Hemp's Budding Economic and Environmental Viability: A Cost-Benefit Analysis

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Contents

Abstract

In the context of accelerating global climate change, stakeholders and institutions often undervalue the potential of industrial hemp - a historically glorified crop for its thousands of applications, yet one intricately intertwined with public marijuana sentiment. The 2014 Farm Bill in the United States authorized state governments and academic institutions the permit to research hemp. Subsequently, the 2018 Farm Bill removed hemp from the Controlled Substances Act due to its low concentration (below 0.3%) of the psychoactive compound tetrahydrocannabinol (THC), thereby effectively legalizing it as an agricultural commodity. The passage of these legislative benchmarks, driven by a more positive public perception, has sparked enthusiasm and capital investments in the wide-ranging applications of hemp, from pharmaceuticals to construction, textiles, biofuels, environmental cleanup, and climate change mitigation. Nevertheless, misinformation, bias, data inconsistency, and a lack of research have hindered the progress of hemp utilization. This paper will provide an improved exploration of the direct social, economic, and environmental impacts of hemp production in light of the 2018 Farm Bill and the controversial 2023 Farm Bill to question if hemp's value is greater than its demonstrable costs for every hectare produced. To quantify the various facets of hemp, this research draws data from several government institutions and firms to examine the market and non-market values of hemp in a Cost-Benefit Analysis. This analysis finds a carbon sequestration net benefit of $765 to $3,604 and, after production, a net impact range of $-2,627.20 to $47,627.52 depending on application. Alternatively, a Net-Benefit Ratio Analysis yielded that every hectare of dollar spent producing hemp goods is associated with a value between $0.82 and $10.42, averaging $3.35. By comprehensively analyzing the net effects of increased industrial hemp funding and legalization, this paper offers valuable insights for stakeholders and governments to consider when developing agricultural initiatives and policies.

1: Introduction

This research relates to the novel industry presented by the recently decriminalized cultivation of hemp spurred by the United States Congress. Following an extended hiatus, industrial hemp offers the United States a unique opportunity to build a versatile, commercially promising market sustainably and to scale. Hemp, however, is hindered by its long established correlation to the psychoactive marijuana derivative in the same botanical classification. While hemp does not produce a "high" so to say, it can produce an initially surprising supply of consumer goods, efficiently sequester emitted greenhouse gases, remediate brownfield sites, substitute traditional pharmaceuticals, and even fuel transportation (Mark et al., 2020). With that said, the crop appears well positioned to address concerns related to sustainability, economic well being, and healthcare.

Established as one of the first crops cultivated by society, hemp has had a pivotal role in global development. Primarily used then to produce clothing, rope, lamp oil, food, wagon covers, and paper, the first records of hemp are from China as early as 8000 BC ("Hemp in History," 2024). Today appreciated for its cannabidiol (CBD) induced healing properties, China in 2800 BC recognized hemp for its treatment of malaria, rheumatism and as a sedative ("Industrial Hemp Production," 2023). Migration and trade with Europe led to its increasing globalization, brought to the New World in Chile the year 1545 and to New England by the Puritans in 1645 ("Industrial Hemp in the United States," 2023). Cultivation flourished in Virginia, Kentucky, and Illinois around the 1840's, where the highly-demanded crop became integral for cordage and sailcloth by the U.S. Navy. America's oldest navy vessel, the 44-gun USS Constitution, includes over 120,000 pounds of hemp fiber (Alcheikh, 2015). There is a significantly established historical relevance associated with the crop including the Gutenberg Bible, Magna Carta, and

Declaration of Independence drafts being developed on hemp paper (Gill et al., 2023). Following this production surge for various industries and applications, rising market competition given substitutes like cotton and the recreational use of marijuana led to a dampened appetite for hemp. This culminated into Congress' 1937 Marijuana Tax Act, positioning all *Cannabis* cultures under the regulatory control of the U.S. Treasury Department (Schumacher et al., 2020). With importation and production now overseen and taxed with jail time for violations, hemp became less economical and increasingly demonized by politicians and religious organizations ("Industrial Hemp Production," 2023). Public support correspondingly diminished and, despite a cultivation peak during World War II, the crop's progress stood relatively dormant due to anti-marijuana legislation.

As a result, a primary, significant distinction to make is that between hemp and marijuana. The term "hemp" refers to the plant *Cannabis sativa L*. and any derivatives, extracts, acids, or oils with a delta-9 tetrahydrocannabinol (THC) concentration of not more than 0.3% on a dry weight basis. Such a line in the sand is imperative as hemp, unlike Marijuana at 5-20%, contains a negligible amount of the psychoactive, "high" producing, component THC (Shipman, 2019). As synthesized in Figure 1, there are a variety of derivatives from *Cannabis sativa L.* with unique chemical structures and attributes. Accordingly, while the same species, marijuana plants are ideal for recreational or medicinal opportunities; they have shorter stems with broader leaves though the two appear quite similar to the untrained eye. Despite this critical difference in THC, hemp is consistently demonized for its association and lumped into anti-drug sentiment.

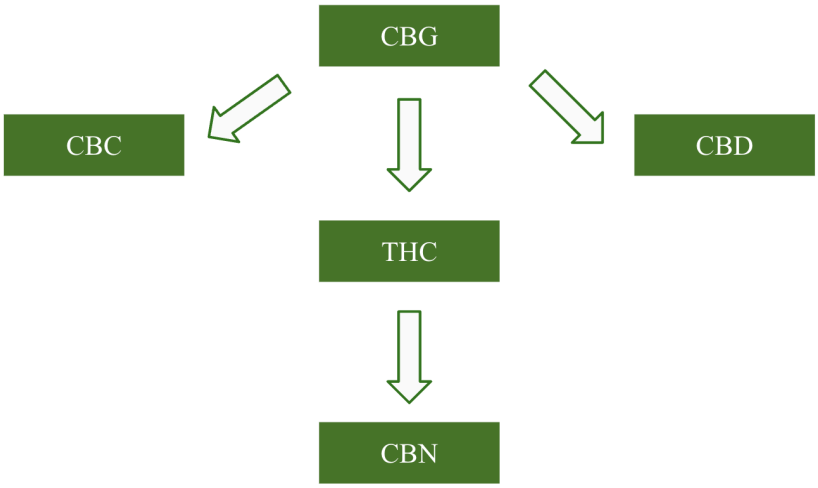


Figure 1: Biosynthetic pathways of the principal cannabinoids.

Essentially, hemp is not associated with psychoactivity. Rather, it is related to over 25,000 diverse applications, ranging from fuel and infrastructure to pharmaceuticals, food, land remediation, and textiles (Rupasinghe et al., 2020). Amidst the background of accelerating global Carbon Dioxide emissions and the increasing threat of climate change, hemp has value for its capacity to sequester great amounts of CO_2 from the atmosphere - 22 tons of carbon dioxide per hectare ("Hemp-30 Phase I Final Report," 2022). This is surprisingly greater than any other crop or woodland and even double the rate of a small forest ("The Role of Industrial Hemp in Carbon Farming," n.d). This implies that hemp cultivation is environmentally beneficial and increasingly relevant.

Recognizing hemp's versatility and effectiveness, the United States Department of Agriculture recently sparked interest in and production of hemp. The Agricultural Act of 2014, the "Farm Bill," removed hemp as a Schedule I drug under the Controlled Substance Act and cleared production for hemp research at higher education institutions, by state departments, and for farmers in state-regulated pilot programs (H.R.2642, 2014). Correspondingly, U.S. hemp

holdings jumped from zero in 2013 to over 90,000 acres in 2018, the largest cultivation since 146,200 in 1943 for the military (Mark et al., 2020). Nationally, the number of approved hemp licenses increased from 292 in 2014 to 3,852 in 2018, indicating crop diversification, revenue, and job opportunities (Mark et al., 2020). Provided this initial success, the 2018 Farm Bill comprehensively legalized hemp, establishing just minimal restrictions on its sale, production, transport, or possession so long as it meets the below 0.3% threshold (Hudak, 2018). Subsequently, there is a revived hemp industry following an extended criminalization. Despite such progress, governments, firms, and individuals often exhibit ignorance towards the plant itself and its applications. The general public misconception on hemp versus marijuana stands according to research, exacerbated by a lack of awareness as to hemp's non-psychoactive, important uses (Mikos, 2019). The industry must overcome resistance to a product that is often mistakenly tied to recreational drug use. Furthermore, inconsistency in data collection and variability in reporting transparency by state have complicated a holistic understanding of hemp's true market, social, and environmental potential.

While previous studies have examined the economic potential of hemp cultivation, few have conducted comprehensive cost-benefit analyses that consider both market and non-market aspects of production (Polanski, 2021). This study seeks to address this gap by employing non-market valuation methods and cost-benefit analysis to quantify hemp cultivation's economic and environmental impacts. By doing so, it aims to provide a more nuanced understanding of the true costs and benefits associated with hemp production, thereby contributing to the existing literature on hemp economics. Furthermore, while some research has highlighted the environmental benefits of hemp cultivation, such as its carbon sequestration potential, there remains a lack of consensus on the magnitude of these benefits and their implications for climate

change mitigation (“The Role of Industrial Hemp in Carbon Farming,” n.d). This study seeks to fill this gap by empirically quantifying the carbon sequestration potential of hemp cultivation and evaluating its implications for climate change mitigation. Providing empirical evidence on this topic aims to advance our understanding of hemp's environmental sustainability and its role in addressing climate change challenges. Moreover, existing literature often overlooks the regulatory and policy landscape surrounding hemp cultivation, particularly in the context of recent legislative changes (Mark et al., 2020). This study addresses this gap by providing a comprehensive overview of hemp's history and regulatory environment, providing valuable context for understanding current trends and policy implications. By doing so, it seeks to contribute to the existing literature on hemp regulation and policy, informing future policy decisions and regulatory frameworks related to hemp cultivation.

This study is positioned to address the emerging need for research as to the real costs and benefits of producing hemp at a national level. This paper aims to address this fault, examining hemp’s values in energy, medicine, infrastructure, land remediation, and carbon sequestration as well as its associated revenue and economic contributions. Some notable costs related to hemp are that of production, lost opportunity, and start-up being that this is an Infant Industry with a ways to go before it reaches scale. To foster an improved recognition of hemp’s assets and drawbacks, this paper utilizes a Cost-Benefit Analysis and assigns real dollar values on hemp’s application for every hectare of production. Analyzing data from the USDA, academic literature, the Environmental Protection Agency (EPA), and the National Institute of Health, this research employs non-market valuation methods to quantitatively gauge some of hemp’s impacts since the Farm Bill’s legalization. Given hemp’s wide range of applications, these calculations inherently

underestimate total costs (TC) and total benefits (TB), although this study offers partial explanations in Chapter 4.

This thesis is divided into several sections to explore the multifaceted aspects of industrial hemp. With the deficit in environmental economics literature pertaining to *Cannabis,* little do academic reports analyze non-market environmental values, especially in the context of a crop that has been historically criminalized, inhibiting data collection. As a result, this thesis supplements additional literature on hemp's monetary and sustainable applications while uniquely analyzing their costs and benefits. To remediate this gap in understanding, the goal of this study is four-fold: 1.) to evaluate the viability of the hemp market, 2.) to delineate hemp's history and regulatory environment, 3.) to quantify the market and non-market aspects of production, and 4.) to uncover the crop's challenges and future prospects. To do so, the paper examines hemp's economic values in energy, medicine, infrastructure, land remediation, and carbon sequestration. Through the lens of cost-benefit analysis and non-market valuation methods, this research sheds light on the multifaceted impacts of industrial hemp, offering insights for policymakers, individuals, and firms navigating the evolving landscape of hemp production and consumption.

2: Literature Review

The foundation of hemp's current reality is built on economic considerations, sensationalist media campaigns, and political agendas. Hemp, colloquially referred to as Mary Jane, Mary Warner, Weed, and marijuana, of course, is derived from the Greek *kannabis* and Latin *cannabis* (CBP, 2024). The plant was appreciated for its therapeutic and commercial uses until several state governments and other countries banned the drug in the early 1930s. This is as

hemp boasts a rich and versatile historical significance predating the 1900s that is outside the scope of this thesis (Abernathy, 2022; Fike, 2019; Godwin, 2015; Reed, 2015). This chapter, however, aims to provide an overview of the existing literature on industrial hemp's social, economic, and environmental dimensions beginning with its extended end in the 1900s.

2.1 Prior to Legalization

With a changing political climate, the founding commissioner of the Federal Bureau of Narcotics (FBN) Harry Anslinger led "one of the most successful disinformation campaigns in US history" (McGettigan, 2020). This fresh department was to enforce the Harrison Narcotics Act of 1914, a revenue-producing document to track overall drug trade and implement fines for violators of its provisions. This office consisted of 15 Districts with 271 agents, 426 office employees, and a budget of $1,712,998 (DEA, 2024). With public opinion continuing to see hemp as an economic lifeblood following its historical prevalence, Anslinger was given the tall order to construct the perception that hemp was not a harmless weed, rather the downfall of society. As a result, Anslinger concocted the "Reefer Madness" framework that ultimately encouraged the dawn of marijuana-specific regulation (Anslinger and Cooper, 1937). For example, one circulated paper noted that "Marihuana is a short cut to the insane asylum. Smoke marihuana cigarettes for a month and what was once your brain will be nothing but a storehouse of horrid specters. Hasheesh makes a murderer who kills for the love of killing" (Speaker, 2002). This quote reflects the alarmist diction and misinformation surrounding cannabis use, perpetuating unfounded anxiety about its effect on mental state and violence.

The truth was fundamentally irrelevant; Anslinger aimed to promote anti-cannabis hysteria to maximize federal funding for his department (Dickson, 1968). Passionate as he may

have been, the campaign originally fell on deaf ears given the public had never experienced the hemp horrors Anslinger preached. Instead, residents were living in towns extolling hemp's virtues: Hempfield (PA), Hemphill (KY), Hemp Island (FL), Hemphill Bend (AL), Hempstead (NY), Hemp (GA), Hempton Lake (WI), Hempfield Lake (MS), and Hempfork, (VA) (Chelsea, 2021). Consistently, environmental advocates, then-hemp producers, and papers reiterated hemp's benefits, despite ongoing debate. "Racism and Its Effect on Cannabis Research" speaks to what ultimately changed the tide on cannabis perception: motivating racism (Solomon, 2020). Connecting racist paranoia with cannabis consumption, Anslinger testified that, "Reefer makes darkies think they're as good as white men" (Hoston, 2016). Anslinger exacerbated racial tensions by then claiming that marijuana triggered uncontrollable sexual desires:

> "There are 100,000 total marijuana smokers in the U.S., and most are Negroes, Hispanics, Filipinos and entertainers. Their Satanic music, jazz and swing result from marijuana use. This marijuana causes white women to seek sexual relations with Negroes, entertainers and any others" (Lee, 2012).

Speaking to Anslinger's deliberate employment of racial stereotypes and fear-mongering tactics, this statement emphasizes the vilification of marijuana use among marginalized communities, further entrenching racial divisions and discrimination in society.

Solomon (2020) notes that Anslinger even helped popularize "Marihuana" over "Cannabis" to relate the drug with anti-Mexican prejudice. As Anslinger incorporated racism into the anti-cannabis crusade, the "Reefer Madness" phenomenon exploded. Newspaper tycoon William Randolph Hearst, recognizing that hemp posed competition to his significant investments in lumber for paper, supported the charge. With the ability to disseminate information to thousands of impressionable Americans, Hearst's papers often criticized the plant:

“Marijuana was known in India as the ‘murder drug,’ it was common for a man to ‘catch up a knife and run through the streets, hacking and killing everyone he [encountered]” (Solomon, 2020). This report also notes that additional significant contributors to the prohibition of cannabis were the DuPont family, whose chemical enterprise had recently developed nylon and purportedly feared competition from hemp fiber. Andrew Mellon, the wealthiest individual in the country and the Secretary of the Treasury, held substantial investments in DuPont and attacked the plant politically. Interestingly enough, speaking to the interconnectedness between these players, Anslinger was unemployed until his appointment to the FBN by Andrew Mellon, his wife’s uncle (Solomon, 2020). The author emphasizes the significant criticism this familial relationship has raised about a potential conflict of interest in the federal drug-related regulatory framework.

With the growing public hesitancy over narcotics following the media and bureaucratic charges, President Franklin D. Roosevelt committed his support to regulation in 1933. In a letter to the president of the World Narcotic Defense Association, Roosevelt employed similar claims of innate drug evil and risk, though this specifically pertained to heroin, morphine, and cocaine (“Roosevelt Asks for Narcotic War Aid,” 1935). Given this support for regulation, the United States was one of the premier ten ratifiers of the Geneva Narcotic Limitation Convention Treaty. This influenced the supply and trade of various drugs to a degree, yet further restriction came with the passage of the 1934 Uniform State Narcotic Act. Extending beyond the Harrison Act in 1914, the Narcotic Act allowed for police enforcement of uniform federal laws relating to the transportation, sale, and possession of various substances (DEA, 2024). With impetus from the Federal Bureau of Narcotics, these legislative landmarks serve as the federal government’s primary foray into narcotic oversight.

Together, the campaign against cannabis led to the enactment of the Marihuana Tax Act on August 2, 1937, with an important emphasis on tax. Explicitly, House Resolution (H.R.) 6906 is "An act to impose an occupational excise tax upon certain dealers in Marihuana, to impose a transfer tax upon certain dealings in Marihuana, and to safeguard the revenue there from by registry and recording" (Marihuana Tax Act, 1937). This broadly regulated the importation, cultivation, possession of, and distribution of marijuana. One provision mandated importers to register and pay an annual tax of $24, approximately $460 in 2024. Meanwhile, shipments were subject to seizures, frisks, and forfeitures. A custom's collector at the port of entry retained possession of imported marijuana until the necessary documents were obtained, and similar regulations applied to marijuana exports. Even further, violation of the act led to a fine not exceeding $2000 then or an imprisonment to a limit of five years. By adding these additional hindrances onto the production and distribution of the cannabis crop, individuals transitioned to the emerging substitutes posed by firms such as DuPont. The years-long discourse on marijuana proved effective, evidenced by over 41,000 acres of hemp in 1917, reducing to just 600 acres in 1929 (Dvorak, 2004). This being the culmination of market competition and social pressure, the powerful anti-marijuana voices further testified at the July of 1937 "Taxation of Marihuana Hearing" before a Subcommittee of the Committee on Finance in the United States Senate. The Committee consisted of representatives from 20 of the 48 states, with the addition of Alaska and Hawaii in 1959.

Naturally, Henry Anslinger proposed the initial statement. Noted in this document, the commissioner contended that "crudely prepared" Marihuana cigarettes were readily circulating at just $0.10 to $0.25 each, destroying individual free-thought and control ("Taxation of Marihuana," 1937). Recognizing the applications of hemp, Anslinger notes that the oil can be

manufactured into paint, soap, pigeon feed, and linoleum, yet its inherent danger overshadows any practical use: "'many violent crimes have been and are being committed by persons under the influence of this drug." Arguing that cannabis is a drug for "hardened criminals" and "high-school children" alike, Anslinger's sentiments are echoed in following testaments. However, other speakers, including representatives of the Hemp Chemical Corporation and the Juneau Fibre Corporation, acknowledged the disproportionate impact that the Act will have on small growers incapable of meeting the proposed regulations and paying the taxes. Producers, slated to pay $5 per year in tax, were also tasked with obtaining licenses and registering returns with the collector of internal revenue. In principle, the Marihuana Tax Act of 1937 sought to reduce recreational use and generate national income. In doing so, it effectively criminalized possession of the "habit-forming," "homicidal mania" inducing cannabis species, acting as the final nail in hemp's coffin throughout the early 20th century. Thus, the trajectory of the act was shaped by racial prejudices, moralistic concerns, and financial interests to ultimately set a precedent for federal intervention in drug regulation.

2.2 Post-1937 Implications and Landscape

This ushered in an era marked with punitive measures and cannabis stigmatization up until World War II. With imports of abaca and jute crop for textiles unavailable given political supply chains, the Government established an emergency program. Using nothing other than hemp, the United States Department of Agriculture supported a quasi-official organization recognized as War Hemp Industries Inc. This encouraged production to a staggering 56,000 acres by 1944 ("The True Story Behind the War Hemp Industry," 2020). To meet the escalating demand for war supplies, the United States Department of Agriculture went so far as to release a

short propaganda film: “Hemp for Victory.” In “Hemp for Victory: A Global Warming Solution,” Davis recognizes that this persuaded farmers from the states of Kentucky and Wisconsin to grow government-subsidized hemp instead of maize for rope, ship sails, shoelaces, and parachute webbing (Davis, 2007). Speaking to the initiative’s success, the documentary’s narrator discerns that “In 1942, at the government’s request, patriotic farmers planted 37,000 acres of seed hemp, an increase of a few thousand percent. The target for 1943 is more than 50.000 acres of seed hemp” (Nuclear Vault, 2016). This surge in hemp cultivation highlights the adaptability of agricultural policies in response to wartime needs. However, at the cessation of the war, the government put a quick stop to legalized production and even mandated the destruction of planted hemp (Davis, 2007). Hemp-cultivation dramatically returned to 1938 levels and stigmatization continued despite emerging reports like “Hemp: The New Billion Dollar Crop” from Popular Mechanics that same year (Limer, 2018). Regardless, the crop’s prohibition was far from over.

The scarcity of hemp cultivation was further solidified with the passage of the Controlled Substances Act (CSA) in 1970, which posited cannabis - including hemp - as an adversary to Nixon’s War on Drugs. The CSA categorized drugs into five distinct schedules based on their perceived risk levels. While substances like methamphetamine, ketamine, and codeine were categorized in lower-risk tiers, hemp was classified as a Schedule I substance, erroneously labeled as the most dangerous despite its negligible psychoactive properties and unfounded health effects. Among heroin and ecstasy, the primary rank was reserved for drugs with a “high abuse potential” and “no accepted medical use” (The Federal Comprehensive Drug Abuse Prevention & Control Act, 1970). Prompting the development of the Drug Enforcement Agency in 1973, this regulation further inhibited the cultivation, prescribing, and transportation of hemp.

This legislation was also critical in defining the industry, noting that, “The term "marihuana" means all parts of the plant *Cannabis sativa L*., whether growing or not; the seeds thereof; the resin extracted from any part of such plant; and every compound, manufacture, salt, derivative, mixture, or preparation of such plant, its seeds, or resin” but excludes mature stalks, fiber, oil, cake, and sterilized seeds incapable of germination (The Federal Comprehensive Drug Abuse Prevention & Control Act, 1970). Evidently, the Controlled Substances Act epitomized the anti-Marijuana sentiment of the current administration, marking a pivotal moment in hemp’s history. By aligning hemp with illicit drugs despite its minimal psychoactive effects, which had been discovered in 1964, hemp’s usage was hindered and the stage was set for stringent regulatory measures (Crocq, 2020). This legislative move impeded hemp’s industrial and medicinal potential for decades, contributing to continued demonization surrounding the plant.

3: Hemp’s Revival and Existing Fields

As 2014 dawned, the second stage of hemp’s domestic history followed, marked by an increasingly optimistic outlook. Accordingly, this chapter pertains to the confluence of factors spurring the hemp industry today and to the existing literature on the interdisciplinary market. Just as it was largely politics that led to hemp’s downfall, the same prompted its revival. This came with The Agricultural Improvement Act of 2014. The United States addresses the food and agricultural landscape through this omnibus package of legislation encompassing domestic nutrition assistance, land conservation, farm commodity revenue supports, rural development, research, forestry, horticulture, farm credit, and horticulture. Commonly referred to as the Farm Bills, these set the legal framework for a variety of integral initiatives affecting the lives of millions of Americans such as the Supplemental Nutrition Assistance Program. The Agricultural

Acts were a response to food and agricultural insecurity in the Great Depression (Plumer, 2024). Ideally revised and passed every five years, the most recent came in 2018 as the 2023 Bill has been delayed given extensive negotiations (Hammerich, 2024). This landmark 2014 Bill was signed by President Obama on February 7, 2014 and is outlined to cost some $956.4 billion over 10 years (Plumer, 2014). Despite impressive funding, most of this (79%) is distributed towards food stamps and nutrition followed by crop insurance, conservation, commodities, and everything else (Plumer, 2014). This infers that the Farm Bills tend to prioritize the food and nutritional landscape over agriculture.

Among these agricultural investments stands the significant legalization of hemp. Given growing recognition of its economic potential, environmental benefits, and versatility, the crop could once more see the light of day. The Farm Bill asserts that hemp may be "grown or cultivated for purposes of research conducted under an agricultural pilot program or other agricultural or academic research" (H.R. 2642). This was spurred by an interest from farmers to identify alternative, profitable crops amidst depressed prices for traditional commodities, exacerbated by changing weather patterns (Mark et al., 2020). Prior to this Farm Bill, in 2007, the first US industrial hemp cultivation licenses in over 50 years were granted to two farmers in North Dakota to produce paper and rope (Adesina et al., 2020). Subsequently, smaller, sporadically-distributed farms were provided sparse clearances to cultivate, until the more holistic 2014 regulations. Data is not available for these initial programs and acreage prior to legalization. Section 7606 of the Bill, "The Legitimacy of Hemp Research," garnered bipartisan support and encouraged the reintroduction of the crop (H.R. 2642). This move was supported by various stakeholders, including farmers, researchers, and advocates, who highlighted the numerous uses of hemp across industries. Acknowledging these benefits, the House-Senate

passed the Farm Bill, permitting cultivation as long as it is legalized by states individually, regulated by State Departments of Agriculture, and meets certain requirements. This includes the degree of psychoactive content.

A pillar of hemp in the Farm Bill includes the establishment of the important difference between hemp and marijuana. Industrial hemp is referred to here as any derivative of the *Cannabis sativa L.* plant with a "delta-9 tetrahydrocannabinol concentration of not more than 0.3% on a dry weight basis" (H.R. 2642). As established, this pales in comparison to traditional marijuana plants with THC concentrations 50 to 100 times greater (Backman, 2023). With hemp finally separated from its psychoactive sibling, hemp seeds made their way to farms and products to shelves. As these pilot programs rolled out across the country, producers began capitalizing on the allowances to cultivate hemp especially in Colorado, Kentucky, and Oregon (Olson et al., 2020). Following the Act's implementation, 28 states saw the passage of legislation that enables hemp farming under the conditions of the Bill. As noted in the USDA National Hemp Report (2023), the year after this Farm Bill saw 3,933 acres planted, growing to 25,713 in 2017. Moreover, in 2015, United States hemp product sales reached $573 million, indicating an emerging source of national income (Hemp Industries Association, 2016). Hence, the legalization of hemp in the 2014 Farm Bill marked a significant step towards exploiting the full potential of this crop in the United States.

3.1 The 2018 Agricultural Improvement Act

Four years later, the 2018 Farm Bill expanded on hemp freedoms and retracted its Schedule 1 drug classification, effectively legalizing its production and distribution nationwide. This pivotal move resulted in a plethora of opportunities for farmers, entrepreneurs, and

investors, as it provided a clear legal framework for the cultivation, processing, and sale of hemp-derived products, including cannabidiol (CBD). This Agricultural Improvement Act was signed on December 20, 2018 by President Trump to increase total spending by less than 1%, $1.8 billion (USDA Economic Research Service, 2018). On a related note, a key player behind this revived production was Kentucky-advocate Senate Majority Leader Mitch McConnell, who aimed to capitalize on hemp's economic potential in a state with a deep and expansive hemp history (Hoban, 2023). McConnell spoke at the hemp provision's Senate hearing regarding the crop's promising future and of unfounded regulation, culminating in an 87-13 vote that day to adopt the conference report (Lesniewski, 2018). With his frequent visits to farms and processing facilities across his home state following 2014, McConnell remained committed to empowering American farmers to tap into the burgeoning hemp market. As he aptly noted, ""There's hemp all over America right now. It's all imported. There's no reason why American farmers shouldn't be able to grow this crop"" (Lesniewski, 2018). Even as many recognize that this advocacy was rooted in his campaign and reelection, McConnell's unwavering support and strategic efforts were instrumental in laying the groundwork for the resurgence of hemp production on American soil. Such a resurgence in market demand post Farm Bills is supported by a dramatic increase in acres between 2018 and 2019 and steady, positive growth in subsequent years. Accordingly, 47 States had passed legislation to allow some form of hemp production by December of 2019 with the exception of Idaho, Mississippi, and South Dakota (Mark et al., 2020). Read in Table 1, Hemp's derived value from greater land dedication following legalization results in immense economic potential for the United States.

Table 1: Profitability of hemp production in the United States by product. Derived from the National Agricultural Statistics Service (2021).

Product	Pounds produced	Hectares harvested	Value derived (in 2021 million USD)
Grain	1.86	3,515	42
Fiber	33.20	12,690	41
Flower	19.70	15,980	623
Seeds	4.37	8,255	6

The Food and Drug Law Institute in "The Legalization of Hemp" conveys the remaining regulations in and status of the hemp industry prompted by the Farm Bill. The Act opened doors for hemp production and distribution at the federal level, establishing a framework for collaborative oversight involving Native American tribal, federal, and state authorities (Lee, 2019). Under the Farm Bill, interstate transfer of hemp products for commercial and medicinal purposes is permitted, contingent on abidance to any unique local and federal standards. Furthermore, the law extends significant financial protections, including crop insurance and financing, to the hemp plant which had previously been afforded just to traditional agricultural commodities. Lee (2019) notes that key regulations on hemp implementation are largely under the jurisdiction of state and tribal governments that can exercise "primary regulatory authority." They are instructed to submit a plan for USDA approval describing procedures for record keeping, testing THC levels, conducting inspections, submitting licensure, addressing plants in violation of the law, and complying with enforcement provisions (Lee, 2019). It must also be certified that the state or tribe has the resources to implement the proposed plan. Meanwhile, the USDA is tasked with annually reporting to Congress and the public in regards to hemp's production, though the author recognizes the inconsistency and underreporting in data collection.

Speaking to violations and enforcement, the report raises that a user or producer convicted of a drug-founded felony is ineligible to participate for a decade while a person who falsifies any application information is barred from future participation. The author concludes with a recognition that the crop is of great significance and that further research into cannabis-derived wellness opportunities is essential.

There are various studies that examine the success of these 2014 forward pilot programs (Gonzales, 2023; Monke, 2024; Shepherd et. al, 2020). Throughout the USDA sponsored "Economic Viability of Industrial Hemp in the United States," the authors emphasize that acreage stood at zero in 2013 and cultivation exploded. Yet, the industry's long-term economic sustainability is uncertain. They contend that this is partially the result of varying state by state requirements, evolving standards, and bias, all contributing to producer hesitation. Interestingly enough, states with high recreational marijuana consumption are not always major hemp producers. Minimal state production is often associated with the area's climate and other established industries. Thus, similar to other agricultural commodities, the economic feasibility of hemp cultivation may vary across states. Even with limited barriers to entry, farmers are unlikely to opt for hemp cultivation if more lucrative alternatives are available - opportunity costs.

As a result, despite these allowances, state production does not solely increase over time. The earliest pilot programs from 2015 and 2015 were not necessarily the largest five years later, remaining more niche experimental projects. Indiana, for instance, stood at just 5 acres in 2015 and raised to 16 in 2018 (Olson, 2020). From this report, Colorado, Kentucky, and Oregon expanded quickly after legalization, becoming some of the largest domestic hemp producers. In general, the pilot programs remained small in early years, with most states initially having fewer

than 5 employees to oversee them in early years (Mark et al., 2020). Despite minimal administrative efforts, the pilot programs are largely deemed a success given the thousands of planted acres across the country.

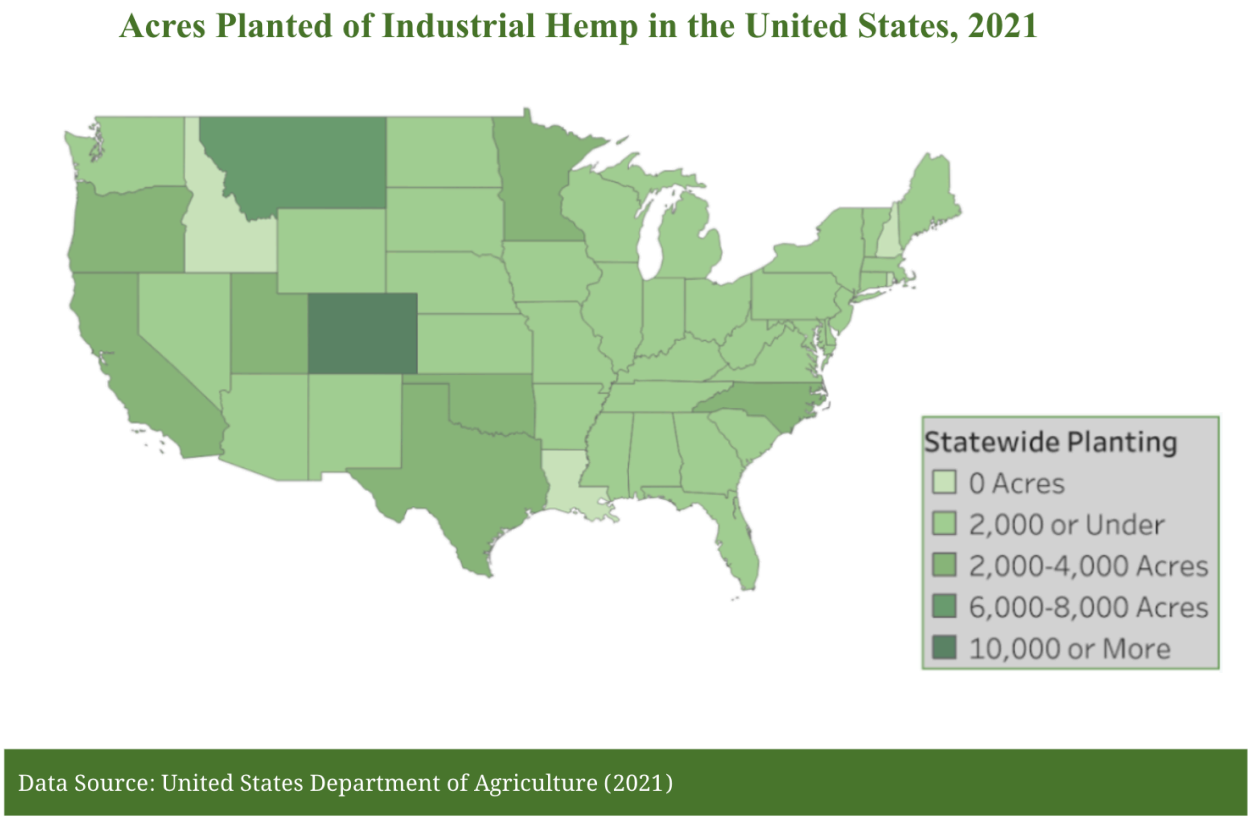


Figure 2: A map of United States hemp cultivation levels since legalization.

Recognizing the potential to diversify operations and profit on a budding cash crop, farmer interest in hemp is clear with the nearly fivefold increase in approved growers from 2018 to 2019 (Ellison, 2020). However, this study observes that 2019 to 2020 saw just a 27% increase in growers. Following a surge in demand from legalization, production often increased rapidly in many areas, subsequently driving down profits for hemp (Rupasinghe et al., 2020). While this oversaturation is not the reality across the entire market, it is a valid concern for farmers in deciding whether or not to cultivate. Consequently, the long-term economic viability of industrial

hemp hinges on several factors, including competition with more established crops for acreage, access to market information and transparency, and the existing regulatory environment.

President Biden signed H.R. 6363, the *Further Continuing Appropriations and Other Extensions Act, 2024,* into law on November 16, 2023 ("Farm Bill Home," 2024). This legislation extends the provisions in the Agriculture Improvement Act of 2018, enabling authorized programs to operate until September 30, 2024. As a result, the status of hemp legalization in the United States is relatively stable for the next few years. However, as reality and research instills, political influences can significantly impact the status of hemp. This lends to the possibility of long-term federal volatility in the market.

Aligning with international climate goals and offering revenue opportunities, it does not appear likely that hemp criminalization will occur in immediate years given bipartisan support of its applications (Hoban, 2023). Thereby, the 2018 Farm Bill represented a significant milestone in the revival of the hemp industry, uncovering its immense economic potential and paving the way for innovation and growth in this emerging sector.

3.2 Agronomic Conditions

Various literature has examined the ideal growing conditions and unique considerations for the hemp plant. Generally, the hemp plant is broadly classified into four sectors: 1.) grain, 2.) seed, 3.) floral, and 4.) fiber. The first categorization utilizes hemp for food products, beauty, personal care, fuel alternatives, and nutritional supplements. The fiber sector utilizes the plant's stalks, particularly the bast and hurd, to produce textiles, paper, infrastructure materials, animal bedding, and other fiber-based products. The floral application, however, is most associated with products such as essential oils, pharmaceuticals, and smokeables given its highest concentration

of CBD. Speaking to this, The University of Wisconsin, Madison evaluated the crop's production reality and agronomic conditions. It found that planting between mid-May and late-June led to the highest yields and lowest risk of frost injury (Conley et al., 2018). While the plant's end-use, variety, and purity dictates its optimal seeding rate, it is broadly agreed that higher seeding rates ensure a higher quality fiber crop (Conley et al., 2018; Roseberg 2019).

Hemp seed has an average germination failure rate of 10% while this may fluctuate from 8% to 70% depending on climate conditions (Conley et al., 2018). Relative to corn, the most grown crop in the United States, Colorado State University found that this competing crop stood at 10% to 15% (Keshavarz, 2024). High hemp mortality in Wisconsin's study is attributed to unfavorable growing conditions while seeding, toxicity due to seed-placed fertilizer, herbicide residue, and excessive seeding depth. It is important to note that corn's success is founded on decades of research into the plant, speaking to the possibility for hemp to achieve similar germination rates if prioritized and researched to this extent. There is no current FDA approved herbicide for industrial hemp, though the crop is susceptible to soil erosion and soil nutrient depletion (Cherney, 2016).

The University of Connecticut's Department of Agricultural and Resource Economics already spoke to the market challenges and production specifics of industrial hemp, though this analysis is limited to just the state. In "CBD Hemp Production Costs and Returns for Connecticut Farmers in 2020," the authors find that hemp for CBD dominates incentive to produce and that the revenue per acre in the sample is $24,375 relative to a cost of $19,289 (Jelliffe et al., 2020). This study employs economic engineering to simulate the best growing practices based on expected market prices and likely outputs and draws in interviews with farmers to validate assumptions. As a result, this sample includes farms with 6 feet row spacing and where

cultivation is done on well-drained land composed of loam clay soils with >3% organic matter, low sodium (Na) and magnesium (Mg), and Cation Exchange Capacity (CEC) from 12 to 20 (Smart and Ullrich 2019). CEC is a soil property that describes the capacity to supply positively charged ions for plant uptake of nutrients with 10 cmol(+)/kg or above being ideal for plant production, demonstrating hemp's strength in this area (Ketterings et al., 2007). To prepare the seedlings in this study for transplant, the researchers use a 30' by 60' heated greenhouse to produce 15,536 seedlings given a 92% germination rate (Jelliffe et al., 2020). The seedlings need just four to five weeks in advance of transplanting. Prior, a cover crop is planted on the 10 acre fields and soil samples are extracted to test for heavy metal and pesticide residue. Upon passing, lime is applied to the soil to reach the desired soil pH with around 6.5 to 15 PPM phosphorus, potassium ranging from 158 to 235 PPM, and Sulphur availability to 10N:1S (Smart and Ullrich 2019). Growers are also recommended to raise beds for drainage and apply plastic mulch to control soil moisture and weed pressure. Connecticut's study asserts that vertebrates, such as deer, groundhogs, mice, moles, voles, and rats are, as with most crops, attracted to hemp, though their risk can be mitigated with traps and electric fences. Similarly, an aphid, corn earworm, European corn borer, Japanese beetle, spotted cucumber beetle, tarnished plant bugs, and Western black flea beetle are noted as relevant insects and mites affecting the hemp industry (Darby, 2020). With climate change leading to the geographic expansion of "pests," the author notes that considering and mitigating hemp's vulnerability in this arena is critical for long-term production. In recognition of environmental sustainability, hemp requires less pesticides or water in cultivation compared to cotton, a representative fiber plant (Yano, 2023). Consistently, Schumacher et al. (2020) concludes that, agriculturally, hemp is one-twelfth the cost of cotton.

Harvesting is generally through a straight combining harvester machine to cut and thresh the crop in one pass, separating the grain from the straw and chaff. However, emerging specialized equipment, swathing, and sickle mowers have been found to increase efficiency and reduce labor costs by the University of Nebraska (Wortmann, 2020). Generally, the production process spans from seed germination to planting, crop maintenance, harvesting, extraction, retting, drying, manufacturing, and quality control (Ahmed, 2022). It is significant to note that hemp fiber, flora, seeds, and grain production generally use the same technology, but have characteristic-specific costs when being produced into value-added products. In this study, value-added products refer to a derivative of hemp that is processed to generate more utility and value. Briefly, these include CBD oils, compost, insulation, skincare, bioplastics, paper, animal bedding, foods, and ethanol (Mark et al., 2020). In fact, there are as many as 50,000 claims as to products that hemp can contribute to or ecosystem services it provides (Carus et al., 2016). Among these, previous research has found that the major product categories with market potential are fiber, oilseed, and pharmaceuticals (Cherney, 2016). While beneficial in understanding the economic potential associated with hemp revival, this paper fails to quantitatively consider the full extent of environmental benefits yielded from cultivation. Numerous agricultural institutions record hemp's acreage, pounds yielded by unit, sectors harvested, and prices received. To date, there has not been an economic analysis of this kind relating the versatility of hemp's market and non-market uses. This paper is centered around a Cost-Benefit Analysis, an increasingly accepted unit of understanding the benefits and drawbacks of a proposed treatment. This way of thought, as to be discussed, has yet been applied to national hemp production - rather site-specific locations (Barnes et al., 2023; Lane, 2017).

With the immense implications from the overarching 2018 Farm Bill, the revived potential of industrial hemp across environmental, social, and economic dimensions has little been reviewed.

3.3 Marijuana Cost-Benefit Analyses

In the academic and agricultural literature, to the best of my knowledge, there is no paper analyzing both market and non-market aspects of industrial hemp production since the Farm Bills. To provide a concise overview, non-market research quantifies environmental benefits and costs, lending insights to their monetary significance beyond traditional market prices. However, traditional cannabis literature has a degree of this economic perspective. Interestingly enough, one analysis written prior to legalization evaluates the status-quo at the time with the controlled-regulated marijuana alternative (Ritter et al., 2014). This study, "Cost Benefit Analysis of Two Policy Options for Cannabis: Status Quo and Legalisation" values each policy on five categories. These include: 1.) direct intervention costs, such as enforcing laws or regulations; 2.) costs or cost savings to other agencies, individuals, or families, such as treatment for dependence; 3.) benefits to the individual or family resulting from the policy; 4.) externalities, which refer to unintended effects on third parties, such as changes in productivity or injuries to third parties; and 5) adverse or spill-over events. This study sought to address the prevalent gap in research for papers that address the costs and benefits of emerging narcotic policies. The researchers use a Monte-Carlo simulation derived from statistical analysis and random sampling, reporting results as a Net Social Benefit (NSB). This being the sum of all valued benefits minus the sum of all valued costs, the study ranks NSB magnitude for each category. It does this for both the status-quo and the legalized policy alternative and, while there is no widely accepted model for legalizing cannabis, it assumes regulated markets include:

monopoly distribution, age restrictions, consumption location restrictions, prohibited advertising, contracts with growers, and producer licenses. To analyze the costs and benefits of legalization, the researchers position an *ex post* alternative (the current status quo) and an *ex ante* alternative (the hypothetical).

To obtain these values, the authors run a Monte Carlo simulation with a normal distribution, conducting 1,000 repetitions to find the 5th and 95th percentiles for a mean. In 2007 Australian dollars, the total benefits are estimated at $362.7 million per annum [$282.1 - $513.0 million] for the status quo and $318.8 million [$222.4 - $394.2 million] for the legalized–regulated alternative. The legalized-regulated model included an additional $659.4 million in net government revenue, resulting in added benefits in the NSB. The total costs are calculated at $80.1 million in the status-quo and $90.72 million in *ex ante.* Excluding government revenue, the mean annual NSB for prohibition was $294.6 million [$201.2 - $392.7] and $234.2 million [$136.4 - $372.3] for the legalized–regulated model. Accounting for retail, the mean NSB in legalized-regulated raises to $727.5 million. Additionally, evaluating non-market considerations, increased consumption is associated with both decreased levels of educational attainment and increased levels of wellbeing from cannabis. While specific to cannabis' psychoactive cannabinoids rather than hemp, fieldwork into the economics of the industry is emphasized as critical given its rampant adoption and commercialization. Although prior to hemp legalization, this study provides a groundwork for understanding economic analyses of illicit crops especially as 128,900,000 to 190,700,000 million people worldwide in 2010 used cannabis (Ritter et al., 2014).

Following hemp decriminalization, "Recreational Marijuana in Ohio: A Cost Benefit Analysis" finds a positive social net benefit from implementing legalized marijuana in Ohio

(Polanski, 2021). The estimated social net benefit experienced by the state totals more than $444 million at the time. The highest sources of economic returns come from tax revenue, jobs, and lower DUI arrest rates that will be created by legalization.

These studies offer insight to the medicinal and recreational market related to the cannabis industry. Prevailing despite legalization, my review found that the comprehensive economic and environmental research extended to competing crops is not yet available for hemp. The burgeoning hemp industry is fostering an entrepreneurial ecosystem, with startups, small businesses, and innovators driving growth and innovation in exploring diverse opportunities, from hemp cultivation and processing to the development of value-added products and services. With this increase in adoption, the hemp plant is uniquely positioned to contribute to broader social, economic, and environmental priorities.

4: Hemp's Applications

With an extensive repertoire of widely-accepted exercises, hemp demonstrates value across medicinal, industrial, and environmental dimensions. These applications have been appreciated for centuries and revived following hemp's legalization in 2018. This chapter aims to offer a concise outline as to the promising uses of and concerns the hemp crop is positioned to address.

4.1 Environmental Contributions

In the context of accelerating global greenhouse gas emissions inducing climate change, hemp finds application in the environmental arena. The crop is recognized as incredibly sustainable given its ability to grow in a wide variety of climates, sequester carbon, improve soil

quality, cultivate with less inputs, and produce a renewable energy source (Cherney, 2016). These applications stand particularly relevant when, in the United States, the electricity and transportation sector each contribute between 20% and 30% of domestic CO_2 emissions. Encompassing these domains, hemp also finds sustainable relevance in the agriculture sector associated with 10% of emissions (EPA, 2024). As the effects of warming continue, farmers increasingly explore sustainable agriculture opportunities, advocating for hemp's legalization and cultivation as both a source of revenue and sustainability.

4.1.1 Role in Carbon Sequestration

Although carbon is routinely mentioned in the context of rising emissions, the novel hemp's growth actively removes carbon from the atmosphere. Hemp facilitates carbon sequestration, the process by which biological, geological, or technological materials capture and store carbon; it is acknowledged as a critical approach for reducing total natural and anthropogenic carbon emissions (Lal, 2007). In what is double the rate of a developing forest, a hectare of hemp can sequester 15 to 22 tons of carbon dioxide over its growth cycle (EU, 2024; "The Role of Industrial Hemp in Carbon Farming," 2020). For reference, the United States' emissions totaled 6,340 million metric tons of greenhouse gases in 2021 (EPA, 2024). Provided the significant increase in hectares of hemp since decriminalization, an environmentalist would advocate that this environmental benefit alone is a viable cause to cultivate.

While photosynthesis is not a revolutionary phenomenon, hemp notably exhibits a rapid biomass production and possesses extensive root systems, enabling efficient carbon capture and storage in both above-ground biomass and soil organic matter. It is noteworthy to highlight that hemp carbon capture is partially dependent on cultivation practices, weather, and soil quality

(Shen et al., 2022). Nevertheless, hemp affords the United States an abundant opportunity to further align itself with international environmental agendas such as the 2015 Paris Climate Accords and the United Nations' Sustainable Development Goals.

Recognizing this potential solution to climate woes, higher-education institutions are progressively designing programs dedicated to hemp science and securing funding for diverse facets of research. The five-year USDA Climate-Smart Commodities grant was just recently awarded to Florida A&M University for $4.9 million (Moore, 2023). This supports research in hemp's production, role in land conservation, and carbon sequestration ability while centering the sentiments of small, underserved farmers. Likewise, Cornell University's School of Integrative Plant Sciences maintains one of the largest and best-funded programs in the country (Buckler, 2024). Seeking to both inform the public and generate market opportunities, educators are investing time and resources in hemp. As a renewable resource, the integration of hemp cultivation into agricultural systems encourages carbon sequestration efforts while additionally yielding valuable consumer products.

4.1.2 Renewable Energy Source

The steady increase in energy consumption coupled with environmental pollution has promoted research in alternative and renewable energy fuels. To address the emerging global energy crisis, there is continuous international development of materials and methods to effectively utilize alternative fuel resources. Renewable fuels, also known as non-conventional or advanced fuels, are any materials or substances that can be used as energy. This contrasts conventional fuels including petroleum, coal, propane, and natural gas), and nuclear materials such as uranium. It is important to note that, despite widespread adoption, fossil fuels are

innately exhaustible and, thus, unsustainable. By definition, however, fuels derived from soy, corn, and the like are renewable. Biofuels are increasingly considered as effective alternatives to traditional petroleum diesel. For instance, biodiesel production has risen to 1.72 million gallons in 2019, up 234% since 2009 (Cheng et al., 2021). However, most of this production is fueled by soybeans or corn. In 2019, 60% of all feedstock consumed for biodiesel was from soybean oil and 30.80 million hectares of agricultural land in the USA was used for soybean cultivation (Cheng et al., 2021). As interest in the supply of renewable energy is heightened to provide a more environmentally beneficial substitute for fossil fuels, hemp finds further application. The high biomass yield and rapid growth of hemp make it a viable and renewable feedstock for biofuel production, although other sources of alternative fuel are significantly more established.

Through a standardized process known as transesterification, hemp seed can be processed into a carbon-neutral biofuel. The University of Connecticut, in evaluating this, noted that the resultant passed all laboratory safety tests and showed a high efficiency of conversion: 97 % of the hemp oil was converted to biodiesel (Buckley, 2010). Various studies have attributed this effectiveness to the plant's high fiber, carbohydrate, and phytochemical content (Parvez et al., 2021; Tulaphol et al., 2021). Effectively, hemp is among the most efficient regarding fuel yield by hectare.

Table 2: Fuel Yields Across Varying Crops.

Crop	Fuel Yield (in gallons/hectare)	Source
Soybean	56	Brown (2006)
Canola	75	USDA (2024)
Sunflower	82	Brown (2006)
Peanut	100	USDA (2024)
Hemp	**207**	**Alcheikh (2015)**
Coconut	230	Brown (2006)
Oil Palm	508	Alcheikh (2015)

Significant to note is that biodiesel stands as the only alternative fuel with the capacity to run in any conventional, unmodified diesel engine (Cheng et al., 2021). With this, hemp fueled over 30 million United States road miles by 2016, suggesting a much higher value for later years without data (NHA, 2016). These benefits applied to the transportation sector, one notorious for considerable carbon dioxide equivalent emissions, are quantified in this analysis, as are breakeven unit production costs. Meanwhile, this study lacks a monetary reflection of the health effect from reduced contamination exposure given findings that the biofuel is 10 times less toxic than table salt (NHA, 2016). Additionally, the biodiesel, derived from hemp and other bio-based sources, is particularly biodegradable, with properties akin to sugar, and exhibits a considerably higher flashpoint of around 300°F, contrasting with the 125°F flashpoint of petroleum diesel (Gaiaca, 2021). This elevated flashpoint indicates the minimum temperature at which a liquid will ignite, highlighting biodiesel's enhanced safety profile. As a result, hemp oil has established promise to supplement the United States' renewable energy portfolio while simultaneously improving environmental and social health. As hemp's chemical and agronomic properties have rendered it a viable biofuel, this derivative can have positive implications for the energy sector.

4.1.3 Hemp Transportation

Globally, the road transport sector consistently emerges as a significant contributor to air pollution, primarily attributed to its high energy intensity and reliance on fossil fuels. Consequently, governments and various stakeholders are engaged in formulating and implementing strategies for decarbonization with a focus on fostering sustainable transportation. This includes the encouragement of electric vehicles, biofuels, natural gas, liquefied petroleum gas, and other substitutes as part of energy planning initiatives aimed at reducing the environmental impact of the transportation sector. One of hemp's 25,000 applications includes its ability for its material to be manufactured into vehicles (Cheng et al., 2020). BMW has an recognized commitment to sustainability, seen with the BMW M Motorsport in Formula E in 2019 created from renewable plant fibers (Seidel, 2022). Other BMW sustainable development initiatives include the use of flax and kenaf fibers to make a carbon neutral coating, resulting in almost a 60% decrease in the total emissions from the car (Seidel, 2022). In the manufacturing of their i3 electric car, BMW has even incorporated biocomposites derived from industrial hemp. This strategic use of industrial hemp-based materials in the vehicle's construction serves to reduce its overall weight. As a result, engineers have successfully extended the travel distance of the BMW i3, enhancing its overall efficiency and performance. Remarkably, the BMW i3 is reportedly composed of 95% recyclable materials, demonstrating the company's commitment to sustainable and environmentally friendly automotive practices (BMW Group, 2022). Decades prior, Ford developed a Hemp car woven with 100 pounds of cannabis fibers that is virtually carbon neutral with the car's body being 10 times stronger than steel and weighing 1000 pounds less (Dutta, 2018). However, production of this vehicle ceased in favor of more traditional automotive components and further firms have yet tried to recreate these findings. Regardless,

hemp fibers can be utilized in the manufacturing of lightweight and durable materials for automotive components, potentially enhancing fuel efficiency and reducing the overall environmental footprint of vehicles.

4.1.4 Hemp with Infrastructure

While hemp is a promising candidate as a biofuel, its applications for the energy sector are similarly relevant due to its nature as an insulant. As global warming or cooling will increase the need for temperature control and, thus energy, hemp's application as an insulant may help reduce the need for further use of fossil fuels. Hemp, with its versatile composition, serves as a sustainable and eco-friendly construction material, offering a myriad of benefits. Two economically valuable parts of hemp stems, the inner hurd or wood, and the outer bast or fiber, contribute to its adaptability. The rigid lignin in the hurd, derived from xylem tissue, is the key component in crafting hempcrete - a material akin to concrete with a lime binder. This also finds applications in paper, fiberboard, and animal bedding (Abernathy, 2022). With construction, the hemp input is relatively low whereas the derived benefits are high. It can grow quickly, and 3 acres, some 7.4 hectares, yields a sufficient supply to build a house after 3 months ("Hemp Fiber," 2024).

What makes hemp-based construction materials stand out is their inherent strength, even when wet, coupled with qualities such as lightweight structure, breathability, insulation capabilities, antimicrobial properties, and the ability to block UV light (Popescu. 2018; Souza, 2020). As a result, hemp emerges not only as an eco-conscious alternative but as a promising contender in the construction industry, aligning with the growing emphasis on sustainable building practices. *The New York Times* reported "In Search for Sustainable Materials,

Developers Turn to Hemp" in 2023. Hempcrete, as this article suggests, is an increasingly employed material despite some logistical challenges. Cape Town, South Africa recently developed the first hemp skyscraper, called 84 Harrington; at 12 stories, this will be the tallest structure in the world that incorporates largely hemp construction (Williams, 2023). These hempcrete products are mold, weather, and fire resistant. Durability wise, hemp structures date to Roman times. A hemp mortar bridge was constructed back in the 6th century, when France was still Gaul (Popescu, 2018). As this article notes, the Hempen Bridge has withstood viking conquests, multiple world wars, natural disasters and, made from over 10% hemp fibers, still stands. As a result, hemp when used as a building and construction material has many attractive, sustainable features. For instance, just one hempcrete block can sequester about 13 pounds of carbon - more than what was expended in the making and shipping of the blocks in many projects (Williams, 2023). The building's carbon equation in this project, thus, tilts negative because it will actually draw carbon from the environment. Being light and porous, as well, hempcrete can quickly store energy and release it gradually, making it effective for climates with high temperature variation between day and night. With these properties to retain heat well, hemp is recognized as a great insulator for homes, offices, shops, and more that can reduce the need for air conditioning and the associated climate impacts. The blocks fit together well, "like Legoes," and are easily constructed together (Williams, 2023). As a result, hempcrete and other hemp products are predominantly safe, non-toxic, and environmentally friendly while also being an easy substitute for other materials, rendering it viable for infrastructure and in cutting emissions.

4.1.6 Phytoremediation Potential and Soil Rehabilitation

Currently produced in over 35 countries, hemp can grow in a wide variety of climates and, in doing so, yields positive environmental returns (Schluntenhoffer et al., 2017). Specific to hemp, all parts of the plant - roots, flowers, stems, leaves, and flora - are usable, resulting in decreased waste and pollution than with other crops whose discarded residue can incur a significant ecological footprint (Yano et al., 2023). When included in a crop rotation, one report finds that hemp establishment is associated with a 10% to 20% increase in wheat yields (UNCTAD, 2022). A crop rotation functions as an agricultural practice to introduce new crops on the same area of land over a sequence of growing seasons; hemp thus contributes to higher yields for and efficiency in producing competing crops. Similarly, hemp cultivation aids in the eradication of soil pests like nematodes and contributes to soil enrichment. This is as the extensive roots of the hemp plant play a crucial role in soil stabilization and erosion prevention. Additionally, hemp acts as a natural weed inhibitor, with its fast-growing canopy shading out competing vegetation (Mark et al., 2020). This shading effect creates an environment where weeds struggle to thrive underneath. Moreover, hemp's structure enables it to access nutrients from deeper soil layers inaccessible to many other plants (Adesina et al., 2020). This soil benefit speaks to hemp's environmental ability.

Even further, hemp extends to land unsuitable for other crops due to heavy metal contamination and other pollutants. Beyond mere cultivation, hemp actively absorbs and detoxifies these pollutants from the soil, including heavy metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and toxins. This process, by which plants either accumulate, remove or render toxic environmental contaminants innocuous, is known as phytoremediation. While planting for willow trees, mustard, and ferns is also associated with the

remediation of contaminated soil, hemp's intrinsic capacity to do so as well cemented its cultivation around Ukraine's Chernobyl nuclear power plant (Tran, 2022). Following this success, international developers increasingly turned to hemp as a viable alternative to traditional remediation methods from excavation to pump-and-treat. While much of this implementation is environmental in focus, it is growingly economical. The Environmental Protection Agency (EPA) ran an analysis of 112 sites containing petroleum-derived compounds to assess average and median remediation costs by method. These locations, including service stations, public water supplies, and industrial sites, cost an average of $299,673 per site with a median value of $210,374 (Wilson, 2004). Specifically, this calculates pump-and-treat at $574,038, soil vapor extraction at $389,042, free product recovery at $237,880, and excavation at $425,300. Bioremediation, almost interchangeable with phytoremediation, costs an average of $446,098 per site. Evidently, while plant-based methods are not the most cost-effective of every option, they serve as less expensive alternatives to more established remediation solutions.

By immobilizing toxins through absorption, hemp is poised to address environmental contamination from mining, oil, and manufacturing. Even the increasing conversion to electric vehicles, generally considered an environmental positive, releases cadmium (Cd), lead (Pb), and nickel (Ni) through battery production (Placido and Lee, 2022). Hemp, proven effective at sequestering these as well as the "forever chemicals" per and polyfluoroalkyl substances (PFAS), stands to address social and environmental concerns from contamination. After offering an essential ecosystem service, the application of hemp does not cease. Toxins accumulate in the plant's roots, leaves, and stalks so, while unsuitable for consumer products like food or personal care after being used for phytoremediation, the stalk can then be utilized for building materials and cloth (Wilson, 2004). Moreover, the polluted harvested biomass can alternatively be a

feedstock for bioenergy production or pyrolyzed into biochar (Amalina et al., 2022). Accordingly, the plant is suitable for remediation and subsequent production, offering non-market environmental benefits with its cultivation alone.

4.2 Medicinal and Social Uses

The nutritional, pharmaceutical, and societal aspects of hemp legalization are attracting attention. With its versatility across industries, hemp is known to produce a variety of value-added products, ranging from cosmetics to bioplastics, paper, tinctures, textiles, animal bedding and, again, biodiesel. However, floral hemp for cannabidiols (CBD) dominates production and consumer understanding of hemp (Mark et al., 2020). This section aims to unveil the status of CBD's research and the opportunities extended to consumers from cultivation.

4.2.1 Cannabidiols and Pharmaceuticals

Various studies have evaluated the effectiveness of alleged hemp-derived CBD "miracle" remedies to ailments such as inflammation, arthritis, anxiety, insomnia, digestive disorders, migraines, and endometriosis (Rupasinghe et al., 2020; Yano, 2023). Hemp has long been intertwined with cultural and medicinal practices spanning ancient China to medieval Europe and, today, is a profitable alternative to common pharmaceuticals. The revival of the global herbal remedies market, valued at $216.40 billion in 2023, is one that the United States has been capitalizing on since the dawn of 2014 (Fortune Business Insights, 2024). Evidently, CBD is a significant application, yet a relatively minimal share of the herbal healthcare market.

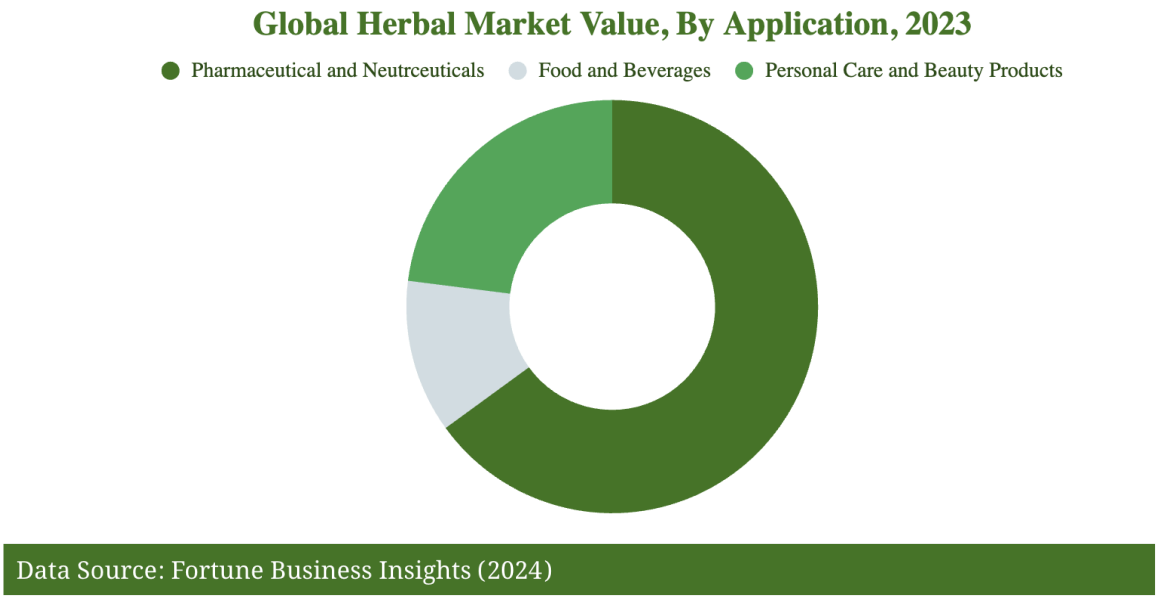


Figure 4: CBD's share (4.3%) of the alternative pharmaceuticals market in 2023.

Even in the early years of production, the hemp-for-pharmaceutical industry dominated (Mark et al., 2020). In 2019, for instance, CBD hemp represented nearly 100% of total hemp acreage in Connecticut (Jelliffe et al., 2020). Consumers maintain a strong affinity for hemp, evidenced by a significant national share clearly dedicated to CBD production (Mark et al., 2020). However, with this increasing appetite comes necessary research.

Hemp's unique chemical makeup and therapeutic properties have led to growing studies on its safety and efficacy. To reiterate, hemp and marijuana both belong to the *Cannabis sativa* plant species. However, hemp stands genetically different and distinguished by its composition; over 100 different chemical compounds (cannabinoids) can be extracted from hemp and popular strains include "Remedy," "Cannatonic," "Charlotte's Web," "Elektra," and "Pennywise" (Wilhelm, 2020). With producers touting its medicinal applications and even consumption among the elderly increasing, a Forbes market study found 60% of respondents have used a CBD product and believe it holds health benefits (Hall, 2024). In 2020, one-third of individuals surveyed consumed a form of CBD ("Cannabidiol (CBD): Potential Harms," 2023). As a result,

there is an augmenting demand for these alternative medicinal products with corresponding research attempting to understand its functionality in treating and soothing conditions.

Rupasinghe et al., synthesizes hemp science research in "Industrial Hemp (*Cannabis sativa*.) as an Emerging Source for Value-Added Functional Food Ingredients and Nutraceuticals" (2020). This defines nutraceuticals as yielding a pharmaceutical effect from a compound or food product. Given hemp's balanced nutritional landscape and the rising interest in plant-based lifestyles, hemp is increasingly produced into protein powders, milks, cooking oil, cookies, and even meat substitutes (Axentii, 2024). These value-added products are supplemented by hemp's impressive nutritional content, containing phosphorus, potassium, sodium, magnesium, sulfur, calcium, iron, and zinc (Callaway. 2004). This paper reports that seeds are primarily composed of easily digestible protein (20–25%), abundant lipids (25–35%), and carbohydrates (20–30%). They are rich in polyunsaturated fatty acids and insoluble fiber; the protein is suitable for both human and animal consumption, predominantly comprising high-quality, easily digestible proteins such as edestin and albumin. Correspondingly, hemp seeds contain as much protein as beef by weight (Callaway, 2004). Plus, hemp seeds contain all 21 known amino acids, particularly the essentials that the human body will not individually produce with a desirable ratio of omega-6 to omega-3's (Callaway, 2004). This study discerns that, with about 11 grams of protein for every 2-3 tablespoons, the Farm Bill has revived potential for hemp as a nutritionally-dense supplement for plant-based diets.

CBD itself has recently received increasing attention since its repeated administration has demonstrated antiepileptic, anxiolytic (anxiety), and antipsychotic therapeutic properties (White, 2019). Hemp also promotes neuroprotective activities and yields benefits against disorders of motility and epilepsy (Rupasinghe et al., 2020). The Food and Drug Administration just recently

approved Epidiolex for 2 epilepsy syndromes, their first ever approval of a cannabis-derived treatment only possible through legalization (Grinspoon, 2024). Further speaking to pharmaceutical applications, Alexander et al., in "Cannabinoids in the Treatment of Cancer" report that cannabinoids contain properties that aid in the treatment of the brain, prostate, breast, skin, pancreas, and colon cancer. Specifically, Sarfaraz et al. found that male prostate carcinoma cells treated with CBD exhibited a pro-apoptotic response, inhibited cell growth, and a lowered secretion of an antigen typically elevated in cancerous cells (2005). Furthermore, Guang and Wenwei developed a process for using hemp protein powder in treating anemia (2023). Established research suggests that the components of CBD like gamma-linolenic acid may reduce risk of osteoporosis, heart disease, and premenstrual syndrome (Filho et al., 2011; Callaway, 2004; Rupasinghe et al., 2020). Of course, these results are not universally accepted and all consumption to address health conditions is still recommended through a consulting physician ("Cannabidiol (CBD): Potential Harms," 2023). This research is interesting, but a significant examination of hemp's medicinal costs and benefits is essential. Further research is needed to explore the impacts of repeated administration and the distinct effects of cartridges, as well as to evaluate the overall effectiveness relative to traditional therapies.

4.2.2 Health Concerns

Consumers are increasingly receptive to the product and, while potentially not fully grasping its distinction from marijuana, are widely adopting, or at least experimenting with, it for their health woes. The Substance Abuse and Mental Health Advisory Services Administration notes this information gap and potential to encourage unsafe drug use through "unclear or misleading" marketing ("Cannabidiol (CBD): Potential Harms," 2023). This is an unfortunate

reality of the Farm Bill's legalization, with tobacco and corner stores increasingly promoting psychoactive delta-8 and hemp-derived products comprising gummies, cartridges, chocolates, brownies, and more. For example, licensed dispensaries sales of products containing delta-8-THC in their titles increased 240 % between 2020 and 2021 (Black, 2021). With these establishments are often at a lower cost than dispensaries, or the only available providers of THC in criminalized states, there is a found potential to encourage unsafe drug use, not to mention the risk of unknown, hazardous chemical inputs. This organization recognizes that prospective harms associated with CBD use include adverse drug interactions, liver toxicity, and reproductive and developmental effects ("Cannabidiol (CBD): Potential Harms," 2023). Similarly, alternative sources of psychoactivity in cannabis not sourced from traditional marijuana exists in an evolving legal landscape.

Again, the federal limit for hemp in any form constitutes 0.3% THC. Significantly, this threshold only applies to delta-9 THC: the only version of THC that is regulated by the federal government (Moldover, 2024). Retailers, thus, advance on the legalized, hemp-derived delta-8 THC alleged to induce the widely-known "high" physiological effect. Likewise, an emerging variant called THC_a does not test positive for delta-9 THC until touched by the consumer's lighter, permitting its sale and transportation (Moldover, 2024). Therefore, the legalization of hemp has sparked research as to its psychoactive effects given consumer interest. While this is evidently beneficial to a market value, it speaks to the longstanding perception that hemp is a like-marijuana functioning crop, overshadowing consumer recognition of its widespread environmental and socioeconomic versatility. Provided, there is a volatile regulatory foundation in the hemp-derived THC industry as well as a likely potential for unsafe drug consumption.

4.2.3 Social Interest

Beyond its medical applications, hemp also holds significance in social contexts. It has been employed throughout religious ceremonies, cultural rituals, and social gatherings, and the 2018 Farm Bill specifically extends rights to tribal communities in cultivating (Olson, 2020). Often symbolizing concepts of healing, fertility, and spirituality, the revival of hemp has reignited its potential as a culturally-relevant, functional crop. Falker et al. (2023) and Bartlett (2019) conduct important qualitative research as to the effects of the Farm Bill's legalization on tribal communities. While this reads beyond the scope of this thesis, national hemp cultivation and trade have revived cultural opportunities for and peaked interest from Native American growers.

Other research has extended to online trend analytics in understanding hemp's relevance. A paper from researchers at the University of California, Johns Hopkins University, and the University of York in the United Kingdom uncovered that, post Farm Bill, Google searches for CBD spiked in 2016 (Leas et al., 2019). Between 2004 and 2017, CBD searches grew by 125.9% and, in the next year alone, grew by 160.4%. Notably, search rates were on par with yoga and e-cigarettes while having seven times more clicks than acupuncture, five times higher than apple cider vinegar, and three times more than meditation. Overall, CBD searches outperformed vaccination, exercise, marijuana, and veganism. This speaks to the point that consumers looking for alternative solutions to common health ailments increasingly demonstrate interest in CBD products. As a result, legalization has extended benefits to health-oriented individuals.

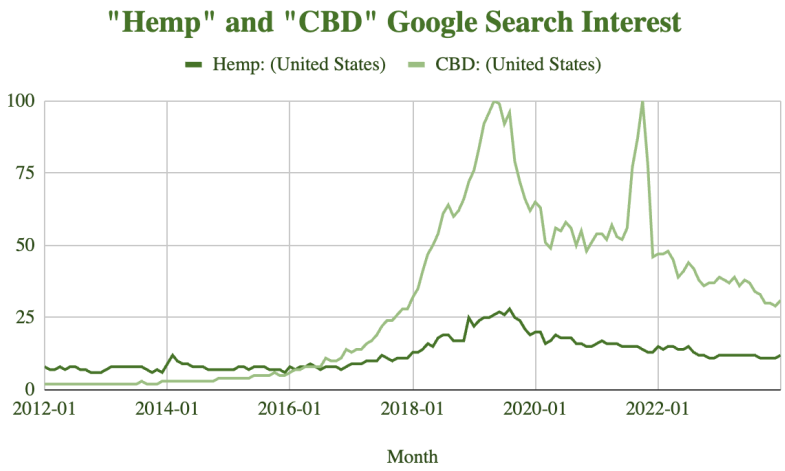
Google search trends are also available for hemp. This records the maximum online interest in the hemp crop from 2012 to 2024, 2012 being selected for its status as a few years before the treatment (Farm Bills) were applied. Evident in Figure 4, hemp interest remained

relatively low, fluctuating around 25, prior to legalization and reached 47 in 2014, the year of the initial relevant Farm Bill. Subsequently, interest exponentially increased until the passage of and implementation of the Farm Bill in 2018 and 2019. Interest, evaluated on Google rates alone, declined following 2020 and, while still expanding, fell short of its peak in 2018.

Data Source: Google Trends
Notes: Values indicate search interest relative to the highest point on the chart for the given region and time. A value of 100 is the term's peak popularity.

Figure 5: Google search analytics as to the interest in "Hemp."

This speaks to the general attitude of growers that the crop's market is oversaturated (Ellison, 2020). However, farmers surveyed still reflect that it is incredibly profitable. While CBD, regardless, continues to dominate production and consumer relevance. Evaluating the search rates for "CBD" and "Hemp," I find that CBD consistently leads in significance, similarly peaking in 2018 and 2019 as a result of decriminalization. In this model, when CBD reaches its maximum at 100 in 2019, hemp stands at just over 25, reflecting CBD's superiority in consumer attention (Figure 6). As a result, while legalization had a profound effect on hemp recognition, hemp's value pales in comparison to that of CBD. As a result, decriminalization has uncovered a variety of new, perceived effective applications of hemp in the pharmaceutical arena.



Data Source: Google Trends
Notes: Values indicate search interest relative to the highest point on the chart for the given region and time. A value of 100 is the term's peak popularity.

Figure 6: Google search analytics as to the interest in "Hemp" and "CBD"

Thus, hemp continues to play a multifaceted role in both social and medicinal spheres, reflecting its enduring importance throughout history. Evidently, the passage of the Farm Bill sparked interests from millions of domestic consumers for it being the first time the federal government legalized a derivative of cannabis since it became illegal in 1937. Nevertheless, the CBD industry is still in its infancy stage due, in large part, to a lack of information. Correspondingly, researchers are continuing to progress through clinical trials and apply for funding to more fully understand the efficacy of CBD.

4.3 Economic Considerations

The permitted cultivation of hemp has yielded revenue opportunities for the United States government, growers, manufacturers, and retailers. The United States Hemp Crop Report estimates that the total number of acres licensed to grow hemp in the United States has grown over 52 times in size from 2016 to 2019 ("National Hemp Report," 2022). With this increase in licenses comes a plethora of opportunities for producers to capitalize on hemp's environmental,

social, and economic applications. Nationally, the number of approved hemp licenses increased from 292 in 2014 to 3,852 in 2018, indicating crop diversification, revenue, and job opportunities (Mark et al., 2020). While many of these licenses were for previously established growers, the dedication of land to industrial hemp generated new sources of employment at retailers and on farms. Indeed (2018) reports that 25 out of every 10,000 jobs listed are related to the cannabis industry, and from April to May 2018, there was a 50% jump in the number of related job listings. Although this surge is intricately tied to hemp decriminalization, it relates to the overall emergence of employment opportunities in this budding industry. At present, Indeed alone promotes over 9,000 cannabis-related job postings (2024). This reveals the increase in job opportunities that, while not hemp specific, the cannabis market offers.

With its versatile applications in industries such as agriculture, textiles, health, and construction, hemp has emerged as a lucrative commodity for farmers, entrepreneurs, and investors alike. The legalization has fostered the growth of a robust hemp industry, creating jobs and stimulating economic growth in rural and urban areas alike. With a global forecast of $21.71 billion by 2028, the legalization of hemp provides the United States with an opportunity to generate a new source of income for various parties (Arehart, 2023). Interviewed for this thesis, the first Pennsylvania farmer to grow hemp - Joshua Leidhecker - noted that he profited right under $500,000 in 2020 and just $40,000 in 2022. Leidhecker attributed this initial success to the hemp pilot programs and its profitability in value-added products but acknowledged that the stark decline is a culmination of market uncertainty and a preference for THC-bearing cannabis. Provided, the cultivation of hemp stands incredibly profitable for smaller, local growers, while coming with a notable amount of volatility. Even further, non-psychoactive cannabis

opportunities are underproduced in favor of more profitable, consumer demanded marijuana varieties.

The aforementioned “Economic Viability of Industrial Hemp in the United States: A Review of State Pilot Programs” speaks to the existing production levels, revenue, and challenges in the industry (2020). Sponsored by the USDA, this research asserts that legalization has yielded promising results in terms of employment and economic growth while recognizing that the market is not to scale. Meanwhile, conventional financial institutions are promoting investment in the cannabis sector, evidenced by Yahoo's publication of recommended hemp stocks to purchase, which include Cresco Labs, Curaleaf Holdings, and Green Thumb Industries (Farooq, 2022). As a result, legalization has increased market opportunities to invest in and grow hemp, yielding new sources of income. As discussed, hemp cultivation further initiates non-market environmental services, such as its ability to improve soil quality for increased yields in later crops. With this, hemp directly contributes to economic growth while also providing benefits to carbon reduction and remediation. As consumer demand for eco-friendly and sustainable products continues to rise, hemp presents a promising avenue for businesses to capitalize on these trends while contributing to environmental conservation efforts. Overall, the legalization of hemp has not only created new revenue streams and business opportunities but has also contributed to the revitalization of communities and the advancement of Sustainable Development Goals.

4.3.1 Global Outlook

Many countries around the world have embraced hemp cultivation as a lucrative and sustainable industry, producing significant quantities of hemp for various applications. A United

Nations Conference on Trade and Development (UNCTAD) report, “Commodities at a glance: Special issue on industrial hemp” notes that in 2019, approximately 40 countries collectively produced around 275,000 tons of raw or semi-processed industrial hemp. However, the majority of global output is concentrated in just four countries. China leads this group, followed by France, Canada, and the United States (Mark et al., 2020). These countries have capitalized on the growing demand for hemp-derived products both domestically and internationally, exporting to markets worldwide and earning substantial revenue from production.

Many of these nations are dedicating funding for hemp research towards specific intentions. China's 13th Five-Year Plan includes the country's intention to plant 3.2 million hectares of hemp fiber for textiles by 2030 (New Frontier Data, 2021). This move is driven by a demand to replace cotton with more sustainable alternatives. Meanwhile, Cape Town, South Africa is seeing a resurgence in hemp infrastructure applications given President Cyril Ramaphosa’s priority to develop the country's hemp and cannabis sector, recognizing that it could create more than 130,000 jobs (Roelf, 2022). This is dominated towards production of buildings constructed by hempcrete. France holds the dominant position in the European hemp industry, boasting the highest share of hemp seed production, along with hemp-based pulp and paper. Between 1993 and 2015, the country accounted for over half of the total hemp produced in Europe (New Frontier Data, 2022). Acreage and price information inaccessible for the United States is obtainable for European countries given that many EU countries lifted production bans in the 1990s. Thus, the United States started relatively late as to permissible hemp cultivation when other countries have been producing the crop for decades. The United States has an opportunity, however, to reduce reliance on foreign hemp imports and generate national income from a lucrative, versatile crop. As hemp regains legal status in the United States, there is a

promising opportunity for the country to enter the global hemp market and leverage its resources and expertise to increase production and exports. With its vast agricultural lands and advanced technological capabilities, the United States stands poised to become a major player in the hemp industry, contributing to economic growth and job creation while meeting the growing demand for sustainable and eco-friendly products on the global stage.

5: Cost-Benefit Analysis

A Cost-Benefit Analysis (CBA) is a well-established economic technique to report the returns and costs of a product, policy, and ecosystem service. In the case of hemp, this approach stands effective in representing how its legislation in the 2018 Farm Bill has revived its production of environmental and economic goods and services. In recognizing that not every aspect of hemp production holds a dollar value, this analysis considers market and non-market dimensions of cultivation; non-market entities are not traded in the economy such as national parks, clean air, and street lighting. Non-market valuation, thus, uses measures such as benefit transfer, willingness to accept and pay, and forecasting to gauge the value of the environment. As a result, this analysis derives the impacts of legalization using CBA; these impacts may be positive (a "benefit") or negative (a "cost"). "Impacts" and "benefits" / "costs" are used interchangeably throughout this report. The fundamental premise of CBA is that a policy is worth approval or an investment worth pursuing if the sum of all benefits per unit is greater than the sum of all costs. In evaluating alternative methods, as acreage was either zero, prohibited, or incredibly minimal before 2014, producing a regression analysis on the specific impact of the Farm Bill would be interesting, yet one with a substantive margin of error given available data. Although this study encountered evident data challenges, a CBA was preferred given its ability

to capture monetary valuation, non-market risk, cost variability, and a greater complexity of factors. In the context of an emerging policy, a CBA is also beneficial in identifying the most economically efficient option to inform decision-makers and evaluate legislation.

5.1 Methods

A Cost-Benefit Analysis and Net-Benefit Ratio attempt to capture hemp's wide variety of considerations. Where suitable, impacts are quantitatively expressed in monetary terms throughout this paper. It is significant to recognize that not all benefits and costs are fully quantifiable and therefore are discussed qualitatively. This being frequent in CBA applications, an impact discussed qualitatively is not less important than another that is quantified. Rather, the means of analysis is dependent on the amount of data, effort, and transparency offered by existing research to quantify the impact. This analysis leverages existing data and methods of non-market valuation to produce a CBA of the United States's hemp reality per every hectare, equivalent to 2.47 acres, cultivated. Recognizing the versatility of hemp's applications, this analysis discerns five common derivatives of hemp - biofuels, seed value-added (V-A) products, floral V-A for pharmaceuticals, grain V-A, and fiber V-A for quantification. A longlist of potential benefits and costs from hemp was developed based on the literature review; while intended to be comprehensive, it was not an attempt to capture the whole universe of possible impacts; immaterial and unfounded impacts were not included. To structure the discussion, market and non-market impacts both estimated and not can be organized within a set of categories and subcategories, as summarized in Table 3.

Table 3: Categories of Potential Benefits and Costs

Impact Categories	Impact Subcategories
Social	1. Health and Wellbeing 2. Cultural relevance 3. Community development 4. Value-Added Products
Environmental	1. Carbon sequestration 2. Soil remediation 3. Biodiversity conservation 4. Reduced pesticide application 5. Renewable fuel
Economic	1. Employment generation 2. Industry development 3. Export potential 4. National revenue

To reiterate, not every established benefit and cost of hemp is quantified in this analysis. It is difficult to estimate, for instance, the monetary benefit yielded to social culture from cultivation. Therefore, the benefits coming from several economic and agricultural aspects (use of rotations, cover crops, employment, remediation, permanent pastures, etc.) have not been included. Conversely, it is challenging to measure how the Farm Bill has potentially encouraged unsafe drug use. Accordingly, provided available data and market significance, I apply economic methods to understand hemp's net impact in 2020 when produced for five example applications.

5.2 Carbon Sequestration and Costs

To obtain the values for the carbon dioxide sequestration benefit, I translated the Environmental Protection Agency's estimate on the Social Cost of Carbon (SCC) for hemp's production. The Social Cost of Carbon represents the monetary cost of the impacts associated with greenhouse gas emissions not automatically reflected in market prices. Put differently, it is the total damage that an additional ton of CO_2 has on society - converted into dollars. This

addresses the frequent issue in environmental economics where individuals struggle to conceptualize the economic value of environmental goods and services. Perceiving environmental assets like clean air or water as financial assets aims to help the public recognize the value of such through supporting policy or various initiatives. Generally calculated using integrated assessment models, the SCC considers emissions relative to outcomes such as weather, agricultural productivity, human health, labor productivity, disaster damages, and biodiversity retention (Backman, 2021). This value becomes a key guide for policymakers, explaining how climate policies can pay for themselves as long as the economic sacrifices do not exceed the carbon benefit.

The past decade has seen great variability in the SCC value (Davenport, 2023). This document asserts that the initially estimated Social Cost of Carbon, introduced during the Obama administration, stood at $43 per ton. Subsequently, during the Trump administration, this estimate dropped to a range of $3 to $5. Under the Biden administration, the estimated SCC hovers around $51 per ton. However, the EPA's latest estimate of the Social Cost of Carbon, unveiled in a legally binding federal regulation, reads nearly four times higher at $190 per ton. As a result, one additional unit of carbon, methane or nitrous oxides is associated with societal burdens of $51 to $190 in 2023.

This range was used in assembling the net benefit of $765 - $3,604 per hectare of industrial hemp. This is in conjunction with hemp's carbon sequestration ability, the process of removing gasses from the atmosphere, for this area of land. The Agriculture and Rural Development division of the European Union asserts that one hectare of hemp sequesters 15 tons of CO_2 from the atmosphere and can be harvested twice a year ("Hemp," 2024). Meanwhile, the Parliament of Australia reports that a hectare is viable to sequester upwards of 22 tons ("The

Role of Industrial Hemp in Carbon Farming," n.d). To obtain the net benefit, I multiplied the values for SCC with the boundary of 15 and 22 tons of carbon dioxide, resulting in the additional benefit of what simply planting hemp adds to the economy after adjusted for inflation. The carbon benefit is at the farm production level and is applied to the net impact for each example derivative. Standard variable production costs, calculated from other literature, are also relevant to every product and, thus, accounted for. The production net value of $-1,528.58 to $1,310.42, expressed as the Carbon Sequestration Potential (CSP) range, is accordingly applied to each subsequent product.

Table 4: Summary of Value-Added Product Net Benefits Before CSP Range Additions

Value-Added Product	Benefits per Hectare	Costs per Hectare	Net Benefit
1. Floral Products CBD Seed CBD Production CBD Additional Labor Total	[60,229.79 - 111,722.69]	 [2,924.23 -8,528.99] 47,662 11,507.18 [62,093.41 - 67,699.17]	**[-1,863.21 - 44,023.52]**
2. Biodiesel	6,203.72	6,441.10	**-237.38**
3. Seed Products Seed-Specific Production Total	28,770.84	 813.20 2,293.58 3,106.78	**19,460.34**
4. Fiber Products Fiber-Specific Production Total	7,942.82	 987.74 2,293.58 3,281.32	**4,661.5**
5. Grain Products Grain-Specific Production Total	1,768.23	 767.50 2,293.58 3,061.08	**-1,292.85**

5.3 Floral Value-Added Products for Pharmaceuticals

Also referred to as Floral Value-Added Products, the CBD industry presented from hemp globally reached $9.4 billion in 2023 (Arehart, 2023). With consumers increasingly reliant on

widely-accessible CBD products to treat various ailments, there is potential for the United States to generate significant national income from its cultivation. I find total benefits at $60,229.79 to $111,722.69 and total costs at $62,093.41 to $67,699.17. Accounting for CSP, this generates a net impact of $-2,627.20 to $47,627.52.

Benefits were assessed by utilizing data sourced from the University of Connecticut (2020) and the publication "The State of Legal Cannabis Markets" (2019). The University of Connecticut conducted a comprehensive analysis incorporating economic modeling, case studies, and farmer feedback to compile a report on projected costs and returns associated with hemp cultivation. For a representative farm, researchers record total revenues at $24,375 per acre, leading to $5,086 in profits per acre (Jelliffe et al., 2020). Grounded in the benefit transfer method to estimate benefits between contexts, I converted from acres to hectares to fit this analysis. Accounting for the size difference between the units of land, provided this study, a hectare of hemp will yield $60,229.79 in market and non-market values January of 2020. The higher end of CBD's economic impact was based on insights derived from the 2019 "State of Legal Cannabis Markets" report by Arcview Market Research and BDS Analytics. On a per-acre level, hemp for CBD could generate $45,203 in revenue compared to $773 with corn (Arcview, 2019). Translated to standardized dollars and units, I find a total benefit of $111,722.69.

In alignment with this University of Connecticut report titled "CBD Hemp Production Costs and Returns for Connecticut Farmers in 2020," detailed breakdowns of expenses related to CBD production are provided. These encompass expenses related to processing floral hemp into consumer products, such as extraction, purification, testing, and packaging. These costs total approximately $19,289 per-acre, becoming $47,662.46 per-hectare in this analysis. Given that CBD seeds must meet higher quality standards for consumption, and only female seeds yield

CBD, additional costs for these on a per-acre basis range from $1200 to $3500 (Russel, 2021). In hectares, this is $2,965 to $8648.38. In January of 2020 with the Consumer Price Index, this is $2,924.23 to $8,528.99. There are also higher labor costs with CBD considered, these being $5,259 per acre (Jelliffe et al., 2020). Accordingly, I converted to hectares and subtracted the cost of CSP's labor to avoid overestimating labor costs in calculating CBD Additional Labor. Accounting for these values, the total floral costs are estimated at $62,093 to $67,699.

As net impact essentially equals total benefits minus total costs, this value is $-1,863 to $44,023. To account for what producing hemp returns and costs by the CSP range, net impact alters. Thus, for every additional hectare of hemp cultivated dedicated to medicinal applications, there is a projected net impact of $-2,627.20 to $47,627.52. There are notable non-quantifiable benefits and costs associated with the medicinal hemp industry, however, to be recognized in later chapters.

5.4 Biofuels

Hemp has a viable market for biofuel production increasingly researched by firms, universities, and federal institutions. In 2016, the Iowa Government commissioned the Industrial Hemp Program Study Committee. This aimed to evaluate the logistics of and potential for establishing an industrial hemp program in the state, including but not limited to the environmental, economic, and political aspects of production (IHPSC, 2016). This Committee finds that hemp yields more per acre than corn with respect to harvest size and price per acre. Specifically, hemp stalk on average will produce 16,000 pounds of biomass per acre, compared to corn at 8,500 pounds. This translates to 640 gallons of hemp-derived ethanol per acre with corn at 340 gallons. Equivalently, this is 1,581.42 gallons of hemp fuel for every hectare that is

produced. Based on available estimates, current hemp oil production containing 10% lipids can yield up to 19.91 million gallons of biodiesel annually (Cheng et al., 2021). Thus, there are significant yields associated with this cultivation.

Bioethanol is a renewable biofuel that can be directly used in most vehicles and behaves similarly to conventional fuels (Dahman et al., 2019). The United States Department of Energy curates an Alternative Fuels Data Center providing monthly reports on the average prices. In January of 2024, biofuels stood at $4.69 per gallon (AFDC, 2024). To find the benefit per acre, I multiplied the biofuel capacity with the average market price received for a biofuel, totalling $7,416.85. In "Economic Perspective of Ethanol and Biodiesel Coproduction from Industrial Hemp," the authors find a breakeven unit production cost of $4.13 per gallon of hemp fuel, equivalent to soybean's (Cheng et al., 2021). Similarly, I multiplied the 1,581.42 gallons viable per acre with this production cost, equalling $6,531.25. Alone, this yields a net benefit of $885.52. As to be discussed, this net benefit turns negative (-237.38) once the total benefit and cost are converted into January 2020 dollars. Thus, the benefits and costs behave uniquely once accounting for inflation over periods. Once this net benefit was adjusted to account for the CSP range, the net value turned $-1,765 to $1,073 per hectare.

5.5 Seed Value-Added Products

Hemp is recognized for its potential to produce protein powders, oils, cosmetics, paint, and milks. The value for hemp seed is substantial, totalling $41.5 million in 2021 according to the National Hemp Report. Correspondingly, hemp acreage for seed stood at an estimated 3,515 acres. Upon calculation, this returns a seed net benefit of $11,806.54 an acre: alternatively, $29,173.57 a hectare in 2021. For standardized dollar units, this yields $28,770.84 a hectare in

2020. To gauge the variable costs of producing hemp, I use the "Enterprise Budget" from Oregon State University and the CEO of Columbia Hemp Trading Company to analyze labor (Roseberg, 2019). This states that tractor driver labor cost is around $22 per hour and all other labor $16 per hour - these rates including social security, workers' compensation, unemployment insurance, and other labor overhead expenses. Here, labor costs totalled $610.47/acre in 2021. Repeating prior methods, this is $1508.45 in labor for a hectare of industrial hemp and nets to $1487.63 in 2020. This labor cost is applied to fiber, grain, and seed value-added products given floral notoriously needing more specialized knowledge (Jelliffe et al., 2020). Also standardized across these applications is the cost of tractors, equipment, irrigation, regulatory compliance, and the land charge. These values are obtained from a Cornell report speaking to per acre costs (Hanchar, 2020). This report also provides seed-specific costs. After summing these costs and factoring in CSP, I find a seed net impact of $18,696.32 to $24,374.76 for this study's unit and time.

Table 5: Seed, Grain, & Fiber Value-Added Product Variable Costs. Derived from "Economics of Producing Industrial Hemp in New York State" (2020) and "Soil, Seedbed Preparation and Seeding for Hemp" (2019).

Expense Category	**Cost (in January 2020 USD)**
Labor	1487.63
Tractor	98.03
Equipment	79.28
Irrigation	308.87
Regulatory compliance	61.77
Land charge	258.00

5.6 Fiber Value-Added Products

Hemp is notably appreciated for its ability to produce paper, rope, insulation, and textiles. To calculate the value that hemp legalization has had on the hemp textile industry, I use the established costs from the National Hemp Report. This is a comprehensive document noting per state production released by the National Agricultural Statistics Service (NASS), the Agricultural Statistics Board, and the United States Department of Agriculture. Released in February of 2022 covering 2021, this includes the values used for hemp fiber, grain, and seed. It shows that the area harvested for hemp grown in the open for fiber in the United States was estimated at 12,700 acres. The average yield for hemp cultivated in open fields for fiber production is 2,620 pounds per acre, with a total value of $41,400,000. To determine the marginal benefit per hectare when dedicated to fibers, the value is divided by the total acreage, resulting in $3,259.84 per acre. When converted to hectares by dividing by approximately 0.4047, the total benefit is calculated as $8,054 per hectare in 2021 and $7,942.82 in 2020. To ascertain the processing cost specific to fiber, data from the National Hemp Report (2022) is consulted, indicating a processing cost of $987.74 per hectare. This cost is derived from the expenses associated with manufacturing, marketing, and transporting various hemp products per acre. All together and adjusted to reflect carbon sequestration and variable costs, the net impact is $3,897.92 to $9,575.92 per hectare in 2020.

5.7 Grain Value-Added Products

Hemp grain can be produced into a sustainable feed and bedding option for livestock as well as a compost. I assume the values provided in the USDA's National Hemp Report referring to grain-dedicated hemp cultivation in acres and market revenue. This delineates that, according

to the National Agricultural Statistics Service, there were 8,255 acres harvested for hemp grown in the open for grain in the United States. Accordingly, the value of hemp for grain totaled $5.99 million in 2021. To obtain the value for hemp's benefits in this CBA, I divide the total market value by the total acreage, then converting to hectares. This yields $1,792.98 per hectare in 2021, and $1,768.23 in 2020 for the purpose of this analysis. Given the standard production costs, further grain-specific costs are derived from Cornell's "Economics of Producing Industrial Hemp in New York State: Projected Costs and Returns, 2019 Budgets." This estimates grain's variable cost of production to be $295.72 an acre, or $730.714 in 2019 hectares. Using the Consumer Price Index to adjust for inflation, this cost is $767.50. Including CSP costs and benefits, grain production total impact is $-2,056.43 to $3,621.57.

5.8 Summary Tables

Presented below is a Cost-Benefit Analysis table and net-benefit ratio for hemp cultivation, offering an improved overview of the financial considerations involved in growing hemp for various applications. These aim to account for the true market value of industrial and environmental hemp in five examples to provide insight on the most economical use of resources.

Table 6: Results of Net-Benefit Ratio (NBR) Analysis for the Lower and Upper Bound Estimates.

	Range of Net-Benefit Ratio (*TB/TC*)	
Application	**Lower Value**	**Upper Value**
1. Floral	$0.98	$1.70
2. Biofuel	$1.08	$1.12
3. Seed	$9.51	$10.42
4. Fiber	$2.65	$3.51
5. Grain	$0.82	$1.75

Table 7: Costs and Benefits in the United States, in January 2020 dollars

Hemp production at farm level	**Benefits per Hectare**	**Costs per Hectare**	**Net Benefit**
Carbon Sequestration	[765 - 3,604]		[-1,528.58 - 1,310.42]
Production: Tractor Equipment Land charge Irrigation Regulatory compliance Labor *Total Costs*		 98.03 79.28 258.00 308.87 61.77 1,487.63 2,293.58	
Value-added products (5 example products)	**Additional Benefits per Hectare**	**Additional Costs per Hectare**	**Net Benefit** ***(including production net benefit at farm level)***
1. Floral Products CBD Seed CBD Production CBD Additional Labor *Total Costs*	[60,229.79 - 111,722.69]	 [2,924.23 -8,528.99] 47,662 11,507.18 [62,093.41 - 67,699.17]	[-2,627.2 - 47,627.52]
2. Biofuel Production *Total Costs*	6,203.72	6,441.10 2,293.58 8,734.68	[-1,765.96 - 1,073.04]
3. Seed Products Seed-Specific Production *Total Costs*	28,770.84	 813.20 2,293.58 3,106.78	[18,696.32 - 24,374.76]
4. Fiber Products Fiber-Specific Production *Total Costs*	7,942.82	 987.74 2,293.58 3,281.32	[3,987.92 - 9,575.92]
5. Grain Products Grain-Specific Production *Total Costs*	1,768.23	 767.50 2,293.58 3,061.08	[-2,056.43 - 3,621.57]
Net-Benefit Range	[-2,627.2 - 47,627.52]		

6: Discussion

The goal of this analysis was to assess the economic and environmental viability of industrial hemp in the United States following its legalization in 2018. While there are carbon sequestration benefits outweighing the production costs at the farm level, multiple example products from hemp generate a net-negative lower range estimate per hectare. This includes floral and grain Value-Added goods as well as biofuel. However, this analysis finds a positive net benefit (benefits > costs) for seed and fiber products. Net value estimates vary from $-2,627.20 to $47,627.52 per hectare, both interestingly from floral V-A cultivation. This aligns with existing findings from Jelliffe et al. (2020) and Mark et al. (2020) that pharmaceutical applications of hemp are incredibly profitable but are associated with higher total production costs than alternative uses ($62,093 versus $3,106 for seeds). Likewise, this analysis uncovers that production costs for seeds, fiber, and grain goods are relatively similar whereas floral products stand more expensive. Across these three examples, seed products return the highest benefit per hectare at $28,770. Meanwhile, medicinal applications of hemp from its flora generate the highest benefits overall, between $60,229 and $111,722. As a result, when initially grown, hemp's net benefit given its carbon sequestration ability is $-1,528 - $1,310. That hectare could be dedicated to floral, seed, fiber, fuel, or grain hemp. Provided, for every hectare of hemp cultivated for each category, the monetary value on that land's potential varies from $-2,627.20 to $47,627.52.

The Net-Benefit Ratio (Table 6) yields an interesting discussion of market benefits. This can be interpreted as every dollar invested in hemp cultivation for these products is associated with value upwards of ten times that. This provides an outlook as to the specific returns of hemp investment on a per hectare basis made possible by the 2014 and 2018 Farm Bills. Seed V-A is

evidently the most promising from this table alone, although floral and grain have benefits outweighing the costs here as well. This is a unique comparison to the Cost-Benefit Analysis that indicates a negative return on investment with the lower bound. In consequence, the hemp market for food, cosmetics, oil, paint, and beverages yields incredibly profitable for the United States, and other international producers, to cultivate.

In Table 7's Cost-Benefit Analysis, I show that hemp cultivation can yield positive returns. Although there is a negative net benefit estimated in some cases, there remains significant value in the industry. Among the upper ranges of example products, I find a mean net benefit of $34,885.516, accounting for the SCC as well. As a result, when land is dedicated to industrial hemp cultivation, a hectare adds an average of $34,885 to the economy, superior to notable competitor corn's estimated revenue of $1,488 (Sandhu et al., 2020). Thus, despite the wide range of hemp's costs and benefits, it generally stands more profitable than competing, well-established crops such as corn or soybean. From the findings of this CBA and complemented by existing research, it is economical to reason that hemp for the purpose of flora and seed V-A products should be further produced. These maintain the highest net benefit per hectares while also providing valuable health services and consumer products. Manufacturing fiber products such as clothing and rope is justified by the greater benefits they offer compared to their costs. Each product example additionally results in valuable carbon sequestration and soil improvement, further highlighting the importance of hemp production in the context of environmental degradation from climate change. As hemp provides sequestration exceeding that of alternative crops, its overall production is encouraged regardless of net benefit as the United States directs time and resources into reducing its carbon emissions.

The results of this study, however, indicate that there is a potential to lose money when investing in hemp, specifically for biofuel and grain products. Floral products, while holding the greatest negative benefit, also yield the highest expected returns per hectare, suggesting expanded production and innovation in the United States. Biofuel and grain, however, have net benefits as low as $-1,765.96 and $-2,821.43. This is accompanied by upper ranges of $1,073.04 to just $17.57. While this justifies that hemp for these derivatives should be little produced, it is important to note that biofuel's negative returns only came after adjusting for inflation. Put differently, the breakeven unit production cost of hemp fuel ($4.13) is actually lower than the market price for biofuel in 2024 ($4.69), indicating that the revenue is actually higher than the costs when inconsiderate of time (Cheng et al., 2021; AFDC, 2024). Thus, this paper will not argue that hemp biofuel production should be ceased; instead, research into efficient processing to reduce costs and improve yields should continue. Likewise, research efforts should aim to decrease production costs at the farm level for expenditures such as labor, equipment, and tractors so as to minimize total costs.

This will greatly benefit the United States' efforts to abide by climate regulations and produce a cost-effective, sustainable production system. Following legalization, hemp acreage has increased, allowing for a degree of research and development in the arena. However, there is great profitability in the market that the United States could harness in the future, evidenced by the United Nations forecast that there will be 7.8 million domestic acres of hemp in 2030, this being 62% for seed, 36% of fiber, and 2% for flower (UNCTAD, 2023). Converting this into hectares and applying my Net-Benefit Ratio for each unit of production in Table 8, this prompts that the United States could see a value extending between $377,761 and $124,514,752 in 2030.

Table 8: Extrapolated NBR 2030 Production Forecast. Derived from the United Nations Conference on Trade and Development, "Hemp in the United States and Canada" (2023).

Category	2030 Acres	2030 Hectares	Lower Value	Upper Value
Seed	4,836,000	11,949,592.3	$113,640,623	$124,514,752
Fiber	2,808,000	6,938,472.94	$18,386,953.3	$24,354,040
Flower	156,000	385,470.72	$377,761.306	$655,300.224

This is a significant range, but it speaks to the great potential of industrial hemp to generate a sound source of income for the United States over time. As the Farm Bill only recently granted production permits for hemp, I implore agricultural economists and growers to extend the same effort in operationalizing hemp as was offered to its competitors. Until adequate research, funding, and focus are directed toward the hemp industry, it will remain in its infancy, characterized by higher production costs. Economic scalability for hemp is currently lacking and will continue to be so without further attention. In the meantime, this study contributes an academic perspective to the foundation of the hemp industry, delivering quantitative and qualitative reviews of the crop.

6.1 Limitations

While this CBA serves beneficial in understanding how hemp can contribute to the national economy, data availability inhibits the complete potential of this analysis. The USDA Farm Service Agency only began collecting data on acreage and costs in 2015, preventing access to acreage, initial enthusiasm, and profits from 2014. As state-by-state hemp reporting methods vary, federal institutions note a demonstrable cost in collecting this information (Rupasinghe et

al., 2020). The consistently referred to, integral “National Hemp Report” from the USDA (2022) recognizes that it must use external data or estimates for 34 out of 50 states that “Withheld to avoid disclosing data for individual operations.” This demonstrates a potential source of error from the misrepresentation of true area harvested and profits by acre by state in 2021, extending to my analysis’ results for 2020.

Prior to legalization, hemp's classification as a Schedule I Controlled Substance hindered data collection significantly from 1937 onward (Mark et al., 2020). This restriction limited the availability of comprehensive information regarding hemp's potential uses and benefits during that period. In the realm of prohibition, hemp’s real market output is undervalued given buyers and sellers in what some may euphemistically call “the recreational pharmaceuticals business.” Put differently, producers of illicit marijuana plants also tend to cultivate hemp being that the infrastructure is already established and that the two species are often substitutable. As it is difficult to discern between a purchase of floral hemp and floral marijuana, producers might cut their product with hemp or, per recent technology, can spray THC on dried hemp flower to induce a psychoactive effect (Detrano, 2023). While contributing to the point that hemp legalization has evoked some risk as to what is actually in the finished product, the unquantified amount of hemp grown by conventional marijuana dealers and its economic impact results in underreporting for this analysis. Another margin of error comes from the reality that data on only hemp market value for V-A products grown in fields is available. Thus, the value of products that have been grown in a greenhouse, thus the benefits per hectare, is underestimated. This is significant yet not detrimental as greenhouses may be used just to propagate the seeds which are then transplanted to fields and accordingly recognized as hemp in the open. Greenhouses may

still witness the plant's full growth to processing, however, indicating that the true benefits from hemp growth are actually greater than reported.

Likewise, the value for carbon sequestration is undervalued given that the crop may be harvested 2 to 4 times annually ("The Role of Industrial Hemp in Carbon Farming," 2023). From research, I assume that a hemp hectare absorbs 15 to 22 tons of carbon. While correct, a hectare of hemp can do so multiple times annually, indicating that the true carbon sequestration benefit in 2020 may actually be twice or quadruple the CBA's estimate. As there is evidently no research as to how much carbon hemp alone sequestered in a year, it is impossible to capture its real environmental impact. Meanwhile, values on V-A specific costs may be undervalued given minimal data as to the processing costs for each example and, even further, how much hemp land is required for production. Although this results in underreporting in this analysis, it speaks to the necessity of further research in hemp production methods to establish more accurate costs.

6.2 Market Challenges and Outlook

Despite its promising attributes, industrial hemp faces notable encumbrances before it advances beyond infancy. One notable impediment is the lack of existing infrastructure for large-scale production and processing of hemp-based products (Williams, 2023). The current agricultural and industrial framework primarily caters to conventional crops, rendering the integration of hemp into mainstream systems a logistical challenge. However, increasing research into predominantly marijuana and hemp cultivation is leading to the development of equipment aimed to improve harvest and production efficiency (Helmer, 2021). Additionally, the economic landscape presents a hurdle, as hemp products tend to be more expensive than their traditional counterparts, raising concerns about the cost-effectiveness of widespread adoption.

For instance, with the cost of hemp biodiesel production at $4.13 a gallon, even environmentally conscious consumers may be hesitant to use a fuel more expensive than traditional petroleum diesel (Cheng et al., 2020). In parallel, retailers including Etsy, Patagonia, and J.Crew are capitalizing on fiber V-A products, selling a basic hemp t-shirt at roughly $30 (Wietstock, 2023). Evidently more expensive than a conventional cotton item, hemp adoption is inhibited by generally higher prices for the same consumer goods. As a result, the purchase of hemp products is significantly dependent on environmental consciousness and consumer income, resulting in disproportionate access to its ability based on socioeconomic status.

Furthermore, the competition from other promising crops like corn and soybean adds complexity to hemp's status. Alternatives with established supply chains and more streamlined production processes may overshadow the potential benefits of hemp, making it a less viable option in comparison. With traditional materials including plastics, wood, and cotton being quite established and profitable for society, further implementing hemp is associated with start-up costs that may discourage production. This implementation also comes with the additional burden of licensing fees, regulatory oversight, and market volatility. Standing as a recently legalized crop still analogous to recreational drug use, Mark et al. (2020) recognizes that variability in State legislation, “inconsistency between State requirements; and lack of basic data and information for decision-making” are complicating adoption. This does not even scratch the surface as to the social stigma towards marijuana and the public’s inattentiveness regarding hemp’s versatility. These drawbacks speak to the need for comprehensive research, investment, and policy initiatives to address the infrastructural gaps and socioeconomic considerations hindering the widespread utilization of industrial hemp.

Furthermore, regulatory uncertainty exacerbates existing challenges faced by hemp farmers. Being a document passed roughly every five years, the postponement of the 2023 Farm Bill has introduced uncertainties regarding the future trajectory of the industry, casting some shadow over its potential impact. Initially heralded as a pivotal moment for hemp cultivation, the Farm Bill was anticipated to usher in a new era of economic viability and clarity. However, the delay has left stakeholders in purgatory, impeding innovation and stifling growth in the sector. Retailers and growers alike still poised to capitalize on the opportunities afforded by the legislation express a degree of hesitation. In March of 2024, President Biden signed a $460 billion appropriations bill for the USDA, FDA, and other departments, indicating that federal funding is partially being directed towards hemp (Farmaid, 2024). At the time of writing, however, no movement on a new Farm Bill has occurred (Hoban, 2024). Thus, the government's failure to further establish hemp funding and initiatives is limiting the market's growth potential and long-term prosperity.

Hemp has been reinstated as a legally permissible crop for cultivation and research in the United States, generating significant interest among producers, processors, and stakeholders who are eager to witness its success. To do so, the crop must circumvent evident religious and social perspectives, scalability issues, and market competition. Results from this study highlight that hemp cultivation is altogether profitable but can achieve greater efficiency and higher net benefits with improved research and recognition. This could be facilitated by financial incentives such as subsidies and tax breaks for farmers and manufacturers transitioning to cultivation. Additionally, low-interest loans for infrastructure development, training programs, educational resources, quality standards, and improved research funding will help transition the market away from infancy. With the increasing discourse on sustainability, it is crucial that hemp's relevance

in this arena be promoted to attract public attention and that efforts prioritize job growth and rural community well-being.

7: Conclusion

In light of the evident advantages that industrial hemp presents in addressing economic, social, and environmental challenges, it is imperative to elevate its recognition in the discourse on sustainability. As the world grapples with escalating emissions, the increasing need for energy alternatives to fossil fuels, contamination, and health crises, hemp emerges as a viable contender in addressing these challenges. In addition to its noteworthy, quantified sequestration of destructive greenhouse gasses, hemp yields practical consumer items in the realms of insulation, clothing, plastics, compost, cosmetics, biofuel, nutrition, paper, and so forth. In the burgeoning CBD market, hemp's versatility extends further, with an array of health wellness products harnessing its beneficial properties. While an incomplete analysis of its true costs and benefits per hectare, this CBA and NBR speak to the further production of this resource particularly for seed-based products where benefits significantly outweigh the costs. Furthermore, the value for fiber and grain suggests further profitability were the market to continually expand and improve efficiency in the United States. Moreover, the CBD market evidently exhibits incredibly volatile impacts amidst rising consumer interest and research towards its efficacy.

Research of this kind is essential for the burgeoning hemp industry to further understand and quantify its potential domestic application. To advance the sustainable development of the hemp industry, it is encouraged to federally address issues in data transparency and raise private sector engagement in the market. Collaboration across various sectors within the hemp industry is critical to explore several research areas and pool together the necessary expertise to

effectively encourage this crop. Furthermore, fostering international partnerships, specifically with better experienced countries in hemp production, is pivotal to address information gaps and enhance existing harvesting and processing methods. As a result, the United States is uniquely positioned to capitalize on this growing opportunity and improve the prospects of a profitable, sustainable global hemp economy. Given the value to hemp cultivation, there is a considerable demand for additional research to comprehensively understand the costs and benefits associated with production, including factors such as time, climate, degree of soil contamination, state, and urbanization status, among others. As updated domestic agricultural policy is forthcoming, this analysis lends insight to hemp's market status, value, and application in an increasingly sustainable national landscape.

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