

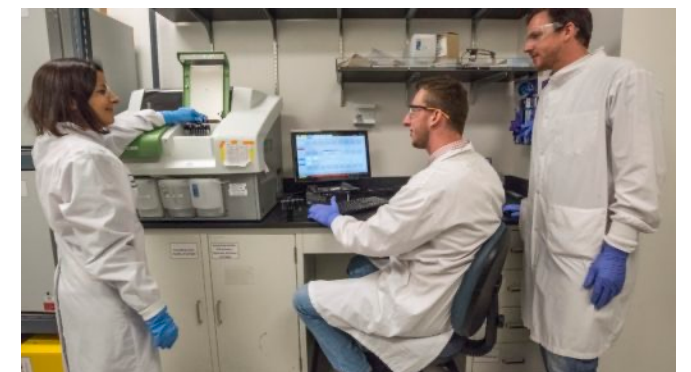
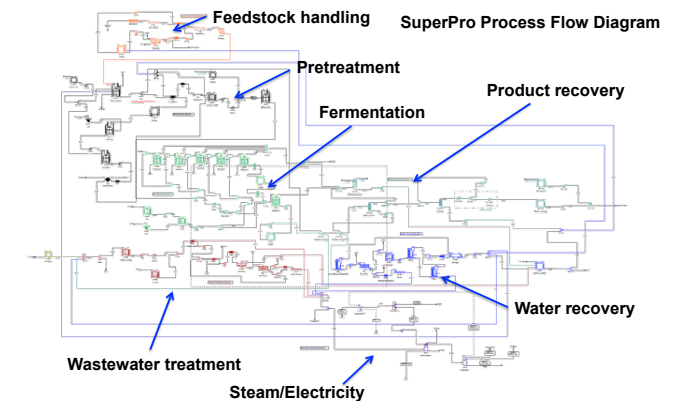
US Biomanufacturing Needs (particularly for chemical manufacturing)

Jay Keasling

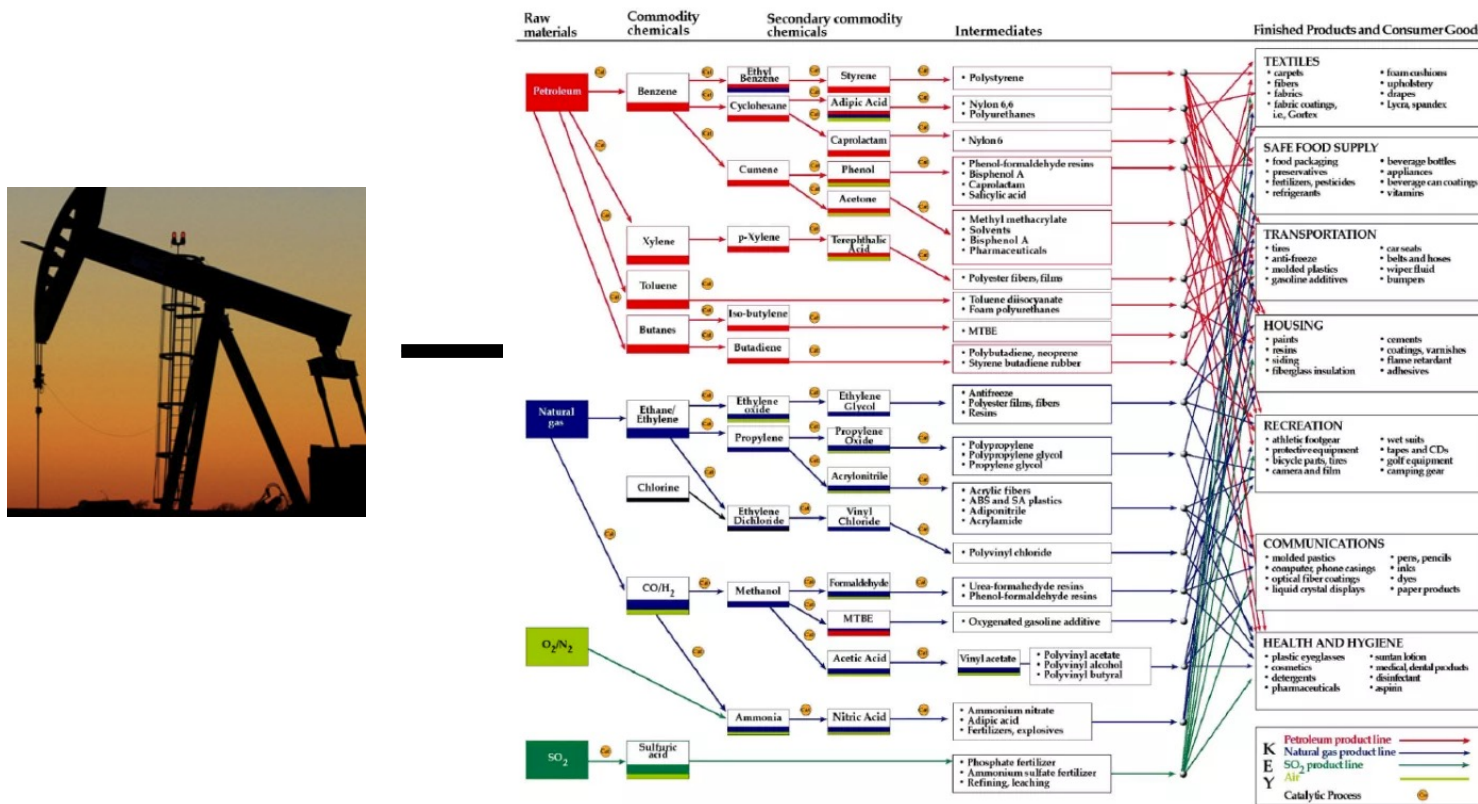
University of California, Berkeley
Lawrence Berkeley National Laboratory
Joint BioEnergy Institute

Executive Summary

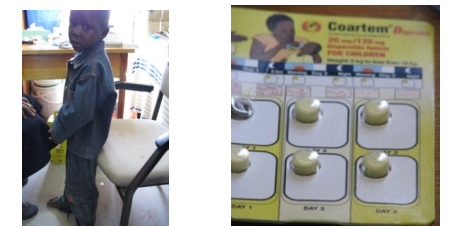
- Bioprocess scaleup facilities at all scales
- Widespread adoption of technoeconomic and life cycle analyses
- Funds for bioprocess engineering research in US universities
- Development of education programs for bioprocess engineers



Most of chemical manufacturing is based on petroleum-derived starting materials

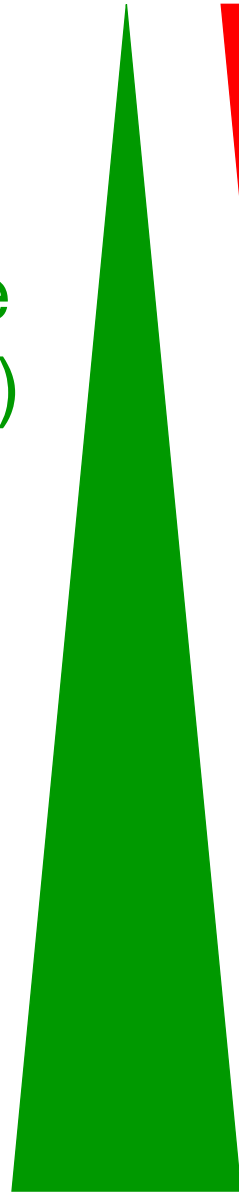


100,000 different molecules
\$2 trillion in US

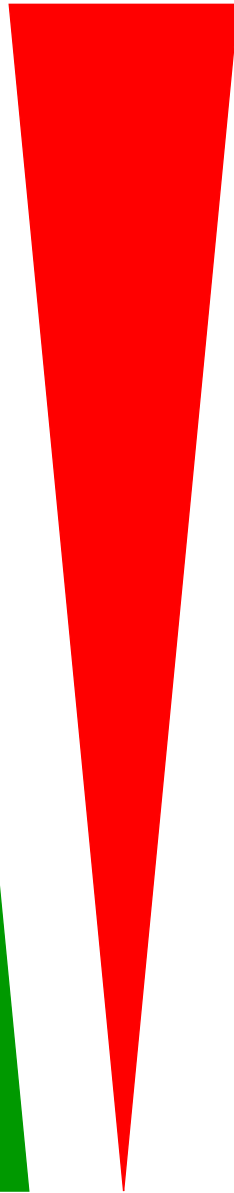


Volume and Value

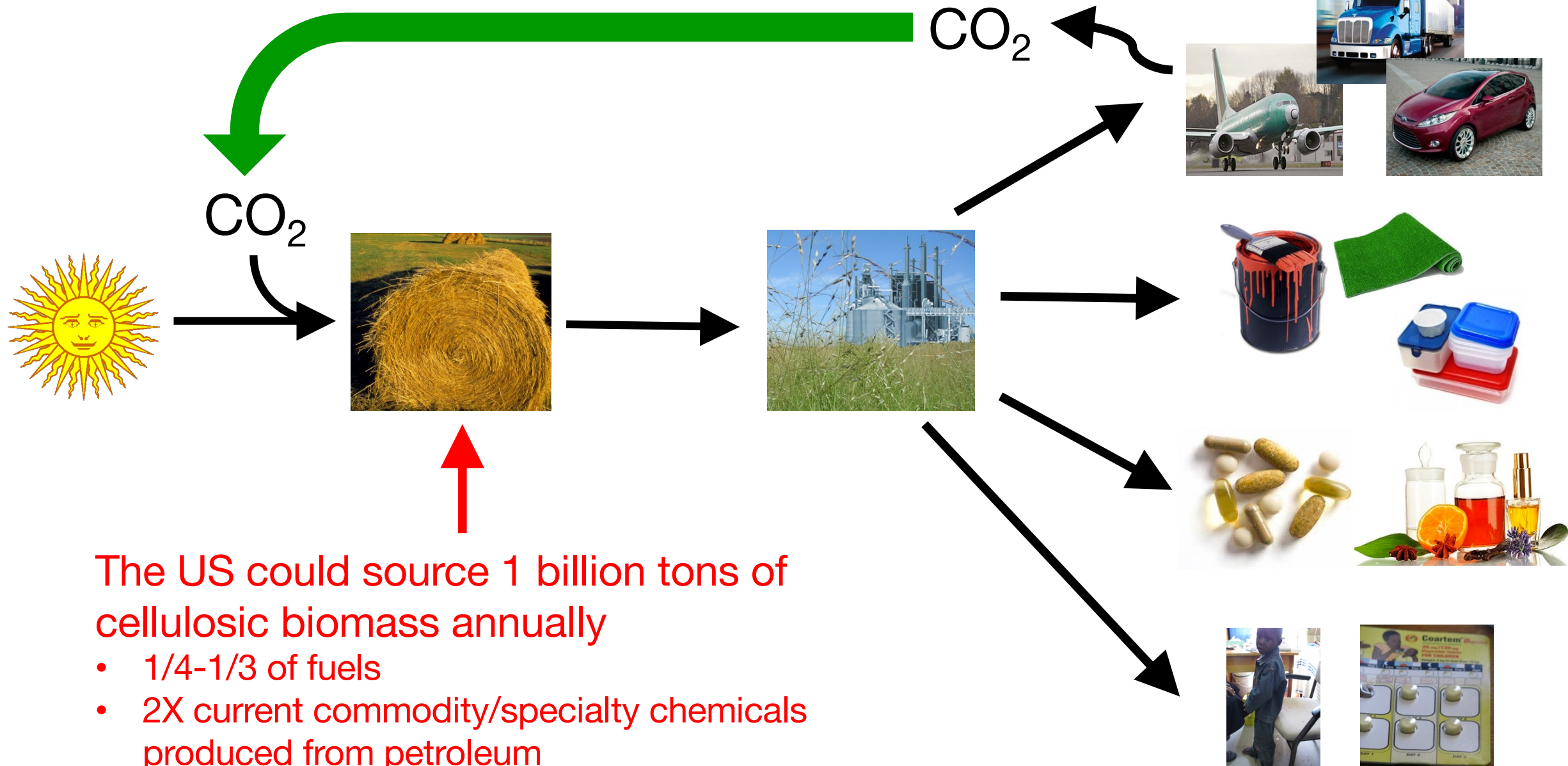
Value
(\$/Kg)



Volume
(T/yr)



Biomass to products

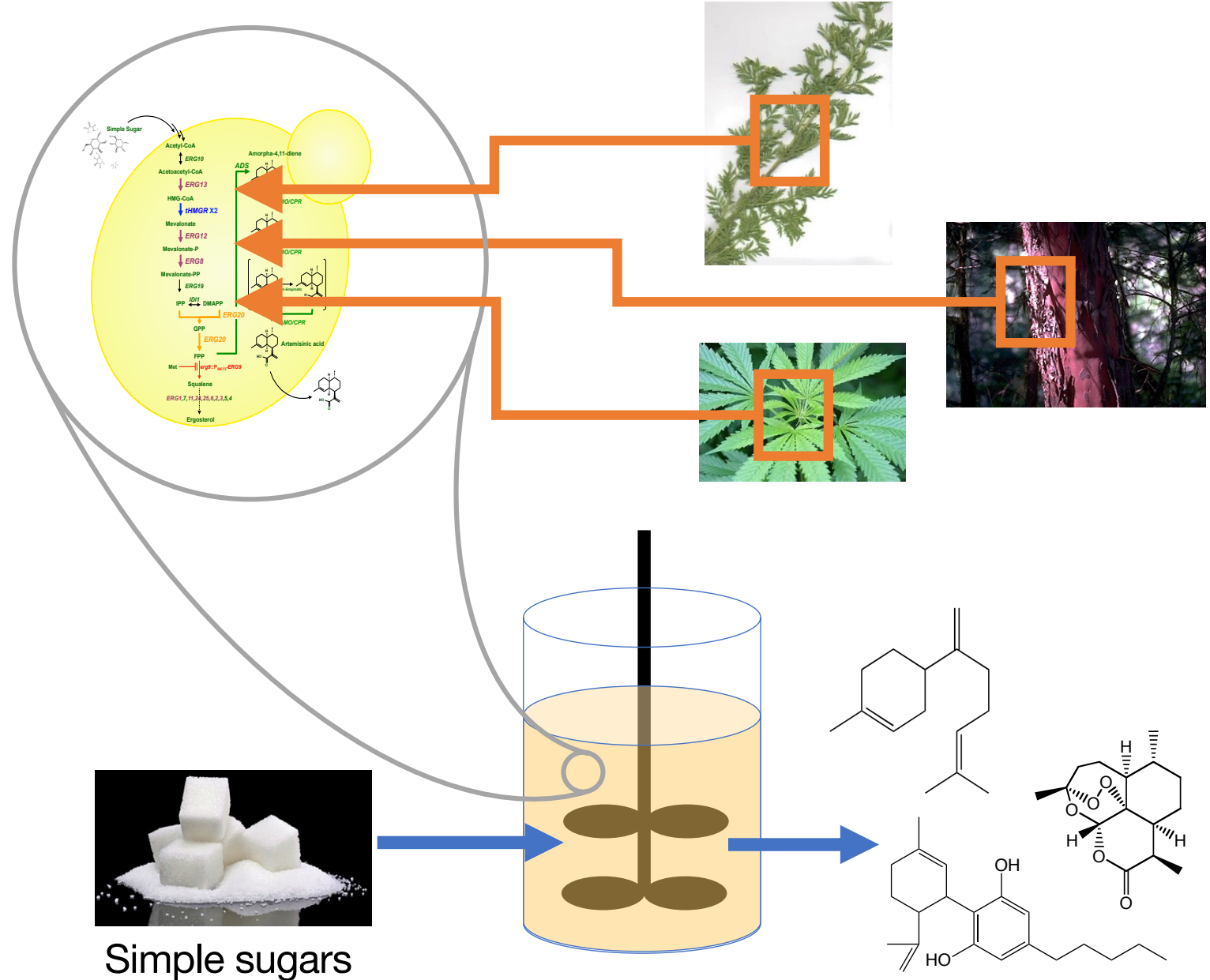




Engineering microbes as chemical factories

Benefits

- Produce rare or unnatural products
- Produce natural products in large quantities at low cost
- Lower inputs of water and energy



Simple sugars

Likelihood for replacement of traditional manufacturing with biomanufacturing

- **Very unlikely without a tax on carbon or mandates**
- **Unlikely if replacing petroleum products.**
- **Likely for products with unique properties.**
- **Very likely for products with biological activity.**
- **Biomanufacturing may be the only way to produce the molecule.**

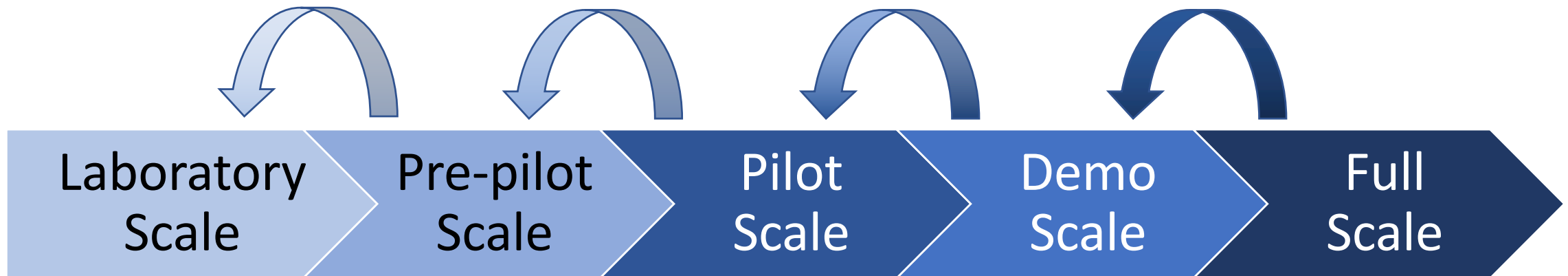


Size/complexity of biomanufacturing facilities

- **Many, very large, dedicated facilities**
- **Some, very large, dedicated facilities**
- **Medium-sized, flexible facilities**
- **Small- to medium-sized, flexible facilities**
- **Specialized, GMP facilities**



Bioprocess scale-up can be prohibitively expensive for small companies to build and maintain



Biomanufacturing facility needs

- Many, highly flexible, small-scale pre-pilot & pilot facilities
 - Example: Advanced Biofuels & Bioproducts Process Demonstration Unit at Lawrence Berkeley National Laboratory (LBNL)
 - Flexible biomass pretreatment, fermentation type, downstream processing (DSP)
- Several, slightly less flexible, demonstration facilities
 - Example: Bioprocessing Pilot Plant at National Renewable Energy Laboratory (NREL)
 - Larger scale fermentation and DSP
- A few toll biomanufacturing facilities



Directory of toll fermentation and cell culture facilities

James E. Flinn, PhD

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**DIRECTORY
OF
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AND
CELL CULTURE FACILITIES
Eleventh Edition**

Edited by

James E. Flinn, Ph.D.

Bio-Endeavors International
Naperville, Illinois

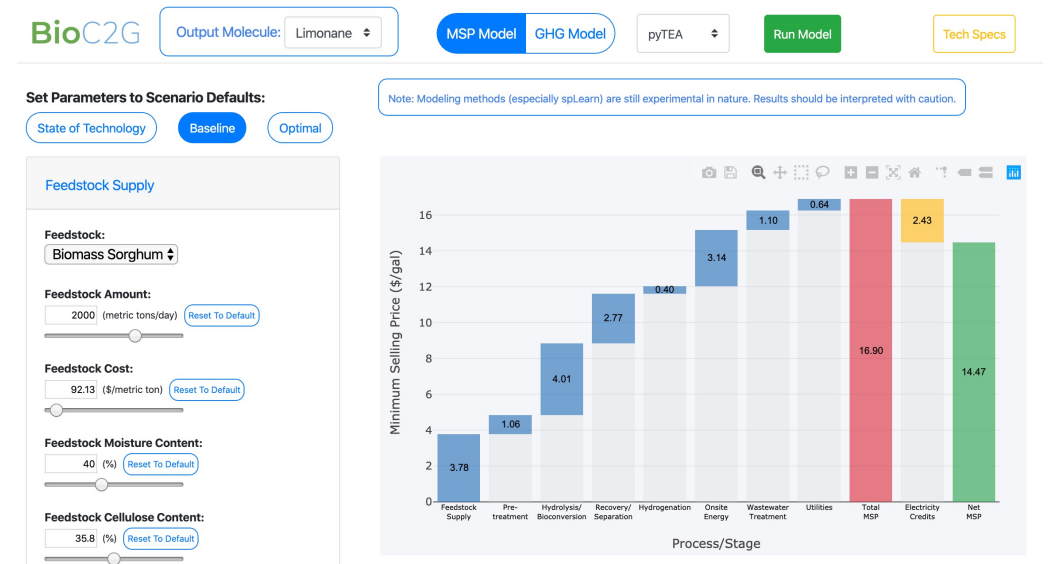
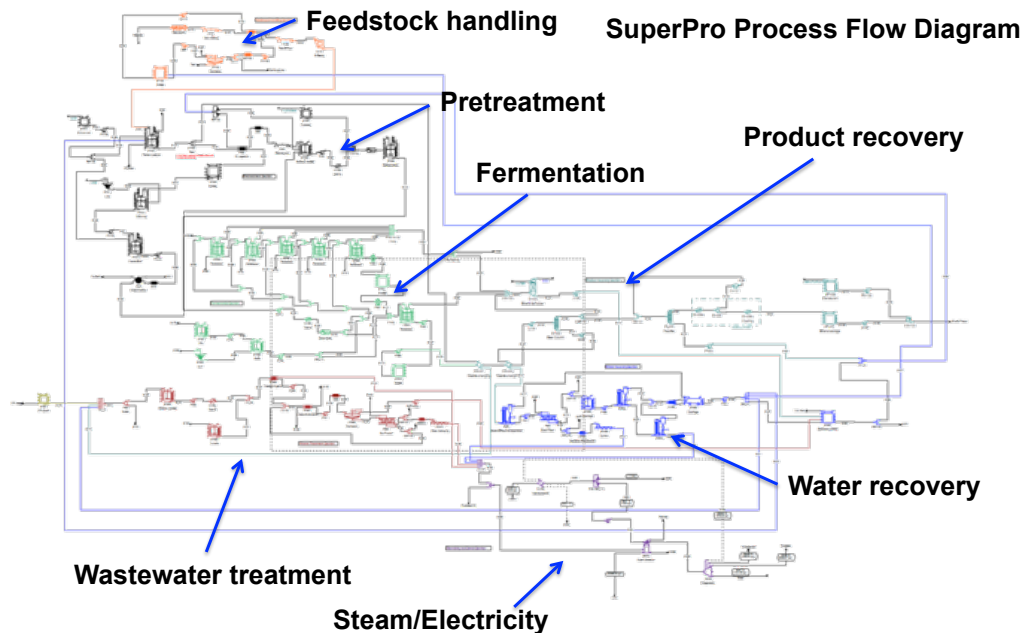
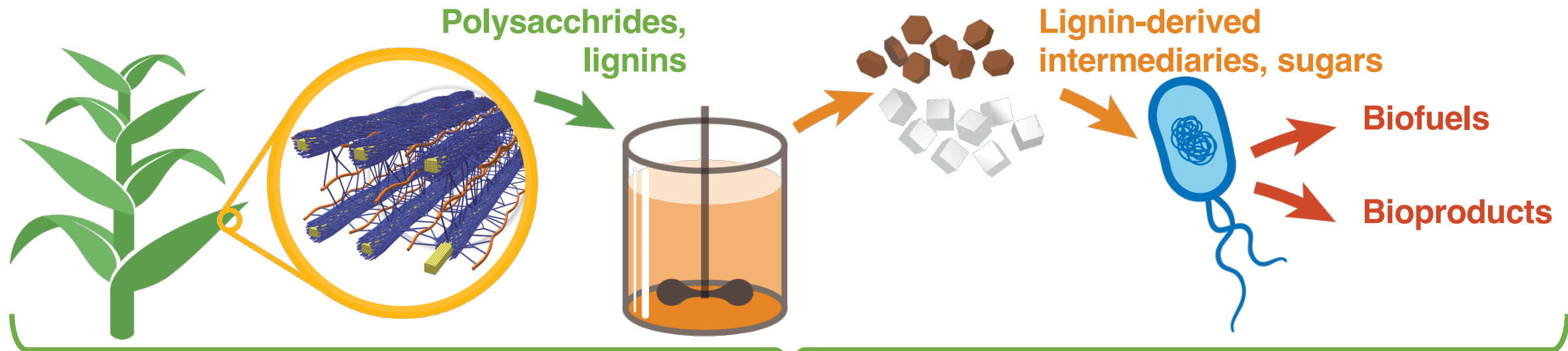
Some pilot, demonstration, and toll biomanufacturing facilities

CMO	Location	Fermenter Size (L)	Industrial or Pharma
ADM	Clinton	525,000	Industrial
Tate and Lyle	Decatur, IL	227,000	Industrial
ADL	Spain	245,000	Industrial
European Target	Europe	200,000+	Industrial
Target	North America	200,000+	Industrial
Fermic	Mexico	190,000	Industrial
REG	Florida	135,000	Industrial
Fermentum	New York	125,000	Industrial
Corden	Germany	120,000	Industrial
EW Biotech	Germany	85,000	Industrial
Fermic	Mexico	50,000	Industrial
Fermic	Mexico	20,000	Industrial
Capua	Italy	35,000	Industrial
ICM	St. Joseph, Mo	26,000	Industrial
Wisconsin Bio	Wisconsin	38,000	Industrial
Tate and Lyle	Decatur, IL	13,000	Industrial
AbbVie	Chicago	100,000	Pharma
Bio Based Europe	Netherlands	15,000	Pharma

A quote from a CEO of one of my companies ...

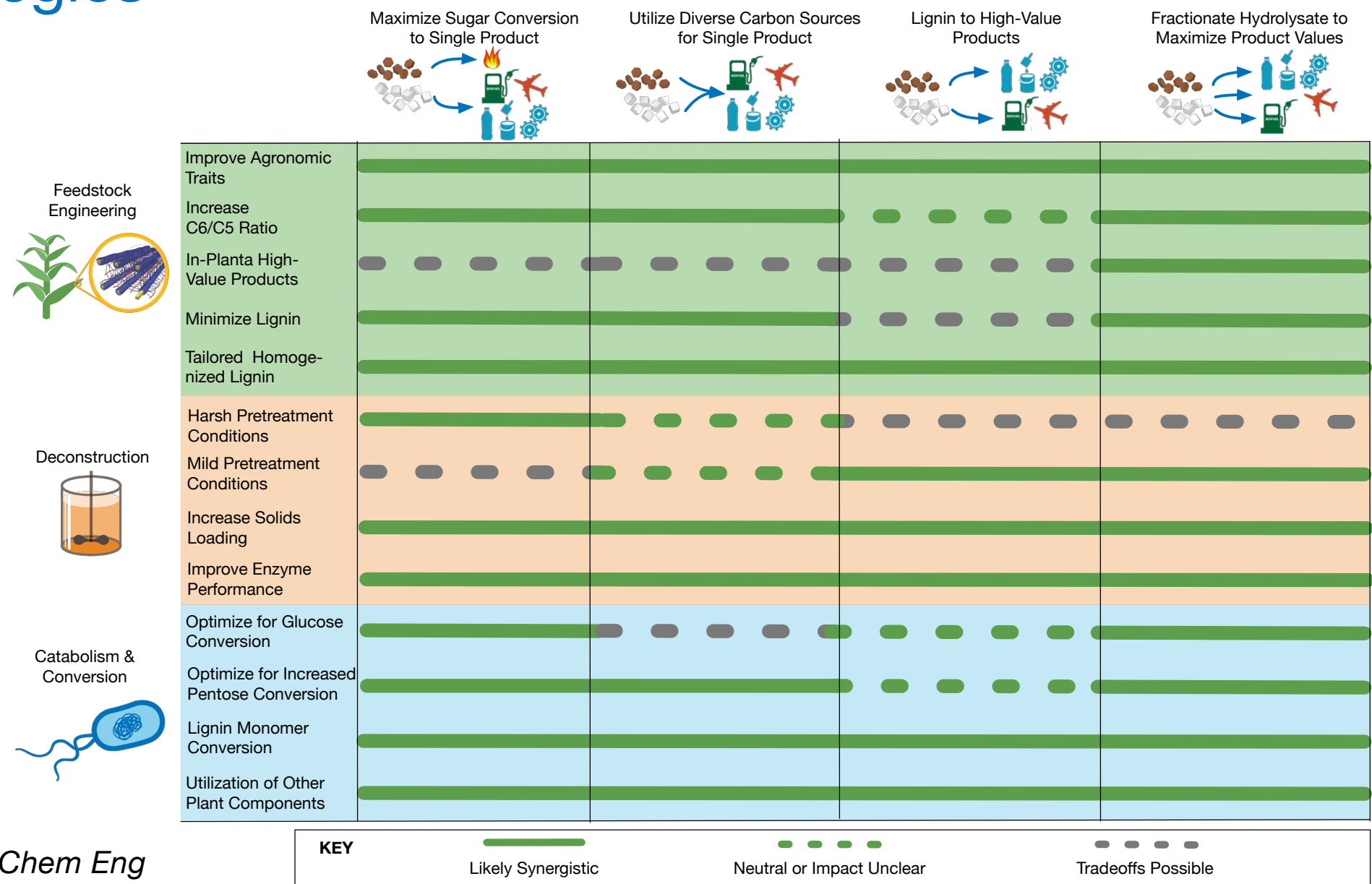
“I'd just add that a lot of **the US ones that aren't pharma are pretty run down**. The analogy I've been using is that CMOs are just like cars - as they are used and age, they need repairs and upkeep. That hasn't happened very much in the US outside of the pharma plants. In the US, a number of them are like a Ford F150 with 200,000 miles on them already. The European plants tend to be much better maintained (50,000 - 100,000 miles).”

Technoeconomic models and life-cycle analyses should be widely used and standardized



Value of research approaches in different biomass-to-biofuel strategies

- TEA models help us understand trade-offs and synergies
- Helps JBEI Research Committee prioritize research strategies



Research, training, and workforce development in bioprocess engineering

- Recent advances in synthetic biology enable biomanufacturing of many, diverse products
 - Require development of new bioprocesses, especially downstream processing (post fermentation)
- Biomanufacturing companies need engineers trained in bioprocess engineering
 - US universities don't train many of these individuals because of the lack of faculty to teach these courses
 - Certificate/Associates Degree, BS, MS, PhD
- There are very few faculty in major US research universities who do research in bioprocess engineering
 - There is significant research in these areas in European and Asian universities
 - US research has focused on molecular & microbial engineering
 - Few faculty who can teach bioprocess engineering

Recommendations for research, training, and workforce development

- Federal research funding agencies should fund research in bioprocess engineer
 - NSF, DOE
 - PhDs in bioprocess engineering
- Develop community college programs to train biomanufacturing facilities operators
 - Example: Solano Community College in Vacaville, CA
- Develop more BS and MS programs in bioprocess engineering
 - Example: UC Berkeley's MS program in Bioprocess Engineering

