The Contribution of High Value Lignin to the Economics of a Lignocellulosic Biorefinery

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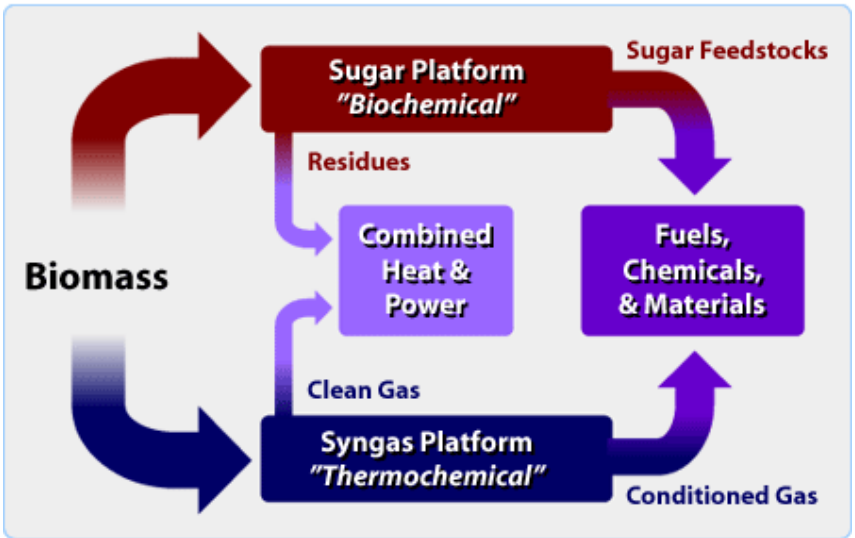
Biorefineries for Lignocellulosic Biomass

- Definition of Biorefinery

NREL has defined a biorefinery as…

"a facility that integrates biomass conversion processes and equipment to produce fuel, power and chemicals from biomass".[1]

Biorefinery Concept



1. National Renewable Energy Laboratory web sit, www.nrel.gov/biomass/biorefinery

Pulp mills are biorefineries

- Kraft and sulfite pulp mills qualify as simple biorefineries
  - most produce chemicals (pulp) and steam and power (from liquor burning in a recovery boiler)
  - some pulp mills produce additional chemicals; tall oil, turpentine, kraft lignin, lignosulfonates, even ethanol from hemicellulose sugars (sulfite)
  - the N. American pulping industry is now seeking revenue opportunities from additional by-products, moving basic pulp mills closer to today's biorefineries

Biorefinery Development

- New biorefinery technologies for woody biomass now under development
- Focus on production of ethanol and other sugar platform chemicals from the cellulose and hemicellulose fractions of biomass
- In most cases residues are burnt
- But economics are challenging, except at very large scale

What is woody biomass?

- Wood, agricultural residues, grasses…
- Woody biomass consists of three major polymers that are physically integrated and chemically bonded
  - Cellulose (~35% to 50%)
  - Hemicellulose (~25% to 35%)
  - Lignin (~12% to 30%)

Biorefinery pretreatment options

- Pretreatment is required to expose the cellulose and hemicellulose to enzymatic hydrolysis to simple sugars
  - disrupting the physical structure of the biomass.
- Typically the first process step in a biorefinery :
  - steam explosion, with or without acid pretreatment
  - mechanical disintegration
  - acid treatment
  - organosolv treatment
- Of these only organosolv delignification removes the lignin from the fibre.

The Fate of Lignin in Biorefineries

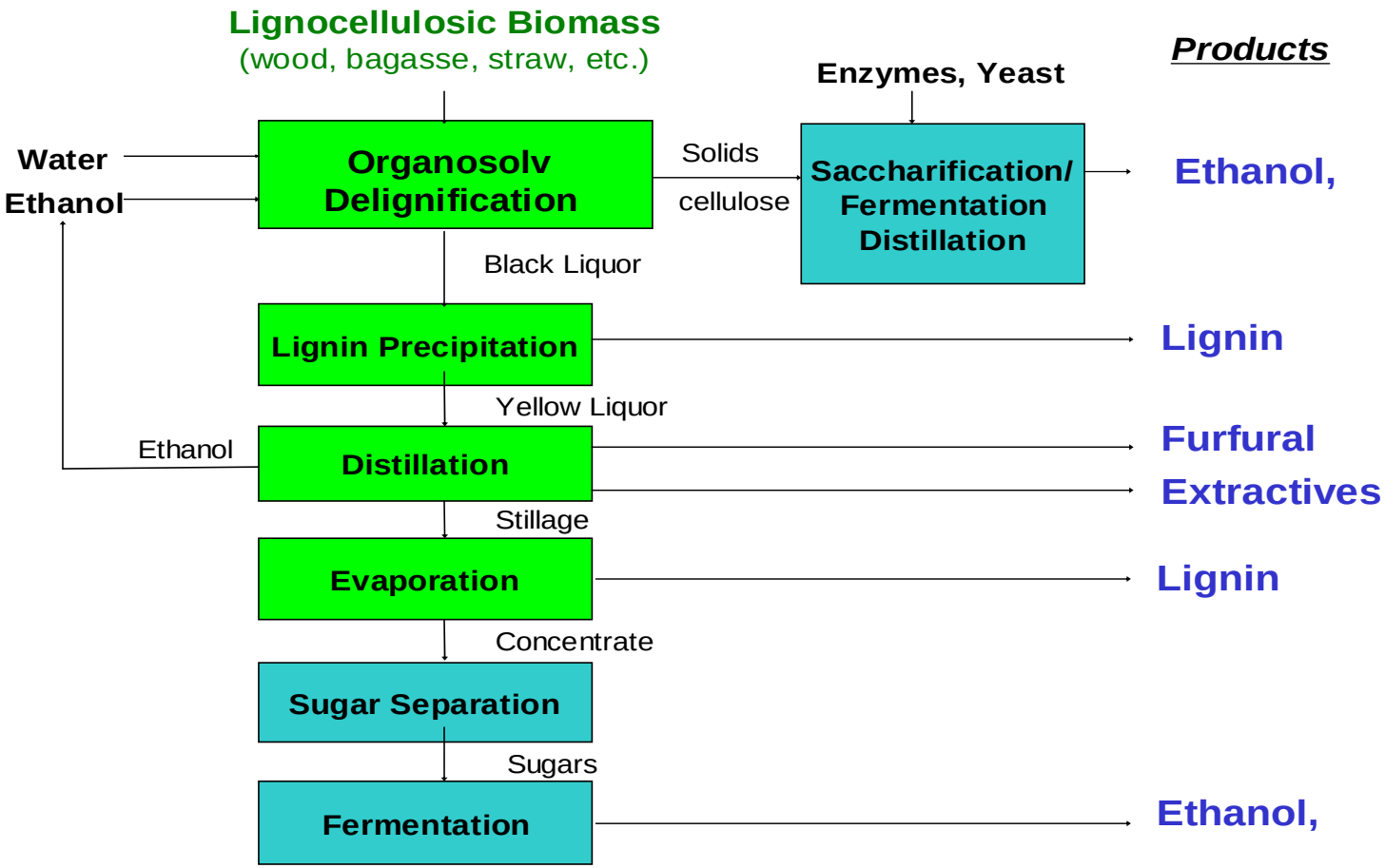
- In all biorefinery pretreatment processes, except organosolv, the lignin remains with the cellulose and hemicellulose
- Disadvantages:
  - Lignin can inhibit the activity of cellulase and hemicellulase enzymes used in hydrolysis of polysaccharides
  - Larger amounts of costly enzymes are required for effective saccharification
  - After saccharification the lignin fraction remains as an impure residue highly contaminated with residual cellulosic fiber
- Impure lignin residue has found little value other than as a boiler fuel

The Lignol Biorefinery Process

- After organosolv pretreatment, lignin is recovered as a pure and valuable co-product
- Process originated as the Repap/Alcell organosolv pulping process

Alcell Demonstration Plant – Miramichi, NB

The Lignol Biorefinery Process



Lignol Biorefinery Products

- Fuel grade ethanol
- Recovery of a pure form of lignin
  - Less than 0.5% sugar
  - Less than 0.1% ash
  - Approximately 3% moisture
  - Less than 0.3 ppm sulfur
  - Very low water solubility
  - Number Average Mol. Wt., approximately 850 daltons
- Recovery of furfural
- Other potential co-products

The Markets for Organosolv Lignin

- Thousands of tons of organosolv wood-based lignin sold by Repap/Alcell into high value markets (1991-97):
  - antioxidants in the formulation of lubricating greases and metal working fluids
  - partial substitute for phenol-formaldehyde (PF) resins in;
    - exterior grade wood panel production (OSB, plywood, etc.)
    - foundry mold resins
    - friction materials (brake linings, brake pads, clutch facings)
  - moisture barrier coatings in packaging materials (roll wrap, etc)
- Successful trials were undertaken for lignin in animal feeds, epoxy and urethane resins, rubber compounding agents, carbon fiber manufacture, etc.

Commercial Products from Organosolv Lignin

Value of Pure Lignin

- Based on the current prices of products being substituted by lignin, values for pure lignin can range from US$0.55 to $1.65 per pound, or more.

Application	Approximate value, US$/lb (CAD/kg)
Dry PF resin in wood panelboards	0.55 (1.34)
Foundry mold resins, friction materials	0.65 (1.59)
Heat resistant molding compounds	1.10 (2.68)
Hindered phenol antioxidant	1.65 (4.03)
Carbon fiber production	0.65 (1.59)

Potential Pure Lignin Markets are Huge

- Given the massive demand for fuel ethanol, are actual and potential markets for pure, co-product lignin sufficiently large?

  For each million litres of ethanol derived from wood approximately 800 tonnes of co-product lignin can be produced.

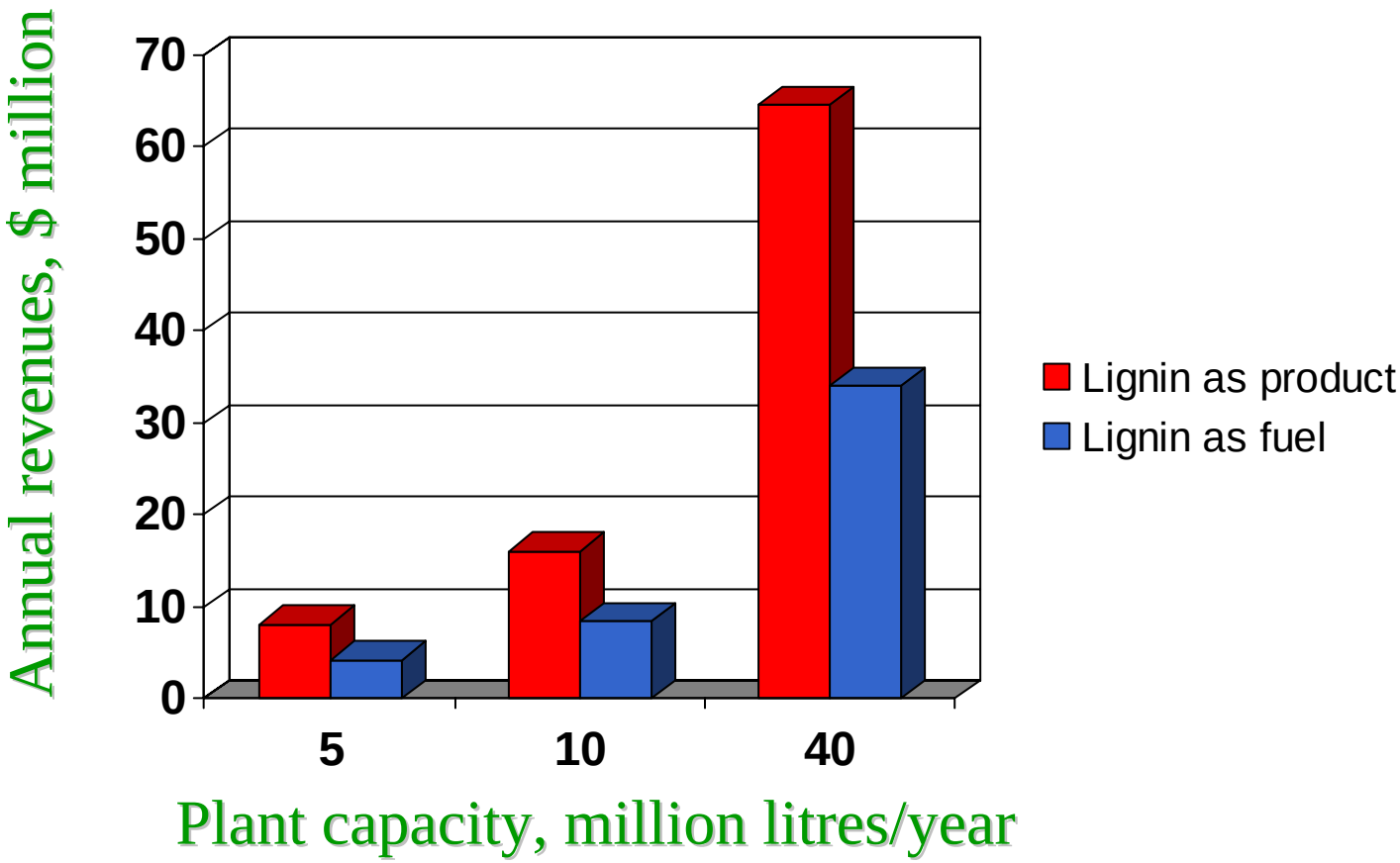
- Examples of current worldwide markets
  - PF and other resins — Approximately 3.5 million tonnes/yr
  - Surfactants, concrete, etc. — Approximately 2.5 million tonnes/yr
- Examples of developing worldwide markets
  - Mid-range carbon fibers — Approximately 20 million tonnes/yr
  - Animal feed additive — Massive potential
- Lignin value enhanced by substitution for oil-based materials and GHG reductions

Financial Impact of Organosolv Lignin on Biorefineries

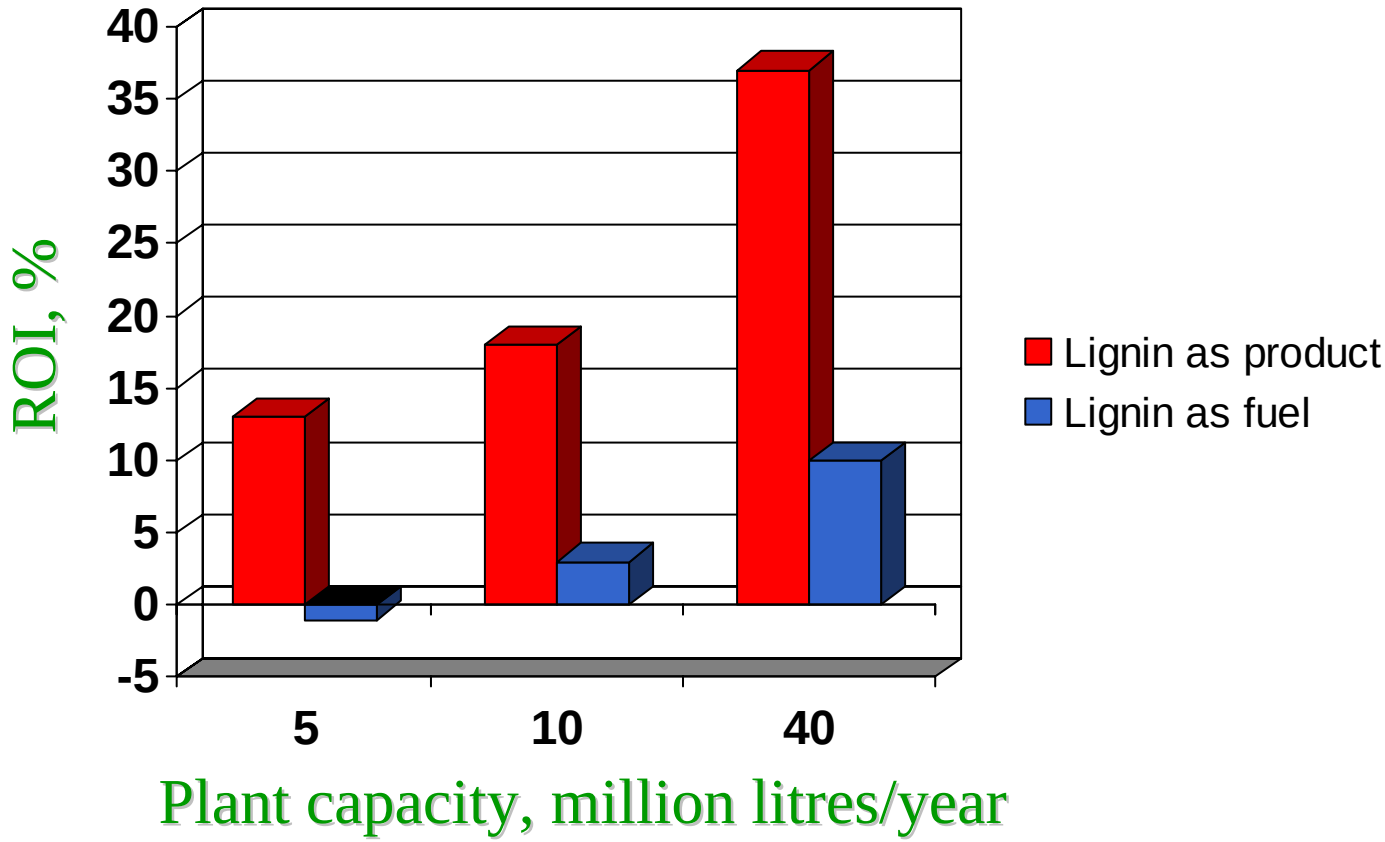
- Chemical Value using conservative market prices:
  - Ethanol: $0.70/l
  - Lignin: $1.30/kg
  - Furfural: $1.65/kg

- Fuel Value conservative view of lignin as fuel:
  - Wet lignin (67% TS) used to displace $8/GJ natural gas
  - Net fuel value of lignin: $0.22/kg

Annual Revenues of a Lignol Biorefinery



ROI of a Lignol Biorefinery



CONCLUSIONS

- The value of pure lignin as a chemical product is many times greater than its fuel value.
- Multiple, large, proven markets exist for wood–based organosolv lignin
- Revenues from sale of organosolv lignin co-product far exceed savings from use of lignin as fuel
- Lignin revenues provide a major boost for biorefinery economics
- Lignin creates economic performance that allows even relatively small biorefineries to be profitable.