Opportunities for Hemp Fiber in Industry Supply Chains

Pennsylvania Industrial Hemp Engine
Industrial and Consumer Product Development R&D
Stakeholder Engagement Meeting
April 9, 2024

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Outline

- Fibers and their characteristics
- Supply chain driven research
- Overview of Hemp in paper and fiber cement
- Discussion!

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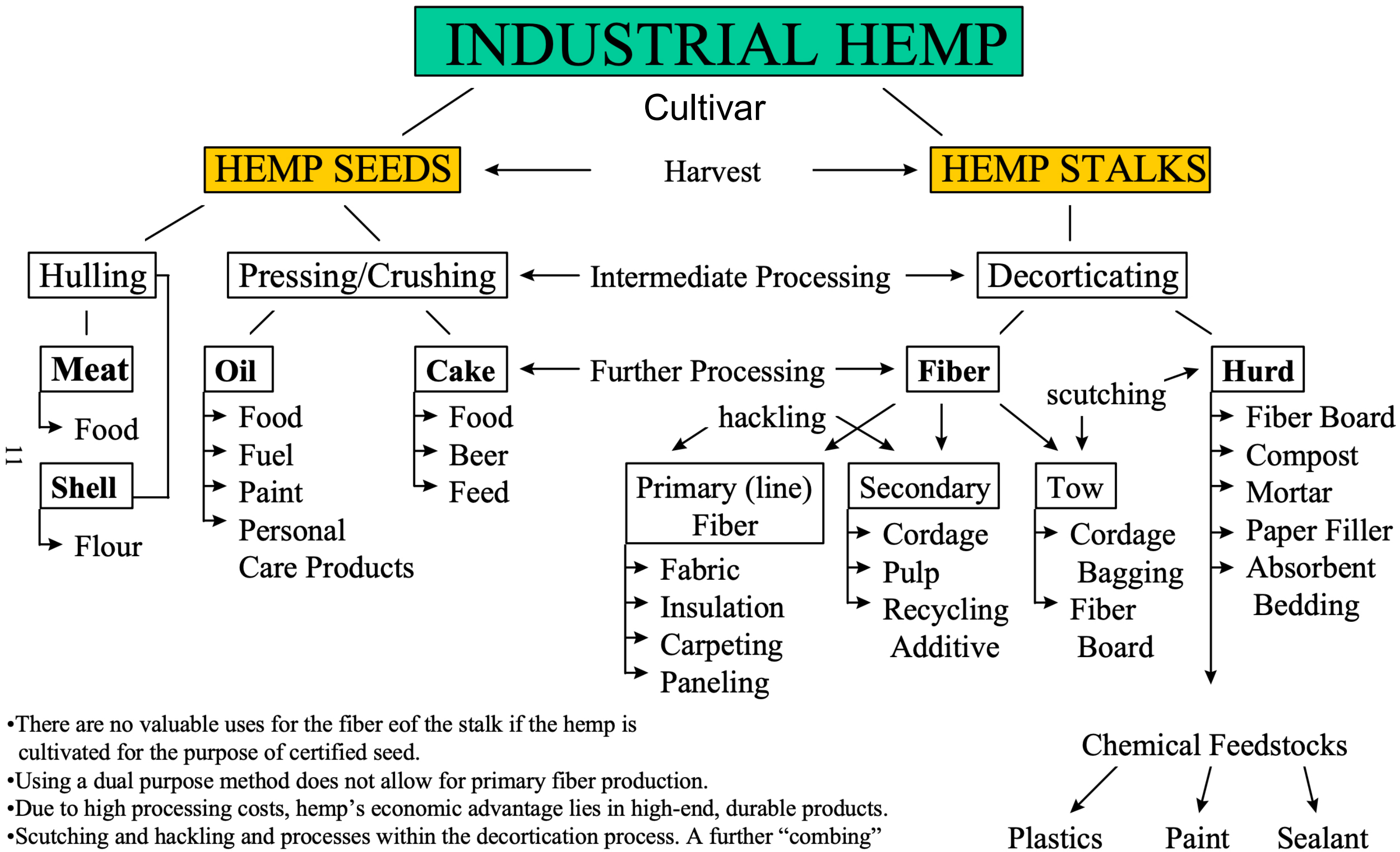
Supply chain driven research



- There are no valuable uses for the fiber eof the stalk if the hemp is cultivated for the purpose of certified seed.
- Using a dual purpose method does not allow for primary fiber production.
- Due to high processing costs, hemp's economic advantage lies in high-end, durable products.
- Scutching and hackling and processes within the decortication process. A further "combing" process, known as cardin, may be performed on the primary fiber.

Figure 4. Hemp Products Flowchart. Processing to End Product Groups. Dustin Mathern, Undergraduate, Jodi L. Young. Department of Agricultural Economics, North Dakota State University, 1998.

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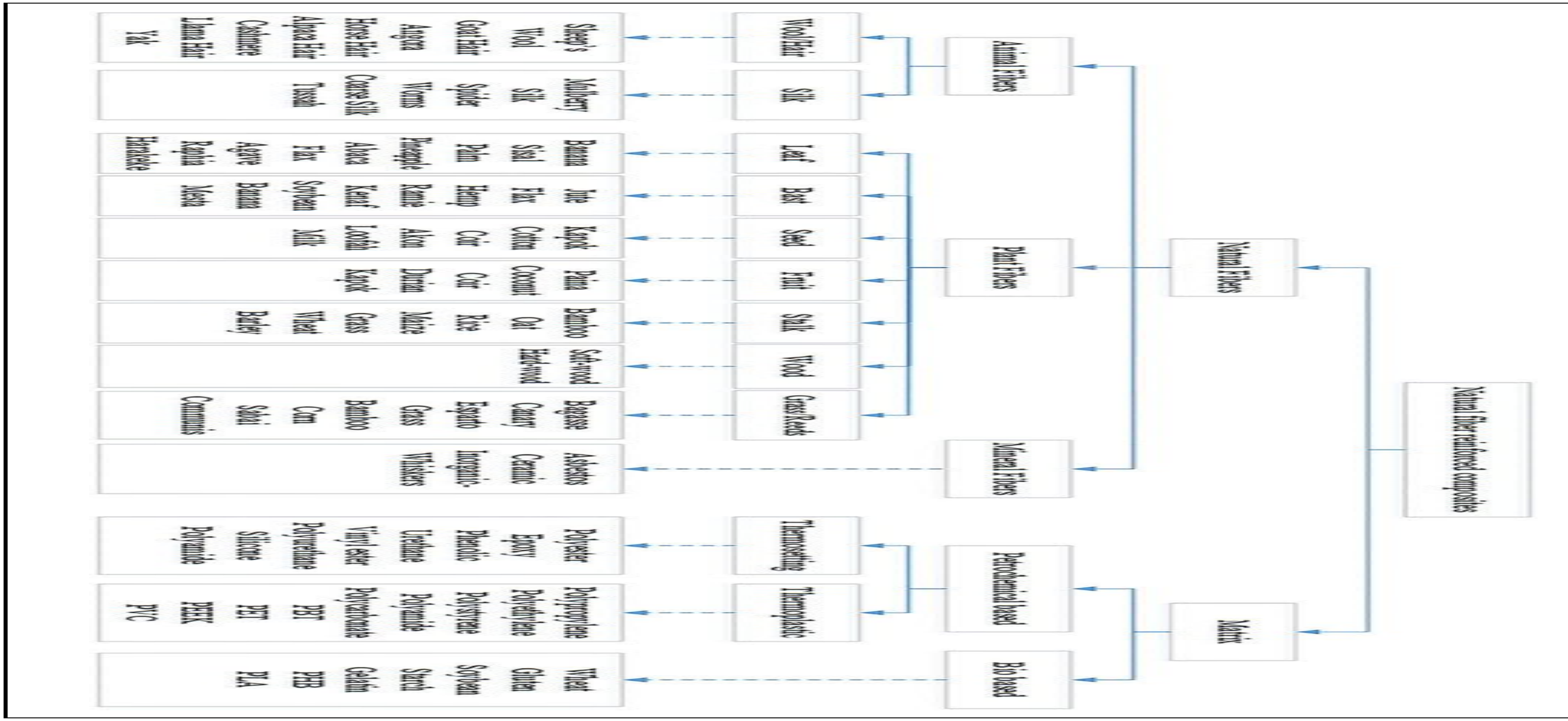
Sources of fiber and composites



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Lotfi, A., Li, H., Dao, D. V., & Prusty, G. (2021). *Natural fiber–reinforced composites: A review on material, manufacturing, and machinability*. SAGE Publications.

Sources of fiber and composites

Hemp Bast fiber

Hemp Hurd fiber

Hemp fiberboard

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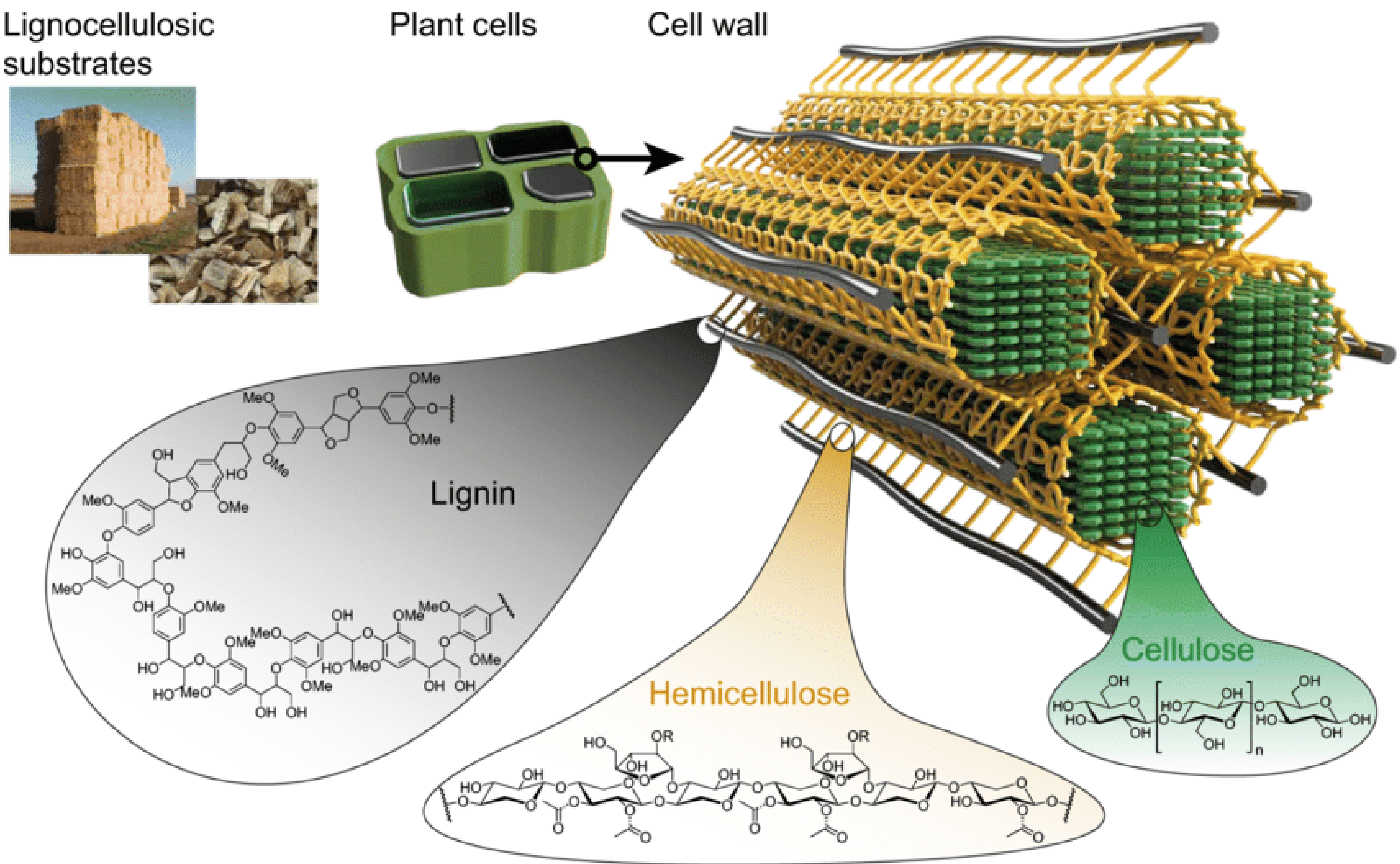
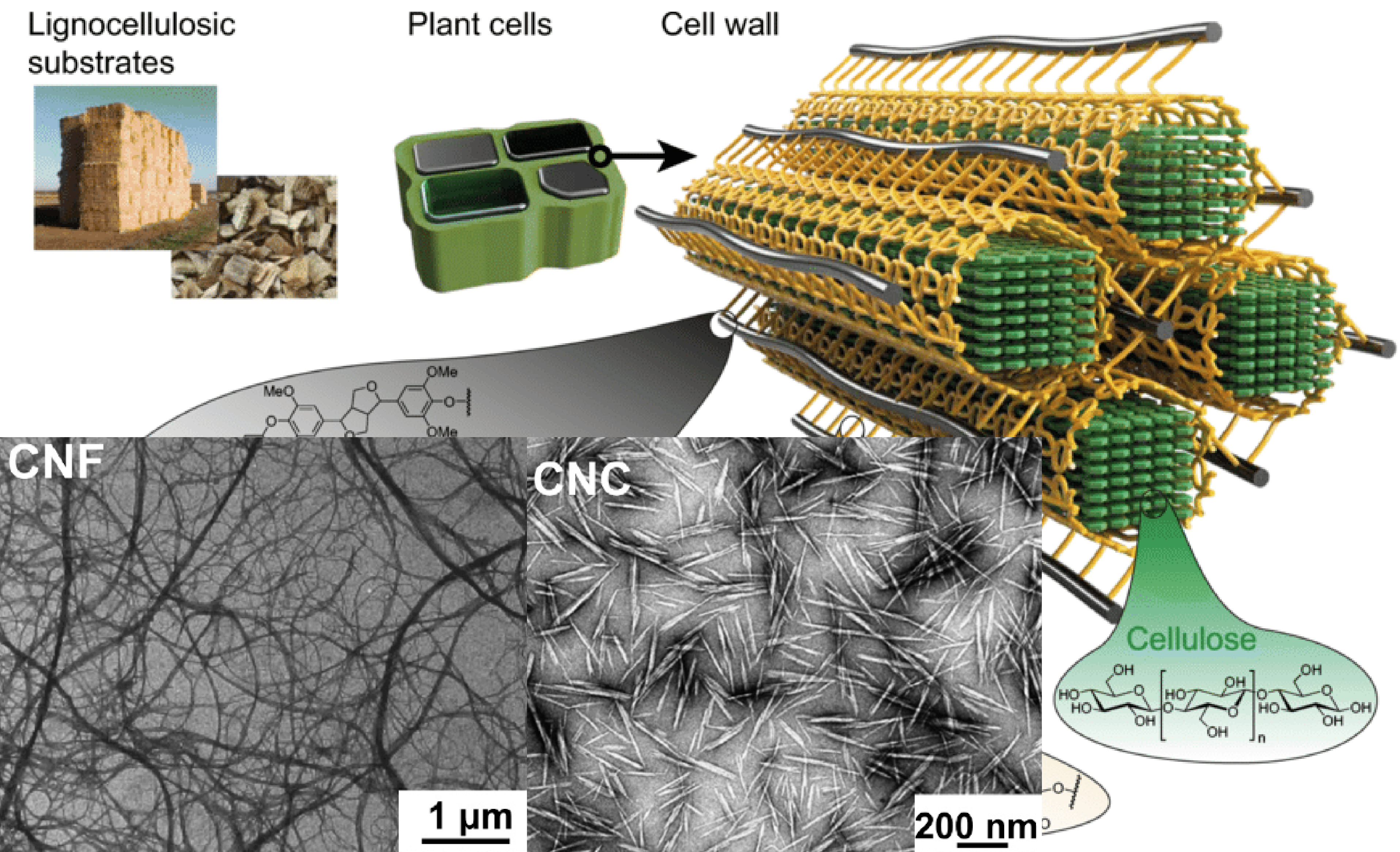
Lotfi, A., Li, H., Dao, D. V., & Prusty, G. (2021). *Natural fiber–reinforced composites: A review on material, manufacturing, and machinability*. SAGE Publications.

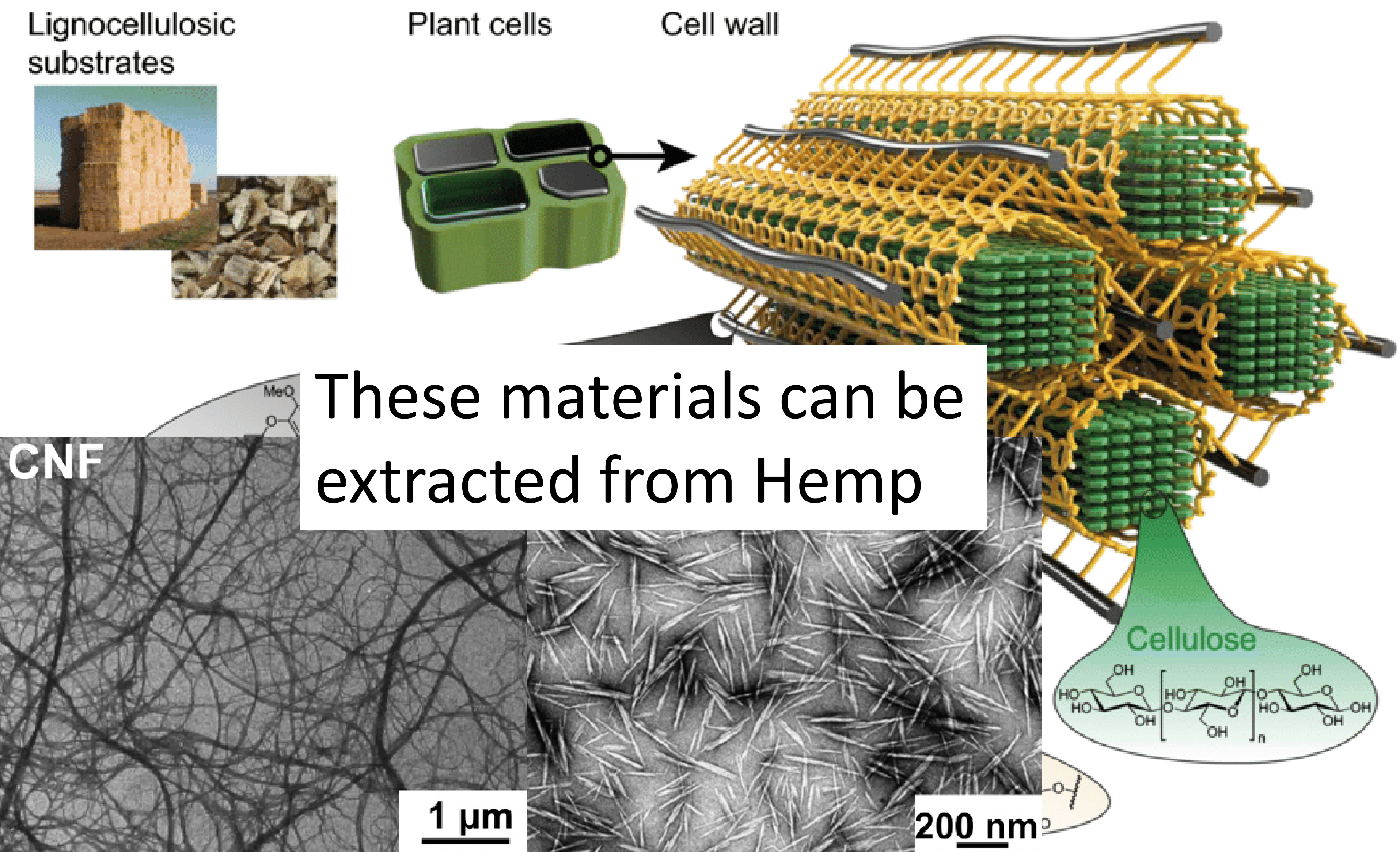
Molecular construction of plant fiber



Molecular construction of plant fiber



Molecular construction of plant fiber



These materials can be extracted from Hemp

Fiber characteristics

Fibers		PP	Polymer	Jute	Ramie	Sisal	Cotton	Bamboo	Hemp
References & variation		4,23	11	5,12,24	5	4,20	14	12,33	
Length (l)	(mm)	19	19	19	19	19	19	19	Bast 5-55/Hurd 0.5-0.6
Diameter (d)	(mm)	0.035	0.0375*	0.28	0.092	0.01	0.003	0.6	Bast 16-50/Hurd 15-40 *microns*
Slenderness (l/d)	(–)	543	507	68	210	190	6333	32	
Number of fibres	(per 1 kg) ($\times 10^3$)	54,704	47,653	855	790	670,126	7,445,845	186	
Total length	(m/kg) ($\times 10^3$)	1039	905	16	15	12,732	141,471	3.5	
Total length of reinforcement (40 × 40 × 160 mm)	(m)	477,9	41,4	7,4	7	5856,7	65,076,7	1,6	
Density	(g/cm^3)	0.89–0.92	0.91–0.93	1.3–1.5	1.0–1.6	1.3–1.6	1.5–1.6	0.5–1.15	1.4-1.5
Young's modulus	(GPa)	0.95–1.77	0.055–0.38	15–30	24.5–128	9–38	5.5–12.6	11–32	23.5-90
Tensile strength	(MPa)	26–41.4	40–78	320–800	400–1000	540–720	287–800	140–800	270-1100
Elongation	(%)	15–700	90–800	1.0–1.9	3.6–3.8	2.0–3.3	3–10	2.5–3.7	1.0-3.5
Cellulose	(%)	–	–	59–70	70–83	65–76	80–94	40–45	Bast 57-77/Hurd 40-48
Hemicellulose	(%)	–	–	15–20	10–17	10–16	–	25	Bast 9-14/Hurd 18-27
Lignin	(%)	–	–	11–15	5–13	7–13	–	24	Bast 5-9/Hurd 31-24
Natural moisture	(%)	0	0	2.5–5	8	5	0	0	6.2-12
Moisture absorption after 24 h	(%)	0,01–0,02	< 0.015	7–12	10–12	95–110	25–50	120–145	33

Fines (%, amount of fiber in a pulp that passes though a 200 mesh [76 microns] screen)
Kappa Number (KN, where lignin content in % is ~0.13-0.16 x KN)
Coarseness (mass of fiber per unit length – higher for fibers with thicker cell walls)
Freeness (CSF [Canadian Standard Freeness test], ability of fibers to separate in water)
Drainabilty (°SR, Schopper-Reigler method)
Any chemical modification
Purity

Strongly influenced by Hemp cultivar!

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Kurpińska, M., Pawelska-Mazur, M., Gu, Y., & Kurpiński, F. (2022). The impact of natural fibers' characteristics on mechanical properties of the cement composites. *Scientific Reports, 12*(1), 20565-20565.

Table 11 Breaking strength of different cultivars/varieties of cotton, canola, flax, and hemp fibres for Weibull two-parameter reliability analysis (N = 80)

Sl	Cotton	Breaking strength (cN/tex)	Canola	Breaking strength (cN/tex)	Flax	Breaking strength (cN/tex)	Hemp	Breaking strength# (cN/tex)
1	FM832 (Avg*: AFIS, HVI)	28.44	Hero	2.3	B5	53	Uso 11 (1995)	61
2	MD51neOK (Avg: AFIS, HVI)	26.72	Reston	5.7	F1	46	Kompolti HTC (1995)	55
3	MD15 (Avg: AFIS, HVI)	36.75	Mercury	4.8	Arawa	52.95	Uso 31 (1995)	58
4	G45 (Avg: Vibro-scope, HVI)	39.33	Venus	2.5	Makaweroa	55.38	Uniko B (1995)	55
5	G87 (Avg: Vibro-scope, HVI)	40.38	Neptune	3	Tapamangu	52.6	VxKompolti	38
6	G88 (Avg: Vibro-scope, HVI)	39.56	Global	3	Hermes (2003)	94.39	Beniko	53
7	G86 (Avg: Vibro-scope, HVI)	40.27	Westar	2.4	Ariane (2002)	86.89	Bialobrzeskie	75
8	G90 (Avg: Vibro-scope, HVI)	32.5	O2R276	2.2	Alaska	44.84	Fedora 19	57
9	Xiangcaimian 2	27.5	Sentry	4.3	Unknown (BTMAH-treated)	41.54	Felina 34	58
10	Wanmian 39	24	Defender	2.3	Agatha	56.12	Futura 77	77
11	Sumian 9	32	Steallar	2.4	Ariane (2007)	47	Novosadski	53
12	Laxmi	47	Apollo	3	Hermes (2007)	36.26	Secuieni 1	63
13	D-33	50	Polo	3	Omega	29.89	Unknown Canadian cultivar	35.52
14	Reba B-50	53	Arid	3.4	Laura	34.6	Uso 11 (1996)	58
15	MCU-8	48	Reward	1.8	Unknown Belgian (short flax) cultivar	35.57	Uso 31 (1996)	48
16	St Vincent (Pressley)	59.92	Red River 1861	1.2	Everest	43.02	Kompolti HTC (1996)	52
17	Giza 12 (Pressley)	49.76	UM 2407	4.2	Alizee	60.81	Uniko B (1996)	75
18	Memphis (Pressley)	41.36	UM 2257	2.4	Oliver	48.74	Fedora 17 (2006)	52.85
19	Texas (Pressley)	43.24	HYHEAR 1	8.5	Hivernal	72.61	Fedora 17 (2009)	24.69
20	Bengals (Pressley)	40.49	Topas	2.9	Marylin	77.67	Fedora 17 (2017)	29.56

*Avg: average of two data-point measurements between two different testing machines

Tensile strength (MPa) = (9.81) x breaking tenacity (gram-force/tex) × (ρ gm/cc) as used by Shuvo et al. (2019) considering densities (g/cc) of 1.54, 1.34, 1.54, and 1.48 for cotton, canola, flax, and hemp, respectively

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Shuvo, I. I. (2020). Fibre attributes and mapping the cultivar influence of different industrial cellulosic crops (cotton, hemp, flax, and canola) on textile properties. *Bioresources and Bioprocessing, 7*(1), 1-28.

Paper and paperboard

- Manufactured mainly from trees.
- Public is demanding forest preservation.
- Some non-wood fiber crops can capture more CO2 and carbon sequestration is also important to the public.
- Using less wood and higher carbon capturing crops would allow paper companies to **brand** products accordingly.
- Non-wood fiber crops may provide better fiber and/or manufacturing processes (made up 8-10% of fiber in 2010).
- Forest resources are dwindling, and forest plantations are less productive in colder climates.
- Hemp may be an alternative fiber crop.
- To compete with wood (spruce, larch, Douglas fir, birch, cereal straw, and genetically modified poplars), the dry biomass yield must be >7 tons/ha (and >6-12/ha tons to compete with gm poplars)
- European paper mills would need 640,000 oven dried metric tons of IH straw requiring 80,000 ha of land to produce (assuming 8 tons/ha yield).

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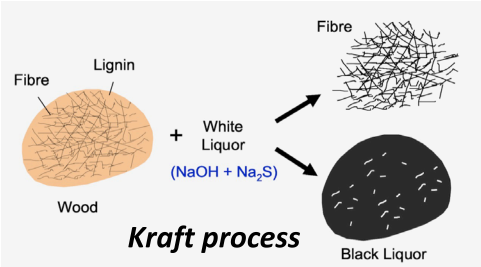
Danielewicz, D. Industrial Hemp as a Potential Nonwood Source of Fibres for European Industrial-Scale Papermaking—A Review. *Materials* **2023**, *16*, 6548.

Paper and paperboard

- IH has advantages for paper making:
  - Lower mineral content than cereal straw.
  - Comparable density to wood.
  - Good or improved handsheet mechanical properties – especially improved tear resistance allowing IH to become a "healing pulp" for low grade pulps.
  - Kraft pulps are easier to produce (lower lignin content) with higher yield.
  - No need for plant protection and pesticides.
  - Good drought tolerance.
  - High crop yield.
- IH deficiencies/issues include:
  - Need for annual sowing.
  - Need to use IH stalks to be price competitive.
  - Need much shorter fiber lengths in IH bast (from as long as 55mm to ~6mm). Can cut stalks but get more short fiber which is also a problem.
  - Need longer lengths (additional 0.2-0.3 mm) in hemp hurd woody core.
  - **Need a "papermaking" hemp cultivar that does not exist.**



Fibers can then be ***bleached*** using hydrogen peroxide and chlorine dioxide

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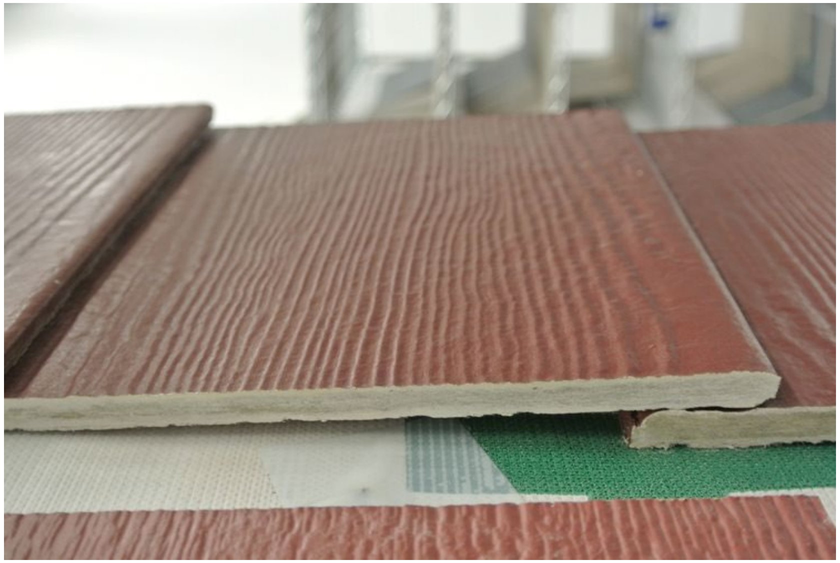
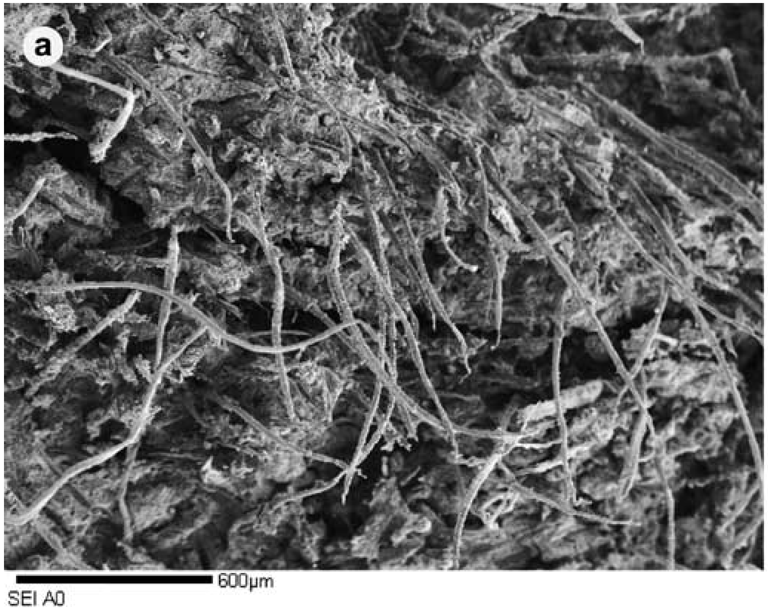
Danielewicz, D. Industrial Hemp as a Potential Nonwood Source of Fibres for European Industrial-Scale Papermaking—A Review. *Materials* **2023**, *16*, 6548.

Fiber Cement





Fiber cement industry led by James Hardie and Allura (Plycem, who purchased the fiber cement division of Saint Gobain)

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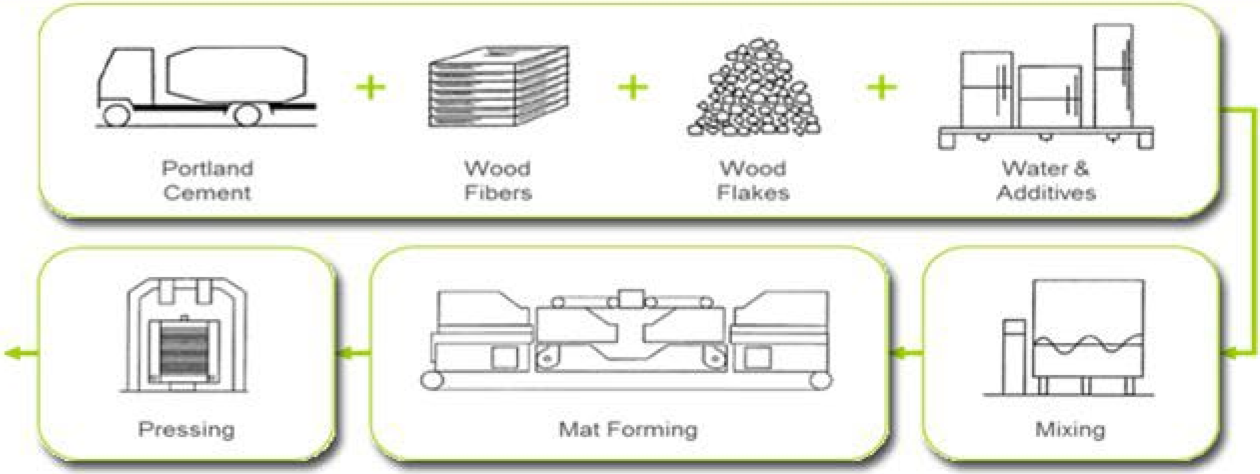
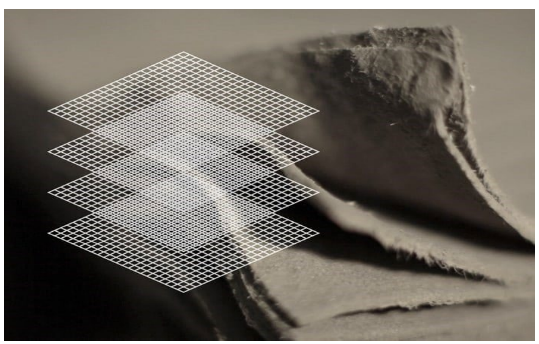
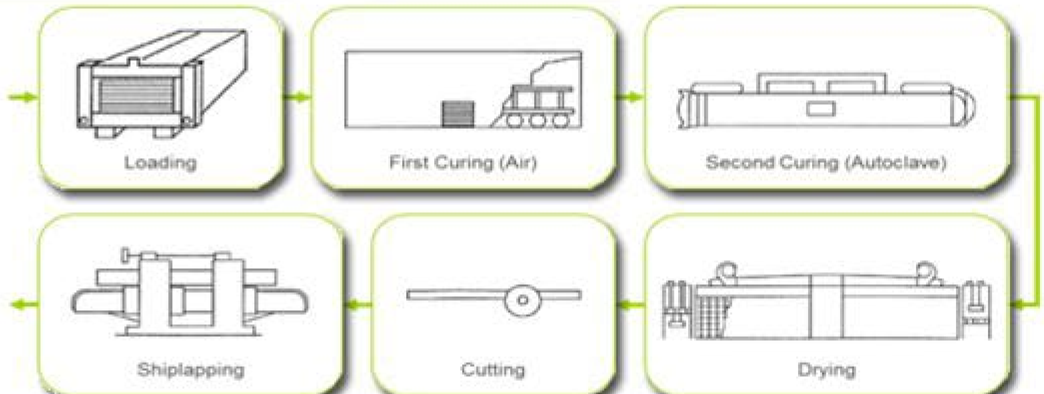
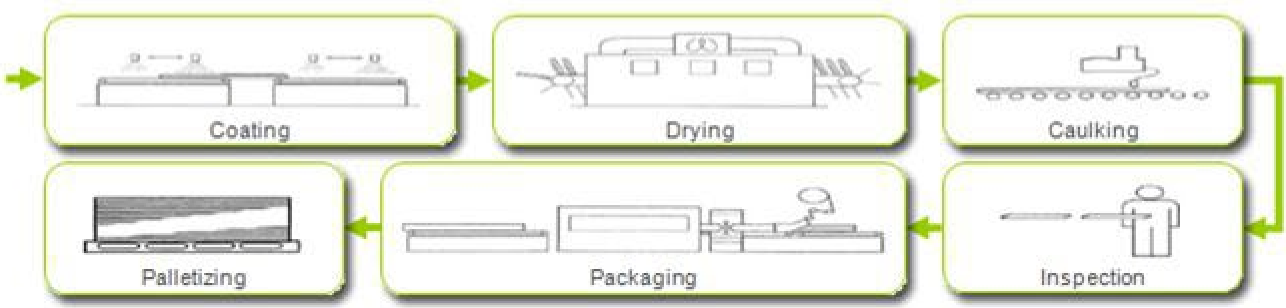
Introduction to Fiber Cement Panels



Manufactured using the Hatschek process



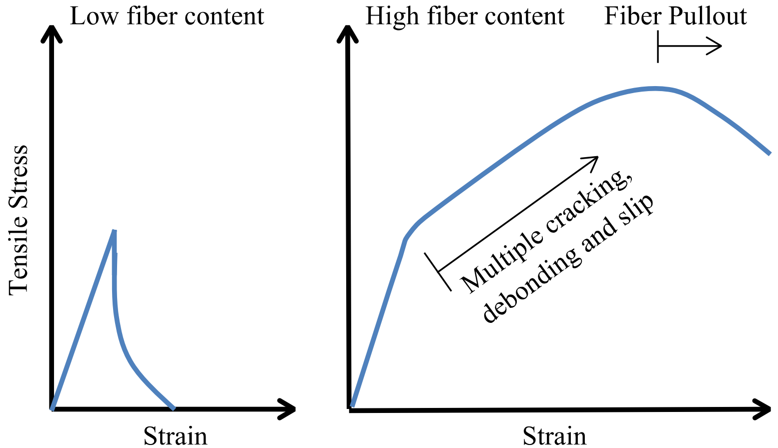


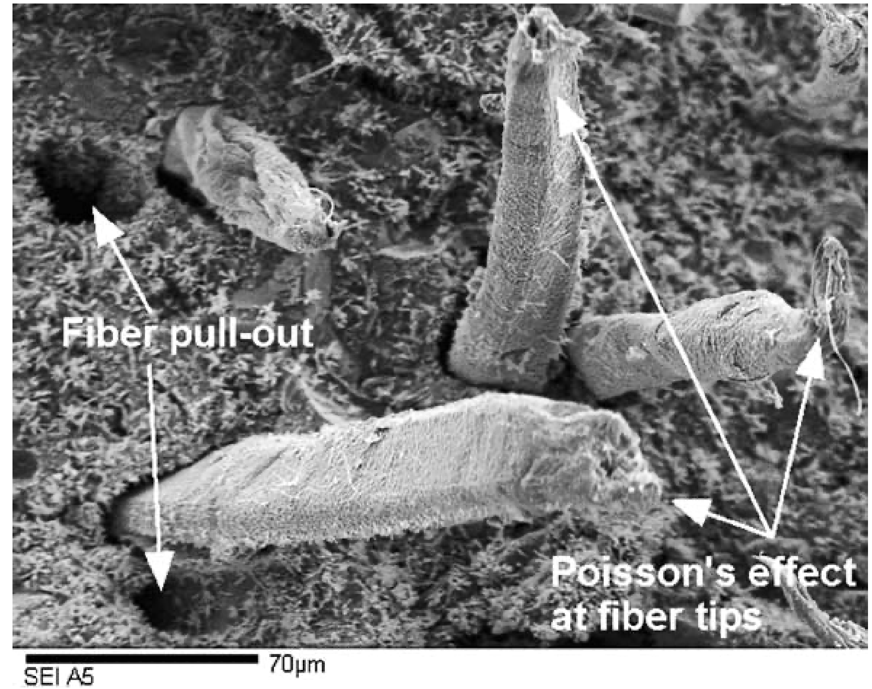


Issues with Fiber Cement

- Long term stability due to alkaline pH ~13 degrading fiber.
- Long term stability under wet/dry and temperature cycling associated in part with water absorbance of fiber and how it influences interface bonding and fiber mineralization.
- Damage to boards during shipment or use in construction due to lack of ductility.

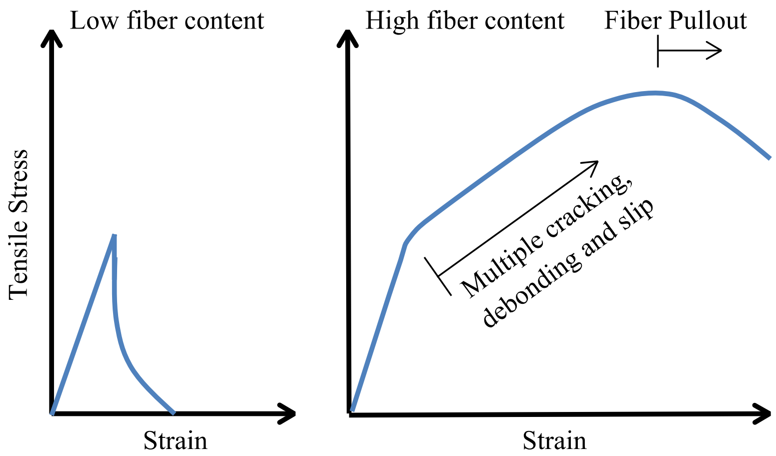
Issues with Fiber Cement

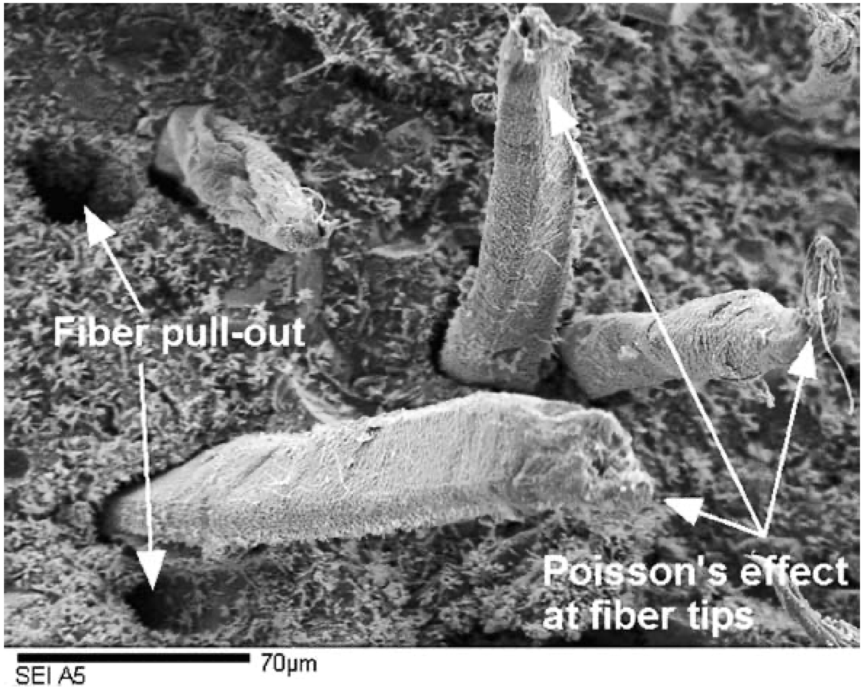




Mohr, B. J., Nanko, H., & Kurtis, K. E. (2005). Durability of kraft pulp fiber–cement composites to wet/dry cycling. *Cement & Concrete Composites, 27*(4), 435-448.

Issues with Fiber Cement





Mohr, B. J., Nanko, H., & Kurtis, K. E. (2005). Durability of kraft pulp fiber–cement composites to wet/dry cycling. *Cement & Concrete Composites, 27*(4), 435-448.

Reduces matrix strength

Farshad Rajabipour, PSU
Interim department head, Civil and Env. Eng.

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Akhavan, A., Catchmark, J., & Rajabipour, F. (2017). Ductility enhancement of autoclaved cellulose fiber reinforced cement boards manufactured using a laboratory method simulating the hatschek process. *Construction & Building Materials, 135*, 251-259.

Fiber Cement

- Typical properties of fiber used in fiber cement

Properties	Specification for Fiber cement pulp
Fiber Length, mm	> 2.5
Fiber Coarseness, mg/100m	> 20
Kappa Number	25 – 28
Zero Span Tensile Strength, km	> 15

- IH has advantages for fiber cement:
  - All the advantages associated with paper.
  - Easy processing to get a Kappa number of ~25.
  - Low cost if IH stalks can be used directly.
  - Benefits of long IH bast fiber which could improve fiber cement if it does not present an issue elsewhere in manufacturing process including difficulty in dispersion.

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No literature could be found studying various hemp fibers used in making fiber cement via the Hatschek process

Where Hemp can shine!

- From the specification sheet K25 pulp for fiber cement (Oji Fiber Solutions, Australia & New Zealand)
- Contains Full LCA analysis

Environmental impact potentials

Table 09: Environmental impact results for 1 metric tonne of air-dried pulp

Indicator	Abbr.	Unit	Upstream (A1)	Core (A2+A3)	Downstream (A4)	Downstream end-of-life (C1-C4)	TOTAL
GWP – total	GWPt	kg CO_2 eq.	-3030	1870	104	150	-906
GWP – fossil	GWPf	kg CO_2 eq.	179	272	103	23.1	577
GWP – biogenic	GWPb	kg CO_2 eq.	-3210	1590	0.977	127	-1490
GWP – land use & land use change	GWPluluc	kg CO_2 eq.	0.0252	0.0204	0.00114	0.00231	0.0491
Ozone depletion	ODP	kg CFC 11 eq.	8.77E-10	1.39E-10	6.84E-12	3.50E-11	1.06E-09
Acidification potential	AP	mol H+ eq.	0.977	0.940	3.09	0.122	5.13
Eutrophication potential - freshwater	EPfw	kg P eq.	2.23E-04	0.104	2.18E-05	7.20E-05	0.104
Eutrophication potential - marine	EPm	kg N eq.	0.327	0.425	0.829	0.0351	1.62
Eutrophication potential - terrestrial	EPt	mol N eq.	3.75	4.20	9.08	0.384	17.4
Photochemical ozone formation potential	POFP	kg NMVOC eq.	0.883	0.955	2.31	0.114	4.26
Abiotic depletion potential – minerals & metals	ADPmm	kg Sb eq.	1.86E-05	1.55E-05	3.40E-06	1.44E-06	3.89E-05
Abiotic depletion potential – fossil fuels*	ADPf	MJ, net calorific value	2340	2940	1270	302	6850
Water Depletion Potential*	WDP	m^3 eq.	21.0	123	0.280	1.60	146

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Where Hemp can shine!

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- Contains Full LCA analysis

Additional indicators

Table 10: Additional indicators results for 1 metric tonne of air-dried pulp

Indicator	Abbr.	Unit	Upstream (A1)	Core (A2+A3)	Downstream (A4)	Downstream end-of-life (C1-C4)	TOTAL
IPCC AR5 GWP (excl. biogenic carbon)	GWP-GHG	kg CO_2-eq.	179	272	103	52.3	606
Particulate Matter emissions	PM	Disease incidences	1.63E-05	6.04E-06	5.23E-05	1.36E-06	7.60E-05
Ionising Radiation – human health**	IRP	kBq U235 eq.	6.18	0.318	0.174	0.180	6.85
Eco-toxicity (freshwater)*	ETPfw	CTUe	4530	72000	804	404	77700
Human Toxicity, cancer*	HTPc	CTUh	1.08E-07	2.97E-07	1.47E-08	1.71E-08	4.37E-07
Human Toxicity, non-cancer*	HTPnc	CTUh	8.06E-06	3.26E-05	6.72E-07	1.83E-06	4.32E-05
Soil quality*	SQP	Pt	221	286	3.63	20.8	531

*The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator

**This impact category deals mainly with the eventual impact of low dose ionising radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionising radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

CTUh - Comparative Toxic Unit for Humans

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More cylinders for the Engine?

- Systems person
- LCA/TEA person

Thank you!

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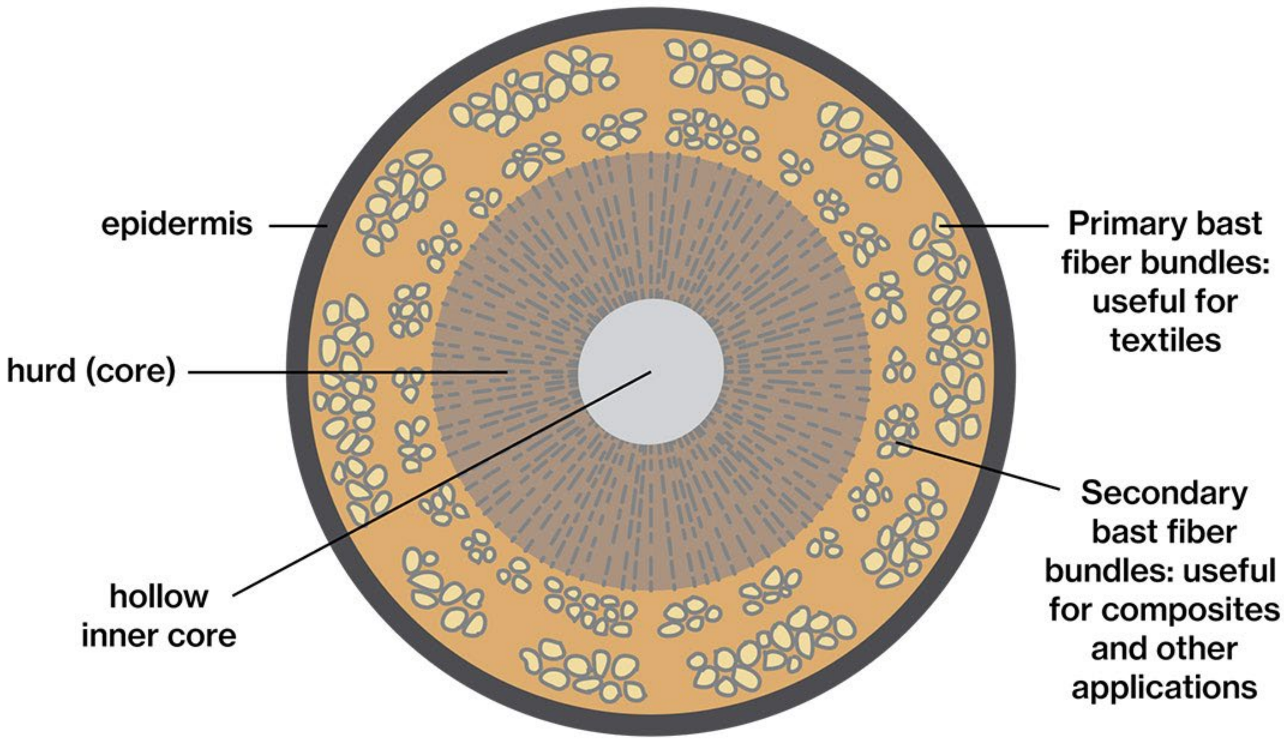
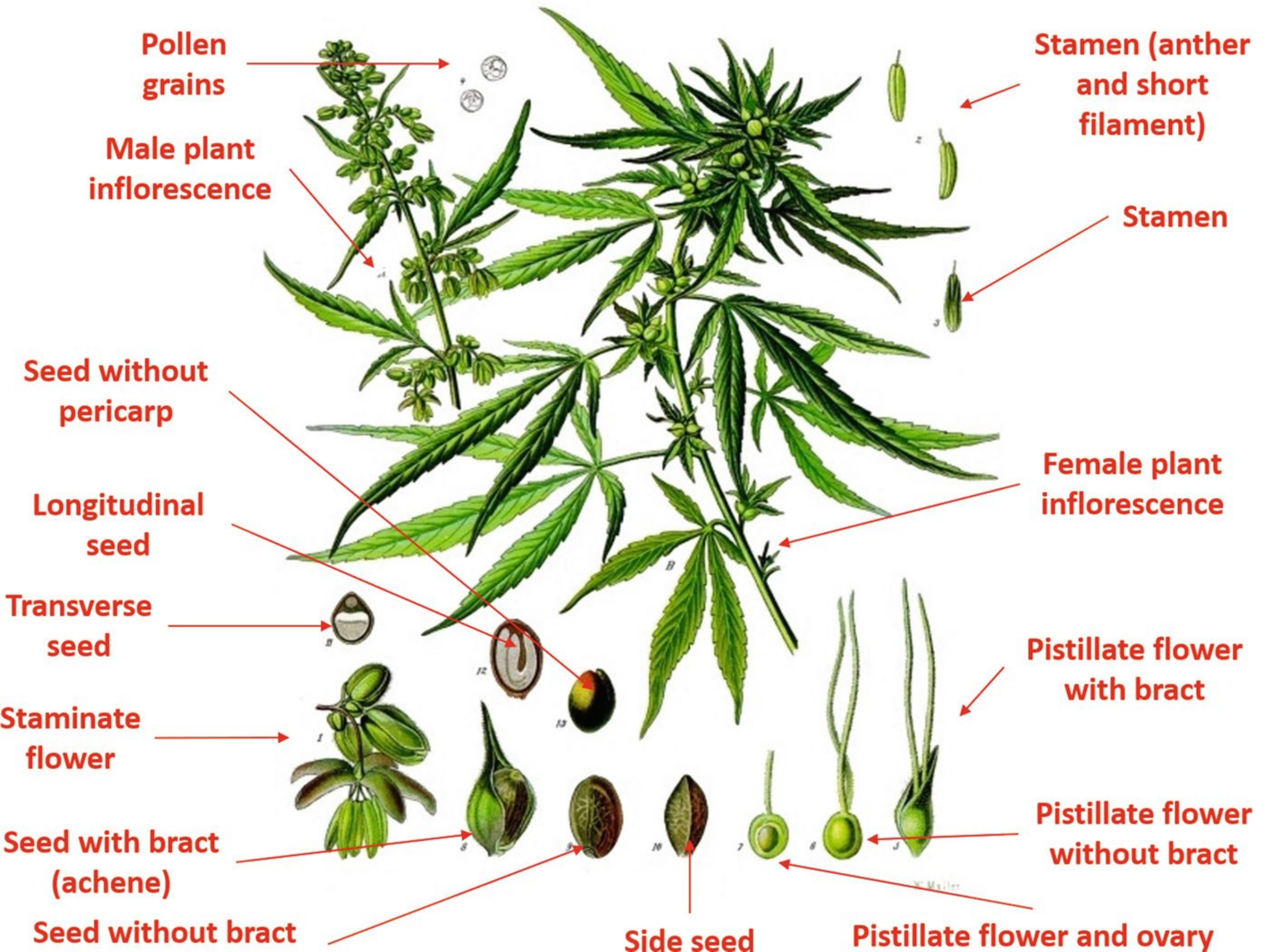
Hemp Fiber

An inside look at a hemp stalk

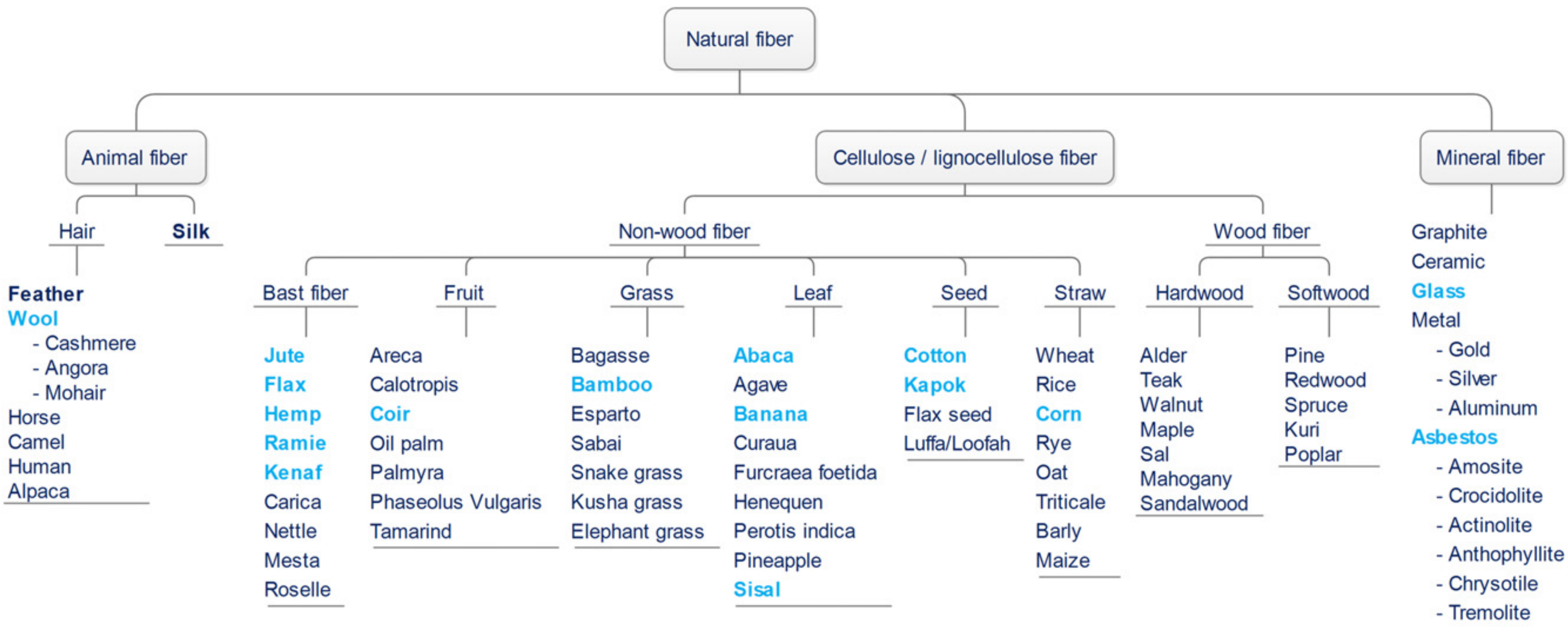


Decorticating is the process that physically separates the outer fibrous part of the stalk from the inner, woody core. Once the raw hemp fibers are separated, they are *degummed* to soften the fibers and break down the lignin, pectin, and other substances that bind them together.



Pollen grains
Male plant inflorescence
Seed without pericarp
Longitudinal seed
Transverse seed
Staminate flower
Seed with bract (achene)
Seed without bract
Side seed
Pistillate flower and ovary
Pistillate flower without bract
Pistillate flower with bract
Female plant inflorescence
Stamen
Stamen (anther and short filament)

Sources of fiber



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