Biological Processing

Part of analysis of conversion technology carried out by Princeton and Dartmouth.

Production of cellulosic ethanol is the main focus

- **Extension of microbial cellulose processing platform to other products considered in co-product analysis (Task 4).**

Cellulosic Ethanol: Mature technology conceptual basis

Pretreatment
- Low energy
- High yield
- No detox.

→

Fermentation
- Cellulose & hemicellulose
- No dedicated cellulase production (CBP)
- High yield
- Sufficient [EtOH]

→

Product Recovery & Downstream Processing

- AFEX appears to meet most requirements.
- Engineering & optimization remain to be completed but should be doable.
- Fermentation of hemicellulose oligomers advantageous.

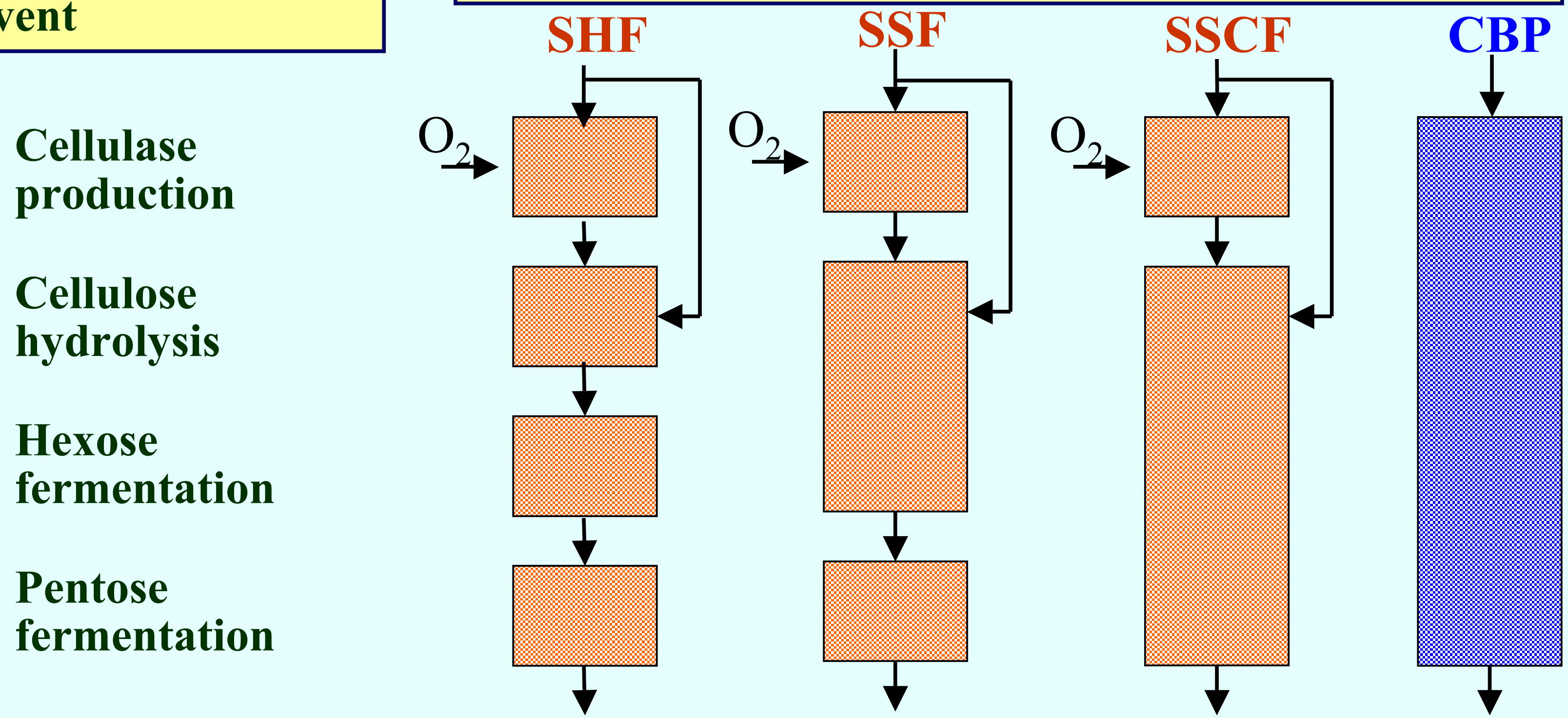
- Modeling, recent lab results supports kinetic & bioenergetic feasibility.
- Requires a major biotechnology development effort.
- Magnitude of challenge/effort not larger than regularly encountered in the pharmaceutical industry.
- Process development with a microbial rather than enzymatic paradigm.

- Modest improvements possible, desirable, but not necessary

Evolution of Biomass Processing Featuring Enzymatic Hydrolysis

Biologically-Mediated Event

Processing Strategy
(each box represents a bioreactor - not to scale)



SHF: Separate hydrolysis & fermentation

SSF: Simultaneous saccharification & fermentation

SSCF: Simultaneous saccharification & co-fermentation

CBP: Consolidated bioprocessing

Process Simulation
(applies to thermochemical as well as biological processing)

Material & Energy Balance Models

- Implemented using ASPEN
- Build on extensive prior work
  - Princeton (thermochemical fuels)
  - NREL & Dartmouth (ethanol)

Equipment Lists & Sizing (ASPEN)

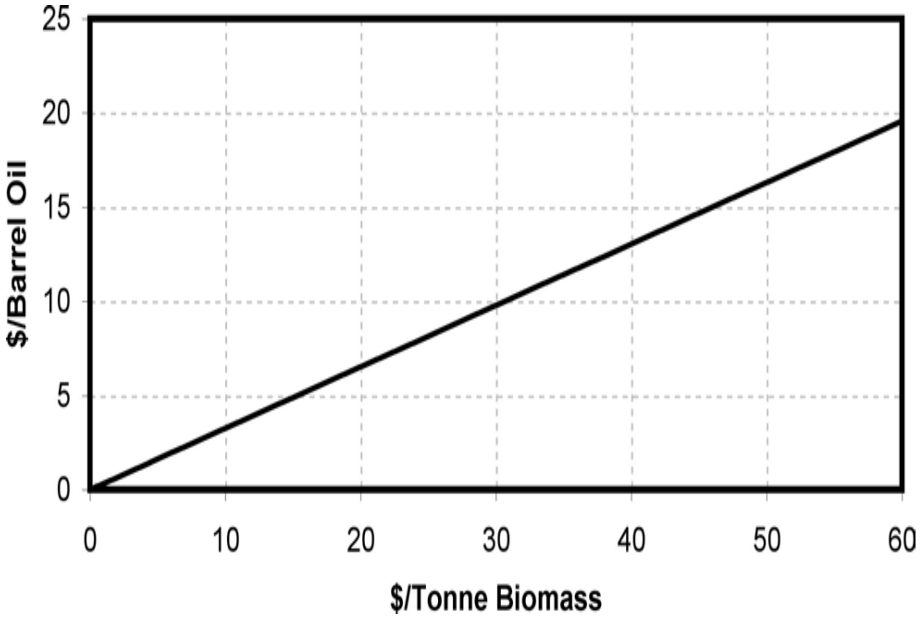
- Include 100s of items for some processes
  - Pumps, heat exchangers as well as larger items
- Sizes calculated based on duty, performance parameters

Integration & Layout

- Pinch analysis using ASPEN
- Judgment
- Not to the level of piping & instrumentation diagrams

Economics

Feedstock



Processing

"Bottom up"

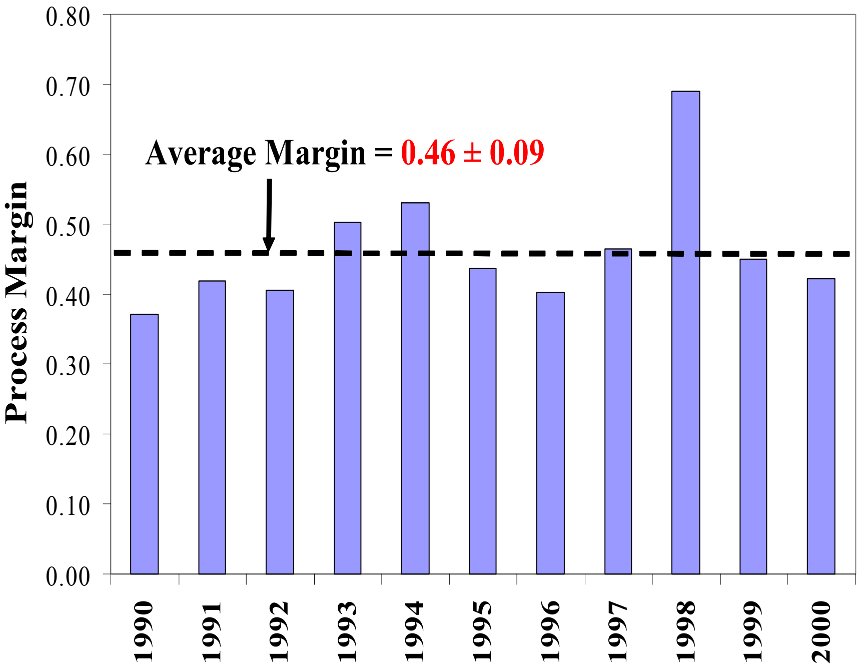
- Installed cost based on ASPEN-generated equipment lists
  - ICARUS
  - Industrial quotes gathered by Princeton, NREL
- Additional costs & cashflow analysis --> allowable selling price

"Top down"

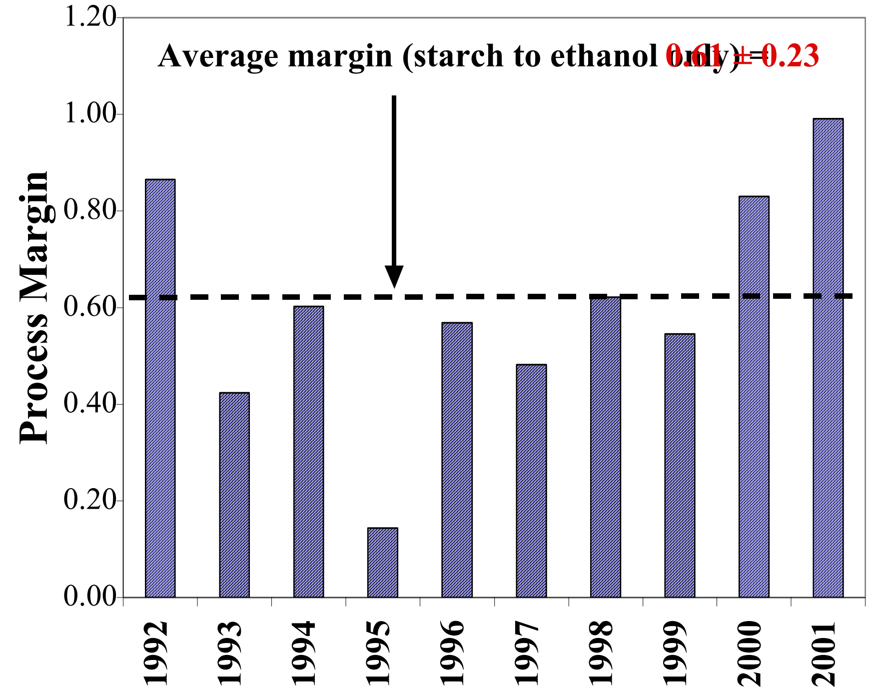
- Processing:feedstock cost ratios for mature commodity processes
- "Operating line analysis"

Figure 2. Relative process margin for petroleum refining and ethanol production from corn.

A. U.S. Petroleum refining.



B. Ethanol production from corn (U.S.)



$$\text{Process margin} = M_R = \frac{V - (F + E)}{F + E}$$

$V = value\ \ of\ all\ \ products$

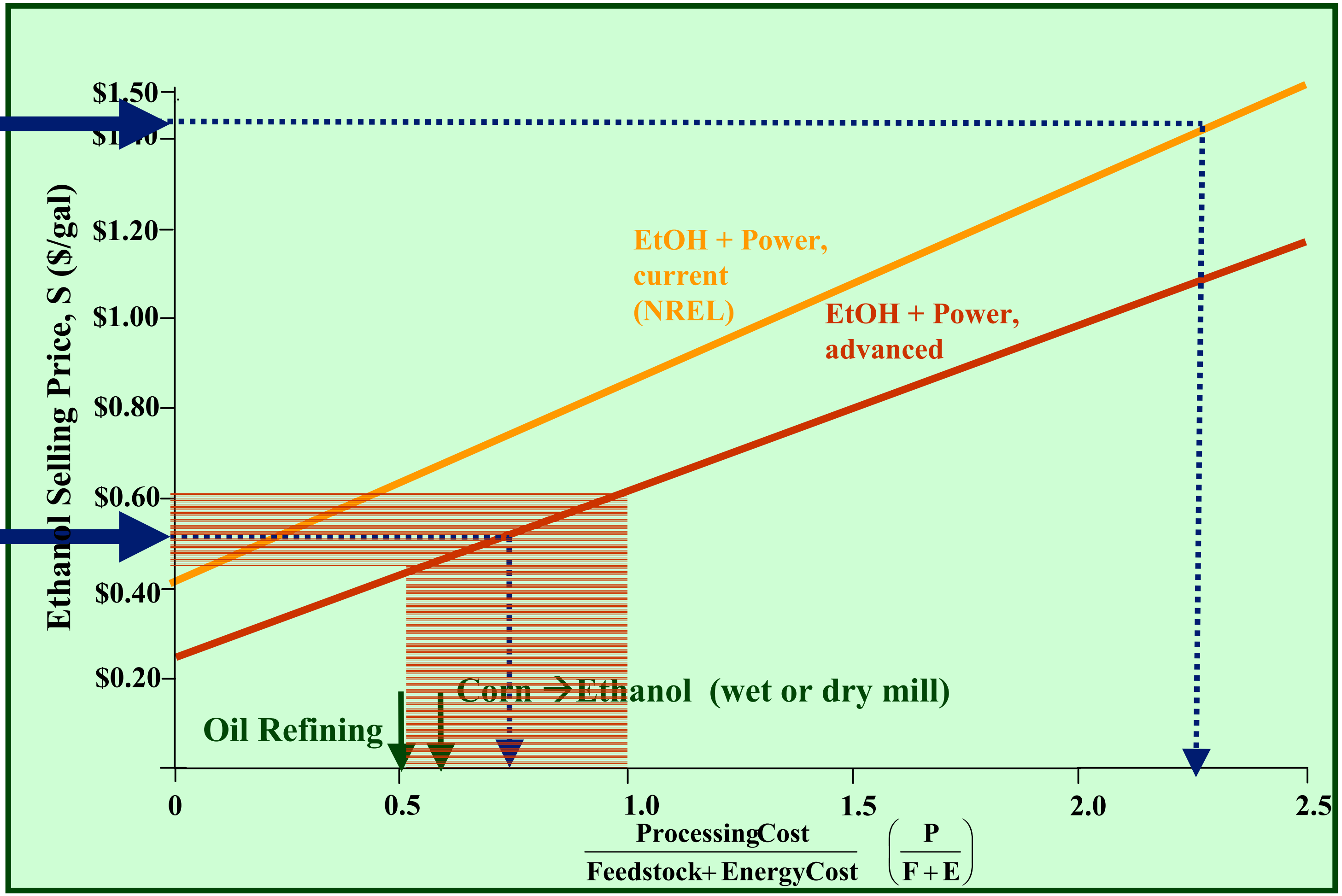
$F = \ cost\ \ of\ feedstock$

$E = \ cost\ of\ purchased\ processed\ energy$

The Selling Price of Ethanol Production via Mature Technology

NREL Base Case
Wooley et al., 1999
\$1.44/gal

Detailed design study, most likely case
Lynd et al., 1996
50 ¢/gal



Ethanol selling price exhibits a linear dependence on P/(F+E):

Without co-products:

$$S = \frac{1}{Y_{P/F}} P + \frac{(F+E)}{Y_{P/F}}$$

With co-products:

$$S = \left(\frac{1}{Y_{P/F}\left(1 - \sum_i f_i\right)} \right) P + \frac{(F+E) - \sum_i S_i \cdot f_i \cdot Y_{i/F}}{Y_{P/F}\left(1 - \sum_i f_i\right)}$$

$Y_{P/F}$ = gal ethanol/ton feedstock

f_i = fraction feedstock → i^{th} co-product

$Y_{P/F}$ = gallons ethanol/ton feedstock

S_i = \$/unit co-product

$Y_{i/F}$ = units co-product/ton feedstock

Consistent Cost Accounting Framework

To the extent possible, we will use the same framework for estimating both thermochemical and biological conversion process economics:

1. Capital cost. Will use common parameters unless there is a reason to do otherwise

- Conversion to base year dollars
- Multiple equipment train cost savings
- Balance-of-plant cost items and scale benefits
- Indirect cost/total direct capital ratio
- Construction period and start-up period

2. Calculate operating costs

3. Determine product price, using same:

- Capital valuation method (capital charge rate)
- Algorithm to account for co-product pricing/revenue

Bioethanol Process Scenarios

Scenario	Status of simulation	Status of cost estimate
Base-case EtOH/Rankine power (A)		
Base-case EtOH/Rankine power (B)		
Advanced EtOH/Rankine power		
Advanced EtOH/Advanced power		
Advanced EtOH/Advanced power/TCF		
Advanced EtOH/Advanced power/H2		
Advanced EtOH/Advanced power/Protein		
Other combinations of above scenarios		

Beginning *Completed*