jbei
Joint BioEnergy Institute

Synthetic Biology for Bio-based Chemicals

Nathan J. Hillson
njhillson@lbl.gov

BBEST Conference
Round Table 4: BRASKEM Bio-based Chemicals
August 18, 2011

U.S. DEPARTMENT OF ENERGY Office of Science

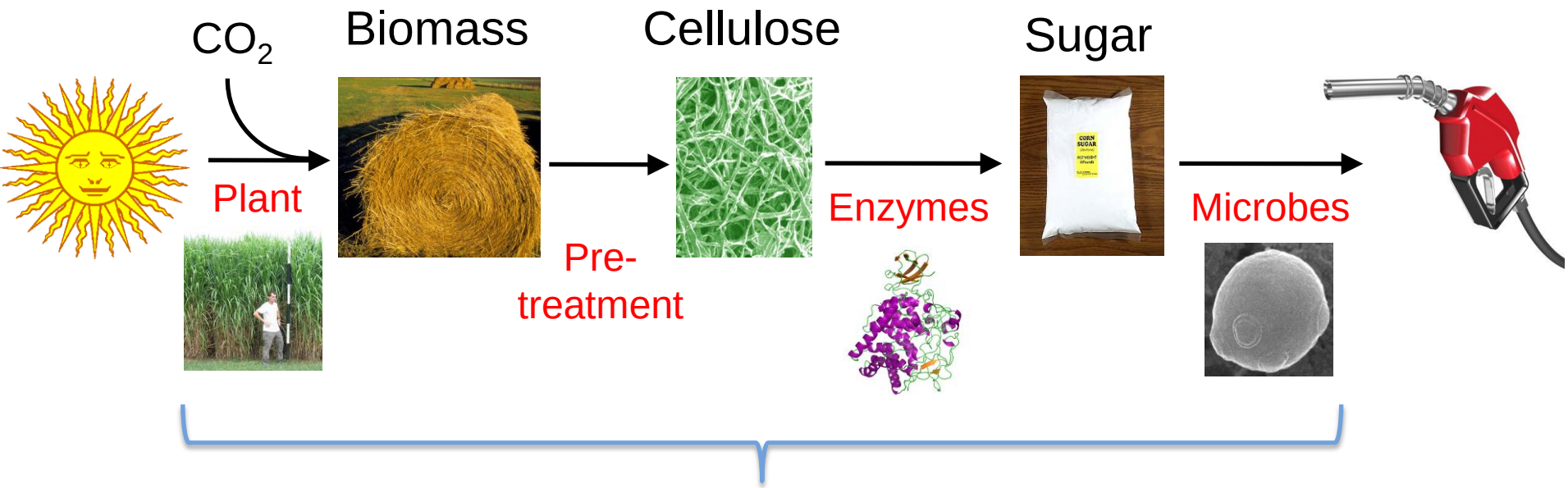
Braskem directives for this talk

- What are the possibilities/constraints for the Synthetic Biology approach?
- How does this approach complement Chemical Conversion and Gasification?
- What are the commercialization prospects? Is it economically feasible?
- How will these commercial applications change over the short/medium/long term?

Outline

- Context – brief introduction to JBEI
- Examples of Synthetic Biology applied to bio-based chemicals
  - Plant (feedstock) engineering
    - Lignin structure (towards aromatics)
    - Targeted lignin expression (greater sugar density)
  - Microbial engineering
    - Access to many different metabolic pathways (custom products)
    - Emerging technologies (BioCAD/CAM, rapid strain construction)
- Commercialization prospects
  - Techo-Economic analysis
  - Commercialization of JBEI technologies

Brief introduction to JBEI



- JBEI
  - is ***not*** a company
  - is a government-funded institute dedicated to basic science
  - is focused on biofuels, ***not*** bio-based chemicals
  - develops technologies that can be transferred to the biofuels and bio-based chemicals industries

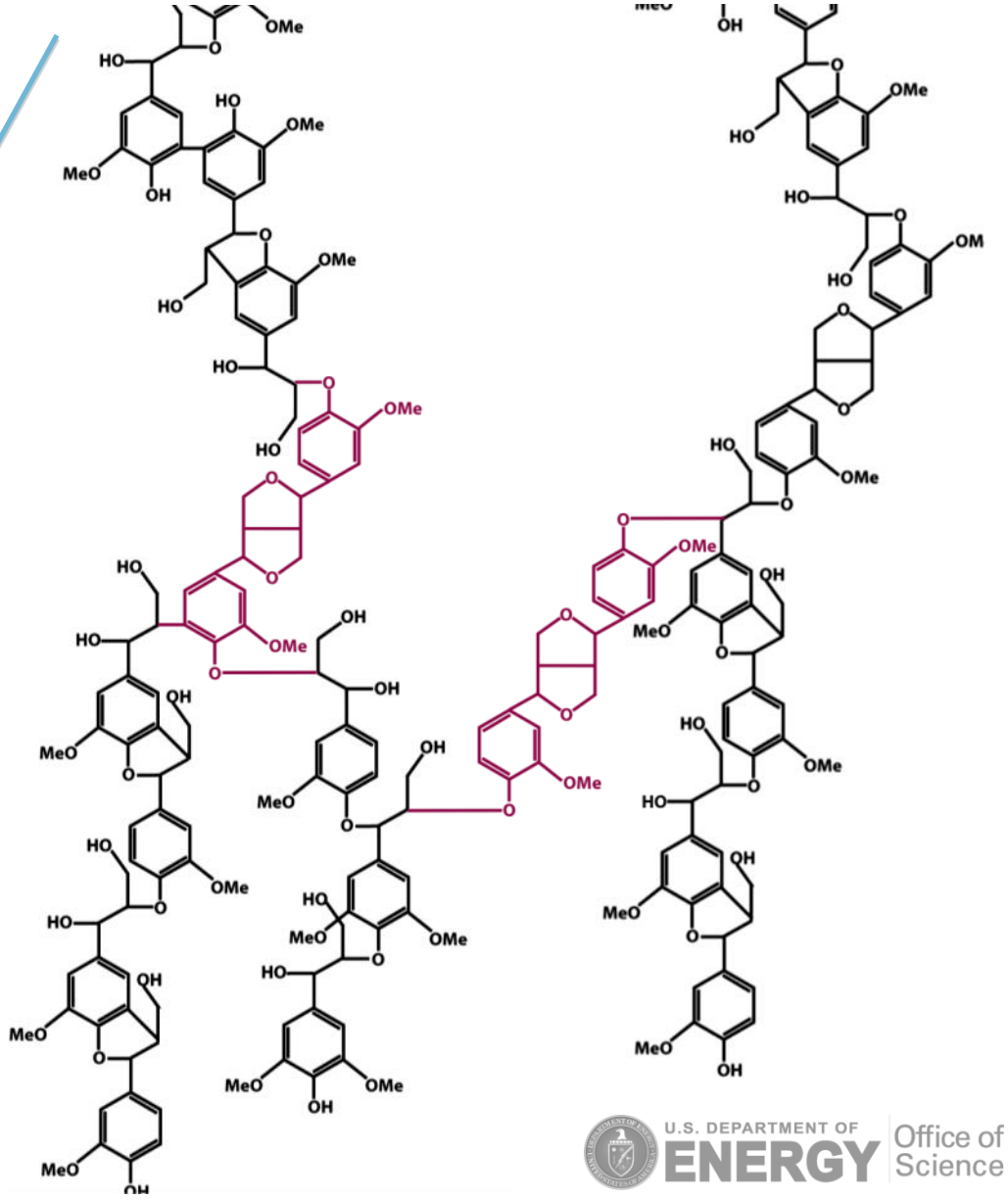
jbei Joint BioEnergy Institute

Outline

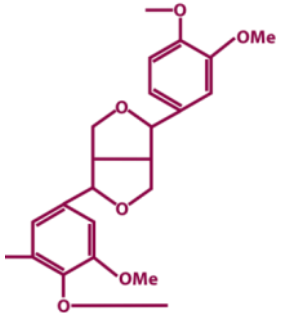
- Context – brief introduction to JBEI
- Examples of Synthetic Biology applied to bio-based chemicals
  - Plant (feedstock) engineering
    - Lignin structure (towards aromatics)
    - Targeted lignin expression (greater sugar density)
  - Microbial engineering
    - Access to many different metabolic pathways (custom products)
    - Emerging technologies (BioCAD/CAM, rapid strain construction)
- Commercialization prospects
  - Techo-Economic analysis
  - Commercialization of JBEI technologies

Engineering lignin structure

Lignin - a complex polymer that occludes cellulose and hemicellulose

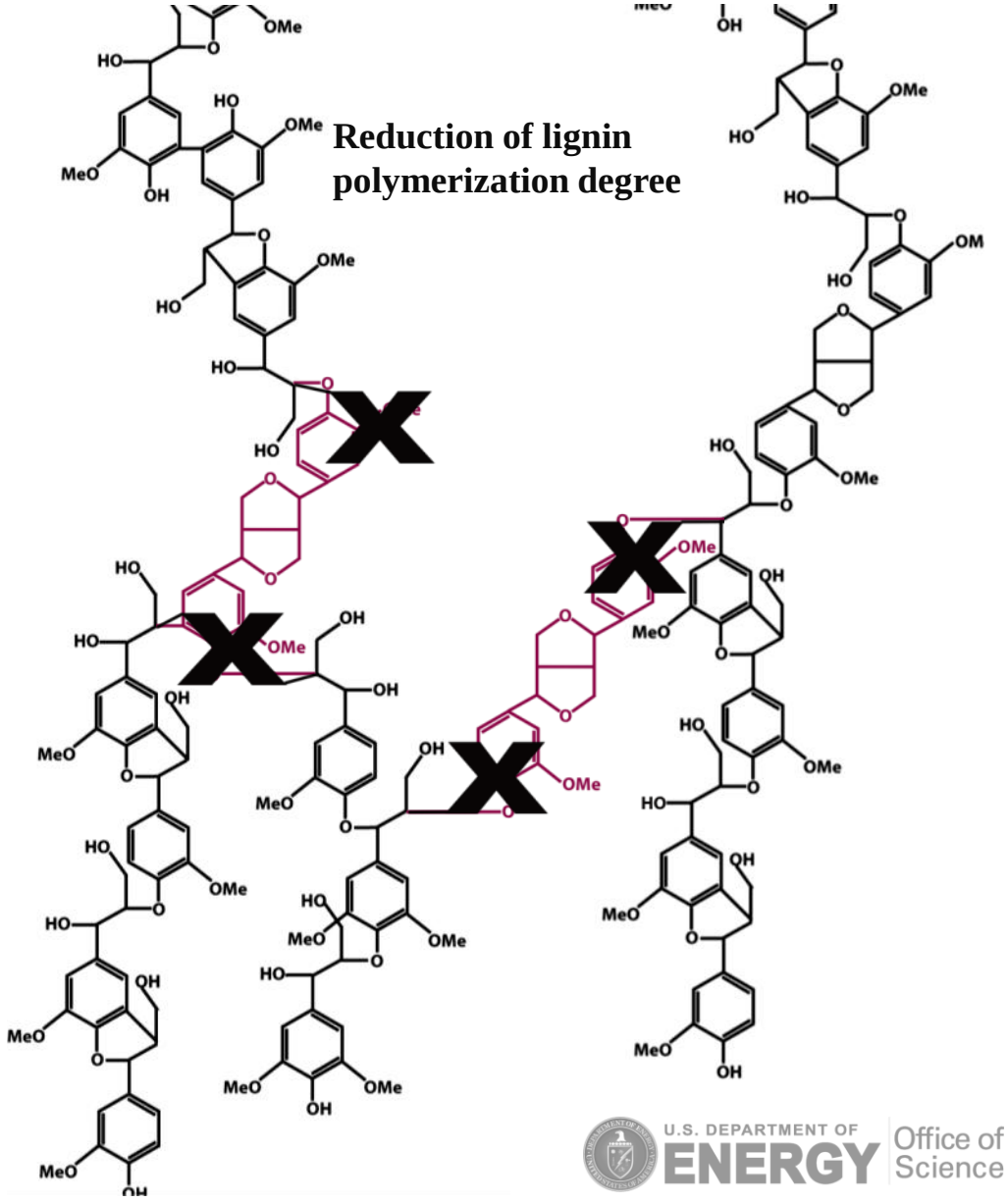


Engineering lignin structure



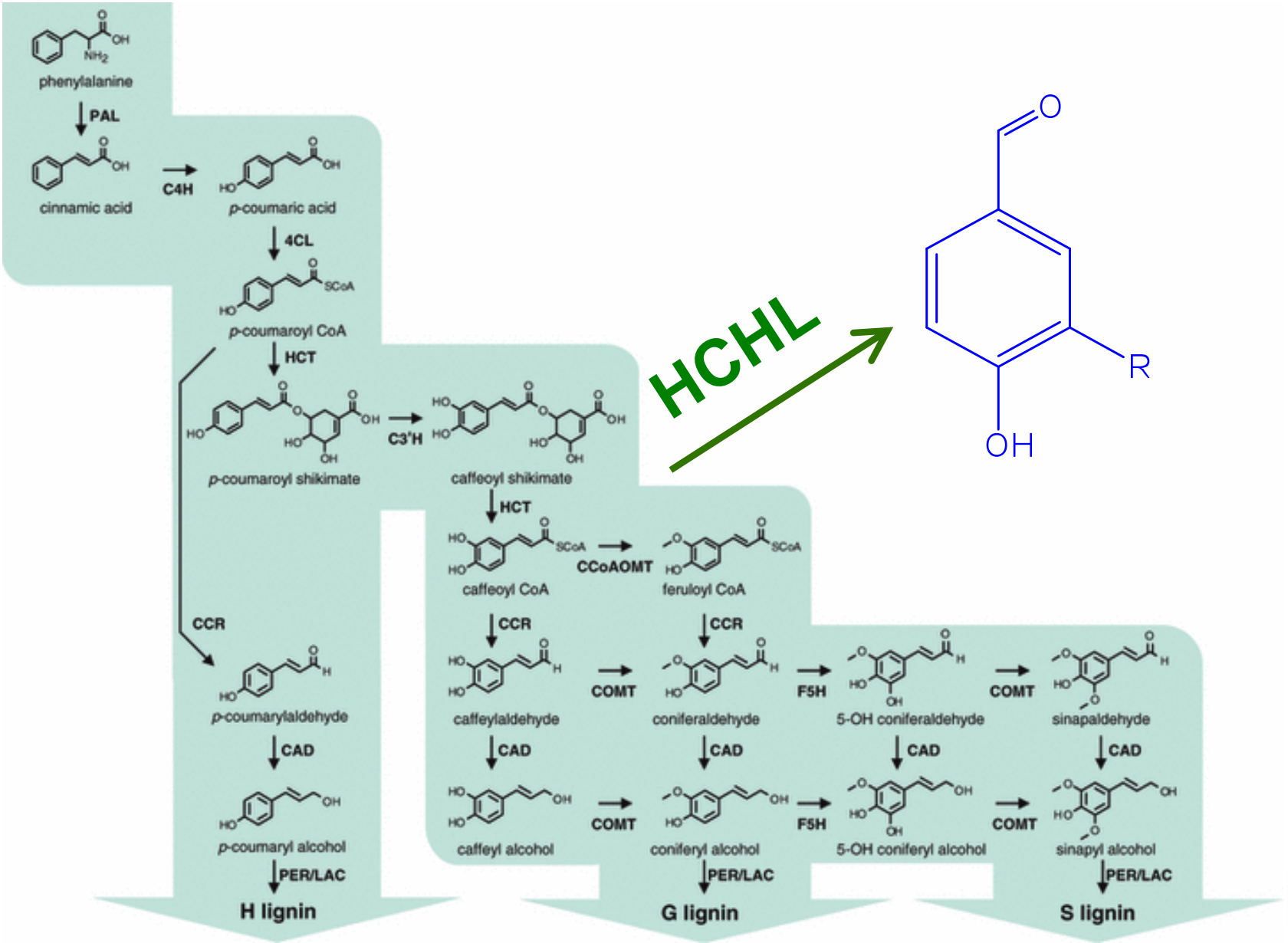
Phenyl-derivative

Reduction of lignin polymerization degree

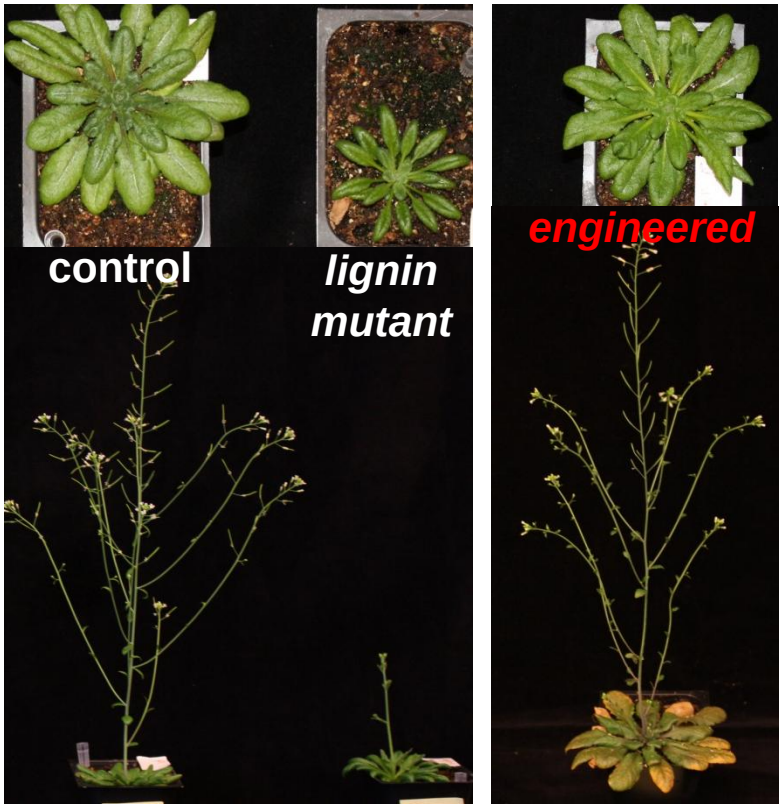


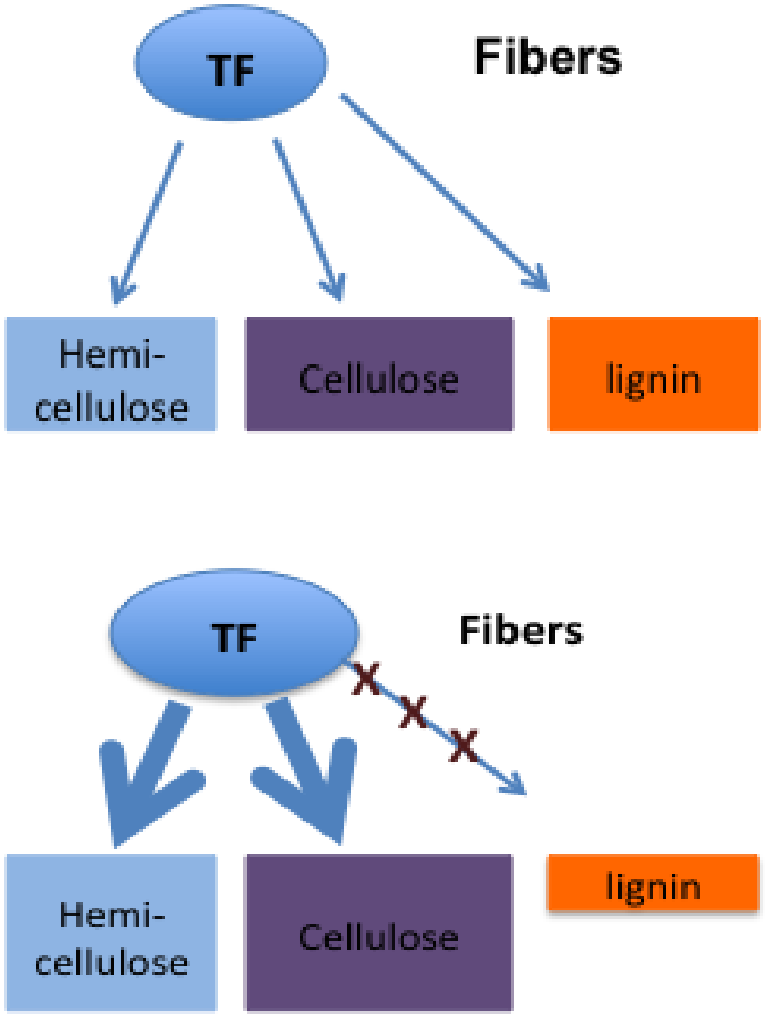
jbei
Joint BioEnergy Institute

Biosynthesis of novel monolignols



Targeted expression of lignin



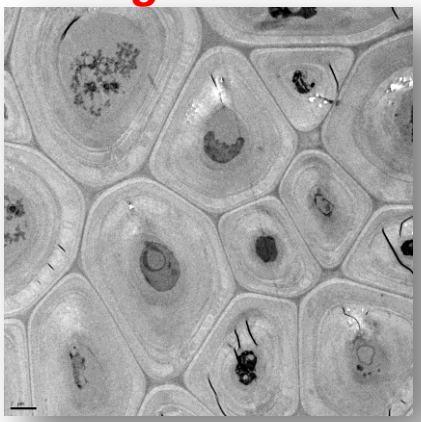


jbei Joint BioEnergy Institute

Targeted expression of lignin

control

engineered



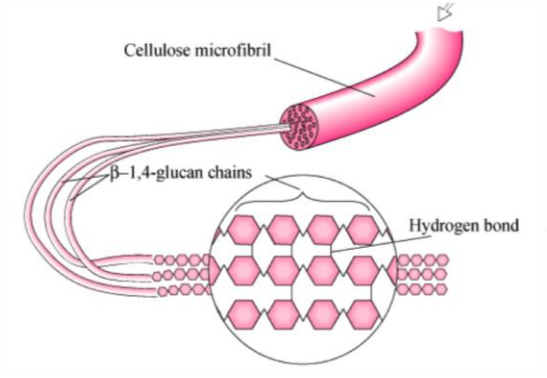
jbei Joint BioEnergy Institute

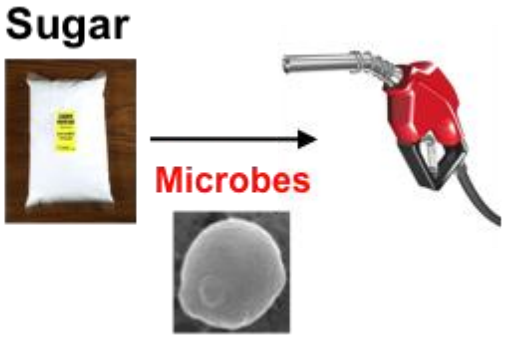
Outline

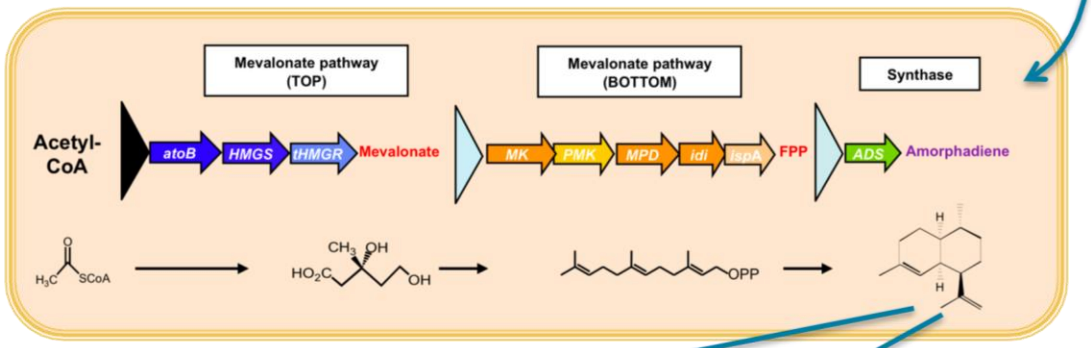
- Context – brief introduction to JBEI
- Examples of Synthetic Biology applied to bio-based chemicals
  - Plant (feedstock) engineering
    - Lignin structure (towards aromatics)
    - Targeted lignin expression (greater sugar density)
  - Microbial engineering
    - Access to many different metabolic pathways (custom products)
    - Emerging technologies (BioCAD/CAM, rapid strain construction)
- Commercialization prospects
  - Techo-Economic analysis
  - Commercialization of JBEI technologies

Engineering microbial metabolism

jbei
Joint BioEnergy Institute



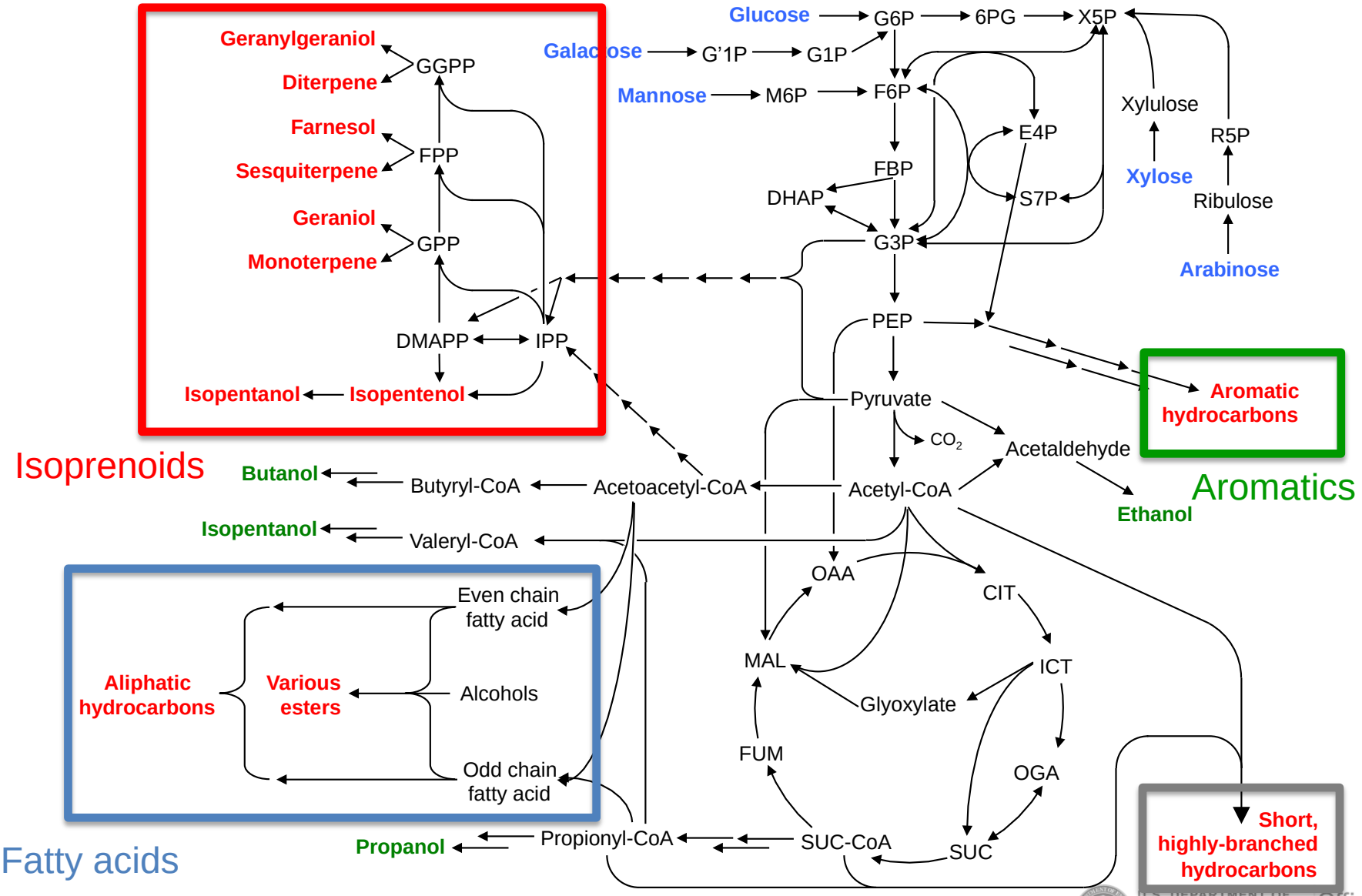




Goal:

Produce hydrocarbons compatible with our existing transportation infrastructure.

Hydrocarbon biosynthetic pathways

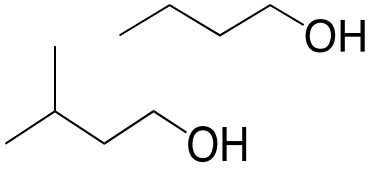


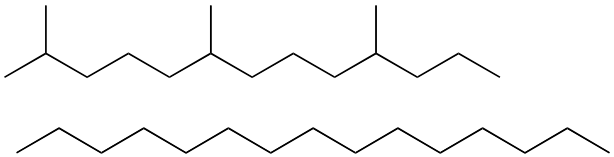
Some advanced biofuels

jbei Joint BioEnergy Institute

Alcohols

- Low miscibility with water
- High octane
- Appropriate vapor pressure



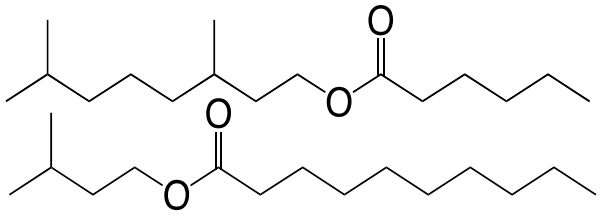


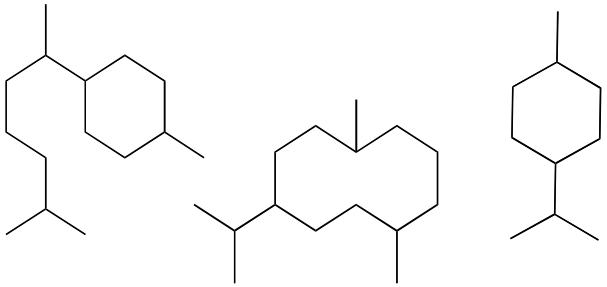
Alkanes

- Diesel (or gasoline) replacements
- Appropriate cetane (or octane) numbers

Esters

- Diesel replacements
- Appropriate cetane nos.



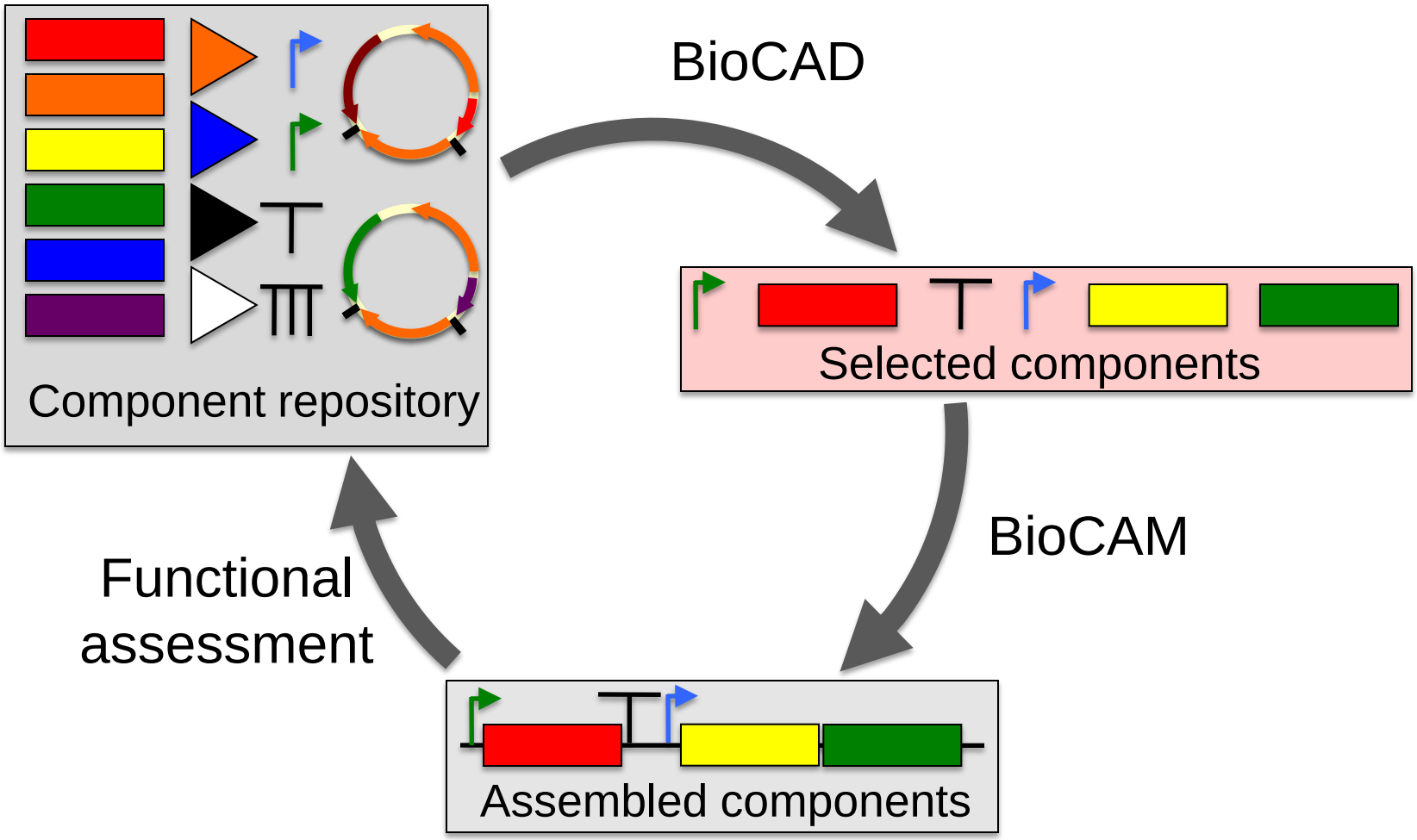


Cyclic alkanes/alkenes

- Jet fuel replacements
- Low freezing point

U.S. DEPARTMENT OF ENERGY Office of Science

Emerging technologies: BioCAD/CAM



BioCAD/CAM example

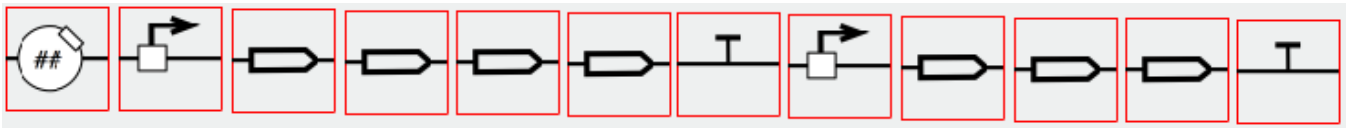
jbei Joint BioEnergy Institute

Metabolic pathway design GLAMM

sugar → A → B → C → D → E → F → G → Bio-based chemical

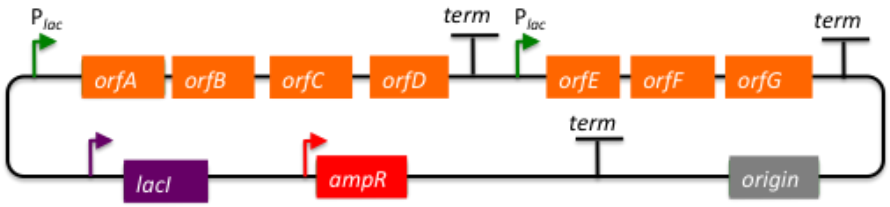
CAD

Gene expression design



CAM

Gene assembly design j5

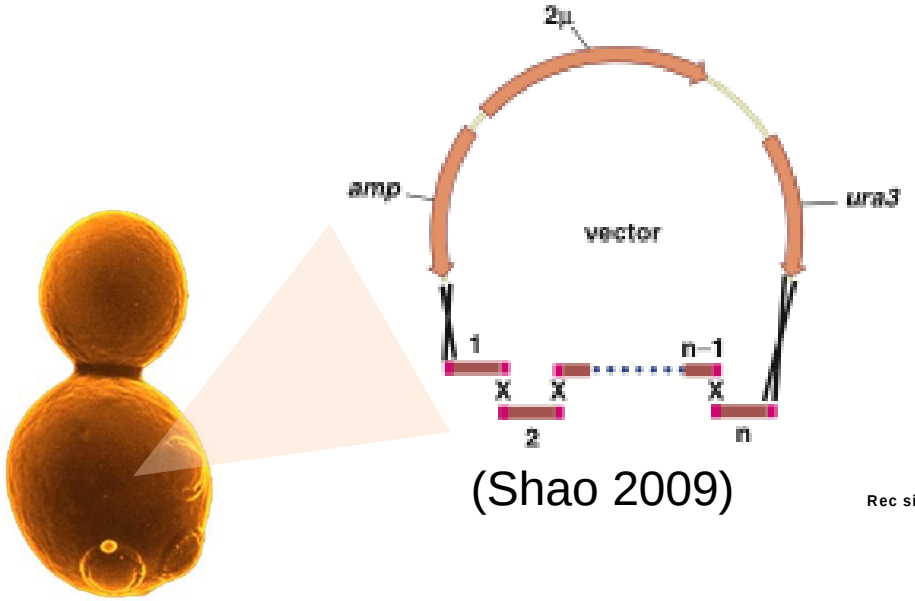


Robotic assembly

U.S. DEPARTMENT OF ENERGY Office of Science

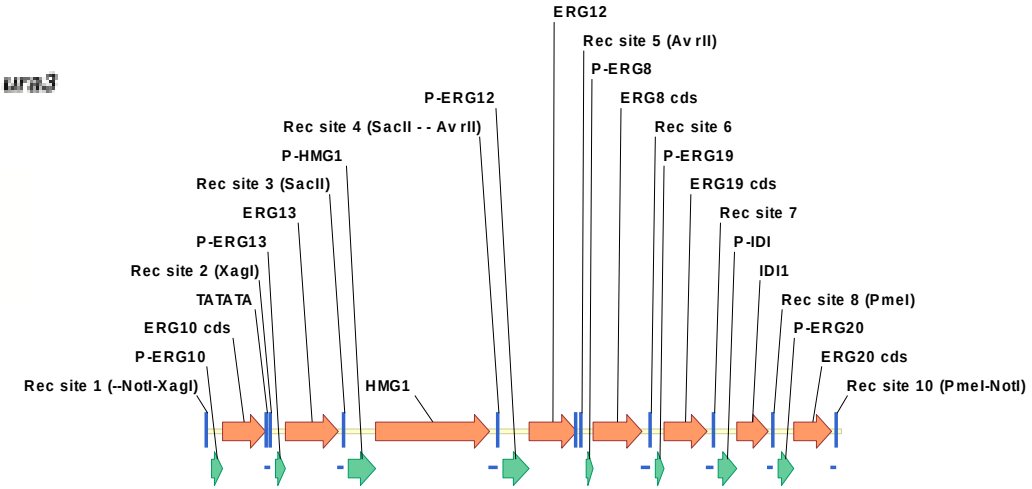
Combinatorial pathway assembly in yeast

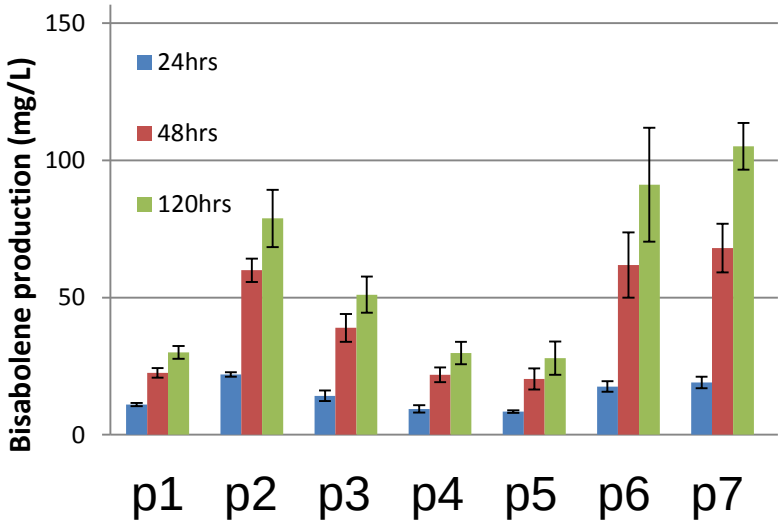
Joint BioEnergy Institute



(Shao 2009)

Mevalonate pathway





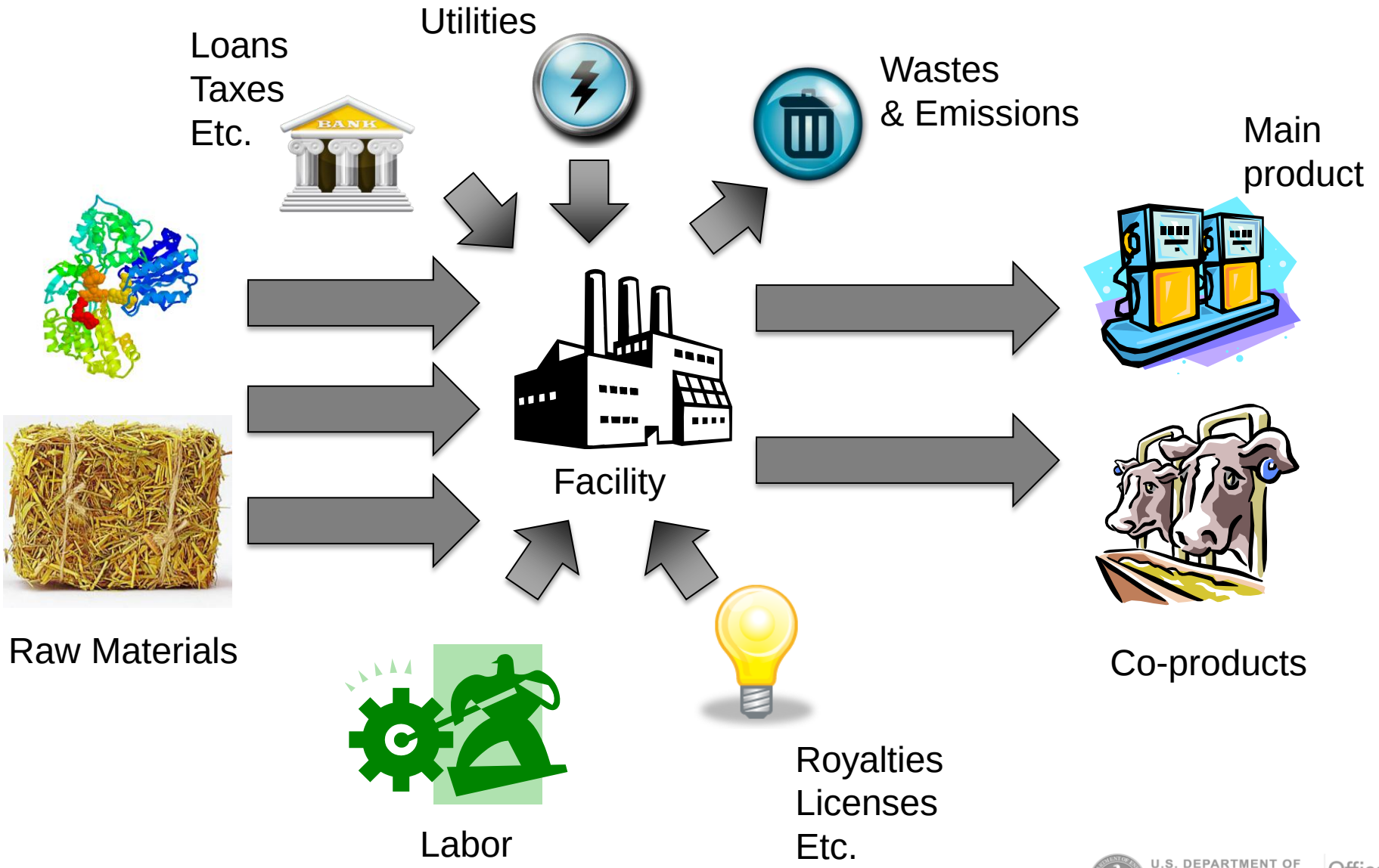
p1 - native pathway
p2 - P_{GAL1}-tHMG1 instead of native HMG1
p3 - P_{GAL1}-t2HMGR instead of native HMG1
p4 - no HMG1 present on vector
p5 - all native pathway with 2μ origin
p6 - p2 with 2μ origin
p7 - p3 with 2μ origin

jbei Joint BioEnergy Institute

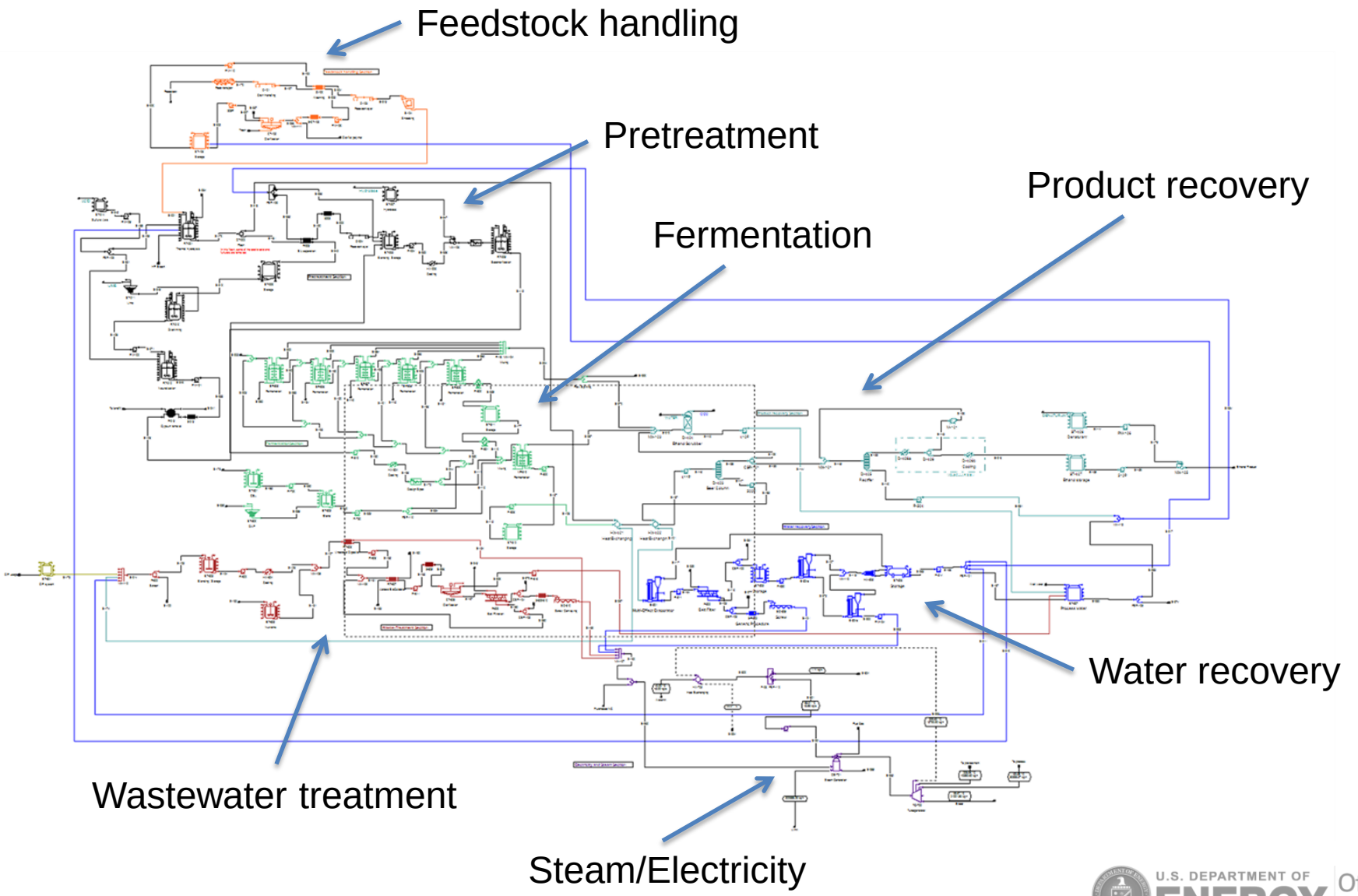
Outline

- Context – brief introduction to JBEI
- Examples of Synthetic Biology applied to bio-based chemicals
  - Plant (feedstock) engineering
    - Lignin structure (towards aromatics)
    - Targeted lignin expression (greater sugar density)
  - Microbial engineering
    - Access to many different metabolic pathways (custom products)
    - Emerging technologies (BioCAD/CAM, rapid strain construction)
- Commercialization prospects
  - Techo-Economic analysis
  - Commercialization of JBEI technologies

Techno-Economic analysis

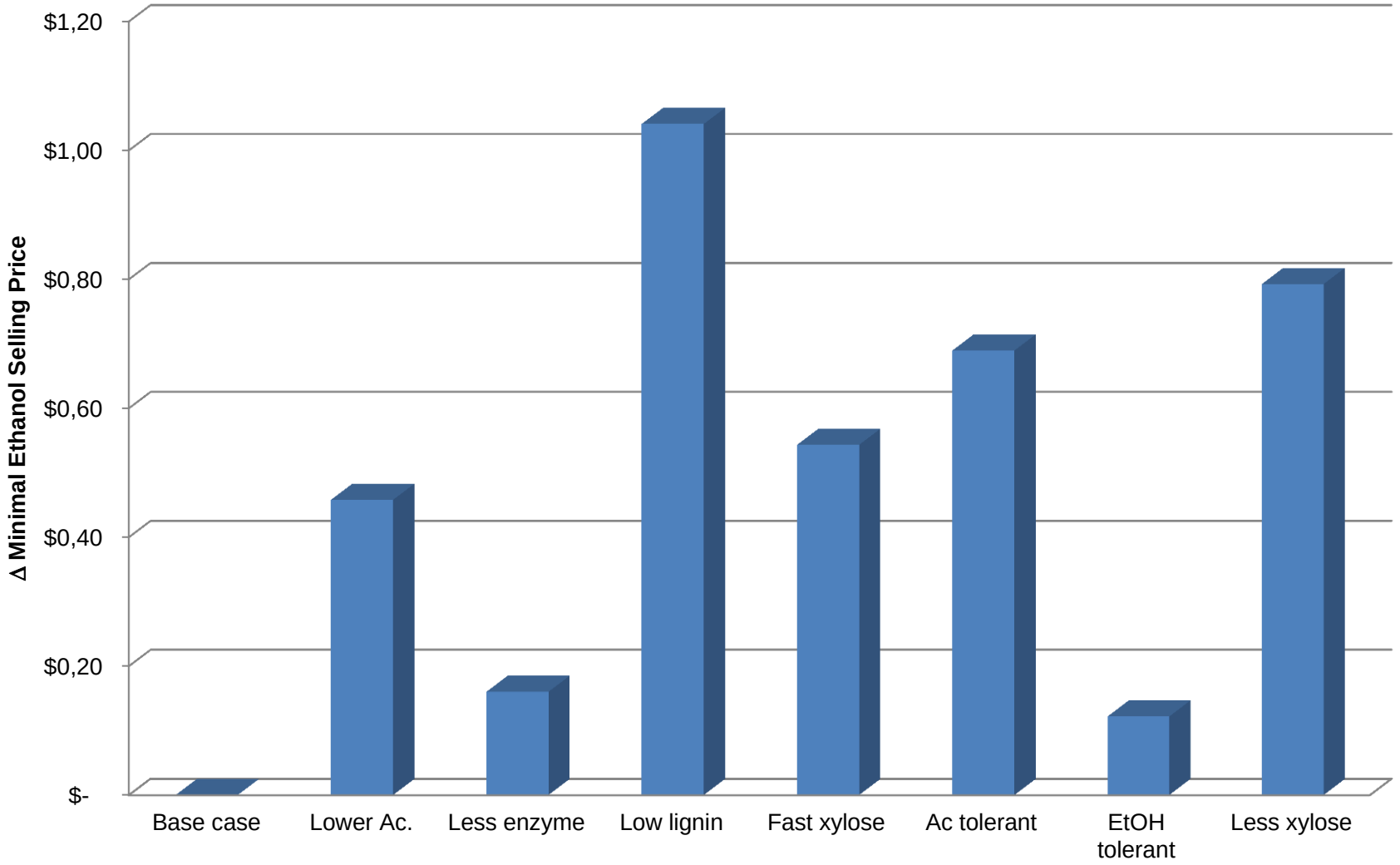


SuperPro process modeling

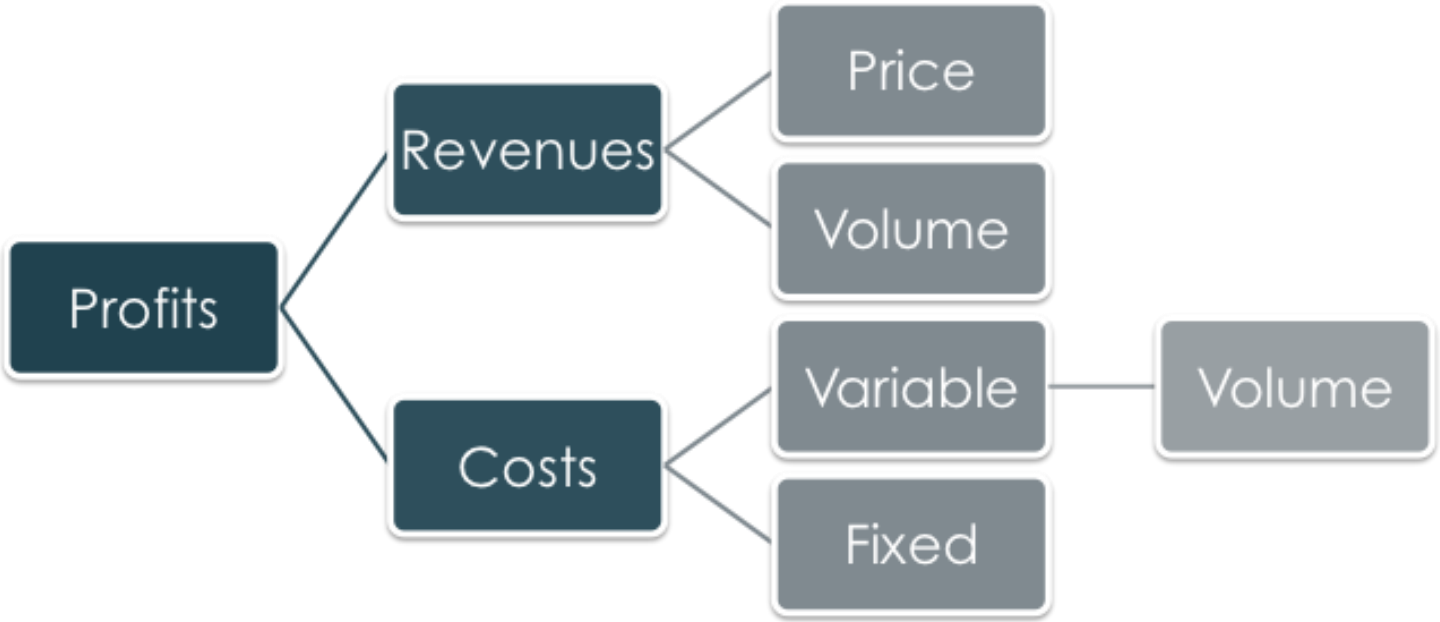


jbei
Joint BioEnergy Institute

Scenarios affecting process costs



Economic barriers to bio-based chemicals

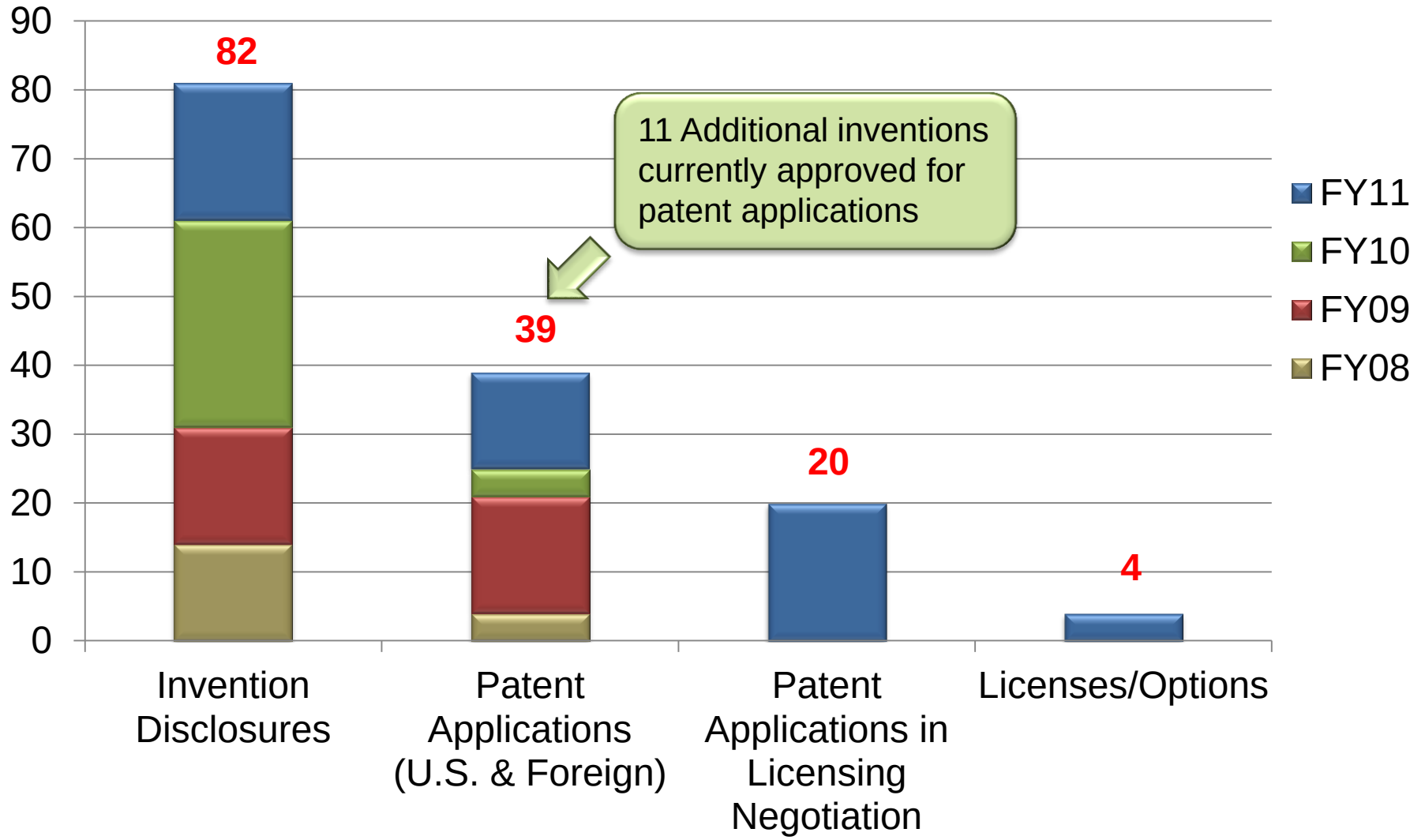


- Price
  - Commodity market
  - Volatility of competing product (petroleum-derived)

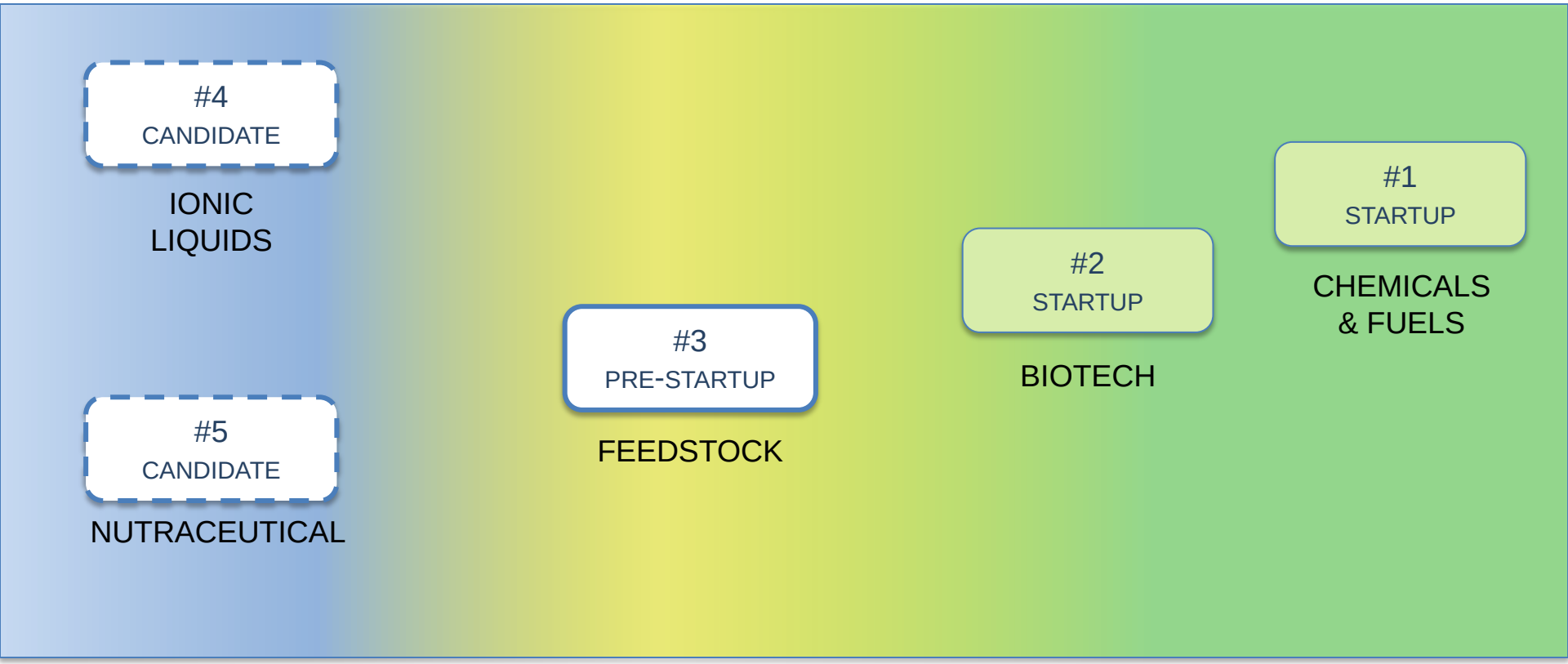
Outline

- Context – brief introduction to JBEI
- Examples of Synthetic Biology applied to bio-based chemicals
  - Plant (feedstock) engineering
    - Lignin structure (towards aromatics)
    - Targeted lignin expression (greater sugar density)
  - Microbial engineering
    - Access to many different metabolic pathways (custom products)
    - Emerging technologies (BioCAD/CAM, rapid strain construction)
- Commercialization prospects
  - Techo-Economic analysis
  - Commercialization of JBEI technologies

JBEI commercialization metrics



JBEI startup pipeline



JBEI Conducts Opportunity, Impact & Industry Analysis → JBEI Forms Internal Startup Development Team → Founders Create/Startup New Company → Company Attracts Investors

jbei Joint BioEnergy Institute

Concluding remarks

- Synthetic Biology, Chemical Conversion, and Gasification are complementary
- Keep abreast of what is possible to achieve with the different approaches
- Process optimization should consider all routes and include economic, social, environmental and political costs.
- There are current examples of commercially viable Synthetic Biology approaches
- Initially, Synthetic Biology will likely contribute to higher-value products, especially those difficult or impossible to achieve through chemical means
- Rapid advances are anticipated for Synthetic Biology

Acknowledgements

Lignin Engineering
Dominique Loque

BioCAD/CAM
GLAMM
http://glamm.lbl.gov
John Bates

DeviceEditor/j5
http://j5.jbei.org
Joanna Chen
Douglas Densmore
Tim Ham

DNA assembly workflow
Rafael Rosengarten

ParPar
Gregory Linshiz

Yeast Pathway Assembly
James Kirby

Techno-Economic Analysis
http://econ.jbei.org
Daniel Klein-Marcuschamer
Blake Simmons
Harvey Blanch

Technology Transfer
Robin Johnston
Everett Kaplan

Funding
DOE Genomics/GTL/BRC (JBEI)
Berkeley Lab LDRD