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Spinning a Budding Industry

An Investigation into the Barriers and Challenges Associated with Developing Domestic Hemp Fiber Supply Chain in the United States

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Abstract

The 2018 Farm Bill federally legalized industrial hemp in the United States following four years of state and tribal pilot programs. Industry actors have since been building a hemp industry from the ground up and have been met with many trials and tribulations that have been due to red tape policies, a lack of infrastructure, and broken supply chains. The weakest point in the supply chain is the processing stage as farmers and manufacturers have other crops and materials to choose from while processors exist almost exclusively for the purpose of the hemp industry.

This thesis was designed to uncover the reality that farmers, processors, and manufacturers face in developing domestic hemp fiber supply chains through discussions with industry actors in those occupations. The findings from these discussions were then analyzed through the lens of transition theory and the multi-level perspective. It has been determined that the hemp industry is not yet sufficiently developed in the United States to be a regime due to hindrances in regulations and the availability of processing equipment. The hindrances are holding the industry back from sufficiently developing the myriad of niche innovations that hold potential to transform the textile industry, the building and construction industry, and the pulp and paper industry.

The trials and tribulations of building an industry from the ground up are many but there are as many amazing initiatives taking place from actors inside and outside of the industry that want to see industrial hemp become the crop that they believe it can be.

Keywords: Hemp fiber, hemp hurd, supply chain development, textile industry, pulp and paper industry, building and construction industry, alternative natural materials, transition theory, multi-level perspective, American industry

Executive Summary

This thesis was influenced by a combination of factors concerning the status of human-environmental relationships, agriculture in the United States, and the author's background as a student of environmental anthropology. The Neolithic Revolution brought forth a fundamental change in human-environmental relationships as the practice of agriculture became one of the defining characteristics that separated humanity from the rest of the animal kingdom as well as our predecessors evolutionarily and culturally. For millennia, different civilizations have cultivated and traded different crops native to their part of the world. One of the most common crops cultivated throughout many of these civilizations was industrial hemp (*Cannabis sativa*).

Throughout the time of the original 13 colonies under the British Empire and up until the mid-20th century, farmers across the United States cultivated hemp, primarily for its fiber which is known for its strength, especially in textile applications such as rope, sails, and canvases. However, with the 1937 Marihuana Tax Act, which sought to strictly regulate the cultivation and use of cannabis for recreational drug purposes, the cultivation of cannabis for any purpose ultimately became economically unappealing and the crop's production dissipated. It was soon classified as a narcotic and hemp cultivation would become dormant for the better part of 80 years.

This thesis was inspired by observations of these challenges that contemporary farmers and American agricultural systems face, including soil erosion, nutrient resource depletion, water scarcity, and extreme weather events. Recalling his lectures in environmental anthropology and the study of human-environmental relationships, the author of this thesis developed a strong interest in the return of industrial hemp to American farms following the 2014 and 2018 Farm Bills. Studies have shown that hemp, when compared to other crops as an agricultural commodity, is an environmental regulator in that its deeper root system pulls hard-to-reach nutrients to the topsoil, it has a lower water demand, can be more easily grown without the use of fertilizers or pesticides, and it acts as a highly efficient carbon sink sequestering of 6.7 tons of CO2 per acre (15 tonnes per hectare). It was further observed that following the 2014 and 2018 Farm Bills, the development of domestic supply chains for hemp fiber in the United States has not been without its trials and tribulations. American farmers have taken to cultivating hemp for many of its resources, including its fiber and hurd, while American based manufacturers have been producing goods that utilize this raw material. However, many of these American based manufacturers have been producing goods with hemp fiber material that has been grown and/or processed by actors in foreign countries that have more established hemp fiber supply chains. This gave the impression that the processors in the middle of the supply chain have not developed in their presence and capacity in many parts of the country to the extent that farmers and manufacturers have.

A literature review yielded further insights to the trials and tribulations of the industry and found that each of these three main groups of industry actors in the supply chain face their own set of barriers and challenges. For farmers it was found that a complex set of red tape policies at both the state and federal levels made the cultivation of hemp more of a burden than the blessing they originally had the impression it would be. Processors were found to be slow to develop and emerge around the country and in their capabilities since the necessary processing equipment is expensive and difficult to find. Manufacturers were then found to be largely removed from the issues plaguing the actors preceding them in the supply chain, but this is not to say, however, that they were not interested or involved in the development of domestic hemp fiber supply chains that would be strong, consistent, and reliable. Their interest in sourcing domestically is threefold: reductions to their environmental footprints, decreasing supply chain costs, and increasing supply chain resiliency. Manufacturers in every industry are especially

conscious of increasing supply chain resiliency given the trending supply chain disruptions that have only been exacerbated by the ongoing coronavirus pandemic.

For this thesis, it was decided that the aim would be to uncover the reality of the trials and tribulations that farmers, processors, and manufacturers face in their day-to-day operations and see what the immediate and long-term barriers and challenges are that each group of actors faces. Data collection for this took the form of interviews and discussions with farmers who have or currently cultivate hemp for fiber, processors that are developing, and manufacturers who make use of this raw material. These interviews were conducted as phone calls and the data was recorded in the form of notes in the interview guides that were prepared for each session. These interview guides were structured around a set of three research questions for this thesis. The research questions were: 1) "What barriers and challenges exist for American stakeholders currently engaged, or interested in, the production and industrial use of hemp fiber at any stage of the supply chain?"; 2) "What do these American stakeholders need, in terms of both actions and resources, to support the development of domestic hemp fiber supply chains in the United States?"; and finally 3) "What pathways exist for stakeholders in moving forward in light of their identified barriers and challenges?". The interviews took place as casually paced discussions with an emphasis on a natural flow where additional questions that dug deeper at responses from the informants were ready if necessary.

The findings from these interviews were then put through a content analysis to uncover recurring themes. After this analysis, the findings were then analyzed through the lens of transition theory, specifically the multi-level perspective. The multi-level perspective maintains that the socio-technical landscape is the place that lends context to the status quo of regimes and socio-technical regimes as well as the development of niche innovations. The multi-level perspective deposits that the socio-technical landscape exerts pressures on the socio-technical regimes, eventually creating what is commonly referred to as a "window of opportunity" for a sufficiently developed niche innovation to move into becoming a socio-technical regime in its own right. In the instance of domestic hemp fiber supply chains in the United States, these pressures exerted on the landscape include the aforementioned pressures put on farms in addition to supply chain disruptions and the increasing demand by informed consumers and manufacturers for alternative natural materials that goods are made from. The current regimes are those which hemp can be an alternative to throughout different industries, including corn, soy, cotton, timber, and wood pulp. The niche innovation is not hemp fiber itself but rather the myriad of innovative products that manufacturers have made from hemp fiber including hemp textile material and hemp textile blends for the textile industry; building materials for the building and construction industry including hempwood, hempcrete, and hemp fiber wall insulation; and finally, hemp paper in the pulp and paper industry. It must be emphasized that hemp fiber and its supply chains in the United States are not yet sufficiently developed and capable of taking advantage of the window of opportunity to become a regime.

For hemp fiber and all of its associated product goods to become sufficiently developed and transform from a niche and into the mainstream as a regime of its own, a set of events that correct the bottlenecks must first occur that will enable this change. The major bottlenecks, interestingly, all occur at the beginning of the supply chain with the farmers on their farms. In order of precedence, states must continue to transfer regulatory oversight to the federal level in order to allow for consistent and standardized practices as state pilot programs continue to expire. Fortunately, this is an event that is naturally occurring. Next, the federal restriction on THC content to 0.3 percent must be addressed. This presents itself as the major bottleneck in the development of the industry as it has proven arduous to find strains of cannabis that germinate and grow well in each American climate, will stay below the federally mandated THC content limit, and still grow tall enough to yield quality fiber. Every farmer that informed this

thesis is in favor of an amendment that either increases this limit based on scientific dose-response studies that reveal the actual THC content needed for psychoactive effects to become present or to remove this restriction entirely in cases where farmers are cultivating for fiber. Some of the more experienced famers that informed this study are actively advising congress members in drafting legislation that would amend this law in one of these manners.

Until then, farmers and academic researchers are actively working to address the next two bottlenecks concerning seed supply as well as genetics and germination. One of the more regularly occurring issues farmers deal with is the combination of inconsistent and expensive seed supplies as they are currently dependent on imported supplies from a handful of European states, Canada, China, and Australia. The current and temporary solution to this has been for farmers to form co-ops that raise funds for securing seed supplies. Seed supply issues are coupled with issues of proper genetics that meet the criteria necessary for quality fiber in the local climate while staying below the THC limit and germination which concerns crops being unable to break through the topsoil due to events such as crusting or damages from shipping and storage. Various academic research institutions are working with farmers to produce seeds that have the proper genetics and will germinate under ideal conditions.

Once these major bottlenecks are addressed and resolved, the next set of events that must occur concern connections to the rest of the supply chain. Farmers are largely interested in cultivating hemp for fiber due to the potential for it to be a highly profitable crop as it is used in so many industries. At present, hemp profits are very thin and come with too much risk. In order to make things more profitable they need price point determination, which this thesis's informants felt confident would naturally occur within the next five years given the resolution of the aforementioned bottlenecks. Processors then need for the farmers to supply raw hemp material at a consistent rate to sustain processing operations.

So far, farmers and processors have been in a classic chicken or the egg scenario in their development when the solution needs to be chicken *and* the egg; meaning that a bilateral effort is needed to develop both sets of industry actors concurrently. The biggest hurdle for developing processors is access to capital to secure the necessary processing equipment, namely decorticators which are the machines that first separate the bast fibers from the woody hurd. Manufacturers then need processors to supply processed hemp material at a steady and reliable rate. This requires further market growth which the processor and manufacturer informants felt confident would develop significantly once the supply chain issues hindering development are resolved and domestic supplies are consistently reliable. For a crop with the environmental performance record that it has, manufacturers are largely interested in utilizing hemp as one of the new natural raw materials that contribute to the manufacturing company's environmental impact reduction plan.

This thesis ultimately serves as an overview for industry actors that feel that all odds are against them. The summary provided herein offers farmers, processors, and manufacturers alike a single resource by which they can remind themselves of the big picture they are all working towards as well as a road map for how to get there. The trials and tribulations of building an industry from the ground up are many but there are as many amazing initiatives taking place from actors inside and outside of the industry that want to see industrial hemp become the crop that they believe it can be. Every informant to this study was convinced that hemp fiber not only holds the potential to be a regime in every industry it plays in but that this transformation will take place by the end of the decade, perhaps within the next five years.

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Abbreviations

CBD: Cannabidiol

MLP: Multi-level Perspective

STS: Social-technical System

THC: Delta-9 Tetrahydrocannabinol

USDA: United States Department of Agriculture

VBI: Vertical Business Integration

1 Introduction

The defining characteristic of modern human society was the collective transition of mankind from hunter-gatherer societies to agrarian societies around 10,000 B.C. (Nair, 2017). This transformation is known as the Neolithic Revolution. Contemporary human society began in 1760 with another revolution, the Industrial Revolution, which saw the rise of industrial manufacturing (The Editors of Encyclopaedia Britannica, 2021) and a transformation of Western economies to economies of scale (Hartwell, 2017). This included scaling many farms to that of plantations (Hartwell, 2017). From the events that transpired beginning in 1760 to the beginnings of the fourth agricultural revolution today, human-environmental relationships have changed drastically. This developing agricultural revolution sees the application of the latest technologies, including GMOs, automation, and artificial intelligence to our farmlands and livestock pens. While many of these new technologies seem promising, a familiar crop has recently been granted permission to return to American farmlands – *Cannabis sativa*, or industrial hemp.

Contemporary agriculture is in a peculiar situation as it both contributes to and bares no exception from the effects of the environmental crises ravaging our planet. Specifically, contemporary agriculture is plagued by issues of soil erosion, nutrient resource depletion, water scarcity, and extreme weather events that are increasing in both severity and frequency which include heatwaves, droughts, floods, plus irregular and shifting patterns of precipitation. In response to these issues there have been a range of reactions from social activists and farmers who are all concerned about where these issues may lead if left unchecked. One of the few things that activists and famers can agree on is the need for more regenerative farming methods which have seen increased global application in recent years. Regenerative farming is essentially a change in approach to the methods used in agriculture with a focus on improving the quality of the ecosystem while continuing to cultivate the land and practice livestock husbandry. It seeks to utilize crops that replenish soil nutrients thus improving topsoil health; increase the farmland biodiversity; harbor improvements for local water cycles via the health of the local watershed; utilize ecosystem services; and employ crops that are good at bio sequestration.

Part of what makes hemp an exciting crop is that it is good for regenerative farming, especially if implemented in crop rotations. Cannabis grows with a root system that reaches 45-90 cm deep (Adesina et al., 2020), which is deeper than most other agricultural commodities, and allows it to pull up nutrients to the topsoil. Concerning water needs, hemp has been found to require much less than cotton. One study found that a kilogram of hemp fiber will require as much as 500 liters compared to 10,000 liters required to produce a kilogram of cotton (Cherrett et al., 2005). For biodiversity support and utilization of ecosystem services, another study found hemp to be a heavy producer of pollen which is ecologically valuable for local pollinators such as bees (O'Brien & Arathi, 2019). Finally, hemp is excellent for bio sequestration as found by the same study that looked at topsoil health in hemp fields. That study also found that "one hectare of hemp can absorb 22 tons of CO2 per hectare" which they state is more than some forests (Adesina et al., 2020).

Hemp is a crop that is both old and new to American farmers. During the colonial era, both indigenous *Indian Hemp* and *Cannabis sativa* were widely cultivated as cannabis despite little to no concern for THC levels and it was used mostly for naval purposes of rope, sails, and heavy canvases (Swenson, 2015). Post-revolution and up until the 1937 Marihuana tax Act, hemp fiber, seeds, and oils were used extensively for industrial applications (U.S. Customs and Border Protection, 2019). While the 1937 Marihuana Tax Act only made illegal the use of cannabis for recreational use, anti-doping legislation managed to get industrial hemp caught up in politics

which ultimately led to it becoming less economical compared to crops such as cotton and timber (U.S. Customs and Border Protection, 2019).

For the year 2021, the USDA has reported that a total of 54,152 acres (21,914.5 hectares) of hemp were planted across the nation (Nseir, 2022). This is compared to the 11,025,710 acres (4,461,946 hectares) of cotton, including both extra-long staple cotton and the dominant *Gossypium hirsutum*, commonly referred to as upland cotton or Mexican cotton (Farm Service Agency, 2022). The 2021 numbers for timber harvested for pulpwood are 769,766 CCF which equates to about 1,767 acre-feet (218 hectare meters) (U.S. Forest Service, 2021). While reliable market data remains scarce given the crop's decades-long absence, the United States Department of Agriculture (USDA) Economic Research Service published a report in 2000 that synthesizes the findings a 1995 report from the Kentucky Task Force and found that the potential net returns for hemp fiber ranged from a "low price/low yield estimate of -$170 [USD] per acre to a high price/high yield return of $759 [USD] per acre" (-69 to 307 USD/hectare) (Economic Research Service, 2000).

If this felicitous crop is to play a meaningful and impactful role in mitigating these issues, then we need to utilize hemp to its fullest extent and develop supply chains that take it from seed to shelf in an efficient and timely manner. Further, while there are many American farmers growing hemp and some manufacturers producing goods from hemp textile material, the middle part of that supply chain needs development as manufacturers import most of their hemp textile material from other countries. Also considering the current global supply chain shortages exacerbated by the ongoing COVID-19 pandemic, it is even more appropriate to develop a fully domestic hemp fiber supply chain. It is also beneficial that a fully domestic or concentrated supply chain is most likely to be much less carbon and resource intensive than a global one.

1.1 Problem Definition

The drug-related legislation hemp's Cannabis counterpart was subjected to had adverse effects on hemp as well, which ultimately led to the dissipation of the hemp industry during the first half of the 20th century. The general status of hemp fiber in the textile industry is best put by Malone & Gomez (pg. 7, 2019): "Since the cultivation of industrial hemp is strictly regulated, supply chains are broken or nonexistent in the United States." Industrial hemp is a crop with a wide range of industrial applications. Hemp also offers considerable environmental benefits for farmlands that face the issues of soil erosion, nutrient resource depletion, water scarcity, and various extreme weather events, making it an ideal option for practicing regenerative agriculture. However, despite these marketable benefits and the growing market demand from American consumers post-legalization, the industrial conditions and differing regulatory policies between state and tribal pilot programs in the United States currently, has presented barriers and challenges for establishing dependable and robust domestic hemp fiber supply chains.

Now, with hemp's newly granted legal status and lucrative appeal, American farmers across the nation jumped at the opportunity to gain experience in cultivating hemp. The market for hemp products shifted around for a few years as farmers experimented with cultivating hemp for different resources, including grain, seed oil, flower, CBD, and fiber. The most success farmers had was initially in the CBD market which itself has grown massively in the years since legalization, but not without its own trials and tribulations - especially over rising concerns with CBD-derived delta-8 THC. More recently, the market for hemp has shifted to fiber and more farmers have begun to attempt to cultivate specific varieties of hemp that yield high-quality fiber, thus allowing them to act on the growing interest from actors in other industries. While there is considerable interest and demand from the textile, building and construction, and pulp and paper industries for hemp fiber, the multi-generational absence of hemp has created a

situation where involved actors are having to build an entire industry from the ground up with no native varieties to start with. During the 80 years hemp has been absent from American farms, agricultural supply chains have evolved. Changes have occurred in how farmers harvest raw materials, how they are distributed, and how they are made into goods. There are American farmers cultivating hemp for fiber and there are American-based manufacturing companies that are producing goods and products out of hemp fiber but many of those manufacturers are souring their hemp fiber from foreign suppliers. This gives the impression that the middle part of the supply chain concerning processing is not as developed in the United States as the stages around it. This situation is visualized in Figure 1 below.

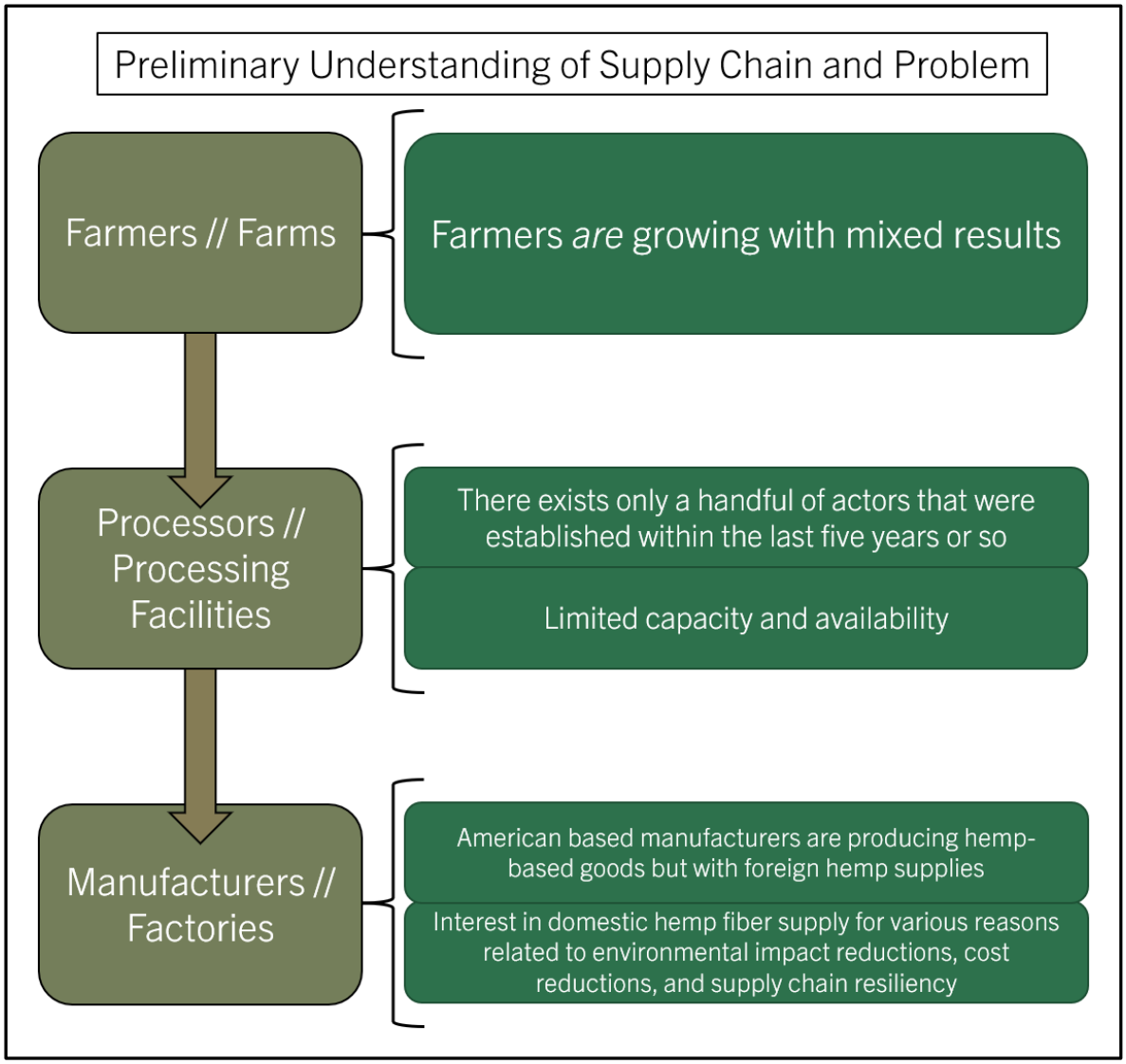

Figure 1: Preliminary Understanding of Supply Chain and Problem

Actors and stakeholders across the supply chain are searching for pathways to connect their pieces of the supply chain with others in an entirely domestic setting. It is not known what the specific challenges are that these actors and stakeholders face. The field is constantly evolving and adapting to new regulations and opportunities. What is known, is that manufacturers are interested in contributing to the development of entirely domestic hemp fiber supply chains in the United States as its benefits would be threefold: reductions to their environmental footprints, decreasing supply chain costs, and increasing supply chain resiliency. Manufacturers

in every industry are especially conscious of increasing supply chain resiliency given the trending supply chain disruptions that have only been exacerbated by the ongoing coronavirus pandemic.

1.2 Aim and Research Questions

The principal aim of this thesis is to support stakeholders and initiatives that are seeking to connect and develop domestic supply chains for hemp fiber-based products in the United States. As such, initiatives may ultimately lead to environmental improvements by expanding the market for, and thus the production of, locally grown hemp and by enabling further supply of domestically produced hemp-based products that may replace alternatives with a significantly higher environmental impact. By answering the research questions below, this thesis seeks to address the knowledge gap identified above and *identify pathways for hemp industry stakeholders to continue to grow their operations.* The stakeholders identified are industry actors who hold positions of farmers, processors, and manufacturing companies. A set of research questions have been generated to achieve this aim.

- *"What barriers and challenges exist for American stakeholders currently engaged, or interested in, the production and industrial use of hemp fiber at any stage of the supply chain?"*
- *"What do these American stakeholders need, in terms of both actions and resources, to support the development of domestic hemp fiber supply chains in the United States?"*
- *"What pathways exist for stakeholders in moving forward in light of their identified barriers and challenges?"*

The ideal outcome that develops from the successful achievement of the research aims are an identification of the ideal conditions for a vibrant market for hemp fiber products across the textile industry, building and construction industry, and the pulp and paper industry. This thesis is not intended to completely solve or eradicate the barriers and challenges that stakeholders face but may still identify potential pathways for development or offer suggestions. As demonstrated later in Section 2.1.4, the industry goals for developing domestic hemp fiber supply chains in the United States held by the author of this thesis are shared by numerous actors across all associated industries, various levels and branches of government, and other actors such as organizations and academic institutions.

1.3 Scope and Delimitations

As this study is focused on domestic supply chains in the United States, but this is also a master's student thesis project with limited time and resources, the scope is limited to companies and practitioners in the contiguous United States, most of which will be in the southeastern United States as the research is being carried out from North Carolina. Various European countries, plus Canada, China, and Australia already have supply chains developed for hemp fiber and have been providing seeds, raw hemp material, and processed hemp material for American based manufacturers to source. This thesis is focused on the ground-up development of hemp fiber supply chains from almost nothing in the United States.

1.4 Ethical Considerations

1.4.1 Researcher honesty and personal integrity

For full disclosure it should be stated that I am a proponent of hemp in all its applications, especially for fiber. However, the purpose of this research project is not to assess nor promote the benefits of hemp but rather focus on identifying potential pathways to recreate domestic industrial production and assess the challenges therein. Bearing this in mind, I am an independent researcher and am not affiliated with any organization or influencing agency outside of my advisors in the International Institute for Industrial Environmental Economics. All thoughts, ideas, assessments, and conclusions are my own unless otherwise noted.

1.4.2 Ethical responsibilities to the subjects of research, such as consent, confidentiality, and courtesy.

Ethical considerations have been considered, participation in this research project is voluntary, anonymity has been preserved, and there is no reason to suspect that harm or damage may come to the research informants or their reputation. All information and data collected from interviews is stored in a password-protected file that is locally located on a hard drive and not in a cloud service.

1.4.3 The outcomes of research – what may the findings be used for.

The anticipated outcomes of this thesis do not indicate plausible harm to the reputation, dignity, or privacy of any involved individual or organization. All information provided is completely voluntary and backed by forms of consent. If an instance occurs where an informant needs to be identified, they will be anonymized and referred to by appropriately vague means.

1.4.4 The way you handle, store, and/or make available data records.

All spreadsheets and transcripts that contain identifiable information will be kept on a local hard drive and not stored in any cloud service. No information that would be potentially damaging to any research subject will be recorded. This measure will be taken so that no damaging information has any potential to leak.

1.5 Audience

This thesis project has been designed to support the development of the industrial hemp industry in the United States overall but is especially relevant for practitioners along the hemp fiber supply chain. This includes farmers who cultivate hemp for fiber; processors who process hemp biomass for use in textiles, building and construction, and paper; and manufacturers who buy processed hemp material to manufacture products various products and goods for use in the identified industries. The findings of this project are additionally relevant to outside actors such as the governments of various states and the federal government and others who provide access to capital or invest in hemp fiber companies and the development of supply chains.

1.6 Disposition

Chapter 1 kicks off this thesis with a surface level look at the problem under investigation, the history of the topic, why it is relevant, and what the research aims questions are. It then considers the scope of the research, ethical considerations, and finally addresses who the research is intended to benefit.

Chapter 2 moves to the literature review which begins with an in-depth introduction to transition theory and the multi-level perspective. A framework is then introduced based on this theory in the form of a to-do list for industry actors. It moves then to a more in-depth examination of what is currently known related to domestic hemp fiber supply chains in the United States. This section takes a funneling approach by beginning with a look at human-environmental relationships and how that relationship has led to the issues contemporary agriculture faces today and why industrial hemp is a felicitous solution to begin addressing them. It then moves to survey some of the more noteworthy and easily identifiable industry actors.

Chapter 3 concerns the research design and methodology.

Chapters 4 through 6 compose the second half of this thesis and are reflective of everything post-data collection. Chapter 4 specifically looks at the findings from the data, or what the actors that informed this study shared about their perspective positions in the industry. This information is presented based on the framework introduced in Chapter 2. It then concludes with an analysis of the findings to identify the bottlenecks in the development of the industry.

Chapter 5 takes the bottlenecks from Chapter 4 and offers suggestions for how industry actors could choose to address them.

Chapter 6 offers some concluding remarks.

2 Literature Review

2.1 Theories, Tentative Explanations, and Conceptual Frameworks of Relevance to Domestic Hemp Fiber Supply Chains

2.1.1 Socio-Technical Systems and Transitions

Like all supply chains, domestic hemp fiber supply chains are socio-technical systems (STS) and their development from niche to mainstream can be examined through the lens of transition theory and the multi-level perspective (MLP). STS are composed of hardware and software components. In the case of hemp fiber supply chains, the hardware would consist of[1] the hemp material including the bast fibers and the hurd, the farm resources for growing and cultivating, the machinery to harvest and process, financial capital at each stage, and the necessary energy inputs along the way. The software components include[2] the physical labor of workers, the necessary skills and knowledge at every stage of the supply chain, the organizations and companies behind every decision, and every other stakeholder and actor with influence on the system in the hemp industry and associated industries.

The hemp industry is defined by the set of processes and outcomes it engages with. The processes include all the interrelated actions or tasks that transform inputs into outputs. In the context of the hemp industry, this is commonly referred to as "seed to shelf" as it describes the holistic process beginning on the farm, through processing and manufacturing, and ending as products for consumer and industrial use applications found on the market.

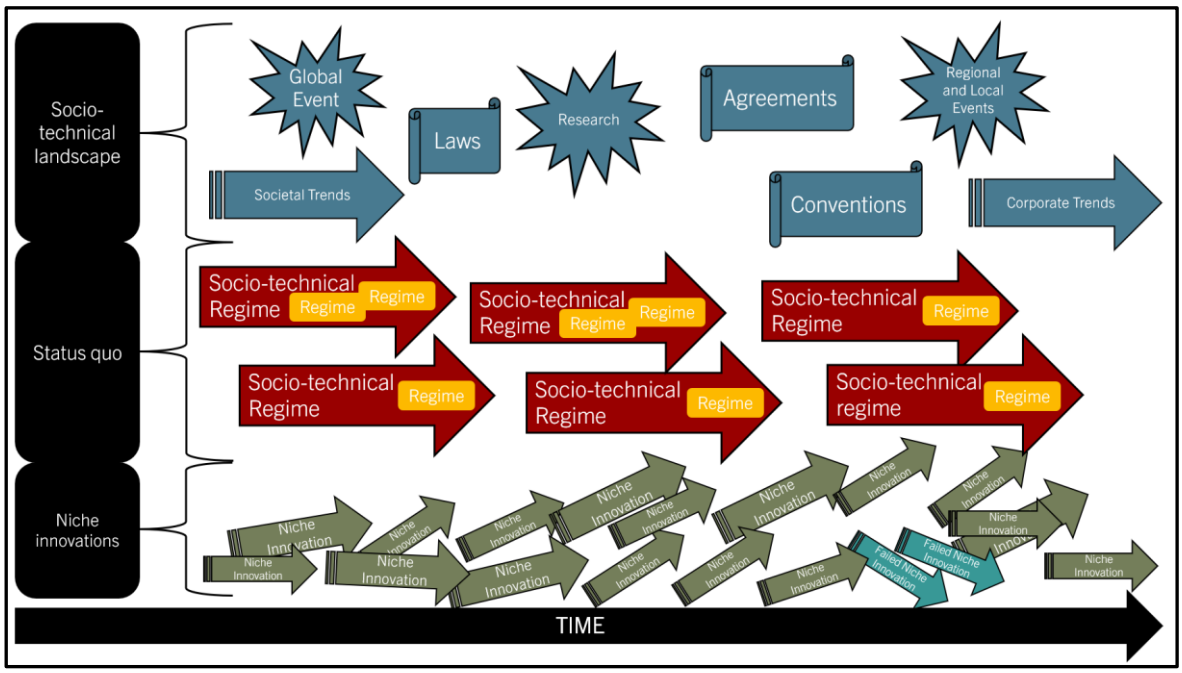

Figure 2: The Multi-level Perspective Phase 1

One of the more referred to iterations of transition theory employs the multi-level perspective which deposits that socio-technical regimes and niches exist within a socio-technical landscape (Geels, 2002). Figure 2 offers a visual of what the MLP looks like before transitions occur. The

[1] This is a non-exhaustive list of every individual hardware component but instead a summary of the major inputs.

[2] This is a non-exhaustive list of every individual software component but instead a summary of the major imputs.

socio-technical landscape (top row of items in Figure 2) is shaped by major events and describes all the context and trends throughout society regarding the regimes and niches. The regimes referred to here can be thought of as the status quo (middle row of items in Figure 2) and can be split into two categories: technological and socio technological. The former (yellow boxes inside red arrows in Figure 2) is the *technology, resource, or product* produced by the latter (red arrows in middle row of items from Figure 2) which refers to all the *people*, be it the users, policy makers, societal groups, etc., that influence and interact with the socio-technical landscape as well as the *processes* they employ in producing the technological regime. Finally, the niches (bottom row of green arrows in Figure 2) that exist within this socio-technical landscape are the radical innovations that are developing and are taking shape, most often in response to the issues and challenges manifested by the interactions between the socio-technical landscape and the status quo.

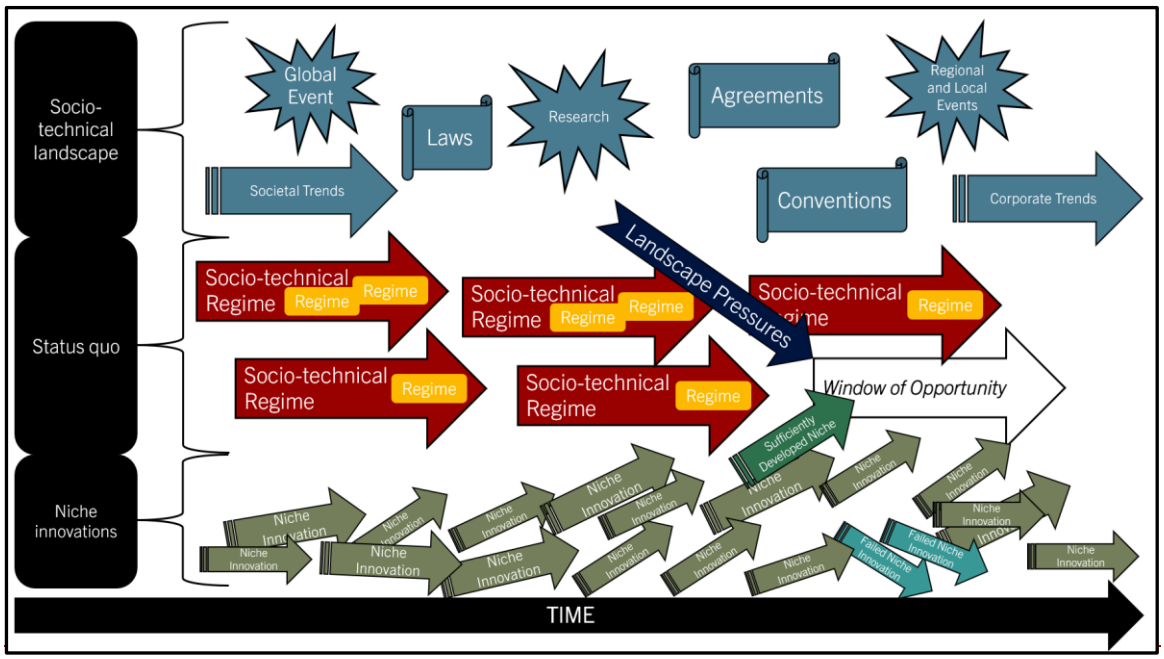

Figure 3: The Multi-level Perspective Phase 2

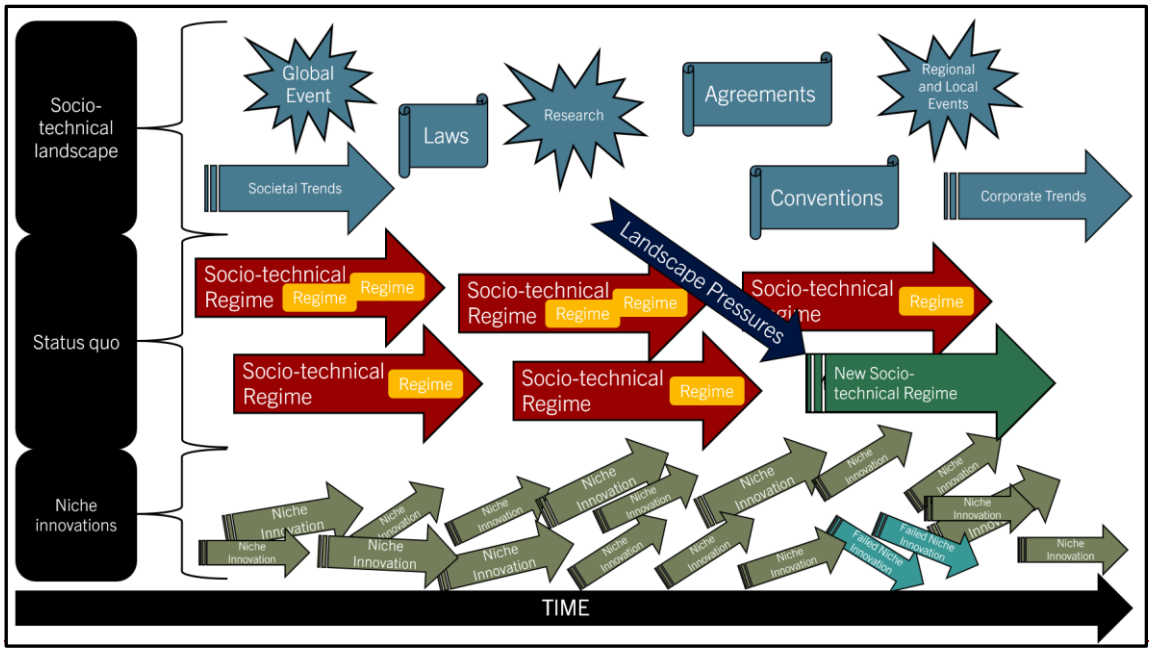

Figure 4: The Multi-level Perspective Phase 3

The MLP states that socio-technical transitions occur under three conditions: 1) when there is significant pressure from the socio-technical landscape; 2) when regimes become unstable and open for changes; and 3) when sufficiently developed niche innovations are made available following thorough development (Geels, 2002). Figure 3 provides a visual for these three criteria while Figure 4 visualizes a completed transition of a niche innovation into the mainstream. The interactions between the cumulative socio-technical landscape pressures and the regimes in the status quo destabilize certain socio-technical regimes and technological regimes creating what is often referred to as a "window of opportunity" for sufficiently developed niche innovations to emerge as new regimes in their own right. These sufficiently developed niche innovations may be technological niches, socio-technological niches, or both.

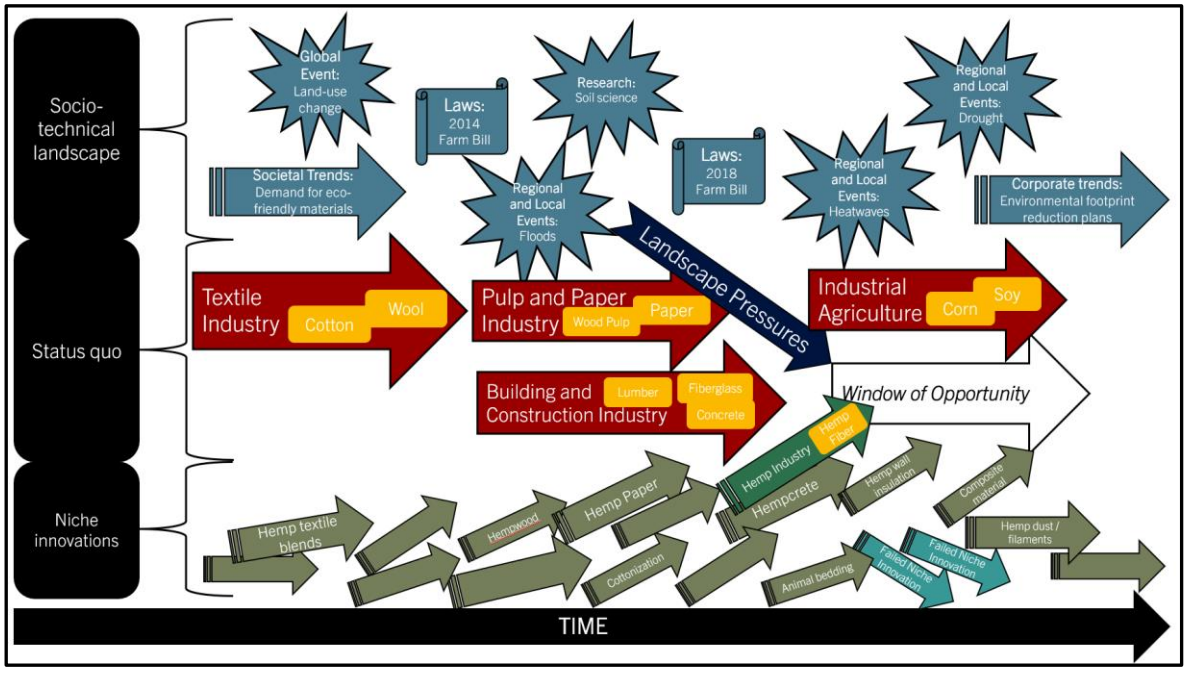

Figure 5: The Multi-level Perspective application to hemp fiber Phases 1 and 2

In the context of hemp fiber in the United States, visualized by Figure 5, it is today a niche that is taking shape in response to the issues created and aggravated by the interactions between the socio-technical regimes in the status quo and the pressures exerted from the socio-technical landscape. Hemp fiber itself is not the niche innovation. The developments of hemp fiber goods and products are the niche innovations that are often collectively referred to as the hemp (fiber) industry which is a socio-technical niche. The socio-technical regimes concerning the hemp industry include several other industries surrounding industrial agricultural, textiles, pulp and paper, and building and construction. The socio-technical landscape is the space that is home to the contextual events from actors who engage as federal and state legislators, the USDA, advocacy organizations, and all the actors along the different stages of the developing supply chains. This space includes[3] major events at the global and local levels such as land-use change and extreme weather events; new and amended laws such as the 2014 and 2018 Farm Bills; plus, new research outputs and findings from various institutes such as studies on advancing soil erosion, nutrient resource depletion, and the environmental regulatory performance capabilities of hemp. All of these contextual events in the socio-technological landscape interact with the regimes in the status quo and create pressure that destabilizes the regimes. For hemp, this means that the textile industry is looking for alternative natural fibers while both the building and construction and pulp and paper industries are looking for alternative bio sources that can be harvested with less impact on the environment. The technological regimes themselves are the products of those industries including, but not limited to, corn, soy, cotton, synthetic fibers, lumber, wood pulp, fiber glass, and fossil-based plastics.

The three research questions presented in Chapter 1 of this thesis can be linked to the three criteria of the MLP. The first research question, which examines what barriers and challenges exist for actors in the supply chain, can be linked to an investigation into the nature of and the interactions between both the socio-technical landscape pressures and the regimes. The second research question, which concerns the needs of industry actors, is linked to the development of the niche innovations industry actors are working towards. Finally, the third research question, examining the potential pathways for stakeholders, is linked to all three criteria as specific technological niche innovations require exploitation of specific socio-technical landscape pressures and windows of opportunity from different industries already in the status quo.

The case has been made for actors in the aforementioned industries to look for alternative natural sources of raw materials for their production based on these three criteria. There already exists tremendous pressure from the socio-technical landscape today in the form of various environmental crises including soil erosion, nutrient and resource depletion, water scarcities, irregular and shifting patterns of precipitation, extreme weather events increasing in both frequency and severity, deforestation, biodiversity and habitat loss, immense land-use change, damaging biogeochemical flows of nitrogen and phosphorus from fertilizers, and drastic levels of pollution – all of which influence one another. There are additional pressures from the socio-technical landscape related to matters concerned with supply chain disruptions stemming from container shortages, transportation network fragility, labor shortages, workers' rights and abuses, worker safety concerns, and more recently a pandemic which has further exacerbated all of this.

These pressures were created by a dependency on overly complex and equally fragile supply chains, distribution networks, and material harvesting allowing for the current regimes to become unstable and widely showcased as such with recent events including, but not limited to, the blocking of the Suez Canal in March 2021 (Leggett, 2021), global Amazon strikes in late

[3] This is a non-exhaustive list of every contextual event that would exert pressure from the socio-technical landscape and is instead intended to be an exemplary summary of key events

2021 (Azees, 2021), and ongoing droughts across the American West, High Plains, and South regions (National Drought Mitigation Center, 2022). The blocking off the Suez Canal is an example of a situation that has manufacturers across all industries looking for options that would enable increases to supply chain resiliency and cost reductions. Similarly, the Amazon worker strikes have been provocative in sending manufacturing companies in search for resolutions that would ease internal pressures that, when resolved, would enable further increases to supply chain resiliency in addition to granting fair worker wages and safety. Lastly, the ongoing droughts across much of the interior United States have led to necessary increases in irrigation which only make worse situations of water scarcity for local and regional watersheds. For the textile and agricultural industries, there are specific issues unique to the production and cultivation of cotton as a contemporary agricultural commodity that the other industries are not as concerned with. These include soil erosion, nutrient and resource depletion, water scarcities, land-use change, and damaging biogeochemical flows of nitrogen and phosphorus from over-fertilization leading to decreases in plant growth and diversity, eutrophication, and water pollution which all-together ironically often necessitates increased fertilization. Similarly, there are unique issues stemming from the timber industry that feeds both the pulp and paper industry and the building and construction industry such as deforestation, biodiversity and habitat loss, and land-use change.

The combination, then, of these socio-technical landscape pressures and the instability of regimes has collectively led industry actors in search of alternative raw materials to experiment with and a common potential alternative of these industries is hemp fiber. What is left for the niche of hemp fiber to transition into the mainstream as a technological regime comes down to what can be viewed as a checklist of events and situations which address the bottlenecks of the developing industry. Once these bottlenecks have been sufficiently addressed, the hemp industry will be poised to take advantage of the "window of opportunity" created by the interactions of the socio-technical landscape pressures and the status quo. Then, following expansion of the market for hemp-based products, hemp fiber's resurgence in American agriculture and industry may be fully realized. This is visualized in Figure 5.

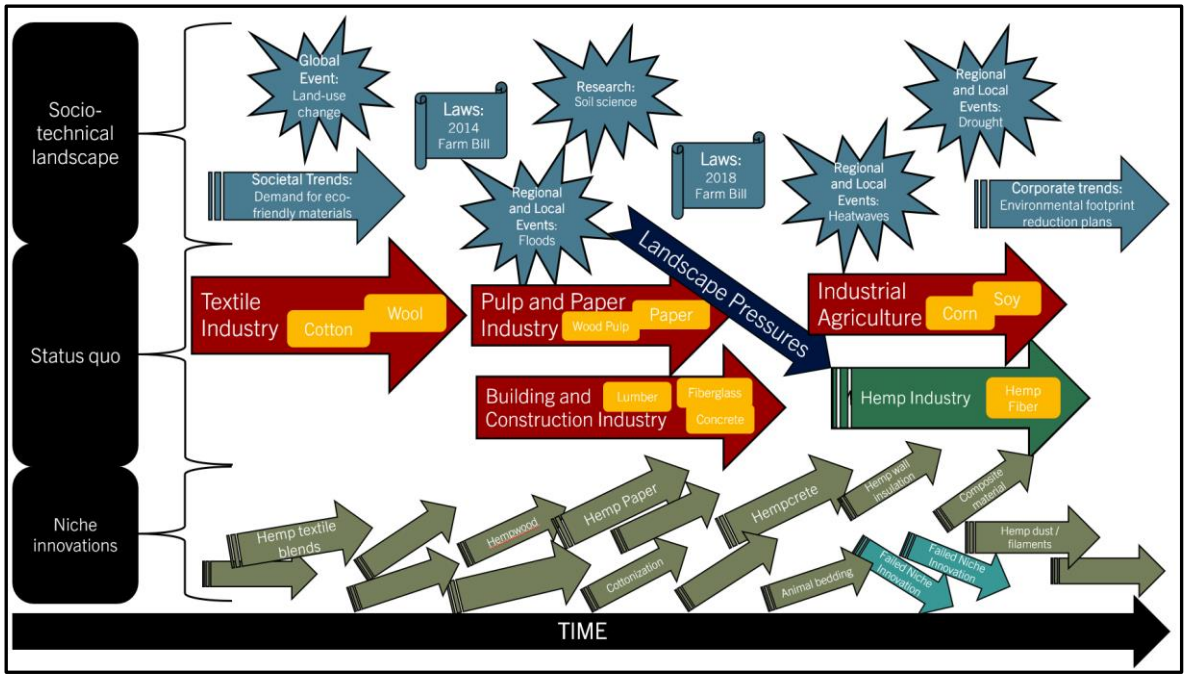

Figure 6: The Multi-level Perspective application to hemp fiber Phase 3

2.1.2 Transition Pathways and Building a Checklist

There exists a number of transition pathways, or ways for hemp fiber to transition from a niche into the mainstream as a regime. The most likely transition pathways for hemp fiber include *reproduction*, which is when there is an ongoing change at the regime level; *technological substitution*, which is when a regime(s) grows incumbent and is subsequently replaced by a revolutionary innovation; and *dealignment and realignment*, which occurs when an existing regime's weaknesses pave the way for something new. The general preference for actors in the textile industry is for hemp to not replace cotton or other fibers entirely but emerge and exist alongside them for the purpose of various textile blends, each with their own use cases. For actors in the other industries that have been experimenting with hemp fiber, it is beginning to be viewed more favorably as an absolute alternative to the existing regimes as experimentation continues to yield promising results. This is the case for hempwood (Crye, 2020), hemp wool insulation (*HempWool*, 2021), hempcrete (Hempitecture, 2021), and hemp paper (Printed On Hemp, 2022; TreeFreeHemp, 2020).

Perhaps, then, in the case of domestic hemp fiber supply chains in the United States, a mix of all three transition pathways described above would be preferable. Hemp fiber, or rather hemp as a whole, holds the potential to bring strides in addressing the wide range of issues and challenges already described in this thesis but no one is expecting it to solve them completely and independently. Hemp fiber is currently on a trajectory to be advantageous given the existing issues in the current regimes, but it is entirely plausible within a few decades another source of fiber, such as jute, bamboo, or even mushrooms will become equally favorable or greater for the same purposes. This is the basic argument for why the reproduction pathway is favorable; it is an ever-evolving space where regimes exist in the landscape. Before hemp fiber can enter that space, however, it must exploit the weaknesses in the current regimes and assert itself as a solution to them, making use of the dealignment and realignment pathway. Further, the multitude of industries it can play in is only going to work as an advantage for hemp fiber. With so many industries interested in further exploring hemp's potential uses and benefits there is a considerable amount of push for the increase in processing capability of hemp fibers that will ultimately lead to technological substitution as supply chains continue to be built out and developed.

If a checklist of conditions and analyses were to be assembled as a framework for industry actors following these pathways, it would include three main steps, each with their own series of agenda items. This is visualized in Figure 6 below.

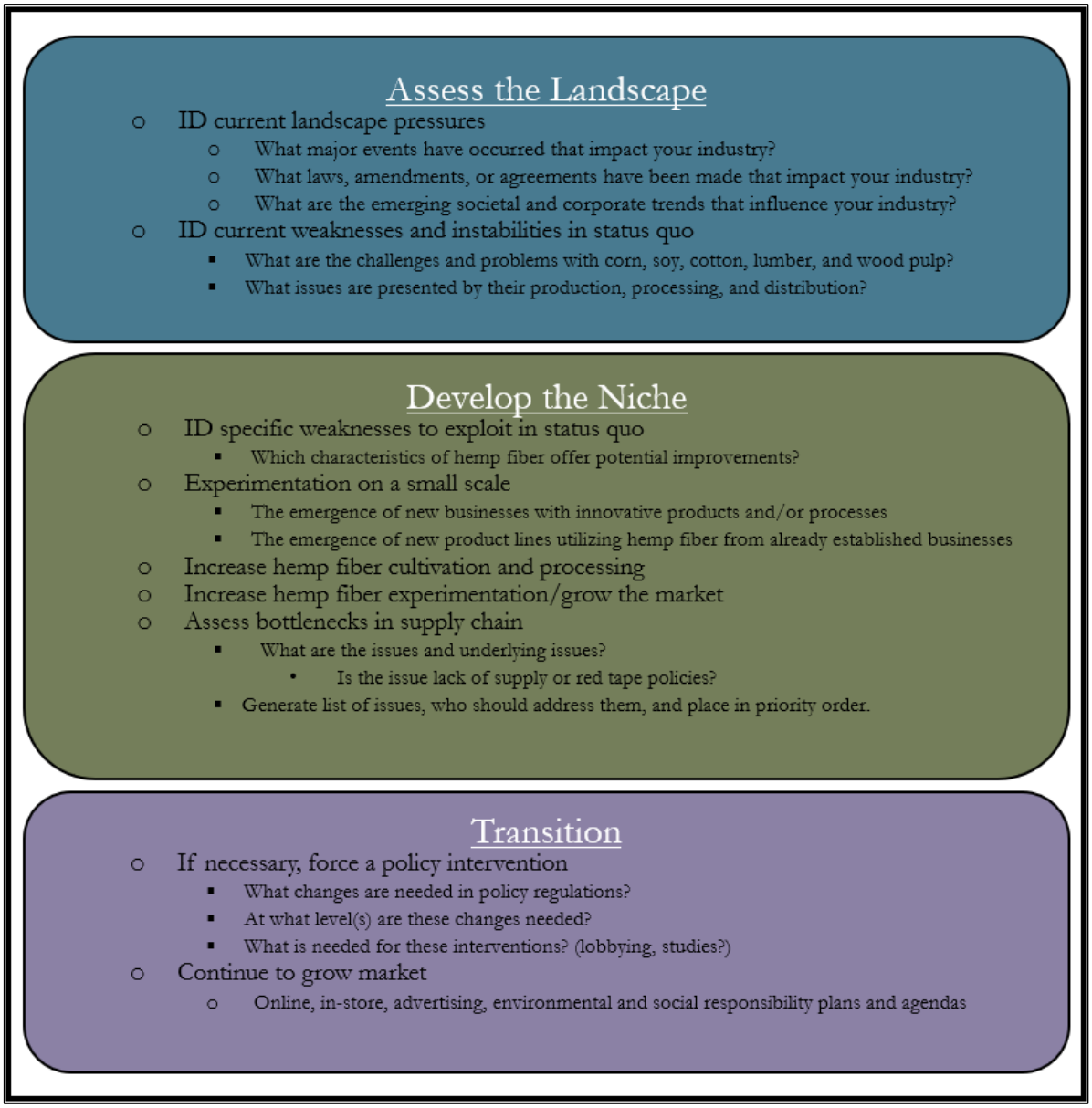

Figure 7: A Framework for Industry Actors in Search of Transitions

2.2 Current Knowledge Related to Domestic Hemp Fiber Supply Chains

2.2.1 The Environmental Benefits of Hemp Cultivation

Industrial agriculture today often contributes to and endures the issues of soil erosion, nutrient resource depletion, water scarcity, and extreme weather events including floods, droughts, heatwaves, as well as shifting and irregular patterns of precipitation. Soil erosion and nutrient resource depletion, particularly of topsoil and of phosphorus, respectively (Alewell et al., 2020), run in increasingly intensifying cycles together with increased fertilizer and chemical use (Erdenesanaa, 2021). Water scarcity brings forth another set of complicated problems. Industrial agriculture often requires irrigation, which is the provision of water to a field or crops at regular intervals through artificial means such as dug canals or water sprinkling systems in order to supply sufficient amounts of water to the crops when natural precipitation is scarce (National Geographic, 2011). In order to supply these irrigation systems with water, accessible bodies of

water are required, such as lakes or rivers on the surface, or groundwater sources – all of which are depleting due to intensifying droughts, heatwaves, land-use changes, and shifting patterns of precipitation (Porkka et al., 2016). At the same time, when heavy rains follow a time of little to no precipitation, there is immense topsoil erosion leading to polluted water sources (Gilley, 2005) that lead to additional environmental damages such as sedimentation and reduced water quality.

Industrial hemp cannot reverse these trends on its own, but it is a crop that can make strides in doing so. Adesina et al. (pg. 1, 2020) state that "Hemp... has significant environmental benefits since it has the potential to remediate contaminated soils through phytoremediation, convert high amounts of atmospheric CO2 to biomass through bio-sequestration, and hemp biomass for bioenergy production." Cannabis grows with a root system that reaches 45-90 cm deep (Adesina et al., 2020), which is deeper than most other agricultural commodities, and allows it to pull up nutrients to the topsoil. Ranalli & Venturi (pg. 2, 2004) found that hemp is a water saver as well, "requiring 250–400 mm of water, ...much less than other conventional crops." A report from a 2005 study conducted by the Stockholm Environmental Institute in the United Kingdom stated that 300-500 liters of water are required to produce one kilogram of hemp fiber whereas an average of 10,000 liters are required to produce one kilogram of cotton (Cherrett et al., 2005). No single crop can do anything about reducing extreme weather events, but hemp can contribute greatly to increasing a farms resilience to extreme weather events by way of mitigating the other issues.

2.3 Industrial Hemp in the United States

The Agricultural Act of 2014 (the 2014 Farm Bill) brought new opportunities for farmers across the nation and many state governments as it allowed for states and tribes to establish their own industrial hemp pilot programs after 45[4] years of hemp absence (Mark et al., 2020). This was exciting not just for farmers, but for conservationists as well due to the wide-ranging environmental benefits of hemp cultivation (Adesina et al., 2020). The general positive attitude farmers had towards hemp from 2014 to 2018 indicated overall success of the state and tribal pilot programs from 2014 which led to a provision of the Agricultural Improvement Act of 2018 (the 2018 Farm Bill) federally legalizing industrial hemp (*Cannabis sativa*), also referred to simply as hemp. Specifically, it removed hemp from the Drug Enforcement Administration's schedule of Controlled Substances and directed the United States Department of Agriculture (USDA) to generate regulations for cultivation beyond the state or tribal pilot program's expiry date (USDA, 2021). Those early years under the pilot programs were prosperous for the re-emergence of industrial hemp and the farmers involved, especially those cultivating hemp for CBD, with market prices around $40-45 per pound ($88-99/kg) of hemp biomass (Quinton, 2021). Come 2019, however, market prices began to plummet before finally reaching around $2.50 per pound in December 2020 (Oleck, 2020). These newly experienced hemp farmers became rightfully hesitant to plant more when they still have leftover stock from 2019 filling their freezers and barns while they wait for better market prices and demand (Quinton, 2021).

This dilemma begged the question, for a crop that had been so heavily championed by farmers and conservationists alike, with the immense successes to back them, why the sudden tribulations? This question was the focus of a preliminary mini study designed to support this thesis. The preliminary study found that the issue of price plummets was the result of a market glut generated by farmers oversupplying hemp biomass while there were not enough processors

[4] 45 years if counting the brief stint during WWII, otherwise most non-government sources cite 80 years since it was last cultivated as an agricultural commodity

to keep up with the demand. This was further complicated by legal regulatory discrepancies between state/tribal and federal legal statutes. Furthermore, it was found that most of the hemp cultivation and processing in the United States was for hemp seed oil and CBD extracts for use in a variety of products applicable to a range of industries. This even further contributed to the legal discrepancies as delta-8 THC (Tetrahydrocannabinol), derived from legal CBD, was later found to be contributing to a legal loophole that allowed quasi-legal THC, the psychoactive compound in marijuana. However, these issues of over supplying, low processing capacities and options, and legal regulatory discrepancies are felt by farmers cultivating hemp for any of its resources.

Following these market gluts in the CBD market, the hemp market in general began to shift more heavily to fiber. The development of infrastructure and the building out of domestic supply chains for hemp fiber in the United States has been comparatively slower for fiber than for hemp seed oil and CBD extracts. The processing of hemp fiber requires specialized equipment that is scarce to find in the United States and is expensive to have imported from countries that do manufacture the necessary equipment. The development of domestic hemp fiber supply chains is outlined in the next sub-section.

2.3.1 The Hemp Fiber Supply Chain

There are existing and extensive bodies of literature on supply chains both in the general sense but also for the different industries specifically. There is also some peer-reviewed literature (Duque Schumacher et al., 2020; Fike, 2016; Shahzad, 2012), but mostly grey literature (Hemp Benchmarks, 2021; Nichols, 2022), on the hemp industry in the United States of which some concerns the use of hemp fiber. Most of this literature, however, is concerned with performance comparisons, cultivation and growing practices, and resource cost comparisons. There is little in the way of specific pieces for hemp fiber supply chains. What is in plentiful supply are government reports, advocacy organization documents, and news publications that speak on the legal regulatory uncertainties that many famers and processors experienced after federal legalization and how many practitioners went about addressing this dilemma. To summarize these uncertainties, many practitioners were unsure how the legalization of hemp after the 2018 Farm Bill would change the way in which they were regulated. Many were uncertain if they would continue to be regulated by their pilot program that had yet to expire or if they would fall under federal regulation as federal laws generally apply before state or tribal laws.

Many of these advocacy organization documents and news pieces also indicated that a popular approach that practitioners are taking up in response to both the legal uncertainties and to a lack of supply chain infrastructure is of vertical business integration (VBI) (Bennett, 2021). VBI allows the practitioner to control the quality of their product but also avoid the sources of some of their uncertainties (Tarver, 2021). This is commonly referred to as "seed to shelf" management in the context of hemp.

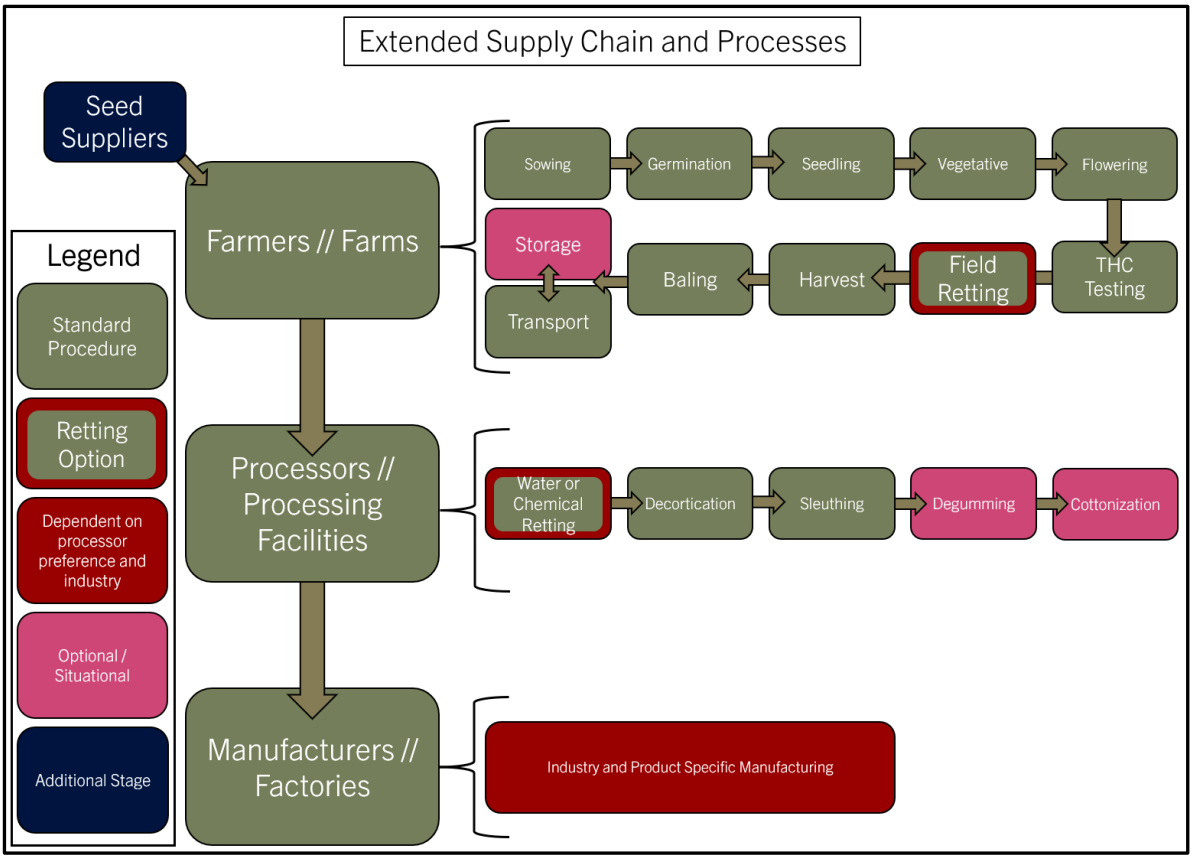

Figure 8: Extended Supply Chain and Processes

The supply chain for hemp fiber generally follows the same stages as other fibers but with the appropriate differences in processing and the addition of a laboratory testing stage, per federal regulations. This is visualized in Figure 8 above.

The Farming Process

Farmers must first obtain seeds before they can produce any crop. Seeds are purchased from seed suppliers which are their own entities. After the land has been cultivated, farmers can sow their seeds which is the process of scattering or planting seeds in the topsoil. Assuming ideal conditions of moist and warm soil are met, germination should occur within a few days of dormancy (Amsterdam Seed Supply, 2018). Germination is the process of a seed transitioning into a spore and breaking through the topsoil. The crop then grows in both directions with the plant's iconic leaves emerging up top and the roots establishing down below which is indicative of being in the seedling phase (Luce Farm, 2019). Most of the plants vertical growth then occurs during the vegetative phase. When cultivating for fiber, farmers are hoping for the plants to grow close to its maximum height around 15 feet (4.5 meters) (Ag Marketing Resource Center, 2022). Finally, the crop begins to show signs of maturation when buds appear, and purple/pink flowers emerge (Luce Farm, 2019). It is in these buds where most of the crop's cannabinoids are. However, when cultivating for fiber, farmers will harvest their fields before the flowering phase can be completed (Harper et al., 2018).

In most instances, farmers will kick off the processing stage before selling to processors. Specifically, they oversee the retting phase which has three variants, one of which is field retting and is the only one that farmers may be responsible for. Retting is what allows for easy separation of the bast fibers from the core of the stalk in later processing stages (USDA ERS, 2000). In field retting, the crop is first cut at most a few inches off the ground if not as close to

the ground as possible. It is then left scattered on the field, often where it was left to naturally lay after being cut for up to five weeks. Moisture is the key here but microorganisms on the stem and in the soil also play a vital role. The idea is to let the moisture from rains and dew create an environment for the microorganisms to breakdown the outer layer of the stem. It will turn from green to a yellowish color and must be turned occasionally to allow for even retting which is complete when it darkens in color. Farmers must be careful to not allow over-retting to occur nor to allow the crops to soak for too long so they can dry out properly for bailing. Despite oftentimes yielding lower quality fiber than alternative retting methods, this natural retting method is often favorable as it is an inexpensive and mechanized process which requires no additional resource inputs.

Farmers then dry the stalks and bale them in round or square bales before either selling them straight to the processors or storing them in a facility (Harper et al., 2018). The specifics of this process may vary based on processor agreements and which industries the processors supply material for.

The Processing Process

The first stage is the retting, which if not performed by the farmers with field retting, becomes the responsibility of the processors. Water retting is the second of the three variants and is less common in the United States (USDA ERS, 2000). In water retting, the stalks are submerged in bacteria-rich tanks or natural bodies of surface water. While this variant of retting yields higher quality fiber, the process is very labor and economically intensive as it has to be frequently monitored as well as being subjected to stricter environmental regulations before the used water can be discharged naturally or in municipal wastewater treatment plants. The third and final variant of retting is chemical retting and much like water retting, is labor and economically intensive while also required specialized knowledge to properly perform. Water and chemical retting may be advantageous over field retting for both time and fiber quality.

The next major step is a mechanical separation process known as decortication and is the process by which the soft bast fibers on the exterior of the stem are separated from the tough woody interior hurd. This itself is a multi-step process that begins with a machine properly referred to as a decorticator. This machine takes the stalks and runs them through fluted rollers that break the woody hurd into smaller pieces that then naturally separate from the bast fibers. The remaining broken pieces of hurd are then removed through scutching, which is essentially beating the remnants out, often through additional rubber rollers or beating them with revolving drums.

The separated bast fibers are then processed depending on their industrial applications. For most use cases aside from textiles, the bast fibers will retain their natural glue or lignin. Bast fibers that are to be used then for textiles will undergo a degumming process that also comes with some variance but ultimately separates the fibers from the lignin so that they may be spun or milled like other fibers. In some cases, following degumming, the fibers may be additionally processed through a newly developed process called "cottonization" which works the fibers to behave like cotton making them easier to spin with the same machinery as cotton.

2.3.2 Existing Hemp Fiber Uses, Initiatives, and Stakeholders in the United States and Beyond

Fully domestic hemp fiber supply chains are far and few between in the United States. As previously observed, hemp fiber is being used to manufacture various goods and products across different industries that are placed on the American market, which includes both brick and mortar retailers and the online marketplace(s). Much of the global hemp fiber production is beginning on American farms but most products and goods on the American marketplace are made with foreign supplies of hemp material. Currently, manufacturers are largely sourcing their supplies of hemp fiber from China, Canada, and a few European nations. In the textile industry, aside from clothing companies, there are not many companies committed to utilizing hemp fiber in their products. There do exist a few one-off niche products from luxury brands and companies in other industries such as bedding, furniture upholstery, household goods, various bags, coffee filters, woven cables, and straps. Most of the innovation in hemp fiber manufacturing that does utilize fully domestic supply chains are of products in the building and construction industry.

American Textile Manufacturers

For textiles, most manufacturing actors are specialty clothing and outdoor gear companies. Most notably in the United States, there exists Patagonia, Hempy's, and Levi Strauss & Co. Of these companies, the California based company, Patagonia, is arguably the most involved actor. The company advocates often in their newsletters and on their website for hemp fiber and for building out hemp fiber supply chains and market demand in the United States. Their customer base is typically composed of outdoor recreation enthusiasts who demand outdoor clothing and gear that was produced with a focus on social and environmental responsibility. While the company does not use hemp exclusively throughout all of their product lines, it is the primary fabric in their Workwear line of clothing that is poised to compete with hard-wearing clothes from other brands such as Carhartt and Dickies. Their Workwear line is made of their signature Iron Forge Hemp™ canvas which is an organic hemp-cotton blend with 55/27/18 blends of hemp, recycled polyester, and organic cotton (Byars, 2017). Currently, hemp fabric blends also appear in 68 other product styles throughout different product lines on their online marketplace (Patagonia, 2022).

Patagonia currently imports their hemp fiber material from Hemp Fortex, a certified supplier based in Rushan, Shangdong, China, but Patagonia states that there is work to be done in building up the demand and infrastructure in order to foster a domestic market for hemp fiber. In anticipation of this, they have already begun investing in family farms in Colorado and Kentucky as part of their "Bring Hemp Home" campaign (*Bring Hemp Home*, 2021; McElroy, 2020). It seems that Patagonia's current strategy is to continue to import hemp textile material from Hemp Fortex while they build out the market demand for hemp fiber products that will then lead to the establishment of domestic hemp fiber supply chains.

Also out of California is Hempy's, who has been making more casual hemp clothing since 1995. They also manufacture various other textile-based goods such as wallets, face masks, and baby blankets, plus hemp paper journals. On their website, they state that while they "look forward to the day when [they] can source finished hemp fabrics from domestic hemp grown in the U.S.," they currently source their hemp textile supply from China and Romania (Hempy's, 2022).

One of the most well-known causal apparel companies in the world is another California based company, Levi's, who is especially known for their denim jeans and jackets. As part of their commitment to do better for the environment, they have introduced garments made from

"cottonized" hemp material (Levi's, 2022). The company states on their webpage that pioneered the unique process for cottonization with fiber technology specialists and the result is a hemp fabric material they claim is "almost indistinguishable from cotton" (Levi's, 2022). The company only makes a handful of garments at present but states that they will continue to improve the process and introduce more products that feature cottonized hemp material.

Foreign Textile Manufacturers

The hemp fiber industry is a newly developing one for the United States but there exists other developed markets and supply chains in foreign countries. Many of the other manufacturing actors with a dominant presence on the global hemp market are foreign based manufacturers. These include other specialty and outdoor clothing and gear companies as well as unique innovators. This sub-section provides a brief overview of some of these notable foreign actors.

One of Patagonia's competitor companies in the outdoor clothing and gear market is the Swedish company, Fjällräven. Their website lists hemp as a material they use for its performance as an agricultural commodity, which gives the company credit for environmental responsibility, as well as its durable performance as a fiber in the garments they produce (Fjällräven, 2022). Currently, the only products they offer made from hemp textile material are a small selection of men's and women's long sleeve and short sleeve button up travel shirts which feature 55/45 hemp-polyester blends.

Also, originally out of Sweden is perhaps the country's most famous retailer, IKEA, whose headquarters is now in The Netherlands. While the company does not list hemp as one of their materials, a search for "hemp" on the American version of their online marketplace yields results for a product line of eight items they have named *Nereby* (IKEA, 2022). This product line is split half and half between hanging storage bags and rails/shelves to hang them from. The hanging bags are all made out of an 80/20 hemp-cotton blend.

The company that could perhaps compete most with Patagonia's social and environmental reputation is the emerging Canadian based company, Tentree. Tentree was founded between Hawai'i and Canada and what sets them apart from every other clothing company in the global marketplace is that for every item they sell on their website, they plant ten trees, hence the company name (tentree, 2022a). Currently, they have planted over 77 million trees since their founding in 2012 and have a goal to plant 1 billion by 2030. They are also B Corp Certified and Climate Neutral Certified. Hemp is a featured material in many of their product lines for men and women and from more casual to more dressed up garments including casual t-shirts, button-ups, polos, tank tops, jackets, shorts, chinos, joggers, dresses, hats, masks, socks, and wallets. All of these are made with various hemp blends with synthetic materials and cotton. They state clearly on their website that hemp is their solution to eroding soil health and fertility aggravated by the apparel industry as it is uses less water and yields more fiber than conventional cotton (tentree, 2022b). They also promote hemp as a preferred material because it is durable, natural, and breathable.

Anyone who has spent time searching the online marketplace for hemp fiber textiles is likely going to come across advertisements for a very different innovation for hemp fibers in the form of hemp shoes from a Portuguese company by the name of 8000Kicks. They claim to produce the world's first waterproof hemp shoe which they produce both in Portugal and in China (8000kicks, 2022). The company has also recently begun to branch out in manufacturing backpacks, socks, masks, and wallets.

Another company with a strong advertising presence in the online marketplace for hemp textile consumers is Hemp & Hope in Nepal. The company was founded by a Scottish woman who designs all of their products from home while the supply chain from seed to shelf occurs in Nepal (hemp&hope, n.d.). Their webpage states that their hemp is grown, harvested, processed, and spun by women in the villages of Baglung and Bajura where it is then sent to facilities in Kathmandu and Pokhara where the material is manufactured into backpacks, bags, and clothing. All of their product offerings are made from 100 percent or majority hemp blends with cotton.

Building and Construction Manufacturers

As previously stated, most of the innovation for hemp fiber in the United States is in the building and construction industry. There are two major companies that have emerged in recent years who are hoping to revolutionize their industry. The first of these is the Idaho based company, Hempitecture. They use hemp fibers in their two products, Hempwool and Hempcrete. The former makes use of the outer fibers from the hemp stalk to produce Hempwool which is used as thermal insulation (Hempitecture, 2022) as an alternative to more traditional insulation materials such as fiberglass or spray foam. The company also makes use of the woody inner core of the stalks to produce a lime binder that becomes Hempcrete which is used as an alternative to tradition concrete in specific non-load bearing applications (Hempitecture, 2022).

The other major innovator in this sector is the Kentucky based company, Hempwood, who produces a series of products of the same name. Their website claims that their entire supply chain from seed to shelf is domestic and that their products may be used in all the ways that traditional lumber is (Crye, 2020).

Paper Manufacturers

In the United States, there are a few companies that have emerged to produced eco-friendly alternatives to contemporary wood pulp paper. The California based Green Field Paper Company produces a whole range of hemp paper for various purposes and has all of their product offerings available for wholesale from their website (Green Field Paper Comapny, 2022).

Similar to Green Field Paper Company is the Colorado based TreeFreeHemp company who, since 2013, has produced hemp-blended post-consumer recycled paper products. More recently, they have also begun to produce 100 percent hemp paper products, such as business cards, event tickets, and posters all of which they claim "is the first commercially milled 100% hemp paper to be produced in the USA in more than a century. This paper is produced with no toxic chemicals and is an eco-friendly alternative to wood based paper" (Tree Free Hemp, 2022).

American Processors

On the processing side of the supply chain development there exists a handful of companies at different levels of readiness and capability scattered around the United States. Below are overviews of a few of the more noteworthy companies.

Renaissance Fiber is a North Carolina based hemp fiber processor that claims to operate the only "all-America sustainable hemp fiber supply chain" and they have the stated mission of "building a hemp textiles supply chain within the United States" (Renaissance Fiber, 2022). Their website also claims they have a patented degumming process that is carbon negative, which they call "ecologically invisible".

BastCore in Alabama has been ahead of many of the developing processors as they have been in operation since 2014. They claim on their website that they have been consistently innovating the creation of products from the entire plant for manufacturers in the construction and textile industries as well as energy producers. They run their own farms, processing facilities, and host their own warehouses (Bastcore, 2021).

South Bend Industrial Hemp out of Kansas is a company that started as a family farm but grew to include a processor division as their region needed a processor of hemp fiber and hurd (SBIH, 2020). Their website states that they are the primary hemp processing facility in the American Midwest.

2.4 Tentative Explanations

There are a few tentative explanations as to why the processing side of the supply chain is developing much more slowly in the United States. It is possible that the three main challenges are related to matters of financial capital, infrastructure, and limited physical capabilities. Not all, but some hemp fiber manufacturing companies likely follow suite with several other manufacturing industries in sourcing labor elsewhere in countries that do not have as high a standard of working conditions or minimum pay thus allowing for lower production costs – especially when manufacturing on such a large scale.

Processing also requires knowledge and infrastructure including machines, processes, and distribution networks. All of this would require immense financial capital to establish and develop in the United States, especially when an entire industry is being built from the ground up. For many new companies, it is critical to balance your risks to protect the business margins when entering a new market and a common course of action is to outsource the processing, and much of the manufacturing, to other locations in the world that have already developed such knowledge and infrastructure. Even though hemp fiber supply chains are being developed in the United States, American based manufacturers may only consider transitioning to American supplies if they have concerns over supply chain costs, supply chain resiliency, or their environmental and social impacts.

The National Association of Manufacturers found that in 2018, about 62 percent of manufacturing firms in the United States were considered small, as defined by less than 500 employees. In fact, they claimed that 75 percent of those small firms had fewer than 20 employees (NAM, 2022). From this, it is safe to assume that the firms that have since established themselves in the United States to process hemp fiber material and manufacture products are entirely likely to have been established with fewer than 20 employees. With only a handful of small firms existing in the United States, it is probable that the actual physical capabilities of them have been operating at full capacity since their inception.

3 Research Design, Materials, and Methods

3.1 Research Design

This thesis puts focus on interviewing practitioners along the supply chain of hemp fiber on what the barriers and challenges they have run into are in establishing domestic hemp fiber supply chains in the United States. The primary data for this thesis come from discussions with industry actors at different stages of the supply chain. Secondary data comes from various sources including various USDA publications as well as industry actor webpages and publications. The desired goal is to hold discussions with at least three practitioners at each of the three main stages of the hemp fiber supply chain, namely farmers, processors, and manufacturers.

This thesis takes a pragmatic world view and seeks to understand and describe the industry as it is within its context. Beginning with a set of research questions based on perceived and identified problems, this thesis seeks to answer them through discussions with the industry actors about the through real-world processes and experiences they have. It is a qualitative study where the data collection is primarily phenomenological, and the individual informants consulted are case studies in their own capacity.

3.2 Data Collection Methodology

Primary data collection will be of practitioner perspectives. Interviews and discussions with industry actors will take the form of phone calls. This form of data collection has been determined to be the most appropriate method of data collection for this particular thesis study as the hemp industry is a newly emerging one and, as an industry based in agriculture, which is always evolving and adapting, those with the most up-to-date knowledge are the practitioners. The discussions will be semi-structured and encouraged to flow naturally. Notes will be taken on an interview guide containing the research questions and follow-up questions designed to guide the discussions if need be. This thesis and the methodology it employs has been designed to be simple in order to avoid overcomplicating an already overcomplicated industry in development. The three research questions, therefore, provide the basis of the interview guide's structure and will be directly asked to the informants. The interview questions will be attached in the appendix of this thesis in the form of an interview guide.

The interview guide first begins with a set of pre-questions designed to establish a better understanding of the informant and what the business of their business is. For farmers, this includes questions of: "How long have you been cultivating for fiber?"; "In the time you have been operating, how has the market evolved in terms of size?"; "What sort of entity or organizations do you sell to?"; and "Why have you chosen to work in the industrial hemp sector?".

Processors and manufacturers will be asked a similar set of questions including: "How long have you been active?"; "What do you produce and consider producing from industrial hemp?"; "Do you source material from the US or import?"; "In the time you have been operating, how has the market evolved in terms of size and product differentiation?"; "What sort of other companies or organizations are your main customers?"; and "Why have you chosen to work in the industrial hemp sector?".

Moving then into the first of three main questions is the first research question: "What sort of barriers or challenges exist for your operation?" which may be elaborated on by asking "do you

face or risk facing challenges related to capital, resources, regulations, or market conditions?". With this question, informants are encouraged to speak on how they understand their role and position in a domestic hemp fiber supply chain and who else in the supply chain they work with.

The second research question comes in two parts. Informants will first be asked: "What do you need to overcome the challenges you spoke on previously?" and then specifically in terms of *actions* that other stakeholders in their operations may take that would benefit them. It is then asked again but in terms of what *resources* they need to overcome the previously discussed challenges. More specific questions may be asked such as "What sort of financial resources are necessary for starting a processing plant?" or "Where do financial resources for industrial transitions usually come from in your experience as a manufacturer?".

For the third and final research question, informants are simply asked "What pathways or options do you see in moving forward past or around these barriers?". This question is intended to transition from an answer given to the previous questions into a question of how to overcome the identified barrier or challenge. For example, if a manufacturer responds to a question of what challenges they face by talking about how the market demand is not currently sufficient to support an investment in American processors, then a follow up question of how they would like to address this lack of market demand will be asked. Ultimately, this research question is about identifying what it would take to switch from foreign suppliers to domestic suppliers and what it would take to increase hemp materials over alternatives.

The discussions will conclude with a final follow-up question of who else they think would be a good source of information for this thesis. This is the snowballing method in practice.

3.3 Materials Collected

The material collected for this research project will be qualitative data obtained from interviews and discussions with industry actors. Informants will first be given a brief overview of who the researcher is, what this study is for, what the problem definition is, and why they may be a good source of data. Informants are then given an opportunity to ask any questions they may have before data collection officially begins. Materials collected in addition to data include information for a password-protected spreadsheet of informant names, organizations, industry position(s), and their operation's location.

3.4 Methods Used to Process Information

The collected data will be assessed in a content analysis, specifically a conceptual analysis of the interview transcripts in search of common themes that may appear such as frequent words, phrases, and ideas. In the context of this research project, a conceptual analysis would analyze the transcripts from the interviews on farmers and determine what common themes appear, if any.

4 Findings and Analysis

4.1 Some Introductory Chapter Notes

The literature review presented in Chapter 2 is reflective of what information was widely available at the start of this study in early 2022. The hemp industry is a rapidly developing one and new sources of information have since come to fruition as well as the emergence of more regionally focused practitioners in the media. There exist several farmers, processors, and manufacturers across the United States who do not have a strong media presence if at all and, therefore, were not represented or accounted for in the initial literature review. Many of the absent industry actors were informants to this study and were discovered through snowballing, which is when other informants provide the names and contact information of additional prospective informants. Few farmers are ever present in the media or in research publications in the same capacity as established businesses or organizations. Most of the informants to this study were processors, a couple of which were also farmers and presented themselves as a vertically integrated business. On the manufacturing side of things, there are several big-name industry actors with large market shares that are easy to get publicly available information about but much more difficult to get in contact with for discussion.

Contact was successfully made with four manufacturers for this study but only one of which was able and willing to discuss their operations and perspective. Secondary data will therefore make up for the bulk of the data for manufacturer perspectives.

All the involved industries where hemp fiber has a presence contain one or more big-name manufacturing actors who are engaging in closed-door discussions with prospective processors, many who were informants to this study, about supplying processed hemp fiber material.[5] The supply of this processed hemp material would be for the manufacturing of goods to be sold as commercial products, mostly in textiles and paper, or for products used by contractors in building and construction. Aside from textile applications including clothing, household goods, and decorations, the dominant use of hemp fiber in the United States is in building and construction which has seen a more recent development in the use of hemp materials with little historical precedence. This industry has begun to yield products utilizing not just hemp fiber, but its hurd and dust which were previously viewed in large as by-products from the processing of the bast fibers. Collectively, there are innovators in the industry which have begun to yield such products as wall insulation, hempcrete, hempwood, composite material, animal bedding, and filaments for 3D printing.

Innovations continue still in the textile and paper industries, and it seems that for nearly every textile or paper product on the market today, there likely exists a company that either has succeeded or is trying to make an alternative hemp version of it. This includes product categories such as coffee filters, towels, handbags, rugs, speaker grills, shoes, curtains, seat covers, bedding, woven cable wraps, and canvas material for various additional uses, to name a few. Other innovations in manufacturing that utilize hemp fiber can be grouped together under the plastics industry, specifically bioplastics, which is the latest industry to explore the potential uses of hemp fibers. Hemp-based plastic uses hemp cellulose, which are hemp fibers that have been heated and chemically treated. As such and in similar fashion to textiles and paper, there are emerging innovations for hemp-based plastics in a wide range of products. Some notable examples that have recently entered the market include electronic components, protective cases, interior automotive components, vinyl LPs, writing utensils, cutlery, and additional various

[5] Due to confidentiality reasons, the identities of these "big-name manufacturers" are being withheld at this time.

home goods.

4.2 Intertwined Description of Findings

The discussions had with the informants for this study yielded an abundance of insightful and revealing details. The findings from the data collection will be presented here based on the framework introduced in Chapter 2.

4.2.1 Assess the Landscape

Assessing the landscape as it applies to farmers offers a unique perspective that provides insights to underlying issues that are ultimately affecting the entire supply chain. Hemp supply chains are rooted in agriculture which is a volatile and reactive industry as it is subject to weather patterns that change rapidly and frequently requiring adaptations to be made just as swiftly. Farmers have a lot of options for which crops they cultivate their land for and are constantly doing their own version of a landscape analysis, usually in the form of a market analysis. Interestingly, all five farmers interviewed for this study discussed price performance more than field performance and impacts. Two of them specifically compared hemp fiber cultivation to corn and soybeans which are currently experiencing an all-time high at 0.11 USD/lb[6] (0.24 USD per kg) and 0.25 USD/lb.[7] (0.55 USD per kg), respectively. This shows that farmers are more interested in hemp production not necessarily for the benefit of the hemp industry but rather their private benefit as agriculturalists. Every farmer interviewed began cultivating hemp for fiber within two years of their state's pilot program and interest was generated due to initially lucrative financial opportunity. The farmers that informed this thesis felt that these opportunities were supported by its wide-ranging industrial applications and the rapid emergence of processors promising to buy from them. A couple of them further stated that the environmental benefits hemp can bring to the farm were just a bonus, but a welcome one. One farmer stated that after price point determination occurs, harvesting three tons per acre at 0.15 USD per pound (900 USD per acre or 2,223 USD per hectare), assuming that stays at a relatively steady rate, hemp will be poised to compete firmly with corn and soybeans. This is further supported by hemp's short growing time allowing for two or more yields in a single growing season depending on the climate.

Manufacturers have learned from cotton farmers which routinely cultivate cotton that there is a high-water demand that comes with cotton production. It also tends to be on well-established fields that are used almost exclusively for cotton production leading to increased rates of soil erosion and nutrient resource depletion. These issues necessitate farmers to apply fertilizers to their cotton fields, many of which are synthetic. Considering also that only 0.2 percent of cotton production in the United States is organic (Organic Trade Association, 2021), most farmers are also applying pesticides to their cotton fields which continues a cycle of soil erosion and nutrient resource depletion which also perpetuate a cycle of water pollution leading to increased eutrophication. The average price point of cotton in the United States for 2021 was 1.34 USD per pound (2.95 USD per kilogram) (USDA AMS, 2022).

For the purposes of this study, timber is used to refer to harvested trees and their wood that has yet to be cut or processed and lumber refers to processed wood that is ready to be used in applications for building and construction. According to the USDA, per capita consumption of

[6] USDA reports $9.17 per bushel in February 2022 which works out to 56 pounds per bushel.

[7] USDA reports $14.80 per bushel in February 2022 which works out to 60 pounds per bushel.

roundwood, or timber, in the United States for 2017 was 52.4 cubic feet (1.484 cubic meters). 32 million tons (29,029,911 tonnes) of paper was consumed in 2017 (Howard & Liang, 2019). Tree species harvested for timber require time that numbers in the decades in order to fully mature for them to be harvested again. The contemporary harvesting of timber for lumber to be used in building and construction as well as for pulp and paper also adds to global deforestation which in turn increases biodiversity and habitat loss. Hemp fibers and lignin have historically been used as raw materials for producing paper and more recent innovations have seen hemp fibers being turned into alternative wood materials that can rival hardwood lumber that would be used for interior building purposes. Hemp is advantageous against timber as it only requires a period of four to six months from when it was sowed to harvest it. In some climates, this allows for farmers to get in more than one yield in a single growing season. When a farmer repeatedly cultivates and grows hemp, it utilizes the same land rather than cutting down additional swaths of forest.

The one manufacturer that informed this thesis explained that they were not using hemp necessarily for the benefit of the hemp industry but because it was what they determined was the solution to the environmental issues they identified with the building and construction industry. The informant explained that their industry is currently operating with a carbon intensive and resourcefully wasteful status quo. The solution to these problems was in bioresources and after experimenting with what options existed in that space, hemp was found to be the ideal candidate. The result of this experimentation were innovations in two of the most common building materials for the building and construction industry that now feature hemp fibers. What sets them apart from other manufacturers of the same products made with more traditional resources is that they are not producing their hemp goods for the purpose of supplying other contractors with hemp products but rather for their own use. Instead of manufacturing an innovative product that could potentially transform the market for construction and building materials, they are entering the market themselves as a differentiated actor with a product offering that is differentiated from what already exists.

While only one manufacturer made themselves available to inform this study, it is reasonable to assume that their logic of coming from another industry perspective is a commonality with manufacturers in other industries that are considering hemp. It is reasonable to suspect a similar thought-process for actors in the textile industry that are looking for alternative natural fibers that offer improvements on the environmental footprints over other well-established fibers in the textile market. The same logic applies for actors in the pulp and paper industry that are looking for raw materials that offer improvements on the environmental footprint of their industry, especially when they are feeling the landscape pressures of deforestation and habitat and biodiversity loss. However, all of this is currently a niche within a niche market. Hemp fiber products are just one option in a market of alternative materials that offer improved environmental footprints for different industries. The status quo at present is a collection of industries that have a set of established materials, supply chains for them, and ways of doing business. It is a niche for actors in these industries to want to make improvements to their supply chains and manufacturing processes that reduce their impact on the global environment. Of those actors, utilizing hemp is a niche option that exists alongside other alternatives such as recycled materials, mushrooms, bamboo, coconut fibers, and other bioplastics.

Assessing the landscape as a processor is perhaps a more fascinating experience than for farmers or manufacturers because they are, in most cases, developing in their existence for the benefit of the hemp industry. Farmers have other crops they could grow, and manufacturers have alternative materials to consider. Processors, however, are typically specialized organizations due to the differences in the necessary equipment so when a processor of hemp fiber comes along to participate in the development of American supply chains, they show not only

commitment to the hemp industry, but determination to make an impact on all of the related industries. The exception, of course, are when farmers are forced to become their own processors. This was the case with two of the four processors that informed this study. They started off as farmers exploring what hemp fiber cultivation could do for them but when issues with previous processors or investors arose, they found themselves moving forward on their own and evolving their operations to include processing capabilities for themselves and their local and regional farming communities.

4.2.2 Develop the Niche

Niches cannot exploit a window of opportunity until they are sufficiently developed. This itself is a strenuous process that requires trial and error by innovative actors willing to weather those losses until they find success. The actors doing the experimentation are primarily going to be the manufacturers. These can include both existing manufacturers looking to add hemp products to their catalogue or replace existing ones as well as new manufacturers that focused solely on utilizing hemp fibers. Most actors that identify as the former tend to be in the textile industry whereas actors in the latter categorization tend to be in building and construction, but this is not the case exclusively. Both are necessary to support the development of the supply chain. After success has been had, the manufacturers that led the development of the successful innovation need to focus on market creation and growth for their innovation. This is the process of further developing the niche so that it may become sufficiently developed.

In developing the niche of hemp fiber products, the bulk of the issues in the supply chain seem to be related to the front end with farmers which manifests further issues such as inconsistent supply rates to later stages of the supply chain. Below are some of the different barriers and challenges that the informants spoke on in developing their part of the supply chain.

Before farmers apply for loans or ship samples off for testing, they are grappling with the underlying issues of seed sourcing as well as genetics and germination. One farmer went into detail explaining that the last time hemp was legally cultivated for fiber in the United States was during WWII and the varieties that were grown then were subsequently heavily taxed and classified as a scheduled drug allowing for the crop to die out again and the native varieties lost to time. The farmers interviewed collectively pointed to sourcing seeds from suppliers in France, Poland, Ukraine, China, Australia, and Canada in hopes that one of the varieties from one of these countries will have the proper genetics to germinate in the local American climate and weather conditions while yielding quality fiber that stays below the THC limit. There are a wide range of variables at play here and farmers actually only have control over which seeds they put in their ground and how much irrigation they provide. To complicate matters further, most seed suppliers have proprietary rights over their seeds which adds to the renewed upfront cost every time farmers wish to grow again. One farmer detailed that with their current import seed supplier, they are paying around 4 USD per pound and roughly 80 pounds are sowed per acre and acreage ranges between 50 and up to 1000 (8.8 USD per kilogram – 440 kilograms per hectare – 20 to 404 hectares).

One of the first challenges that processors pointed to was that the United States is playing catch-up with the world, namely Europe and China according to one informant. Processors feel this especially so because their part of the supply chain is dependent on infrastructure in the form of technology and machinery that is severely lacking in the United States. This machinery includes specialized combine heads for harvesting hemp stalks on the farm as well as the decorticators and degumming machines. Not only is this machinery scarce to come by in the United States, but any interested party wishing to buy this equipment is faced with steep prices for equipment that comes fully operational and specially designed as it has to be imported,

usually from Europe. At present, the processors that informed this study stated that this is the most financially pressing barrier they face and that current production rates do not justify making this purchase but also stated that they expect this to be improving over the next five years as the industry continues to evolve and grow market demand. In the meantime, the processors that have found success so far are mostly operating with equipment for processing other resources that has been modified or retooled in order to be compatible with hemp stems.

The overall single most pressing issue for processors overall is the need for a consistent supply of ready-to-be-processed raw hemp biomass from farmers. This translates at present to mean that the various issues and challenges that farmers already face in regulation and capital, are also problems for processors, albeit indirectly. As such, the two informants to this study that started off as farmers, today supply themselves up to 80 percent of their own hemp material for processing. This sort of vertical business integration in the context of an agricultural business helps to address the price premiums that comes with niche innovations by keeping consumer prices in check while ensuring that every supply chain member, especially farmers, stand to make a profit at the end of the day.

The issues that farmers had with shipping companies, banks, and credit card companies were similarly felt by the manufacturing informant. During the discussion, they touched on similar concerns from business partners in handling hemp material and products. Their solution to this is to eventually develop and roll out a handling license that would ensure compliance with federal and local laws concerning the handling of hemp materials.

In developing a niche innovation, partnerships are often necessary and beneficial to both parties. Two of the farmers that informed this thesis are both located in North Carolina and both farmers stated that their decision to continue cultivating hemp for fiber and assuming the risks around it comes down to an effort by other North Carolina farmers, processors, and manufacturers to not only contribute to the development of an American hemp fiber supply chain but to establish a North Carolina specific supply chain that will breathe new life into the state's historic textile industry. As is the case with jobs in other manufacturing industries, jobs in textiles in the state have been lost overseas. These two farmers both spoke on initiatives they are a apart of that will produce textiles from "seed to garment" within the state's borders and they expect this to be a reality within the next five years at most.

4.2.3 Transition

After industry actors have assessed the landscape and begun to sufficiently develop their niche, they must begin to split their focus from development to transitioning their space in the landscape. This may require transitioning back and forth between further developments in the niche and jumping through the window of opportunity in the status quo as they adapt to changing contexts in the landscape. Only a sufficiently developed niche can exploit a window of opportunity and establish itself as a regime in the status quo. As hemp fibers are utilized in multiple industries, it may be that hemp fibers establish themselves first as a status quo in one industry while its use in other industries continues to develop.

Current Policy Regulations

Most regulation pertaining to hemp is placed on the farmers. Presently, farmers wishing to grow and cultivate hemp for any purpose are required to first obtain a license. The two requirements for this were generally said to be securing an agreement with a processor who would buy the harvested hemp material and supplying up-to-date GPS coordinates for the hemp fields for satellite monitoring. The specifics of these requirements for a hemp growers license varied by

state under the individual state pilot programs. In licensing, the most common variance was that some states did not require agreements to be finalized so long as the "intent to buy" was evident. This turned into a nightmare as described by a few of the informants when processors backed out at the last minute to buy due to bankruptcy and having promised too many farmers leading to an oversupply of material for processing when there were suddenly no processors available for many farmers in different parts of the country. The regulatory variance between states also carried over to matters concerning the testing, distribution, and use of the hemp material. Some states did not permit farmers to secure agreements with processors out-of-state which quickly eradicated most options available to them. The farmers that informed this thesis all began cultivating hemp under their state pilot programs and some are still under such programs while others are now subject to federal regulation by the USDA.

Hemp centric media outlets have toted the idea that the dominant issue farmers face in cultivating hemp is battling the 0.3 percent THC content limit. If this limit is crossed then the farmers are required to destroy their crops, usually by burning or mowing, under the supervision of a regulating authority. Despite establishing such strict regulations, little to no support for farmers in getting their crops tested is offered by state departments of agriculture or by the USDA. The first hurdle with testing is that they have to pay for the testing themselves and many have made a habit of getting their crop samples privately tested before they are officially tested under the supervision of regulating authorities. Farmers have taken to this practice because multiple failed tests can result in having their growers license expelled for up to five years. In all cases of testing, farmers ran into issues with the United States Postal Service and private shipping companies who were hesitant or refusing to take custody of shipments containing raw cannabis material for THC content testing on the grounds that they have to assume it is marijuana until proven otherwise. One of the farmers informing this study mentioned that the USPS eventually accepted parcels if they were double packaged. Farmers faced similar issues with banks and credit card companies who did not want to grant loans for any activities related to cannabis nor would they handle cannabis money coming in or out. Testing further proved to be an ordeal for farmers because testing for THC content is always on the flower. When growing for fiber, the crop needs to be harvested when it begins to bud and before it flowers. The farmers felt that this does not make sense because it is not the flower they are growing for.

The American innovations in hemp fiber usage without historical precedence are all occurring in the building and construction industry. The natural progression for these new building materials is the establishment of building codes specific to them. Currently, certain hemp-based building materials are being cleared for use under exemptions but as one of my processor informants stated, "you can't build an industry out of exemptions!" The same informant went on to explain that the US Hemp Building Association based in Nashville, TN was said to be developing official building codes for these innovative materials alongside the National Association of Home Builders based in Washington, D.C. While local and state laws are ultimately responsible for local building codes, most choose to implement nationally and internationally standardized codes and then make the necessary amendments to them. The most commonly adopted building codes are from the International Code Council's International Building Code which the National Association of Home Builders adopts and amends for domestic applications.

4.3 Analysis: Identifying the Bottlenecks

To now trace the supply chain and map out the issues that the informants all spoke on would provide a list of the key bottlenecks that can be used to produce a checklist of items for the industry to address. Beginning at the start of the supply chain are the farmers. The first issue farmers run into is actually the doing of actors in the landscape, this being legislators and the

laws they have put in place that outline the processes and requirements for licensing and regulation. The requirements for obtaining a grower's license and the subsequent regulations for growing, harvesting, and testing are, aside from being nonsensical and overly present, inconsistent between states. This introduces barriers and challenges for all involved parties wishing to play a part in developing a domestic hemp fiber supply chain in the United States and thus expanding the country's presence in the global hemp market.

The next largest bottleneck concerns the THC content limit – which is arguably the most consistent regulation. This number is a deterrent for the industry for two reasons: it is not backed by any dose-response studies showing this is the dosage where psychoactive effects are experienced and that it is so incredibly low that it is arduous for farmers to comply with. If this requirement were to be amended to increase the limit or removed entirely, farmers would have more options available to them in the varieties they grow. This leads to the next set of related bottlenecks that farmers face in regard to seed supply as well as genetics and germination. The contemporary practice of agriculture requires farmers to purchase their seeds in bulk from dedicated actors in the supply chain as seed suppliers, rather than save from previous harvests that were successful. Since the United States is lacking in native hemp varieties, all seeds are instead being imported which introduces more potential problems that some have faced including damage by shipping companies, inconsistent quality supplies, and additional supply chain distribution hurdles. Every farmer who informed this thesis also spoke on issues they had with genetics and germination. Genetics here refers to seeds that will grow well in the local climate, grow tall enough to produce quality fiber before flowering, and contains THC content well below the limit so as to account for the volatile nature of agriculture. Germination concerns a crops ability to break through the topsoil and become a seedling. When a crop does not germinate this may be due to a combination of factors from genetics, crusting[8], or damages from shipping and storage.

The final bottleneck that impacts farmers, unfortunately has direct consequences for the rest of the supply chain and this is the matter of price point determination. This refers to a fair selling price for farmers to sell to the next in line of the supply chain and so forth which ultimately influences the price that consumers pay. Most major actors in the manufacturing space are not using hemp materials because it is currently viewed as a premium material warranting a higher end-market cost as a result of its short supply. The niche manufacturers and differentiated product lines that currently exist often advertise their hemp products and goods as premium products or as "competitively priced" compared to the alternatives in the appropriate regimes. After price point determination occurs then farmers will begin to see more favorable profit margins that encourages continued hemp cultivation and the price that consumers pay for hemp products and goods will be lowered. Unfortunately, this is one the industry's "chicken or the egg" scenarios meaning that there is great debate on which stage of the supply chain needs to cement their prices first thus influencing the rest of the supply chain's price point determination.

The following set of bottlenecks is a continuation of direct impact from lacking price point determination on the rest of the supply chain: farmers are not growing enough material to supply processors, which means that the processors are not processing enough material to supply manufacturers, which ultimately means that manufacturers are not growing the market space for hemp products and goods.

[8] Crusting is when the topsoil dries and solidifies before the underlying layer of soil where the seeds are, creating a "crust" that the sprouts have difficulty breaking

4.4 Discussing your results against that which was already known

The contribution of this thesis is primarily beneficial to the whole of the hemp industry, including the actors in the supply chains and the legislators in the United States. Transition theory has been around for some time but had not yet been applied specifically to hemp fiber supply chains in the United States. The ultimate contribution of this study on behalf of the actors in the supply chains comes from the 4th and 5th chapters. Presenting the barriers and challenges faced by all of the informants to this thesis as outlined by the framework developed from the MLP and following it up with an analysis that identifies the key bottlenecks provides the industry with a road map by which they can use to focus their efforts to grow ultimately grow the industry and their operations.

4.5 Reflecting on the Results of the Study

In reflecting on the methodological and theoretical choices made during this thesis, the overall research design was sound. This thesis was inspired by observations about the status of the developing hemp fiber supply chain in the United States which showed that different stages were developing at different rates while all stages were facing issues that had implications for the rest of the supply chain. Data, then, was going to have to be qualitative rather than quantitative in order to collect the proper information to understand the landscape and trajectory of the industry.

There are numerous variations on transition theory and a number of them would have been applicable. The decision to make use of the MLP was both a matter of convenience for the author as well as intentional to avoid over-complicating an already complicated series of situations.

The legitimacy of the research questions is evident by the data collected. The three research questions of this study were used as the three main points of discussion for the informants to the thesis and all had something to say about each question. Depending on how the informants responded to each question, additional questions were prepared to further guide the discussion on the topic each research question sought to address. Further research would only strengthen the legitimacy and analysis of the research questions, the data collected, and the conclusions of the author. Further potential research questions did arise but at a level more specific to actors in certain stages of the supply chain. Examples include "What variables do farmers take into consideration when deciding what crops to sow?" and "What variables do processors evaluate when deciding to what length they process, how they operate, and who they sign agreements with?".

There exists a lot of contextual parameters to this thesis on the barriers and challenges associated with the development of domestic hemp fiber supply chains in the United States. The matter of confiding the study to one country was a decision made since the country under investigation is a considerably large one with considerable opportunity for actors in the different industries examined herein. Had this study been on the barriers and challenges of hemp fiber supply chains in the European Union, the content of Europe, North America, or globally then a similar research design and methodology would have been produced with the appropriate alterations of relevance to each scope and context. In terms of generalizability for these different scopes and contexts, the conclusions of this study apply as far as transition theory is relevant for hemp fiber in the markets of those contexts. Hemp fiber is still considered a niche innovation in the global marketplace but in some individual countries it is closer to a regime than a niche. This is more so a reality in countries and markets that have long standing hemp fiber supply chains, such as China, France, and Canada. Had this study looked at other hemp applications in grain,

oil, or CBD then it generally would remain applicable with specific differences regarding THC testing for CBD farming.

5 Discussion

Having presented the findings in the previous chapter and having analyzed them to identify the main bottlenecks, this thesis moves now to offer suggestions for addressing each of the bottlenecks. The three figures below (Figures 9, 10, and 11) all present the bottlenecks in order of prevalence in the supply chain and then suggests what the industry needs to properly address them. For some, there are interim solutions or workarounds that are currently being exercised by industry actors and for others there is actual progress being made by other stakeholders who have an interest in seeing the hemp industry develop further.

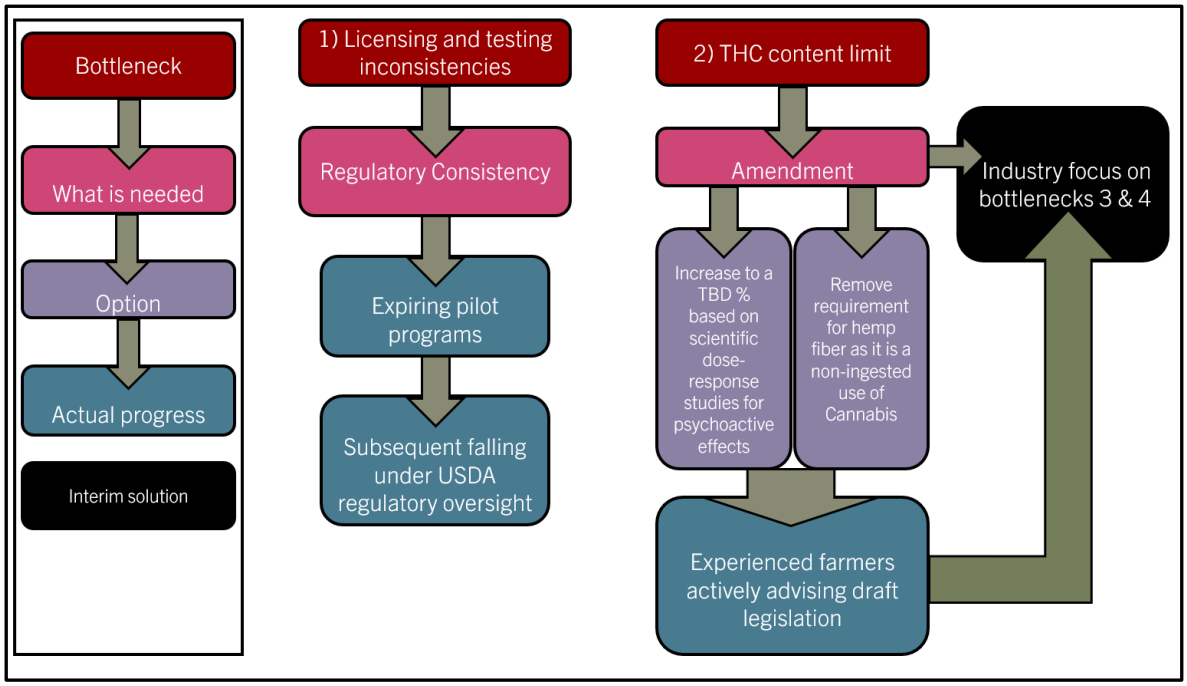

Figure 9: Bottlenecks 1 and 2

Figure 9 above examines more closely the first two bottlenecks of regulatory inconsistencies and THC content testing. For the former, what the industry needs is simply the opposite, regulatory consistency. Fortunately, many farmers across the nation are now seeing their state pilot programs expire and their licenses being granted by the federal government via the USDA which is bringing about nationwide consistency in licensing and regulation. The final rule was developed in early 2021 and became effective in March of that year. It is officially known as Establishment of a Domestic Hemp Production Program. The USDA states on their website that this program "provides requirements for maintaining records about the land where hemp is produced, testing the levels of total delta-9 tetrahydrocannabinol, disposing of non-compliant plants, licensing hemp producers, and ensuring compliance under the new program" (USDA AMS, 2021).

The bottleneck surrounding the THC content limit then becomes the actual largest hindrance for the industry. Since this limit was set by a federal law, the solution needs to be an amendment to that law. Every farmer that informed this thesis is in favor of an amendment to that law and all of them either spoke on rumors they have heard, discussions they have had with state government officials, or their role in advising draft legislation with their state senator that would amend the law. Two of them talked about increasing the limit but gave different numbers based on discussions they had had in recent weeks with other farmers and state government officials. One farmer talked about potential increases to 1 percent, 5 percent, and 10 percent while another talked about increases to 0.5 percent. Three farmers also stated that their personal

preference would be for increases based on dose-response studies that determine the actual THC content necessary for psychoactive effects to be present. Two of the more experienced famers that informed this study are actively advising their representative in the United States Senate as consultants on draft legislation that would introduce an amendment. One of them is working on an amendment to increase this limit to 1 percent while the other is working with their senator to remove this requirement entirely for farmers who are specifically cultivating hemp for fiber. As the American political process is a lengthy one, there is not hope that an amendment will be passed anytime in the near future.

It has been a long-standing belief pushed by hemp centric media outlets and in farmer communities that have grown hemp that the natural response for the plant during environmental stresses, such as heatwaves or drought, is an increase in THC content which can easily put a yield over the 0.3 percent limit. A Cornell study published in 2021 has found that genetics are ultimately responsible for total THC content and that the environment has no effect on THC or CBD content levels (Toth et al., 2021).

Until an amendment is passed, focus is being placed on addressing the next two bottlenecks which are visualized by Figure 10 below.

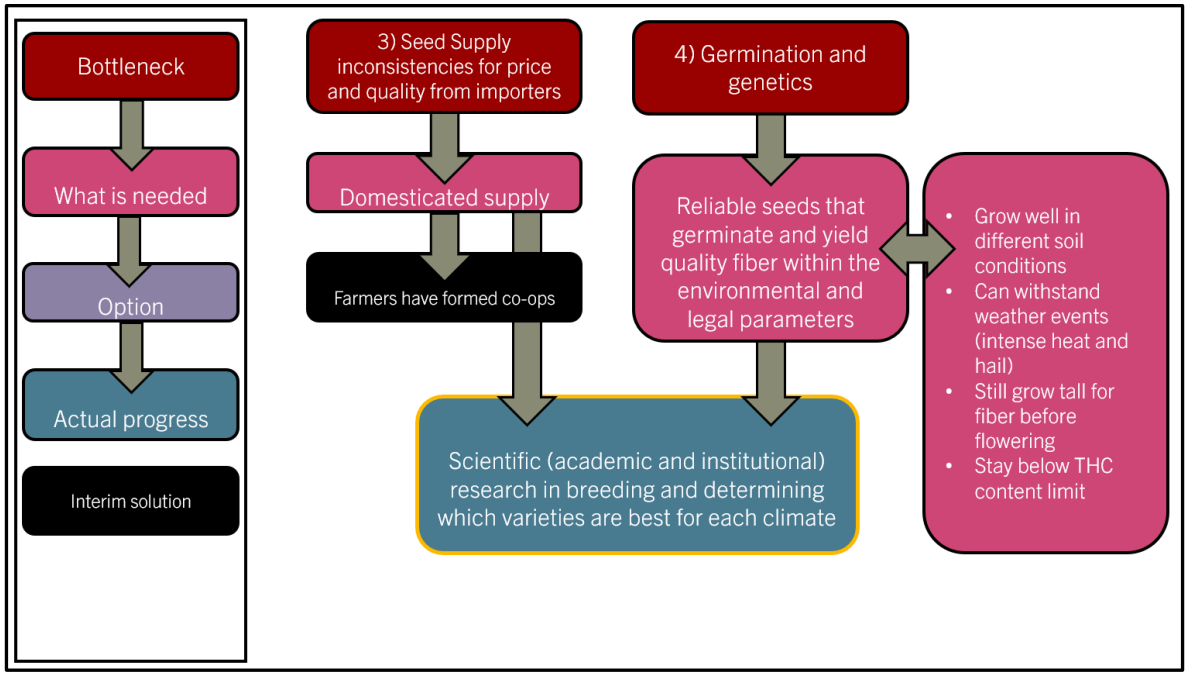

Figure 10: Bottlenecks 3 and 4

The matter of seed supply inconsistencies for price and quality from importers requires domesticating seed supply. However, this cannot be done until proper genetics have been identified and/or bred which is the concern of the fourth bottleneck. Until a domestic supply for seed is established, some farming communities have formed co-ops to raise funds and support one another in buying their import seeds in bulk. This is not an ideal solution and is a temporary one. In addressing genetics and germination, farmers need seeds that will reliably germinate, withstand extreme weather events such as heatwaves and hailstorms, grow tall for a high quantity of quality fiber, and remain under the THC content limit. Like the three bottlenecks before it, the matter of genetics and germination benefits from a collection of stakeholders that actively want to see the hemp industry come into fruition. Two of the farmers informing this thesis spoke about their assistance in reporting crop performance characteristics to North Carolina State University Extension who is actively trying to breed seeds that would

perform ideally under ideal conditions for the climate and varying soil types of North Carolina and the surround southeastern states. Another farmer strives to make public their efforts to collect data about crop germination and performance along with climate models showing what they are working with. These sorts of efforts are encouraged to continue for the benefit of all involved.

A further literature review on this has revealed a handful of other agricultural research institutions doing their part to breed seeds with the proper genetics for their part of the country and create seed banks for suppliers. The University of California, Davis offers an annual in-person course on "Hemp Breeding and Seed Production" (Filmer, 2020). The University of Oregon's College of Agricultural Sciences is home to the Global Hemp Innovation Center which focuses on a myriad of dimensions related to hemp cultivation and uses (Global Hemp Innovation Center, 2019). Cornell University has partnered with the USDA Ag Research Service to establish a hemp seed bank based on the work of one of the university's professors in hemp breeding and genetics (Manning, 2019). Other universities across the nation also have dedicated departments or faculty researchers on other matters related to hemp production, aside from breeding.

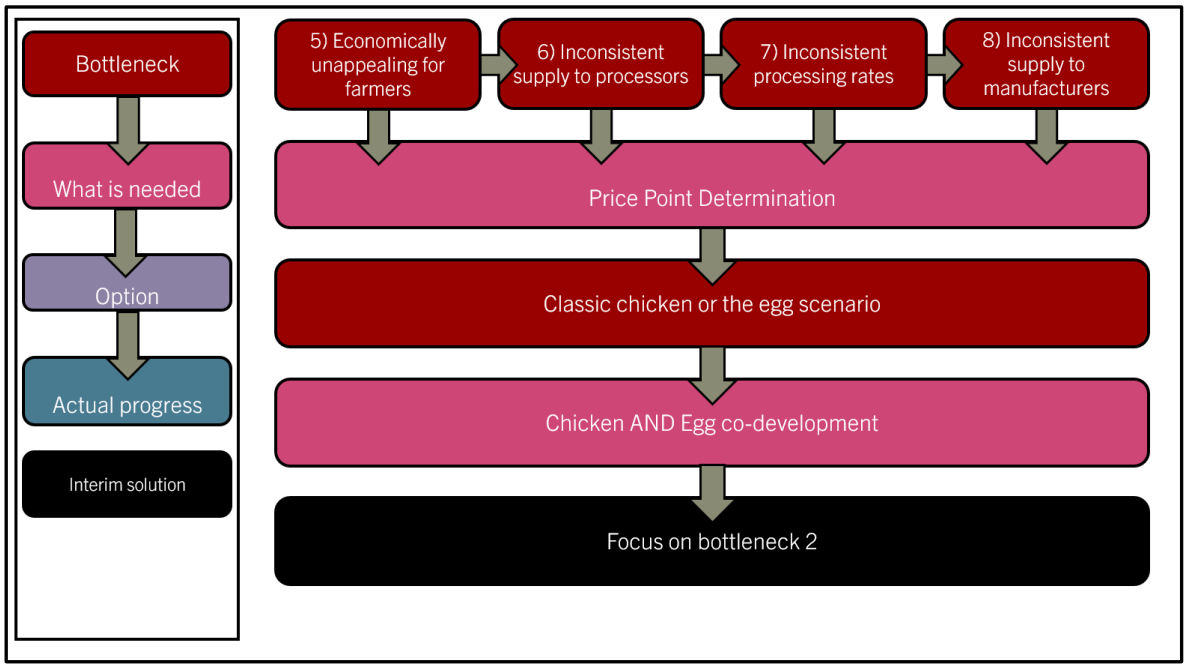

Figure 11: Bottlenecks 5, 6, 7, and 8

Figure 11, above, presents the last set of bottlenecks that were previously stated to have a direct impact on one another down the supply chain. The risk that farmers assume when cultivating hemp and the lack of dependable processors has made hemp an economically unappealing crop. Few farmers assume this risk which means that the processors that do exist do not have a consistent input of material for processing. American based manufacturers, then, are either sourcing hemp material from foreign suppliers or not using hemp at all which ultimately does not help grow the market for hemp products and goods. Collectively, the required solution is price point determination. However, as previously showcased, this presents a "chicken or the egg" scenario for where price point determination must first occur. Alternatively, the solution is not a matter of chicken *or* the egg but rather chicken *and* the egg. Actors across the supply chain must coordinate with one another to increase their productivity rates and grow in their capacity concurrently. Price point determination naturally occurs as manufactures introduce products and goods on the market at different price points with mixed results of successes and

failures. The price range where consumers are consuming goods more frequently is where the price point(s) need to be determined.

Unfortunately, given the preceding bottlenecks, manufacturers are slow to introduce new products on the market while the supply chains are broken and in development which draws out the time necessary for price point determination to occur. The industry then focuses on bottleneck 2 or simultaneously on 3 and 4, ultimately coming back to the golden box in Figure 10 focusing on the work of research institutions. At present, it could be argued that the industry will remain stagnant until either an amendment is passed addressing the THC content limit or breakthroughs in research on breeding and genetics results in a supply of seeds best suited for each climate in the United States where hemp is grown.

Final Points of Discussion

Regarding the issue where farmers have raised concern about testing the flower when cultivating for fiber, it is easy to believe this is a nonsensical decision in regulation, but farmers must bear in mind that this is the part of the plant where the majority of the crop's cannabinoids are present. It makes sense that the regulatory authorities need to be certain that the varieties that are being cultivated for fiber could not be illegally cultivated for marijuana. However, farmers are still valid in their concern that they need to let their crops fully flower before harvesting as this occurs after the optimal time for cutting and beginning the process of field retting.

Finally, it seems that the manufacturers that have used hemp fiber in their production of products and goods exist on a spectrum that spans from hemp dedicated and new player on the market on one side to previously established and differentiated product line manufacturer. The manufacturing companies that exist for their innovation in hemp fiber or use it almost exclusively (considering blends with other materials) all seem to be new companies. This is in contrast to the manufacturing companies that have used hemp materials in their production but are somewhere between a single differentiated product line and beginning to use it more frequently but not as a complete replacement for other materials. Textiles are represented throughout the spectrum. Building materials are at the end of exclusivity along with plastics. Paper is a little closer to the middle as they still require post-consumer inputs. Figure 12 below visualizes this.

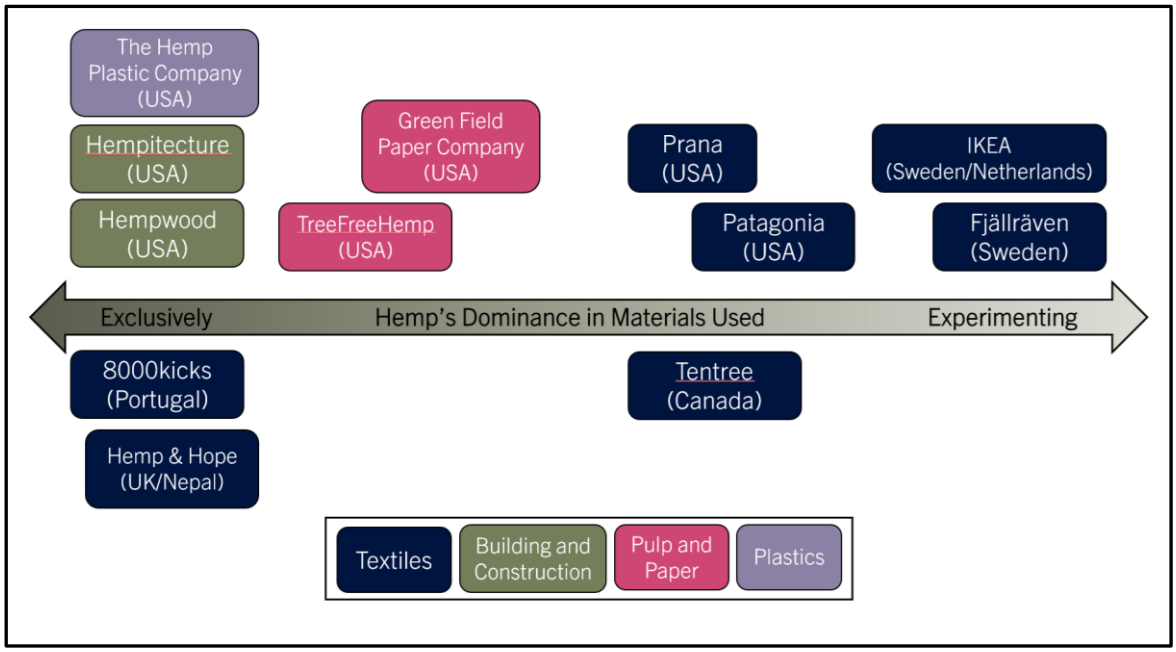

Figure 12: Spectrum of Manufacturer Use of Hemp Fiber in Relation to Emergence on the Market

6 Conclusions

This study started out by looking at the supply chain for hemp fiber in the United States as a whole with the idea to identify the weak points. The literature review indicated that while there are American farmers cultivating for fiber and there are American based manufacturers producing goods out of hemp material, many of those manufacturers are doing so out of imported material grown and/or processed in foreign countries thus indicating that the middle stage of processing is not as developed in the United States as what exists around it. Further literature indicated this may be due to differences in regulations, state pilot program designs, and the fact that the industry started from scratch less than a decade ago.

A framework was designed based on transition theory and the multi-level perspective to act as a to-do list for industry actors looking to play a part in the transformation of hemp fiber as a niche, with many exciting innovations, into becoming a regime in the status quo. This framework began by evaluating the socio-technical landscape to examine the relationship between the landscape pressures that are being exerted on the currently established regimes and the socio-technical regimes themselves. Essentially, this is looking to determine if a window of opportunity is present for innovative manufacturers to exploit. If it is determined that a window of opportunity does exist, then a niche must be sufficiently developed in order to take advantage of it.

It must be stressed that in the case of hemp fiber and all of its innovations in the United States, none are presently sufficiently developed to become mainstream. Further development is necessary. After discussions with a handful of American farmers, processors, and a manufacturer, it can be concluded that the industry currently faces a series of bottlenecks that is hindering further development. The majority of these bottlenecks fall on farmers who are at the forefront of the supply chain thus impacting the rest of the supply chain. Further development cannot be made on scale until these bottlenecks are addressed. Fortunately, the most pressing bottlenecks influence the rest of them. The most pressing bottleneck at present is inconsistencies in licensing and regulations – but this is taking care of itself as pilot programs expire and states continue under the authority of the United States Department of Agriculture.

The largest bottleneck, then, is the THC content limit, followed by seed supply inconsistencies as well as genetics and germination. These three bottlenecks influence one another in that the resolution of one will increase the likelihood that the following will be sufficiently resolved. If the THC content limit is increased or removed for fiber cultivation, then more varieties will be available to choose from that already exist in the United States. If seed supplies are domesticated, then genetics and germination research can be improved. If genetics and germination research yields seeds fit for every American climate where hemp is grown, then farmers will be able to assume less risk and successfully produce more hemp to supply the supply chain with.

Overall, there is immense interest and desire from farmers nationwide to see hemp return to their fields and establish itself as a fully realized commodity but there is still work to be done in making it make regulatory and financial sense. Every farmer that participated in this study has done something in their spare time to show support for the crop including lobbying and forming co-ops, to running for Agricultural Commissioner, and investing time and money in other farmers to keep production rates up. Once farmers are able to grow hemp without the burden of red tape policies and from seeds that are virtually guaranteed to germinate and produce quality fiber that is legal, the development of the supply chain will come along rapidly. The market can then expect to be inundated with hemp fiber textiles, building materials, and paper all the while building back the quality of American farm soils.

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Appendix

Interview Guide

Barriers and Challenges for a Domestic Industrial Hemp Fiber Supply Chain

This interview guide is part of a master's thesis project for Jansen Haneline at Lund University

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Pre: **What is the business of your business?**
Farmers: How long have you been cultivating for fiber? In the time you have been operating, how has the market evolved in terms of size? What sort of entity or organization do you sell to? Why have you chosen to work in the industrial hemp sector?

Processors and Manufacturers: How long have you been active? What do you produce and consider producing from industrial hemp? Do you source material from the US or import? In the time you have been operating, how has the market evolved in terms of size and product differentiation? What sort of other companies or organizations are your main customers? Why have you chosen to
work in the industrial hemp sector?

Q1: **What sort of barriers or challenges exist for your operation?**
For example, do you face or risk facing challenges related to capital, resources, regulations, time scales, weather patterns, or market conditions?

Is it a matter of not being able to scale up production? If so, why? Hard to get hold of the right equipment of capital for investments in full scale production? Who are the ones typically financing investments in the industrial hemp sector? Is there access to specific support for expanding the hemp sector?

Is there a too limited market and how do they view the opportunity to expand the existing market or enter new product markets? How to reach the (potential) customers?

Is the market limited or hindered by legislation?
What about skills and knowledge on how to process fibers and produce products? From where do they get new knowledge and trained people?

What about RnD in new hemp-based products and communication to the potential market actors on these new products? Who are promoting them? Do you see any actors that could/should help in promoting them?

Practical problems like time scales from convincing farmers to produce the fibers to establishing the processing and production to market penetration?

Q2: **What do you need to overcome these challenges?**

- What sort of **actions** taken by other stakeholders would benefit you and who are these other stakeholders? For example, would a change of some sort in federal/state/county government regulation or partnerships with other farmers/processors/manufacturers be of value?
- What sort of **resources** would enable you to address or overcome these barriers? For example, would financial assistance from another Farm Bill enable you to address or overcome these barriers?

Q3: **What pathways or options do you see in moving forward past or around these barriers?**

Follow-Up: Who else do you think I should talk to? Farmer, processor, manufacturer, other?

Email consent form: _____

CONSENT FORM

This form is to ensure that you have been given information about the research project and to give you opportunity to confirm that you are willing to take part in this research. For all activities below, please indicate with an X that which applies to you.

	I have been **familiarized** with the thesis project, I have had the possibility to ask questions and I have received satisfactory answers to my questions.
	As a research participant, I am **aware of my right** to withdraw participation at any time.
	I give my consent that the **content of my interview can be transcribed, analyzed, and published** in research outputs for the project.
Check only one of the following	
	I give my consent to be **identified by name**.
	I give my consent to be **identified only by my position in the organization**.
	I give my consent to be **identified only by my organization**.
	I request to be **anonymized**.

Note: Your participation is voluntary. As an interviewee, you do not have to answer all the questions that are asked; you reserve the right to refuse or cease participation in the interview process without stating your reason and may request to keep certain materials confidential. At any stage of the research (until May 20, 2022), you have a right as a research participant to gain access to your own personal data, request its correction or deletion or limitation to processing of data as well as file a complaint about how your personal data is used.

Please, sign below to confirm your consent.

For any enquiries regarding this research, please contact:

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Tel: +xxx | Alt Tel: +xxx