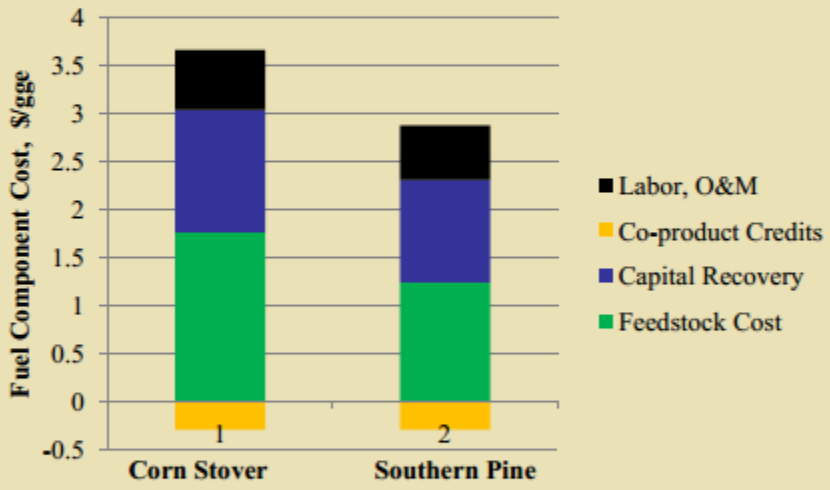
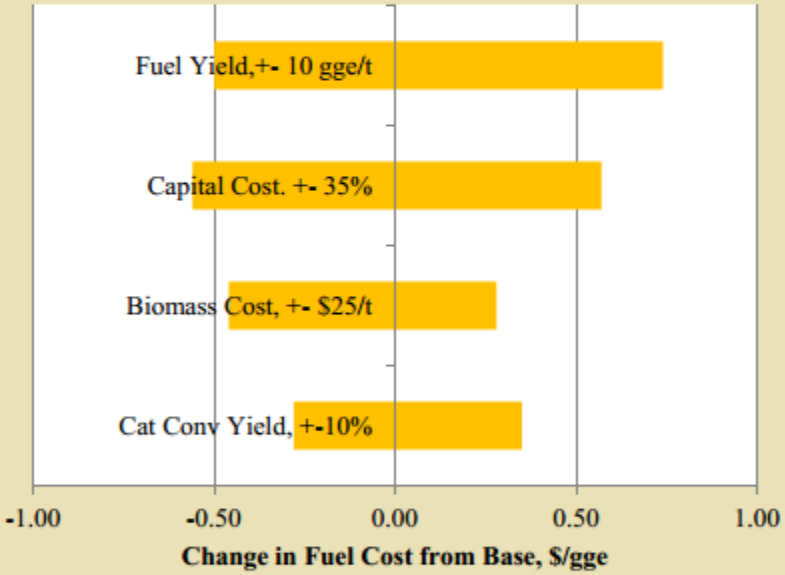
Fast Pyrolysis: Techno-Economics

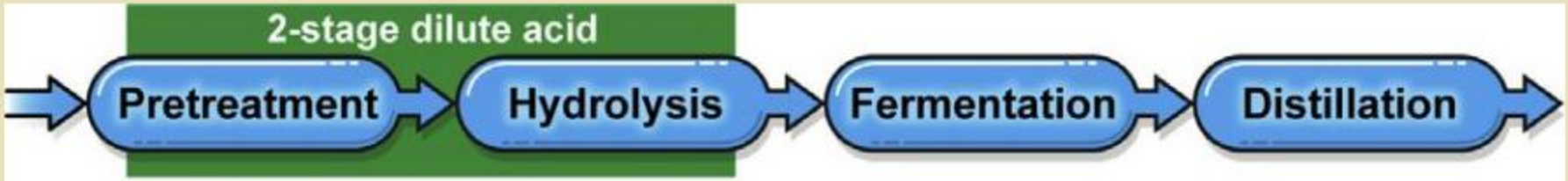
Fuel Cost



Cost Sensitivity

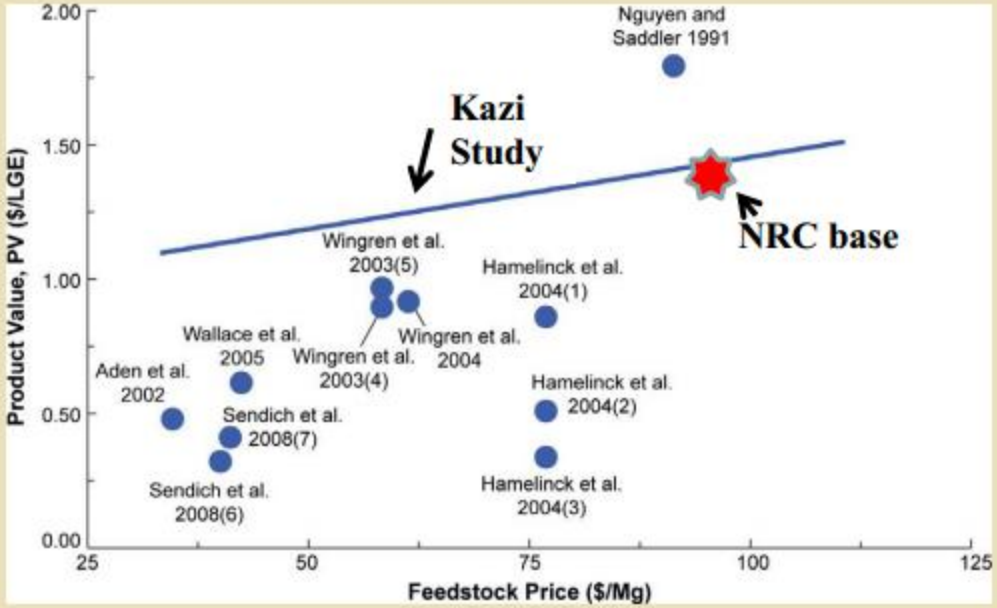


Biochemical: Cellulosic Ethanol



- Technology is pre-commercial
- Several demonstration plants are in various stages of start-up, exploring various options for pretreatment/hydrolysis steps
- Biomass cellulose and hemicellulose hydrolysis to sugars is the most challenging step and represents more than 50% of the total conversion cost
- Last two steps are very similar to those used in corn grain or sugar cane conversion to ethanol and well understood, low in cost
- Cost of cellulase enzyme to free sugars from cellulose is the largest variable in current cost analyses
- Capital cost is on the low end of capital cost for bio-fuels processes

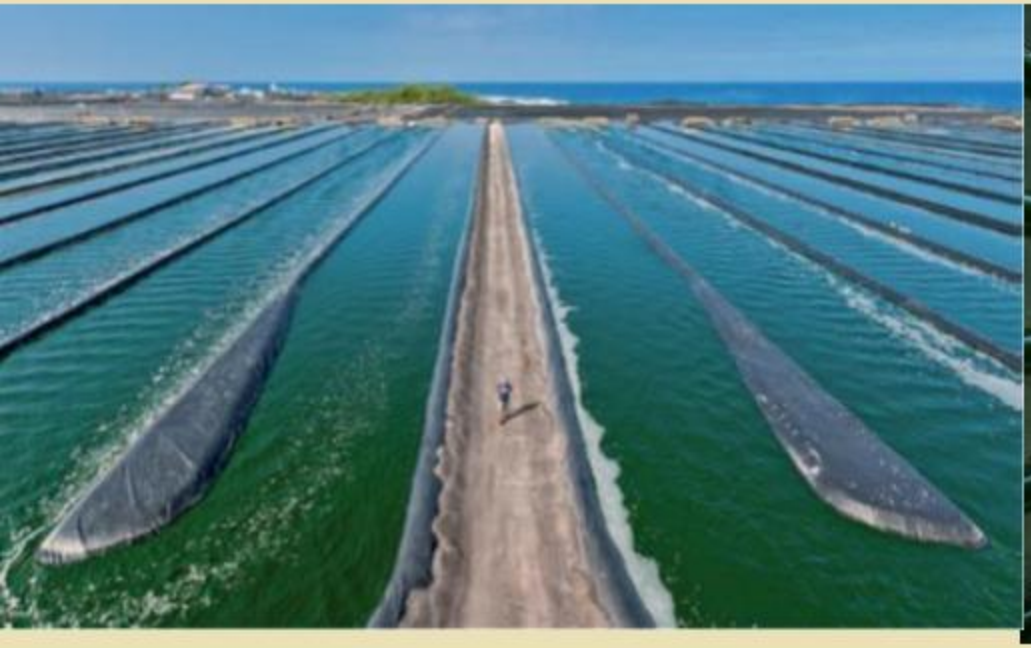
Biochemical: Cellulosic Ethanol



From Kazi et al., Fuel, 2010

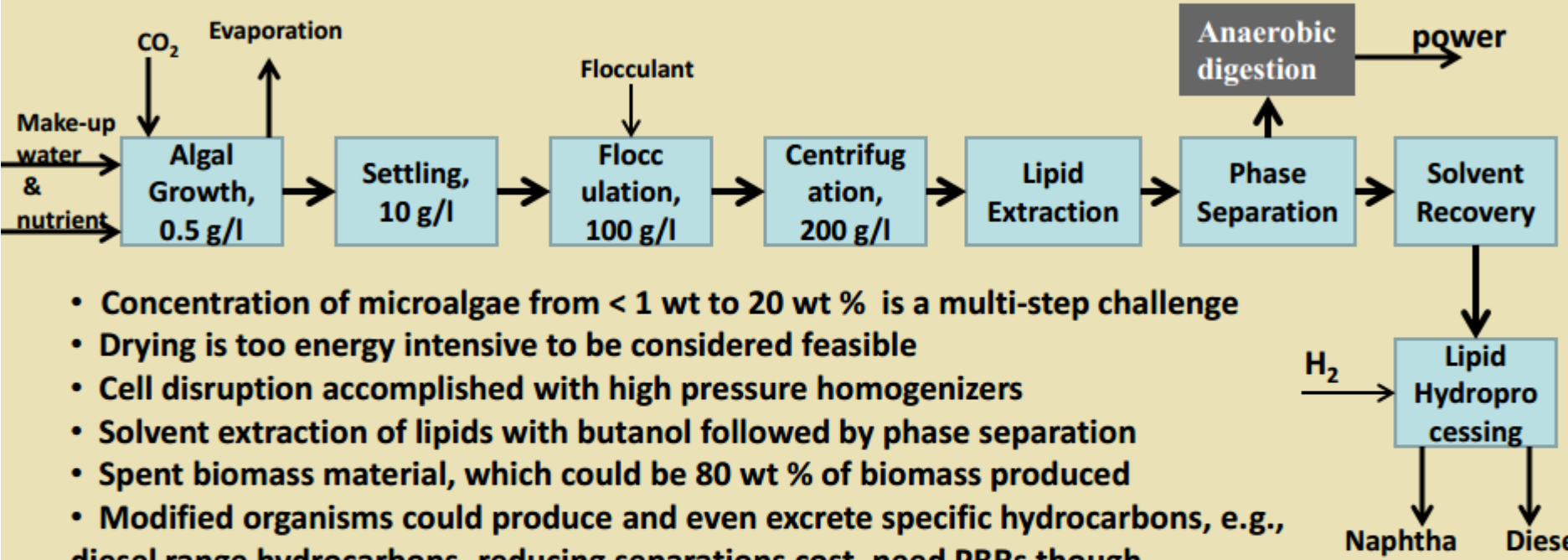
- Estimated cost on a comparable economics basis is about $5.10/gge
- Ethanol is not a “drop-in” fuel and has infrastructure challenges to overcome
- More development needed

Biochemical: Algal-Based Fuels



- Algal production of other specialty chemicals, beauty products, drugs currently exits
- Growth rates of 20 to 50 g(dry)/m^2/day observed; 25 g/m^2/day reasonable estimate
- Lipid content of10 to 50 wt(dry)% demonstrated; 25 wt % a good estimate
- Reduced-nutrient growth increases lipid content but reduces growth rate
- Observed growth rates are well below calculated maximum growth rate
- Very low starting biomass concentration challenges separation

Biochemical: Algal-Based Fuel Process



- Concentration of microalgae from < 1 wt to 20 wt % is a multi-step challenge
- Drying is too energy intensive to be considered feasible
- Cell disruption accomplished with high pressure homogenizers
- Solvent extraction of lipids with butanol followed by phase separation
- Spent biomass material, which could be 80 wt % of biomass produced
- Modified organisms could produce and even excrete specific hydrocarbons, e.g., diesel range hydrocarbons, reducing separations cost, need PBRs though

Open Pond:

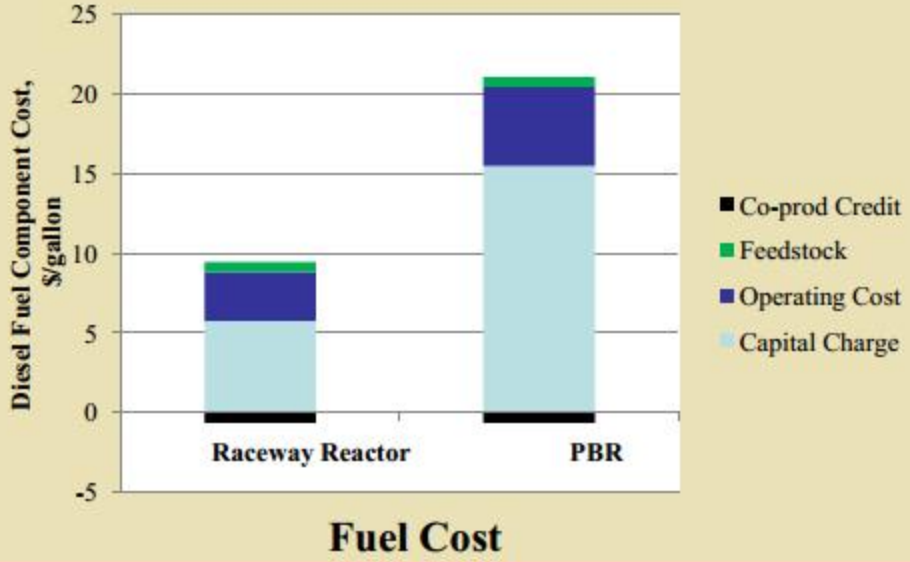
- Capital costs distributed evenly across the total system
- Water consumption is about 300 bbl/bbl of fuel

Closed photobioreactor:

- Capital cost dominated by reactor cost which is ~15-fold higher than than open-pond system; total capital cost is about 3-fold higher
- Energy consumption for pumping fluids through tubes very high
- Water consumption is about 90 bbl/bbl of fuel

Biochemical: Algal-Based Fuel Cost

GREENFUEL'S CLOSED SYSTEM ALGAE BIOREACTOR



Fuel Cost

- Technology is pre-commercial
- Fuel costs driven by capital costs
- Lipid content and growth rate have the largest impact on cost
- Near term by-products can help economics; for fuel scale application major biological and engineering advancements needed