From a Kraft mill to a Forest Products Biorefinery

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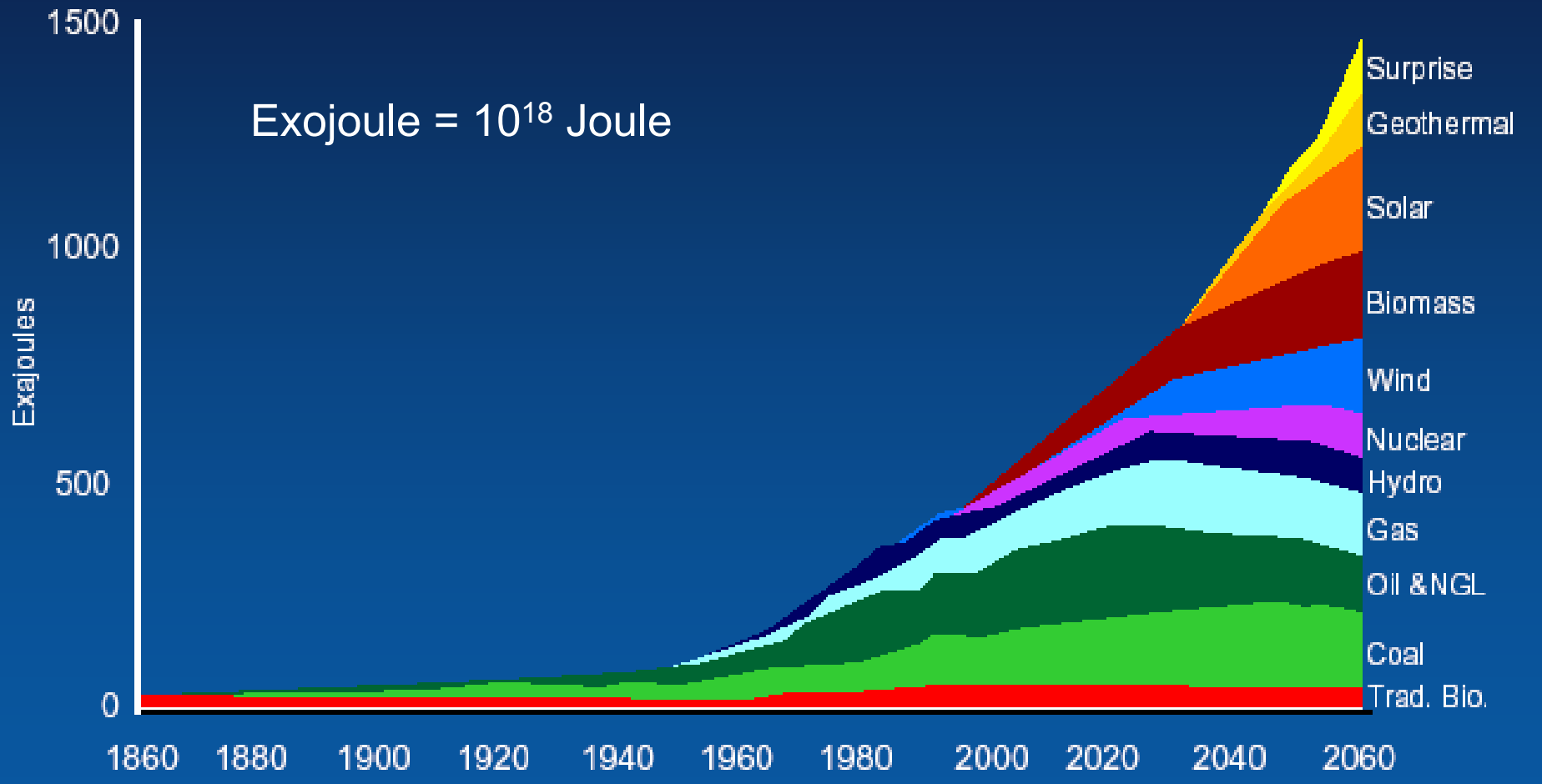
Global Reserves/Price of oil

- Present estimates of world oil reserves: about 1200 x 10^9 barrels (BP, end of 2004)
- Current annual world consumption rate: 31 x 10^9 barrels
- Oil reserves are still large, but finite
- Price determined by fast growing demand, limitations in supply and geopolitics
- “Peak oil or Hubberts peak”

Future World Energy Sources
Shell International – Sustained Growth Scenario



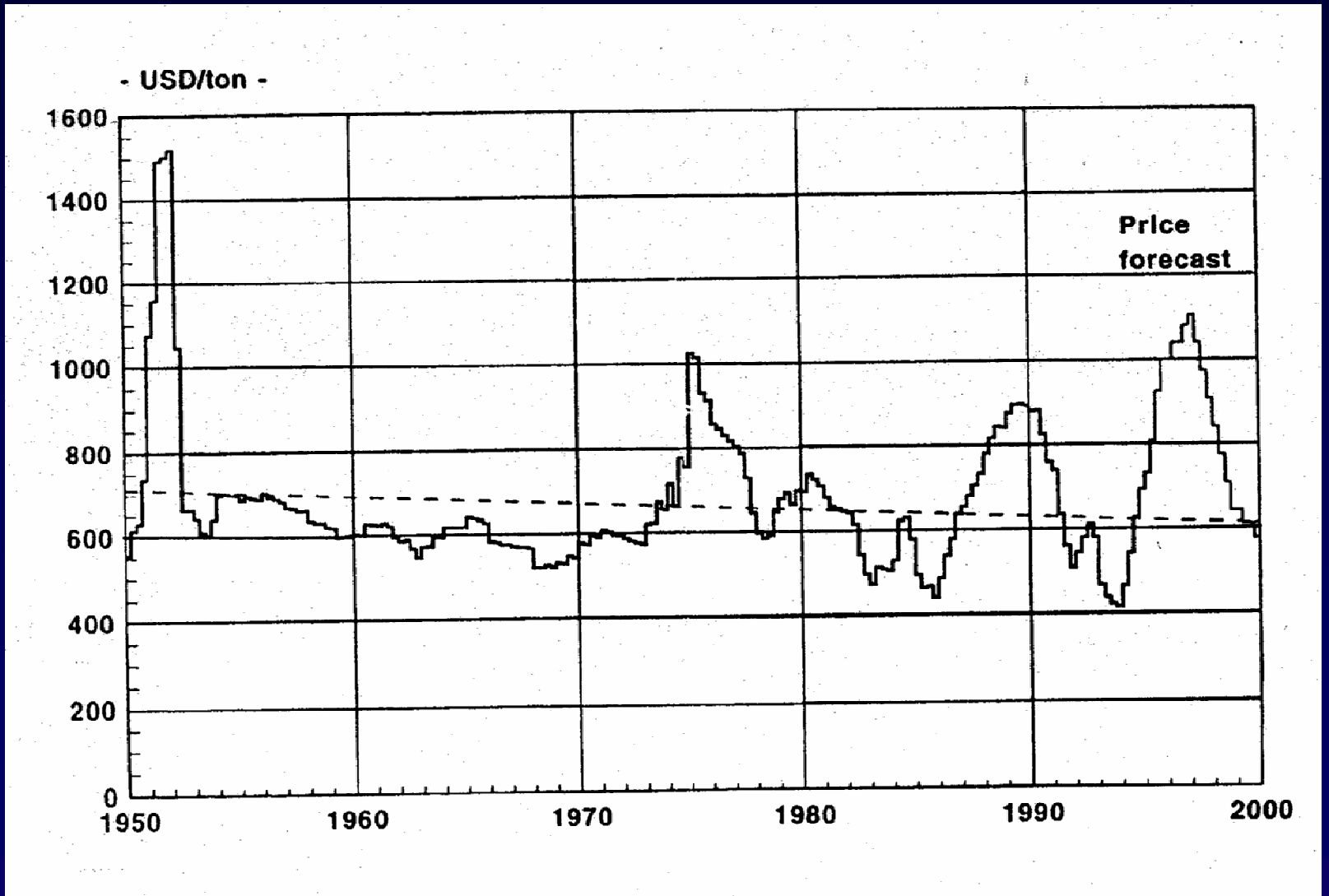
Source: *Shell, The Evolution of the World's Energy Systems*, 1995

Forest Biomass Potential

- Cellulose is the most abundant organic chemical on earth at an annual terrestrial production of 90 billion tonnes/year
- On energy basis, carbon synthesis by plants is equivalent to ~10 times world consumption
- Forest biomass is carbon neutral

➔Managed forests have enormous potential to reduce “green-house gas” emissions by generating liquid fuels and bioproducts

Inflation Corrected Price of Northern Bleached Softwood Kraft Pulp



US Forest Products Industry Challenge

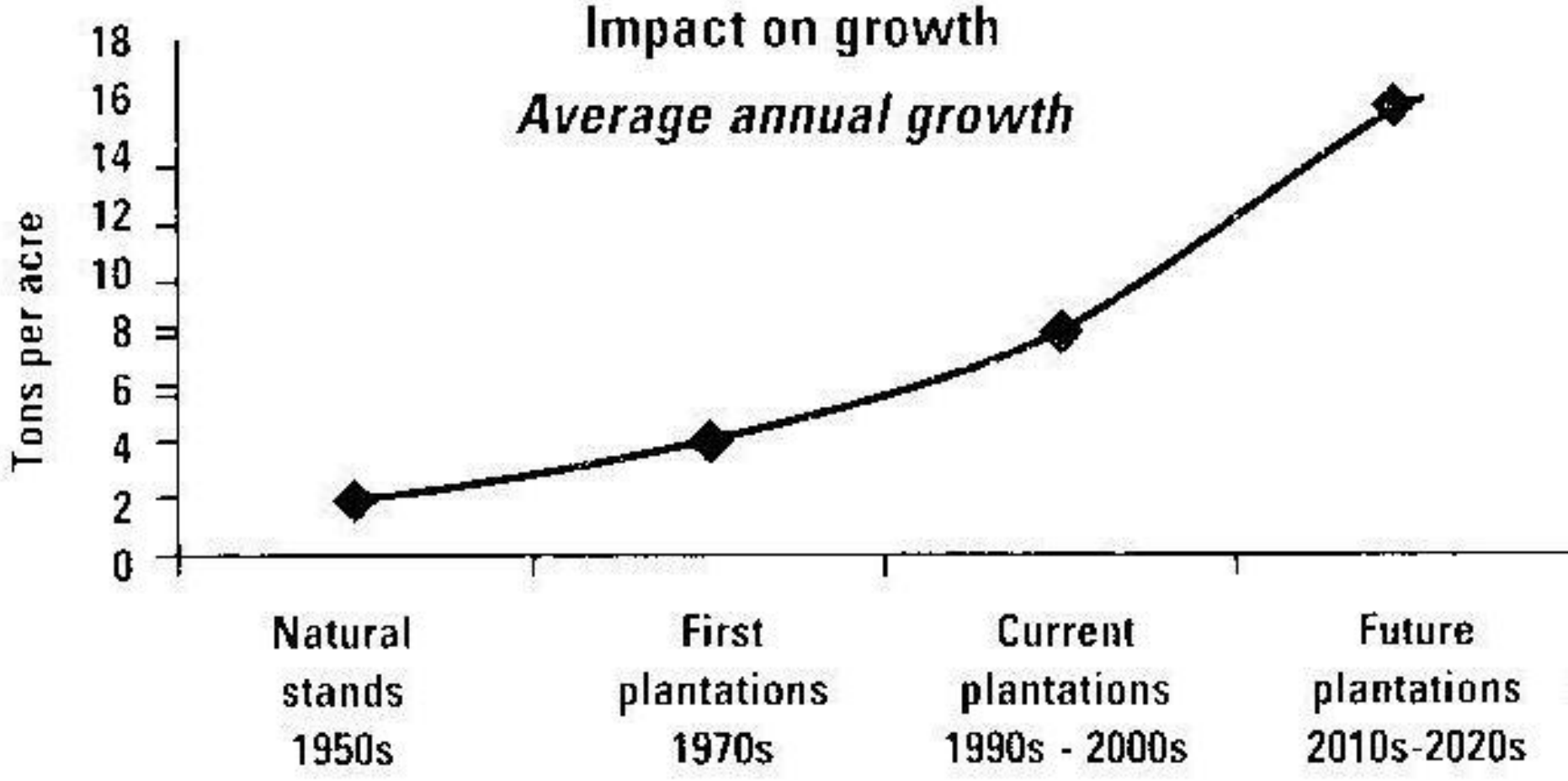
- Prices for forest products decrease by about 1% per year.
- US forest industry faces global competition
- New competitors of US have low wood and labor costs, and latest and largest technology

➔US. forest products industry needs more revenue by increased pulp yield and higher value-added products from black liquor

Supply and Market for New Value-Added Products from Biomass (2004)

- US corn production: ~140 million tonnes/year
- US pulp + paper production: ~100 million tonnes/year
- US potential biomass: ~1300 million tonnes/year (368 million from forest; 933 million from agriculture)
- This is 6 x present production, and could provide 1/3 of US gasoline consumption of 140 billion gallons/year
- US corn ethanol: 3.3 billion gallons of ethanol (or ~10 million tonnes) represents 12% of corn production
- US styrene market: 5 million tonnes/year
- US ethylene glycol market: 3 million tonnes/year

Productivity of Loblolly Pine Plantations



Forest Biorefinery Development

- Initial biorefinery will be pulp mill with biofuels and biomaterials as co-products
- Intermediate biorefinery will make several bioproducts including pulp fiber products
- Mature biorefinery may not have cellullosic pulp as final product

Principles for Initial Biorefinery

- Kraft pulp mill has most of the infrastructure and equipment for a Forest Biorefinery!
- Hemicelluloses heating value of is half of lignin. So do not burn hemicelluloses but use for ethanol, chemicals or polymer production.
- Extract hemicelluloses before pulping.
- Gasify lignin to produce syngas and then generate transportation fuel

Increasing Revenue

Present situation

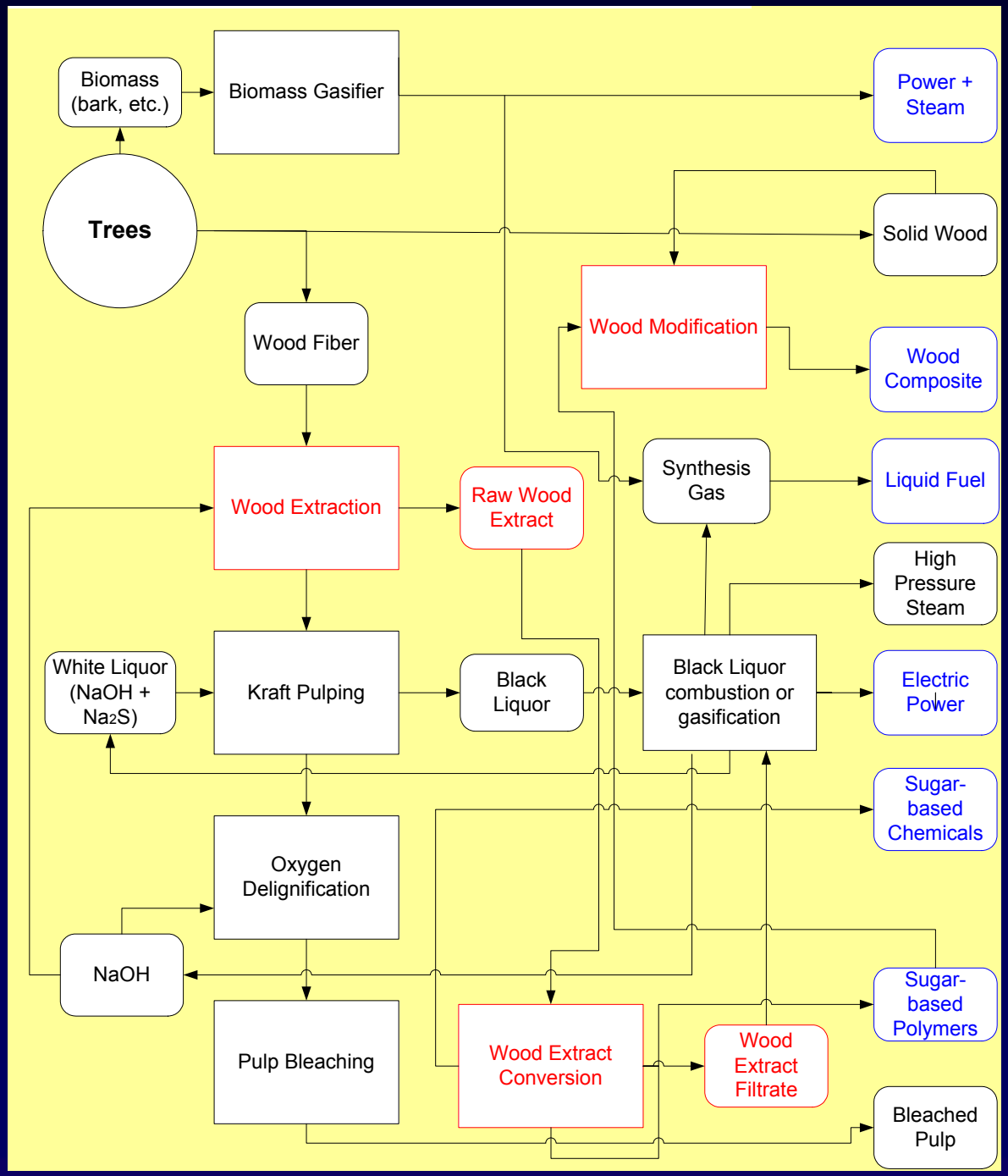
Product	Price ($/ODMT)	Yield (%)	Value (ct/lb od wood)
Kraft Pulp	680	45	13.9
Wood as fuel	100	55	2.6
Total		**100**	**16.5**

Future Situation

Product	Price	Wood Yield (%)	Conversion Yield (%)	Value (ct/lb od wood)
Kraft Pulp	$680/ODMT	48	100	14.8
Ethanol	$2.00/gallon	20	50	2.4
Diesel	$2.00/gallon	32	70	5.1
Total		**100**		**22.3**

- **Potential revenue increase of 35%**

IFPR



Legend

= Products

= New Processes

= New Products

Selective Extraction of Hemis and their Integration in Pulp Production

- Removal of hemis as polymers
- Use only techniques and chemicals which are compatible with the kraft process
- Minimize the amount of additional water introduced in the pulping process
- Hardwood and softwood need different approaches because the hemicelluloses are chemically different
- Pulp production yield and rate and pulp quality may also be increased

Potential Benefits of Hemi Extraction

- Decreased alkali consumption
- Reduced organic + inorganic load to recovery
- Increased delignification rate
- Improved properties of pulp

Ethanol from Lignocellulosics

- 78 US plants produce 3.3 billion gallons ethanol from starchy grains such as corn in 2004. Expected 5 billion gallons in 2012
- Iogen in Canada produced world's first cellulose based ethanol at 260,000 gallons/yr starting April 2004
- Shell Global Solutions, partner of Iogen, expects global biofuels market > $10 billion by 2012
- "Life Cycle Analysis" for wood is 8 – 10 energy units generated per unit invested compared to 1.3 for corn
- 20 fold reduction in enzyme cost to < $0.30/gallon for cellulose conversion in last 5 years by biotechnology and improved pretreatment
- Further research aims to reduce enzyme cost to $0.10/gallon ethanol

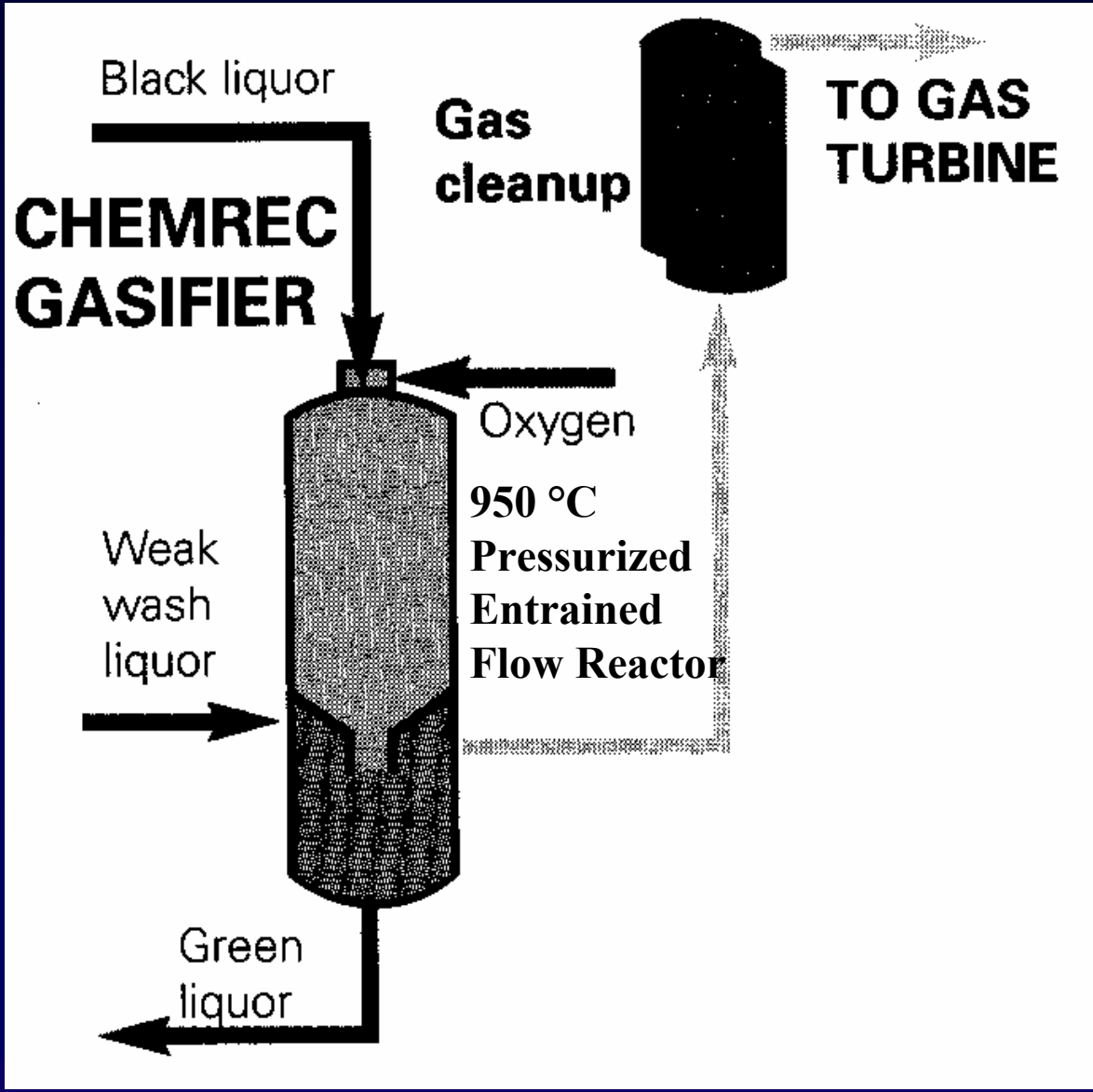
Top 12 Chemical Building Blocks from Sugars according to DOE

1,4 diacids (succinic, fumaric and malic)
2,5 furan dicarboxylic acid
3 hydroxy propionic acid
aspartic acid
glucaric acid
glutamic acid
itaconic acid
levulinic acid
3-hydroxybutyrolactone
glycerol
sorbitol
xylitol/arabinitol

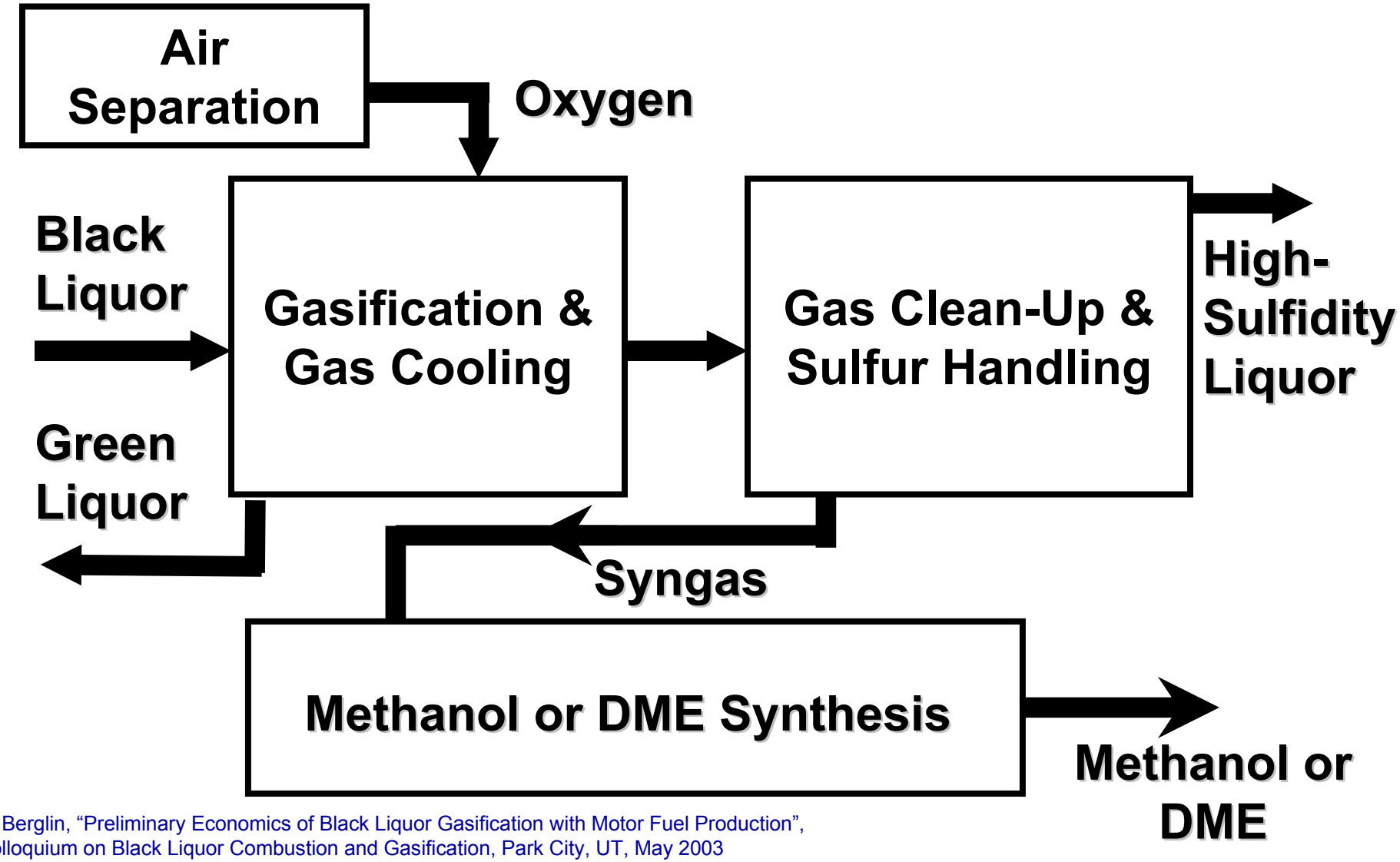
Examples of Hemicellulose-Derived Chemicals

- **Ethyl levulinate**, a diesel additive. Made from esterification of levulinic acid with ethanol
- **1,3 propane diol**, the monomer for Dupont polyester Sonomo® made from this diol and phtalic anhydride. Diol is made from DHP.
- **Hyper-branched polyesters.** Made by reaction of diacids with monomer or polymer sugars.
- **Engineered wood products**. Use of the new polyesters in products such as SMC (sheet molding compound)

High Temperature Gasifier



Black Liquor Gasification with Motor Fuels Production



N. Berglin, "Preliminary Economics of Black Liquor Gasification with Motor Fuel Production", Colloquium on Black Liquor Combustion and Gasification, Park City, UT, May 2003

Conclusions

Benefits of Forest Biorefinery:

- **Protects the Core**: Increases the profits in support of traditional forest products production
- **Ecofriendly**: Transportation fuels, power, and bioproducts from a carbon-neutral, renewable resource
- **Low Capital**: Use existing pulping equipment and infrastructure for production of new, high value-added products besides traditional wood and paper products
- **Synergy**: Full integration of the traditional forest products and new bioproducts will lead to synergies
- **Self-Sufficiency**: Replacement of imported fossil fuels by domestic renewable fuel
- **Employment**: Preserves and creates jobs in rural forest-based communities