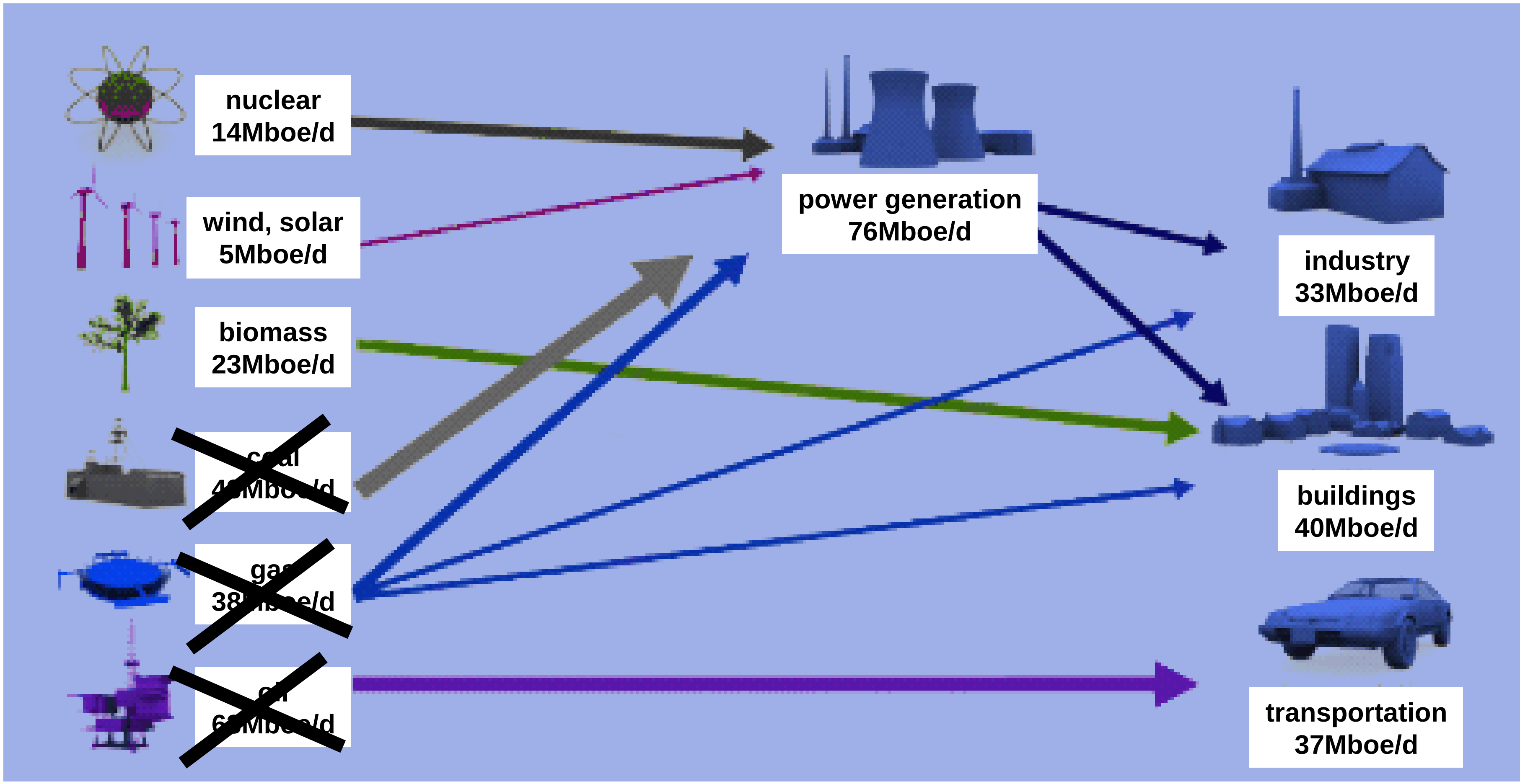
- **Lignocellulosic biofuels**
  - Feedstocks
  - Deconstruction/Depolymerization
  - Biofuels production
  - Environmental, social and economic dimensions
- **Fossil fuel microbiology**
  - Microbially-enhanced hydrocarbon recovery
  - Control of reservoir biosouring

Whole-system approach to biofuels



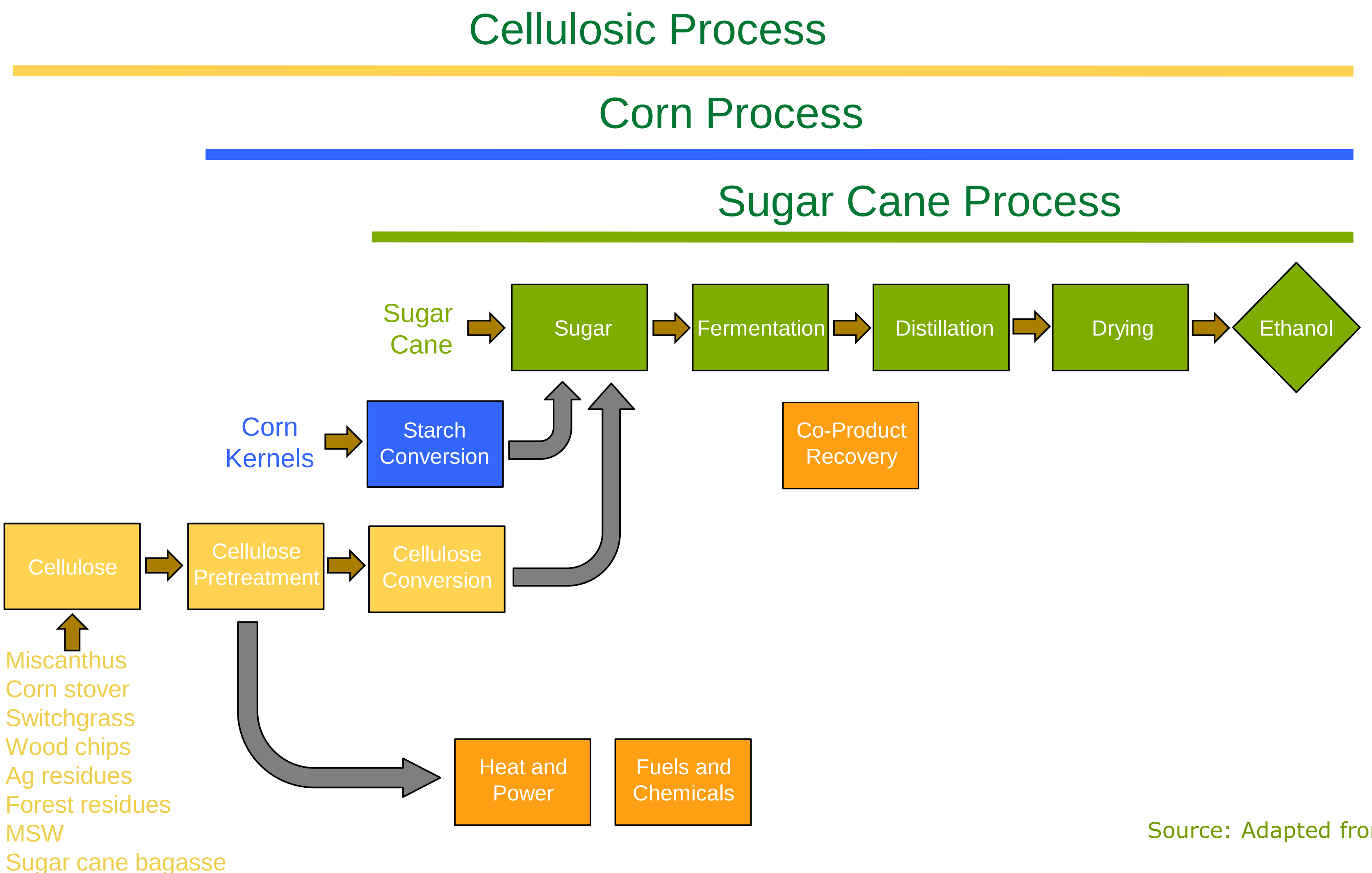
Energy sources and uses

Not all energy is the same



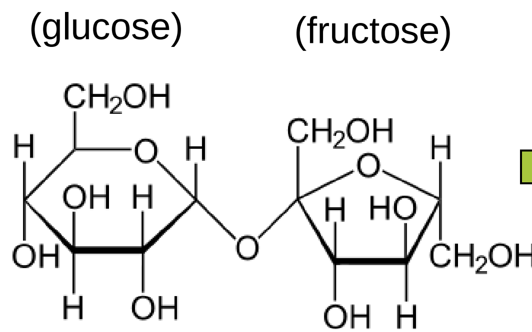
Source: IEA WEO

Ethanol Production



Source: Adapted from B. Dale

Sucrose from sugar cane



sucrose

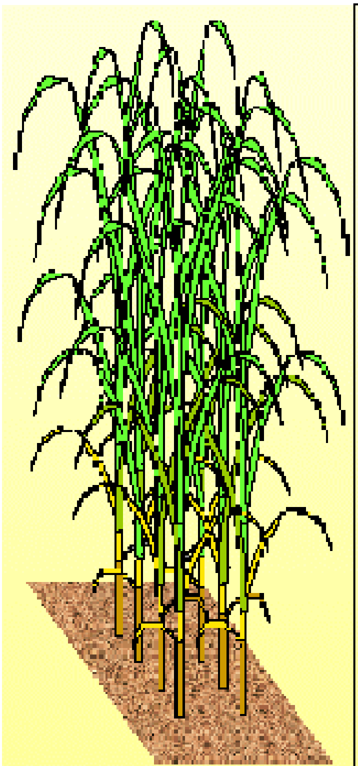
sugar
or
ethanol

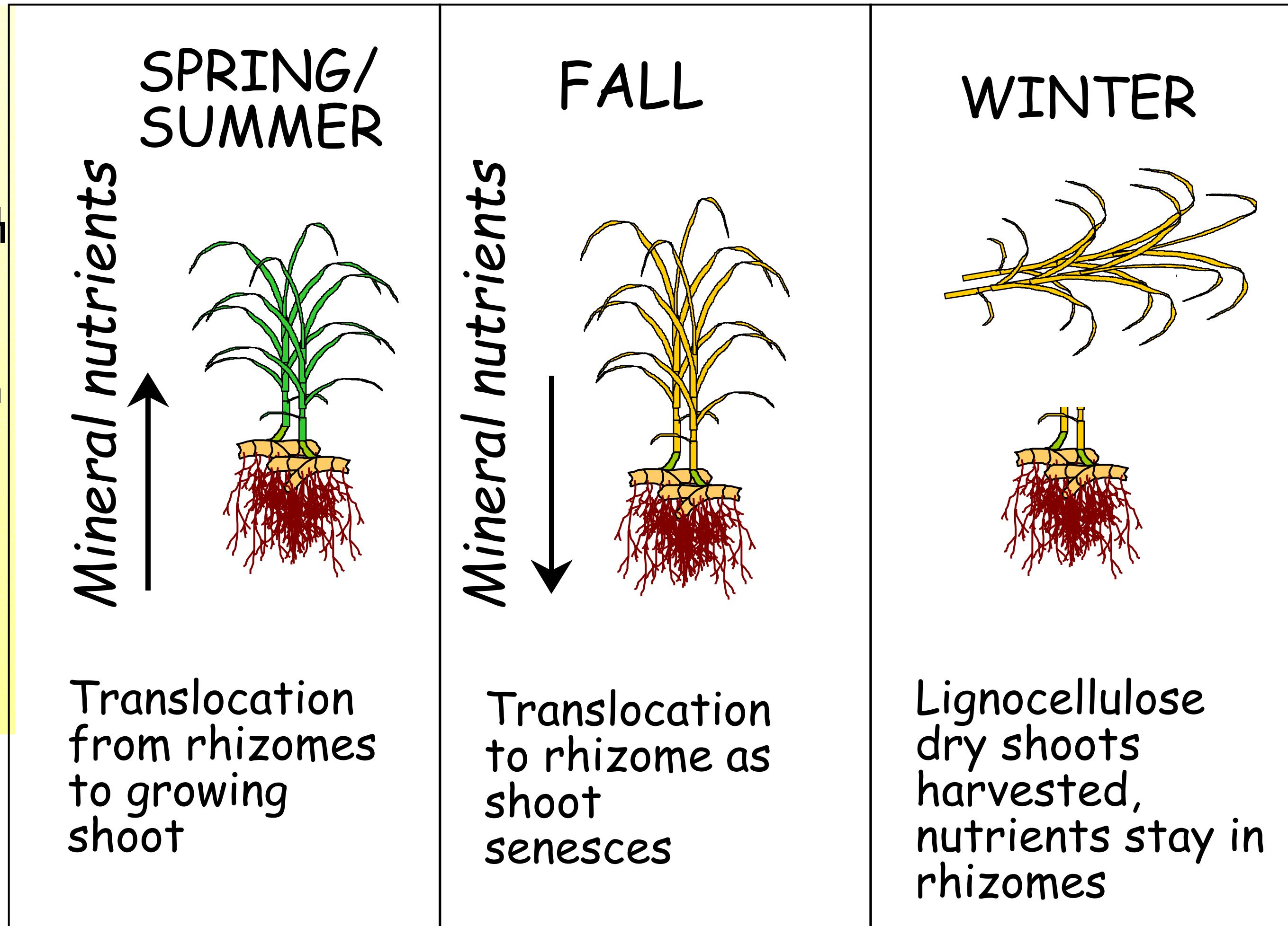
bagasse

electricity

cellulosic ethanol

Energy Grasses - *Miscanthus*



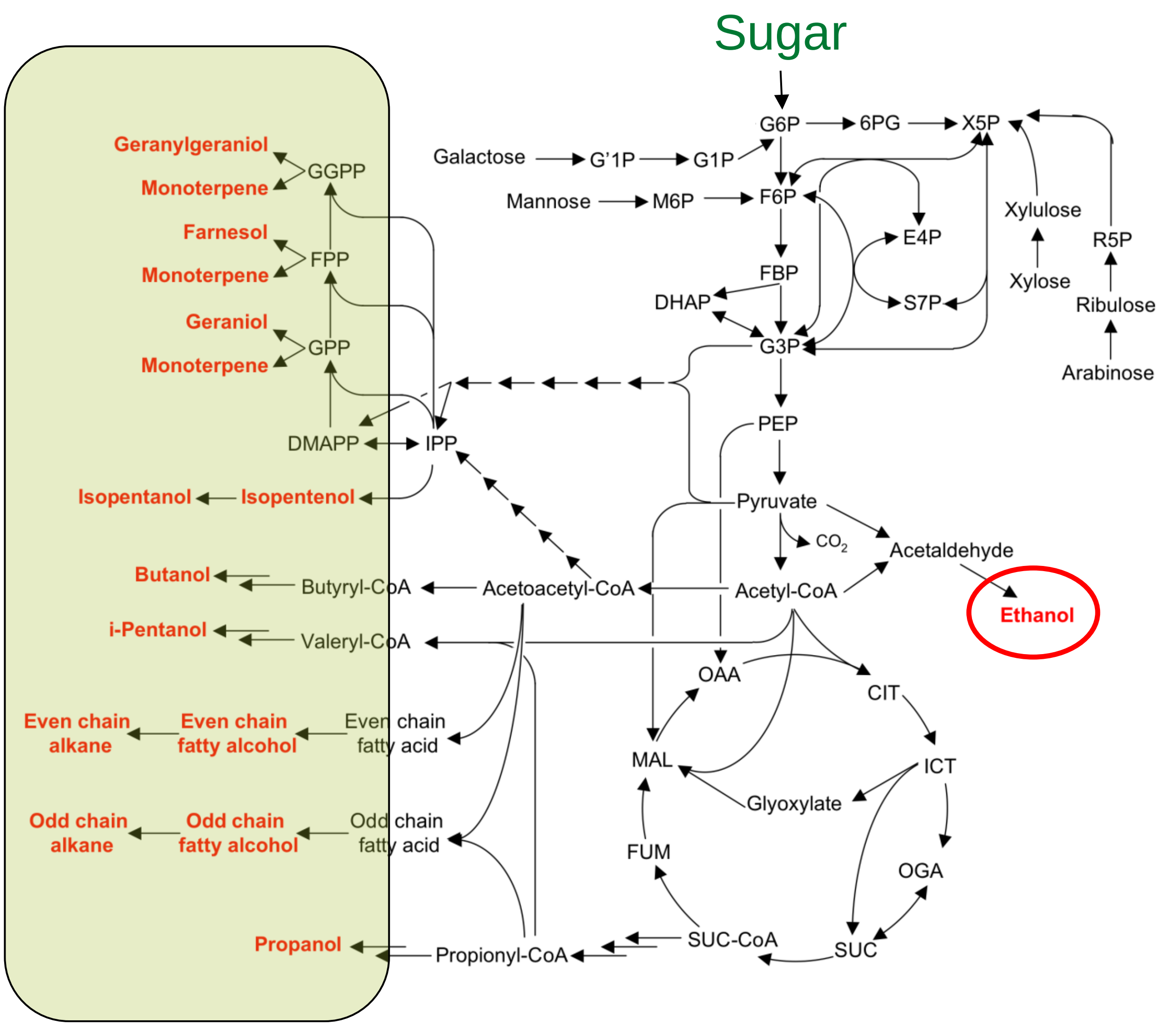


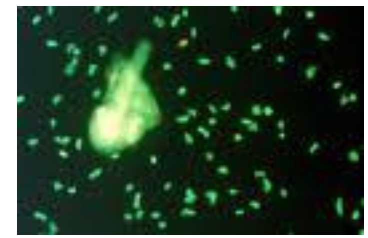
Courtesy of Steve Long, et al

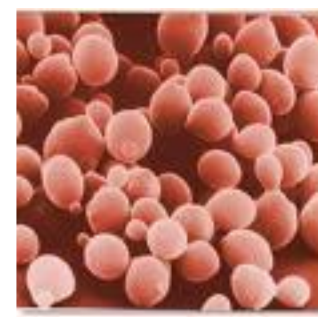
Agave in Semi-arid Regions

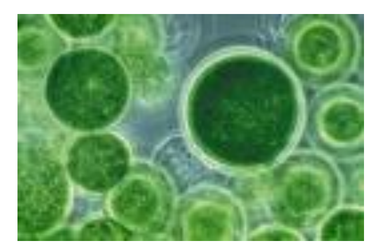
Borland et al. (2009) J. Exp. Bot. doi:10.1093/jxb/erp118

Biofuel Production

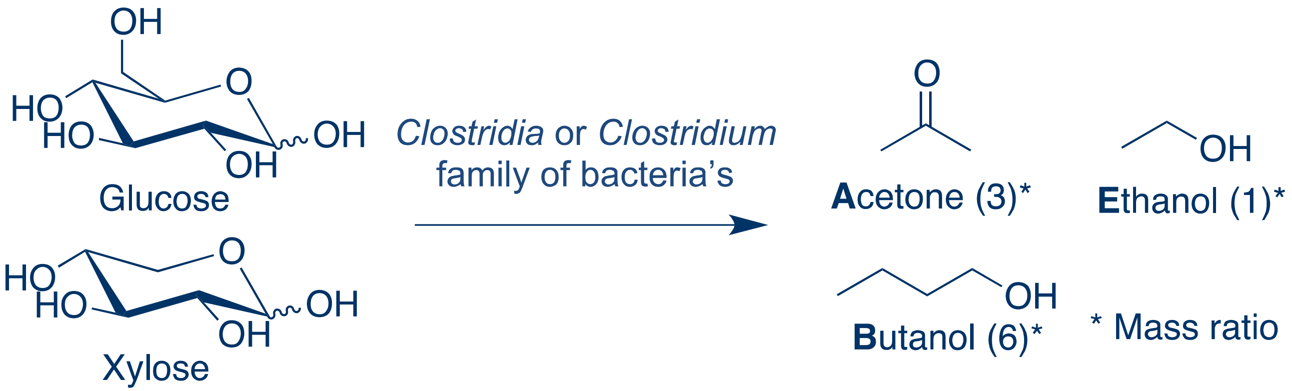






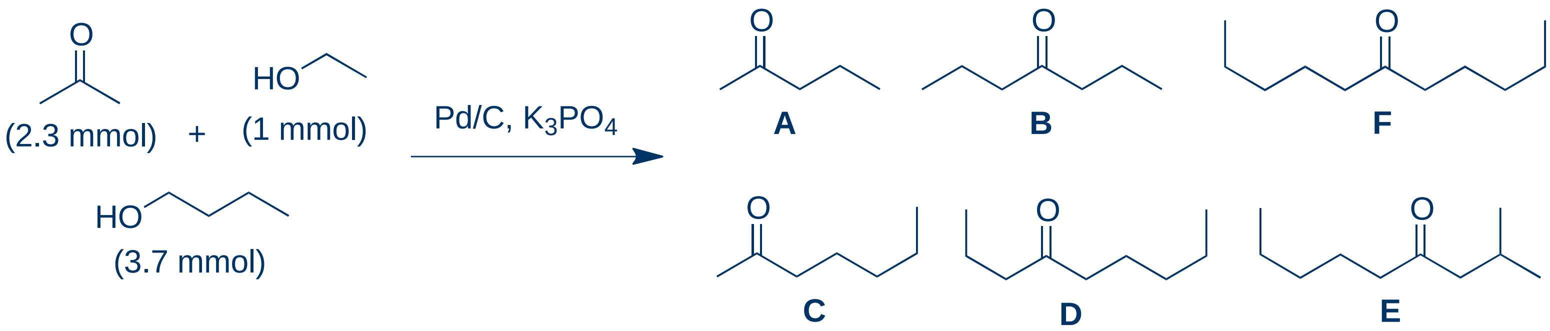


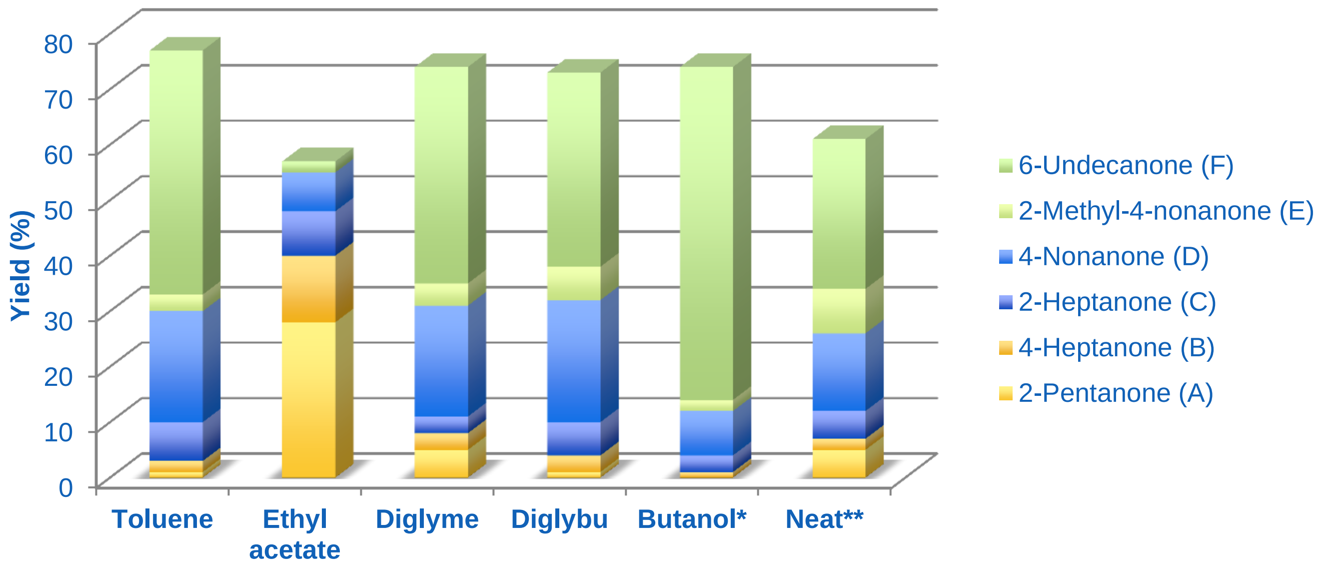
ABE fermentation



Oldest fermentation processes used for the commercial production of a chemical from carbohydrates and one of the efficient methods for the production of acetone and butanol from biomass-derived carbohydrates

Combine biology and chemistry





Pd/C (0.21 mol%), K_3PO_4 (98 mol%), Solvent (1.5 mL), 145 ° C, 20 h; * 32 mol% of K_3PO_4; ** two fold of the original conditions with same amount of Pd/C (0.1 mol%) Yields were determined by GC.

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Lessons learned…

- **This is not biotechnology**
  - Larger scale, lower value
- **Global industry**
  - Regional supply issues
  - Policies and regulations
- **Investment time frames are longer than anticipated**

Mandates didn't work

NEW RENEWABLE FUELS STANDARD SCHEDULE

Year	Renew-able Biofuel	Advanced Biofuel	Cellulosic Biofuel	Biomass-based Diesel	Undiffer-entiated Advanced Biofuel	Total RFS
2008	9.0					9.0
2009	10.5	.6		.5	0.1	11.1
2010	12	.95	.1	.65	0.2	12.95
2011	12.6	1.35	.25	.8	0.3	13.95
2012	13.2	2	.5	1	0.5	15.2
2013	13.8	2.75	1		1.75	16.55
2014	14.4	3.75	1.75		2	18.15
2015	15	5.5	3		2.5	20.5
2016	15	7.25	4.25		3.0	22.25
2017	15	9	5.5		3.5	24
2018	15	11	7		4.0	26
2019	15	13	8.5		4.5	28
2020	15	15	10.5		4.5	30
2021	15	18	13.5		4.5	33
2022	15	21	16		5	36

- Original LC target was 1.75 billion gallons by 2014
- LC estimated capacity for 2014 ~50 million gallons

Scale-up

What's the problem with scale-up?

- Efficient use of capital
- Full process integration
- Mechanical operations
- Recycle streams
- Impurities and contamination
- Stability over time
- Process robustness
- Time, money and risk

Time and Money

Time and Money

- Basic lab work: 5 M$, 3 years
- Design build and run pilot plant: 15 M$, 3 years
- Design build and run Demo plant: 100 M$, 3 years
- Design build and run first commercial plant: 500 M$, 3 years
- Many times there are re-cycles
- Linear progress takes 12 years till commercial rollout!

Conclusions

Conclusions

- Still many competing forces and pathways
- Potential for LC biofuels continues to be big
- A matter of when we will get there, not if
- Significant science and innovation still needed
- Process scale up is
  - Inherently risky
  - Time consuming
  - Expensive
  - Innovation cannot be mandated
- Business success requires scale up **<u>and</u>** a commercially winning proposition

LC Capacity in the US

- Abengoa (Kansas)
  - Investment: $500M
  - Capacity: 25 Mgal/year
- POET-DSM (Iowa)
  - Investment: $250M
  - Capacity: 25 Mgal/year
- QCCP-ACE (Iowa)
  - Investment: $9M
  - Capacity: 3.75 Mgal/year

Improvements are possible

Abengoa (Hugoton, Kansas)

•using agricultural (stover) waste

•projected price for LC EtOH - $2.00-$2.30/gal by end of 2015

•contrast to Corn EtOH at $2.31 and gasoline at $2.23

•current feedstock costs:

- corn at $2/gal,
- ag waste at $0.70/gal

•current enzyme costs

- $1.40/gal – dropping to $0.50 by 2016 (Dyadic International)

Environmental, social and economic dimensions

- Environmental
  - GHGs, water use, land use, ecosystem impacts/services
- Societal
  - Food and fuel, employment, quality of life
- Economics
  - Micro: farmers and biorefineries (markets and networks, investments)
  - Macro: national and international levels (trade)
- Law and Policy
  - Federal and state regulations and mandates, subsidies, taxes

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Need continuous process