Biorefinery – An Overview

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Topics:

- Facts and figures
- Background information related to biorefinery concepts
- Various options for woody biomass conversion to ethanol
- Results on maple and Eucalyptus
  - VPP concept
- Conclusions

Drivers for Biorefinery

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- Reduce dependence on petroleum
- Improve profits of the stagnant Paper Industry –

Bio-Product	Current	2020	2090
Liquid Fuels	1-2%	10%	50%
Chemicals	10%	25%	>90%
Materials	90 %	95%	99%

NRC Report - 2000

- **Chemicals – Petroleum-based feed stock for chemical industry was 50% prior to WWII**
- **Biomass Availability - 368 million tpy tree and 998 million TPY agri-residues available for meeting 30% energy demand (DOE/USDA “Billion Ton” study)**

US Forest Products Industry Overview

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- Manufacturers of pulp, paper, paperboard, and wood products
- $230 billion per year to the US economy
- Employment – 1.3 million; Payroll - $50 billion
- 7% of US manufacturing base; top 10 manufacturing in 42 of 50 states
- Converts 270 million tons/yr for products
- US consumption about 210 million tons/yr
- Post-consumer recovery of paper and paperboard is 50%

Biorefinery
Changing the Basis and Rules of Competition

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- A forest biorefinery is a facility that integrates biomass conversion processes and equipment into an existing chemical pulp mill to produce fuels, chemicals, and/or renewable energy, in addition to manufacturing traditional pulp products.

- The purpose of biorefinery is to improve pulp mill profitability and competitiveness.

Some Facts:

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- Hemicellulose is worth more as ethanol than as energy
- Lignin is worth more as ethanol (syngas) than as energy from direct combustion
- Cellulose is worth more as pulp than as ethanol

Various options for the conversion of cellulose material to ethanol

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- AVAP (American Value-added Pulping™) process
- Biomass gasification
- Conversion of cellulosic material to ethanol – Mascoma Corporation approach
- Re-purposing of an existing Kraft mill – N. C. State
- Value prior to pulping

The AVAP Process

- Produces ethanol from wood
- Co-produces ethanol with pulp
- Site uses all the tree
- Site is energy self-sufficient
  - (Transportation fuels used to deliver wood)
- Cost of ethanol production by AVAP
  - ~$0.30 - $0.60/USG

AVAP Biorefinery

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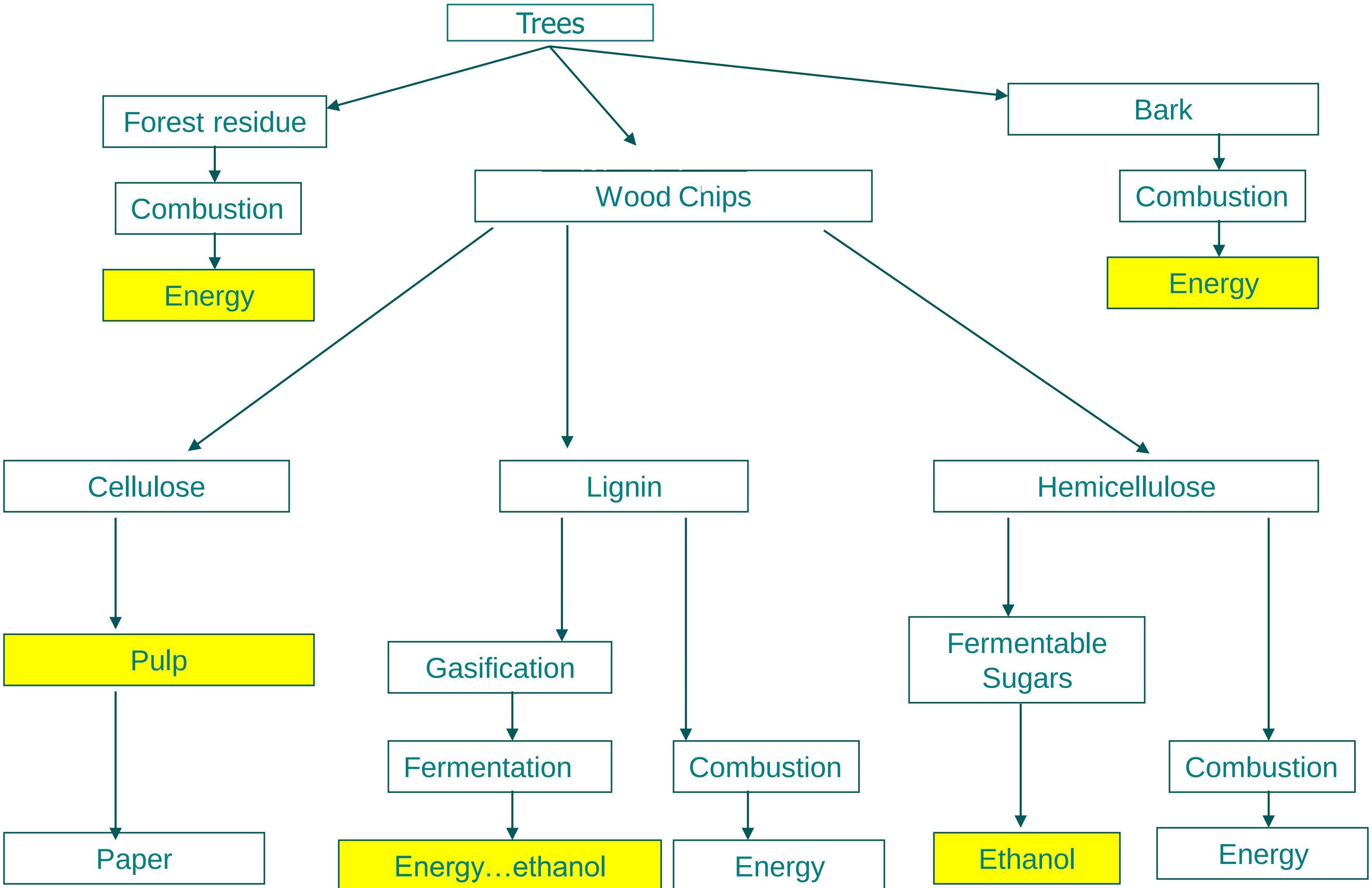
- Fast cooking in alcohol sulfite environment
  - Hemicelluloses hydrolyze to sugars
  - Easily bleachable pulp produced – furnish to paper machine
  - Lignin sulfonated
- Sugars are fermented to ethanol
- Lignin is precipitated
  - Gasifier produces syngas
  - Syngas is:
    - Used to make heat and power in the first phase
    - Can be used to make transportation fuels in the future
- Process and heat integration maximized
  - Reuse of chemicals and heat minimizes production costs
- Start a design for 20 million gallons annual cellulosic ethanol plant for Flambeau River Paper as early as 2009

AMERICAN PROCESS

AVAP Process Highlights

- Fast cooking (2-3 hr. batch cooks at 300°F)
- Cooking liquor ethanol and SO_2
- Wash presses to reduce liquor losses
- MVR pre-evaps/stripping to evaporate concentrated cooking chemicals
- Neutralization of liquor to precipitate lignin
  - Filtered to high solids, gasified, and converted to ethanol
- Fermentable sugars are concentrated
  - Fermentation, distillation, and dehydration to convert in fuel ethanol (100%)

Biorefinery Revenue Streams



Reasons for biomass gasification

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- Biomass cost - $1-2/MM BTU
- Burned biomass to replace steam - $4/MM BTU
- Biomass gasification generation of syngases to replace natural gas – 6-10/MM BTU

Biomass gasification: background

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- Potlatch is proposing potential site for industry biorefinery demonstration
- Fully integrated agric/forest biorefinery using both biochemical (VPP) and thermochemical conversion (biomass gasification)
- Driver is finding low cost ways to reduce or eliminate the mill's dependency on natural gas while developing new products from the forest residuals
- Potlatch interest is to support whatever will "get this done" on behalf of the industry

Key Participants (as of January 15, 2005)

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- Potlatch Corporation
- Winrock International
- State of Arkansas
- Agenda 2020 Technology Alliance
  - Weyerhaeuser
  - Stora Enso
  - Others pending

- Potential Partners: local refinery and energy utility

Arkansas IFPB: Raw Materials

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- **Large quantities of low cost Bio-mass are available:**
  - **From the Forest: about 2/3 of the trees are left in the forest**
  - **From Farming: We believe up to 2/3 of the plants are left on the ground**
  - **Pulping**
    - **Lignin (black liquor): Virtually all the lignin in the chips (about ½) is removed and burned in a recovery boiler**
    - **Hemicellulose: Makes up 20 to 30% of the chips and is lost in the pulping process**
  - **Selected Manufacturing and Municipal Waste: There may be opportunities to recover a portion of these waste streams**
  - **Ethanol Plants: If a conventional ethanol plant was close by its waste stream could also be processed**

Conversion of lignocellulosic material to ethanol from an existing mill

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➢ Two main schools of thought:

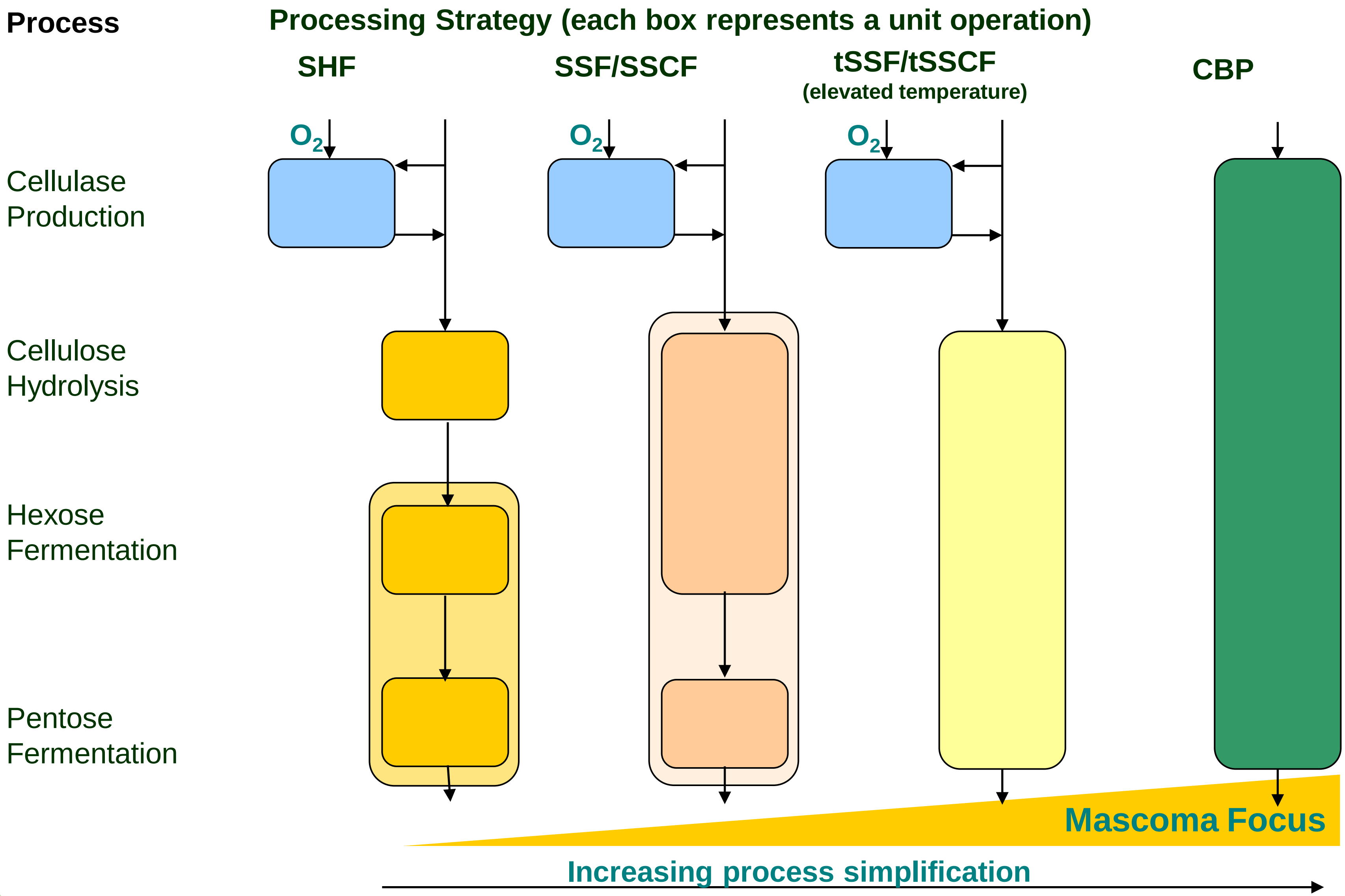
- Repurposing an existing mill with the purpose of making ethanol only

- Extracting hemis prior to pulping and still making unchanged pulp and paper products (VPP)

Mascoma

- Established August 2005 in Cambridge, MA
- Found from many years of leading cellulosic ethanol research by Dr. Lee Lynd and Dr. Wyman at Dartmouth college
- Venture capital funded for technology development and commercialization
- Dedicated to converting biomass cellulose to low-cost renewable fuels
- Converting biomass (paper sludge, wood chips, switch grass, corn stover, etc.) to ethanol by hydrolysis, saccharification, fermentation in a separate or combined process
- Announced a plan to build a $20 million 15,000 square foot cellulosic biomass ethanol demonstration facility in New York State

Evolution of Biomass Processing Featuring Enzymatic Hydrolysis



SHF: Separate hydrolysis & fermentation
SSF: Simultaneous saccharification & fermentation
SSCF: Simultaneous saccharification & co-fermentation
CBP: Consolidated bioprocessing

North Carolina State University

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- Repurpose an uneconomical pulp mill to a wood-ethanol plant
- Redeploy the supply chain, equipment, and people assets
- The proposed technology consists of prehydrolysis, high yield pulping, and separate or simultaneous saccharification/fermentation
- Prehydrolysis of wood chips and residuals (tops and limbs) in digester for hemicelluloses fermented to ethanol
- Cook the prehydrolysed wood to 10% lignin content, exiting the digester as single fibers
- Subject the cooked (high yield) fibers to hydrolysis enzymes for sugars followed by fermentation to ethanol
- Spent liquor after prehydrolysis (along with other biomass) can be concentrated and burned in the existing chemical recovery for energy or processed for the value of lignin
- The carbohydrate hydrolysis and fermentation yields being the key to the technology's success

Kraft mill re-purposed to biochemicals

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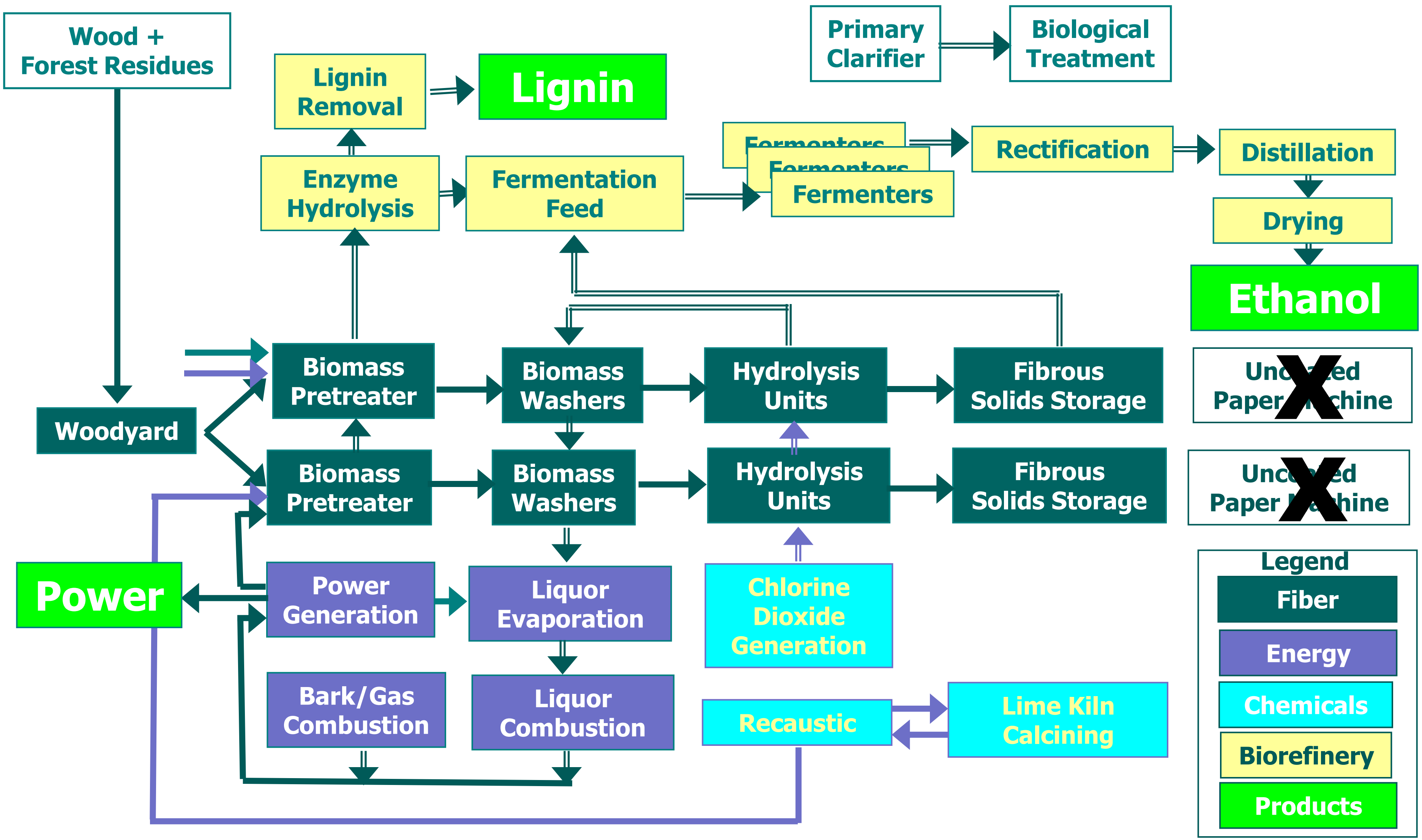

Chemical Pathway (Fermentation)

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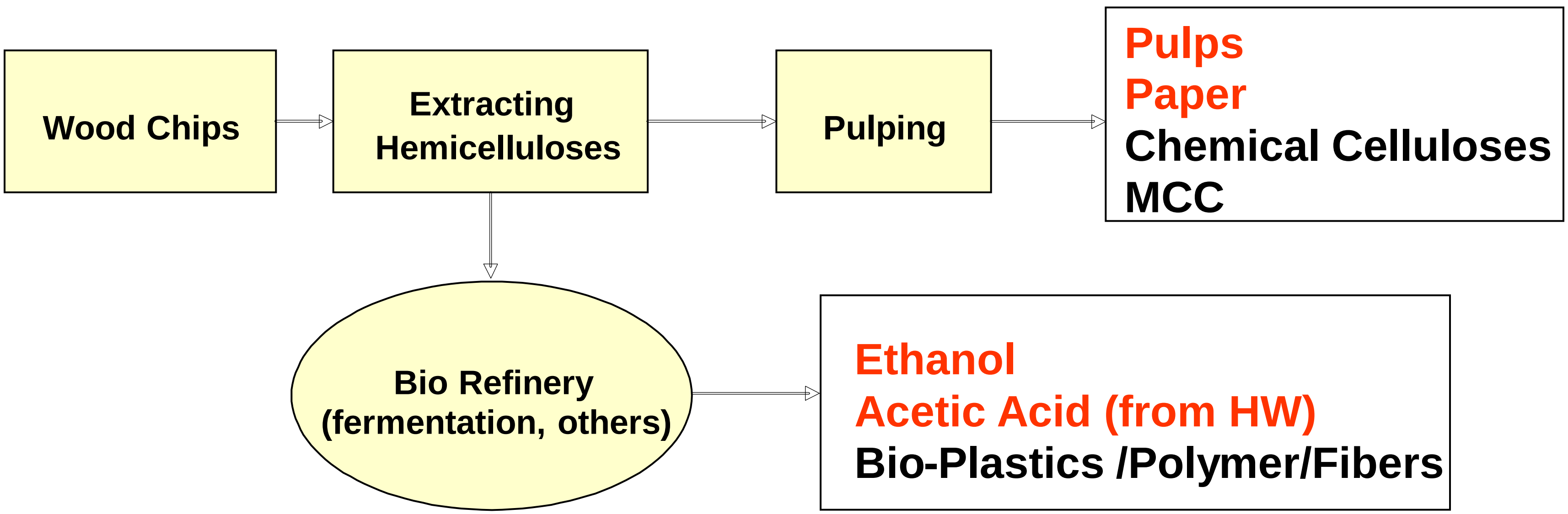
- Hemicellulose makes up about 20 to 30% of the wood used in the pulping process and is considered a waste product
- We believe the hemicellulose can be extracted prior to pulping chips without damaging the fiber
- Once extracted and concentrated the hemicellulose can be fermented, then distilled into ethanol – yielding about 35 gallons per ton of paper (possibly more)

Value Prior to Pulping

A Simple Flow Diagram For The Value Prior To Pulping



New Value Streams from Wood

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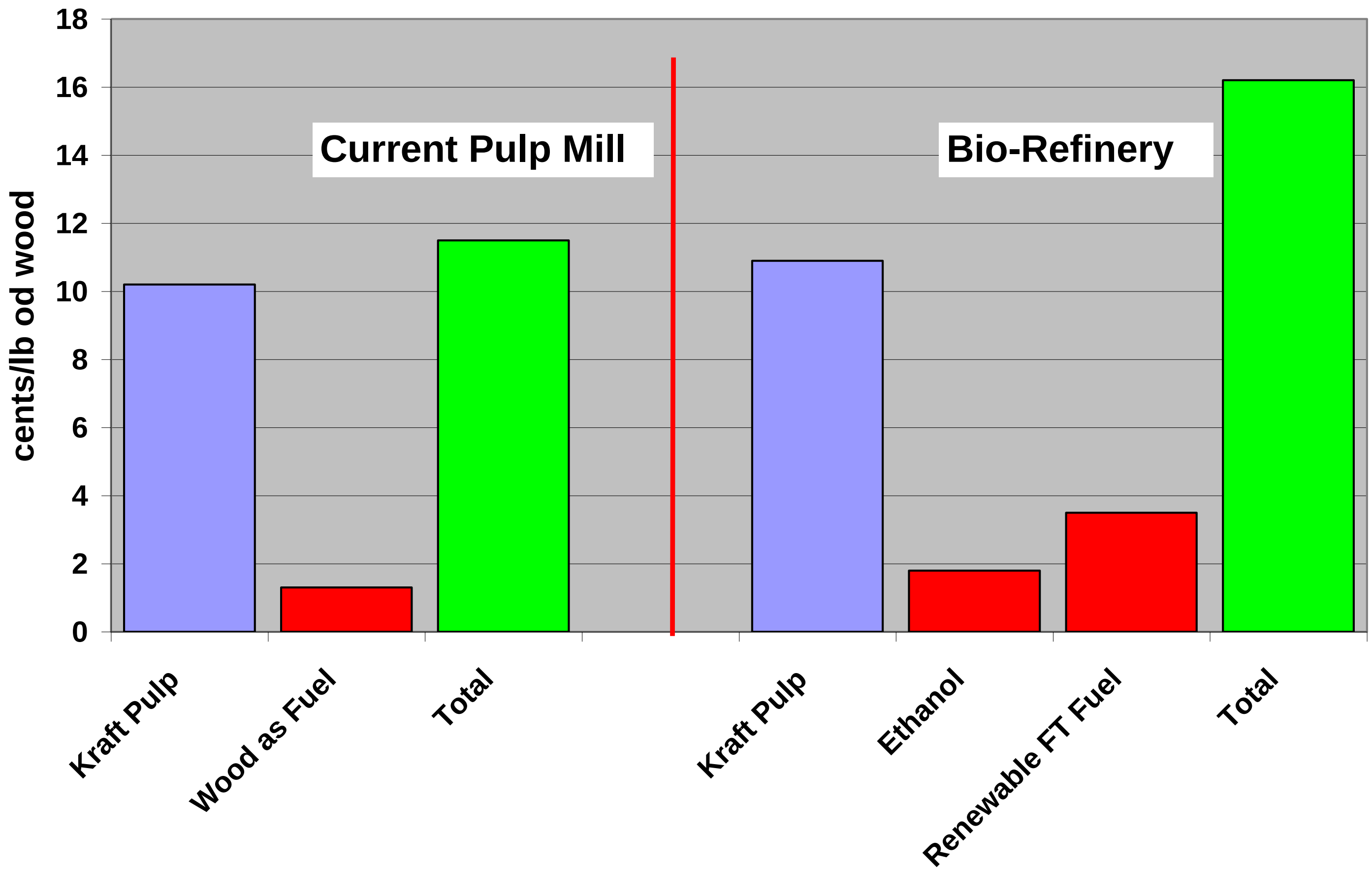
Biorefinery could potentially increase the value of wood by 41%.



VPP Consortium

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- Outgrowth of unfunded proposal to DOE
- Goal – Demonstrate feasibility of concept
- Be ready for demonstration plant in 2008
- Participants
  - 7 paper companies
  - 2 enzyme companies
  - 3 universities
  - NREL
  - FPL
  - CTT
  - State of Wisconsin

Effect of time and temperature on mass removal for maple and Eucalyptus chips

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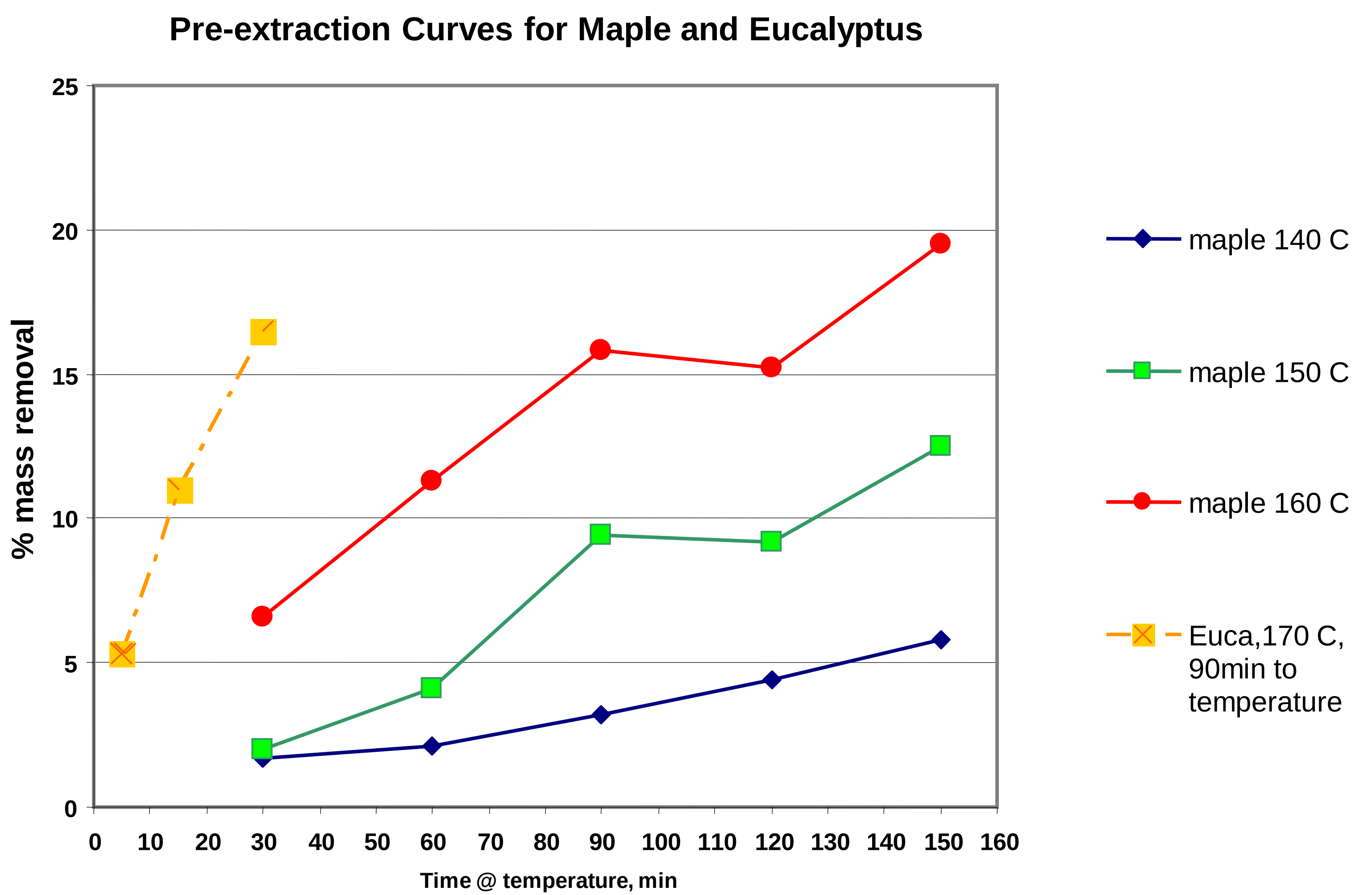
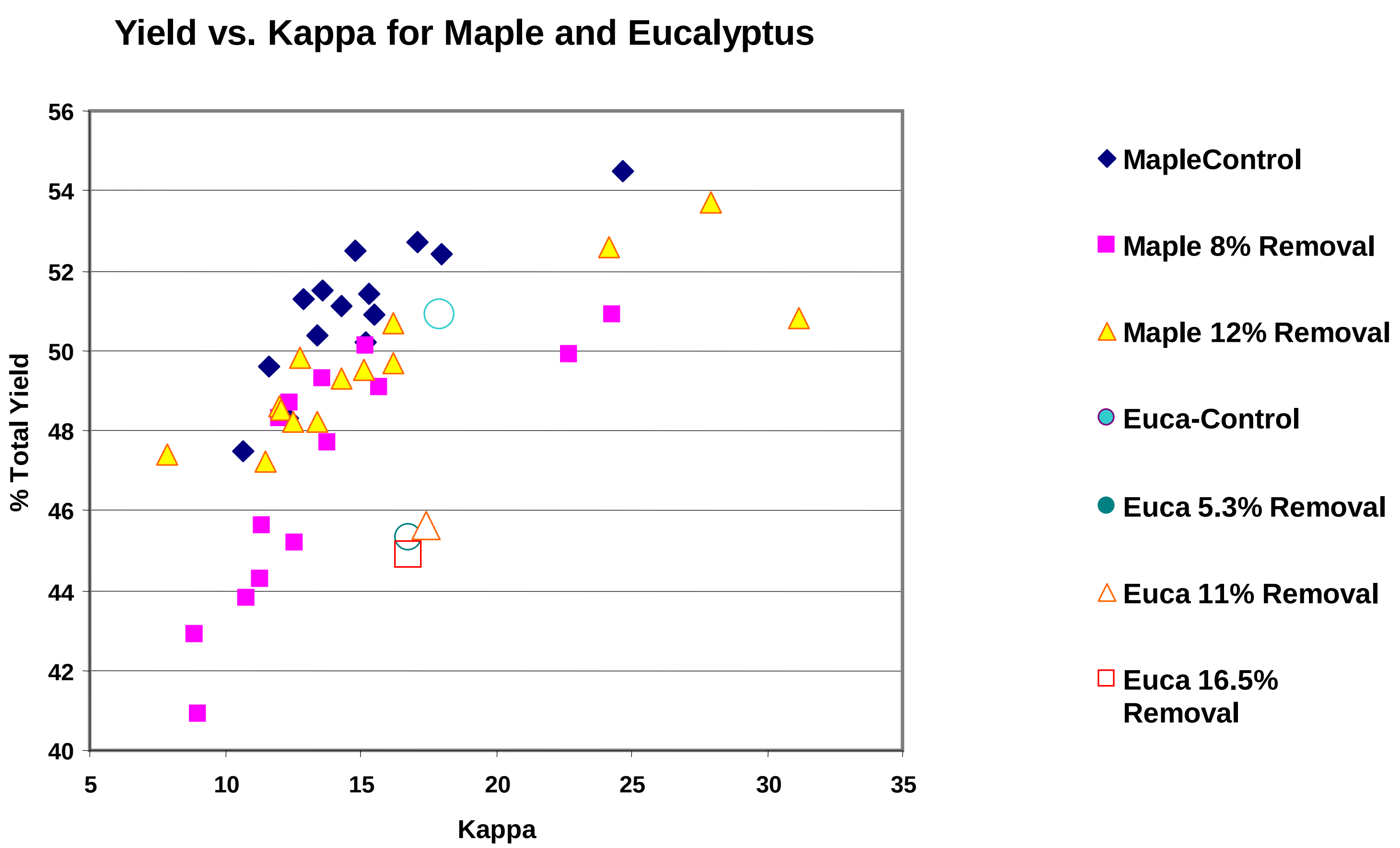


Yield vs. kappa relationship for control and extracted maple and Eucalyptus chips



Cooking & Bleaching of Ti Maple

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H FACTOR/COOKING TIME AS A FUNCTION OF PULP KAPPA *STUDY CONDUCTED BY CONSORTIUM AT ESF* *16% AA AND 90 MIN TO 165 C*				
	Control chips	Biorefined Chips		
		8% Removal	12% removal	
Kappa **Cooking time at 165 C** **H Factor**	**18** **90** **986**	**18** **45** **531**	**18** **45** **531**	**25** **30** **248**

TI MAPLE PULP LAB BLEACHING RESULTS *STUDY CONDUCTED BY CONSORTIUM AT ESF* *ODE$_p$D BLEACHING*			
Pulp	Control pulp	12% biorefined pulp	12% biorefined pulp Projected
Kappa **Kappa factor** **Total ClO_2, %** **Brightness, %**	**18** **0.154** **1.45** **87.4**	**17** **0.12** **1.2** **89.8**	**25** **0.12** **1.54** **88-89**
Other bleaching chemicals – 2% NaOH, 0.25% H_2O_2, 0.8% H_2SO_4			

PROPOSED BIOREFINING BUSINESS CASE FOR TI MAPLE CHIP *STUDY CONDUCTED BY CONSORTIUM AT ESF* *16% AA AND 90 MIN TO 165 C*		
	Control	Biorefining @ 12% removal
Kappa **Cooking time at 165 C** **H factor** **Projected ClO_2 usage, %** **Projected brightness, %**	**18** **90** **983** **1.45** **87.4**	**25** **30** **248** **1.55** **88-89**

- Pulping extracted chips to the same kappa results in a 2% lower pulp yield. For a 1,000 TPD mill the wood demand would go up by 365 tons/day (assuming 12% extraction and 48% yield from the extracted chips).

- Pulping to higher kappa, compared to control, the bleaching cost would be neutral due to easier bleachability of the pulp. The wood consumption would go up 272 TPD (assuming 12% extraction and 50% pulp yield from extracted chips.)

Refining energy response for control and the pulp made from maple extracted chips

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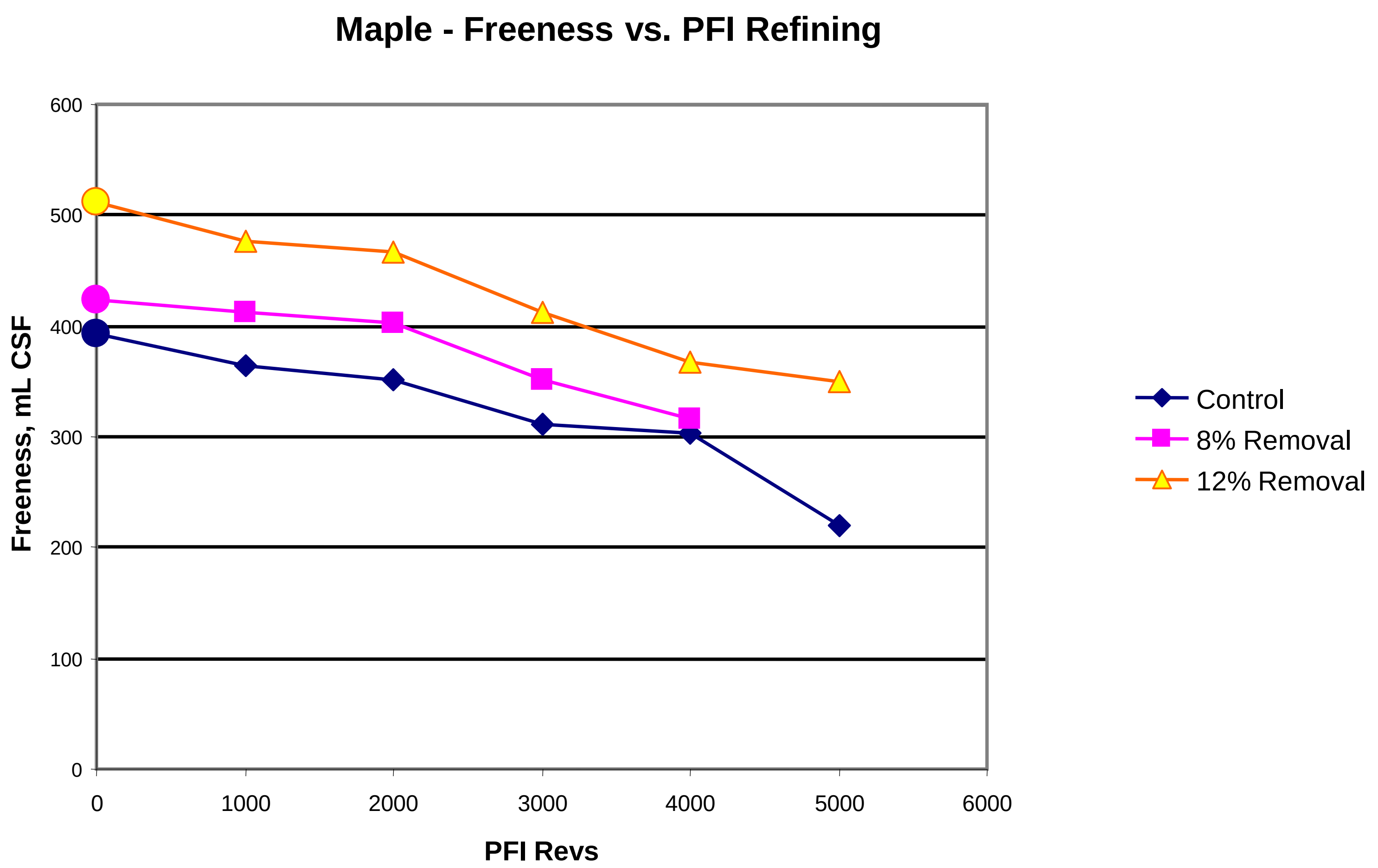

Tensile index vs. freeness for control and the pulp made from extracted chips for maple

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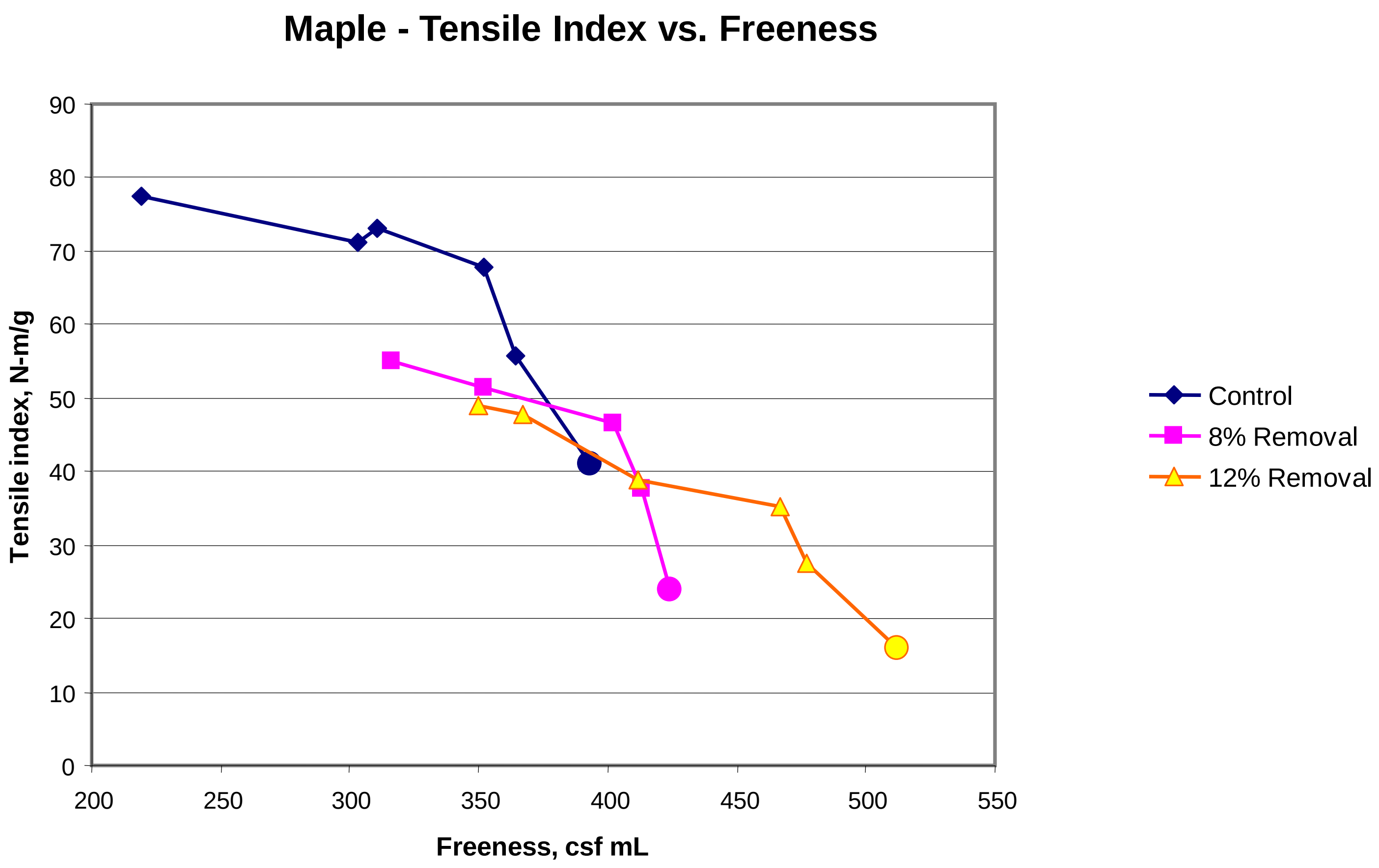
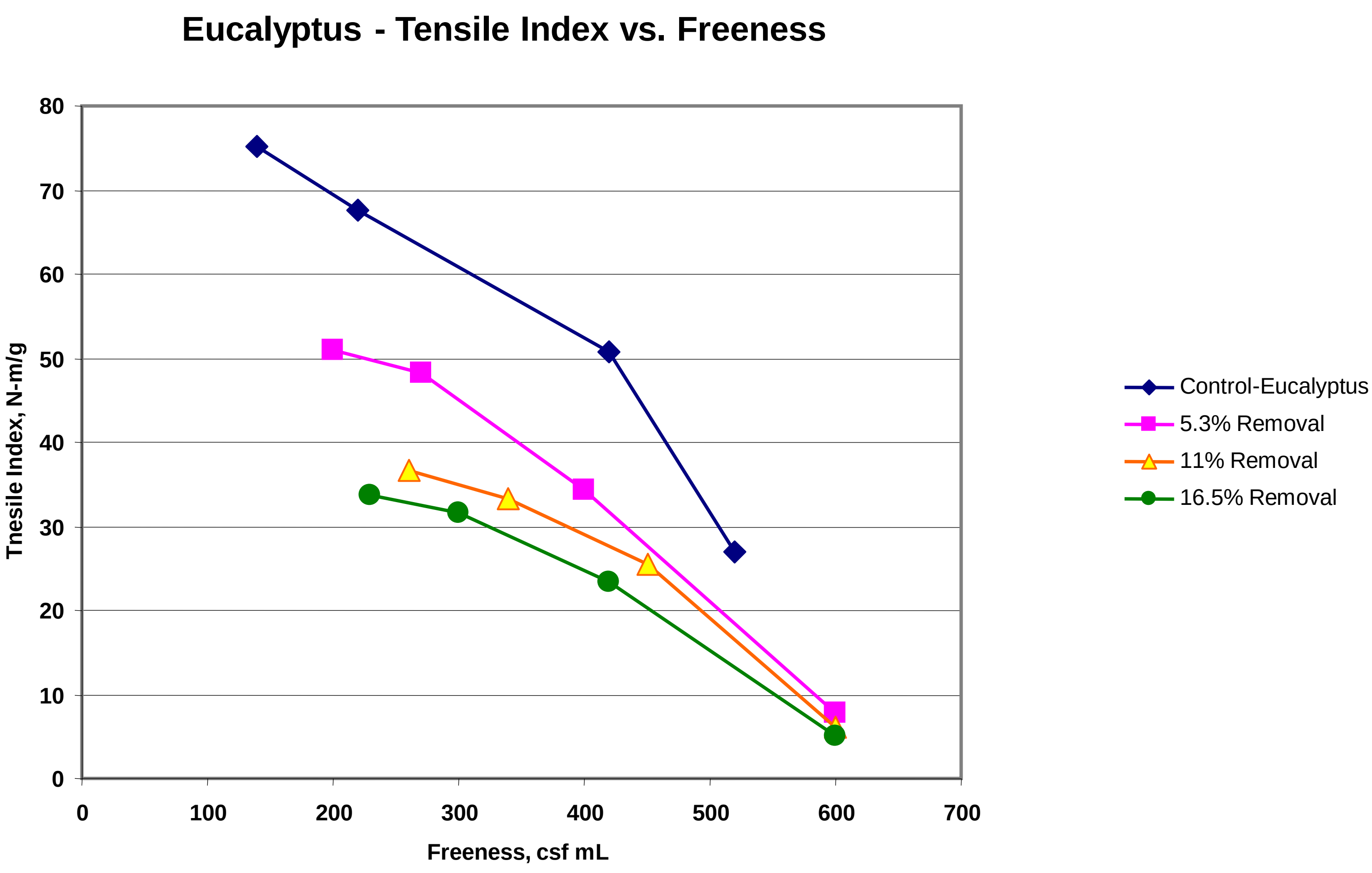
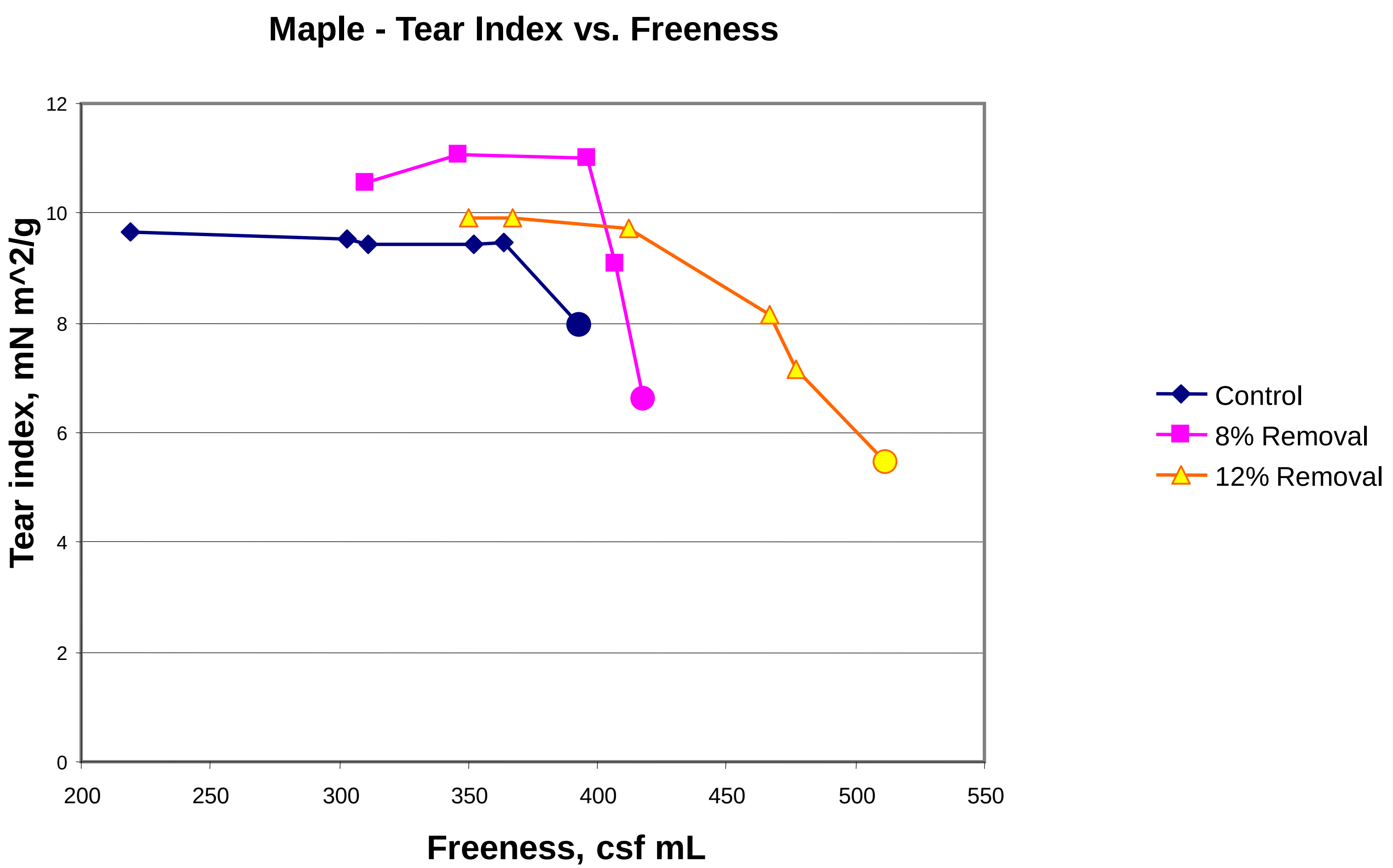


Tensile index vs. freeness for control and the pulp made from extracted chips for Eucalyptus



Tear index vs. freeness for control and the pulp made from extracted chips for maple



Tear index vs. freeness for control and the pulp made from extracted chips for Eucalyptus

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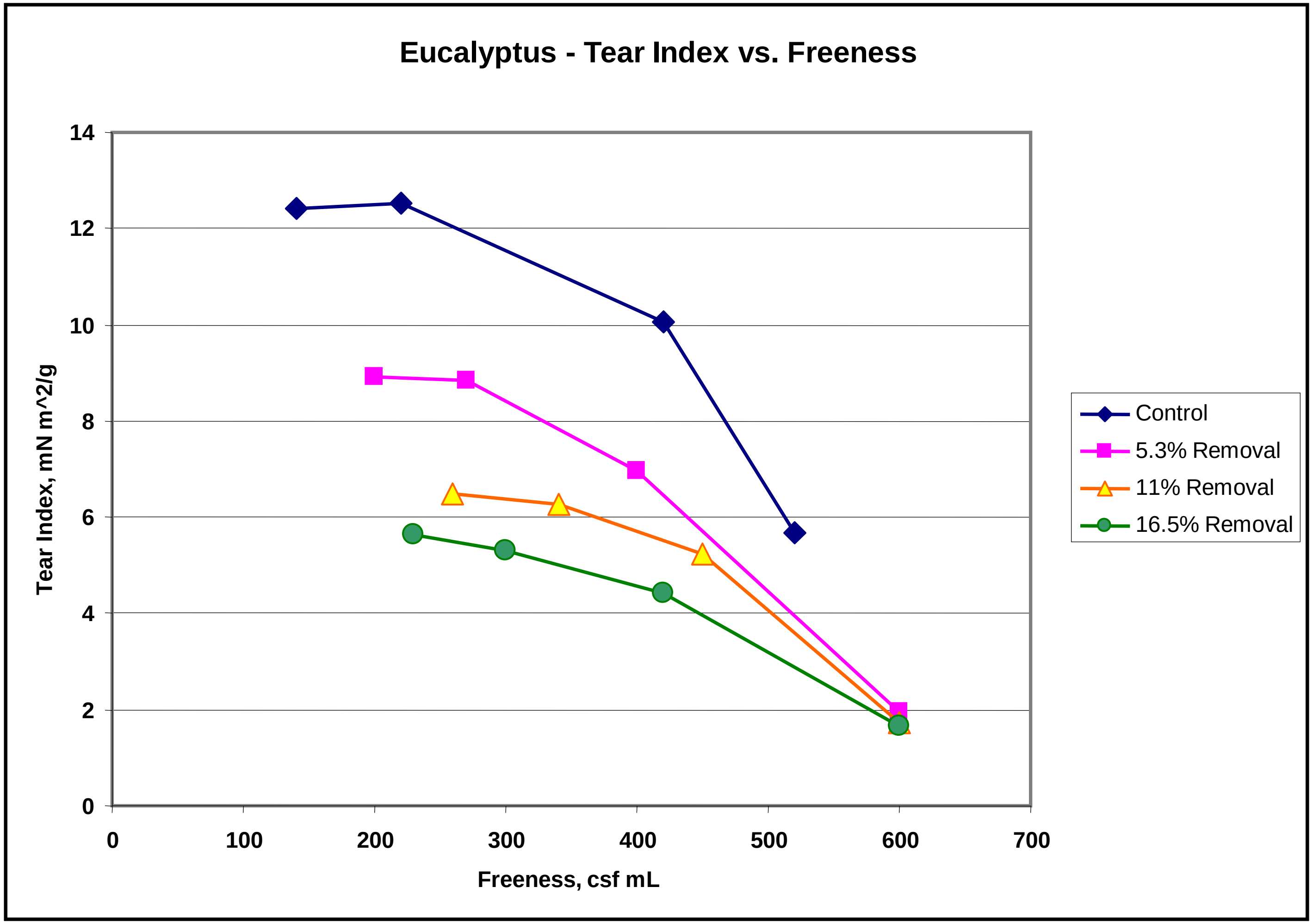
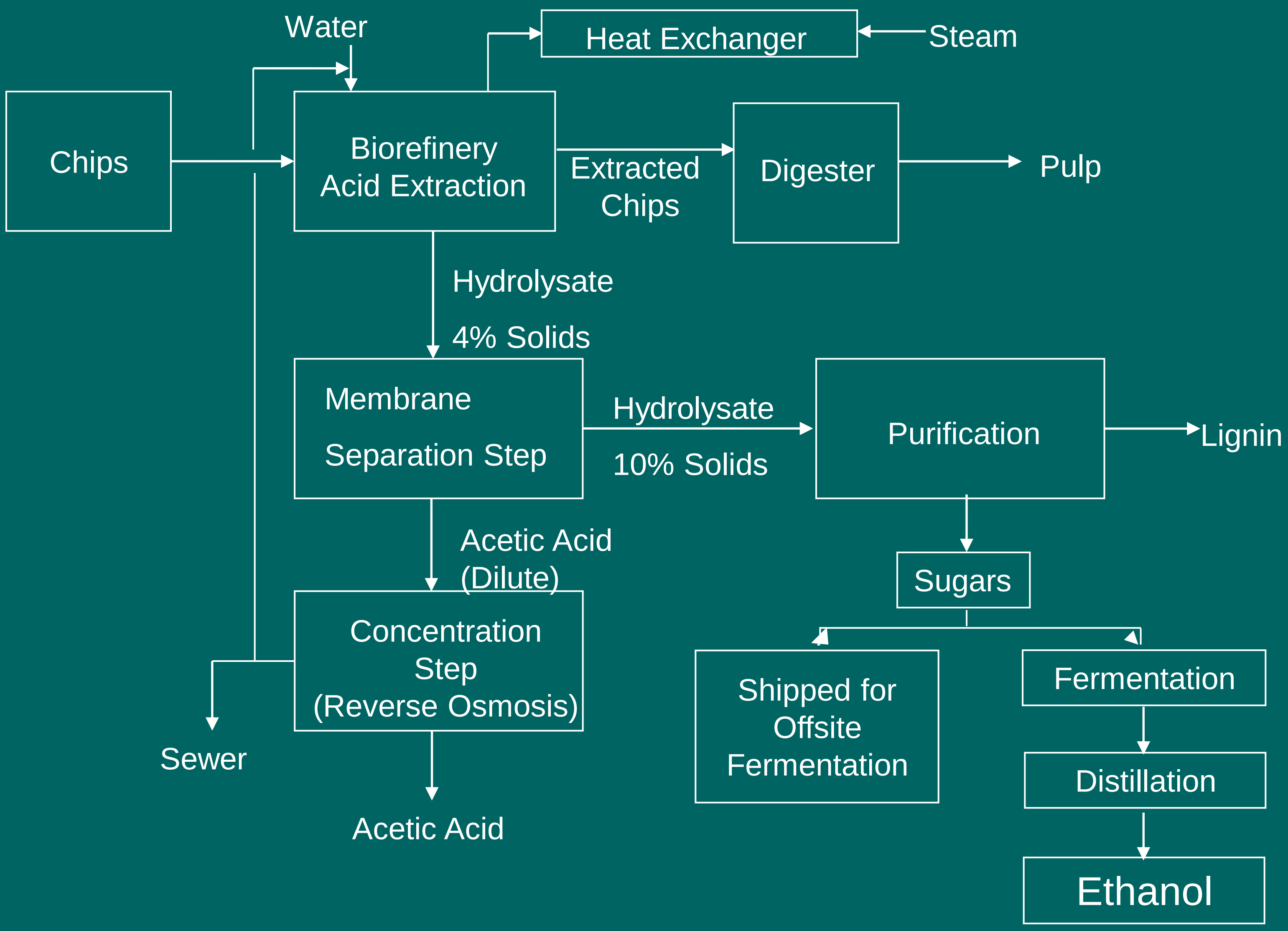


TI Maple Biorefinery Business Model



IFPB: Forest Products Industry Advantages

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- **Forest-based materials as feedstock**
  - Forest-based materials represent 30% of resources needed to support emerging bio-industries
  - Ethanol production from wood-based hemicellulose uses significantly less fossil fuel than production from other biomass resources
  - Managed forests have positive ecological impacts that are not mirrored in other biomass feedstocks

- **Industry has infrastructure and expertise**
  - Industry owns and manages operations for feedstock harvesting
  - Raw material already is being supplied to mills
  - Industry has experience in chemical processing and handling in compliance with related standards and regulations
  - Location of facilities in rural areas can realize important synergies between agricultural and forest-based feedstocks

Challenges:

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- Biomass gasification technology and conversion to higher value chemicals is new
- Technical and financial risk are high
- No individual company is likely to take the risk of being first. Therefore we need:
  - Financial resources
  - Partners

Benefits if Successful

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- Technology can be implemented at any manufacturing site that has access to bio-mass and a use for the waste heat
- Provides new products from untapped resources
- Market for bio-fuels and chemical is vase (room for many players)
- If implemented industry-wide the State's and nation's dependency on fossil fuel would be reduced
- Agricultural and Forest products industries would be more viable
- Creates new high-paying jobs (direct and indirect added to the economy)
- Increased tax revenue for the State

Conclusions

- The VPP option is by far the most extensively investigated so far. If the yield disadvantages can be overcome so that the same amount of wood is required to keep the same pulp production level, then this could be a very attractive option.
- Repurposing a Kraft mill and gasification of biomass have their own merits, but commercial success of both these approaches is yet to be seen.
- Pulps made from extracted maple and Eucalyptus chips exhibited very different characteristics in terms of pulping, bleaching, and strength properties. Pulp with satisfactory strength properties from extracted maple chips could be made, whereas Eucalyptus pulps were significantly lower in tear and tensile properties.
- A thorough business case analysis needs to be done for any of the options because return on investment is very site-specific depending on wood and energy cost.

Questions?