Packaging Prototypes

canopy

www.canopyplanet.org

SAFI

sustainable & alternative fibers initiative

www.go.ncsu.edu/SAFI


Photo by Adrian Dorst.

canopy

www.canopyplanet.org

Canopy is a solutions-driven environmental not-for-profit dedicated to protecting the world's forests, species, and climate. In collaboration with 1,000+ global brands, Canopy drives transformative action to eliminate the use of Ancient and Endangered Forests in packaging and textiles while scaling Next Gen solutions.

Canopy is supporting diversification of the pulp fibre basket to include alternatives to wood in order to address the problem that current market demand for forest products far exceeds a sustainable supply.

Next Gen Solutions, as demonstrated in this sample binder, use agricultural by-products and fibres instead of forests to make paper, paper packaging, and textiles.

By harnessing agricultural residues and other Next Generation alternatives, we can transform paper packaging supply chains, reduce financial and operational risk, and save forests all over the world. It's time to resize, redesign, repurpose, and add Next Gen fibres alongside more recycled content.

SAFI

sustainable & alternative fibers initiative

www.go.ncsu.edu/SAFI

SAFI, at North Carolina State University, is a global research initiative focused on developing and promoting conventional and alternative fibers for the pulp and paper industry. Its research explores innovative pulping processes, techno-economic feasibility, and the environmental carbon footprint of using non-wood fibers such as wheat straw, miscanthus, and hemp for tissue and packaging applications.

The impact of SAFI extends beyond scientific research, as it actively bridges academia and industry to accelerate the commercialization of sustainable fibers. As a result, SAFI is shaping the future of the pulp and paper industry by providing actionable strategies for reducing environmental impact, enhancing supply chain resilience, and fostering a more sustainable and economically viable fiber ecosystem.

NC STATE UNIVERSITY

UNBLEACHED KRAFT PULPS

30% Wheat Straw 70% OCC	
Basis weight (g/m^2)	222
Caliper (µm)	337
Tensile Index (N.m/g)	59.5
Short span compressive strength (N.m/g)	25.2
CMT (kPa)	588
Taber Stiffness (mN.m)	6.82

30% Miscanthus 70% OCC	
Basis weight (g/m^2)	223
Caliper (µm)	383
Tensile Index (N.m/g)	36.1
Short span compressive strength (N.m/g)	19.4
CMT (kPa)	405
Taber Stiffness (mN.m)	7.60

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

UNBLEACHED KRAFT PULPS

30% Whole Hemp 70% OCC	
Basis weight (g/m^2)	213
Caliper (µm)	353
Tensile Index (N.m/g)	42.2
Short span compressive strength (N.m/g)	22.2
CMT (kPa)	410
Taber Stiffness (mN.m)	6.28

30% Hemp Hurd 70% OCC	
Basis weight (g/m^2)	225
Caliper (µm)	355
Tensile Index (N.m/g)	44.7
Short span compressive strength (N.m/g)	23.4
CMT (kPa)	455
Taber Stiffness (mN.m)	6.77

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

UNBLEACHED CHEMI-THERMO MECHANICAL PULPS

30% Wheat Straw 70% OCC	
Basis weight (g/m^2)	224
Caliper (µm)	407
Tensile Index (N.m/g)	42.6
Short span compressive strength (N.m/g)	20.6
CMT (kPa)	359
Taber Stiffness (mN.m)	7.55

30% Miscanthus 70% OCC	
Basis weight (g/m^2)	227
Caliper (µm)	430
Tensile Index (N.m/g)	31.6
Short span compressive strength (N.m/g)	17.9
CMT (kPa)	369
Taber Stiffness (mN.m)	8.83

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

UNBLEACHED CHEMI-THERMO MECHANICAL PULPS

30% Whole Hemp 70% OCC	
Basis weight (g/m^2)	215
Caliper (µm)	375
Tensile Index (N.m/g)	33.3
Short span compressive strength (N.m/g)	19.3
CMT (kPa)	284
Taber Stiffness (mN.m)	7.35

30% Hemp Hurd 70% OCC	
Basis weight (g/m^2)	224
Caliper (µm)	381
Tensile Index (N.m/g)	34.5
Short span compressive strength (N.m/g)	20.7
CMT (kPa)	396
Taber Stiffness (mN.m)	6.96

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

UNBLEACHED SULFITE PULPS

30% Wheat Straw 70% OCC	
Basis weight (g/m^2)	220
Caliper (µm)	370
Tensile Index (N.m/g)	47.3
Short span compressive strength (N.m/g)	22.6
CMT (kPa)	401
Taber Stiffness (mN.m)	8.24

30% Miscanthus 70% OCC	
Basis weight (g/m^2)	222
Caliper (µm)	379
Tensile Index (N.m/g)	37.1
Short span compressive strength (N.m/g)	21.2
CMT (kPa)	390
Taber Stiffness (mN.m)	7.31

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

UNBLEACHED SULFITE PULPS

30% Whole Hemp 70% OCC	
Basis weight (g/m^2)	218
Caliper (µm)	345
Tensile Index (N.m/g)	37.1
Short span compressive strength (N.m/g)	20.2
CMT (kPa)	392
Taber Stiffness (mN.m)	7.21

30% Hemp Hurd 70% OCC	
Basis weight (g/m^2)	226
Caliper (µm)	354
Tensile Index (N.m/g)	55.0
Short span compressive strength (N.m/g)	27.2
CMT (kPa)	542
Taber Stiffness (mN.m)	7.94

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

OLD CORRUGATED CONTAINERBOARD (OCC)

100% OCC	
Basis weight (g/m^2)	228
Caliper (μm)	400
Tensile Index (N.m/g)	33.7
Short span compressive strength (N.m/g)	17.9
CMT (kPa)	306
Taber Stiffness (mN.m)	7.35

Notes

- Feedstocks were sourced from the US.
- Feedstocks from different regions/countries may perform differently.
- This binder was printed in 100% recycled paper.

OCC: Old Corrugated Containerboard. CMT: corrugated medium test.

Addendum - Packaging Prototypes

Evaluation of Non-Wood Fibers for Containerboard and Paperboard Applications: A Comparative Analysis with Old-Corrugated Containerboard (OCC) and Virgin Wood Commercial Products

1. MATERIALS AND METHODS

1.1 Biomass Types and Sources

- Wheat straw: Sourced from Ag. Processing Solutions Inc., Montana; collected in 2024.
- Miscanthus giganteus: Supplied by Genera Energy Inc., Tennessee; collected in 2024.
- Hemp and hemp hurd: Obtained from a private plantation in North Carolina; collected in 2024.
- Old Corrugated Containers (OCC): Provided by the SAFI consortium; collected in 2024.

1.2 Size Reduction and Classification

All biomass samples, except OCC, were processed using a hammer mill manufactured by the C. S. Bell Co. Post-milling, particle classification was performed using Chip Class™ equipment. Only biomass particles falling within the experimentally determined accepted range (>3 mm round, and <45 mm round) were used in subsequent treatments.

1.3 Chemical and Refining Treatment of Biomass

Chemical treatments were applied according to the pulping processes outlined in Table 1.

Table 1. Biomass feedstocks and corresponding chemical processes

Feedstock	Process	Chemicals & Conditions
Wheat straw	Kraft	NaOH + Na2S, LW - 6:1
	Sulfite	Ammonium Sulfite, LW - 6:1
	CTMP	NaOH + Na2SO3, Refiner 20 psi / gap 0.010
Miscanthus	Kraft	NaOH + Na2S, LW - 6:1
	Sulfite	Ammonium Sulfite, LW - 6:1
	CTMP	NaOH + Na2SO3, Refiner 20 psi / gap 0.010
Whole hemp	Kraft	NaOH + Na2S, LW - 6:1
	Sulfite	Ammonium Sulfite, LW - 6:1
	CTMP	NaOH + Na2SO3, Refiner 20 psi / gap 0.010
Hemp Hurd	Kraft	NaOH + Na2S, LW - 6:1
	Sulfite	Ammonium Sulfite, LW - 6:1
	CTMP	NaOH + Na2SO3, Refiner 20 psi / gap 0.010

After pulping, Kraft and Sulfite pulps were disintegrated using a propeller stirrer for 20 minutes, washed through a 200-mesh metal screen, and centrifuged to determine consistency and yield.

Pulp screening was conducted using a 0.010” slot to separate rejects. Accepted pulp was stored in a cold room for subsequent analyses. For CTMP pulps, a second refining stage was applied using a single-disc atmospheric refiner at a 0.010” plate gap, followed by the same screening procedure.

1.4 Handsheet Formation

Handsheets targeting a basis weight of 220 g/m^2 were prepared according to TAPPI Method T 205 sp-24 (Forming Handsheets for Physical Testing of Pulp). Each non-wood pulp was blended with OCC in a 30:70 ratio on an oven-dry basis. After formation, the handsheets were conditioned at 50% relative humidity and 23°C prior to testing. Ten replicates were produced by each combination (biomass x pulping method).

1.5 Paper Testing

Paper properties were evaluated using the standard TAPPI methods listed below:

Method	Test description
T 410 om-19	Grammage of paper and paperboard
T 411 om-21	Thickness (caliper) of paper, paperboard, and combined board
T 494 om-22	Tensile breaking properties of paper and paperboard
T 489 om-22	Bending resistance (stiffness) of paper and paperboard
T 825 om-24	Flat crush test of corrugated board
T 826 om-21	Short span compressive strength of containerboard

2. GENERAL FINDINGS

Table 2 summarizes the findings for the present study. The CTMP pulps from non-wood and its blends consistently demonstrated higher bulk (caliper) and stiffness than OCC. While tensile strength was generally lower than chemical pulps, it remained on par with recycled fiber. CTMP processes also benefit from higher yields and lower capital investment, that may favor small operations in potential integration.

Table 2: Mechanical properties of handsheets containing 30% non-wood fiber blended with OCC

		g/m2		Caliper (µm)		Tensile Index, N.m/g		Short-span compressive test (STFI), N.m/g		CMT (Concora), kPa		Taber Stiffness (15°), mN.m	
Feed stock	**Process**	**Avg**	**St.dev**	**Avg**	**St.dev**	**Avg**	**St.dev**	**Avg**	**St.dev**	**Avg**	**St.dev**	**Avg**	**St.dev**
OCC (bench mark)	Recycling	228	6	400	3	33.7	0.2	17.9	1.0	306	6	7.35	0.14
Wheat Straw	Kraft	222	4	337	2	59.5	0.1	25.2	1.1	588	2	6.82	0.21
	Sulfite	220	5	370	2	47.3	0.9	22.6	1.4	401	8	8.24	0.14
	CTMP	224	3	407	3	42.6	0.7	20.6	1.2	359	14	7.55	0.41
Miscanthus	Kraft	223	3	383	3	36.1	1.7	19.4	0.9	405	19	7.60	0.63
	Sulfite	222	5	379	2	37.1	1.9	21.2	1.3	390	15	7.31	0.07
	CTMP	227	7	430	1	31.6	2.7	17.9	0.8	369	12	8.83	0.00
Whole Hemp	Kraft	213	6	353	2	42.2	0.6	22.2	0.7	410	16	6.28	0.27
	Sulfite	218	8	345	2	37.1	0.8	20.2	1.1	392	23	7.21	0.07
	CTMP	215	5	375	2	33.3	1.5	19.3	1.1	284	2	7.35	0.56
Hemp Hurd	Kraft	225	4	355	2	44.7	1.9	23.4	0.7	455	14	6.77	0.00
	Sulfite	226	5	354	3	55.0	0.4	27.2	0.7	542	16	7.94	0.27
	CTMP	224	4	381	3	34.5	0.8	20.7	1.2	396	21	6.96	0.00

Practical Constraints and Upscaling Implications:

These findings are based on laboratory data under controlled conditions. Industrial-scale implementation may introduce variability due to refining, sheet forming, and process dynamics. Therefore, pilot trials and cost-benefit analyses are essential to validate the feasibility of scaling up.

2.1 Comparison of Non-Woods with OCC

OCC (Old Corrugated Containerboard) represents the industry benchmark for recycled containerboard and paperboard due to its availability and cost-effectiveness. In this laboratory evaluation, OCC showed moderate mechanical properties, including a tensile index of 33.7 N·m/g, STFI of 17.9 N·m/g, CMT of 306 kPa, and Taber stiffness of 7.35 mN·m. Its caliper of 400 µm offers a high bulk profile.

Wheat straw kraft pulp blended at 30% with OCC:

The wheat straw blend achieved the highest tensile index (59.5 N·m/g) and CMT (588 kPa), indicating superior fiber bonding and strength. CTMP wheat straw presented excellent caliper

(407 µm) and stiffness (7.55 mN·m), exceeding OCC in both while maintaining competitive compression strength. These properties are well-suited for corrugated medium applications.

Miscanthus CTMP pulp blended at 30% with OCC:
Miscanthus CTMP stood out with the highest Taber stiffness (8.83 mN·m) and caliper (430 µm), suggesting its potential for lightweight, rigid paperboard applications. While tensile and compression properties were modest, its rigidity could compensate for structural performance.

Whole Hemp kraft pulp blended at 30% with OCC:
Whole hemp kraft pulp exhibited balanced strength (tensile index 42.2, STFI 22.2, CMT 410 kPa). The CTMP version, while lower in strength, matched OCC in STFI and surpassed it in caliper and stiffness, highlighting its potential to be used paperboard or containerboard grades.

Hemp Hurd sulfite pulp blended at 30% with OCC:
Hemp Hurd sulfite pulp delivered exceptional strength (tensile index 55.0, STFI 27.2, CMT 542 kPa). It is a high-performance option. The CTMP pulp also showed promising results with higher CMT (396 kPa) and comparable stiffness (6.96 mN·m) to OCC. This may be suitable for corrugated medium grade.

2.2 Comparison of Non-Woods with Wood-Based Market Products

When evaluating virgin wood packaging materials, it is essential to understand the role that structural properties play in determining the end-use performance of paper and board grades. Each material category—corrugated medium and kraft paperboard (folding carton) —has been developed to fulfill a specific function in packaging applications, and their physical properties reflect these demands.

Corrugated medium, typically used as the fluted inner layer in corrugated board, is optimized for compression strength and formability. It generally has a lower basis weight (112–195 g/m^2) and modest caliper values (229–381 µm), designed to maintain structural integrity under vertical loads when formed into arches. One of the key properties is the Concora Medium Test (CMT), which simulates the compressive performance of the flutes. CMT values range from 372 to 552 kPa, demonstrating the medium's ability to resist collapse under stacking conditions. However, tensile strength and bending stiffness are less emphasized, as the medium is not intended to resist direct tearing or folding.

In contrast, kraft paperboard (folding carton) is used in more demanding structural and print applications, either as linerboard in corrugated packaging or as standalone folding cartonboard. Both the tensile index and stiffness are significantly higher. With basis weights ranging from 225 to 410 g/m^2 and calipers between 330 and 762 µm, kraft board offers enhanced mechanical strength. The tensile index peaks near 64.8 N·m/g, indicating strong resistance to tension per unit mass—critical during converting operations such as die-cutting or folding. Taber stiffness, which gauges resistance to bending, increases sharply with weight (from 8 to 67 mN·m), reinforcing kraft board's suitability for stackable and protective packaging.

Non-wood fibers such as wheat straw, Miscanthus, and hemp, blended at 30% with recycled OCC, offer a promising alternative to conventional wood-based fibers. These materials were evaluated using different pulping methods (kraft, sulfite, CTMP), offering a relevant comparison to traditional packaging substrates (Table 2). Despite being at the laboratory scale, many of the non-wood combinations match and, in some cases, exceed the mechanical performance of commercial corrugated medium and closely approach that of kraft paperboard (Fig 1 and 2). Linerboard was not included in this analysis as non-wood prototypes are largely off-specification for this application.

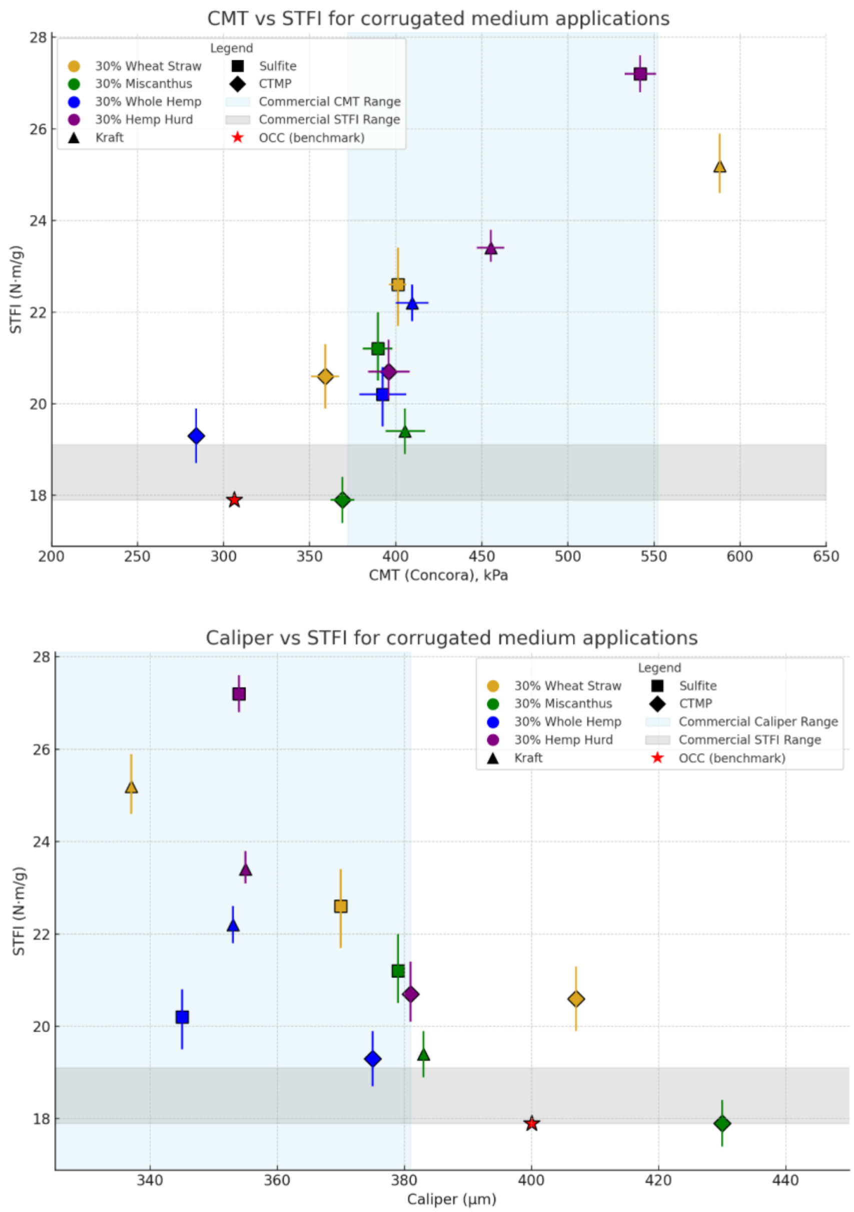

Fig 1. Comparison of non-wood (30%) and OCC (70%) blends vs wood-based commercial products for corrugated medium applications (Table 2 vs Table 3). The colored background represents the value ranges for the wood products (Table 3).

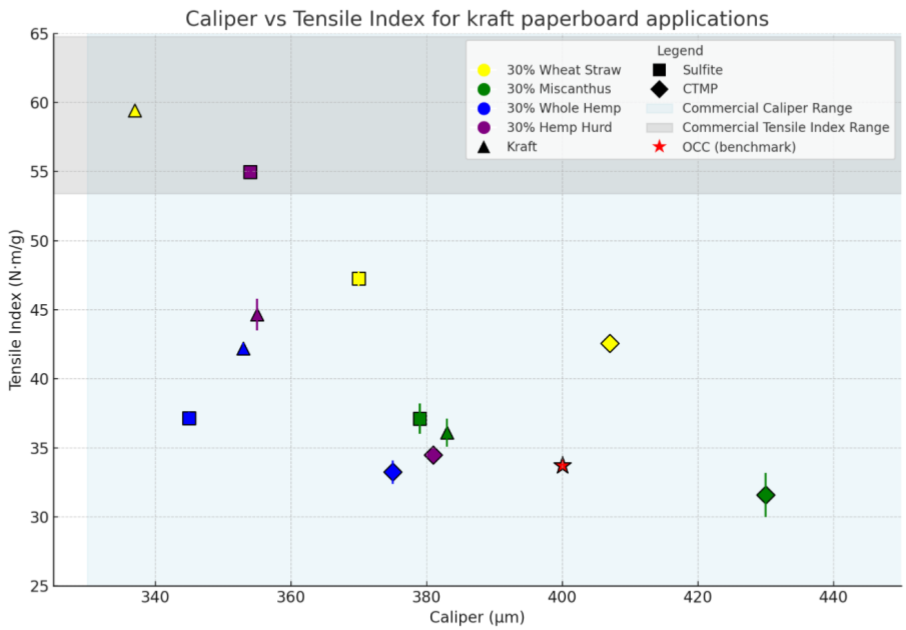

Fig 2. Comparison of non-wood (30%) and OCC (70%) blends vs wood-based commercial products for kraft paperboard applications (folding carton) (Table 2 vs Table 3). The colored background represents the value ranges for the wood products (Table 3).

3. CONCLUSIONS

This study highlights the potential of non-wood fibers—wheat straw, miscanthus, and hemp—as alternatives to conventional packaging materials. The performance of these fibers, particularly when processed via CTMP and blended at 30% with OCC, demonstrates mechanical properties comparable to or exceeding those of recycled OCC and, in some cases, approaching the standards of virgin wood-based paperboard. Notably, wheat straw kraft pulp delivered tensile and compression strengths surpassing both OCC and even the lower range of kraft paperboard benchmarks. Miscanthus CTMP's high stiffness and caliper suggest suitability for rigid paperboard applications. Hemp and hemp hurd pulps exhibited robust mechanical properties, further reinforcing their potential role in containerboard grades.

When compared with commercial wood-based products, the non-wood blends closely matched the compressive strength and stiffness of corrugated medium, and in select cases, approached the higher tensile and stiffness benchmarks typical of kraft paperboard. However, key limitations, such as variability in non-wood feedstocks, processing challenges (e.g., high silica content), and scale-up complexities, must be addressed before broad industrial adoption. Pilot-scale trials and comprehensive economic assessments will be crucial in determining the feasibility of replacing or supplementing wood-based packaging materials with these alternative fibers.

Table 3. Some Commercial Wood-Based Paper Grades and Their Specifications – Compiled from Online Sources

Grade	g/m²	Caliper (μm)	Tensile Index, N.m/g	Short-span compressive test (STFI), N.m/g	CMT (Concora), kPa	Taber Stiffness (15°), mN.m
Corrugated medium [1]	112	229	---	18.7	372	---
	127	254	---	18.6	414	---
	147	279	---	19.1	448	---
	161	305	---	18.5	483	---
	176	330	---	17.9	517	---
	186	356	---	17.9	538	---
	195	381	---	17.9	552	---
Kraft Paperboard [2]	225	330	54.7	---	---	8
	225	381	62.2	---	---	11
	244	432	64.8	---	---	14
	259	457	64.1	---	---	17
	283	508	63.3	---	---	22
	307	559	62.9	---	---	29
	332	610	60.5	---	---	36
	356	660	58.1	---	---	45
	386	711	55.4	---	---	56
	410	762	53.4	---	---	67

[1] "Containerboard | ND Paper | Sustainable Paper, Pulp, & Packaging." Accessed: May 07, 2025. [Online]. Available: https://us.ndpaper.com/products/containerboard/

[2] "KraftPak® Kraft Paperboard |Unbleached & Uncoated Paperboard." Accessed: May 07, 2025. [Online]. Available: https://www.westrock.com/products/paperboard/kraftpak

DEFINITIONS

Kraft pulping: It is a chemical process used to convert biomass into pulp. It involves cooking biomass chips with white liquor—a mixture of sodium hydroxide (NaOH) and sodium sulfide (Na_2S)—at high temperature and pressure. This treatment dissolves lignin and hemicellulose, separating the cellulose fibers. The digester yield ranges between 40-50%. The resulting pulp is washed, screened, and can be bleached for higher brightness. The process is widely used due to its strength yield and chemical recovery efficiency. Using non-wood materials in this technology is limited because they contain more silica than wood. This higher silica content makes it difficult to use recovery boilers in mills.

Sulfite pulping: Sulfite pulping is a chemical process that uses mixtures of sulfur dioxide and bases to remove lignin from biomass and liberate cellulose fibers. Unlike kraft pulping, it can operate under acidic, neutral, or alkaline conditions depending on the base used (e.g., calcium, magnesium, sodium, or ammonium). The digester yield will depend on the final application and can range from 30-70%. The process yields pulp with high brightness and smoothness, often suited for specialty papers. Recovery of spent sulfite liquor can be complex but enables lignosulfonate co-product generation, avoiding the constraints for non-woods utilization.

Chemi-thermo mechanical pulps: Chemi-thermo mechanical pulping (CTMP) is a high-yield process that combines mild chemical pre-treatment with mechanical refining to separate wood fibers. Wood chips are impregnated with chemicals—typically sodium sulfite or sodium hydroxide—before being mechanically defibrated under elevated temperature and pressure. The chemical treatment softens lignin, reducing energy consumption and fiber damage during refining. CTMP retains most of the lignin and hemicellulose, resulting in bulky, stiff pulps ideal for tissue, packaging, and printing grades. The digester yield ranges between 70-80%. The process offers a balance between strength, optical properties, and cost efficiency.

ACRONYMS

CMT: corrugated medium test
OCC: old corrugated containerboard
CTMP: Chemi-thermo mechanical pulp
STFI: Short-span compressive test

canopy

www.canopyplanet.org

SAFI

sustainable & alternative fibers initiative

www.go.ncsu.edu/SAFI