Biomass Feedstocks

$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2$$

Potential : 15% of the world's energy by 2050.

Fischer and Schrattenholzer, *Biomass and Bioenergy* 20 (2001) 151-159.

Crop residues
Forest residues
Energy crops
Animal waste
Municipal waste

Issues: Biomass Availability, Cost and Physical and Chemical Properties

Biorefineries of the Future

Biomass Feedstocks

- Trees
- Grasses
- Bio-product Crops
- Agricultural Crops
- Agricultural Residues
- Animal Wastes
- Municipal Solid Waste

Conversion Processes

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Gasification
- Product Synthesis from Syn-gas
- Combustion
- Co-firing

Products

Fuels:
- Ethanol
- Renewable Diesel
- Methanol
- Hydrogen

Electricity

Heat

Chemicals:
- Plastics
- Solvents
- Pharmaceuticals
- Chemical Intermediates
- Phenolic Compounds
- Adhesives
- Furfural
- Fatty acids
- Acetic Acid
- Carbon black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Etc.

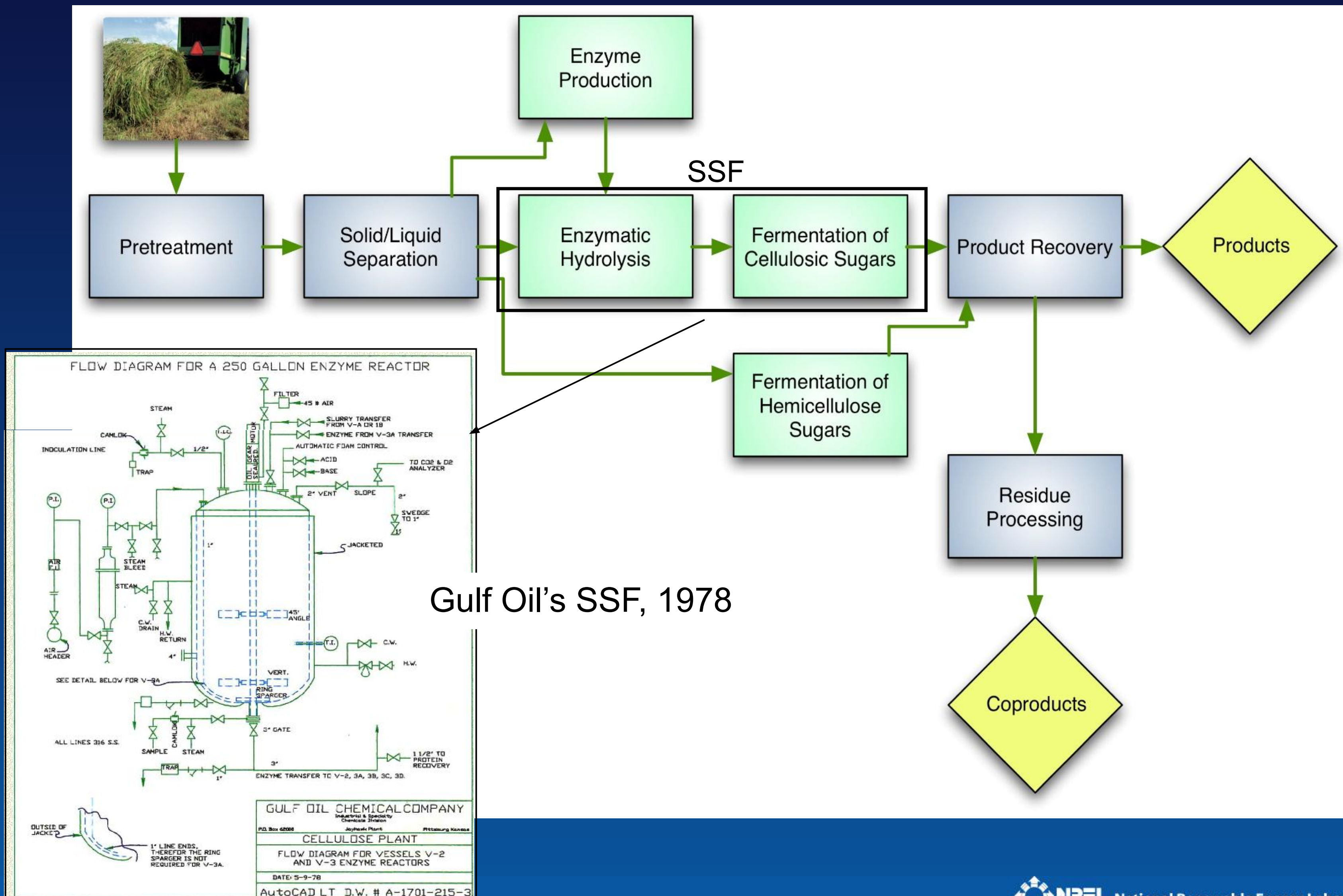
Biodiesel (B100)

- ASTM PS 121 Biodiesel Fuel Standard
  - similar to ASTM D 975
- Used pure or blended with #2 or #1 diesel, JP8, Kerosene, or Jet A.
  - Use pure or blends in existing diesel engines
    - on road, marine, off road, stationary, turbines, air craft
  - B100 has 10% less energy than #2 diesel
  - Power loss and fuel economy loss
    - 1% for every 10% biodiesel in fuel
  - Reduces CO, PM, toxicity of PM, and HC emissions

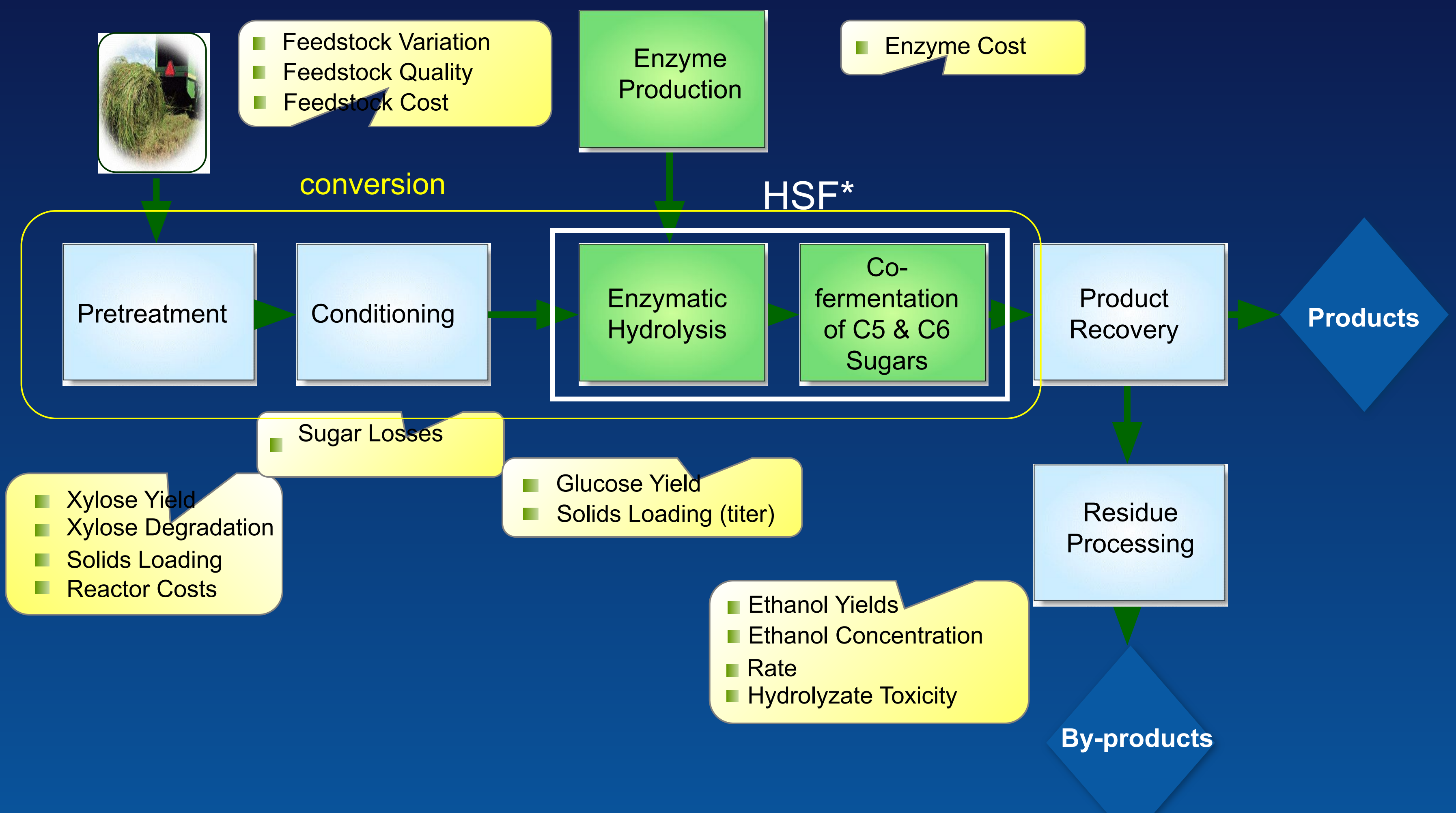
Handles Just Like Diesel

- No engine modifications required for B20, if using B100 then:
  - rubber seals may deteriorate
  - metals (Zn, Cu, W, bronze, brass) lead to oxidation
- Storage stability up to 6 months
- More sensitive to cold weather (Cloud pt = 0^oC)
- Cetane number = 47 to 70
- No sulfur, no aromatics, 11% oxygen by wt
- Stays blended even in presence of water
- Use biocides if needed

Next Generation Biology will Reduce Costs of Cellulosic Ethanol Production: SSF



Technical Barrier Areas for $1.07 Biochemical Ethanol

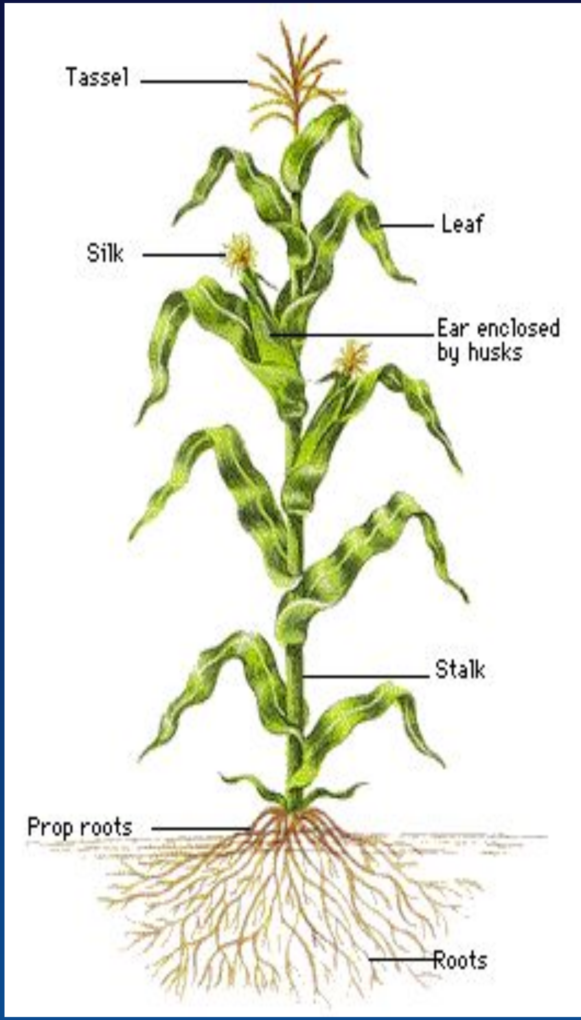


*Hybrid Saccharification & Fermentation - HSF

NREL National Renewable Energy Laboratory

Feedstock Engineering

- ✔ Increase crop production (agronomics and plant engineering)
- ✔ Increase composition of desirable polysaccharides (cellulose)
- ✔ Decrease composition of undesirable polymers (lignins)

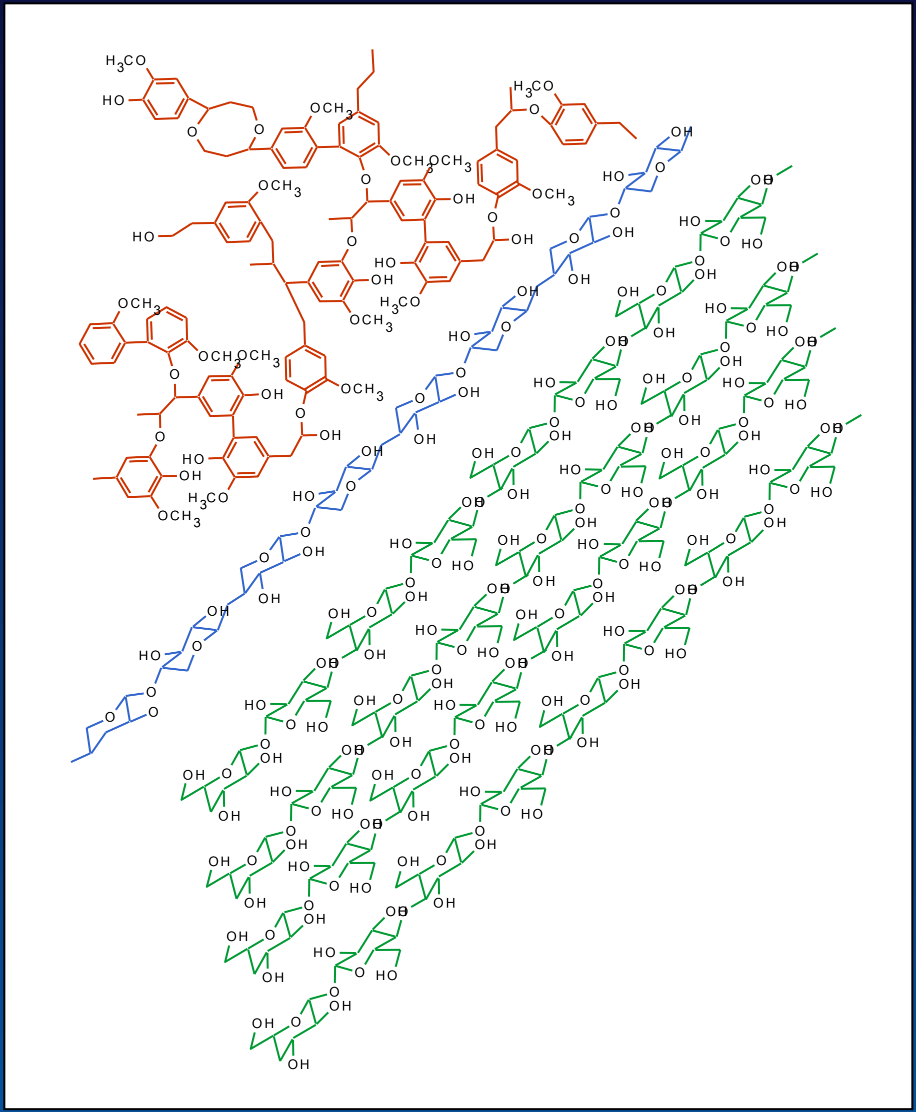


www.nefb.org/ ag-ed/corn.html

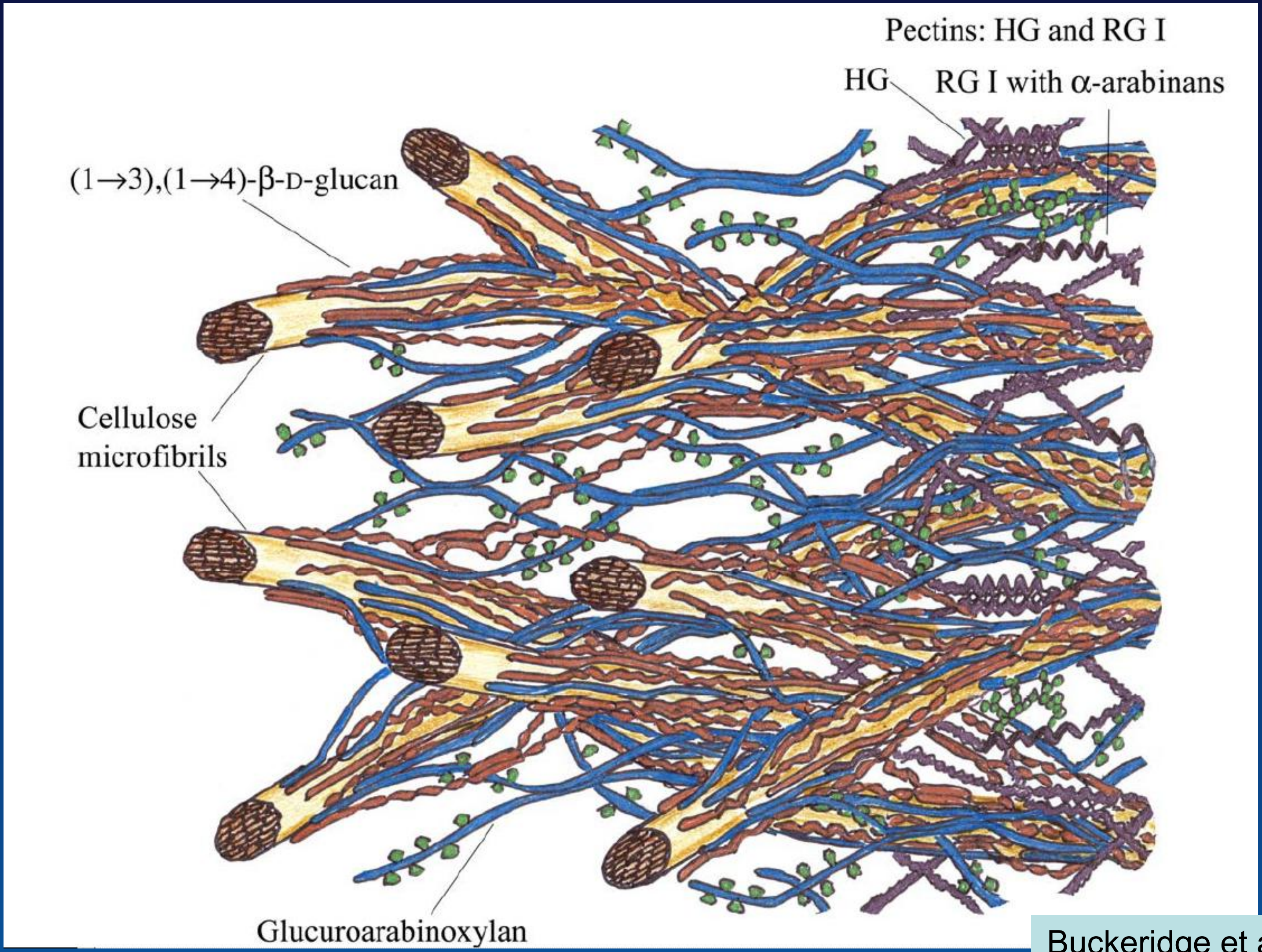
Glucan	36.1 %
Xylan	21.4 %
Arabinan	3.5 %
Mannan	1.8 %
Galactan	2.5 %
Lignin	17.2 %
Protein	4.0 %
Acetyl	3.2 %
Ash	7.1 %
Uronic Acid	3.6 %
Non-structural Sugars	1.2 %

Constituents of Biomass

- Lignin: 15%–25%
  - Complex aromatic structure
  - Very high energy content
  - Resists biochemical conversion
- Hemicellulose: 23%–32%
  - Xylose is the second most abundant sugar in the biosphere
  - Polymer of 5- and 6-carbon sugars, marginal biochemical feed
- Cellulose: 38%–50%
  - Most abundant form of carbon
    in biosphere
  - Polymer of glucose, good biochemical feedstock

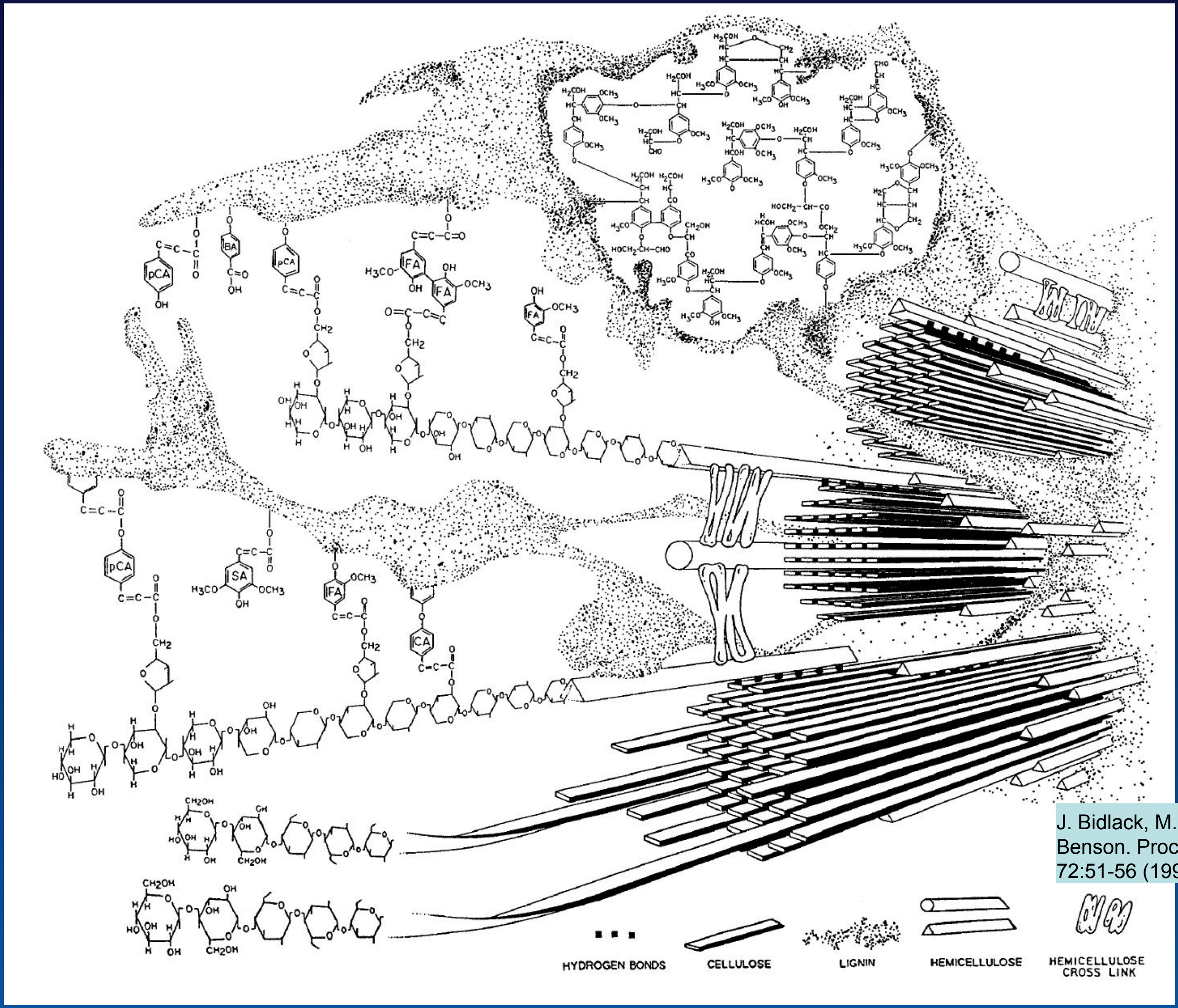


Plant Cell Wall Models



Buckeridge et al., 2004

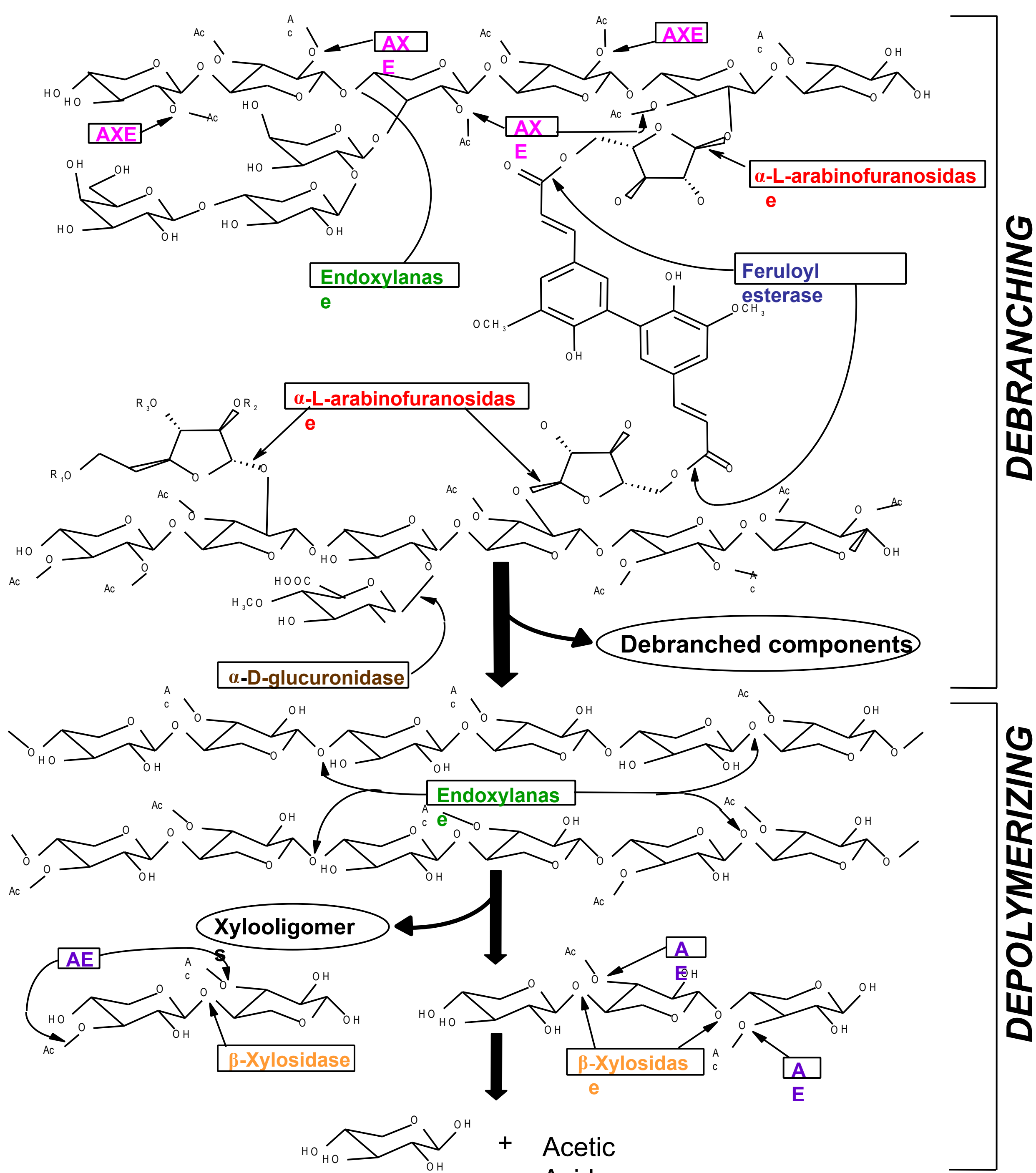
Plant Cell Wall Models



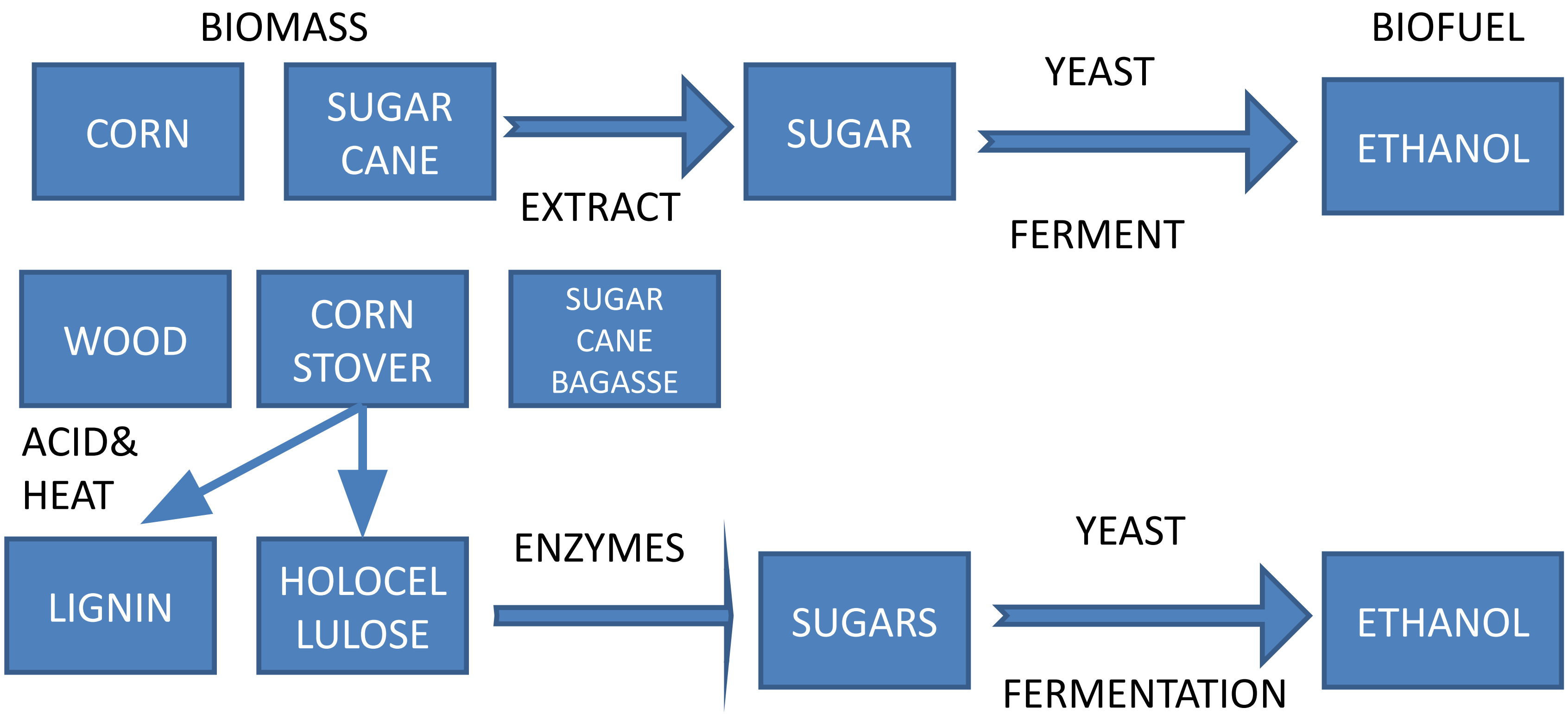
J. Bidlack, M. Malone, and R. Benson. Proc. Okla. Acad. Sci. 72:51-56 (1992)

Hemicellulose Structure

- Complicated branching and bond structure
  - Affect solubility and enzyme accessibility
  - Different bonds affected by different pretreatments
    - i.e. Esters cleaved at alkaline pH, elevated T°
- Highly variable across species
  - Xylans, mannans
  - Glucomannans
  - Xyloglucans
  - Etc.

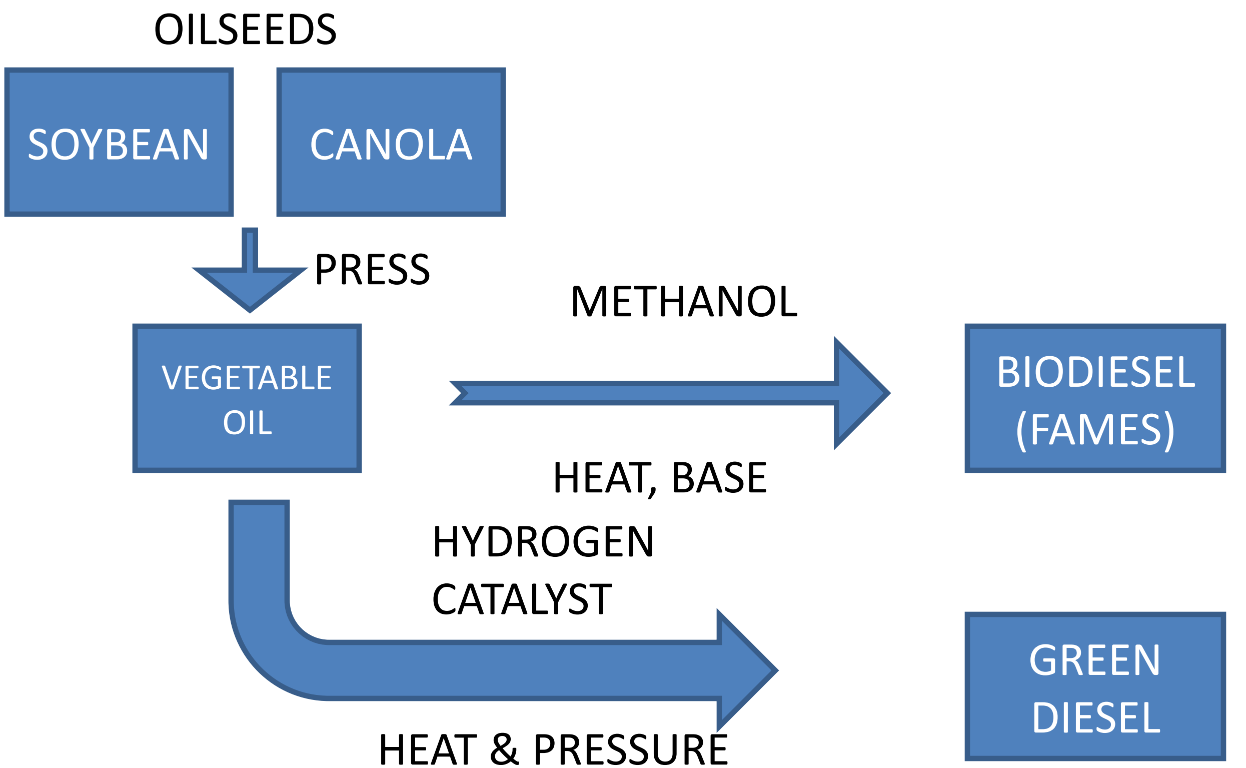


Biofuels from Biomass



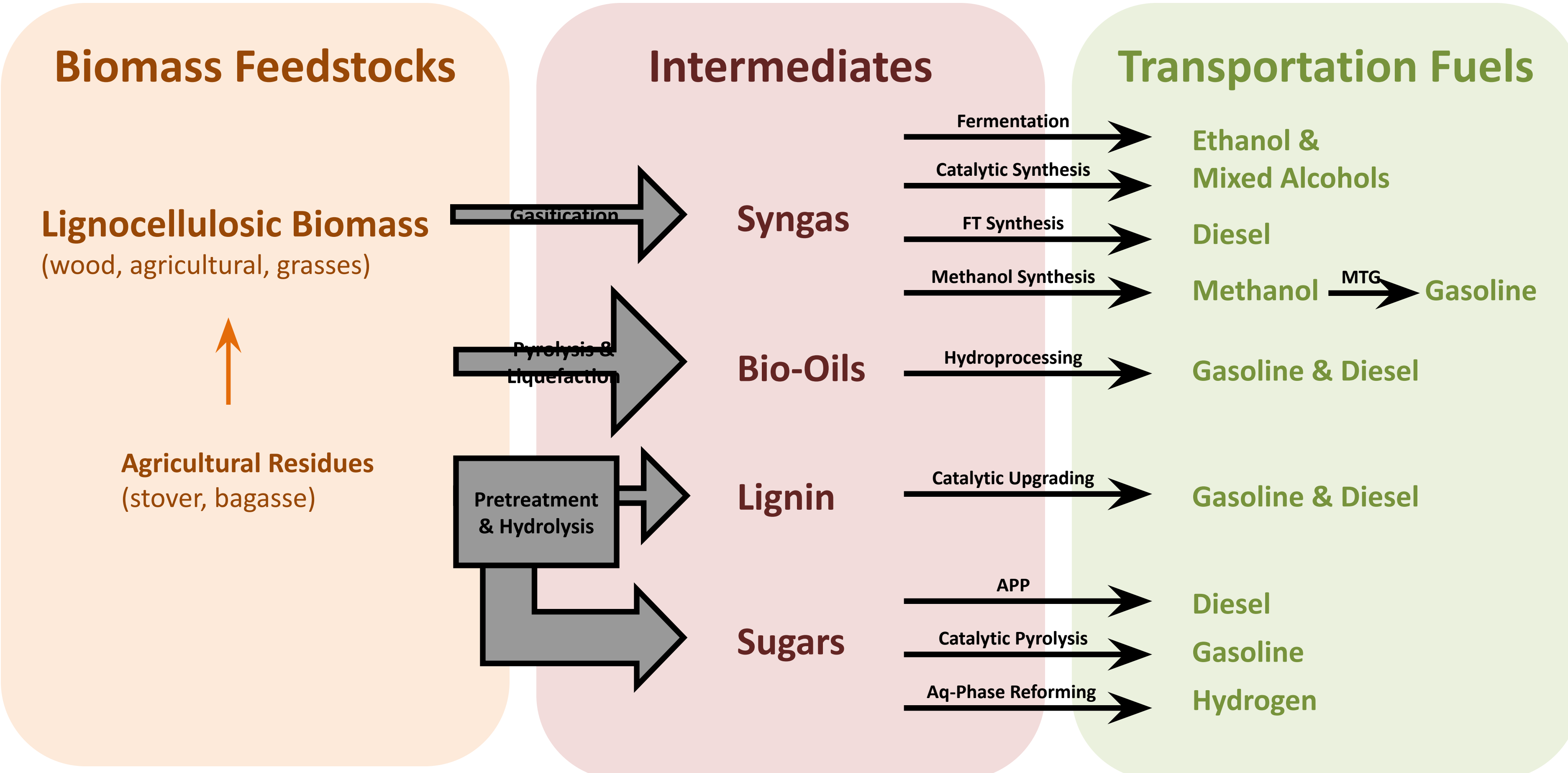
- Other organisms produce butanol or isobutanol

Diesel Biofuels from Biomass



- Green diesel is virtually identical to petroleum-derived diesel, can make a true jet fuel as well

Thermochemical Pathways



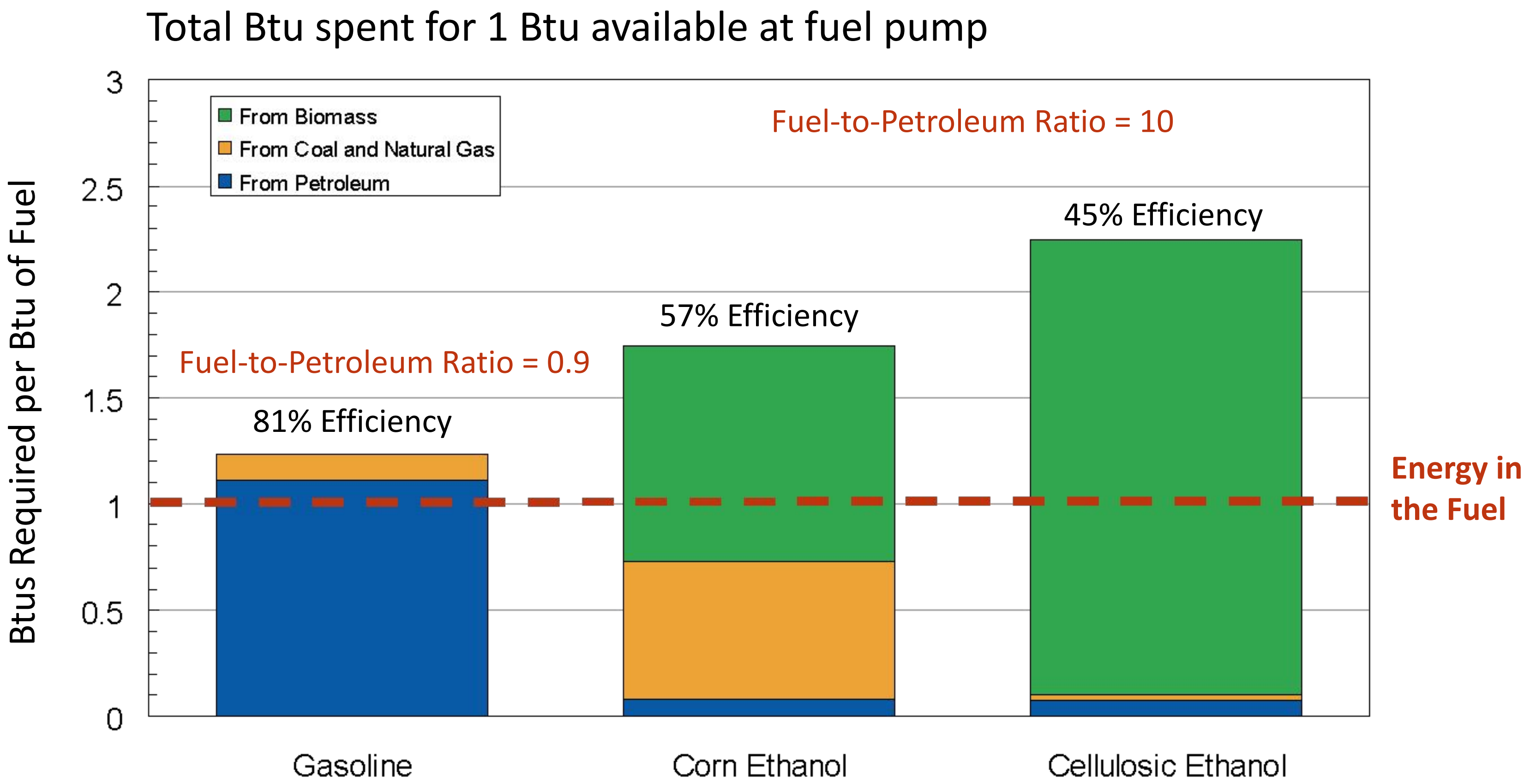
- Gasification is high temperature with air or steam
- Pyrolysis is moderate temperature

Comparison of feeds and processes

- Biochemical is low temperature but long times
- Thermochemical is high-throughput but high temperature and sometimes high pressure
- Not enough sugar except perhaps sugar cane in Brazil
- Oil-seed yields too low for high impact
- Ligno-cellulosic feeds high yields but more difficult to process
- Algae has high yields but many processing difficulties

Sustainability of Cellulosic Ethanol

Requires Much Less Fossil Energy Than Gasoline from Petroleum or ethanol from corn

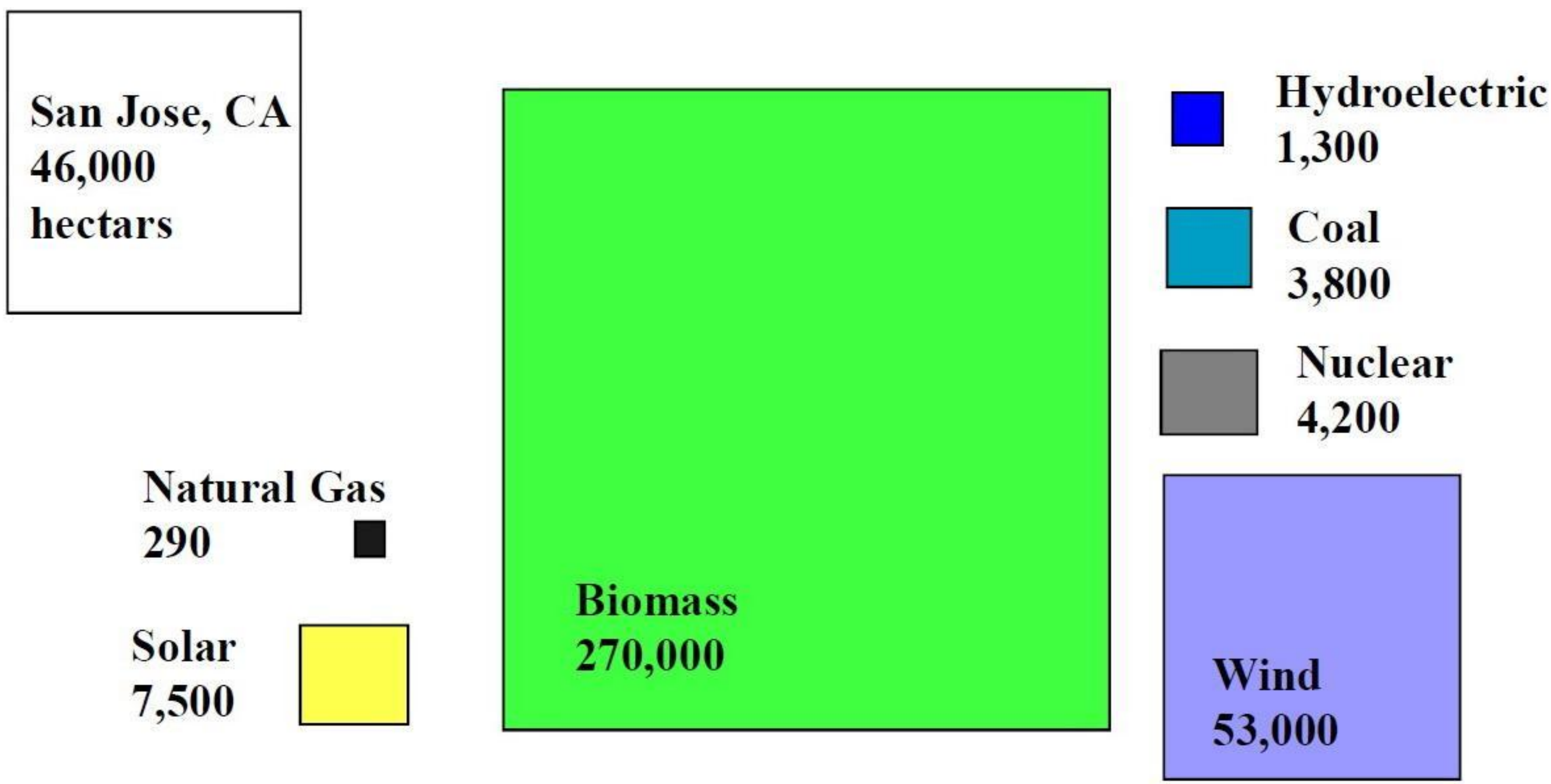


Based on "Well to Wheels Analysis of Advanced Fuel/Vehicle Systems" by Wang, et. al. (2005)

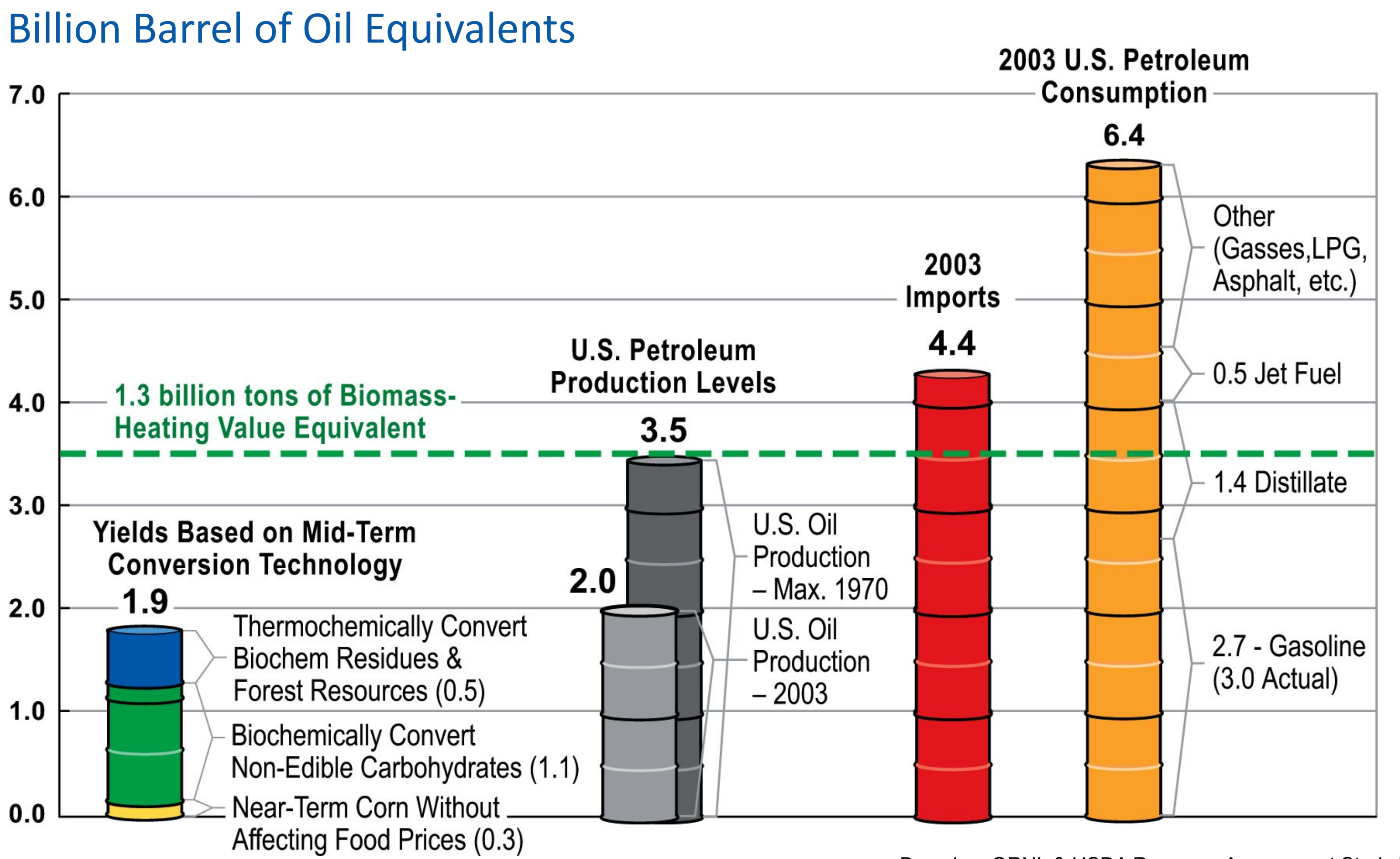
Is there enough land?

- If biomass competes with food crops for farm land, then food prices will rise causing the poor to suffer

Scaling Up Alternative Energy
(City of San Jose, pop. 1 M; power use - 740 MW)
Land needed, in hectars, to power San Jose



The 1.3 Billion Ton Biomass Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Have enough land to replace a large amount of oil but still need appropriate import and agriculture policies to prevent driving up fuel prices and getting too much fossil input into biofuels

When will the fuels come?

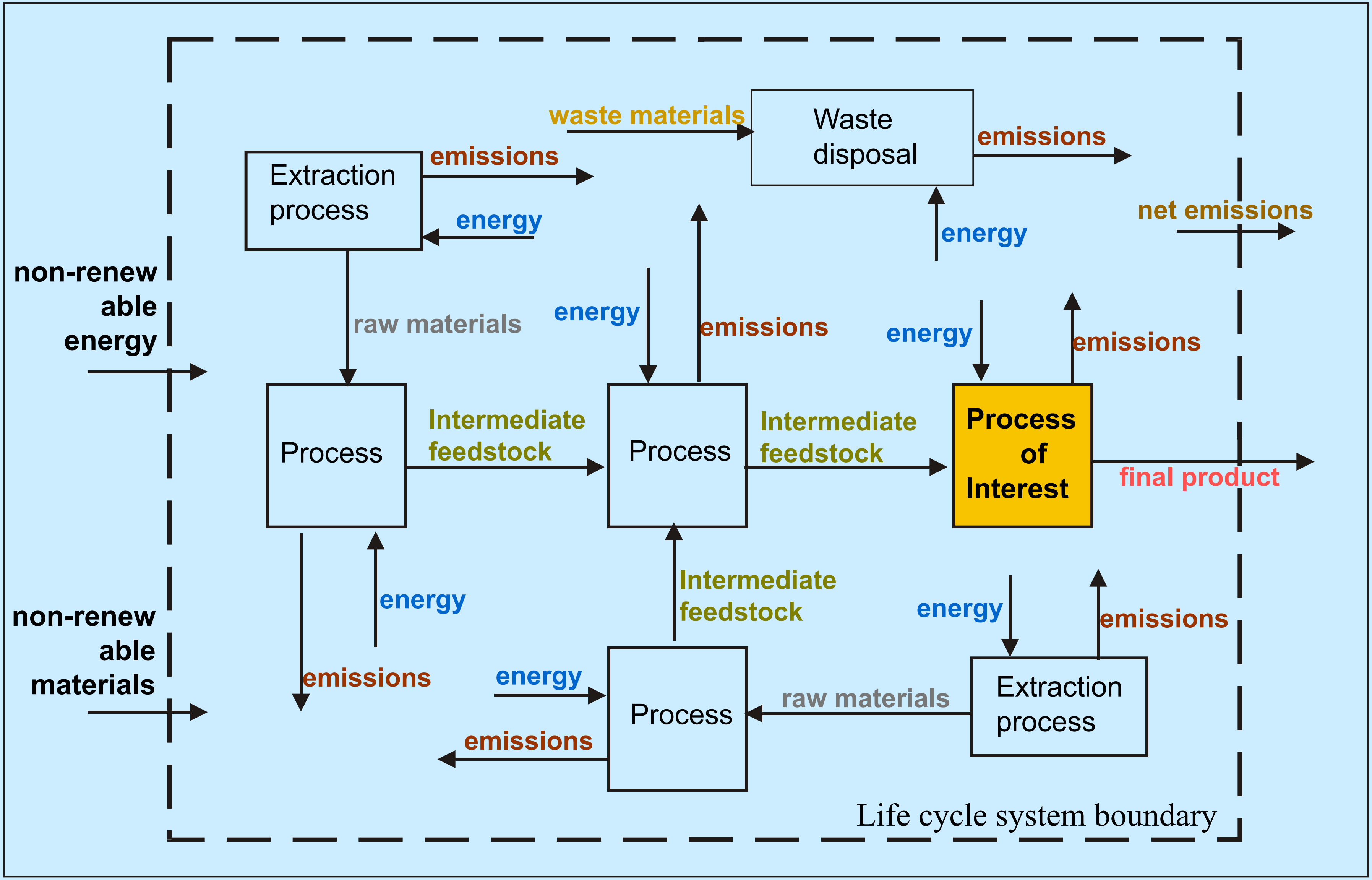
- Corn ethanol and biodiesel are here now to some extent
- Cellulosic ethanol, mixed alcohols, and green diesel are rather near, 15% ethanol will be allowed in near future
- Hydrocarbons from biomass are further away
- Algal fuels are a long way off

Life Cycle Assessment: Definition

LCA

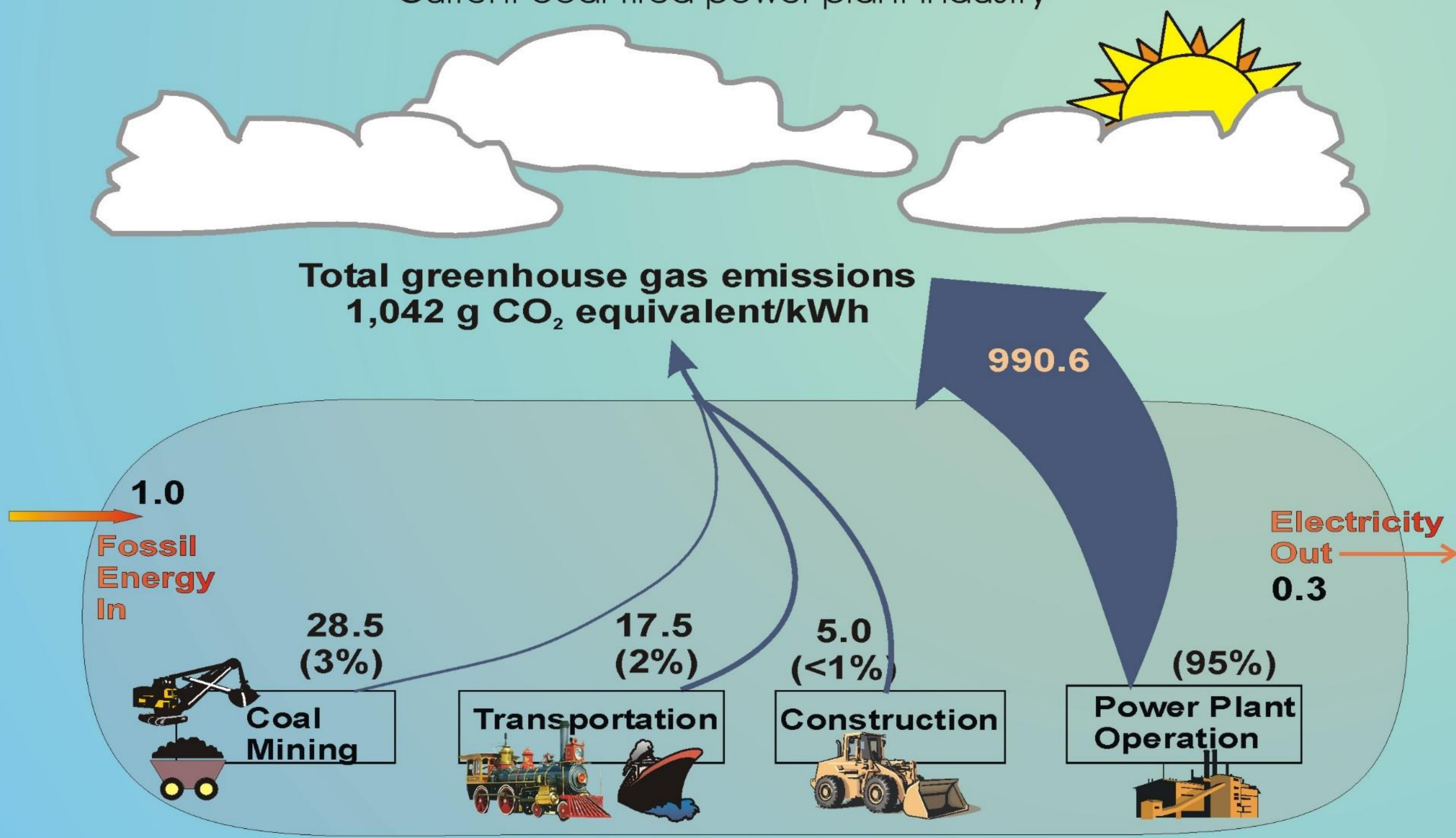
- Is a systematic analytical method
- Used to quantify environmental benefits and drawbacks of a system
- Performed on all operations, cradle-to-grave, resource extraction to final disposal
- Ideal for comparing new technologies to the status quo
- Helps to pinpoint areas that deserve special attention
- Reveals unexpected environmental consequences (no showstopping surprises)

System Concept in Life Cycle Assessment



Life Cycle GWP and Energy Balance for a Coal-fired Power System

Current coal-fired power plant industry

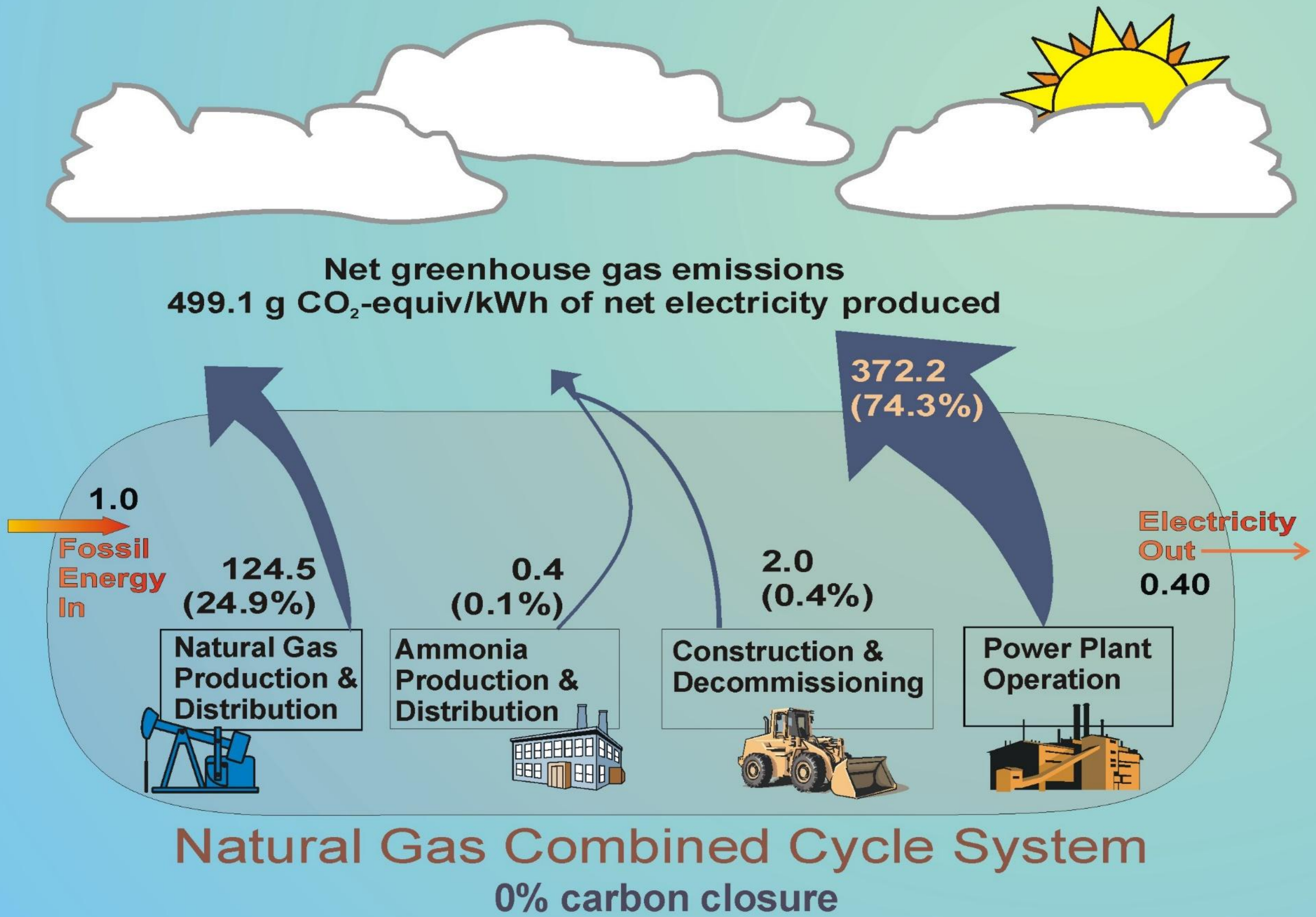


Coal Power System

0% carbon closure

GWP = global warming potential

Life Cycle GWP and Energy Balance for a Natural Gas Combined-Cycle System

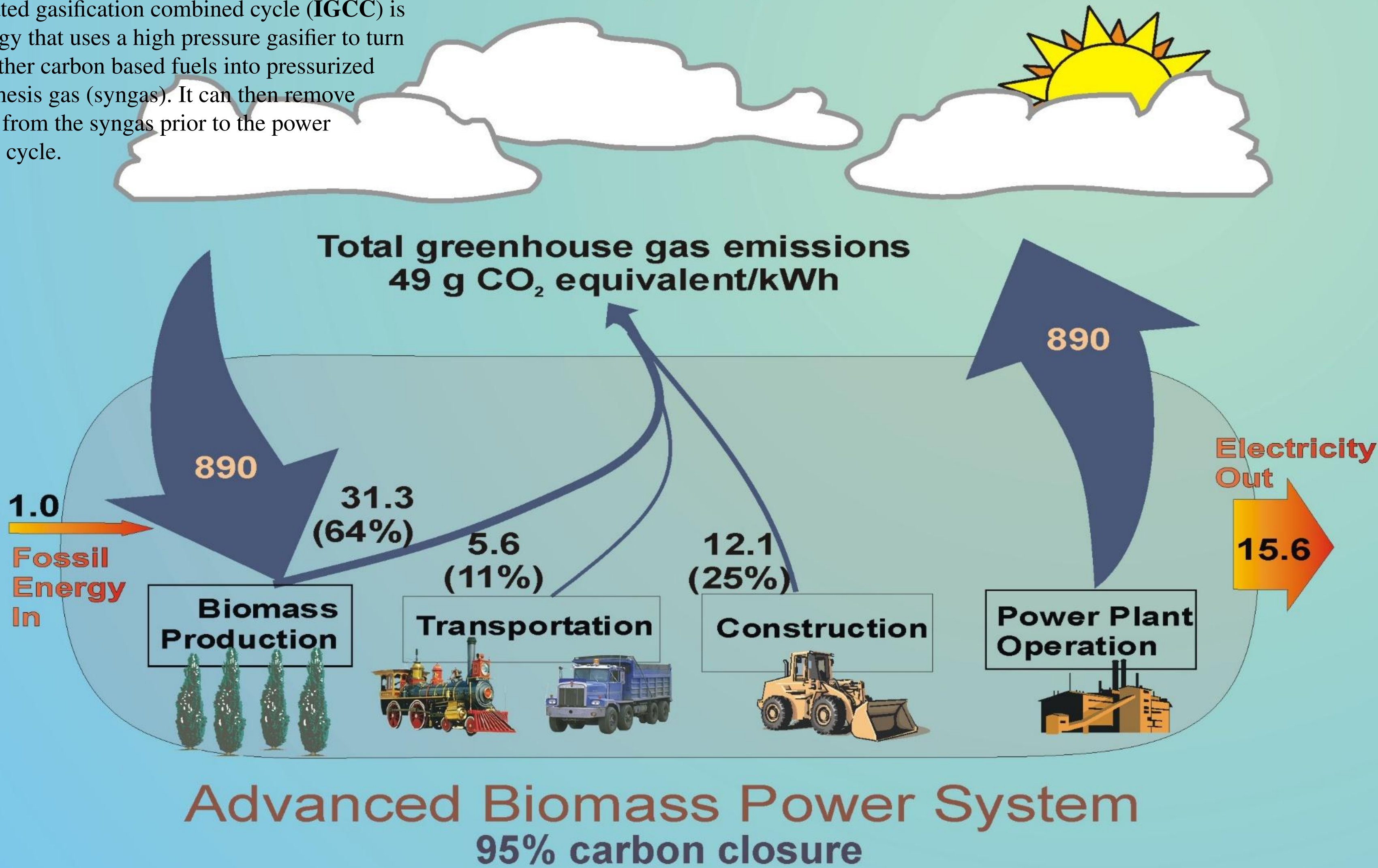


GWP = global warming potential

Life Cycle GWP and Energy Balance for Advanced IGCC Technology using Energy Crop Biomass

Future, wide-spread potential

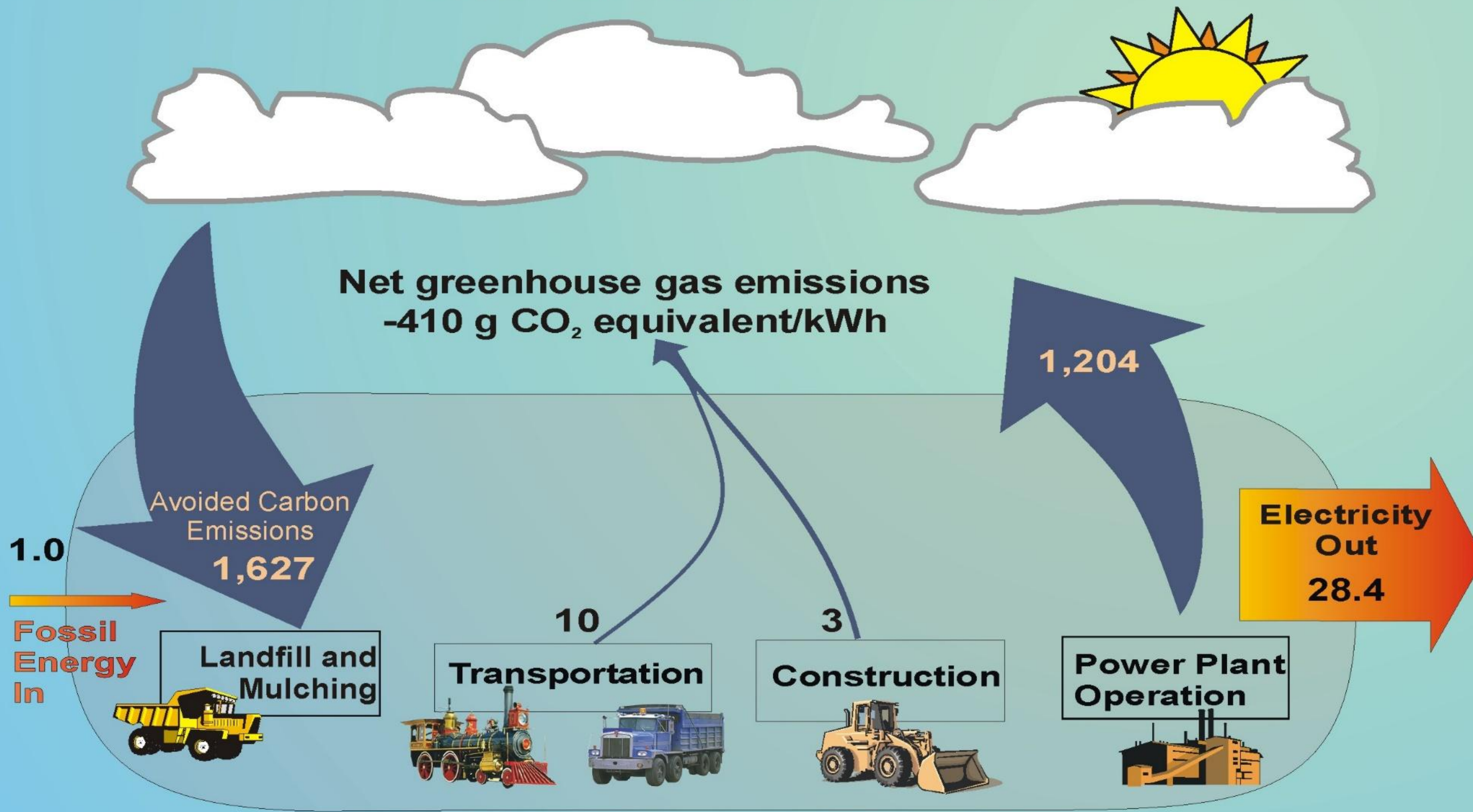
An integrated gasification combined cycle (**IGCC**) is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas—synthesis gas (syngas). It can then remove impurities from the syngas prior to the power generation cycle.



GWP = global warming potential

Life Cycle GWP and Energy Balance for a Direct-Fired Residue-Biomass Power System

Current biomass power industry



Direct-Fired Biomass Residue System

134% carbon closure

GWP = global warming potential

Summary

- Energy is the driver of everything we do in today's society
- Energy has an enormous impact on the environment
- Looking at the emissions of the production plant is not enough
- LCA allows us to evaluate the broader environmental impacts
- Renewable energy
  - Not zero impact, but lower and more sustainable
  - Different impacts; be careful of shifts (e.g., CO2 to land-use)
  - Often more distributed impact
- Solutions do exist to reduce our energy / environmental problems