



Office of the Chief Scientist
U.S. DEPARTMENT OF AGRICULTURE

The background of the cover features a close-up of vibrant green hemp leaves. In the lower-left corner, there is a small glass jar filled with golden-yellow hemp oil, topped with a cork stopper. Below the jar is a wooden spoon filled with dark hemp seeds, with a few more seeds scattered on the white surface next to a small sprig of hemp leaves.

HEMP RESEARCH NEEDS ROADMAP

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Contents

3	Contents
5	Introduction
8	Needs Area 1: Breeding and Genetics
9	Overarching Research Goals <ul style="list-style-type: none">Creating consistent varietal improvements through foundational researchProducing varietal improvements for regional adaptationAchieving trait-based goals for specific end-uses Potential Roles for Public and Private Sectors
10	Needs Area 2: Best Practices for Production
11	Overarching Research Goals <ul style="list-style-type: none">Optimizing and regionalizing best management practicesUnderstanding pest and disease managementIdentifying sustainable production practices Potential Roles for Public and Private Sectors
12	Needs Area 3: Biobased Products Manufacturing for End-uses
13	Overarching Research Goals <ul style="list-style-type: none">Integrating end-use goals throughout productionOptimizing processing methodsEvaluating properties of hemp products to ensure compliance with regulatory policies and to meet consumer needsEvaluating properties of hemp fiber and grain products for comparison with other feedstock commodities and biobased products in the bioeconomy Potential Roles for Public and Private Sectors
14	Potential Roles for Public and Private Sectors
15	Needs Area 4: Transparency and Consistency
16	Overarching Research Goals <ul style="list-style-type: none">Advancing consumer education on products and usesEmpowering farmers to take part in the industryDeveloping science-based definitions to underpin value chain development and markets Potential Roles for Public and Private Sectors
17	Developing a hemp consortium
18	International Engagement: technology transfer, capacity-building and trade
18	Conclusion



Introduction

Hemp has great potential for uses in food, feed, fiber, and other industrial products that can improve the livelihoods of U.S. producers and offer consumers biobased products. However, the hemp industry is young and, therefore, it is critical to engage with stakeholders to identify needs from those investing in the hemp arena. To create an environment for sustained investment and growth, technological knowledge that has been the basis of U.S. agriculture's success, developed from global advancements, and discovered from other fields of research must be transferred to all aspects of hemp industry so products can be produced at scale and delivered to consumers around the world.

Research can identify new applications and innovations for hemp production and facilitate the development of successful hemp industry sectors. Changes to the legal status of hemp from the 2018 Farm Bill paved the way for hemp innovations that can advance its production and commercialization through areas such as hemp breeding and genetics, sustainable management practices, processing, and biobased manufacturing for different end-uses, and understanding consumer demand for hemp products.

The hemp industry recognizes the importance of ensuring that research must be impactful across the entire supply chain, from seed to end product. As such, the industry is depending upon the public sector to leverage land-grant university and USDA agency partnerships to advance research, education, and extension to accelerate successful hemp operations. Leveraging collaborations between the public and private sectors can culminate in the establishment of interdisciplinary approaches to define hemp's role in U.S. agriculture, optimize production and manufacturing capacities, and create opportunities to improve economic development across rural areas.



Hemp seed products:
hearts, protein powder, oil & milk

To build upon ongoing collaborations and coordination across the hemp industry, Oregon State University's Global Hemp Innovation Center and the USDA co-organized the National Hemp Industry Research Needs Workshop in November 2022. The workshop brought together leaders from academia, industry, and government to identify the significant gaps, challenges, and opportunities for research to support development of a globally competitive U.S. hemp industry. The Workshop focused on six topics spanning all aspects of hemp value chains: plant breeding and genetics, sustainable agricultural production, harvest and materials processing, product manufacturing and supply chains, economics and markets, and testing and compliance.

This roadmap is the synthesis of stakeholder input from the National Hemp Industry Needs Workshop and identifies the greatest four areas of immediate need based on feedback from leaders and constituents of the hemp industry: Breeding and Genetics, Best Practices for Production, Biobased Products Manufacturing for End-uses, and Transparency and Consistency. These four Needs Areas cut across the hemp supply chain topical areas emphasized at the National Hemp Industry Needs Workshop and are vital to bolster the hemp industry with research (Table 1). Success in addressing the research needs reflected in this roadmap will depend on transformative research that relies on public-private partnerships across industry, academia, and government.





















		Cross-Cutting Research Needs Areas			
		 Breeding and Genetics	 Best Practices for Production	 Biobased Products Manufacturing for End-Uses	 Transparency and Consistency
Topical Areas for the 2022 National Hemp Industry Research Needs Workshop	Plant Breeding and Genetics				
	Sustainable Agricultural Protection				
	Harvest Materials and Processing				
	Product Manufacturing and Supply Chains				
	Economics and Markets				
	Testing and Compliance				

Table 1. Hemp Research Needs Area highlighted across topical areas of the 2022 National Hemp Industry Research Needs Workshop.



NEEDS AREA 1

Breeding and Genetics

High-quality, consistent, and stable varieties are a necessity to establish value across the hemp industry. Given the unique biological characteristics of hemp, both foundational and applied research will be required to unlock value, and it is critical that public-private partnerships are preserved to continually generate genetic gain.

Overarching Research Goals

1. Creating consistent varietal improvements through foundational research

To establish stable hemp varieties, foundational genetic research is needed to achieve upstream breeding goals demanded by the supply chain. A genetic basis should be developed through evaluating current cultivars, mapping populations, attaining genetic stability, understanding the storage and flow of pollen, and identifying key differences in mono- and dioecious strains. Utilizing state-of-the-art technologies including biotechnology can unlock key outcomes in double haploid technology, functional genomics, and cytoplasmic male sterility. Furthermore, data produced in genetics research must be shared throughout the hemp industry to ensure widespread progress and diverse availability.

2. Producing varietal improvements for regional adaptation

A wide range of regional adaptation for hemp is needed to facilitate determining when and where hemp fits into the production landscape. This includes climate adaption for water, heat, and other environmental stresses; durable plant and disease resistance for current and predicted biological stress; and photoperiod sensitivities with specific efforts to develop autoflowering varieties. Additionally, by developing and implementing regional varieties, a diverse production system can be established to create resilient and flexible response to supply chain stress.

3. Achieving trait-based goals for specific end-uses

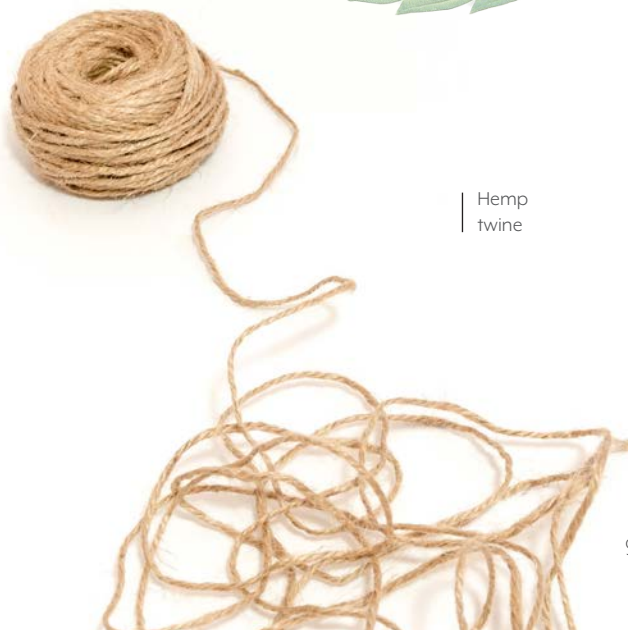
Hemp has a diverse set of end-uses and products that would be enhanced by developing varieties with traits tailored to meet needs for seed, grain, and food bioproducts; fiber and biomaterials; and chemicals and biopharma. Many traits could also be improved for specific post-harvest processes to optimize processing and manufacturing pipelines (e.g., curing, retting, and fungal control). Specific breeding goals must also be considered for any medicinal purposes including antimicrobial functions and phytochemical efficacy (e.g., major and minor cannabinoids,

terpenes, and flavonoids). A trait-based approach may also facilitate progress towards dual-use hemp, specifically hemp produced for both grain and fiber.



Potential Roles for Public and Private Sectors

Robust collaboration and partnership between public and private sectors are imperative for continual genetic gain, regional adaption, and trait-based improvements in hemp. The public sector can document past research endeavors and publish current research progress to bolster scientific advancements industry-wide including the identification, validation, and compilation of public datasets, genetic markers, and germplasm. This should occur in parallel to establishing standards and phenotyping protocols for traits of interest. Direct connections between producer, processor, and consumer in the private sector will be crucial for defining, validating, and discovering specific end-use traits. Plant breeding and genetics companies will have a critical role in identifying and implementing trait packages designed for the hemp value chain. Additionally, the biotechnology arena will need input from both public and private sectors to develop foundational techniques for genetic insertion and suppression and the application of that technology to specific traits for product advancement, respectively.



Hemp
twine

NEEDS AREA 2

Best Practices for Production

U.S. producers (and the entire supply chain) depend upon accurate and timely information to achieve quality yields and profits. While the hemp industry has made great strides in production, there is immense opportunity for optimizing production practices and systems. Research can reveal best management practices for hemp production, identify critical practices for pest and disease management, and elucidate how sustainability, stewardship, and climate needs may position hemp into the existing agricultural landscape.



Overarching Research Goals

1. Optimizing and regionalizing best management practices

Currently, much variability exists across many hemp production practices from planting to harvest. As new and improved varieties become more stable, specific optimization can be achieved for growing season timelines. Furthermore, management decisions such as seed treatments, crop protection, nutrient management, weed management, agroforestry systems management, and irrigation require additional research to identify ideal mechanisms and applications. Optimal management decisions can also be evaluated in parallel with new varieties developed for specific climates and regions to create region-specific best management practices.

2. Understanding pest and disease management

As with all crops, proper management of pest and disease is key to maintaining yields, quality, and profits. Science-backed decisions surrounding pesticides and disease treatments for hemp still require fundamental data to allow for product labeling and use. Progress must be made to ensure producers have the necessary options to manage their fields. Research is needed to unlock opportunities for integrated pest management and biopesticides to be incorporated as feasible solutions. Finally, testing for pesticide and other treatment residues must be evaluated for all biobased product types.

3. Identifying sustainable production practices

Crop production systems must balance high productivity, natural resource conservation, environmental quality, and producer quality of life. As systems are optimized, specific consideration must be given to the methods for sustainable production. Methods that integrate production management and conservation practices must be evaluated, including minimal tillage, cover crops, crop rotation, concurrent grazing, use in agroforestry, and irrigation management. Doing so is critical for providing producers with opportunities to reduce input costs,

build soil health, increase carbon sequestration, and produce climate smart outcomes. Hemp production will need to be evaluated for short- and long-term impacts on carbon life cycles and phytoremediation efforts. In addition, labor requirements throughout the hemp industry will need to be determined and optimized for labor efficiency and sustainable employee engagement and community stewardship.



Potential Roles for Public and Private Sectors

To identify and adopt optimized hemp production practices, the public and private sectors must recognize what producers need. The public sector should coordinate large-scale and regionalized performance trials for foundational management knowledge including planting and harvest schedules, input usage, and variety recommendations. Furthermore, the public sector should facilitate the sharing of knowledge through variety choice guides, production guides, and enterprise budgets to show potential costs and returns. The public sector also has a key role in identifying sustainable practices for hemp production and how best to encourage those practices. The private sector must forge partnerships across companies to facilitate the concurrent development of innovative products to serve the needs of producers and the large production landscape. Additionally, the private sector must develop products with a common goal of generating returns on investment for both companies and the producer.



Hemp
oil & seeds



Hemp roots in
hydroponic system

NEEDS AREA 3

Biobased Products Manufacturing for End-uses

The versatility of hemp is both an opportunity and challenge for the hemp industry. While diverse end-use capabilities provide many potential sources of value, the wide-ranging types of raw material processing required to capture that value and the current lack of efficient processing infrastructure are bottlenecks. To determine how hemp best fits into U.S. agriculture and markets, research is necessary to optimize production and processing systems for understanding and unlocking consistent production and valuation of hemp-based products through a value-chain assessment/mapping effort.

Overarching Research Goals

1. Integrating end-use goals throughout production

Different hemp varieties offer properties suitable for varied end-uses. Therefore, end-uses should be considered throughout production and biobased manufacturing systems. Breeders, producers, and manufacturers should collaborate to identify trait-based properties that inform the development of new hemp varieties, optimize varieties for different uses, improve processing efficiencies, and identify new products and uses. Research can inform the development of new products from food, feed, fiber, chemical, and other industrial market classes. In addition, research can identify new uses for current hemp materials or products to expand the market share of hemp, e.g., expanding hemp seed oil use from markets in the health and wellness industry to potentially new biofuels markets; creating biocomposites for use in plastics and activated carbon for soil amendments, filters, and energy storage devices; and refining high-performance textiles. Success in this area will ensure that chemical and physical properties of hemp materials and products meet industry quality standards and consumer demand.

2. Optimizing processing methods

To capture optimal value from genetic and production improvements, processing methods will need to effectively and efficiently create products for a myriad of end-uses. Traditional processing methods such as retting, drying, degumming, ensiling, baling, and handling are critical to creating short-term value at scale. Additionally, processing infrastructure developments for stalk, textile, and non-woven fabrics are needed to determine specific chemistries, processes, and equipment for meeting industry standard and consumer demand. However, there are many uncertainties surrounding the ideal, advanced manufacturing technologies needed to compete across markets, and infrastructure and processing facility gaps prevent efficient development of equipment and processes. Research must unlock efficient and cost-effective biomanufacturing systems for producing the diverse range of hemp products.

3. Evaluating properties of hemp products to ensure compliance with regulatory policies and to meet consumer needs

To support market development and trade of hemp products, the hemp industry must be able to measure chemical compounds and physical components of products accurately and transparently to achieve greater consumer buy-in and adhere to regulations. Research is vital in developing methods to reliably measure cannabinoids for composition and toxicology, nutritional values and residue content for feed and food products, and chemical and physical properties of industrial materials. Further implementation will require the development of universal protocols to standardize the quality evaluation of hemp products and the development of new or adherence to current regulatory frameworks e.g., a nonbiased chemical assay system and optimizing hemp fiber testing instrumentation. Current methods for analysis need to be optimized to improve the speed and accuracy in testing hemp for different chemical components and physical properties across the life cycle and different varieties.

4. Evaluating properties of hemp fiber and grain products for comparison with other feedstock commodities and biobased products in the bioeconomy

Research is needed to evaluate the potential of the production and manufacturing of hemp fiber and grain for key indicators such as rural economic development, resilience of domestic supply chains, and decarbonization/life cycle analysis to prioritize public and private investments, particularly where such information already exists for other commodities and product types. This will support more informed decisions about the extent to which historic increases in funding and demand for bioeconomy development are to be oriented toward hemp fiber and grain when compared to other commodities and product types.





Potential Roles for Public and Private Sectors

The public and private sectors can advance the production of hemp for new and existing end-uses by collaborating to identify and coalesce the industry around bioeconomy development zones that would elevate certain hemp products that have a high consumer demand and clear market incentives. The private sector can focus on developing hemp-specific and product-specific zones for the market, while the public sector can offer initiatives aimed at creating new zones that expand the industry. By developing specific zones, the private sector can help identify which hemp products may have an increased consumer demand and can collaborate with the public sector on how research can best support new bioeconomy development zones for the hemp industry. In addition, the public sector can continue to convene groups that span industry, academia, and government around different end-uses to foster collaboration amongst these groups to drive the success of new and emerging opportunities. The private sector can also work with researchers to validate new innovative uses for hemp being developed in the lab and support researchers in scaling these products as they move from the lab to the market, playing a leadership role in focusing the industry on the most important products for hemp end-uses, such as food and fiber production. Private industry can also work as a connector to facilitate collaborations between plant breeders and down-stream processors to work together on shaping new varieties.



Hemp
fiber



NEEDS AREA 4

Transparency and Consistency

Research combined with other efforts are required to improve efficiency, efficacy, and access across the hemp supply chain. Producer and consumer education programs will be essential for ensuring growth in the industry and must be implemented to support successful hemp production and utilization. Extension and education partnerships with land-grant universities can be leveraged to support education on new and emerging hemp products, and an understanding of unique community needs will be essential to ensuring equitable and inclusive support across hemp producers.

Overarching Research Goals

1. Advancing consumer education on products and uses

As the hemp industry expands, consumer education will be essential to delineate between hemp and other Cannabis products to disseminate the benefits of incorporating hemp products into daily lives. Social science will be vital to understand what consumers will value in hemp products and how different market characteristics will influence consumer buy-in. A better understanding of consumer perception can inform market pricing alongside other price discovery mechanisms to provide the industry with consistent pricing standards based on quality and grade of specific products. The area of market pricing has already been bolstered by the USDA Agricultural Marketing Service, providing access to market prices for consumers and industry members. In parallel with consumer education, land-grant universities can also partner with the industry to offer high-quality internships and training opportunities for students in jobs throughout the hemp value chain. By partnering with land-grant universities, the hemp industry can also bring new, high-quality jobs to rural communities.

2. Empowering farmers to take part in the industry

Producers are the foundation of a successful hemp industry, as they ensure the quantity and quality of hemp grown to meet industry needs. Therefore, it is essential to understand the unique needs of diverse producer communities to support an equitable, diverse, and inclusive hemp industry. To support diverse communities and producer types, including underserved communities and small-scale producers, extension networks can be engaged to understand local and regional challenges associated with growing hemp. This will assist the hemp industry in addressing barriers to producers entering the market and working to directly support producer needs. In addition, extension networks can be leveraged to bridge gaps between producers and manufacturers to support the development of processing facilities near growers. This model would bring economic development to rural communities, provide nearby buyers for hemp producers, and provide new and high-quality jobs in these areas.

3. Developing science-based definitions to underpin value chain development and markets

A major challenge in identifying and scaling new hemp products will be ensuring standardization of new and existing products. Therefore, developing or expanding industry-approved standards for food, feed, fiber, chemical, and other industrial uses is essential to improve trust and transparency for consumers and encourage industry growth. Clear standardization will help to improve the production and marketability of hemp products and can be driven by scientifically-backed definitions for testing and legal compliance, material and product quality standards, and health and safety metrics. Alongside developing standards for market classes, these scientifically sound definitions can help to improve scientific integrity, elevate material and product quality, and accelerate trade across the hemp industry.



Potential Roles for Public and Private Sectors

The public sector is especially important in advancing education and engagement around the hemp industry. Crucial public partners such as extension networks and land-grant universities have built relationships and trust within their communities and can help engagement with the hemp industry. Extension is also a great tool for understanding unique producer needs and connecting those needs back to researchers to inform the development of science priorities. Currently, hemp research is funded by a variety of public funding sources. To help industry and researchers navigate the current research, the public sector can establish a database to track federally funded hemp research projects to avoid duplicative projects in the hemp industry. Private industry can augment this work by developing and testing communication materials to market and promote hemp products. The private sector can partner with the public sector to disseminate these resources and others to educate consumers on hemp products. Finally, a major hurdle to advancing hemp is de-risking the industry for investors. The private sector can help to educate investors on the work the industry is doing to base standardization and testing in sound science to de-risk the investors perception of the industry and invite large-scale investors to the community.



Developing a Hemp Consortium

Throughout this roadmap, it is recognized that partnerships and collaborations are critical to ensuring value along the entire hemp supply chain. To encourage positive interactions and cooperation, a public-private hemp consortium should be pursued to advance opportunities and tackle challenges in each Needs Area. The goal of a hemp consortium would be to facilitate a concerted effort to enhance relationships, streamline research endeavors, improve risk management, and pool resources when applicable. While a consortium may take many forms, potential steps could include involvement with the USDA Biopreferred program, emphasizing research to commercialization through USDA Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, and elevating hemp to a sub-group of the National Bioeconomy Board. The National Industrial Hemp Council (NIHC), a recipient of the USDA Market Access Program, is also central to the U.S. industrial hemp industry's market development efforts and would be a key partner for ensuring value chain development. Potential outcomes from a hemp consortium could include a platform for dataset creation and sharing, consolidation of private sector representation, and publicly led, privately informed standards and testing for end-user traits.

International Engagement: Technology Transfer, Capacity-Building and Trade

USDA's hemp fiber and grain research agenda should include significant attention to international engagement. Industrial hemp production and manufacturing has been largely absent in the United States since World War II, but not in other parts of the world. China and much of Europe have continued to develop their industrial hemp sectors without interruption. Just as Europe was a key source of expertise for USDA's modernization of U.S. forestry a century ago, so too can it be for industrial hemp today. Much can also be learned through bilateral and multilateral development collaborations. Naturally, any such international engagements also support USDA equities toward increasing the global competitiveness of American agriculture and supporting export market access for its producers and manufacturers.

Conclusion

Research on hemp and its industry needs has been growing since the legalization of hemp with the 2018 Farm Bill. Much of the prior knowledge on hemp genetics, agronomy, and processing was, at best, on hold since the end of World War II and, at worst, any interaction with hemp could result in criminal penalties since the 1970s. Because of this, there is much to learn about the research needs of the nascent hemp industry. Other countries have developed a successful hemp industry, and the United States has the capabilities and resources to become a viable competitor with other hemp-producing nations after key research challenges of genetics, productions, and processing have been addressed and workable solutions identified.

This roadmap categorized four hemp research needs areas with overarching goals:



**Breeding
and Genetics**



**Best Practices
for Production**




**Biobased Products
Manufacturing for
End-Uses**



**Transparency
and Consistency**

Successful advancement in each area will set the stage for the U.S. hemp industry to grow, process, and distribute hemp equitably, sustainably, and profitably. To meet these overarching goals, transdisciplinary approaches are required to ensure entire value chains are developed that utilize best business and science-based practices to create productive and profitable systems that conserve natural resource quality, create jobs, and ensure livelihoods.



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