FOREST TO FIBER:

Next-Generation Pathways for Vermont and Regional Leadership in Wood-Based Fiber and Textiles

Vermont Sustainable Jobs Fund

Forest to Fiber: Next-Generation Pathways

The year 2023 feels like a pivot point for Vermont: the record-breaking floods in July that caused catastrophic damage in some communities, including our state capital of Montpelier, are a stark reminder that our climate is changing, and bringing with it more extreme weather events that will force us to re-think how and where we re-build, as well as how we develop as a society.

Vermont's forest economy is also at an important point: the Vermont Department of Forests, Parks and Recreation is leading the Vermont Forest Future Strategic Roadmap process, which will plot a 10-year course for how to strengthen, modernize, promote, and protect Vermont's forest products sector and the broader forest economy. And, a coalition of organizations in Maine, New Hampshire and Vermont, including the Vermont Sustainable Jobs Fund, are embarking on a region-wide effort to help transform the Northern Forest region into a modern forest products innovation hub.

The research presented in the following pages was prompted by VSJF's desire to explore some of the emerging technologies and markets that show promise for using low grade wood to replace oil-based plastics. **This market opportunity assessment investigates one such product category: textiles made from wood.** Given that the global textiles market tops $1 trillion and that nearly two-thirds of all fibers we wear and use are made from oil, we felt compelled to investigate whether our region's wood basket could contribute to a global solution that reduces our dependence on oil in favor of a sustainable and renewable resource for fiber.

Unlike viscose, a wood-based textile that requires harsh chemicals to create, new pilot-scale technologies are emerging that can break down the cellulose in trees mechanically, tenabling the development of eco-friendly wood-based textiles that have many potential uses.

As we look at how to diversify the kinds of products we can make out of sustainably harvested wood from our state and region, wood-based textiles offer a promising possibility worthy of further consideration. Coupled with efforts to recycle existing textiles to reduce the need for more virgin fiber, the potential for Vermont and the Northern Forest region to become leaders in a more circular approach to the next generation of textile production is exciting.

I want to thank Common Threads Consulting, LLC for leading this research, and also the Vermont Housing and Conservation Board, the Northern Forest Center, the Endowment for Forestry

and Communities, and the U.S. Economic Development Administration (EDA) for their financial support of this market opportunity assessment. We look forward to sharing it widely with forest economy leaders as well as leaders in the textiles space.

There are no silver bullet solutions to climate change or the myriad other environmental challenges our society faces; however, we need look no further than our forests to find ideas, and dare I say solutions, that benefit people and the planet.

Christine McGowan
Director, Forest Products Development Program
Vermont Sustainable Jobs Fund
September 2023

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The project team gratefully acknowledges the time and expertise of all interviewees for this report (identified in Appendix 1).

The team also relied on the detailed prior research conducted by key forestry and textile industry processes and organizations, including:

- Forest Opportunity Roadmap/Maine (FOR/Maine)
- North East State Foresters Association (NEFA)
- Textile Exchange
- Interim conclusions from the Vermont Forest Future Strategic Roadmap

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Design: Scott Sawyer

Glossary

Cellulose: The cellulose molecule is the main structural component of the primary cell wall in plants: it is consequently the most abundant natural polymer on Earth.

Man-Made Cellulosic Fibers (MMCFs): According to Textile Exchange, MMCFs are fibers coming from the cellulosic matter of plants (usually trees or bamboo) or reclaimed feedstock that is processed into a pulp, dissolved and then re-generated into a staple or filament fiber through a chemical process. Viscose (rayon) and acetate are the most common manmade cellulosic fibers. Others include lyocell, modal, and cupro.

MMCF Types:

Viscose: Viscose, or rayon, is an artificial textile material composed of regenerated and purified cellulose derived from plant sources.

Lyocell: Lyocell is the generic name for a wood-based fiber made from dissolving pulp through methods that require less energy than traditional viscose manufacturing, and where the chemicals used have lower toxicity and are recycled in a closed-loop process.

Modal: A variant of the basic viscose process has been trademarked as "Modal." While the same chemicals are applied throughout the process, modified chemical baths contribute to higher wet strength of fibers.

Acetate: Acetate differs from rayon in the employment of acetic acid in production. The two fabrics are now required to be listed distinctly on garment labels.

Cupro: Cupro is a silky fabric made from cotton fibers that are chemically processed. Cupro (Cuprammonium rayon) is no longer made in the U.S. because its producers could not meet air- and water-quality requirements.

Cellulosic Nanofibrils or Nanofibers (CNFs): These materials are derived from cellulosic molecules and have diameters ranging from 5 to 30 nanometers and lengths that can approach several microns.

Dissolving Pulp: This is a special type of bleached wood pulp that has a high cellulose content (>90%) and a low hemicellulose and lignin content–well below that of wood pulp used for papermaking.

Microfibrillated cellulose (MFC): The distinction between microfibrillated cellulose or cellulose microfibrils (MFC) and nanofibrillated cellulose or cellulose nanofibrils (CNF) is not clear cut. If nano- or micro-scale is not specified, the material is included under MFC.

Woven: This is a textile type produced by interlacing two sets of threads, horizontal and vertical, in crossing patterns to form fabric lengths.

Nonwoven: This textile type is *not* made by weaving or knitting and does not require converting the fibers to yarn. Nonwoven textiles are made by entangling fibers/filaments mechanically, thermally, or chemically.

Slash: Slash is logging debris left in the forest after a harvest.

Tonne vs. ton: These units of mass are not interchangeable. A ton equates to about 2,240 pounds, or roughly 1,015 kilograms. A tonne (also called a metric ton) is a metric measurement and equates to 1,000 kilograms.

Three Pathways: Summary and Key Milestones

JULY 2023 | JAN 2024 | JULY 2024 | JAN 2025 | JULY 2025 | JAN 2026 | 2033 | 2035 | 2043

Pathway 1
Catalyze local development of cellulosic nanofibers for textiles

JULY 2023
Vermont Forest Futures Roadmap draft findings released

JAN 2024
Final Roadmap published

Integrate CNF for nonwoven textiles into plans

2034
Vermont Forest Futures 10-year Roadmap culminates

CONFIR NSF Engines Development Grant period (ends Apr 30, 2025)

EDA National Technical Assistance NOFA open (no deadline)

SEPT 2025
NSF Engines full proposal due

Potential **CONFIR Full NSF Development Grant** (10 years, up to $160 million allowed)

Pathways 1 and 2 converge by 2025

Pathway 2
Partner with global innovators in non-chemical wood fibers

MAY 2023
Spinnova/Suzano Woodspin JV plant opens in Finland — fully non-chemical wood fiber

END OF 2023
Spinnova/Tearfil non-chemical wood spinning plant to open in Portugal

END OF 2024
Spinnova/Suzano Woodspin JV project second plant

2033
Spinnova goal is 1 million tons of non-chemical wood fiber annually

JUNE 2023
EU regulation on deforestation-free supply chain goes into effect; increases demand for traceable wood

Pathways 1 and 3 converge by 2033

Pathway 3
Invest in the next horizon: recycled textiles + wood fiber

JUNE 2023
EU LIFE TREATS grant to **Södra** and **Lenzig** to expand OnceMore production

NSF Engines grant to **Industrial Commons/Material Return** in NC may be approved — model/potential partner for regional recycled textile products (winter ‘23-’24)

Revisit **VT Textile Use and Recycling** report: support development of textile collecting capacity, explore partnerships with hospitality industry for used textiles

EU mandated textile waste collection begins in 2025

VT Materials Management Plan calls for 10% solid waste reduction by 2025

JULY 2025
New solid waste management facility opens in Chittenden County — opportunity for textile waste pilot?

Vermont’s only landfill—Coventry—is full by 2043

1. Introduction

At the mention of the word "textiles," most people reflexively look at what they are wearing, and reasonably so. Together with food and shelter, clothing is among the few non-negotiable necessities of life. However, clothing and footwear are far from the only type of textile present in our daily lives. In a word, textiles are ubiquitous. On any given day, towels, bedding, carpeting, and car upholstery might surround us. Textile types known as "nonwovens," such as cleaning wipes, baby diapers, agricultural ground covers, and reusable shopping bags, are a regular part of 21st century life. And with the COVID-19 pandemic, nonwoven face masks became part of daily reality, joining a wide variety of other biomedical textile products such as hospital gowns, wound dressings, and even implantable textile products.

Since prehistoric times, textiles in many forms have been made from wood. Present-day wood-fiber textile production accounts for only about 6.5% of the global textile market,[1] yet it is one of the fastest-growing categories of fibers. But the conventional process for making wood-based fibers is coming under increasing scrutiny as part of the problem in a chemical-intensive, overproducing global textile industry. As Vermont and the region contend with climate change-driven shifts in the forest industry and the forest itself, a new horizon is emerging: next-generation, non-chemical methods for producing fibers and textiles from wood. This field is early-stage and will require a lab-scale, R&D approach to set the stage for commercialization. Fortunately, this accords well with the preferred scenario emerging from the Vermont Forest Future Strategic Roadmap, as well as with other regional processes, collaborations, and resources.

In this report, we lay out **three pathways**, developed through our research and interviews, that hold promise for Vermont and the Northern Forest Region to be part of the solution to balancing environmental and economic development considerations in the growing field of wood-based fibers.

- **Pathway 1: Catalyze the local development of cellulosic nanofibers (CNF) for textiles**
- **Pathway 2: Partner with global innovators in non-chemical wood fibers**
- **Pathway 3: Invest in the next horizon: recycled textiles + wood fiber**

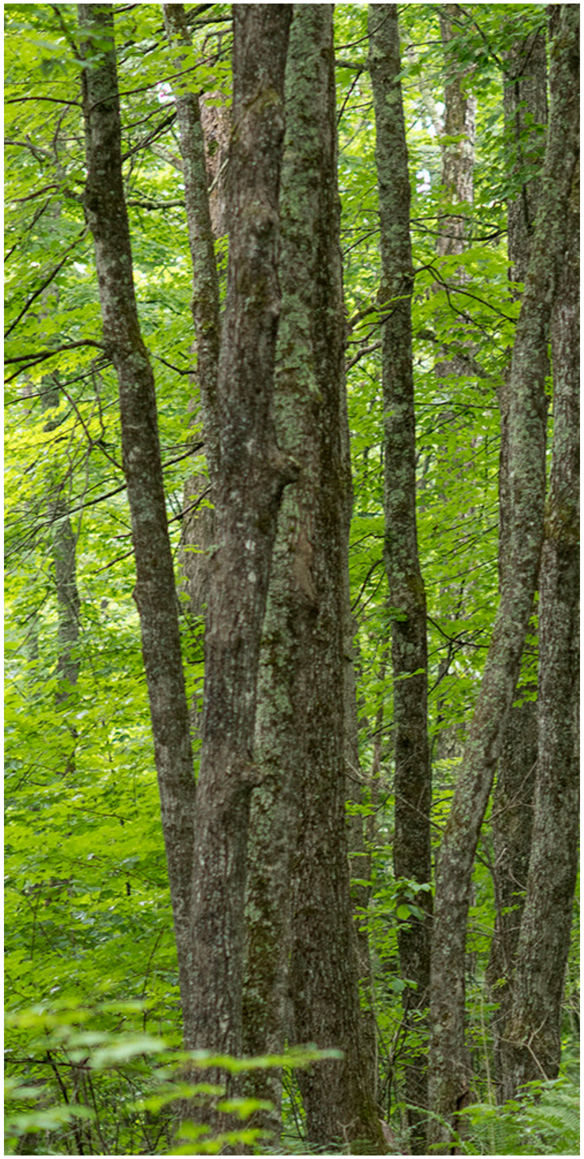


PHOTO CREDIT: ERICA HOUSEKEEPER

Purpose and Scope of the Project

Vermont Sustainable Jobs Fund (VSJF) sought a Market Opportunity Assessment on the development of wood-based fibers and textiles in Vermont and the surrounding states. The goal of this assessment is to focus on specific opportunities and challenges for developing wood-based textiles that utilize low grade wood from Vermont and surrounding states. VSJF asked for an assessment that:

- Analyzes the current state of wood fiber production for textiles, globally and in US;
- Assesses the Vermont and overall Northeast potential fiber supply which could be mobilized for wood fiber textiles;
- Describes the potential market size and demand for US wood fiber textiles;
- Identifies what currently exists and what is missing in the processing supply chain for Vermont and US wood fibers;
- Identifies market opportunities and barriers for foresters and loggers, for existing brands, potential buyers, and for funders and investors.

Principles and Values Guiding the Research

VSJF's stated purpose is "to serve the needs and interests of Vermont businesses, organizations, and government partners who are working hard to strengthen our local and regional food system, rebuild the forest products industry, meet Vermont's renewable energy goal, and invent clean technologies that benefit society." With this focus on clean, sustainable economic development in mind, the project team decided early to pursue only those leading edge, non-chemical wood fiber options that are non-polluting and environmentally sustainable. We also took into account the negative impacts of the current global apparel industry and aimed to ensure that our recommendations would allow Vermont and the region to be part of the solution, not part of the problem.

In the development of this report, the Forest Opportunity Roadmap / Maine (FOR/Maine) comprehensive process and report provided important background on wood-based textiles. The FOR/Maine report identified dissolving pulp, which it notes is mainly used in the textile industry, as one of its top six products to explore. FOR/Maine's analysis noted some key disadvantages for this product, including high capital costs for dissolving pulp facilities, high emissions intensity, and high level of competitiveness in the dissolving pulp market.[2] Since the initial FOR/Maine research was completed in 2018, numerous industry reports have raised additional concerns about the chemical processes used in traditional dissolving pulp textile production for conventional viscose.[3] Interviewees for this project also expressed skepticism about the suitability of legacy dissolving pulp and viscose textile production for Vermont and the surrounding region.

Our project team fully agrees with these conclusions and concerns about the traditional dissolving pulp / viscose process—***and* we fully believe that alternative, non-chemical pathways exist for Vermont and the region to invest in next-generation wood-based fibers as a component of the regional bioeconomy.**

In just the past few years, fast-moving innovations, new companies, and policy developments in the wood-based fiber sector have fundamentally changed the landscape and allowed these pathways to take shape.

We fully believe that alternative, non-chemical pathways exist for Vermont and the region to invest in next-generation wood-based fibers as a component of the regional bioeconomy.

Research Approach

The project team reviewed over 200 sources of written information (e.g., scientific journals, commissioned reports, websites, patent requests, media stories, and more) and spoke with over 30 stakeholders from the forestry, wood products, engineering, academic research, and textiles industries (See the Endnotes and Appendix for a complete list of information sources referenced and individuals interviewed for this project).

With initial research and interviews quickly ruling out the conventional viscose pathway, and with the rapid pace of innovation in the sector, our interviews proceeded iteratively, with each conversation uncovering new developments, companies, and options. Due to the early R&D stage of next-generation wood-based fibers and the concerns about apparel industry growth impacts, we also de-emphasized the apparel sector and instead focused on innovative uses *beyond* apparel. We particularly focused on nonwoven textiles and biomedical applications for two reasons.

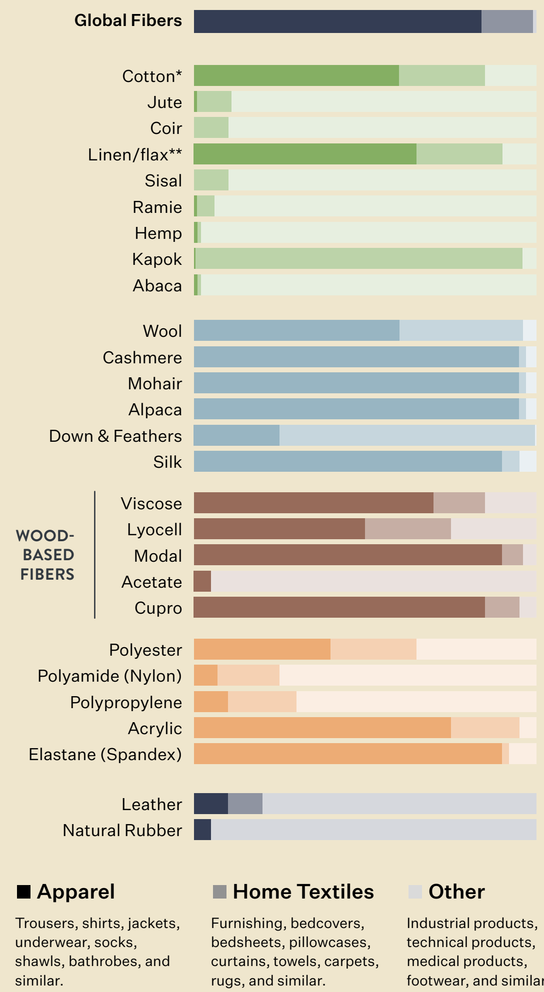
First, technical research indicates that **next-generation wood-based fibers, especially cellulosic nanofibers (CNF) for textile applications, are well suited for nonwoven application and more easily formed into nonwoven textiles with fewer production steps.** Lundahl et al. (2017) noted that "Mechanical binding with cellulosic materials has been of special interest because it enables cost efficient production of biodegradable

TEXTILES BEYOND APPAREL

Textiles are ubiquitous. And yet few of us recognize the scope and variety of their use beyond clothing and footwear. Just a few examples include:

- Face masks
- Upholstery fabrics and furniture linings
- Rugs and carpets
- Sheets and towels
- Personal care textiles such as baby wipes, makeup wipes, and hand-cleaning wipes
- Baby diapers, feminine hygiene products, and adult incontinence products
- Automotive applications such as car upholstery, insulation, and safety harnesses and seat belts for recreational, automotive, and aerospace applications
- PPE for military personnel, divers, firefighters, law enforcement, etc.
- Medical textiles such as bandages, dressings, and hospital gowns.

Textile Exchange's 2022 Preferred Fiber and Materials Market report provides a snapshot of fiber and textile uses beyond apparel. As the report notes, "While solid figures do not exist on a global level, the graphic [at right] is meant to visualize the rough average percentage estimates by application for the different fibers and materials. The main purpose of the graph is to show that the percentages used for apparel vary by fiber and material and that only parts of all fibers and materials produced...are used by the apparel and home textile industry." Textile Exchange adds the key caveats that percentages change frequently over time and that regional differences exist as well.[4]



Source: Textile Exchange, October 2022, Preferred Fiber & Materials Market Report.

While the majority of global wood-based fiber, shown in dark brown, is currently used for apparel, the graphic shows that many fiber types can be used for non-apparel applications. Next-generation wood-based fibers, therefore, have ample scope for application and for replacing both synthetic and other natural fibers in these applications as the technology develops.

structures...the properties of CNF filaments introduce a possibility to develop stronger nonwovens with a lowered environmental impact."[5] In addition, textile industry market research indicates that demand for textiles in the technical segment is expected to grow at the fastest rate of any of the subcategories analyzed, 7.7% over the period from 2023-2030.[6] Some research on medical textiles projects that the global medical textiles market will expand at a compound annual growth rate of 3.0% from 2021 to 2028. While this is a comparatively slower growth rate, the potential for localized development of this industry and early adopter competitive advantage for Vermont and the region suggest that the biomedical textiles field could be a unique and profitable niche.

Finally, we heard a strong emphasis on the growing importance of recycled textile feedstocks for next-generation fibers. While this approach extends beyond the project scope of wood-based fibers, we came to see great additional potential in this cross-sector approach.

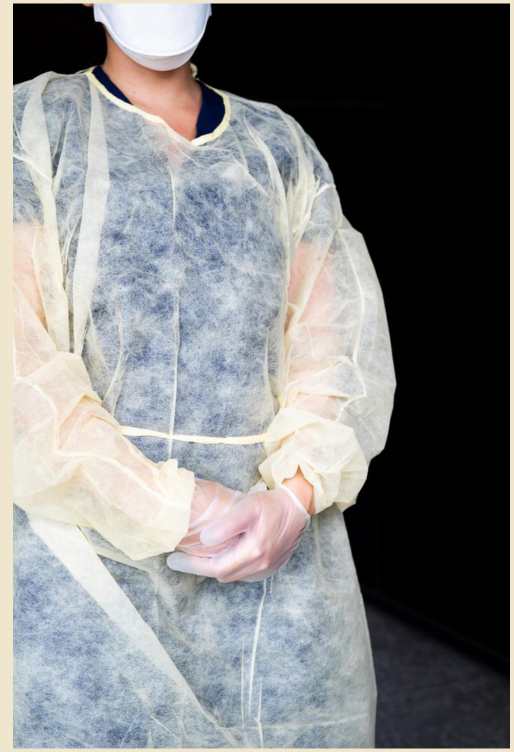
WOVENS VS. NONWOVENS

The majority of the textiles we wear or use in home furnishings are woven (i.e., produced by interlacing two sets of threads, horizontal and vertical, in crossing patterns to form fabric lengths). In contrast, nonwoven fabrics utilize a different process. According to [INDA, the Association of the Nonwoven Fabrics Industry](), "Nonwoven fabrics are broadly defined as sheet or web structures bonded together by entangling fiber or filaments (and by perforating films) mechanically, thermally, or chemically. They are flat, porous sheets that are made directly from separate fibers...They are not made by weaving or knitting and do not require converting the fibers to yarn."[7]

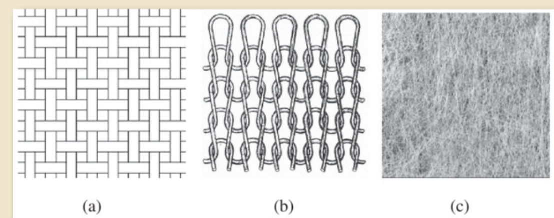
The history of nonwovens is rooted in the goal of waste reduction. In the 19th century, realizing that large amounts of fiber were wasted as trim, an English textile engineer named Garnett developed a special carding device to shred this waste material back to fibrous form. This fiber was used as a filling material for pillows. The Garnett Machine, greatly modified, still retains its name and is a major component in the nonwoven industry. Later on, manufacturers in Northern England began binding these fibers mechanically (using needles) and chemically (using glue) into batts. These were the precursors of today's nonwovens.[8]

INDA provides an extensive list of potential applications for nonwoven textiles in today's market, including:

Apparel linings	Household & personal wipes
Automotive upholstery	Hygiene products
Carpeting	Insulation
Civil engineering geotextiles	Labels
Disposable diapers	Laundry aids
Envelopes	Sterile medical-use products
Filters	Upholstery



Nonwoven fabrics may present an opportunity for Vermont's forest products industry.



Types of common fabric: (a) woven, (b) knitted, and (c) non-woven fabrics.

Source: Reprinted from Mohd Iqbal Misnon et al., July 2014, "[Potentiality of Utilising Natural Textile Materials for Engineering Composite Applications]()," *Materials & Design*, 59: 359-368, with permission from Elsevier.

Global and Local Policy Context

GLOBAL POLICY CONTEXT

During the course of this project, the global context for wood-based fiber opportunities has been significantly and positively impacted by several major new European regulations that are already influencing the textile industry. These include:

- The European Union's new **Deforestation Regulation** (EU DR), set to go into effect in early 2024.[9] This regulation aims to ensure a "deforestation-free" supply chain in wood products, including textiles. The new regime will require EU importers to confirm that cattle, cocoa, coffee, oil palm, rubber, soya, wood and derived products have been sourced using methods that do not contribute to deforestation.

  According to Nicholas Johnson, Fiber and Materials Strategy Lead for Manmade Cellulosic Fibers at Textile Exchange, the EU DR will feature more stringent chain of custody requirements than exist today: "Even the criteria used by Forest Stewardship Council and Sustainable Forestry Initiative likely won't be compliant." Johnson adds, "This means that to be viable in Europe, any [wood-derived] product hoping to get to market will have to address EU DR." These regulations will increase pressure for full transparency and traceability to the start of the supply chain, offering a potential advantage to forest products from Vermont and the region.

- The **EU Waste Framework Directive (WFD)**; in particular the requirement for separate collection of textile waste by 2025. According to a summary, the EU WFD legislates that, "Member States should promote re-use activity and repair networks, facilitating proper waste management and that **by 1st January 2025 Member States shall set up separate collection for textiles.**"[10] [emphasis added]. This directive has already increased global awareness of the issue of textile waste.

- New proposals for **EU Extended Producer Responsibility (EPR) for Textiles**, released on July 5, 2023. As summarized by EcoTextile News, "The EPR scheme would make producers responsible for the full lifecycle of textile products and support the sustainable management of textile waste across the European Union, according to the commission... Producers would pay fees to cover the costs of the management of textile waste, a system which the commission says will also give them incentives to reduce waste and increase the circularity of textile products."[11]

- In the area of nonwoven textiles, the earlier 2018 **EU Single-Use Plastics Directive** has also created pressure to identify non-synthetic material options for certain nonwoven items included in the Directive's list, such as baby wipes, hand wipes, and feminine hygiene products.[12] This policy has also raised expectations that other single-use nonwoven products could be added to the list in future, driving demand for non-synthetic substitute feedstocks such as cellulosic fibers.

These EU policy levers will have three key impacts:

1. Greatly increase the value of full transparency and traceability of wood-based fibers;
2. Strengthen the incentives for recycling of textiles and the incorporation of textile waste into new fibers and products; and
3. Drive demand for non-synthetic feedstocks for single-use items, including nonwoven textile items.

VERMONT POLICY CONTEXT

Adding to this global policy context, Vermont has recently passed several pieces of legislation that further impact sourcing and management decisions for the state's forest resource.

- In 2020, the Vermont Legislature passed the **Global Warming Solutions Act (Act 153 as Enacted)**, which created legally binding emission reduction requirements.[13] The Act requires Vermont to reduce greenhouse gas (GHG) pollution to 26% below 2005 levels by 2025. Among the seven goals set by the Climate Council in its 2021 Climate Action Plan are to:

  achieve long-term sequestration and storage of carbon and promote best management practices to achieve climate mitigation, adaption, and resilience on natural working lands;

  limit the use of chemicals, substances, or products that contribute to climate change; and

  reduce greenhouse gas emissions from the transportation, building, regulated utility, industrial, commercial, and agricultural sectors.[14]

This legislation further strengthened our conclusion that additional investment in the traditional dissolving pulp/viscose pathway was not a viable option for the state and region.

- On June 12, 2023, **House bill H.126** passed into law. This new law establishes a goal of permanently conserving 30% of Vermont's total land area by 2030 and 50% by 2050,[15] and it also creates categories for land conservation. Those categories include "ecological reserve areas," where land would be managed passively to become wild; "biodiversity conservation areas," where land would be carefully managed in an active manner to improve biodiversity for certain species and habitats; and "natural resources management areas," where long-term, sustainable logging could take place. In all of these categories, conversion of large areas—for housing development, for example—would not be allowed.

These new Vermont state laws have critical implications for this project. Any wood-based fibers pathway for Vermont must take into account the state's climate and GHG reduction goals. This will impact the amount of wood that can be used (versus being left in the forest for carbon sequestration benefits) and the allowable GHG emissions of any recommended wood fiber processing options.

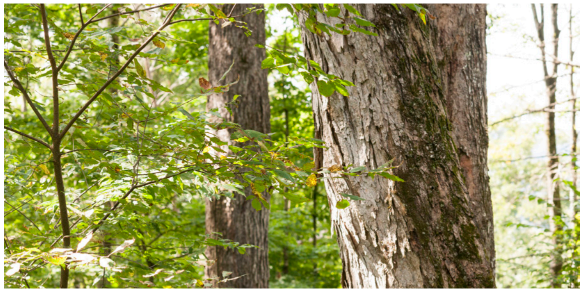


PHOTO CREDIT: ERICA HOUSEKEEPER

Aligning with Current Processes and Research

In addition to this fast-moving policy context, two regional efforts have taken shape during the course of this project that offer key opportunities for future alignment. These efforts involve several of the project sponsors and interviewees, and they set the stage for the inclusion of next-generation wood-based fibers in future forestry and economic development plans for Vermont and the region.

VERMONT FOREST FUTURE STRATEGIC ROADMAP

This state process was initiated by Act 183 of 2022, which instructs the Commissioner of Forests, Parks and Recreation to create the Vermont Forest Future Strategic Roadmap.[16] Advisory Council members have been meeting since November 2022, and a draft that includes findings and a Roadmap framework was provided to the General Assembly on July 31, 2023.

Based on these interim recommendations, the project team believes that our proposed pathways below would all align well with the preferred "Scenario B" developed through the extensive stakeholder engagement process: "This scenario forecasts a future where intentional forest management is coupled with proactive industry adaptation—helping drive innovation and vibrancy in the forest economy."[17]

Our proposed pathways also align with the "Research, Innovation, And Technology" pillar of the Vermont Forest Future Roadmap, which includes the strategic objective of "Promoting innovation and adaptability in the Vermont forest products sector by supporting technological development, cross-sector collaboration, and processing capability for both new and existing forest products." Themes for this pillar include:

- Boost investment to develop new and innovative uses of Vermont forest products;
- Accelerate the adoption of technical innovation; and
- Examine the optimal multi-use future forest economy.

With the process of developing detailed recommendations for the Roadmap already underway, we hope that our report can help ensure that next-generation wood-based textiles are on the radar screen for the Vermont Forest Future Advisory Panel and consultants as the process continues. In an interview for this project, Vermont's Commissioner of Forests, Parks and Recreation, Danielle Fitzko, noted that although the Roadmap process is still in development, everyone involved is keen to ensure that recommendations are acted upon and not only bound up in a written report. As she put it, "The goal is to come out with a living plan—we identified many state plans where the forest products sector is mentioned, but this one needs to be a catalyst for action going forward." More specifically, she remarked, "we need to bring value to low-grade wood—that is huge. Some have found opportunity there, but if we could add more value along the way and keep it in Vermont, that's a real niche." Looking to next steps, Fitzko added, "it's fantastic that you have identified a direction forward, and we are going to need your voice—we will have work groups to hear what people think is needed to move the pillars forward. What does it really take to get us there, to that desired future condition?"

CONFIR PROJECT: NATIONAL SCIENCE FOUNDATION (NSF) ENGINES DEVELOPMENT AWARD

Since this project began, several of the project's sponsors have received a National Science Foundation "Engines Development Award" for their proposed collaboration, known as the CONFIR project (Coalition of Northern Forest Innovation and Research). The CONFIR project is led by the Northern Forest Center, with additional core partners including University of Maine, University of New Hampshire, University of New Hampshire Cooperative Extension, University of Vermont, Northern Vermont University (now Vermont State University), Maine Development Foundation, and the Vermont Sustainable Jobs Fund.

As described in the project's press release:

"The coalition will link forest-focused expertise and resources across the three states towards three objectives:

1. Accelerate adoption and implementation of advancements in resource management, wood products manufacturing, and new forest-based technologies.
2. Develop and promote adoption of best practices for smart utilization of Northern Forest resources for economic, ecological, and climate benefits.
3. Increase workforce skills and participation in forest-based careers, including expanded participation by historically underrepresented populations."[18]

The CONFIR project set the stage for several of our key interviews and will remain vital for decisions and next steps related to all of our proposed pathways.

PHOTO CREDIT: ERICA HOUSEKEEPER

2. Wood-Based Fiber in the Textile Sector

Background: Cellulose is the Key

Production of fibers and textile products from wood relies on one of the most critical molecules on earth: cellulose. Cellulose is the main structural constituent of the primary cell wall in plants; it is thus "[t]he most abundant natural polymer on planet Earth… representing over 30-40% of all terrestrial biomass."[19] Cellulose is biodegradable, renewable, biocompatible (i.e., not toxic or physiologically reactive to living systems), and abundant, providing both current and potential future uses for plastic replacements, coatings, textiles, and composites. As it relates to fiber production, the cellulose in wood is the same molecule as the cellulose in cotton, flax (used to produce linen), and fiber hemp used for textiles. However, cotton fiber contains approximately 90% cellulose, while wood contains 40–55% cellulose, which is bound together in the tree with other wood components including lignin and hemicellulose.[20] The development of fiber and textile products from wood thus requires some method to separate the cellulose bundles from each other and from the lignin and hemicellulose. Accomplishing this step without the use of harsh chemicals is the central challenge currently facing the wood-based textiles sector globally.

A Brief History of Textiles from Wood Fiber

Since ancient times, humans have produced textiles from cellulosic materials, including hemp, flax, cotton, other plant fibers, bark, and wood. Evidence from an archaeological site in France suggests that Neanderthals developed the ability to make cord from bark fibers between 41,000 to 52,000 years ago.[21] In 1883, French scientist Hilaire de Chardonnet invented a commercial wood-based fiber that he marketed as a replacement for silk. That first formulation was so flammable that it was pulled from the market, but the process was later redeveloped, and in 1892 three scientists in Great Britain patented the "viscose" production process for wood-based fibers. By 1905, viscose was on the market,[22] and by the 1920s, it had become commonly used in the US, though it was known here as rayon.

Fast-forward to the present day: wood-derived fibers are now one of the fastest-growing components of a fast-growing global industry.

Key Issues in the Current Textile Industry

The global fiber and textile industry is a massive, rapidly growing, and often extractive sector. Some of the best available data on this industry comes from Textile Exchange, a global nonprofit with over 800 brand and industry members. Textile Exchange's 2022 Preferred Fiber and Materials Market Report provides key information on the size and scope of the global textile industry:

- "Global fiber production increased again to a record 113 million tonnes [125 million tons] in 2021, after a slight decline due to COVID-19 in 2020. In the last 20 years, the global fiber production has almost doubled from 58 million tonnes [64 million tons] in 2000 to 113 million tonnes in 2021 [125 million tons] and is expected to grow to 149 million tonnes [164 million tons] in 2030 if business as usual continues.

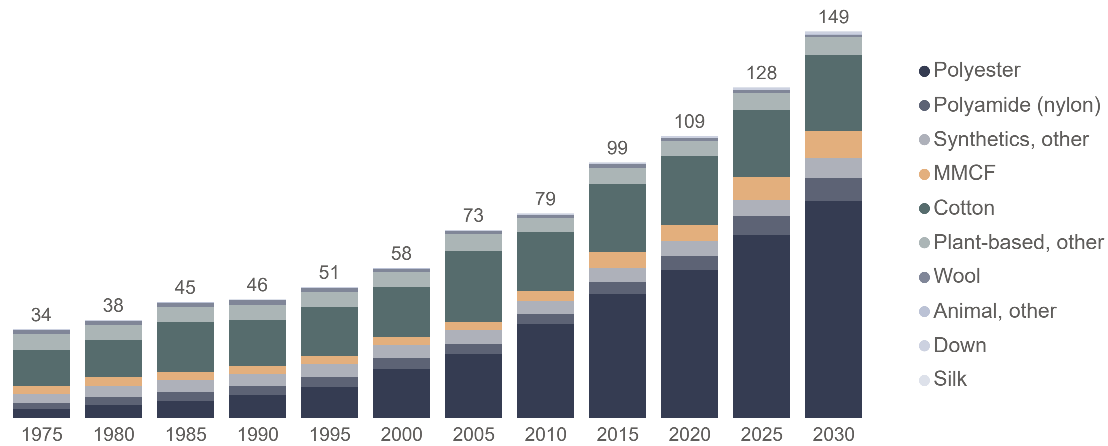
- "Global fiber production per person increased from 8.4 kilograms [18.5 lbs] per person in 1975 to 14.3 kilograms [31.5 lbs] per person in 2021."[23]

This growth is fueled by the dominant role of petroleum-derived synthetic fibers, which currently account for 64% of global production. **Put more simply, nearly two-thirds of all the fibers we wear and use are made from oil.**

Textile Exchange concludes: "The growth in fiber production has significant impacts on people and the planet. Awareness of the urgent need for more responsible use of resources and decoupling growth from resource consumption is growing; however, change is not yet happening at the scale and speed required. **Without rethinking growth, the industry will not stay within the 1.5° pathway.**"

This rapid growth is the driver of a broader set of impacts from the global textile industry. In recent years, the industry has come under great scrutiny for its environmental and social

Global Fiber Production (Million Tonnes)



Source: Textile Exchange based on data from ICAC, FAO, IWTO, Mohair South Africa, inserco, CIRFS, IVC, Maia Research, and its own modeling.

justice costs. Key points on the industry's impacts from reliable sources include:

- Over 8% of total global greenhouse gas emissions are produced by the apparel/footwear industry.[24]
- If the industry continues on its current path, by 2050 it could use more than 26% of the total global carbon budget.[25]
- According to World Bank estimates, 20% of all water pollution is created during the runoff processes of textile dyeing and rinsing of natural (mostly cotton) fabrics.[26]
- Over 8,000 chemicals are used to turn raw materials into clothing. Workers come in direct contact with these chemicals—often without adequate safety protections—and are at risk of developing deadly diseases.[27]
- Plastic microfibers shed from synthetic clothing into the water account for 85% of the human-made material found along ocean shores, threatening marine wildlife and ending up in our food supply.[28]

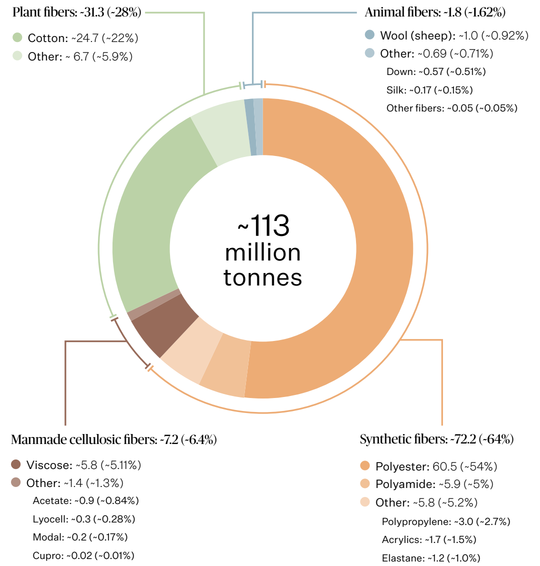
Nearly ⅔ of all fibers we wear and use are made from oil

Current Wood-Based Fiber Production

Within this picture of global fiber production, wood-based fibers are part of a category called, in industry parlance, "manmade cellulosic fibers" (MMCFs). MMCFs are currently primarily produced from wood, and the intensive production processes needed to extract and regenerate the cellulose fibers are the reason they are not considered "natural" fibers, but instead placed in the hybrid MMCF category. Other authors refer to these as "regenerated cellulosic fibers" (RCFs). As Textile Exchange's data show, with an annual production volume of around 7.2 million tonnes [7.9 million tons], MMCFs have a market share of around 6.4% of the total fiber production volume. Global MMCF production volume has more than doubled from around 3 million tonnes [3.3 million tons] in 1990 to approximately 7.2 million tonnes [7.9 million tons] in 2021, and it is projected to continue growing in the coming years.

Global MMCF production currently includes the subcategories of viscose, acetate, lyocell (brand name Tencel™), modal, and cupro.[29] All of these fiber types start from the traditional dissolving pulp process. According to Textile Exchange's data, viscose is the most important MMCF, with a market share of around 80% of all MMCFs and a production volume of around 5.8 million tonnes [6.4 million tons] in 2021. Other conventional MMCF categories represent smaller shares.[30]

Global Fiber Production in 2021 (Million Tonnes)



Source: Textile Exchange, 2022, Preferred Fiber & Materials Market Report.

Within the textile industry, traditional dissolving pulp / viscose textile production has emerged as part of the problem with current industry practices. Currently, conventional MMCFs such as viscose require the use of toxic chemicals, including carbon disulfide and others, to dissolve the wood pulp. Even more recently-developed MMCFs such as lyocell (Tencel™) require the use of chemical solvents, although they are used in nearly closed-loop systems. These impacts have been highlighted through the extensive research and advocacy of nonprofits like Changing Markets Foundation and Canopy.

For these reasons, as well as the capital-intensive nature of wood-based fiber production on the conventional pathway, **our research and interviews quickly led us to rule out the conventional dissolving pulp / viscose production approach for wood-based fiber production in Vermont and the Northern Forest Region.**

However, despite the current problems with conventional dissolving-pulp-based MMCF production, the overall area of cellulose-based fibers holds great promise for environmental benefits. In particular, recent research has reinforced the key sustainability and biodegradability assets of wood-based fibers. In a study conducted by the USC-San Diego Scripps Institution of Oceanography, ten types of cellulose-based fabrics, including lyocell, modal and viscose, were tested against fabrics made with Polylactic Acid (PLA), considered a biodegradable plastic. The cellulose-based fibers took four weeks to completely degrade in the ocean, while the PLA-based fabrics had not biodegraded at all after a year.[31] The study reinforces the fact that cellulose-based fibers and textiles can be truly biodegradable. These core qualities call for a new approach to wood-based fibers using Vermont and Northeast region wood stocks.

Negative Impacts from Textile Waste

Beyond the impacts associated with textile production, a new concern has emerged in recent years: the growing volume of textile waste.

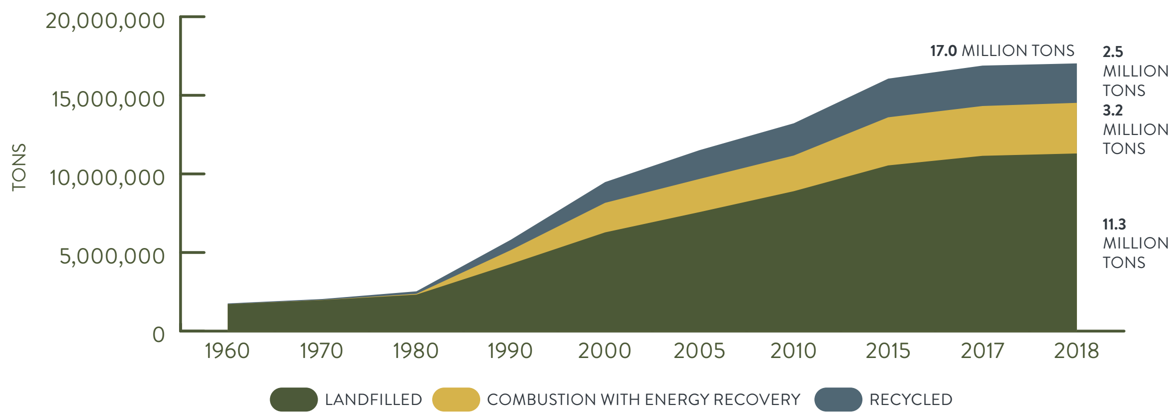
The promotion and over-production of low-quality "fast fashion" made from fossil fuel-derived fibers, and the near-wholesale failure to reuse or recycle the massive amounts of apparel discarded each year, are exacerbating the textile industry's already significant impacts. Global consumption of apparel has risen to an approximate 62 million tonnes [68 million tons)] per year and is projected to reach 102 million tonnes [112 million tons] by the year 2030.[32] Clothing sales are now growing faster than the world's population or GDP,[33] and the average consumer now buys 60% more items of clothing than 15 years ago but wears each garment fewer times before discarding it. Such cheap clothing is resulting in literal mountains of clothing waste piling up in garbage dumps and on beaches around the globe, especially in the Global South.[34]

About 75% of textile waste is landfilled worldwide, while only 25% is recycled or reused.[35] Within the landfilled component, the main source of textiles in municipal solid waste (MSW) is discarded clothing, although other smaller sources include furniture, carpets, footwear, and other goods such as sheets and towels. **In the U.S., the EPA finds that textile waste is now the fastest-growing component of municipal solid waste.[36]**

PHOTO CREDIT: NEENAWAT KHENYOTHAA

Clothing waste is frequently exported to Southeast Asia and Chile.

U.S. Textiles Waste Management, 1960-2018



Source: U.S. Environmental Protection Agency, Textiles: Material-Specific Data.

New Horizons for Wood-Based Fibers

As a result of these trends, Textile Exchange and other forward-thinking organizations and brands are increasingly focused on the need for "degrowth" in the textile and apparel industry.[37] This approach includes reducing production overall, brand take-backs and Extended Producer Responsibility (EPR) policies, recycling of used textiles, and development of closed loop textile-to-textile recycling approaches.

In terms of the next horizon for MMCFs, Nicholas Johnson of Textile Exchange sees an increasing interest in the textile industry overall in alternative non-forest-derived feedstocks. "Recycling of textiles and use of recycled garments (mostly cotton) is a big trend," he states. "The big interest, in other words, is in reuse of 'end-of-life' feedstocks for MMCF production."

In addition to recycled feedstocks, cutting-edge approaches to the production of cellulosic nanofibers (CNFs) represent another key development horizon for textiles, with over 700 journal articles published on this research area over the past two decades[38] and key leadership from the University of Maine-Orono Process Development Center.

Given current textile industry impacts and the rapidly evolving policy landscape, Vermont and the region can and must be part of the solution, not part of the problem, when it comes to pathways for wood-based fiber production. The state and the region have a tremendous and timely opportunity to invest in the future of textile production through fully closed-loop, non-chemical, and biodegradable wood-based fiber production, especially a lab-scale approach to novel CNF production for textile uses. Furthermore, the state could increase its impact and open new job-creating opportunities by investing in the pathway of combined recycled fiber + wood fiber textile production. Finally, we believe the state and region should eschew investing in the highly competitive, far-flung apparel industry and instead focus on the fast-growing field of nonwovens, biomedical textiles, and other specialized industrial textiles.

In the sections below, we discuss supply and demand factors in light of these conclusions. This report does not attempt to present an exhaustive overview of supply factors in Vermont and the regional forest system, nor a comparison of next-generation wood-based fibers with other potential uses, as these areas have been treated in detail by prior reports including the FOR/Maine and NEFA report series.

Next-generation, non-chemical, and recycled MMCF's hold major promise and potential for Vermont and the Northeast region to offer cutting-edge solutions to the global industry.

3. Supply: Current Conditions in the Vermont and Regional Forestry Sector

Vermont's forest resource inventory, key species, and supply chain assets have been recently and thoroughly mapped by the 2021 North East State Foresters (NEFA) report series, *Northeast Wood Markets Retention and New Market Recruitment Initiative* for New Hampshire, New York & Vermont.[39] These reports also included in depth analysis and projections of future timber stocking volumes. In terms of projected supply, the authors found that "annually, over 8.6 million cords (21.5 million tons) of excess timber can be found across the three-state region. If all of this excess timber were utilized annually, the states would have stable forest inventories as this already accounts for existing uses…[this data] **merely confirms that timber supply is not a restraint to forest products markets expansion in the region** [emphasis added]."[40] The NEFA reports further show that these supplies are plentiful across all species, both hardwood and softwood.

Further key supply details for our analysis include:

- The forest economy in Vermont and across the Northern Forest has experienced declines over the past decades as a result of downturns in the wood products markets and demographic shifts. However, as the NEFA report notes, "The supply chain infrastructure in the region, though stressed in recent years due to the reduction in low-grade timber markets, is still robust and covers the entire 3-state region."[41] The bulk of the negative impacts has been concentrated on the pulp and paper sector and resulting softwood demand.

- Because they lack markets for low-grade timber, most loggers today, whether manual or mechanized, are leaving slash, tops, and limbs behind in the forest and drawing out only dimensionally suitable saw stock. Hardwood slash is predominantly sold into the firewood market where demand is more or less equal to supply. The only regional markets for softwood slash are Burlington Electric, Ryegate Power, Finch Prime (NY) and a small pellet plant in North Clarendon,[42] as well as an additional small-scale pellet mill that recently opened in Richford.[43]

- Research indicates that both softwood and hardwood species can be used for CNF production, with the structure and properties of the CNFs impacted by the original wood source.[44] UMaine researchers Carter et al. began their process with softwood kraft pulp.[45]

With this information as a resource, the project team focused its efforts on developing an understanding of the amount of softwood slash that could theoretically be available for next-generation CNF and MMCF production.

What's Being Left on the Forest or Sawmill Floor?

Interviews for this project provided key estimates that we have drawn on to develop working estimates of the amount of wood potentially available for next-generation wood-based fiber production. As noted above, due both to current supply and the early R&D stage of development in this sector, volumes of wood are not currently the limiting factor. Availability of R&D funds, research, infrastructure, and commercialization pathways are the current significant bottlenecks. However, having a rough estimate for available volumes has proved important for conversations with potential manufacturing, licensing, and funding partners.

- According to Matt Langlais, County Forester for Caledonia and Essex Counties, there are roughly 2 million acres of forestland (excluding what the state owns) under active silviculture management in Vermont. A rule of thumb provided by Langlais is that managed forests are typically cut at a rate of about 5-10% of total available forest, leading to the estimate that there are approximately 100,000-200,000 acres of wood being cut on private managed lands annually.[46]

PHOTO CREDIT: ERICA HOUSEKEEPER

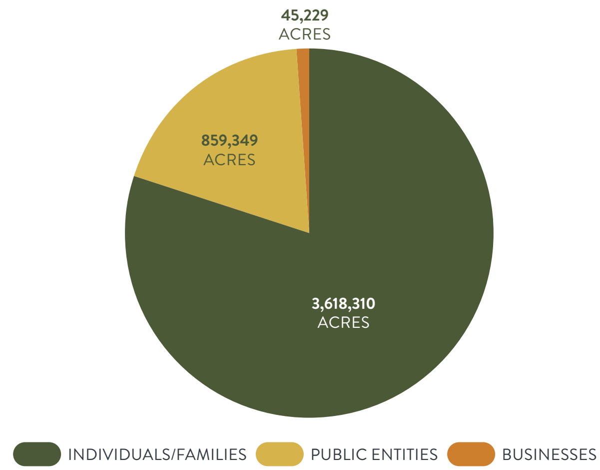
- Approximately four cord of softwood slash is left behind per acre of forest cut for dimensional lumber or other marketable products, leading to our working assumption that **roughly 500,000 cords of softwood suitable for fiber and textile production is now being left in the woods by loggers.**[47]

Supply in the Context of Ecosystem Health and Climate Change

These supply considerations must be placed in the context of overall ecosystem needs, particularly recent findings that emphasize the challenges of striking a balance between economic development and ecological resilience for Vermont and the Northern Forest Region.

- Vermont has an estimated 4,522,888 acres of forestland.[48] Over 80% of this forestland is held by individuals and families; 19% is held by public entities. Unlike other northeastern states with large corporate ownerships, only 1% of Vermont's forest is owned by businesses, including timberland investment management organizations (TIMOs) and Real Estate Investment Trusts (REITs).[49] This patchwork of private ownership is a potentially complicating factor for the consistent forecasting and collection of waste wood for next-generation wood fibers.

Vermont Forestland by Ownership Type



Source: Vermont Department of Forests, Parks, and Recreation, [Overview of Vermont's Forests](#).

- In 2020 the [US Department of Agriculture](#) reported that, as of that year, more than 12,600 acres of Vermont's forestland were being converted for other uses each year.
- The [Vermont Center for Ecostudies](#) recently released a report that characterized the range of biodiversity in Vermont—and predicted that the state will lose about 6% of its species by 2100 due to climate change.[50]

These additional details call for the careful consideration of ecosystem, biodiversity, and climate resilience factors in determining how much leftover wood in the forest is truly "waste," versus being important as habitat and critical for future forest regeneration.

Dr. Alexandra (Ali) Kosiba, Extension Assistant Professor of Forestry at the University of Vermont, highlighted the need to balance forest health with the desire to promote economic activity in the woods by leaving a portion of the slash on the forest floor. As she put it, "More and more, we are seeing the balance of leaving that material for regeneration and nutrient cycling. That is a concern we have in Vermont where we have a perilous regeneration situation because of the stress from deer browse." Kosiba added that loggers understand the importance of not taking everything they've cut out with them: "Some operators will actually drag some materials back into the woods—they recommend 30% to leave in the woods. Or they can do cut-to-length in the woods and leave (tops, limbs, etc.) where they fall. The value of this approach depends on the soils at the site, the species, the rate of decomposition."

Factoring in the recommendation to leave behind 30% of the slash for ecological benefit, we can revise our estimate to around 350,000 cords of available softwood slash on an annual basis from Vermont alone.

While supplies are not currently the limiting factor, it is important to note that waste wood from sawmills and other processing sites could also be mobilized for future next-generation CNF and MMCF production.

The changing climate is already impacting the wood supply for Vermont and the Northern region, and climate impacts must be a central consideration for the wood-based fiber pathways recommended for this project. Annual average temperatures in Vermont have increased about 3°F since the beginning of the 20th century, with particularly notable impacts in the winter months. Annual average precipitation trends have been above the historic average, and 2005 to 2014 were the wettest periods observed in Vermont on record. Precipitation is projected to increase, with more rain than snow expected.[51]

A Northern Forest Products Supply Chain Climate Adaptation Toolkit by Bick and co-authors highlights that climate change is already significantly impacting the Northeast's forest products supply chain:

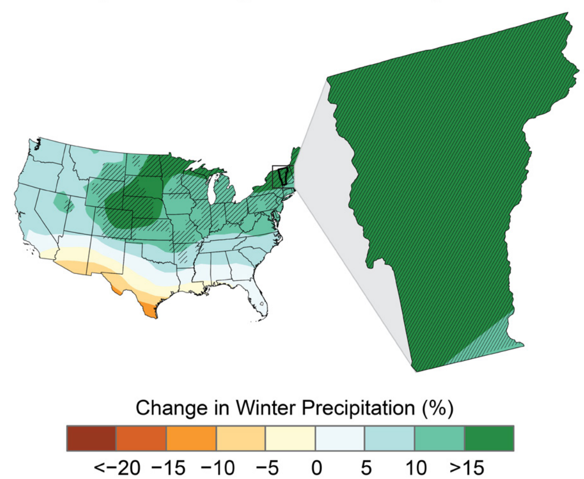
> "Harvest scheduling has become more challenging, often requiring longer contract terms to ensure that suitable weather conditions will arise; BMP compliance has forced innovation among forest products professionals, but also sometimes results in temporary work stoppages, increasing costs while reducing profits; Road maintenance and improvements are necessary to accommodate supply chain demands and climate challenges."[52]

Vermont Average Temperature

	1980s	2010s	Change
JAN	14.3°	18.0°	**3.7°**
FEB	19.2°	20.4°	**1.2°**
MAR	27.9°	28.4°	**0.5°**
APR	41.6°	41.2°	**-0.4°**
MAY	53.5°	55.0°	**2.0°**
JUN	60.4°	61.5°	**1.1°**
JUL	66.3°	67.9°	**1.6°**
AUG	63.8°	65.6°	**1.8°**
SEP	55.9°	59.2°	**3.3°**
OCT	44.3°	47.6°	**3.3°**
NOV	33.6°	34.2°	**0.6°**
DEC	20.0°	24.8°	**4.8°**

Source: National Centers for Environmental Information, Statewide Time Series.

Projected Change in Winter Precipitation



Source: Jennifer Runkle et al., 2022, Vermont State Climate Summary 2022, NOAA Technical Report NESDIS 150-VT, NOAA/NESDIS, Silver Spring, MD, 4 pp.

In the context of the severe July 2023 flooding event in Vermont and New Hampshire, these predictions can be seen as just a preview of the ways that climate change-driven severe weather events will impact every aspect of Vermont's forest-focused economic development pathways, from logging to manufacturing to transportation. The impacts of wet winters, warmer climate, changing species mix, and generational change will continue to require creative adaptation for the industry.

Overall, the lab-scale, R&D approach recommended in the pathways to follow lends itself well to co-development with the changing species mix in Vermont's forests. Researchers can begin now to experiment with wood fibers from those species that will be increasingly prominent under a warming climate, while lab facilities and eventual manufacturing sites can be designed with climate resilience in mind.

The project team hopes that the Vermont Forest Future Roadmap project will provide additional guidance on changing species mixes and climate resilience for the state over the coming decades, as well as a workstream that will allow more detailed analysis of the potential of these emerging species as next-generation CNF and MMCF technologies also develop. As discussed further below, these elements could be a component of a next-step Think Tank on wood-based fibers.

Wet forest roads with pooling water due to heavy rainfall.

PHOTO CREDIT: DR. ALEXANDRA (ALI) KOSIBA

Forest roads that were traveled on by ATVs when the ground was not frozen.

4. Demand: Emerging Segments for Wood-Based Textiles

Based on the problematic trends in the apparel industry discussed previously, and the race-to-the-bottom business model that often characterizes the industry, the project team recommends that Vermont and the region do not focus future efforts on wood-based fibers for the apparel industry. **Instead, we recommend focusing on the significant field of nonwoven textiles overall, and particularly on the growing specialty field of industrial and biomedical textiles.**

Textiles are produced for a variety of end uses, not just clothing. Non-apparel items such as household furnishings, industrial textiles, and carpets comprise a significant proportion of textile end uses. And micro- and nanofibers are increasingly used in medicine and biotech for both research and treatment purposes.

A 2003 report from the U.S. Department of Commerce reported that the top five industry segments that are heavy users of textile and apparel products (outside of those industries themselves) are motor vehicles, furniture and fixtures, rubber and miscellaneous plastics, health services, and new construction.[53] While values and specific industries have shifted since the report's release, this finding indicates the importance of looking beyond the textile industry itself for demand indicators. The Department of Commerce report concludes that, even as of two decades ago, U.S. textile and apparel firms were already increasingly "focusing on 'niche,' higher value-added product markets, which may be less labor intensive, more profitable, and more competitive in the international markets."[54]

Recent report summaries from the global market research firm Grand View Research help map the demand for different segments of the textile market and help strengthen the case for such niche approaches.

Textile Market

According to a 2022 report summary by Grand View Research, "The global textile market...was valued at USD 1,695.13 billion [~$1.7 trillion] in 2022 and is anticipated to grow at a compound annual growth rate (CAGR) of 7.6% in terms of revenue from 2023 to 2030. The ever-increasing apparel demand from the fashion industry, coupled with the meteoric growth of e-commerce platforms, is expected to drive market growth over the forecast period."[55]

Other key demand trends outlined in this report include:

- "The rapidly growing consumer preference towards sustainable products is forcing major textile companies to focus on restructuring their business and investing in manufacturing practices that target sustainable products."
- "The natural fibers product segment led the market and accounted for a revenue share of 44.1% in 2022... Increasing environmental concerns, coupled with the continued consumer shift to use sustainable products, [are] further expected to increase the demand for natural fibers, thereby driving the growth of the overall textiles market."

"**Demand for textiles in the technical segment is expected to grow at the fastest rate of 7.7% in terms of revenue over the projected period,** [emphasis added] owing to its high-performance properties and end-user applications. In addition, increasing application in construction, transportation, medical and protective clothing have boosted their use, which is consequently driving the textiles market…In addition, the consumption of textile fibers such as synthetic and cellulose fibers needed for filtration in industrial applications is expected to have a positive impact on the market growth over the forecast period."[56]

Overall Textile Market Report

Market value in 2023	$1.84 trillion
Revenue forecast in 2030	$3.05 trillion
Growth Rate	CAGR of 7.6% from 2023 to 2030

Nonwovens

According to additional coverage of the Grand View report, "The global nonwoven fabrics market size is projected to grow from $40.5 billion in 2020 to $53.5 billion by 2025,"[57] representing a CAGR of 5.7%.

Nonwovens Market Report[58]

Market value in 2020	$40.5 billion
Revenue forecast in 2025	$53.5 billion
Growth Rate	CAGR of 5.7% from 2020 to 2025

Biomedical Textiles

A 2023 Grand View report on medical textiles found that the global medical textiles market size was valued at USD 24.70 billion in 2020 and is projected to expand at a compound annual growth rate (CAGR) of 3.0% from 2021 to 2028.

This report notes that "The demand for medical-grade textile products is expected to grow on account of the increasing awareness regarding better healthcare services and efficient medical treatments. The growing use of medical textile-based implantable goods, such as artificial ligaments, tendons, and body part enhancements, is expected to drive the market."[59]

Within the biomedical segment, Grand View forecasts, "The non-woven segment led the market and accounted for over 65.0% share of the global revenue in 2020 and is expected to witness the fastest growth over the forecast period. This is attributed to superior properties offered by the [nonwoven] product such as high air permeability, superior strength to weight ratio, high bacterial resistance, and better water vapor transmission capacity. Non-woven medical textiles have witnessed a spike in demand due to the global outbreak of the COVID-19 pandemic."[60]

Finally, the report forecasts that "The healthcare and hygiene products segment led the market and accounted for over 45.0% share of the global revenue in 2020. The segment is also expected to witness the highest growth in the years to come. Health and hygiene products such as face masks, gowns, medical bags, shoe covers, bedsheets, incontinence pads, maternity pads, drapes, caps, wipes, and sanitary napkins form one of the largest application areas of medical textiles."[61]

While the acute demand for face masks caused by the pandemic has abated (e.g., demand figures for this category dropped between 2021 and 2022), Grand View forecasts steady growth between 2023-2028, with a CAGR of 3.0%.

Biomedical Textiles Market Report

Market value in 2020	$24.7 billion
Revenue forecast in 2028	$26.2 billion
Growth Rate	CAGR 3.0% from 2021 to 2028

PHOTO CREDIT: INDA, THE ASSOCIATION OF THE NONWOVEN FABRICS INDUSTRY

The presence of biomedical textile companies in the region may suggest potential partners for this sector. A few examples of such companies and their focus areas, selected from the INDA member list, include:

- Alkegen
  ROCHESTER, NH

  Alkegen engineers technical nonwovens, membranes, and composite products.

- FG Clean Wipes
  CHICOPEE, MA

  Manufacturer of specialized wiping materials for over 100 years. Their target markets are life sciences manufacturing facilities and other controlled environments (e.g., clean-room wipes).

- High-Tech Conversions
  ENFIELD, CT

  Global manufacturer of innovative cleanroom supplies and cleaning products for a variety of high-tech industries.

- Hollingsworth & Vose Company
  EAST WALPOLE, MA

  H&V products are found in applications such as engine filtration, high efficiency air and liquid filtration, battery separators, gasket materials, and specialty and industrial nonwovens.

- Nice-Pak/PDI
  ORANGEBURG, NY

  Nice-Pak/PDI is a multi-national private label manufacturer of wet wipes for baby and healthcare applications from textile fabrics and spunlace nonwovens.

- Shinemound Enterprise
  NORTH BILLERICA, MA

  Shinemound purchases nonwoven fabrics to produce medical and non-medical products.

- Valmet
  BIDDEFORD, ME

  Valment is a global supplier of sustainable technology and services for mining, construction, power generation, automation, recycling and the pulp and paper industries.

- Web Industries
  MARLBOROUGH, MA

  Web Industries is a leader in flexible material contract manufacturing with a long history of helping Fortune 500 companies roll out new products quickly and efficiently.

- Owens and Minor / Halyard
  ALPHARETTA, GA (located outside of Northeast, but specifically focused on medical textiles).

  A leading manufacturer of nonwovens-based PPE and sterilization products in the healthcare industry. The company has a program that reclaims their sterilization wrap from hospitals for recycling.

- Advanced Functional Fabrics of America (AFFOA)
  CAMBRIDGE, MA

  AFFOA is a nonprofit organization supporting a transformation of traditional fibers, yarns, and textiles into highly sophisticated integrated and networked devices and systems.

While demand numbers and CAGR for apparel outpace those for nonwovens and biomedical textiles and may look more impressive, the project team believes the growth of the apparel and fast fashion sector is unsustainable. In contrast, **we propose that nonwovens and particularly biomedical textiles offer Vermont and the region options to gain an early adopter advantage by meeting the growing demand for specialized textiles that are designed from the start for circularity and full biodegradability.** Incorporating recycled textiles and wood-based CNF fibers into the feedstock offers a further competitive advantage and makes a positive contribution to the textile industry's growth issues overall.

5. Labor and Economic Justice Considerations

The three pathways were influenced by key factors related to labor, training, and economic justice that we heard about in our interviews. Specific considerations include:

- Communities in the Northern Forest region that have experienced the decline of the forest economy, particularly the closing of paper mills, are wary of becoming reliant on any single, large new employer. As expressed by Shane O'Neill, Forest Industry Business Development Manager at the University of Maine, after meetings with residents in about a dozen former mill towns to explore how they'd like to see their communities evolve, it became clear to him and his colleagues that, "It doesn't really matter if you can bring the technology, manufacturer, or investment to town if the community doesn't want it."

  Back when the tissue mill was in operation in Lincoln, Maine, everyone called it "Stinkin' Lincoln." Though the town mourned the loss of jobs when the mill closed, "The locals didn't want a repeat of that experience," O'Neill said. A company called Biofine is reutilizing the old plant to make biofuels. "The community is receptive (to that company) because they're producing a value-added product that will be used by people in the town."

- In response to questions about generational changes in the forest products industry, Paul Frederick, Forest Economy Program Manager at the Vermont Department of Forests, Parks and Recreation, noted that, "Most of the young folks going into logging come from logging families. Very few start from scratch. Finding young operators is tough. Younger people value their leisure more than their parents' generation. Loggers work and sleep, that's about it." In contrast, the Vermont Forest Future Roadmap has already identified "rapid growth in people who are connected to working forests through areas such as outdoor recreation, non-timber forest products (such as maple sap), and environmental services (such as soil conservation and water quality)."[62]

- Nicholas Johnson of Textile Exchange echoed O'Neill's caution about the impact on communities when mills close. Reflecting on the need for new manufacturing to be different from the old "company town" model, Johnson also expressed a hope that new jobs in the wood-based industry might fit within a more diversified and innovative Just Transition framework. He wondered, for example, whether additional jobs could be created by scaling nimble, small-scale, precision harvesting systems that could work more sustainably in the woods. Technological innovations in manufacturing with wood—including next-generation CNFs and MMCFs for textiles—hold promise for creating diversified new jobs and businesses for the state and region that also address growing climate change concerns.

Pursuing any of the three pathways would likely attract new people to Vermont, which is necessary for the continued vitality of the state's economy. The lab-scale/R&D emphasis of the pathways could encourage individuals and businesses with advanced bioscience, engineering, and entrepreneurial skills to relocate to Vermont. However, despite the need for more workers, there are already intense pressures on Vermont's housing, child care, transportation, and other infrastructure systems. And efforts to add to Vermont's population could accelerate the pace of land conversion from forests and farms. For these reasons, we recommend that the project sponsors integrate labor and economic justice considerations from the outset in any of the pathways and next steps suggested. Without such early consideration, the patterns that perpetuate inequality are too often left unaddressed.

In the pathways that follow we outline additional considerations related to labor and economic justice.

PHOTO CREDIT: WINNIEVINZENCE

The lab-scale/R&D emphasis of the pathways could encourage individuals and businesses with advanced bioscience, engineering, and entrepreneurial skills to relocate to Vermont.

6. New Horizons for Wood-Based Fibers: Three Pathways

Based on our interviews and research, and on the intersecting supply and demand factors above, we propose three potential pathways for Vermont's and the Northern Forest Region's participation in the wood fiber supply chain. These are not mutually exclusive, and in fact, in our vision, could converge in a cutting-edge opportunity for the state and region to be part of the next generation of wood-based fiber production.

- **Pathway 1: Catalyze the local development of cellulosic nanofibers (CNF) for textiles, with a focus on nonwoven biomedical and industrial textiles.**

- **Pathway 2: Secure Vermont's place in the race for non-chemical, next-generation MMCF production through technology partnerships with global innovators.**

- **Pathway 3: Recycled textiles + wood fiber: Invest in the textile industry's most important and sustainable "degrowth" area, which offers job creation prospects in its own right.**

Pathway 1: Catalyze the local development of cellulosic nanofibers (CNF) for textiles, with a focus on nonwoven biomedical and industrial textiles.

New Developments in Non-Chemical CNFs for Textile Use

A global race is on to replace the legacy dissolving pulp manufacturing process and its chemical processes with non-chemical, mechanical, and non-polluting approaches to turning wood into fibers and textiles. In a 2021 review, Felgueiras et al. summarize the promise of this pathway: "Cellulose presents unique structural features, being the most important and available renewable resource for textiles...Recently developed technologies allow the production of filaments with the strongest tensile performance without dissolution or any other harmful and complex chemical processes. **[Cellulose] fibers without solvents are thus on the verge of commercialization."[63]**

Information obtained for this project from interviewees, the scientific research literature, and trade publications reinforced the proposition that a non-toxic process for producing wood fiber textiles at a commercial scale is on the horizon.

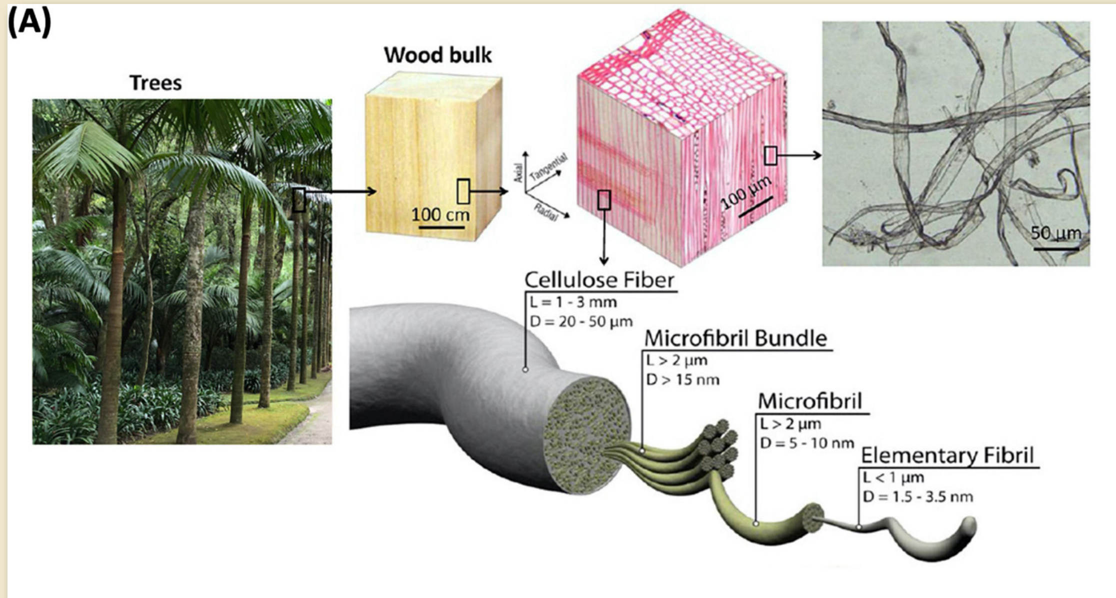
Non-chemical methods to break down wood fiber into a cellulosic polymer with the potential to create a usable fabric are being researched by labs and companies around the world. Breaking down wood biomass into cellulose and lignin fractions can be achieved via mechanical and hydrothermal routes that are non-toxic, well-studied, and already in use at pilot scale. While the cellulose can be used for the development of textiles, the lignin byproduct can also be utilized to yield commercially viable end products,[64] further improving the economic potential of these new methods.

For this pathway, Vermont and the Northern Forest Region are fortunate to have a cutting-edge partner nearby, and a formal partner in the NSF Engines CONFIR development project, in the UMaine Process Development Center (PDC). The PDC is a global leader in the development of a group of materials that holds great promise for next-generation textile development. These are known as cellulosic nanofibers or nanofibrils (CNF), although they can be referred to by other general or trademarked names.

A 2021 article by UMaine researchers Carter et al. defines cellulosic nanomaterials overall and CNFs specifically as follows: "The term cellulose nanomaterial refers to a variety of cellulose-based materials with at least one dimension on the nanoscale...Cellulose nanofibers (CNF), alternatively known as cellulose nanofibrils[,] have diameters ranging from 5 to 30 nm with lengths that can approach several microns."[65] This scale is not a minor detail; the nanoscale of these fibers gives them special qualities, as researchers Kramar and Gonzalez-Benito explain in a 2022 research paper: "nano-sizes provide a high surface-to-volume ratio, which can have important consequences on many properties, such as the wettability."[66]

CNFs can be produced through either chemical or mechanical processes. According to Shane O'Neill, Forest Industry Business Development Manager at UMaine and a collaborator with the PDC, "The big delineation is mechanical versus chemical—that's the big schism on how you can make CNF products."

Hierarchical Structure of Wood Fibers



This illustration from Felgueiras et al. (2021) provides a visual representation of the scale of the fibers utilized. Used under Creative Commons Attribution License (CC BY).

A major advantage of the UMaine PDC process, and a significant point of alignment with the values discussed above, is that their process is fully mechanical. As Carter et al. (2021) describe this process:

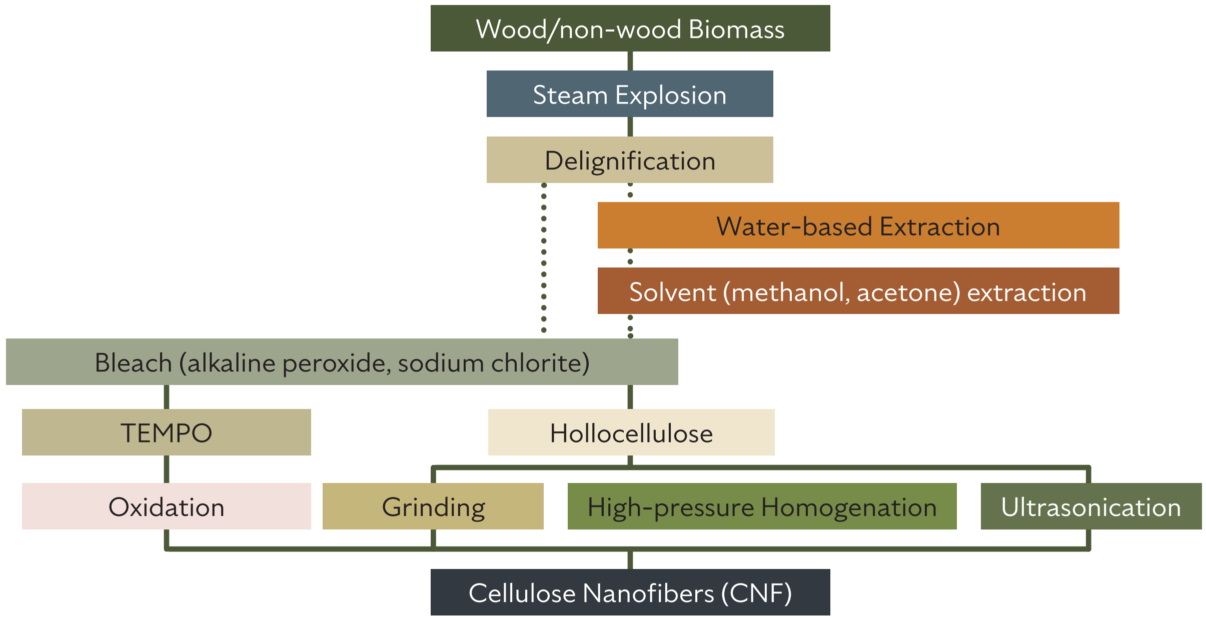
> "The mechanical defibrillation technique, such as that employed in [their] present work, continuously breaks down cellulose fibers suspended in water via segmentation and defibrillation through grinding and refining. The process is typically operated until a desired level of fines is achieved in the resultant slurry of cellulose nanofiber (CNF), alternatively known as cellulose nanofibril."[67]

Once produced by the mechanical method above, CNFs can be utilized in a wide variety of applications. These are outlined, in part, in the FOR/Maine study. As that report notes, "Nanocellulose consists of incredibly light and strong fibers that can be used in a variety of applications, from coatings for packaging papers to high performance textiles and medical products. The University of Maine is a global leader in the R&D of nanocellulose applications."[68] Nanocellulose was in fact one of the FOR/Maine report's Top 6 prospects for Maine's forest sector, but the report did not focus on the potential application of CNF for textiles.[69] **Since the 2018 FOR/Maine research, technical developments and market demand for the types of textiles that can be produced from CNFs have both greatly increased, leading to our conclusion that this pathway merits significant re-examination, research, and investment.**

Similarly, in the 2021 NEFA Wood Markets and Retention report, Levesque and co-authors placed nanocellulose among the 10th-ranked products on their list (products 10-14 had identical rankings). In particular, they noted that "it is assumed that we cannot expect more than a $250 million investment for any one facility in the region (i.e., a new pulp mill or something of that mega-scale will not be built in this region in the foreseeable future or long-term)." Thus, for their potential use categories of Lignin, Furfural and Nano Cellulose, the NEFA authors eliminated these products based on the assumption that "these require a pulp mill."[70]

As in the case of the FOR/Maine report, the project team believes that developments even since the NEFA report's release, especially the advancement of the UMaine PDC's production capacity for non-chemical CNFs and the increase in demand for next-generation cellulosic fibers and nonwoven applications, merit a re-examination of these

CNFs Produced From Steam-Explosion-based General Route Biorefinery



This illustration, adapted from Asada, Sholahuddin, and Nakamura (2021),[71] highlights processes for making cellulose nanofibers. The figure highlights some key technologies and shows that these processes are often connected or interrelated in various experimental and proprietary approaches to cellulosic fiber production. Used under the terms of the Creative Commons Attribution 3.0 License.

assumptions and the prospects for textile production from CNFs.

It should be emphasized that the process of producing textiles from CNF is fundamentally different from the traditional dissolving pulp process for textiles in several regards: the non-chemical option for CNF, the current scale of development, the current capital requirements to continue commercialization of this technology, and the most likely and suitable end products.

CNFs for Textiles: Commercialization Opportunities, Challenges, and Partners

The pathway to localized CNF production for textiles will require significant additional investment. However, research indicates that CNFs are particularly suited for the development of nonwoven textiles and that the commercialization pathway for this approach is increasingly feasible. In a 2017 review, Finnish researchers at Aalto University described the potential benefits of CNFs for nonwovens:

"Cellulose-based products such as pulp and viscose are widely used to produce nonwovens, which can be used in, e.g., filters, surgical gowns, wipes, packaging and geotextiles... **Although natural or regenerated fibers may be used, the properties of CNF filaments introduce a possibility to develop stronger nonwovens with a lowered environmental impact** [emphasis added]."[72]

A comprehensive 2022 literature review by Kramar and González-Benito provides a sense of the active lab-scale research focused on development of textile fibers from CNFs. As these researchers note, "Two distinctive approaches are currently utilized when dealing with cellulose nanofibers, the so-called top-down approach in which cellulose nanofibers and nanocrystals are isolated from various cellulose sources [and then spun], and the ...bottom-up approach, wherein cellulose nanofibers are spun from precursors into non-aligned or aligned filaments to generate mats or membranes."[73] These "mats or membranes" represent the nonwoven type of textile.

Differences Between Traditional Dissolving Pulp Process and Non-Chemical CNF for Textiles

	TRADITIONAL DP / VISCOSE PROCESS	CNF FOR TEXTILES
Process	Chemical	Can be fully mechanical
Current scale of development	Commercialized / global / highly competitive	Lab-scale / pre-commercial / early adopter potential
Capital requirements for entry	~\$500M - ~\$1B	~\$10M - ~\$30M
Likely / suitable end products	Apparel and "fast fashion"	Nonwovens, biomedical textiles

From their review of over 700 relevant research articles, the authors cover a range of spinning techniques for CNFs and potential applications for the resulting materials, particularly noting applications including high-strength nonwovens and filaments, filtration membranes, and biomedical applications. Additional recent research supports the growing number of biomedical applications for CNFs textile products, including wound dressings, transdermal drug delivery patches, and more.[74]

This pathway offers Vermont and the Northern Forest Region the opportunity to support the localized development of this industry. **In particular, the partners in the current CONFIR NSF Engines Development project, described in Section 1, bring key capabilities for the commercialization stage.**

The UMaine PDC describes its work and recent developments as follows:

"Leveraging more than a decade in wood pulp refining experience, the PDC developed and patented a process for producing cellulose nanofiber that has been licensed to Valmet. This ongoing and key relationship has allowed for the further development of this technology in coordination with Valmet. Currently, the PDC is in the midst of an expansion to bring on three new refiners. With this added capacity, we will continue to optimize cellulose nanofiber production toward a two ton/day continuous process."[75]

In an interview with UMaine PDC Director Colleen Walker and Shane O'Neill, Walker explained that "nanocellulose is a catchall phrase. It's vanilla, and you can make a lot of different flavors. We've made it from hemp, flax, wheat straw, [and] a small project where you can make it out of cotton. That crystalline structure is the same." Walker continues, "The language is very important—our commercial partner calls it microfibrillated cellulose, even though it's the same stuff, because they don't want to call it 'nano.'"

PHOTO CREDIT: UNIVERSITY OF MAINE

The University of Maine Process Development Center has a Nanomaterial Pilot Plant that provides samples of biobased materials for application development.

According to Walker, there are currently only a few commercial-scale CNF facilities. These are located at existing pulp and paper facilities, allowing them to efficiently "take a slipstream of their product" for conversion to CNF. In terms of scale, "that is two players, there are five to ten of those facilities, and they can produce up to five tons per day of CNFs." Aside from those, Walker says, "the PDC supplies everyone else that wants to work with it—we can do two to four tons per day." Currently, the PDC is actively working to develop markets for its CNF product. One challenge with CNFs is that, due to the slurry process used in their development, the product has a high water content. Walker and O'Neill describe it as being about 3% solids and 97% liquid, giving it "the consistency of yogurt." The PDC is currently able to press the product and reduce it to 15-20% water, at which point "it feels like cookie dough or modeling clay," which significantly reduces shipping costs.

Walker expressed support for the idea of adding textile production to the list of potential uses for CNF. As she notes, "I do think there's an opportunity to go to textiles." Walker and O'Neill were also positive about the idea of focusing on biomedical textiles. They noted that in their initial conversations with global innovative textile manufacturers, the processing chain for apparel fabrics had been offshored to such a degree that the fibers would have had to follow a convoluted multi-national path, exponentially increasing costs and complexities for manufacturing. O'Neill saw potential in the opportunity to develop a new, localized supply chain for biomedical textiles, noting that "as a university, we always want to move things from lab to commercial scale: 'beakers to buckets to barrels.'"

Both the University of Vermont and UMaine also house biomedical divisions that could be key partners for this approach. At UVM, the Department of Electrical and Biomedical Engineering (EBE), and its biomedical engineering program is one of the fastest-growing programs at the school.[76] At UMaine, the Graduate School of Biomedical Science and Engineering houses researchers such as the authors on the Carter et al. (2021) paper on CNFs for biomedical applications, led by Dr. David Neivandt.

Another key asset in this regard is the Vermont State University Forestry Accelerator, which just announced the participants in their second cohort of entrepreneurs. This competitively-selected four month program is open to North American-based pre-seed and seed stage companies. The program focuses on supporting companies developing products or services in three broad areas within the forest and wood products industry: new markets for low-grade wood; industry operations improvements; and wood for energy applications. Among the innovative Vermont-based companies that the Forestry Accelerator has attracted to date are Sylvacurl, a company that produces biodegradable and compostable packaging made from wood curls; and Green State Biochar, which produces biochar from waste wood. The Forestry Accelerator could serve as an important building block for the kind of lab-scale-to-commercialization ecosystem needed to bring CNFs for nonwoven textile applications to life.

Forestry Accelerator Program Manager Jared Reynolds was open to this prospect in our project interview. As he put it, existing or potential VC funds tend to be more focused on companies at the Series A or B funding stage, but significant support is needed at earlier stages—"that seems like a gap in the industry that would be a relative advantage for us, and it could attract some existing industry investors that might want to invest. I'd be interested to work on how to integrate what we are doing with your project, tailoring our work to what you are doing. Other industries have done this: climate tech, electric vehicle research—what is the same [for textiles] and what can we learn?"

Alongside these commercialization-focused partners, the University of Vermont's Forestry Program, another CONFIR partner, will provide critical balance for the ecological and forest management angles of this pathway. Project interviews with Anthony D'Amato, Director of the UVM Forestry program, and Alexandra Kosiba, Extension Assistant Professor, highlighted UVM's expertise in forestry ecology, climate change impacts, and adaptation and resilience—vital considerations for the long-term pathway.

Recent local company launches including Timber HP and Glavel (see Section 7) have shown that, with strong wraparound support, local entrepreneurs can use emerging technologies to build businesses that offer local jobs, economic development, and control of intellectual property and assets. Both the CONFIR development grant and the Vermont Forest Future Roadmap have begun to bring together multiple partners and stakeholders that set the stage for localized commercialization of CNFs for textile use.

Pathway 1: Short-Term

Integrate the option to use CNFs for textile fibers into the planning process for the NSF Engines development grant. Work with the CONFIR partners, including the PDC, UVM, and Forestry Accelerator, to develop a home-grown accelerator approach to developing nonwoven textiles from CNFs, with a particular focus on the biomedical textile industry.

Specific questions and areas for development through the CONFIR process could include:

- Look for ways to strengthen connections with biomedical faculty at the participating universities to identify research pathways for CNFs for nonwoven and biomedical textiles.
- Continue work on the water reduction process to reduce costs of shipping of CNF slurry.
- Forge new connections with regional nonwoven and biomedical textile manufacturers.
- Clarify the specific commercialization supports and infrastructure needed for this technology.

Pathway 1: Long-Term

The longer-term CNF for textiles pathway will require state and federal investment into R&D support infrastructure, in order to allow innovative entrepreneurs to commercialize this technology. The importance this approach is discussed further below in Section 7.

One ideal scenario for longer-term development of the CNF pathway would be for the CONFIR team to apply for and successfully receive a full NSF Engines grant that includes CNF for nonwovens and biomedical textiles in the project plan. Full NSF Engines grants cover a 10-year project period, likely from 2025-2035, and can range up to $160 million. A successful award would set the stage for additional R&D and the commercialization stage of CNF textiles.

Outside of the NSF Engines process—the ultimate fate of which will not be known until the partners apply for the 10-year implementation grant—CONFIR partners including the UMaine PDC, UVM, and Do North can collaborate to adapt the latter's Forestry Accelerator program to attract and support entrepreneurs and investors engaged in developing CNFs in viable form for nonwoven textiles. One key step on this pathway is to secure more reliable funding for the Forestry Accelerator through direct state budget appropriations, or from the state university system's budget. In either case, such a commitment from public funding sources is a prerequisite for leveraging private investment, whether through foundation grants or program-related investments, or from individual donors or angel investors.

Many other key federal funding sources exist that offer prospects. For some programs, nonprofits and government agencies are eligible; for others, for-profit entrepreneurs must apply. Mobilizing this funding ecosystem will thus require a coordinated strategy among many partners. Funding options include:

- Economic Development Administration (EDA) Planning and Local Technical Assistance Program: Support for developing economic development plans and studies designed to build capacity and guide the economic prosperity and resiliency of an area or region (no deadline).
- Economic Development Administration (EDA) Research and National Technical Assistance (RNTA) grants: Designed to leverage existing regional assets and support the implementation of economic development strategies that advance new ideas and creative approaches to advance economic prosperity in distressed communities (no deadline).
- Northern Border Regional Commission Catalyst Program: Projects designed to stimulate growth and inspire partnerships for rural economic vitality in the northern border region (may include infrastructure and non-infrastructure programs).
- Northern Border Regional Commission Forest Economy Program (FEP): Projects designed to support the forest-based economy, and to assist in the industry's evolution to include new technologies and viable business models across the NBRC region.
- Vermont Working Lands Enterprise Initiative Business Enhancement Grants: This program specifically names R&D and infrastructure development as applicable areas of support for Vermont-based enterprises.
- US Forest Service Wood Innovation Grants: The 2023 cohort of grantees in this USFS program included three companies each in Vermont and Maine and two in New Hampshire. One of the Maine companies, Tanbark, a manufacturer of a wood-based cellulose alternative to plastic packaging, is connected with UMaine's PDC. The next round of applications for a USFS grant opens Fall 2023.
- USDA Rural Economic Development Loan & Grant Program: Offers potential to set up a revolving loan fund for wood-based fiber entrepreneurs using USDA Rural Development funding.
- These funding options should operate in concert with pursuing partnerships and R&D agreements with nonwoven and biomedical companies such as those regional companies listed on page 19.

Pathway 2: Secure Vermont's place in the global non-chemical, next-generation cellulosics race through technology partnerships with global innovators

A global race is on to replace the legacy dissolving pulp manufacturing process with non-chemical, mechanical, and non-polluting approaches to turning wood into fibers and textiles. Through our research, we learned that players across the globe—including university researchers, B2B supply chain companies, and consumer-facing companies—are experimenting with many combinations of technologies in this next-gen MMCF race.

The localized commercialization approach described in Pathway 1 will take time. There is a potential opportunity for shorter-term revenue generation through licensing agreements with key global innovators in the area of next-generation wood-based fibers—several of whom are already in dialogue with the UMaine Process Development Center.

Key Companies / Potential Partners for Pathway

SPINNOVA

The Finnish company Spinnova emerged as a key player during research for this project. Spinnova's unique role in the space is summarized by Felgueiras et al. in their 2021 review:

> *"To our knowledge, the first and only company, to produce fibers without solvents, cellulose dissolution or any other harmful and complex chemical processes, is Spinnova Ltd. (Finland). The raw material is pulp from FSC certified wood. After mechanical pulping, the ground pulp passes through a single nozzle, where the fibers and fibrils rotate and align with the flow, providing a strong and elastic fiber network. The fiber is then spun and dried, suitable for spinning into yarn and then knitting or weaving into fabric (Salmela et al., 2016). The future goal is the recycling of the fibers...several times, minimizing the use of virgin materials. Spinnova fiber is now (2020) close to commercialization. The technology has been scaled up from a small pilot scale to an industrial pilot scale."*[77]

Spinnova's patents, which are publicly available, provide further detail on its technological advances,[78] and the company has partnerships with brands including The North Face, Adidas, and Ecco. During 2022, Spinnova experienced significant growth and promising partnerships. The company partnered with the Brazilian pulp maker Suzano in Woodspin, a joint venture. Through this partnership they expect to be able to produce 1 million tonnes of annual microfibrillated cellulose capacity by 2031, building on investment in the partnership by Suzano of 22 Million Euro.[79] (Spinnova refers to their fiber as "microfibrillated cellulose," but this term is often used interchangeably with CNF.)[80]

Despite the promise of its technology, however, Spinnova appears to have experienced some turmoil in recent months, including the replacement of their founding CEO, the departure of the new CEO after eight months, the appointment of an interim CEO, and the apparent abandonment of a planned Finnish spinning plant in favor of a location in Portugal.[81] As of mid-June 2023, *Sourcing Journal* reported that the technology delivery and installation for the Portuguese mill "are expected to take place in the fall of this year, with the spinning line expected to be operational by the end of the year [2023]."[82]

In addition to Spinnova, many other companies are engaged in the development of fibers using a combination of recycled textile and wood-based fibers, including Södra, Eastman, and textile recycling innovators (see table on page 37). These companies could also represent potential options for licensing, sourcing, and supply partnerships for the state and region.

Pathway 2: Short-Term

To pursue this pathway, the project team recommends that the project sponsors and partners explore licensing and partnership options with Spinnova and other potential partners as a revenue generation strategy that also builds partnership. This could allow short-term revenue generation for Vermont and the region while regional commercialization capacity develops. This approach could also be pursued with global innovators working on the recycled fibers + wood fibers approach, including Södra and Eastman, as described below.

Pathway 2: Long-Term

Licensing agreements with global innovators could extend into long-term arrangements or facility co-location, as in the case of Spinnova's new development of a factory in Portugal. However, this approach will not provide Vermont and the region with full control of the intellectual property and localized economic development. Instead, the longer-term option could dovetail with the home-grown lab-scale approach following Pathway 1.

PHOTO CREDITS: SPINNOVA

Spinnova (the Finnish sustainable textile company) and Suzano (the world's largest pulp producer based in Brazil) developed a joint venture, Woodspin, to open the first commercial-scale facility producing wood-based Spinnova fiber.

Pathway 3: Recycled textiles and wood fiber: Invest in the textile industry's most important and sustainable "degrowth" area, which offers job creation prospects in its own right.

Key Opportunities and Players in Recycled Textiles + Wood Fibers

The third pathway we outline is based on the fact that the basic molecule in both cotton and wood is cellulose. As a result, a few innovative companies have begun experimenting with approaches that combine recycled textile waste with virgin wood pulp. As Nicholas Johnson of Textile Exchange emphasized, recycled fiber feedstock is the top priority for the textile and apparel industry overall and especially for the cellulosic fiber category. Textile Exchange's 2022 Preferred Fiber and Materials Market Report provides ample evidence of this, listing at least 15 companies that are actively working on recycled MMCFs.[83] Importantly, however, all of these processes are currently using the legacy dissolving pulp method to produce the wood pulp component of their combined textiles.

We see opportunities for Vermont and the region to leapfrog ahead in this area by combining Vermont softwood slash, the innovative, non-chemical CNF processes being pioneered at UMaine's PDC, and investments in a new industry—textile recycling—that will serve as an additional job-creation option for Vermont. This pathway is especially timely as the global impacts of the textile waste problem and the new EU Waste Directive begin to be felt. This will not be the easiest or fastest pathway, but we believe it is the one that offers Vermont and the region the biggest long-term payoff and the biggest opportunity for enduring regional, national, and even global leadership.

We focused on two key companies that are actively pursuing recycled textile + wood fiber combinations: Södra with its OnceMore® process and Eastman with its Naia™ Renew line.

SÖDRA – ONCE MORE®

The Swedish company Södra is actually a "forest owners association" with 52,000 forest land-owning member-owners. In 2019, Södra launched the OnceMore® line of fibers made of recycled textiles plus wood fibers. As Södra describes its process: "...Södra's new technique can separate the cotton and polyester in poly-cotton blends, which are one of the most widely used textiles on the market. The pure cotton fibres are then added our wood-derived textile pulp, which can then be used to make new textiles."[84] Extensive detail and perspectives on the process and value chain are provided in the company's podcast series on the OnceMore® process.[85]

In mid-June 2023, Södra and the Austrian company Lenzing were awarded a 10 million Euro grant from the EU-financed "EU LIFE 2022 Circular Economy and Quality of Life" program to scale up OnceMore®, a project that offers potential partnership pathways for Vermont and the region.

According to the project records for this grant, known as LIFE TREATS (Textile Recycling in Europe AT Scale):

> "LIFE TREATS (Textile Recycling in Europe AT Scale) is a joint project by Södra and Lenzing aiming to demonstrate an innovative industrial-scale system for chemical recycling of textile waste. The two companies have combined their decades-long experience, knowledge, and technology to develop a unique process. For the first time, the proposed solution will allow handling a wide variety of complex post-consumer-coloured textiles containing a mix of cotton, polyester, and other components such as elastane. The partners will scale up the new technology at the project site of Södra Cell Mörrum in Sweden. The plant will be capable of processing 50,000 tons of coloured blended post-consumer textile waste, producing 63,000 tons of pulp with 50% recycled content.

> In line with the EU Circular Economy Action Plan, this project will make sizeable contributions, diverting large volumes of coloured blended textile waste from being downcycled, landfilled, or incinerated... As it is the first project at such a scale, LIFE TREATS will impact the whole textile industry, open new circular business opportunities, and increase the proportion of recycled fibers used in new clothing. **In addition, the recycling system has the potential to be replicated in other sites in the EU and across the world"** [emphasis added].[86]

In a related project, Lenzing and Södra are already partnering in a large-scale textile recycling project announced in May 2023. A press release on this project includes some key elements relating to the economic development and labor aspects of textile recycling that could provide important options for regional employment of those with physical or mental disabilities:

> "In this pilot project, used textiles collected by Salesianer Miettex that are not suitable for reuse will be...delivered to Caritas for sorting by hand at a recycling plant. The Caritas recycling facility provides secure employment to more than 70 people with disabilities. After the sorting process, the textiles will be delivered to Södra for recycling and processing to produce OnceMore® pulp. This method is a world first in the industrial recycling of textile waste made from blended fibers."[87]

PHOTO CREDIT: SÖDRA

Combining post-consumer textile waste and wood pulp, Södra's OnceMore® line of fibers is the world's first large-scale process for recycling blended fabrics.

EASTMAN - NAIA™ RENEW:

Tennessee-based Eastman launched the Naia™ Renew line in 2020. According to the company's information, Naia™ Renew is produced from 60% sustainably sourced wood pulp and 40% certified recycled waste material."[88] Importantly, the recycled material in Naia™ Renew is waste plastic, not cellulosic material. This material may be derived from a variety of sources, including single-use plastics, textiles, and carpet.[89] However, as Eastman is the only known company working on the combination of recycled content + wood fiber in the US, the project team believes it would be valuable to explore options for engaging with Eastman.[90]

As noted above, the current used textile suppliers for the Södra OnceMore® process draw on the hospitality industry to provide sheets, towels, and tablecloths as a more uniform quality of used textiles. Starting with more consistent all-cotton or polyester-cotton materials simplifies that sorting and recycling process. Ironically, the type of disposable, fast fashion clothing that is creating many of the textile industry's waste problems also tends to contain a wide variety of blended, synthetic fiber types and accessories like zippers and decorations that complicate recycling. Fortunately, a wide ecosystem of global innovators is at work to address these challenges. There are dozens of companies operating in this area, though not with a specific focus on incorporating wood fibers. Nonetheless, some of these companies could represent productive partners for the project sponsors and the state for further exploration of Pathway 3.

Recent reports from Textile Exchange, Fashion for Good, and the American Chemistry Society all provide snapshots of this burgeoning landscape, dividing these companies in various ways based on whether their technologies target cellulosic fibers, synthetic fibers, or both and whether they are mechanical or chemical processes. A few notable companies, with descriptions sourced from these reports, include:

- Circular Systems' Texloop, a purely mechanical and hydrothermal process, can also recycle blends, which in turn act as raw material inputs to next-generation fabrics.[91]
- Circ (earlier called Tyton Biosciences) is developing a proprietary polycotton blend recycling process utilizing hydrothermal technology to separate polyester fiber from cotton at any ratio, yielding polyester monomers and dissolving pulp.[92]
- Evrnu is a US-based textile innovations company creating circular solutions through a range of regenerative fiber technologies including cellulosics, polyester, recoverable stretch and bioengineered materials.[93]
- Renewcell, founded in 2012, is a Swedish chemical recycler that turns cotton waste into dissolving pulp. They have the largest commercial production output of any of the innovators, with their Kristinehamn demonstration plant capable of producing around 7,000 tonnes of pulp annually.[94]
- UK-based Worn Again Technologies separates, decontaminates, and extracts polyethylene terephthalate and cellulose from blended polyester and cotton waste textiles.[95]

Vermont's and the Region's Prior Engagement in Textile Recycling

Vermont has already begun engaging with the issue of textiles in the waste stream. In 2016, as directed by state statute and the state's Materials Management team, a "Beyond Waste Advisory Group" developed a list of priority materials to evaluate for additional waste diversion. The Advisory Group "determined that textiles fell near the top of that list as a category of material that has some existing diversion infrastructure, but faces some...collection and market challenges."[96] The importance of textile recycling for Vermont specifically lies in two key facts: the state has only one landfill, and this landfill is projected to be full within 20

PHOTO CREDIT: VITALIY KYRYCHUK

Clothing recycling in Stuttgart, Germany

years, by 2043.[97] The state's 2012 Waste Composition Study found that textile and leather waste accounted for an average of 6.8% of residential waste.[98] Recycling any amount of used textiles would thus make an impact for the landfill's longevity.

The 2016 Textiles Stakeholder Series identified challenges with high turnover in the partnerships with national companies that provide textile recycling bins. The top recommendation from the series was to "Request Solid Waste District Managers' Association to consider collaborating on a contract with one or more textiles collection organizations, which could help them find an affordable collector and ensure convenient infrastructure is in place and is maintained for Vermonters."[99]

Since that time, local and global attention to the problem of textile waste has greatly increased, as discussed in Section 2. In Vermont, towns and solid waste districts are working with new partners to provide textile recycling collection, including:

- New Hampshire-based [Apparel Impact]() (Chittenden County);[100]
- [Helpsy](), a New Jersey-based B Corp that is rapidly expanding its operations (Waterbury);[101] and
- [Casella Waste Systems]() and [TerraCycle](), which in April 2023 announced a subscription-based pickup home service for used textiles (Burlington area).[102]

In addition to such partnerships, Vermont and the region have the potential opportunity to support the growth of additional textile collection and recycling businesses—beginning with simple, small-scale, and locally-owned businesses. As noted above, textile recycling facilities can be suitable employers for individuals with physical or intellectual disabilities, adding to the potential benefits of this pathway. The OnceMore® process currently sources used textiles from the hospitality industry (used towels, tablecloths etc.), raising interesting prospects for partnership with the hospitality and tourism industry in Vermont. The example of Minneapolis-based Better Earth Recycling gives a sense of the business model and scale for this approach. As systems are developed, Vermont could invest in next-generation textile sorting equipment, which uses Near Infrared (NIR) Spectroscopy to sort fiber types.[103]

While it is true that wood products are not directly used in this recycled textile stage, following this pathway could offer multiple benefits for the state and region, opening an additional job-creating and waste-reducing sector that eventually merges with non-chemical wood-based fiber production to allow the state and region to take an early leadership position in next-generation recycled textiles + wood-based fibers.

Models for Small-Scale Textile Recycling in Vermont

BETTER EARTH RECYCLING
Minneapolis, MN

Better Earth Recycling is a Minneapolis-based recycler doing business for 10 years. Company president Tim Engel generously shared details of the business and its financial model with the project team.

Better Earth buys only recyclable clothing, limiting its purchases to apparel, shoes and leather goods. The company exports all of its sorted material, the bulk of it to foreign markets. The range of Better Earth's sources includes hospitals, hotels, shopping centers, and Goodwill and related thrift/retail stores. The company sources textiles within a 75-mile radius of Better Earth's headquarters in Minneapolis. All inbound clothing arrives from pick-up points by trucks owned and operated by Better Earth. Payroll numbers 8-13 FT/PT staff based on seasonal variability.

Better Earth's general financials include: purchase of recyclable material at 1-4 cents per pound, based on transport costs (distance to warehouse) and quality and ease-of-sorting of the material; and average export prices of finished goods, baled and prepped for export, of 9-24 cents per pound based on global spot market price variability.

Better Earth began operations at 300,000 lbs of collected material; total inputs now exceed 3,000,000 lbs/year. Overall revenue for this businesses is approximately $500K, with EBITDA of roughly $130K. This scale is feasible even for smaller and rural Vermont communities, and Better Earth's 8-13 FT/PT employees would make a significant contribution in any part of the state.

CERO
Boston, MA

Cooperatively-owned recycling enterprises such as Boston-based CERO (Cooperative Energy, Recycling & Organics), provide models for entrepreneurship options for those too often left out of business ownership opportunities. CERO provides food waste pickup and diversion services for a wide range of commercial clients in the metro Boston area, and transports this organic waste to local farms for composting and reuse as a soil amendment. As the company describes it, "CERO was started by a group of black and brown people from Boston neighborhoods who believed the way to a more equitable, healthy society is through a worker-owned solidarity economy. In 2014 CERO completed a year long Direct Public Offering, raising capital by selling shares of dividend-paying stock to community members. Lenders who were initially hesitant to take a chance on lower income entrepreneurs in the green economy are now on board. CERO is growing and providing the jobs it promised to workers who own the company."

The CERO model could expand to textile recycling, providing ownership opportunities for Vermonters who might otherwise not envision themselves as entrepreneurs or business owners. Such a "shared prosperity" approach promises not only more employment but also more wealth generation, a dimension too often left unaddressed in conventional economic development.

MATERIAL RETURN
Morganton, NC

A textile-specific model for this type of approach is North Carolina's Material Return, a business that collects textile waste from a 75-mile radius in North Carolina's textile manufacturing region and manufactures it into custom circular yarn and textile products as well as a pre-made line of ReturnTex™

fibers. Like CERO, Material Return is a worker-owned enterprise, and it is part of the larger regional economic development model Industrial Commons. In 2023, Material Return worked with SmartWool to launch the U.S.'s first "circular socks."[104] The success of this partnership inspires visions of a similar one in Vermont between a new textile recycling enterprise and a company such as Northfield-based Darn Tough Vermont. Notably, Material Return is a partner with its parent organization Industrial Commons in a separate NSF Engines grant proposal called "Creating a Modern, Green and Inclusive Textile Sector," which has already been selected as an NSF finalist.[105] Models like CERO, Wellspring, and Material Return are viable examples of the Just Transition approach mentioned in Section 5. **The project team highly recommends further dialog with the values-aligned leadership of Material Return and Industrial Commons as part of next steps from this report.**

Pathway 3: Long-term

Vermont and the region could emulate the EU LIFE TREATS project by developing and/or licensing technology for a similarly-scaled regional plant that would combine used textiles and next-generation non-chemical MMCFs or CNFs, drawing on the info developed during the LIFE TREATS project and ideally dovetailing with the NSF Engines and other state and federal funding pathways.

Pathway 3: Short-Term

In this pathway, short-term options could include:

- Södra is actively seeking partners to deliver quality used textiles for OnceMore®. Vermont and the region could explore possibilities to become part of this supply network, and also potentially explore supplying wood pulp to Södra.
- Revisit the recommendations of the 2016 Textile Reuse and Recycling in Vermont report, potentially reconvening some of the stakeholders along with new companies operating in the space to explore developments since the original report.
- Assess short-term options to expand collection of textile waste in Vermont and the region, including textiles from the hospitality industry, to develop additional business opportunities for localized collection, sorting, and shredding.
- Engage in dialog with North Carolina's Material Return to understand the specific challenges and opportunities for localized textile waste collection and recycling.

Once local textile collection and sorting businesses are better established, Vermont could continue to pursue this pathway by strengthening its network of textile recycling businesses, including those with next-generation NIR Spectroscopy sorting equipment, and beginning to import used textiles from neighboring states and other regions of the country. Moving along this pathway would place the state and New England in a strong position to develop a fiber that combines recycled textile fiber with non-chemical CNF, something that could bring the world knocking.

Thanks to well over a decade of leadership of Vermont Farm to Plate and similarly-long working relationships with the global NGO Health Care Without Harm and the regional Farm to Institution New England (FINE), Vermont Sustainable Jobs Fund understands well the promise–and the challenges–of engaging with institutional customers to change their purchasing decisions to favor more local/regional suppliers. VSJF would be able to bring all of this experience to bear on any strategy that this project's sponsors might undertake to collect, sort, bale, and sell recycled textiles.

Innovative Companies and Potential Partners in the Pathways

COMPANY OR ORGANIZATION	LOCATION	TECH FOCUS OR KEY PRODUCTS	OPTIONS FOR PARTNERSHIP	KNOWN CAPITAL SCALE
WOOD-BASED FIBER PRODUCERS				
Spinnova	Finland (new plant planned in Portugal)	Non-chemical, all mechanical wood-based fiber production.	Investor deck states “technology partnerships;” requires further exploration.	2022 revenue: €24.3 million [$26.2 million] (up 300% from FY 2021). 2022 net profit: -€12.3 million [-$13.3 million] (due to Woodspin investment).
Woodspin joint venture - Spinnova + Suzano	Factory in Jyväskylä, Finland	Textile development by Spinnova; using “micro-fibrillated cellulose” (MFC) from Suzano SA, Salvador/Brazil, as raw material.	Investor deck states “technology partnerships;” requires further exploration.	€31M [$33M] investment into factory.
Södra	Sweden	OnceMore®: recycled cotton textile and wood fiber.	Investigate sub-licensing or supplying options.	€10M [$10.8M] EU LIFE Grant award.
Lenzing	Global	The jointly developed OnceMore® pulp will also be used as a raw material for Lenzing’s TENCEL™ x REFIBRA™ branded specialty fibers.	Investigate sub-licensing or supplying options.	€10M [$10.8M] EU LIFE Grant award.
Eastman	Kingsport, Tennessee	NaiaTM Renew: 40% certified recycled waste material (may include synthetic fibers and plastic waste) + 60% wood pulp.	Investigate sub-licensing or supplying options.	2021 investment of $250 million to build one of the largest material-to-material recycling facilities in the world in Kingsport, Tennessee.
Weidmann	Switzerland (Company also has plant in St. Johnsbury, Vermont)	Sustainably sourced wood pulp from Europe is the one and only raw material used in the production of Celova® microfibrillated cellulose.	In 2018, Weidmann invested in the design, build, and commissioning of the first MFC (microfibrillated cellulose) production line in central Europe, supplying the market with more than 100 tons of MFC.	Privately-held company; 2022 global net sales CHF €373M [$422M].
RESEARCH INSTITUTIONS				
University of Maine/Orono Department of Chemical and Biomedical Engineering, Forest Bioproduct Research Institute, and Process Development Center	Orono, Maine	Mechanical defibrillation technique continuously breaks down cellulose fibers suspended in water via segmentation and defibrillation through grinding and refining.	Develop partnership further via CONFIR grant / NSF Engines application.	2022 award of ~$360K to PDC allowed establishment of a “wood fiber thermo-forming knowledge center.”
University of Vermont Biomedical Engineering Department	Burlington, Vermont	Biomedical Engineering faculty engage in cutting-edge research on nanotechnology, wearable sensors, and more.	CONFIR grant partner; possible partner for biomedical textile development.	

Innovative Companies and Potential Partners in the Pathways

COMPANY OR ORGANIZATION	LOCATION	TECH FOCUS OR KEY PRODUCTS	OPTIONS FOR PARTNERSHIP	KNOWN CAPITAL SCALE
EQUIPMENT MANUFACTURERS				
Valmet	Biddeford, Maine/ Global	Valmet provides processes and equipment for CNF and MFC production, including to the UMaine PDC and Spinnova.	Equipment sales and technology pilot.	Value of Valmet equipment sales to Spinnova was not disclosed; value of Valmet equipment sales to Renewcell for textile recycling plant in Sweden was was €25M [$27M].
Guowang Eco	China	Manufacture and sales, waste textile shredding and recycling machines.	Equipment sales and technology pilot.	$508,000 and shipping for a high-tech recycling machine that recycles plastic and textile and combines in a nonwoven.
PICVISA	Spain, Global	Technological solutions based on artificial intelligence and artificial vision for the separation and classification of waste.	Equipment sales and technology pilot.	Up to $1.2M for a spectroscopic sorting textile machine.
PROCESS/MANUFACTURING CONSULTANTS				
AFRY	Stockholm, New York, and offices in 40 countries	Global consultancy working in many industries; textile industry expertise support clients in identifying and implementing business opportunities across the textile value chain.	Offers specific expertise and focus on both wood-based textiles and textile recycling. Potential partner in all phases of implementation, from feasibility studies to project deliveries and support during plant operations; has strong competence both in the mechanical and chemical recycling of textiles.	
Materic	Baltimore, Maryland	"Developing the materials of the future through contract research, custom development, and manufacturing scale up."	Offers expertise in nanomaterials, textile treatments, and development of sustainable materials as well as custom manufacturing projects.	
INNOVATORS IN TEXTILE RECYCLING				
Circular Systems	Los Angeles, California	Transforms crop waste into cellulose fiber, yarn, and textile fabrics for the fashion industry.	Recycled fiber innovators could represent productive partners for further exploration of Pathway 3.	Capital raised in start-up funding rounds: $9.1M.

Innovative Companies and Potential Partners in the Pathways

COMPANY OR ORGANIZATION	LOCATION	TECH FOCUS OR KEY PRODUCTS	OPTIONS FOR PARTNERSHIP	KNOWN CAPITAL SCALE
INNOVATORS IN TEXTILE RECYCLING				
Circ	Danville, Virginia	Extracts cellulose and depolymerizes polyester in blended fabrics with supercritical water—water heated above its boiling point while under pressure.	Recycled fiber innovators could represent productive partners for further exploration of Pathway 3.	Capital raised in start-up funding rounds: $15.5M.
Renewcell	Stockholm, Sweden	Converts cellulose-rich textile waste such as cotton fabric into a slurry or pulp, which can be dried into sheets for transport to fiber and yarn makers.	Recycled fiber innovators could represent productive partners for further exploration of Pathway 3.	Capital raised in start-up funding rounds: $10.6M.
Worn Again	Nottingham, England	Separates, decontaminates, and extracts polyethylene terephthalate and cellulose from blended polyester and cotton waste textiles.	Recycled fiber innovators could represent productive partners for further exploration of Pathway 3.	Capital raised in start-up funding rounds: $15.5M.
Evrnu	Seattle, Washington	Creates circular solutions through a range of regenerative fibre technologies including cellulosics, regenerative polyester, recoverable stretch and bioengineered materials.	Recycled fiber innovators could represent productive partners for further exploration of Pathway 3.	Capital raised in start-up funding rounds: $25.7M.
Material Return	Morgantown, North Carolina	Works with local manufacturers and national brands to transform textile waste into new products—all within 75 miles of its headquarters.	The project team highly recommends further dialog with the values-aligned leadership of Material Return and its parent organization Industrial Commons as part of next steps.	Industrial Commons was named a finalist for NSF Engines grant for its project, "Creating a Modern, Green and Inclusive Textile Sector;" potential for up to $160 million over 10 years.

7. Funding and Financing the Pathways

Creating the Enabling Environment

In order for Vermont and the region to capitalize on the opportunities presented by the three pathways above, interviews and research for this project emphasized the critical need for state and quasi-state agencies to invest in the enabling environment for further R&D and eventual commercialization of wood-based fibers. In Vermont and the region, the sector currently lacks an established pipeline of entrepreneurs and small and medium-sized enterprises that are positioned to take advantage of emerging wood-fiber innovations and pathways. This situation requires early capital types that can serve to incentivize and de-risk eventual investment dollars.

As noted in the FOR/Maine Strategic Investment Attraction Plan for Maine's Forest Industry, **"Investment attraction tends to draw on one or a combination of the following types of incentives: state or federal government grants, loans, loan guarantees, bonds, technical assistance, tax credits, tax exemptions, government co-financing in infrastructure improvement, discounted land acquisition or land lease payments and technical assistance."**[106]

An additional component of the FOR/Maine project provides a key case study in this regard: the "Finland Deep-Dive" that highlights key "drivers of change" for the Finnish bioeconomy. Under the header "Creating the Enabling Environment to Facilitate Industry Transformation," this case study notes that "Several influential public policy decisions were made following the early decline of the traditional forestry industry that put Finland on the trajectory to transform itself."[107] In summary, "Support programs focused on R&D and Commercialization Industry support programs have focused on mitigating risks for research, development and commercialization of new products from wood...The business environment needed to change to be more supportive of small and medium sized companies that play a major role in diversifying the local business environment and creating rural jobs."[108]

Our interview with Janice St. Onge and Casey Johnson of the Vermont Flexible Capital Fund (VFCF) provided additional valuable input on the landscape of funding and financing needed to accelerate regional progress towards any of these three pathways.

Reflecting on the recent "chainsaw-cutting" launch for VFCF's Maine-based portfolio company Timber HP, St. Onge reflected, "They took this idea of innovation that's already being done in Europe for 20 years, bringing that tech from Europe and doing that in the US—and they brought back 120 jobs that were lost, in an old paper mill. Two key pieces: first, they could not have done that without the partnership along the value chain in the forest products industry. They built relationships with the sawmills and the loggers—that part of the value chain is at risk." Second, she added, "Timber HP is a lesson in getting the right people on the bus in the right seats doing the right things. Capital is one piece of this, and you need all kinds of capital... The two [founding] entrepreneurs brought on two or three people who could help them with the capital and rally the angel investors around them. **So it's understanding capital across the continuum—not just to get started, but to grow and to continue to grow."**

St. Onge and Johnson also named other key state resources for R&D stages. Important options include:

- UVM Innovations, which "enables new and existing companies to commercialize new technologies that benefit society."
- The Vermont Small Business Development Center at Vermont Technical College, especially the SBIR Technology and Commercialization advisors who "help technology-driven entrepreneurs and businesses gain a competitive advantage in the commercialization of their innovations, and assist high-growth small businesses in obtaining grant funding for research and development, as well as advising on positioning themselves to attract outside investment."
- Vermont Established Program to Stimulate Competitive Research (VT EPSCoR), which is designed to "build the state's capacity for scientific research and [train] a diverse, prepared science, technology, engineering and mathematics (STEM) workforce."
- The Working Lands Enterprise Fund distributes $10M annually to forest or food-related enterprises. According to St. Onge, the majority of the funds have traditionally been weighted to the food side, and she noted that grantee businesses have to show benefit across the value chain, "so not for the benefit of just one business."

Another key resource on the commercialization continuum is the Forestry Accelerator described in more detail under Pathway 2. In our project interview with Jared Reynolds, Manager of the Forestry Accelerator, he noted that the program had experienced challenges identifying Vermont- and Northeast-based businesses to apply. While the program's second cohort is now launched with a full set of innovative businesses, the majority are based on the West Coast.[109] Reynolds' recent experience emphasizes the need for an intentional continuum of resources and funding support that helps businesses grow from innovative ideas through the early stages of commercialization and capitalization. The EDA-funded Maine Mass Timber Commercialization Center provides one example of this approach.[110]

Businesses at this early stage could also benefit from lessons offered by Vermont entrepreneur Travis Samuels of Zion Growers. Zion Growers' long term goal is to be a processor of fiber hemp. As they work with growers to develop supply, however, Samuels noted in a project interview that many of their revenue sources have been based on their purchase of old mill buildings. As he described it:

> *"There's a lot [of funding] for farmers, but not a lot for processing. Our biggest win is that we are taking over buildings like this. If it's a brownfield site or the site is derelict, we get more support than if we build new ones and can apply for additional tax credits. So those are things we can go to the districts and say, 'here's what we are bringing, and here is the benefit,' before we have even processed a single thing…A lot of the money we have seen is centered around, not hemp-related pieces, but around the buildings."*

Through a deal brokered by the Preservation Trust of Vermont, Samuels was recently able to acquire the abandoned Vermont Marble Finishing Mill building in Proctor, VT. As part of the transfer, the Preservation Trust secured a 99-year lease for the Vermont Marble Museum.[111] As Samuels notes, "Now that we own this building, people are more amicable, and we are looking at a loan through Vermont Economic Development Association (VEDA) for equipment and machinery."

While next-gen MMCF and CNF production will certainly require new facilities with lab capabilities, Samuels' experience offers the possibility that early-stage textile recycling businesses could make use of available mill space in Vermont towns for collection, sorting, baling, and shipping, and thus tap into some of the additional state funding sources and incentives he has utilized as well as private foundation possibilities.

Finally, Vermont and federal tax exemptions and credits for the Forest Products Sector offer additional options to support the enabling environment. The Vermont Department of Taxes offers both a tax exemption and credit for forest products businesses.[112] Enacted in 1981, the federal Research and Development (R&D) Tax Credit allows a credit of up to 13% of eligible spending for new and improved products and processes. The Northern Forest Center has compiled resources from experts around the country to help wood products manufacturers transform their businesses, become more competitive and continue providing quality jobs.[113]

However, according to St. Onge and Johnson, Vermont lacks some elements of the full continuum of capital that are available in Maine and New Hampshire, particularly in the area of angel investing. While key options exist in the state, including Fresh Tracks, the Vermont Seed Capital Fund, the Hula Fund, and the Dudley Fund, St. Onge notes that "all of those are mainly oriented to high-tech, high-growth companies." The state has a group of lenders/investors known as Community Development Financial Institutions (CDFIs), like the Flexible Capital Fund and the Vermont Community Loan Fund, that support working lands businesses. However, collaboration with other regional funders, investors, and CDFIs such as New Hampshire Community Loan Fund or Maine's Coastal Enterprises, Inc. can provide vital support when innovative early-stage businesses need more support than any one funder can provide or more flexibility in the structure of an investment. "So thinking beyond federal funding," St. Onge adds, **"in my perspective, what you are talking about really needs to have a regional approach—because the northern forest is regional, [just as] the food system is regional."**

Two recent examples from the Vermont Flexible Capital Fund portfolio show what is possible when local entrepreneurs have the motivation, market, and support needed to import emerging technologies from Europe and build a business around it in the Northern Forest Region context.

TIMBERHP

TIMBERHP
Madison, ME

TimberHP began manufacturing insulation made from wood fiber in 2023 as an environmentally-friendly and cost-competitive alternative to traditional fiberglass and foam insulation. Made from wood chips and waste from mills in Maine and the Northern Forest, the product...solves two problems. One, it reduces embodied carbon in buildings which are responsible for 40 percent of our carbon footprint in the U.S. and, two, it creates a new, much needed market for low-grade wood.

GLAVEL
FOAM GLASS GRAVEL

GLAVEL
Burlington, VT

Founded in 2017 by Rob Conboy, Glavel is a Vermont-based company that specializes in selling a lightweight building material from post-consumer recycled glass known as foam glass gravel. Because cellular glass is derived from recycled glass, it's petroleum- and chemical-free. Glavel began by importing foam glass gravel from Europe, with the plan to introduce the product to the U.S. market, build up a customer base, and eventually open a domestic manufacturing facility—all while helping to solve the country's glass recycling problem.


PHOTO CREDIT: ERICA HOUSEKEEPER

Models of Other Lab-scale Approaches with Government Support

In addition to the Finnish deep dive study referenced earlier, Vermont and the region can also draw inspiration from other models of clustered economic development that use state or federal support to build regional economic ecosystems around a particular technology, sector, or set of values. These include:

RISE
Sweden

Rise Research Institutes Of Sweden (RISE) is described as "an independent, State-owned research institute, which offers unique expertise and over 100 testbeds and demonstration environments for future-proof technologies." According to the project's website, "In order to increase the outside world's knowledge of lignin-based products, and at the same time promote their development, RISE, in collaboration with representatives from industry, academia, the Paper Province cluster and Region Värmland, has implemented the project "LignoCity 2.0 - Low-carbon economy through the development of LignoCity." Through this clustered approach, RISE notes, "In LignoCity 2.0, small companies that have a concept or technology for lignin processing are provided with access to both the testbed and the knowledge, skills and resources that we and our network possess."[114]

AFFOA
Cambridge, MA

As a nonprofit, public-private partnership and Department of Defense-funded Manufacturing USA Innovation Institute, Advanced Functional Fabrics of America (AFFOA) bridges the gap between early-stage technology and commercialization. AFFOA's mission is "to rekindle the domestic textiles industry by leading a nationwide enterprise for advanced fiber and fabric technology development and manufacturing, enabling revolutionary system capabilities for national security and commercial markets."[115] This nearby partner could offer key perspectives for Vermont and the region.

WELLSPRING COOPERATIVE
Amherst, MA

The Wellspring Cooperative is creating new, community-based, worker-owned companies in inner-city Springfield, Massachusetts. A cooperative development organization with a mission to create a network of worker-owned companies in marginalized neighborhoods, Wellspring provides on-the-job training, employment, and wealth creation opportunities for low-income and unemployed residents of the city. Co-op members focus on industries including upholstery, window restoration, greenhouse vegetable production, healing care, and more.

As a place-based organization, Wellspring's work responds to Springfield's particular circumstances. However, their development strategy can be followed anywhere, including here in Vermont:

- Partner with anchor institutions (i.e., the hospitals, colleges, and other nonprofit organizations) that are the largest employers and purchasers of goods and services in their part of Massachusetts. In our proposed pathways for Vermont, a textile recycling cooperative could focus on collecting discarded clothing, carpeting, curtains, linens, and other fabrics from hospitals, long-term care and nursing homes, universities, public school districts, and other institutions that generate such waste on a regular basis.

- Create worker cooperatives controlled by neighborhood residents and located where it's easiest to meet institutions' purchasing needs. A cooperatively-owned recycled textile manufacturer could focus on supplying Vermont's hospitals and biomedical companies with materials produced to their specifications.
- Provide living wage jobs to low-income and BIPOC individuals who have been excluded from wealth creation opportunities and provide on-the-job training.

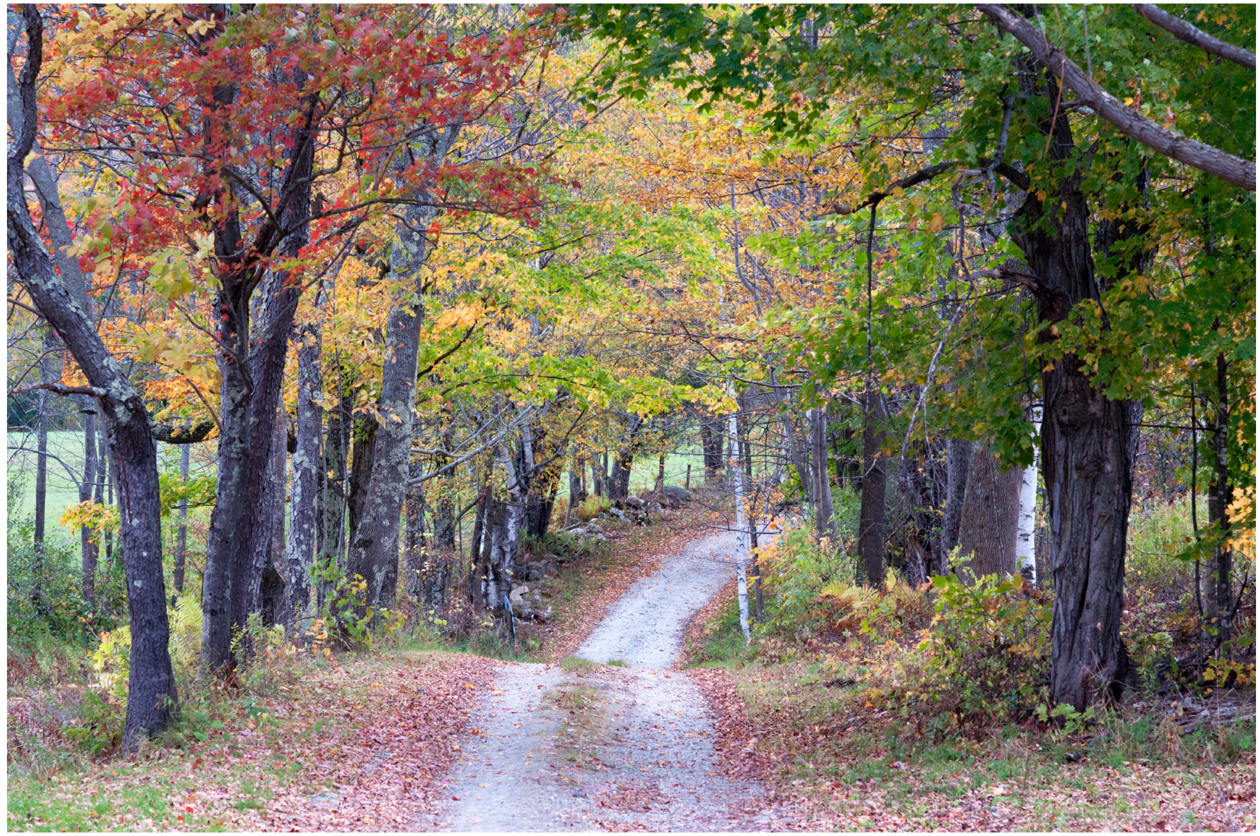


PHOTO CREDIT: ERICA HOUSEKEEPER

8. Conclusions and Next Steps

The models above show what is possible when local entrepreneurs have the motivation, markets, and support needed to build a business around emerging technology in the Northern Forest Region context. Vermont and the region already have many key pieces in place to support the clustered development of wood-based fibers and textiles, and the emerging processes of the Vermont Forest Future Roadmap and the CONFIR NSF Engines Development grant set the stage for further intentional development.

Specific, time-bound next steps to assess and advance our three possible pathways could include:

- **Pathway 1: Incorporate ongoing partnership with CONFIR partners on CNFs for nonwoven textiles into the NSF Engines Development Grant to build a localized industry from the ground up.**
- **Pathway 2: Explore technology and/or supply partnership with Spinnova, Eastman, Södra, or other global innovators in wood-based fiber.**
- **Pathway 3: Revisit conclusions and potentially reconvene stakeholders from the 2016 Vermont Textile Reuse and Recycling study to set the stage for eventual combination of textile waste with non-chemical wood fibers as a Vermont industry.**

One option to further progress on the pathways that could be pursued in the very near-term would be for the sponsors to take inspiration from the Vermont Forest Future Roadmap process and **host a Think Tank focused specifically on wood fiber manufacturing of nonwoven textiles for biomedical and industrial applications.**

Sponsors could invite a broad array of interested parties to workshop this R&D area further, including: regional nonwovens manufacturers; members of the finance community such as Vermont Flexible Capital Fund, the Vermont Seed Capital Fund, and others; partners in the CONFIR consortium; key players in the Vermont Forest Future Roadmap; representatives of the textile recycling industry; and loggers and forestry companies who are interested in pursuing new business options.

The Vermont Forest Future Roadmap process has acclimated people to the think tank concept and set the stage for positive response to such a gathering. The focus of the think tank would be to envision how the wood-based fiber pathways could develop over time and to plan further steps to facilitate progress and address potential roadblocks. The gathering would be a direct response to Janice St. Onge's advice to get "the right people on the bus in the right seats doing the right things." A potential partner in this process is the new UVM Institute for Rural Partnerships, recently launched with a $9.3 million award from the U.S. Department of Agriculture.

As Vermont and the region look ahead, we believe that continued R&D and commercialization for non-chemical, next-generation wood-based fiber deserves a place in the bioeconomy of the Northern Forest Region. As Commissioner Danielle Fitzko of Vermont FPR put it, "If we are going to be innovative, and think 10 years out, we have to take risks, and we need lots of pathways." The state and region have a timely opportunity to integrate wood-based fiber development into the CONFIR partnership, the planning for the larger NSF Engines application, the Vermont Forest Future Roadmap, additional funding efforts, and the overall strategic approaches of the project sponsors and partners. Through the inclusion of one or more of the pathways above, Vermont and the region can stake a claim to early leadership in the next-generation race to go from “Forest to Fiber” in a way that benefits planet, people, and the region’s local economy and quality of life.

PHOTO CREDIT: ERICA HOUSEKEEPER

Three Pathways: Summary and Key Milestones

JULY 2023 | JAN 2024 | JULY 2024 | JAN 2025 | JULY 2025 | JAN 2026 | 2033 | 2035 | 2043

Pathway 1
Catalyze local development of cellulosic nanofibers for textiles

JULY 2023
Vermont Forest Futures Roadmap draft findings released

JAN 2024
Final Roadmap published

Integrate CNF for nonwoven textiles into plans

2034
Vermont Forest Futures 10-year Roadmap culminates

CONFIR NSF Engines Development Grant period (ends Apr 30, 2025)

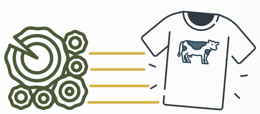
EDA National Technical Assistance NOFA open (no deadline)

SEPT 2025
NSF Engines full proposal due

Potential **CONFIR Full NSF Development Grant** (10 years, up to $160 million allowed)

Pathways 1 and 2 converge by 2025

Pathway 2
Partner with global innovators in non-chemical wood fibers



MAY 2023
Spinnova/Suzano Woodspin JV plant opens in Finland — fully non-chemical wood fiber

END OF 2023
Spinnova/Tearfil non-chemical wood spinning plant to open in Portugal

END OF 2024
Spinnova/Suzano Woodspin JV project second plant

2033
Spinnova goal is 1 million tons of non-chemical wood fiber annually

JUNE 2023
EU regulation on deforestation-free supply chain goes into effect; increases demand for traceable wood

Pathways 1 and 3 converge by 2033

Pathway 3
Invest in the next horizon: recycled textiles + wood fiber

JUNE 2023
EU LIFE TREATS grant to **Södra** and **Lenzig** to expand OnceMore production

NSF Engines grant to **Industrial Commons/Material Return** in NC may be approved — model/potential partner for regional recycled textile products (winter '23-'24)

Revisit **VT Textile Use and Recycling** report: support development of textile collecting capacity, explore partnerships with hospitality industry for used textiles

EU mandated textile waste collection begins in 2025

VT Materials Management Plan calls for 10% solid waste reduction by 2025

JULY 2025
New solid waste management facility opens in Chittenden County — opportunity for textile waste pilot?

Vermont's only landfill—Coventry—is full by 2043

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Appendices

1. Interview List

NAME	ORGANIZATION	LOCATION(S)
Raquel Alonso	PICVISA	Spain, Global
Tomi Amberla	AFRY	Finland, NY, Global
Zach Bacon	Valmet	Finland, ME, Global
Donna Cassesse	Sappi North America	ME
Chris Clark	Valmet	Finland, ME, Global
Cory Creagan	Bennington County Forester	VT
Tony D'Amato	University of Vermont	VT
Tim Engel	Better Earth Recycling	MN
Danielle Fitzko	Department of Forests, Parks, and Recreation	VT
Paul Frederick	Department of Forests, Parks, and Recreation	VT
Nicholas Johnson	Textile Exchange	OR
Casey Johnson	Flexible Capital Fund	VT
Soile Kilpi	AFRY	Finland, ME, Global
Alexandra Kosiba	University of Vermont	VT
Matt Langlais	Department of Forests, Parks, and Recreation	VT
Nathan Nimbargi	Materic	MD
Shane O'Neill	University of Maine School of Forest Resources	ME
Mike Pappalardo	MEI Electric Contractors	VT
Jared Reynolds	Do North Accelerator	VT
Travis Samuels	Zion Growers	VT
Saleh Seddick	PICVISA	Spain, Global
Mark Shea	Rutland County Solid Waste District	VT
David Snedeker	Northeastern Vermont Development Association	VT
Danny St. Onge	Wood products aggregator	VT
Janice St. Onge	Flexible Capital Fund	VT
Stuart Stillwater	Stillwater Forestry, LLC	VT
Tim Tierney	Vermont Department of Economic Development	VT
Colleen Walker	University of Maine Process Development Center	ME
Lucja Wanicka	AFRY	Finland, ME, Global
Sarah Waring	USDA Rural Development	VT
Alvin Zoltan	Jasztex Fibers Inc.	Pointe-Claire, Quebec, Canada
Textile Exchange MMCF Round Table members (brands)	Various	Various

2. Vermont Wood Species Mix and Abundance

CATEGORY (UNITS)	2017	2018	2019	2020	2021
Total Harvest (cds)	946,333	1,046,148	997,880	910,693	897,262
Sawlogs (Mbf)	140,351	136,909	127,658	118,523	120,199
Hardwoods	48,818	45,218	46,357	39,745	47,163
Softwoods	91,533	91,692	81,301	78,778	73,036
Pulpwood (cds)	148,571	163,056	194,177	157,358	130,035
Hardwoods	97,158	99,128	117,443	92,373	82,504
Softwoods	51,413	63,928	76,734	64,985	47,531
Whole Tree Chips (gt)	402,678	484,870	340,539	243,233	271,945
Pulp	*	*	*	*	*
Fuel	402,678	484,870	340,539	243,233	271,945
Roundwood Fuelwood (cds)	355,985	415,326	412,172	418,999	419,051
Hardwoods	353,092	412,031	411,986	418,737	418,837
Softwoods	2,894	3,295	186	261	215
VT Sawmills (# reporting)	40	39	37	41	38
Consumption (Mbf)	91,417	87,980	82,615	76,459	74,381
Hardwoods	40,071	40,217	38,293	34,041	35,961
Softwoods	51,345	47,763	44,322	42,418	38,420

* data not available.

Source: Vermont Forest Resource Harvest Summary, 2021.

Abbreviations:

cds: cords
gt: green tons
Mbf: thousand board feet

Conversion factors:

2 cds = 1 Mbf
1 cd = 2.5 gt

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