Natural Fibers Application and Composites - Potentials for Alternative Non-Wood Fibers

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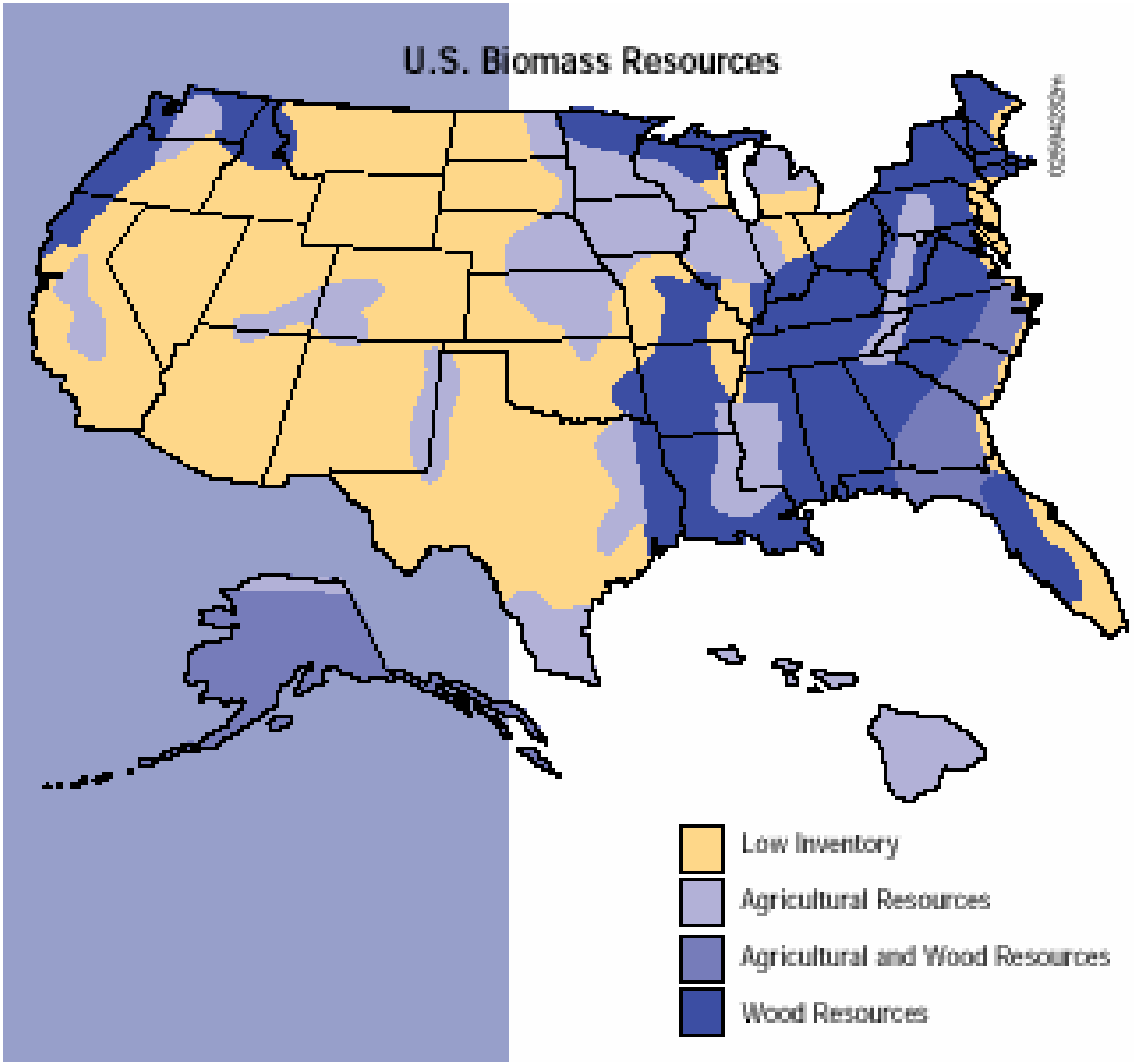
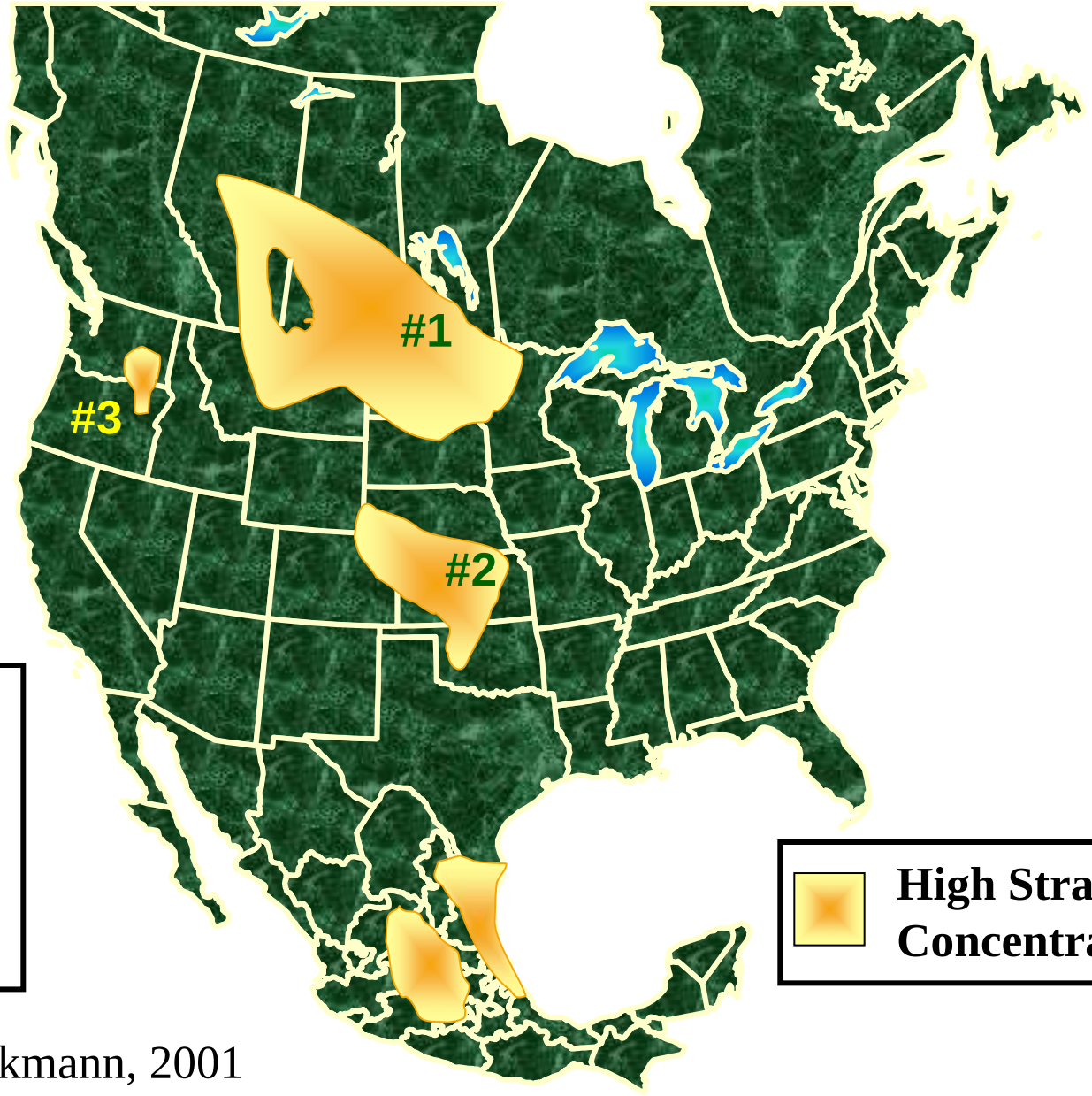

U.S. Biomass Resources
Low Inventory
Agricultural Resources
Agricultural and Wood Resources
Wood Resources

Straw-Rich Regions in North America



#1 North Dakota, Montana, Minnesota

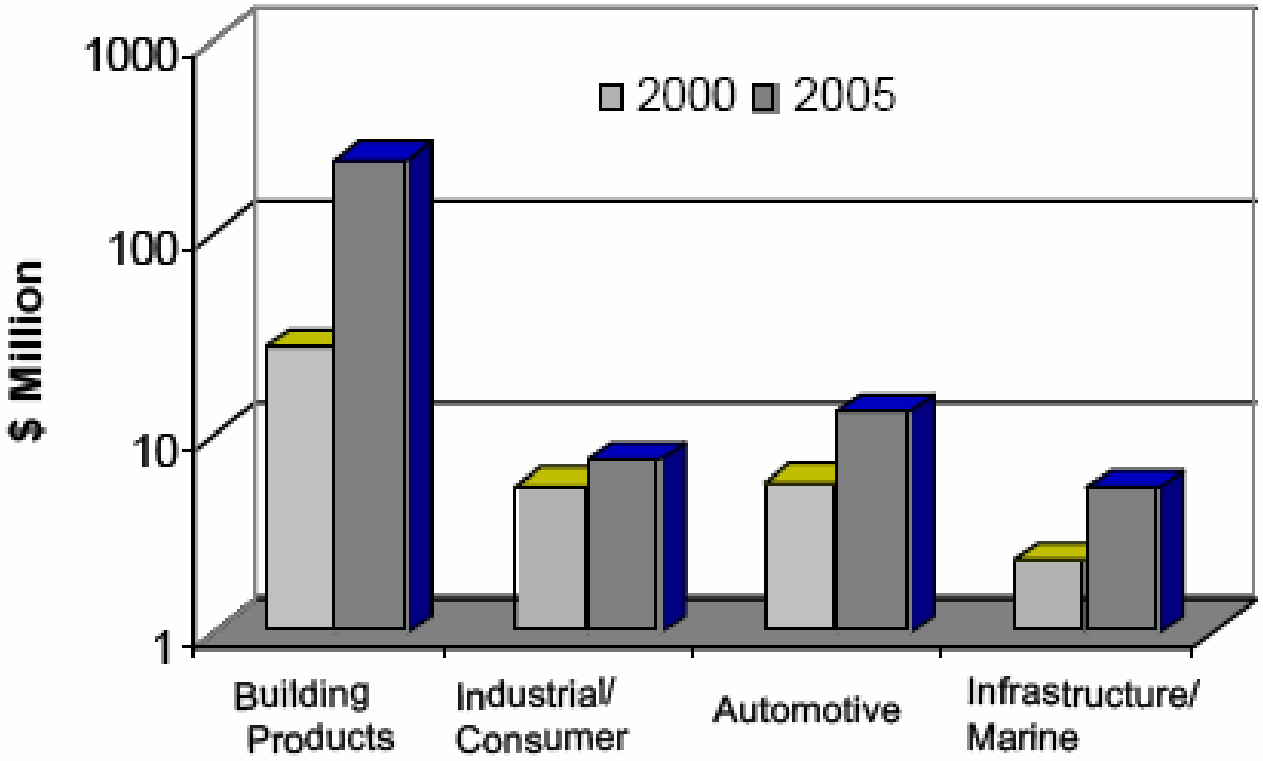
#2 Kansas, Nebraska, Oklahoma

#3 Washington, Oregon

Source: Bowyer and Stockmann, 2001

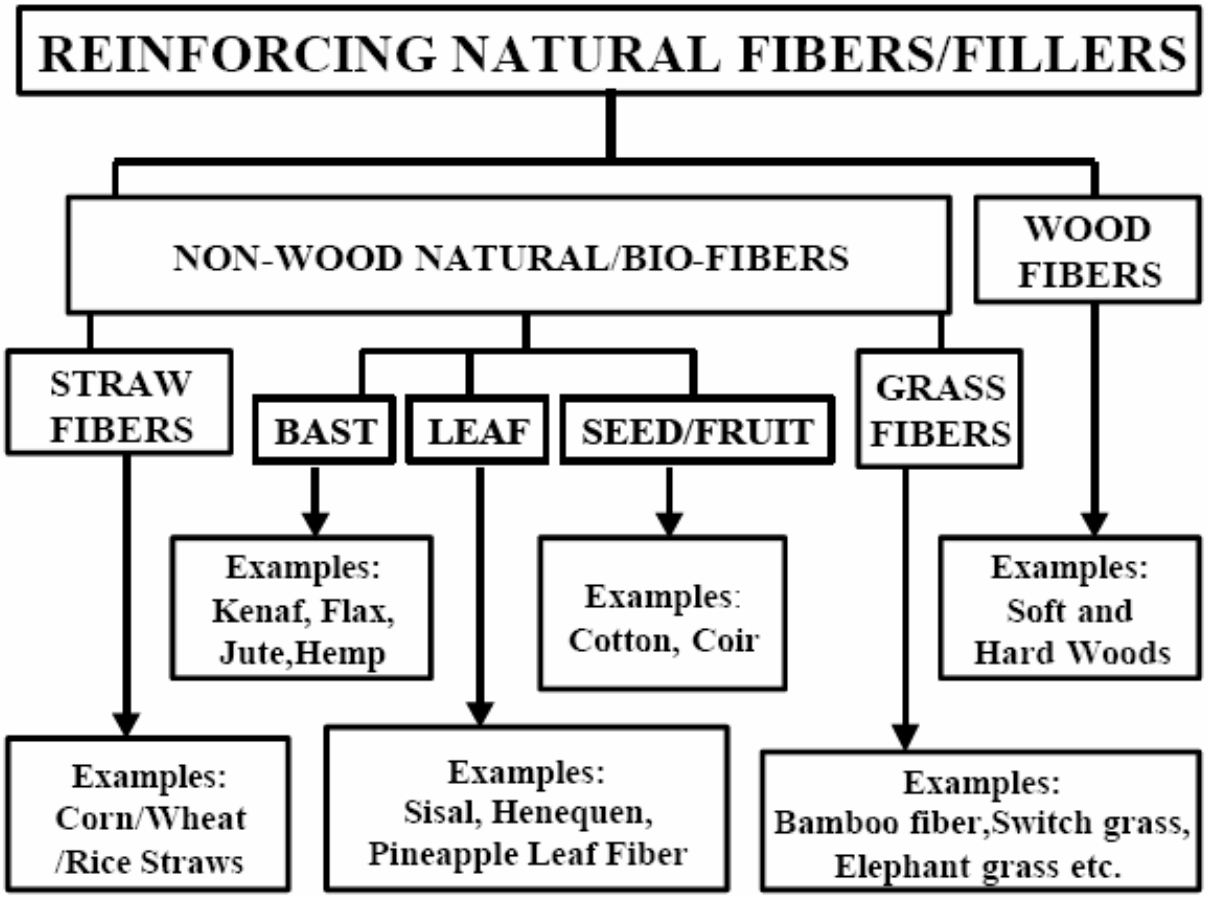
Given the ever increasing cost of wood fiber, increased demand and decreased availability, a potential win-win opportunity exists for wood products industry and the farming community.

Growth Outlook for Bio-based Composites by Applications in the US, 2000-2005



Source: Biobased Structural Composite Materials for Housing and Infrastructure Applications: Oportunities and Challenges, Drzal, L.T., A.K. Mohanty, Burgueno, R., Misra, M. www.pathnet.org

Natural (Wood and non-Wood) Fibers for Bio-composites



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www.pathnet.org

Types and Sources of Bio-fiber

Source: Biobased Structural Composite Materials for Housing and Infrastructure Applications: Oportunities and Challenges, Drzal, L.T., A.K. Mohanty, Burgueno, R., Misra, M.
www.pathnet.org

Comparative Chemical Composition

FIBROUS MATERIAL	CELLU -LOSE	HEMI-CELLULOSE	LIGNIN	EXTRACTIVES	ASH
FLAX	78.5	9.2	8.5	2.3	1.5
HEMP	68.1	15.1	10.6	3.6	2.5
KENAF (bast)	60.8	20.3	11.0	3.2	4.7
CONIFEROUS	48.0	15.0	25.3	11.5	0.2
DECIDUOUS	52.8	21.8	22.3	2.7	0.4

Source: Danforth International, and TAPPI

Chemical Composition of some Non-Wood fibers compared to Wood fibers

Fiber type	Chemical composition (% total)				
	Cellulose	Lignin	Pentosan	Ash	Silica
Stalk					
Rice	28~48	12~16	23~28	15~20	9~14
Wheat	29~51	16~21	26~32	4.5~9	3 ~ 7
Barley	31~45	14~15	24~29	5~7	3 ~ 6
Oat	31~48	14~19	27~38	6~8	4~6.5
Rye	33~50	14~19	27~30	2~5	0.5~4
Cane					
Sugar	32~48	19~24	27~32	1.5~5	0.7~35
Bamboo	26~43	21~31	15~26	1.7~5	0.7
Grass					
Esparto	33~38	17~19	27~32	6~8	-
Sobai	-	22	24	6	-
Reed[a]	44~46	22~24	20	3	2
Bast					
Seed flax	43~47	21~23	24~26	5	-
Kenaf	44~57	15~19	22~23	2~5	-
Jute	45~63	21~26	18~21	0.5~2	
Hemp	57~77	9~13	14~17	0.8	-
Ramie	87~91		5 ~ 8		
core					
Kenaf	37~49	15~21	18~24	2~4	-
Jute	41~48	21~24	18~22	0.8	
Leaf					
Abaca[b]	56~63	7~9	15~17	3	-
Sisal[c]	47~62	7~9	21~24	0.6~1	
Seed hull[d]	85~90	0.7~1.6	3~Jan	0.8~2	1
Wood					
Coniferous	40~45	26~34	7~14	< 1	-
Deciduous	38~49	23~30	19~26	< 1	-

Notes: [a] Phragmites communis, [b] Manila, [c] Agave, [d] Cotton linter.

Source: Properties of Non-wood Fibers, James T. Han
http://www.fpl.fs.fed.us/documnts/pdf1998/han98a.pdf

Comparative Mechanical/Physical Properties of Bast and Wood Materials:

FIBROUS MATERIAL	DENSITY (g/cm3)		LENGTH (mm)		DIAMETER (um)		L/D RATIO	TENSILE STRENGTH (psi)
	FIBER	BUNDLE	RANGE	AVG	RANGE	AVG		
FLAX	1.51	1.2	10 - 65	32	10 - 25	18	1,778	51,000
KENAF (bast)	-	1.2	1.4 - 5	2.6	14 - 23	21	124	58,000
KENAF (core)	0.31	-	0.4 - 1.1	0.6	18 - 37	30	20	-
HEMP	1.48	1.2	7 - 55	25	13 - 30	18	1,087	118,000
S.Y. PINE	0.51	-	2.7 - 4.6	3.7	32 - 43	38	97	11,600
D. FIR	0.48	-	2.7 - 4.6	3.7	32 - 43	38	97	15,600
ASPEN	0.39	-	0.7 - 1.6	1.2	20 - 30	25	48	7,400

Sources: Wood Handbook; Danforth International; W.S.U., WMEL; Columbus, 1996, Institute of Natural Fibers, U.S.D.A., A.R.S.; The BioComposite Center.

Wood and Non-Wood Fibers

• Softwood	3.0 – 4.0 mm
• Hardwood	1.0 – 2.0 mm
• Cereal Straw	0.8 – 1.0 mm
• Corn	0.5 – 2.9 mm
• Bagasse	0.8 – 2.8 mm
• Hemp	5.0 – 7.0 mm
• Flax	3.0 – 6.0 mm

Modulus Comparison of some Natural Biofibers

Fiber Type	Density (g/cm^3)	Elastic Modulus (GPa)	Specific modulus
E-glass	2.55	73	29
Hemp	1.48	70	47
Flax	1.4	60-80	43-57
Jute	1.46	10-30	7-21
Sisal	1.33	38	29
Coir	1.25	6	5
Cotton	1.51	12	8

Source: Biobased Structural Composite Materials for Housing and Infrastructure Applications: Oportunities and Challenges, Drzal, L.T., A.K. Mohanty, Burgueno, R., Misra, M. www.pathnet.org

Non-wood Fibers: Advantages

Most non-wood materials are:

- Readily available
- Easier to pulp
- Easier to bleach
- Bleach better with environmentally friendly chemicals
  - Oxygen, ozone, hydrogen peroxide, enzymes
- May be suitable for mechanical processing for use as particles or fiber in wood composites

  - Economies of scale may be less of an issue

Non-wood Fibers: Main Challenges

- **High Bulk**
  - Costly to ship
  - Need large storage area
  - Need different equipment that can handle bulky material
  - Restricted to small mills - transportation
  - Lack economies of scale – for pulp and paper
- **High levels of silica**
  - Process issues during chemical recovery

Non-wood Fibers Chemical Processing
Short Fibers – Cereal Straw

- **Cereal straw**
  - **Barley, wheat, oat**
- **Traditional process (Soda or Kraft)**
  - **Chemical recovery too expensive**
  - **Feasible as part of an existing mill**
  - **Chemical Recovery with existing system**
- **Ethanol/water process (non-traditional)**
  - **Better economics**
  - **Not yet commercial – but more suitable for Midwest?**

Pulp Properties

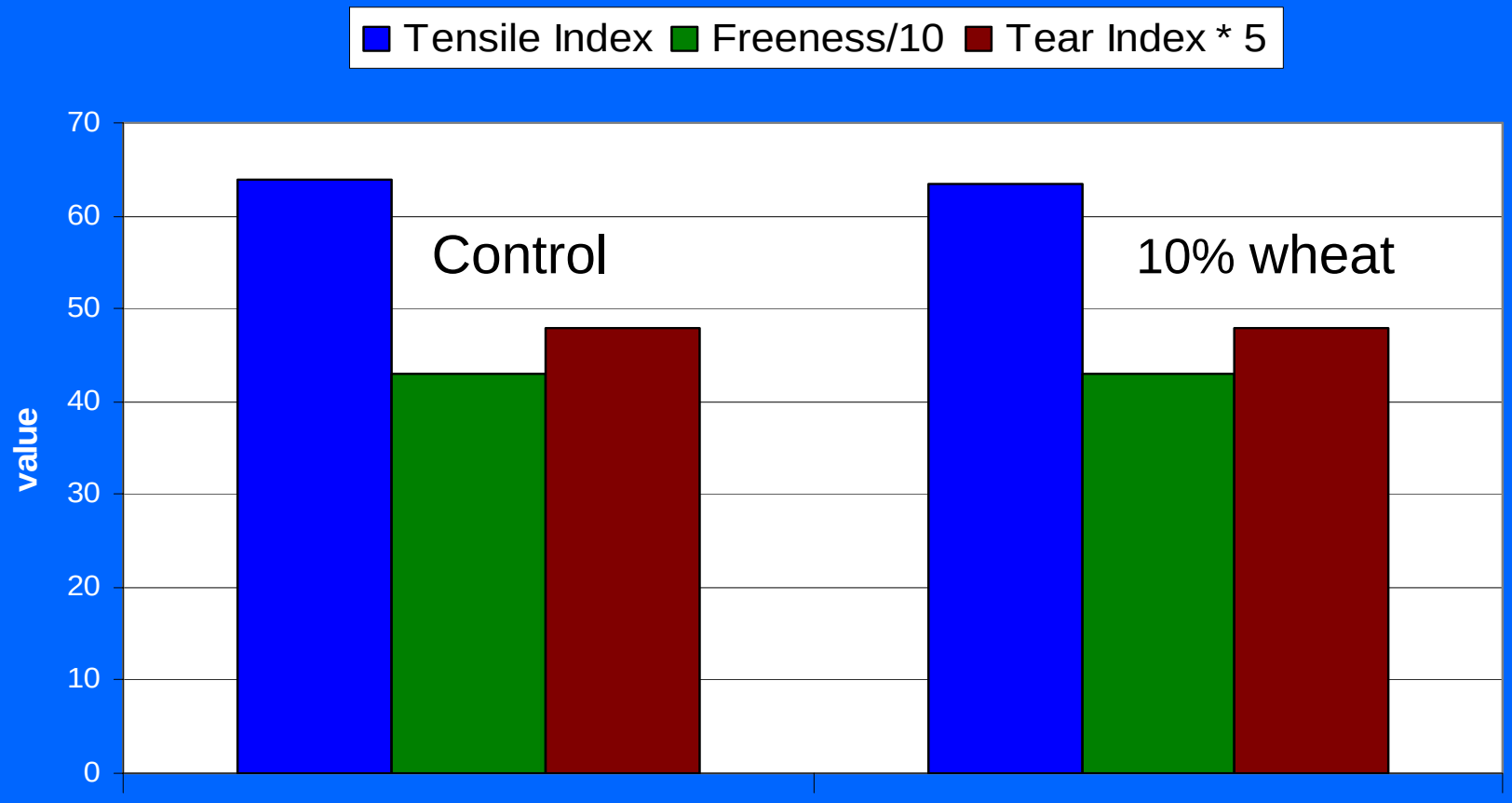
	Soda AQ Wheat Straw	Organosolv Wheat Straw	Commercial bleached Hardwood	Commercial bleached Softwood
Brightness [% ISO]	83	78	80	84
Tensile Index [Nm/g]	85	55	39	26
Tear index [mNm2/g]	5.0	5.4	9.8	19.5
Freeness, ml CSF	280	459	532	684

Feasibility in Papermaking Short Fibers

Pilot scale papermaking trials:

- Common Writing and printing paper (50% SW, 50% HW)
  - 25% cereal straw substituting HW and SW (37.5 % SW, 37.5 % HW)
  - Higher mechanical properties
  - Less energy needed for mechanical treatment
  - Slightly slower drainage on paper machine

CONTROL VS. STRAW CONTAINING FURNISH, DESIGN I



SW 30:HW70:SWR 8000:HWR:5000

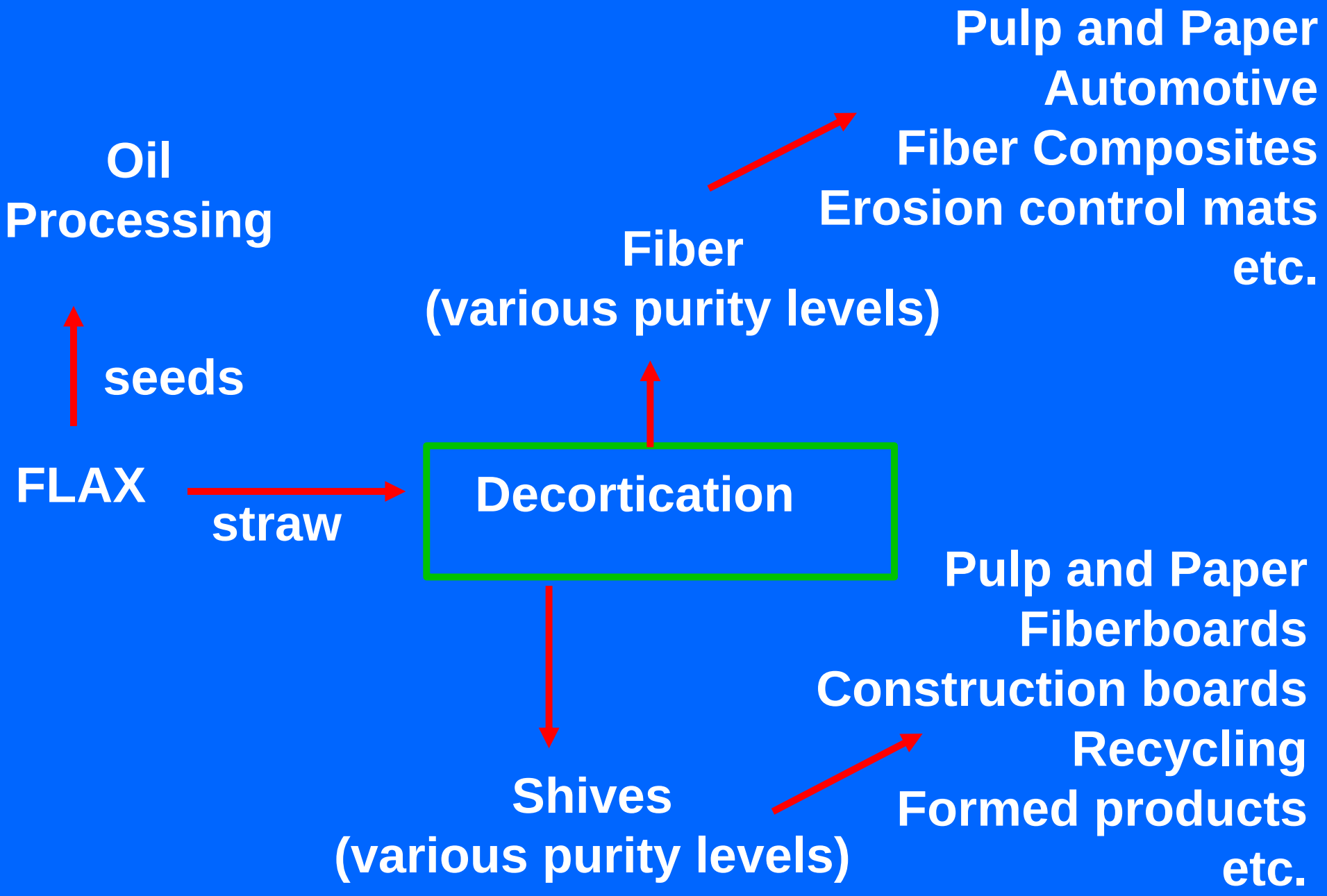
SW 20: HW 70: SWR 5000:HWR 3000

Non-wood Fiber Processing
Long Fiber (Flax)

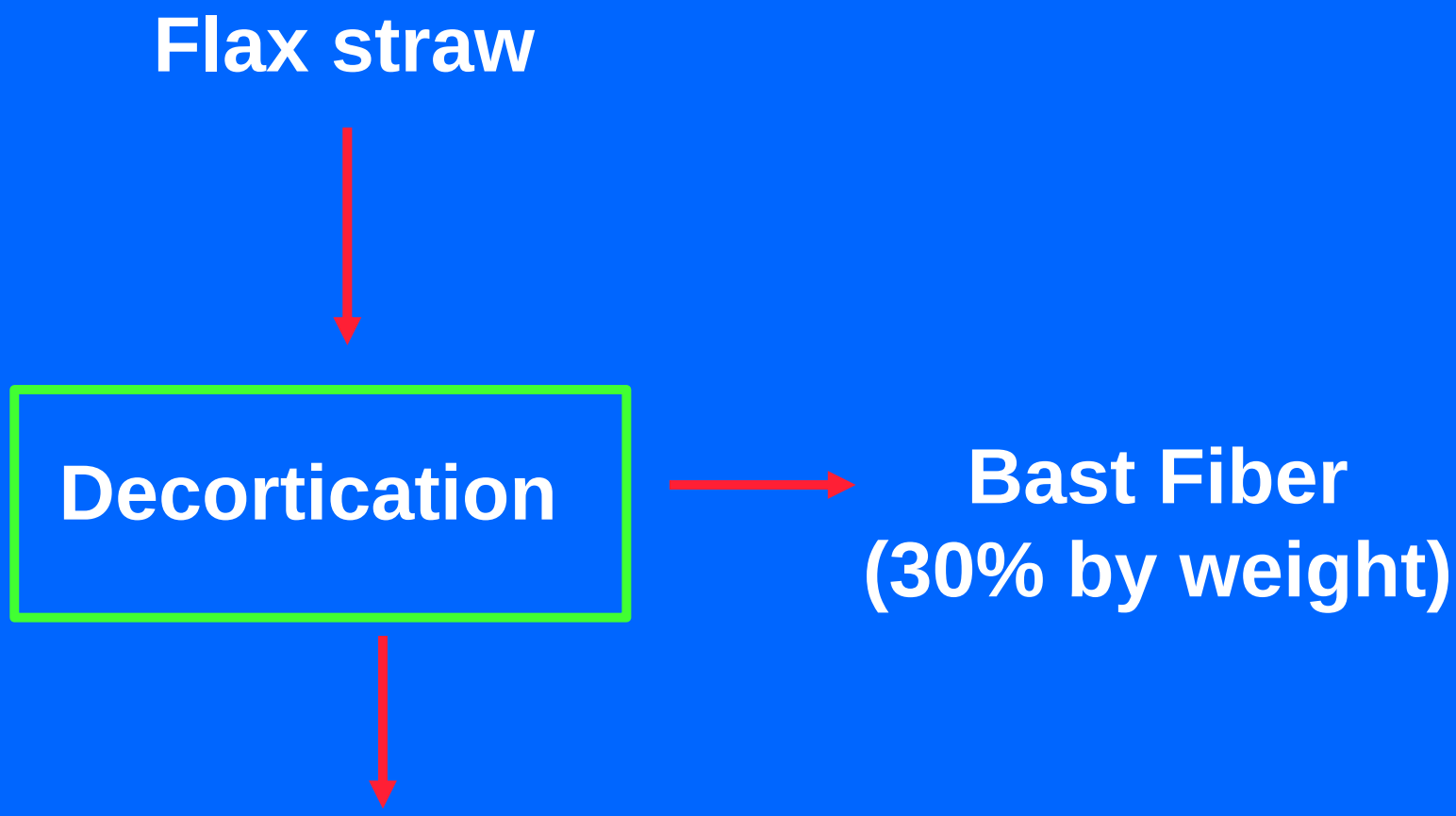
Flax (oilseed flax, Canada)

- Flax cut and mixed with aspen chips (co-processing)
- Up to 20% addition - no change in process
  - Higher strength properties
  - Needed less bleaching chemicals
  - Chemical savings estimated to be $3.30 - $5.80 per metric ton of pulp.
  - For 350, 000 metric ton/year Kraft mill → savings of $ 1.2 – 2.0 million per year.

Utilization of Flax Crop



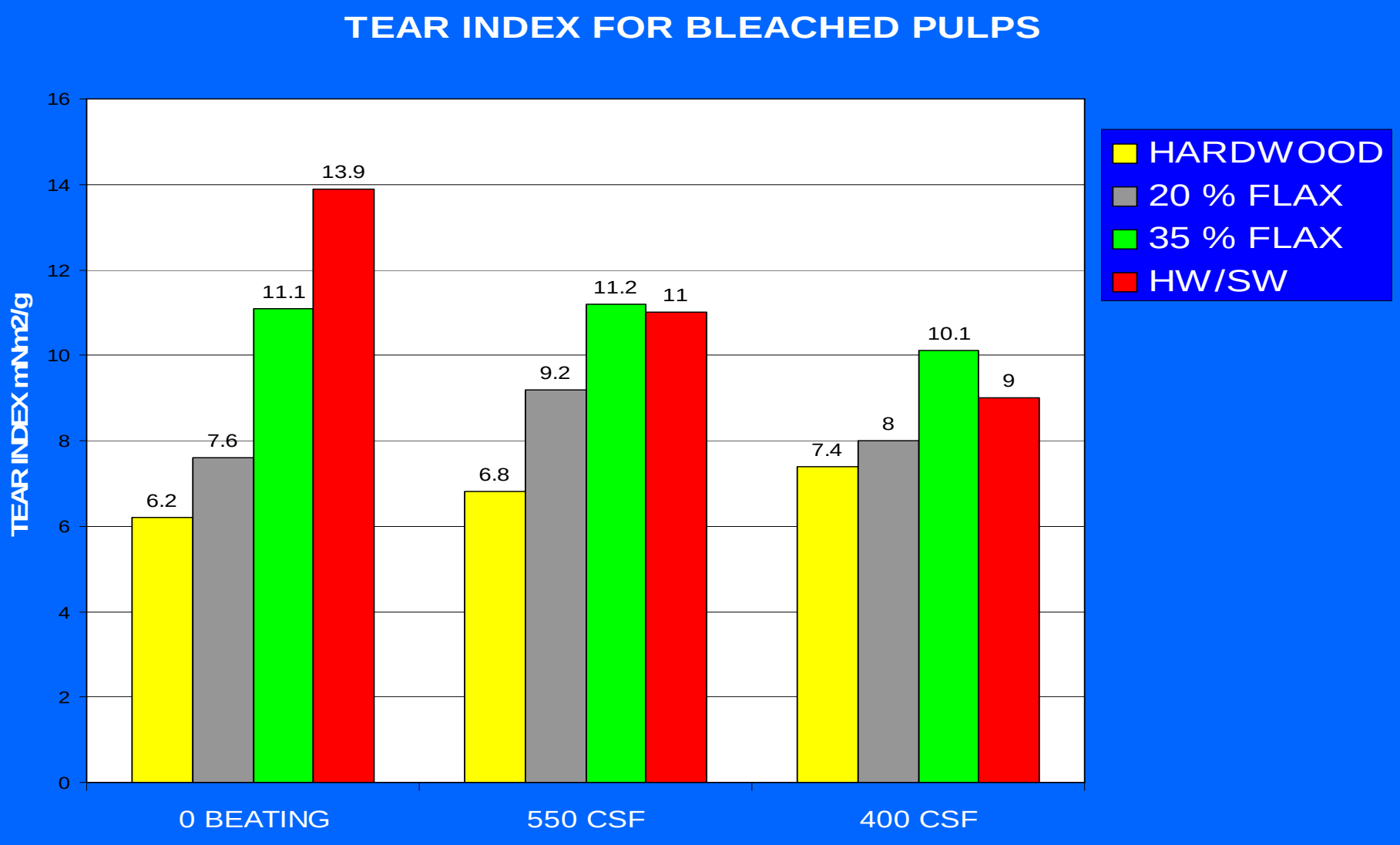
Flax Straw Decortication



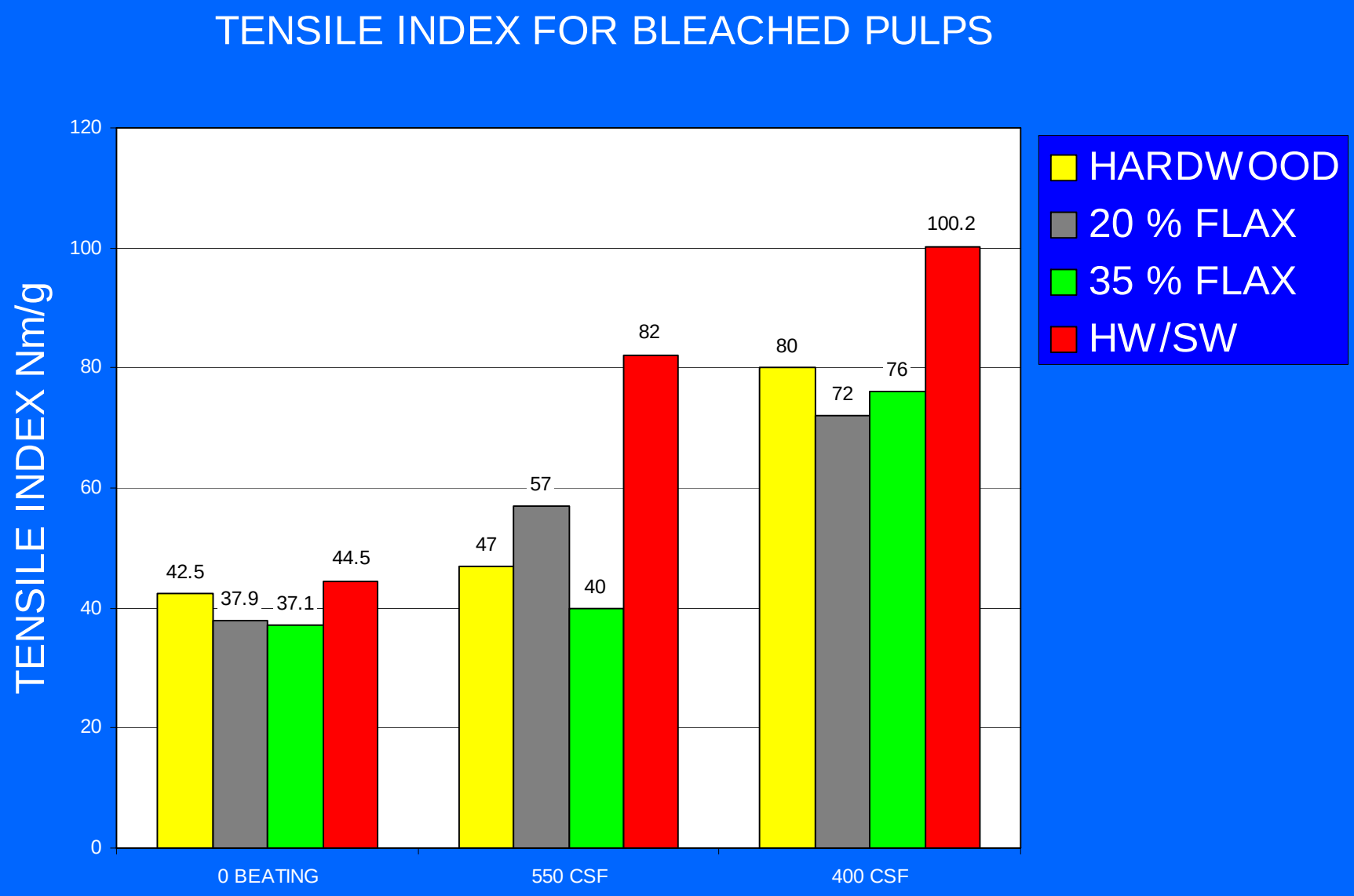
Typical Composition

	Cellulose (%)	Hemi-cellulose(%)	Lignin (%)	Extractives (%)
Flax Straw	63.33	8.16	14.66	2.22
Clean Fiber	78.23	6.16	5.04	1.63
Clean Shives	53.12	13.16	24.01	1.52
Hardwood	43-47	25-35	16-24	2-8
Softwood	40-44	25-29	25-31	5

TEAR INDEX


TEAR INDEX FOR BLEACHED PULPS
TEAR INDEX mNm2/g
16
14
12
10
8
6
4
2
0
6.2
7.6
11.1
13.9
6.8
9.2
11.2
11
7.4
8
10.1
9
0 BEATING
550 CSF
400 CSF
HARDWOOD
20 % FLAX
35 % FLAX
HW/SW

Physical properties of bleached pulp



Feasibility for Flax in Papermaking

- **Flax fiber can be used successfully to improve bleachability and tear strength of hardwood pulps.**
- **Bleaching chemical savings $ 3-6/metric ton**
- **Significantly improved tear strength**
- **No need for additional equipment**
- **No change in throughput**

Use of Non-Wood Fibers

- **Augment wood fiber with non-wood fiber?**

  In paper – up to 20-25% augmentation possible

- **Conventional processes for fiber manufacture**

  stand-alone mills using cereal straw

  currently, economically NOT VIABLE!

- **Simultaneous metering of non-wood with wood**
  – Possible Attractive Alternative!
  Already shown to work for Flax in the lab

- **For non-Paper, bio-based composites applications,**
  Stand-alone Mechanical Fiber Processes
  More economically viable?

Use of Non-wood Fibers

Structural and non-structural panels

- **Past technical research into alternative fiber raw materials for bio-based composites is extensive:**
  - **Sunflower hulls, bagasse, hemp, bamboo, kenaf, cereal straws, cotton linters, etc.**
- **Commodity-type markets only driven by performance and price**

Use of Non-wood Fibers

Structural and non-structural panels

- **Challenges:**
  - Optimal selection - Combinations of natural fibers
  - Surface treatment – improved hydrophobicity
  - Adhesive system compatibility
  - Process development
  - Physical and mechanical properties
    Lower stiffness and impact resistance
  - Moisture and thermal durability
  - Stability enhancement
  - Biodegradability
  - Inherent Variation in Properties

References

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Thank You!

Questions?