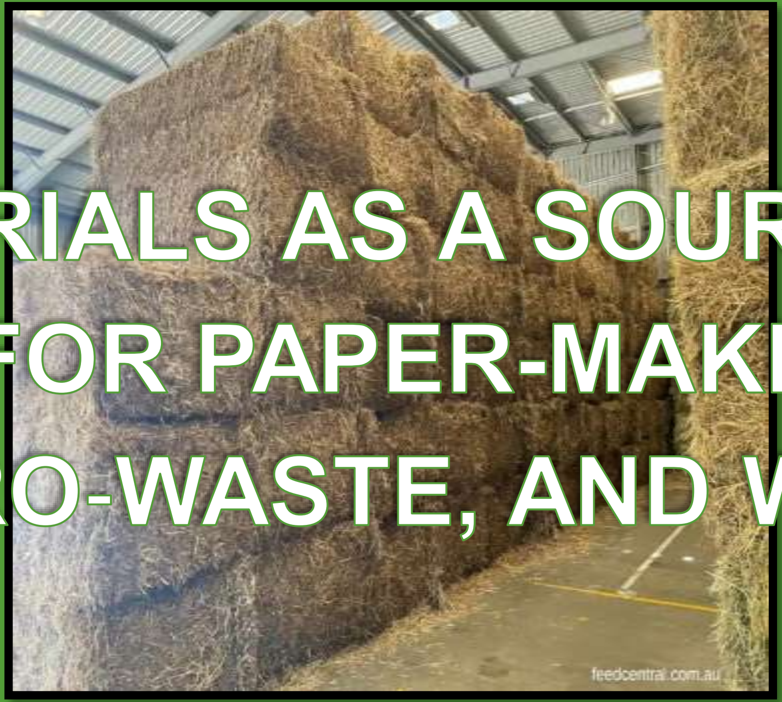
RAW MATERIALS AS A SOURCE OF FIBRES FOR PAPER-MAKING: WOOD, AGRO-WASTE, AND WASTE PAPERS



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https://www.feedcentral.com.au/wp-content/uploads/2022/06/How-to-stack-hay-bales-1-1024x768.webp
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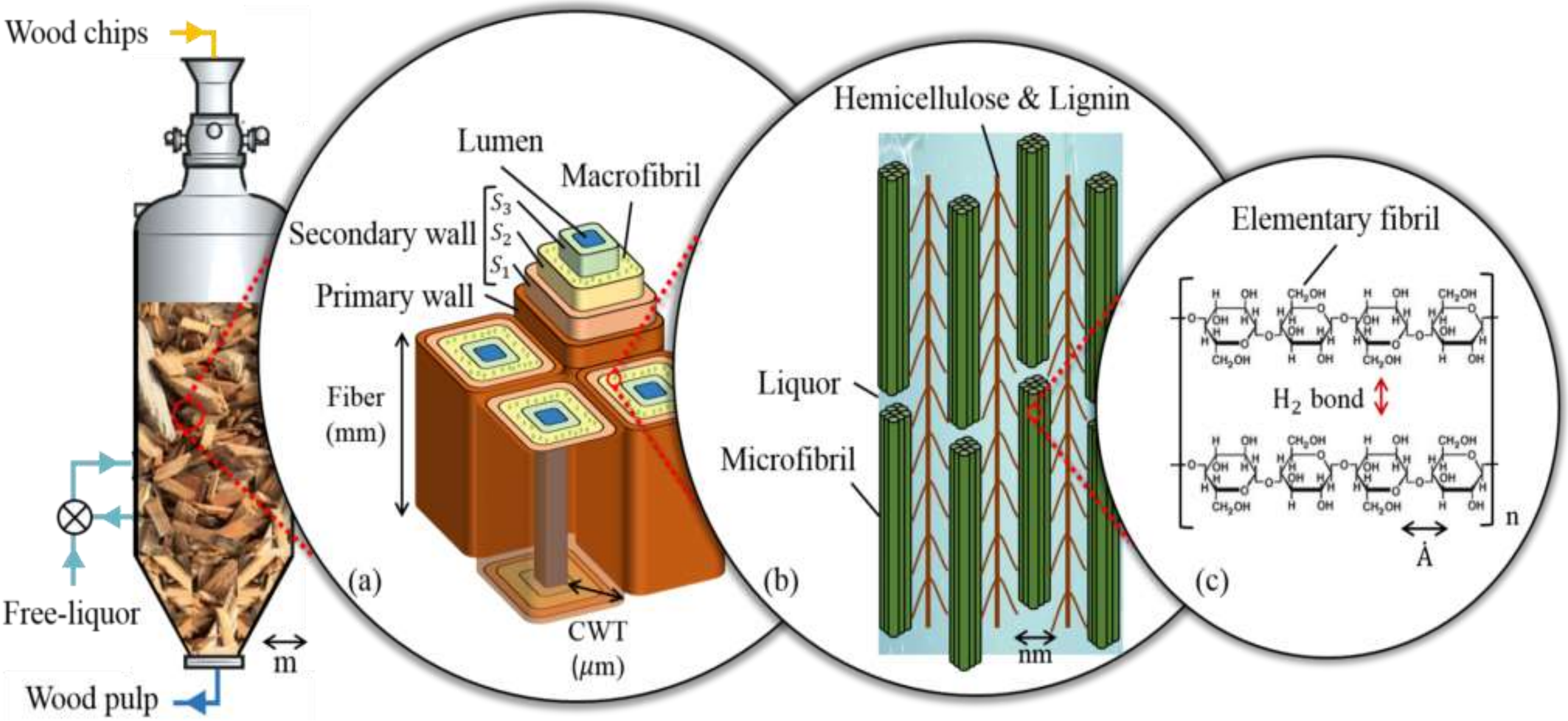
FIBRE STRUCTURE



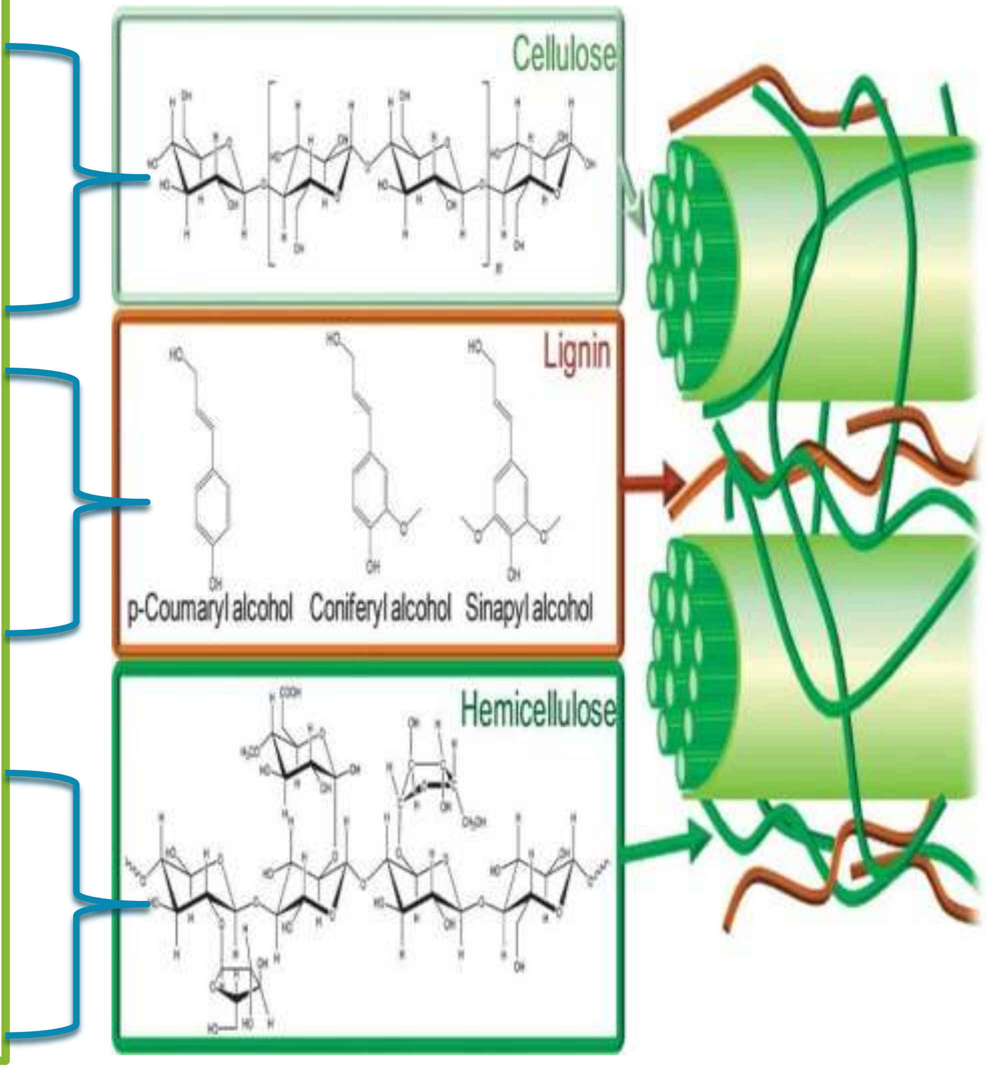
https://kwon.engr.tamu.edu/wp-content/uploads/sites/159/2019/07/Multi28-1024x565.png

STRUCTURAL COMPONENTS OF RAW MATERIALS

Cellulose:
- Long-chain polymer & Main structural component in plant cell walls
- Provides excellent tensile strength
- Forms the principal framework for fibres

Lignin:
- Complex polymer & Binds cellulose and hemicellulose together
- Provides rigidity and resistance to degradation
- Crucial for plant strength but often removed in papermaking to improve fibre quality

Hemicellulose:
- Heterogeneous group of polysaccharides
- Has a branched structure (unlike cellulose)
- Contributes less to tensile strength than cellulose
- Aids in bonding between cellulose fibres



Alonso, D.M., Wettstein, S.G., Dumesic, J.A. (2012) "Bimetallic catalysts for upgrading of biomass to fuels and chemicals," Chemical Society Reviews, 41(24), 8075–8098.

FIBRE STRUCTURE

Primary Cell Wall

Composition:

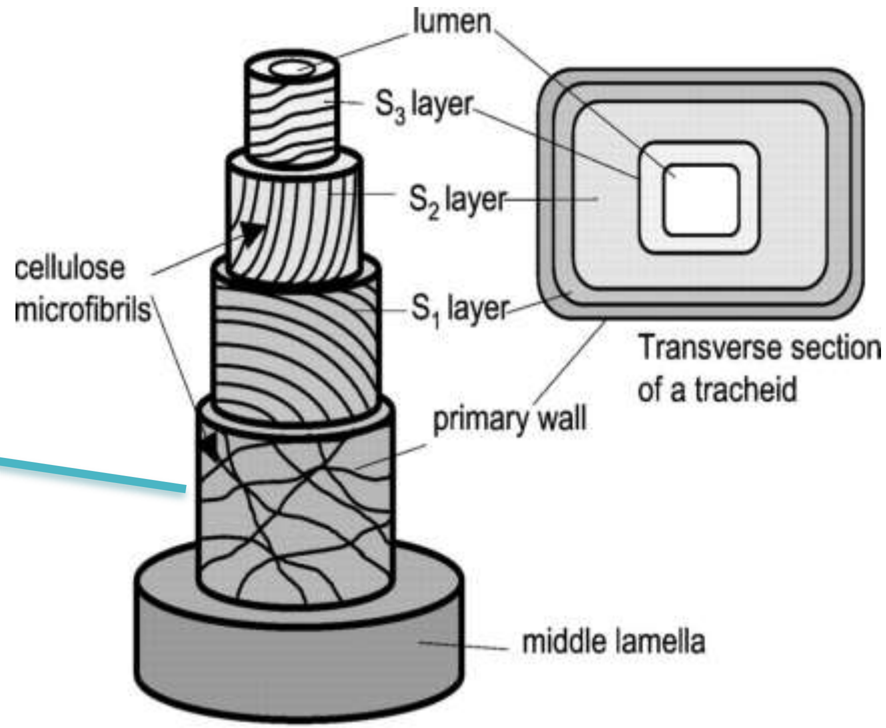
- Mainly cellulose, hemicellulose, and pectins

Features:

- Thin and flexible
- Provides a protective interface for the cell
- Enables growth

Function:

- Elasticity and isotropy
- Allows for expansion and contraction during processing
- Lies just inside the secondary wall
- Provides flexibility and acts as a transition between the rigid outer layer and the lumen



https://sites.nd.edu/biomechanics-in-the-wild/files/2021/04/plphys_v127_4_1513_f2-4-1024x698.jpeg

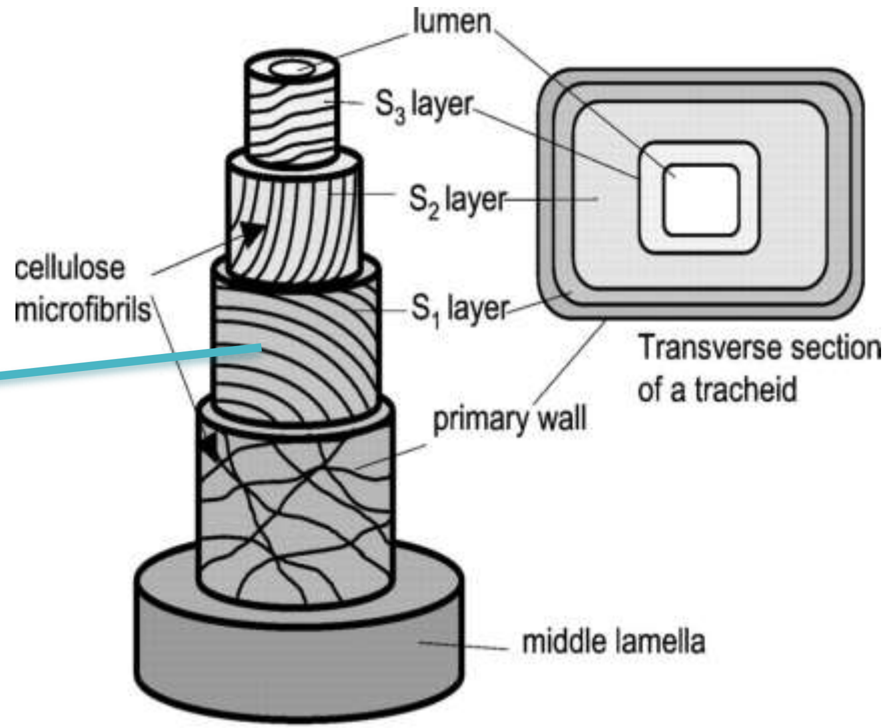
FIBRE STRUCTURE

Secondary Cell Wall

Composition:
- Dominated by high concentrations of cellulose arranged in microfibrils
- Contains hemicelluloses and residual lignin

Sub-Layers:
- Divided into **S1, S2, and S3 layers**
- **S2 layer is the thickest**, with microfibrils oriented at a specific angle
- Microfibril orientation largely determines tensile strength and rigidity

Features:
- **Thicker and more rigid** than the primary wall
- Contributes most to **mechanical strength** of the fibre
- **S2 layer is the most significant** contributor due to high cellulose content and specific microfibril orientation



https://sites.nd.edu/biomechanics-in-the-wild/files/2021/04/plphys_v127_4_1513_f2-4-1024x698.jpeg

FIBRE STRUCTURE

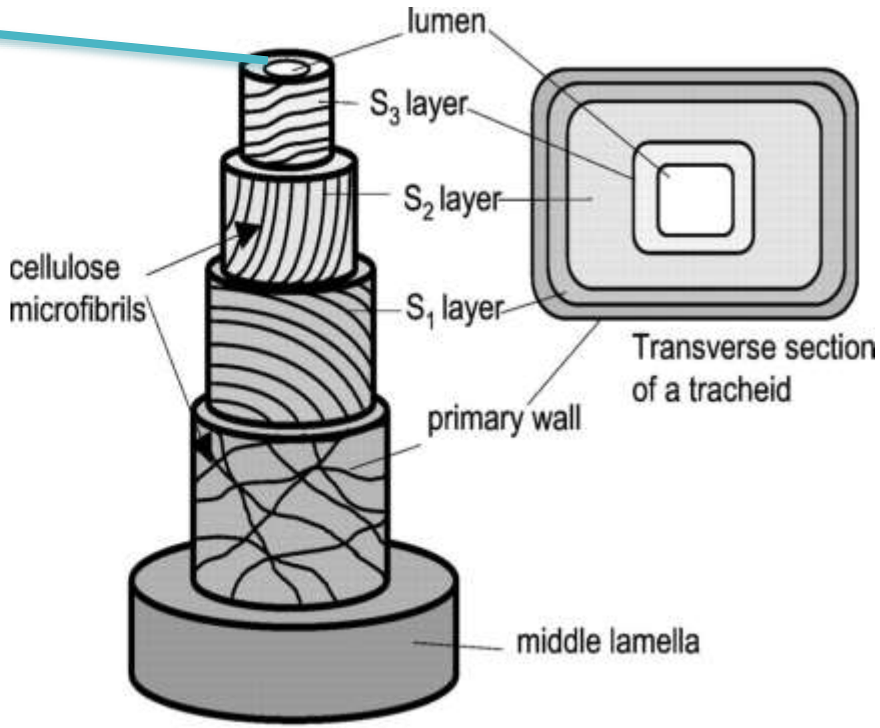
Lumen

Description:

- Hollow central cavity of the fibre

Role:

- Contributes to **flexibility** of the fibre and Influences **water absorption** during pulping
- Helps in **swelling fibres**, improving bonding during sheet formation
- A **well-defined lumen** enhances porosity, affecting **brightness and printability** of paper



https://sites.nd.edu/biomechanics-in-the-wild/files/2021/04/plphys_v127_4_1513_f2-4-1024x698.jpeg

FIBRE STRUCTURE

Middle Lamella

Composition:

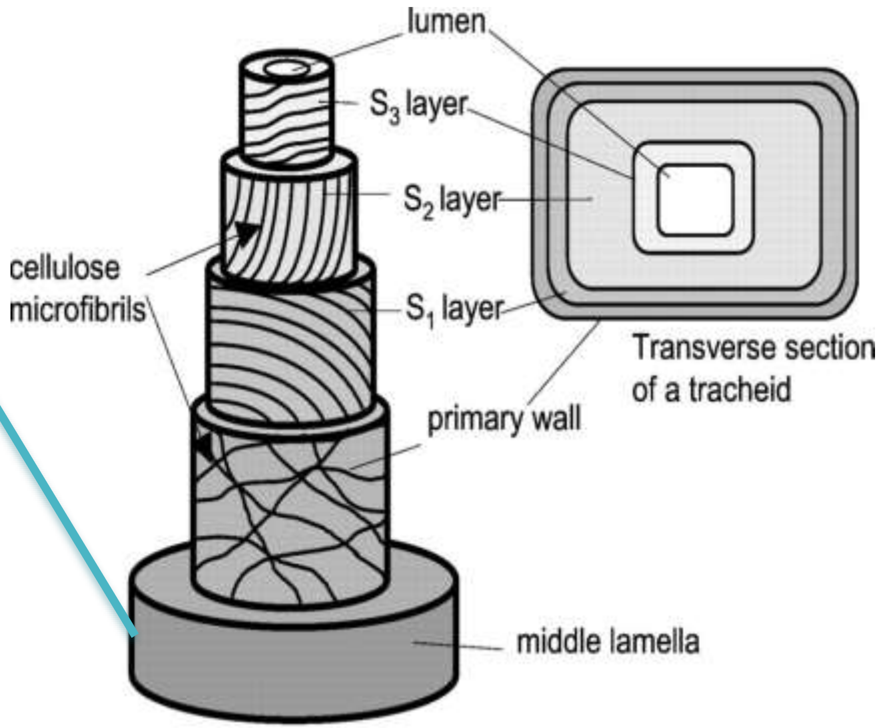
- Rich in **pectins and lignin**
- Acts as an **adhesive** between adjoining cells

Location:

- Not part of an individual fibre cell wall
- **Essential when fibres form bundles**, binding them together in plant tissue

Function:

- Crucial for **aggregated fibres**, cementing them in **natural fibre bundles**



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FIBRE STRUCTURE

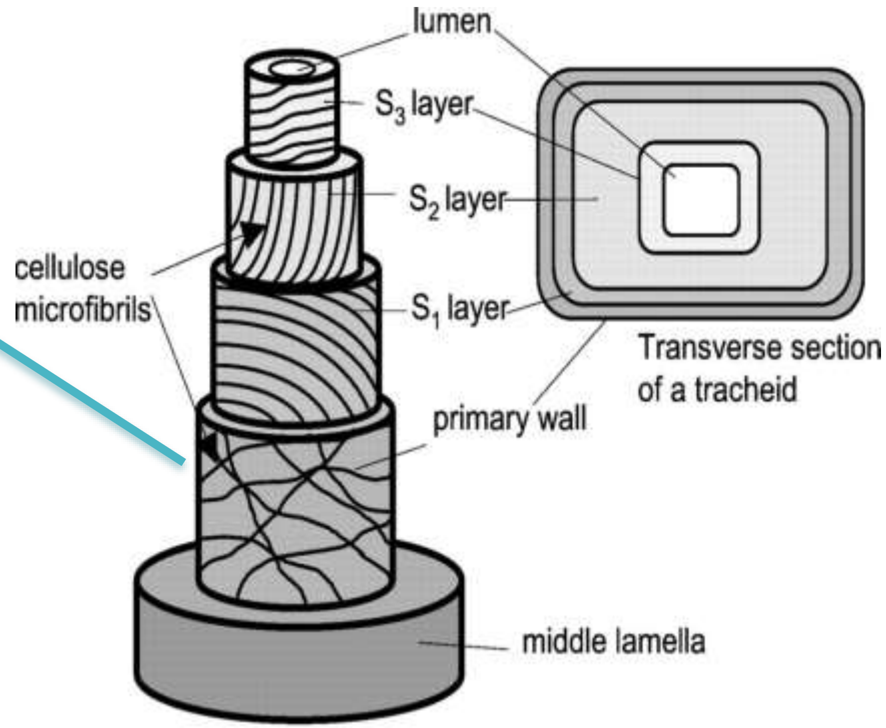
Surface Fibrils and Microfibrils

Structure:

- **Cellulose microfibrils** embedded in a matrix of **hemicellulose and lignin** within the secondary cell wall

Function:

- **Orientation and bonding** of microfibrils (especially in the **S2 layer**) determine:
  - **Tensile strength** of the fibre
  - **Bonding capacity** during papermaking



https://sites.nd.edu/biomechanics-in-the-wild/files/2021/04/plphys_v127_4_1513_f2-4-1024x698.jpeg

RAW MATERIAL SOURCES

Wood

- Traditional & widely used fibre source
- Classified into hardwoods (smooth finish) & softwoods (strength & length)
- Provides uniform fibre structure

Agro-Waste

- Includes straw, husks, bagasse—previously regarded as waste
- Increasingly valued for its fibre potential
- Variable dimensions & cell wall thickness require intensive pretreatment

Waste Paper

- Recycled fibre from previously used paper products
- Recycled fibres degrade over time (shortened length, collapsed lumen)
- Modern recycling processes aim to preserve fibre integrity & remove contaminants

http://www.paperpulpingmachine.com/wp-content/uploads/2018/04/materials-for-papermaking.jpg

WOOD AS A RAW MATERIAL

Hardwood

•Characteristics

✓- Derived from deciduous trees that shed leaves seasonally

✓- Shorter, finer fibres create smooth paper with high opacity

✓- Ideal for printing & writing applications

•Examples

•- Common hardwood sources: eucalyptus, poplar, birch, aspen

•- High fibre quality ensures refined & uniform paper surface

•Usage in Papermaking

•- Used in coatings, specialty papers & high-quality print materials

•- Preferred for applications requiring smooth finish

https://images.fineartamerica.com/images-medium-large-5/eucalyptus-tree-california-zandria-muench-beraldo.jpg https://mvandenoever.nl/wp-content/uploads/2022/05/populus-x-canadensis-robusta-768x1024.jpg

WOOD AS A RAW MATERIAL

Softwood

- **Characteristics**
- - Sourced from coniferous trees like pine, fir, spruce
- - Longer, coarser fibres provide strength & durability
- - Essential for packaging, tissue & industrial paper

- **Examples**
- - Pine & spruce known for high tensile strength
- - Favored in applications requiring structural integrity

- **Usage in Papermaking**
- - Typically blended with hardwood or other fibres
- - Balances strength with smoothness for varied paper products

https://www.coniferousforest.com/wp-content/uploads/2017/02/Eastern-White-Pines.jpg

https://s3.amazonaws.com/eit-planttoolbox-prod/media/images/Picea_mariana_Treeti_xFEGqYByxzqC.jpeg

Hardwood	
Eucalyptus	Sycamore
Birch	Beech
Aspen	Cherry
Poplar	Elm
Acacia	Willow
Maple	Mahogany
Oak	Teak
Chestnut	Pecan
Basswood	Walnut
Rubberwood	Iroko

Softwood	
Scots Pine	Ponderosa Pine
Eastern White Pine	Lodgepole Pine
Norway Spruce	Jack Pine
Sitka Spruce	Grand Fir
Douglas Fir	Longleaf Pine
European Larch	Radiata Pine
Western Hemlock	Slash Pine
Western Red Cedar	Southern Yellow Pine
Cypress	Red Pine
Redwood	Balsam Fir

AGRO-WASTE AS A RAW MATERIAL

Agro-waste encompasses a diverse range of organic materials remaining (residues) after crops have been harvested or processed.

Crop Residues

- Wheat straw, rice straw, corn stalks, barley straw, sorghum residues
- Rich in cellulose, suitable for fibre production

Husks & Shells

- Rice husk, oat husk, coconut husk
- High silica content (rice husk) requires specialized processing

Bagasse

- Sugarcane residue post juice extraction
- Abundant in sugar-producing regions, high in cellulose

Other Residues

- Banana stems, bamboo waste, various crop byproducts
- Explored for potential applications in papermaking

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WtjZ29sanF4dnlnMXo5emNqeWxiZThsa3FucTlpeG14YjBpZ2xrbmxydzhqZm5obGtrajZvN3Yxbmx5eGZheS1yLmpwZw (600×400)

https://www.niir.org/blog/wp-content/uploads/2023/05/14-1.jpg

https://www.biofuelmachines.com/uploads/sugarcane-bagasse.jpg

https://images.pexels.com/photos/320029/pexels-photo-320029.jpeg?cs=srgb&dl=pexels-visionpic-net-320029.jpg&fm=jpg

Stalk Fibres	**Cereals**	Wheat straw
		Oat straw
		Rye straw
		Barley straw
		Rice straw
		Corn stalks
		Grain sorghum stalks
		Millet
	Grasses	Esparto
		Sabai (dragon's beard)
		Lemon
		Kuneria
		Siru
		Mawai
		Ulla
		Munj
		Elephant

Bast Fibres	New Zealand Flax
	Flax
	Kenaf
	Ramie
	Jute
	Okra
	Common hemp
	Sunn hemp
Leaf Fibres	Abaca (Manila Hemp)
	Sisal (Sisal Hemp)
	Henequen
	Caroa
	Palm
	Hesperaloe
Seed Hull Fibres	Cotton
	Coir (coconut fibre)

Stalk Fibres	**Cereals**	Wheat straw
		Oat straw
		Rye straw
		Barley straw
		Rice straw
		Corn stalks
		Grain sorghum stalks
		Millet
	Grasses	Esparto
		Sabai (dragon's beard)
		Lemon
		Kuneria
		Siru
		Mawai
		Ulla
		Munj
		Elephant

WASTE PAPER GRADES

Grade 1 - Low qualities	• Unsorted and sorted mixed paper and board; Old corrugated containers; Unsold magazines; Mixed magazines and newspapers and sorted graphic paper
Grade 2 - Medium qualities	• Newspapers with and without flexographic printing; Lightly or heavily printed white shavings with and without glue; Sorted office paper; computer printout.
Grade 3 - High qualities	• Mixed lightly coloured wood and wood-free printers shavings; Wood-free binders; Tear white shavings; White wood-free letters
Grade 4 - Kraft qualities	• New shavings of corrugated board; Unused and used corrugated kraft; Used kraft paper and board of a natural or white shade.
Grade 5 - Special qualities	• Mixed recovered paper and board; Mixed packaging; Liquid board packaging; Wrapper kraft; Wet labels; Unprinted and printed white wet-strength wood-free papers.

OFFICE PAPERS

Definition: Office paper is a high-quality paper used in business and administrative environments.

Types: Includes printer/copier paper, writing paper, and stationery.

Common Usage: Found in offices, schools, and commercial establishments.

Key Features: Designed for clarity and longevity in written communication.

Fibre Quality: Typically exhibits good fibre uniformity and cleanliness

Implications for Recycling

- High-quality recycled pulp suitable for printing & writing papers
- Requires less intensive de-inking than heavily processed papers

https://sohodox.com/wp-content/uploads/2022/10/How-to-organize-paperwork.jpg

OFFICE PAPERS

Fibre Quality	Surface Properties	Chemical Treatments	Contamination Risks
Refined wood pulps with a high proportion of hardwood fibres	Slick, bright finish enhances printing & copying clarity	Light coatings improve printability & resist ink bleed	Generally clean but may contain toner residues & adhesives
Smooth surface & consistent fibre length distribution		Requires meticulous de-inking during recycling	Minimal processing needed compared to coated papers

https://sohodox.com/wp-content/uploads/2022/10/How-to-organize-paperwork.jpg

NEWSPAPER

Purpose: Primarily used for mass communication.

Wastepaper Abundance: One of the most frequently collected wastepaper types.

Collection Sources: Gathered from households, newsstands, and distribution centers after publication.

Material Quality: Made from lower-quality pulps to ensure cost-effectiveness and rapid production.

Economic Consideration: Designed to be inexpensive for large-scale distribution.

Implications for Recycling

- Valuable resource despite lower fibre quality
- Often blended with high-quality fibres or repurposed for corrugated board & newsprint

https://5.imimg.com/data5/SELLER/Default/2024/1/378078460/HF/DQ/PE/102873168/waste-old-newspaper-scrap-1000x1000.png

NEWSPAPER

Fibre Quality	Ink & Dye Content	Formation & Texture	Contamination Risks
Short fibres with high variability in length	Heavily printed with water-based inks	Looser formation due to rapid production process	Contains residues of printing ink, fillers & sizing agents
Lower tensile strength compared to office paper or virgin sources	•Requires robust de-inking processes for fibre recovery	Suited for applications where high strength is less critical	Requires thorough cleaning for quality recycling

https://5.imimg.com/data5/SELLER/Default/2024/1/378078460/HF/DQ/PE/102873168/waste-old-newspaper-scrap-1000x1000.png

CARDBOARD

Definition: Cardboard refers to paper-based packaging materials.

Types: Includes corrugated board (fluted inner layers with flat liners) and paperboard (single-layer, thicker materials).

Common Applications: Used for packaging boxes, cereal cartons, and various consumer goods.

Waste Collection: Gathered from packaging waste streams in retail, consumer, and industrial sectors.

Material Characteristics: Designed for durability, protection, and cost-effective packaging solutions.

Implications for Recycling

- Requires disassembly of layers & adhesive removal
- Processed pulp repurposed for rigid packaging materials

https://img.freepik.com/premium-photo/cardboard-waste-paper-recycling-center_805187-726.jpg?w=2000

CARDBOARD

Fibre Quality	Adhesives & Coatings	Bulk & Density	Structural Composition
Inner liner contains longer, stronger fibres	Often laminated with adhesives, wax, or polymer coatings	Denser & bulkier than office paper	Multilayered with strong, rigid properties
Corrugated medium has shorter, more variable fibres	•Requires intensive processing for clean pulp recovery	High fibre-to-non-fibre ratio demands effective contaminant removal	Corrugated boards provide cushioning & load-bearing capacity

https://img.freepik.com/premium-photo/cardboard-waste-paper-recycling-center_805187-726.jpg?w=2000

MAGAZINES AND CATALOGUES

Purpose: Designed for visual appeal and advertising.

Paper Quality: Often glossy and high-quality for enhanced aesthetics.

Grouping: Sometimes classified alongside office paper but distinct in production.

Production Process: Involves substantial coatings and heavier printing inks.

Usage: Commonly used for promotional materials, fashion publications, and commercial catalogues.

Implications for Recycling

- Rich fibre source if de-coating & de-inking applied effectively
- Requires additional processing compared to plain office paper

https://www.wastemanaged.co.uk/wp-content/uploads/2024/07/Untitled-design-58.jpg

MAGAZINES AND CATALOGUES

Fibre Quality

- Uses pulps similar to office paper but includes glossy coatings
- De-coating required to restore fibre usability

Print Quality Enhancements

- Coatings & treatments improve image reproduction
- •Complicates fibre liberation during pulping

Contamination Risks

- Adhesives, binding agents & high-quality printing inks
- Requires thorough cleaning & removal processes

Visual & Tactile Properties

- Glossy finish enhances display & readability
- Must be carefully removed to preserve fibre integrity

https://www.wastemanaged.co.uk/wp-content/uploads/2024/07/Untitled-design-58.jpg

MIXED OR UNSORTED WASTE PAPER

Definition: Mixed waste paper consists of unsorted paper materials.

Variety of Contents: Includes documents, packaging materials, junk mail, catalogues, and miscellaneous paper types.

Sorting Process: Not pre-sorted at the source, leading to varied composition**.**

Recycling Challenges: Municipal recycling programs handle large volumes of these mixed waste streams.

Implications for Recycling

- Represents a significant resource despite challenges
- Advanced sorting & de-inking technologies essential for circular economy sustainability

http://www.ner.ie/wp-content/uploads/2013/07/Soft-mix-paper.bmp

MIXED OR UNSORTED WASTE PAPER

Heterogeneous Composition

- Diverse paper types (documents, packaging, catalogues)
- Variability in fibre type, coating, ink content & paper quality

Processing Complexity

- Sorting requires mechanical/optical systems for material separation
- •Advanced facilities extract high-grade fibres from lower-grade waste

Contamination Risks

- High levels of non-paper materials (adhesives, foreign objects)
- Thorough removal processes needed for pulp recovery

Fibre Quality

- Variable fibre length & properties due to mixed sources
- Blending with consistent fibre sources improves final paper characteristics

http://www.ner.ie/wp-content/uploads/2013/07/Soft-mix-paper.bmp

Advantages of using waste papers

- Environmental Savings
- Waste Mitigation
- Economic Benefits
- Promotion of a Circular Economy

Challenges of using waste papers

- Fibre Degradation
- Contamination Issues
- Processing Complexity

COMPARATIVE ANALYSIS

Aspect	Wood	Agro-Waste	Waste paper
Availability	Reliable from managed forests; regional dependencies	Abundant in agricultural regions; widely available as byproducts	Plentiful because of high paper consumption;
Cost	Moderate to high; extraction and management costs	Generally low-cost due to its byproduct status	Low-cost raw material, though processing can add expenses
Durability	Excellent strength (especially softwood fibres); consistent properties	Variable; some agro-residues offer competitive strength, others require blending	Fibre degradation occurs with each recycling cycle; often blended with virgin fibres
Environmental Benefits	Sustainable agro-forestry mitigates deforestation, preserves biodiversity, and maintains carbon sinks	Reduces air pollution from burning, decreases landfill burden, and provides revenue for farmers	Conserves forests, lowers environmental impact through recycling
Challenges	Sustainable harvesting and the high energy/chemical demands of traditional pulping methods	Additional chemicals or energy for processing; fibre variability, need for specialized pretreatment processes to ensure consistent pulp output	Degradation over multiple recycling; contamination issues, fibre weakening, and complexity of processes.

COMPARISON OF MORPHOLOGICAL TRAITS OF RAW MATERIALS

Category	Wood Pulp	Agro-Waste	Wastepaper
Fibre Length and Uniformity	Softwood: long & consistent; Hardwood: shorter but uniform', Longer fibres, with well-oriented microfibrils (especially typical in softwood), contribute to higher tensile strength	Shorter and more variable; non-cellulosic inclusions (e.g., silica) present	Shorter and fragmented; altered surface characteristics due to recycling, may compromise bonding and strength.
Cell Wall and Lumen Characteristics	Thick/thin walls based on species; well-defined lumens for fluid balance	Looser cell walls; larger/irregular lumens with high variability	Thinner walls; partially compromised lumens with remnant contaminants
Surface Fibrillation and Damage	Varied fibrillation; smoother surfaces from gentle chemical treatments	Processing-induced fibrillation for better bonding; less naturally fibrillated	Higher fibrillation and damage; rough surfaces from recycling stresses

FIBRE DIMENSIONS OF VARIOUS RAW MATERIALS

	Fibre source	Length (microns) Max	Min	Avg	Diameter (microns) Max	Min	Avg	L/D Ratio
Wood	Coniferous (softwood)	3600	2700	3000	43	32	30	100:1
	Deciduous (hardwood)	1800	1000	1250	50	20	25	50:1
Non-wood								
Bast fibres								
	Common (industrial) hemp	55000	5000	20000	50	16	22	1000:1
	Jute (1)	4520	470	1060	72	8	26	45:1
	Jute (2)	5000	500	2000	68	8	20	100:1
	Kenaf	7600	980	2740			20	135:1
	Oilseed flax tow	45000	10000	27000	30	16	22	1250:1
	Textile flax tow	55000	16000	28000	28	14	21	1350:1
Core fibres								
	Kenaf	1100	400	600	37	18	30	20:1
Leaf fibres								
	Abaca	12000	2000	6000	36	12	20	300:1
	Sisal	6000	1500	3030			17	180:1
Seed hull fibres								
	Cotton staple	50000	20000	30000	30	12	20	1500:1
	Cotton linters	6000	2000	3500	27	17	21	165:1

	Fibre source	Length (microns) Max	Min	Avg	Diameter (microns) Max	Min	Avg	L/D Ratio
Stalk fibres								
Canes	Sugarcane bagasse	2800	800	1700	34	10	20	85:1
	Bamboo (wide range)	3500 - 9000	375 - 2500	1360 - 4030	25 - 55	3 - 18	8 - 30	135 - 175:1
Cereal straw	Wheat, rye, oats, barley, mixed	3120	680	1480	24	7	13	110:1
	Rice	3480	650	1410	14	5	8	175:1
Grasses	Esparto	1600	600	1100	14	4	9	120:1
	Lemon			1320			9	145:1
	Sabai	4900	450	2080	28	4	9	230:1
	Switchgrass			1370			12.5	110:1
Reeds	Addar grass			1180			15	78:1
	Papyrus	8000	300	1500	25	5	12	125:1
	Nal	3000	100	1500	37	6	20	75:1
Stalks	Corn	2800	680	1260	20	10	16	80:1
	Cotton	2000	700	860			19	45:1
	Grain sorghum			1650	80	30	47	35:1
	Hesperaloe			3200			15	213:1

Sources:
Hurter, Robert W., "Agricultural Residues", TAPPI 1997 Nonwood Fibres Short Course.
Hurter, A.M., "Utilization of Annual Plants and Agricultural Residues for the Production of Pulp and Paper", Nonwood Plant Fibre Pulping Progress Report #19, TAPPI Press, pp. 49-70.
https://www.paperonweb.com/Articles/plant_fibre_characteristics.pdf

CHEMICAL PROPERTIES OF VARIOUS RAW MATERIALS

	Fibre Source	Alpha Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)	Silica (%)
Wood	Coniferous (softwood)	40 - 45	26 - 34	7 - 14	1	<1
	Deciduous (hardwood)	38 - 49	23 - 30	19 - 26	1	<1
Non-woods						
Bast Fibres						
	Jute (1)	39 - 42	21 - 26	18 - 21	0.5 - 1	<1
	Jute sticks (whole jute)	43				
	Kenaf - bast	31 - 39	15 - 18	21 - 23	2 - 5	
	Kenaf - core	34	17.5	19.3	2.5	
	Oilseed flax tow	34	23	25	2 - 5	
	Textile flax tow	50 - 68	10 - 15	6 - 17	2 - 5	<1
Leaf Fibres						
	Abaca	61	9	17	1	<1
	Sisal	43 - 56	8 - 9	21 - 24	0.6 - 1	<1
Seed Hull Fibres						
	Cotton staple	85 - 90	3 - 3.3		1 - 1.5	<1
	Cotton linters	80 - 85	3 - 3.5		1 - 1.2	<1

	Fibre Source	Alpha Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)	Silica (%)
Stalk Fibres						
Canes	sugarcane bagasse	32 - 44	19 - 24	27 - 32	1.5 - 5	0.7 - 3
	bamboo	26 - 43	21 - 31	15 - 26	1.7 - 5	1.5 - 3
Cereal straw	barley	31 - 34	14 - 15	24 - 29	5 - 7	3 - 6
	oat	31 - 37	16 - 19	27 - 38	6 - 8	4 - 7
	rice	28 - 36	12 - 16	23 - 28	15 - 20	9 - 14
	rye	33 - 35	16 - 19	27 - 30	2 - 5	0.5 - 4
	wheat	29 - 35	16 - 21	26 - 32	4 - 9	3 - 7
Grasses	Addar grass	29 - 33	21	28 - 32	4 - 6	1.1 - 1.3
	esparto	33 - 38	17 - 19	27 - 32	6 - 8	2 - 3
	sabai		17 - 22	18 - 24	5 - 7	3 - 4
	switchgrass	43	34 - 36	22 - 24	1.5 - 2	
Reeds	Nal	45	22	20	3	2

Note: For well cleaned raw material - the composition of uncleaned raw material will be different with respect to pentosans, solubles, ash and silica content in many cases.

Sources:

Hurter, Robert W., "Agricultural Residues", TAPPI 1997 Nonwood Fibres Short Course.
Hurter, A.M., "Utilization of Annual Plants and Agricultural Residues for the Production of Pulp and Paper", Nonwood Plant Fibre Pulping Progress Report #19, TAPPI Press, pp. 49-70.
https://www.paperonweb.com/Articles/plant_fibre_characteristics.pdf

PULP FIBRE MORPHOLOGY: HARDWOOD

•Fibre Length

- Shorter fibres (0.5–1.5 mm) create a smoother & more uniform paper surface
- Helps form dense & well-bonded sheets

•Fibre Width & Wall Thickness

- Thinner cell walls & narrower fibre width compared to softwoods
- Offers flexibility but lower strength relative to softwood fibres

•Lumen Characteristics

- Smaller lumens reduce porosity
- Enhances printability & brightness of paper

•Surface Fibrillation

- Smoother surface due to less fibrillation
- Ideal for printing & writing applications requiring high-quality finishes

PULP FIBRE MORPHOLOGY: SOFTWOOD

•Fibre Length	• Long fibres (2.0–4.0 mm) enhance tensile strength & tear resistance
•Fibre Width & Wall Thickness	• Moderate width (20–50 µm) with thick cell walls • Strong wall-to-lumen ratio ideal for high-strength applications
•Lumen Characteristics	• Large lumen aids in absorption of bonding additives & water • Influences paper formation & structural integrity
•Surface Fibrillation	• Mechanical pulping increases fibrillation; chemical pulping maintains smoothness • Degree of fibrillation affects bonding potential & fibre coherence

PULP FIBRE MORPHOLOGY OF AGRO-WASTE

•Fibre Length

- Shorter and more variable in length than wood fibres
- Bagasse: 0.5–2.0 mm, straws display broad size distribution

•Cell Wall Composition & Thickness

- Thinner cell walls compared to wood fibres
- Presence of silica/minerals affects flexibility

•Lumen Size

- Larger or irregular lumen due to loose anatomical structure
- Leads to increased water retention & porosity in paper

•Surface Fibrillation

- Less natural fibrillation, but refining & chemical pretreatment improve bonding

•Morphological Variability

- Significant variation in fibre dimensions & textures across different crops
- Requires specialized processing for consistency in papermaking

MORPHOLOGY OF WASTEPAPER FIBRES

•Fibre Length

- Shorter than virgin wood and agro-waste fibres
- Degraded by repeated mechanical & chemical treatments

•Fibre Surface

- Recycling reduces smoothness, increasing fibrillation
- Enhanced surface fibrillation, bonding, degradation

•Cell Wall Thickness & Lumen

- Thinner cell walls compared to virgin fibres
- Lumen may be collapsed or occluded by residual contaminants

•Contaminants & Residuals

- Presence of inks, adhesives, fillers affecting water absorption & bonding
- De-inking & cleaning aim to minimize residuals

•Heterogeneity

- Mixture of different paper grades leads to variability
- Inconsistencies in fibre dimensions influence paper quality

CONCLUSIONS

- ✓ Traditional backbone of papermaking
- ✓ Provides consistent strength and predictable performance
- ✓ Sustainability depends on forest management, agroforestry & certifications

- ✓ Reduces environmental burden and supports circular economy
- ✓ Low-cost and widely available raw material
- ✓ Challenges: fibre degradation, contamination, and heterogeneity
- ✓ Requires advanced de-inking, refining, and blending with virgin fibres

- Abundant and renewable alternative using agricultural byproducts
- Cost-effective and promotes resource efficiency & circular economy
- Variable fibre length & mineral content require specialized treatments
- Standardized processing techniques needed for quality control

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