Hemp-30
Phase I Final Report

Contents List

Executive Summary 1
1 Technical description of Hemp-30 innovation 2
2 Increasing sustainable biomass 6
3 Wider environmental benefits 9
4 Hemp-30 Phase 2 Project Plan 10
4.1 Timelines 10
4.2 Risks and risk management 15
4.3 Phase 2 project team, controls and governance 15
5 Commercialisation Plan 16
5.1 New plant varieties 17
5.2 New technologies to increase yield per hectare 18
5.3 New processing technologies 18
6 Summary of analysis 20
7 Annex List 20

Executive Summary

The key objective of the Hemp-30 project is to catalyse a major expansion of the breeding, growing, harvesting and utilisation of industrial hemp as a UK crop through the 2020s and 2030s. This will significantly increase UK biomass production and so reduce the country's greenhouse gas emissions and help drive a Green Industrial Revolution. The fast annual growth of industrial hemp allows the crop to sequester up to 22 tonnes of carbon dioxide per hectare each year - more than any other crop or woodland. Industrial hemp also has excellent environmental qualities as a soil health improver with low input needs, representing an excellent alternative break crop for farmers.

At present, the UK grows around 800 hectares of industrial hemp. Hemp-30 will seek to develop and implement a 10-year strategy to increase the amount grown at least 100-fold to 80,000 hectares per annum making industrial hemp a major UK crop. This will add £700 million to the UK economy and sequester or displace 1 million tonnes of carbon dioxide each year.

The Hemp-30 Phase 1 project has involved extensive discussion with hemp supply chain stakeholders and, building upon these discussions, the production of a Landscape Review that describes the current position in the UK and globally regarding industrial hemp as a crop and for the generation of a wide range of products. In addition, a 10-year roadmap has been developed that summarises the main steps required to deliver the proposed 100-fold increase in the amount of hemp grown in the UK by 2031.

The 3-year Hemp-30 Phase 2 project will develop and demonstrate industrial hemp-related innovations that fall into four main areas as follows:

(1) Breeding of new industrial hemp varieties and seed multiplication - the University of York has established a hemp fast-track plant breeding platform that has been used to develop new hemp varieties and secure plant breeders' rights. The project will develop a pipeline of new hemp varieties with commercially valuable traits to be utilised alongside a major expansion of existing cultivars. Multi-site field trials and seed multiplication will run alongside new variety development.
(2) Development of novel methodologies to increase hemp biomass yield per hectare – the project will demonstrate innovative harvesting technology for the efficient collection of industrial hemp from the field. In addition, the project will evaluate the use of novel biological and chemical treatments to increase the biomass yield of industrial hemp.
(3) Demonstration of innovative on-farm hemp processing technologies – the project will assess the use of industrial hemp processing technologies linked to (1) bioenergy; (2) construction materials and (3) fibre for textiles, all of which have the potential to be located on farms that grow industrial hemp.
(4) Develop UK supply, value and innovation chains for industrial hemp – the project will develop a comprehensive programme of networking, communication materials and information sharing that will address disconnects between stakeholders in the industrial hemp value chain.

These innovations will help to drive a step change in hemp growing and product development in the UK in line with the 10-year roadmap that has been developed in Phase 1 of the Hemp-30 project.

1 Technical description of Hemp-30 innovation

The overarching innovation that the Hemp-30 project seeks to deploy is the transformative change – at least 100-fold increase over 10 years - of industrial hemp biomass grown as a major new, low-input break crop for arable crop rotations in the UK.

The Hemp-30 Phase 1 project, including a Landscape Review and the development of a 10-year Roadmap (Annex 1), has identified four key barriers inhibiting a step-change in industrial hemp cultivation in the UK and these are outlined below along with the innovations that will be delivered to overcome them.

Barrier 1: Cultivars of industrial hemp are not optimised for UK markets or for UK agriculture and seed is expensive and difficult for UK growers to access

INNOVATION: Develop new industrial hemp varieties and seed supplies
The workflow for the development of new varieties, shown in Annex 2 Fig 1, will build upon a molecular breeding platform, established by the University of York (UoY) over the last 15 years, to develop and register new hemp varieties with valuable commercial traits and Annex 2 Fig 2 shows the route to achieving this. Proof of concept has already been established with the successful registration of a new hemp variety by UoY in 2021 (CNAP1HOH, UK PBR grant number 8851; Bielecka et al., 2015 – see Annex 10 for reference details). The Hemp-30 Phase 2 (Hemp-30 P2) project will involve further testing and validation of this and other new varieties already in development. Elsoms Seeds Ltd (ESL), the UK's leading independent seeds specialist and plant breeder, will conduct multi-site replicated field trials during Hemp-30 P2 in preparation for commercial release of the first new variety in 2025.

The UoY Centre for Novel Agricultural Products (CNAP) has developed CNAP1HOH as a dual purpose, high oleic acid variety that produces seed and biomass (shiv and fibre). The novel high oleic acid seed oil trait is five times more stable than conventional hemp seed oil at 20°C, offering new functionality and opportunity to the food processing industry Annex 2 Fig 3. Additional novel seed oil traits are already confirmed in other lines, including elevated Gamma-Linolenic Acid (GLA), forming a pipeline for registration and commercialisation with ESL. Advances in the ability to rapidly sequence and assemble whole plant genomes combined with gamma radiation mutagenesis that results in point, frame-shift, deletion and duplication mutations, has given rise to Genomics-led Predictive Mutation Breeding. A high-quality reference genome assembly of the industrial hemp variety used in the CNAP mutation breeding platform (Laverty et al 2019) now makes possible the in-silico identification of mutations in the DNA sequence of candidate genes from a population of mutagenised plants. The bioinformatics methodology for detection of mutations in the heterozygous state in candidate genes has recently been developed at UoY and will be deployed on a new gamma-radiated mutant population of industrial hemp that will be established as part of Hemp-30 P2.

The effectiveness of gamma radiation in plant breeding is well established in multiple crops and the lead applicant has used it in conjunction with a reference genome to develop new commercial varieties of opium poppy. Based on existing experience and outputs from mutation breeding, the establishment of a Genomics-led mutation

breeding platform in hemp is expected to represent a game changer for development of improved traits that are under the control of one or a few major quantitative trait loci. Hemp-30 P1 feedback from growers and end users has indicated that cannabinoid content, biomass yield and retting ability are priority targets for crop improvement. and feasible targets for crop improvement.

Barrier 2: The performance of industrial hemp under UK conditions in terms of yield, quality, carbon and biodiversity is poorly characterised deterring growers and industrial users from adopting the crop and inhibiting access to voluntary carbon markets and environmental support schemes

INNOVATION: Generate UK-specific industrial hemp agronomy data sets
ESL will conduct multi-site replicated agronomic trials over the 3-year duration of the Hemp-30 P2 project. This will provide agronomic information and will also generate comparative yield and performance data for growers to achieve best results. ESL will coordinate this activity with other Hemp-30 P2 participants – Stockbridge Technology Centre (STC) and KJ Voase & Sons (KJV) that, building upon the depth of expertise ESL and partners possess, is both technically and scientifically feasible within the timescale of the project.

INNOVATION: Define UK-specific industrial hemp soil and biodiversity benefits
The other side of this innovation will be the generation of a data set for UK soil, water and biodiversity benefits and will build the UK evidence base for the agri-environmental benefits of hemp as a crop which improves soil health and biodiversity. During P1 project the Hemp-30 team sought input from Defra ELMS and Soil Health teams to steer the design of these studies and field-based soil analysis will be led by UoY that has plant-microbe-soil interactions expertise. The impact of industrial hemp as a break crop on arable land soil composition will focus on a dedicated 3-year trial site designed and operated by sub-contractor STC, an agricultural centre of excellence with a licence to grow industrial hemp. The Game and Wildlife Conservation Trust (GWCT) will lead on baseline assessments of pollinator and natural pest enemy communities at the East Yorkshire Hemp farm site run by subcontractor KJV who has been growing industrial hemp since 2002. GWCT will trial and develop pollinator monitoring methods that are suitable for future use by farmers in and monitor bee diversity and abundance on flowers of industrial hemp in Canada (O'Brien et al, 2019).

Barrier 3: Technologies for growers to add value before the farm gate require demonstration to release investment in on-farm growing and processing capabilities

INNOVATION: Evaluate sustainable nitrogen solutions
Subcontractor Azotic Technologies Ltd (ATL) are a UK company that produce EnvitaTM and N-Fix® nitrogen fixing bacteria products that work across multiple crops, are applied in liquid formulation and are reported to reduce synthetic nitrogen fertilizer use by 25-50% while maintaining yield. Currently nitrogen is the only significant agri-chemical input required for optimal industrial hemp growth in the UK. As part of Hemp-30 P2, ATL will conduct initial trials to establish the efficacy of their

products on industrial hemp with positive outcomes being factored into demonstration trials in Yr3 of Hemp-30 P2.

INNOVATION: Optimise and provide information on harvesting technology
The fibrous nature of hemp biomass can cause issues when harvesting. The Hemp-30 team will work with the East Yorkshire Hemp farm to assess harvesting innovations developed by Hemp-30 P2 subcontractor KJV. The project team will also create a publicly accessible database of machinery for harvesting hemp and review technologies being developed within the UK by farm equipment manufacturers including subcontractor Tatham Engineering Ltd (TEL), as well as designs from other countries. Information on hemp harvesting equipment that is available for share or contract farming will be compiled. Feedback on experiences of farmers will also be shared with UK farm equipment manufacturers to allow them to further innovate and improve UK built machinery for this growing market.

INNOVATION: Accelerate or bypass farm retting
Currently, retting to breakdown hemp cell wall components is conducted in the field, and is reliant on favourable weather conditions, which are becoming increasingly problematic with climate change patterns. Other countries use harsh chemicals and processes that are toxic and polluting. Subcontractor the Biorenewables Development Centre (BDC) will investigate sustainable options using industrial biotechnology solutions, such as enzymatic treatments, to produce more consistent quality fibre and shiv to meet market requirements. BDC and UoY have world leading plant cell wall R&D capabilities and are very well placed to deliver this work.

INNOVATION: Evaluate advanced fibre processing for textiles
Subcontractor TEL will lead on trials for improved decortication, cleaning and finishing for hemp-based wipes and other non-woven products and subcontractor SeFF Fibre Ltd (SFL) will lead on the added value processing, using their patented high voltage pulsed electrical discharge process, for ‘cottonised’ fibre for the premium textiles market. This methodology has been tested extensively outside the UK, showing feasibility, but has not been demonstrated within the UK.

INNOVATION: Assessment of hemp-based construction materials
The BDC has warehouse space that will be used to produce and showcase a range of hemp-based construction materials including Hempcrete, hemp-based internal boards and hemp-based insulation materials. Subcontractors HempCrete Ltd (HCL) and Simpson York Limited (SYL) will assess these products in terms of their functionality, cost and ease of access for the various building development projects SYL are undertaking.

INNOVATION: Assess hemp biomass as a feedstock for bioenergy generation
BDC warehouse and laboratory space and existing pilot scale equipment will also be used to assess hemp-based bioenergy and bio-based chemicals production through:

- Anaerobic digestion – using BDC 30 litre AD facilities
- Hemp-based pellet production and analysis – using BDC pelleting and analytical facilities

- Hemp-based bioethanol production – using BDC 5 and 30 litre hydrolysis and bioreactor facilities

  BDC has extensive experience delivering pilot scale projects of this kind and has the expertise and equipment in place to support this work.

Barrier 4: Connections between stakeholders in supply, value and innovation chains are not well established

INNOVATION: Develop UK supply, value and innovation chains for industrial hemp

The Hemp-30 project team will develop supply, value and innovation chains for industrial hemp. This will include:

- Better knowledge sharing to accelerate adoption of industrial hemp, speed up innovation and enable better regulation
- Scaling the crop beyond its current niche markets to help establish connections between potential large-scale users of hemp, investors and the growing community
- Establish a UK industrial hemp industries 'voice' in the form of an Industrial Hemp Trade Association to connect with policy makers and to promote its products and expertise internationally
- Generate an evidence base for carbon & biodiversity impacts of industrial hemp cultivation and use in the UK is needed to underpin access to Voluntary Carbon Markets (VCMs) and the Environmental Land Management Scheme (ELMS).

BDC has extensive experience in establishing and delivering supply, value and innovation chain groups in specific bioeconomy sectors. In addition, the 15 Hemp-30 project participants cover all aspects of the hemp supply chain and therefore have the technical, scientific and business strengths to deliver this innovation during the timeframe of the Hemp-30 P2 project.

2 Increasing sustainable biomass

The overarching aim of Hemp-30 is to develop a supply of biomass feedstock for a thriving ecosystem of hemp-based industries that adds 700 million pounds to the UK economy and sequesters or displaces 1 million tonnes of CO_2 each year by 2030 (See Annex 1). The Hemp-30 project will underpin production of industrial hemp on at least 80,000 hectares of UK arable land as a profitable and soil-friendly break crop in cereal rotations with many growers adding value through on-farm processing of the crop at regional hubs. By catalysing connectivity between growers, end users, researchers and regulators, the project will realise the potential of hemp as raw material not only in fuel and bioenergy but also to displace carbon intensive resources within food, feed and construction as well as textiles and high value health and wellbeing products. The robust evidence base that will be developed by the Hemp-30 project will ensure that UK hemp-based products are sought after in voluntary carbon markets and will play an important role in decarbonising the construction industry.

Unlike perennial short rotation coppice or miscanthus, hemp can be slotted into existing arable rotations, giving an annual revenue without the lag time of establishing a perennial and the long-term dedicated land use. This allows rapid expansion of supply as well as fulfilling an urgent need for new break crops in UK agriculture.

The Hemp-30 P1 team has estimated that cultivation of hemp on 80,000 ha will produce 640 kt pa dry biomass by 2031. This is a conservative projection - double this yield has already been reported in environments comparable to the UK. 640kt is approximately 12% of Defra's estimate of UK straw production in 2019 (5.3 million t) and around five times the combined mass of miscanthus and short rotation coppice produced in 2019. 640 kt hemp could supply sufficient feedstock for construction and insulation of around 250,000 homes, a commercial scale biorefinery producing aviation fuel precursors or biorenewable chemicals as well as 150kt pellets for production of electricity, biogas or heat.

Processing of hemp at regional on-farm facilities will generate products that can capture value before the farm gate, enhancing farmer incomes and growing the rural economy across the UK. Hemp can feed markets which have higher value than bioenergy or biofuels and simultaneously offer better decarbonisation opportunities for instance by sequestering carbon in construction products. This means that expansion of hemp will add more value to UK PLC than most other sources of biomass. Hempo-30 team modelling suggests that hemp, in products for construction and textiles, together with applications such as food, feed and personal care could have a value of £700m pa to the UK economy within ten years (See Annex 1).

The Hemp-30 project innovations have been selected to drive a major step change in the growing and utilisation of industrial hemp in the UK. Discussions with supply chain stakeholders during Phase 1 indicate potential for significant growth in three key markets:

- As a raw material for bioenergy generation through combustion of biomass, anaerobic digestion and second-generation bioethanol production

- As the key ingredient of bio-based building materials such as Hempcrete and hemp-based fibreboard
- As a high-quality fibre in the production of both woven and non-woven textiles, particularly as a replacement for plastics-containing wipes

Hemp 30 innovations will increase the efficiency and profitability of UK hemp industries by

1. developing a platform based on advanced genetics to breed hemp varieties that are optimised for UK conditions and markets
2. demonstrating the performance of hemp as a break crop in UK cereal rotations
3. demonstrating advanced biological treatments to improve yield and reduce inputs
4. demonstrating on farm processing technologies to establish their techno-economic viability
5. analysing the environmental performance of hemp to underpin income from ELMS for farmers and VCMs for the wider hemp industries.
6. Connecting hemp value, innovation and supply chains in diverse markets and establishing hemp as a raw material in mainstream markets

KPIs that will indicate the success or otherwise of the HEMP 30 project will include:

1. area of UK-bred hemp cultivated in the UK (baseline = zero)
2. area of hemp under cultivation (baseline = 800 ha)
3. volume of hemp being processed on farm (baseline = 3kt)
4. volume of UK-grown hemp being supplied into key markets (baseline = 5 kt)

A sustainable UK hemp industry will support a sustainable bioeconomy, which in turn will support the development of high value, skilled jobs. In the USA, recent designation of hemp as an agricultural crop (removing it from the controlled substances regulations) has seen a 27% annual growth. The market for hemp products in the US (non-medical) in 2017 was $820 million, this is on track to increase to $2.6 billion (US domestic sales) by 2022.

The ‘before the farm gate” innovations proposed in the Hemp-30 project will accelerate a sustainable supply of UK-grown hemp, enabling significant progress in decarbonising and adding value to the UK economy beyond the farm gate.

- **Construction**: Targets for net zero homes by 2050 necessitate use of biorenewable materials. These targets have been defined in the UKGBC Net Zero Whole Life Carbon Roadmap https://www.ukgbc.org/ukgbc-work/net-zero-whole-life-roadmap-for-the-built-environment/ and aim to achieve a net zero carbon UK built environment by 2050, in relation to the construction, operation, and demolition of buildings and infrastructure.
- Hempcrete and hemp insulation batts can be used to decarbonise construction, insulate homes and create healthy, natural living and working environments that are carbon negative through developing a sustainable supply of hemp. Hemp-30 team modelling predicts construction products worth £300m that sequester or displace >0.5Mt CO_2 pa by 2031 (Annex 1).
- **Textiles**: Hemp, with its strong but biodegradable fibre, is well positioned to replace plastics in non-woven products such as wipes. New technology to cottonise hemp fibre will open markets in woven textiles, avoiding the social and environmental drawbacks of cotton.

- **Automotive and Aerospace -** hemp produces strong lightweight materials for use in interior panels for cars and the aerospace market. With some technology development, the wind industry could use hemp fibre in turbine blades.
- **Food & feed:** The healthy profile of hempseed oil and protein is attractive for human and animal diets. Hempseed meal is well placed to meet exponentially growing UK markets for plant based 'meat' products, replacing imported soy as raw material.
- **Health & wellbeing** The UK is home to a thriving CBD industry generating sales worth £700m in 2021; oil from imported hempseed is already widely used in personal care products and pharmaceuticals founded in cannabis have UK markets of £1bn by 2025.
- **Bioenergy** Bioenergy from pelleted hemp biomass is a market that will drive increased hemp cultivation and sequester CO_2 from 2027, as BECCS is commercialised,
- **Biofuel** Hemp-30 could secure a consistent source of feedstock sufficient to establish commercial scale biorefining in the UK for manufacture of biorenewable aviation fuels and chemicals
- **Voluntary carbon markets**: companies which have committed to net zero will need to purchase carbon offsets: the well documented, reliable carbon sequestration underpinned by Hemp-30 will have value in these markets
- **Biomass processing equipment** UK biomass processing technology providers - such as Hemp-30 P2 subcontractor TEL and Wilson Knowles, textile engineering manufacturers (Bradford) - will expand and grow their world leading biomass processing technologies, already in demand globally.
- **Paper** - hemp can improve the productivity, sustainability and resilience of our agriculture and forestry, where an acre of hemp provides four times more paper than trees.
- **Greater social innovation** - as a product with multiple end-uses, hemp presents the opportunity for rural communities and businesses to develop local supply and processing networks - eg hemp processing for low carbon building materials, sourced close to the point of production.
- **Promoting rural entrepreneurship and industries** - a vibrant hemp industry will provide new manufacturing opportunities in innovative product areas such as alternatives to plastics, low carbon building materials and healthier foods such as Good Hemp oil and dairy-free milk.
- **Bridging the age gap for UK farmers** - Hemp presents an attractive offer to younger farmers and growers supporting new jobs and skills, in developing and growing new varieties and processing innovations for ancillary hemp industries.

3 Wider environmental benefits

Hemp has been shown to fix up to 22 tons CO_2 per hectare, significantly more than pasture, wheat or miscanthus at 4, 8 and 15 t /ha respectively. Hemp is a more efficient carbon store than any other commercial crop, including woodland. Depending on the final use of the plant material, this sequestered carbon can potentially be stored indefinitely in products such as loft insulation, Hempcrete and biochar. Bio-composite products like Hempcrete (made from the woody shiv) can both offset a carbon intensive building material (such as concrete) and simultaneously provide a long-term carbon store.

Hemp-30 P1 team modelling (see Annex 1) suggests that use of hemp in construction, for bioenergy with BECCS and biochar will sequester around 0.5 million tonnes CO_2 and displace a further 0.5 million tons per year by 2031, contributing to the UK's net zero ambitions.

Hemp can slot easily into existing arable rotations, fulfilling an urgent need for new break crops for cereal cultivation. Break crops are used in rotation with cereal crops to suppress weeds and pests and improve soil quality. Increased reliance on oilseed rape (OSR) as a break crop has led to problems with herbicide resistant black grass, which is costing UK farmers £400m pa and reducing wheat yields by 800,000 t pa. The ban on neonicotinoids together with outbreaks of cabbage stem flea beetle have also led to OSR crop failures. Hemp has been reported to deliver significant benefits in rotations, increasing subsequent yield of winter wheat by up to 47%. Its canopy effect and possibly allelopathic compounds suppress weeds. It also reduces nematode populations in subsequent sugar beet crops.

Hemp's deep tap root system allows the crop to access nutrients outside the reach of most annual crops that may otherwise pollute groundwater and rivers. The root system helps to decompact and add carbon to arable soils. These have lost 40-60% of their organic carbon and represent a key challenge for UK agriculture.

Hemp is a low input crop which uses nitrogen very efficiently. Replacement of 1 ha of OSR with industrial hemp could save 100 kg nitrate, 4 herbicide, 3 fungicide, 3 insecticide and 1 growth regulator spray rounds, benefitting local soil microbiota, insect, bird, mammal, amphibian, and fish populations, both directly and indirectly. Hemp has a complementary flowering season to mainstream crops, ensuring an extended season pollen supply, especially when there is scarcity from other crops.

Whilst wider cultivation of hemp may give rise to new pests and diseases that do not currently affect the crop, the breeding programme will provide germplasm with broad range resistance that can be rapidly integrated into elite cultivars of hemp.

4 Hemp-30 Phase 2 Project Plan

The Hemp-30 P2 project will be delivered through 8 parallel Work Packages (WPs) that are described below and in the attached P2 Gantt Chart (Annex 3) and Milestone and Deliverable table (Annex 4) that show the project's key deliverables, deliverable dependencies, overall project milestones and timescales.

The P2 project will represent the first 3-year phase of a 10-year strategy to deliver transformative change to UK biomass production by increasing, at least 100-fold, the level of industrial hemp grown in the country. This 10-year roadmap for Hemp-30 is included with this report as Annex 1.

4.1 Timelines

Work Package 1 (WP1) - Hemp-30 P2 project management – UoY/BDC

The project will be led by the UoY and, as for Phase 1, involve BDC, Lucid Insight Ltd (LIL) and Kepier & Co Ltd (KCL) as key project subcontractors. In addition, a further 11 subcontractor organisations will be involved, all of whom have specific expertise relating to particular Hemp-30 P2 activities. The project will have a Management Team that meets monthly to assess project performance and addresses any issues. A Project Operations Group will also be established, with a representative from all 15 participating organisations, that will meet quarterly to report on project progress. Importantly, a Hemp-30 Industrial Advisory Group has also been put in place made up of key industry stakeholders including Drax Group, the NFU, UK hemp, IndiNature, the Rowett Institute (nutrition and human health) and Nestle, that will provide insight into the various commercialisation pathways for UK hemp. The management team will report to BEIS through monthly monitoring meetings, quarterly reports and through bi-annual stage-gate reviews. The management structure of the project as a whole, including how the broader financial, legal and administrative capabilities of UoY will be drawn upon to help deliver the project, is described in Annex 5.

The remaining 7 WPs of this 3-year innovation programme have been designed to deliver 4 overarching objectives that will overcome 4 key barriers to the wider deployment of industrial hemp as a biomass feedstock identified during Phase 1 of the Hemp-30 project.

OBJECTIVE 1 Accelerate development and make available varieties of industrial hemp suitable for UK growing conditions and end uses

WP2 will deliver an industrial hemp breeding programme - UoY

UoY has previously developed new seed oil varieties of industrial hemp that relied on the use of chemical mutagenesis and reverse genetics to identify mutations in candidate genes. Annex 2 Fig 1 and 3 summarise this approach.

Hemp-30 P2 will advance both the capability and capacity of that approach through the development of a **Genomics-led Predictive Breeding Platform.** Gamma radiation will be used to massively increase the genetic variation that can be

accessed for crop improvement compared to either natural or chemically induced variation. Low coverage genome sequencing will be used to generate an *in-silico* genome catalogue of M2 progeny from gamma-radiated seed. *In-silico* identification of homozygous and heterozygous/hemizygous mutations in candidate genes will be confirmed by follow-up molecular genetic and phenotypic analysis of individuals retrieved from bar-coded seed stocks using an established Laboratory Information Management System. This genomics-led breeding platform will be the first of its kind for industrial hemp and will yield new genetic variation and capability for rapid screening, identification and retrieval of mutations in candidate genes.

Hemp-30 Phase 2 will focus on two key targets for crop improvement:

(1) cannabinoid composition and (2) biomass yield and post-harvest retting.

Cannabinoid composition

Developing a new industrial hemp variety with zero cannabinoids would represent a game-changing innovation for prospective growers and may lead to a shift in Government policy regarding licencing. Deletion of cannabinoid synthesising genes by genomics led predictive breeding should result in a stable zero cannabinoid industrial hemp variety. Existing knowledge of candidate genes together with a high-quality reference genome in the public domain (Lavery *et* al., 2019) provide the knowledge base for genomics-led predictive breeding to deliver pre-commercial zero-cannabinoid industrial hemp lines within the period of Hemp-30 P2.

Biomass yield and post-harvest retting

A recent report (Biswal *et* al., (2019) showed that it is possible to increase biomass yield and digestibility without compromising plant growth in both woody (poplar) and grass (switchgrass) species by down-regulating a key gene involved in pectin biosynthesis. UoY will use a Genomics-led Predictive Breeding platform to identify mutations in plant cell wall biosynthetic genes including hemp orthologues of those shown to be effective at increasing biomass yield and digestibility in woody and grass species – UoY has already established that such orthologues are present in industrial hemp. Phenotyping of genetically stable mutants for biomass yield, sugar extractability relevant to second generation biofuel and retting will be conducted using established platforms. Importantly for the Hemp-30 P2 programme, while the mutant population will be generated in an early flowering seed variety that allows three generations per annum under glass, once identified, new biomass traits can be crossed into later flowering biomass material and registered as new distinct uniform and stable UK varieties that are optimised for UK growing conditions and markets.

Variety Registration and National Listing of High (8%) GLA hemp variety

UoY based mutation breeding has already produced a novel hemp line with double the amount of Gamma-linolenic acid as present in existing commercial hemp oil (Annex 1 Fig 3). GLA is considered to have health beneficial effects and this new trait represents an excellent opportunity to register a second new industrial hemp variety for the UK market during Hemp-30 P2 following established procedures – see Annex 2 Fig 2.

This WP will therefore take target traits from idea through to stable genetic improvement before passing on to WP3 and WP4 for seed multiplication and field trials respectively.

WP3 is designed to deliver industrial hemp seed multiplication - ESL

Certified seed of the UoY generated variety, CNAP1HOH, and other selected hemp varieties are essential as a bank of stock seed and will be needed for future large-scale seed multiplications to meet market demand. Seed is also needed to perform agronomic trials across 3 years and a range of regions, growing conditions and agronomic practices to allow comparison of varieties for farmer/grower information and selection. Seed storage trials will be needed to ensure that the seed produced from seed productions remains viable in store / transport, etc and meets commercial requirements, such as minimum germination levels.

The basic target is to generate 1 tonne of seed available for commercial launch in 2025 following the end of the P2 project period. In addition, enough seed needs to be generated throughout the project period for trialling in seasons 2022, 2023 and 2024.

During 2022 seed will be generated using polytunnel grown hemp by ESL and then in 2023 in glasshouses. During 2023 and 2024, field production will be conducted to check for commercial scale production performance.

OBJECTIVE 2 Develop methods to increase biomass yield/hectare whilst reducing inputs

WP4 is focused upon the characterisation of industrial hemp as a crop - ESL

Field trials of existing industrial hemp varieties will be undertaken by ESL under UK conditions along with the characterisation of hemp as a break crop for wheat. This will include analysis of carbon sequestration above and below ground and the biodiversity effect of growing hemp.

ESL will conduct multi-site replicated agronomic trials over the 3-year duration of the project. This will provide agronomic information and will also generate comparative yield and performance data for growers to achieve best results. ESL will coordinate this activity with other partners that, building upon the depth of expertise ESL and partners possess, is both technically and scientifically feasible within the timescale of the project.

In addition, a data set will be generated for UK soil and biodiversity benefits and will build the UK evidence base for the agri-environmental benefits of hemp as a crop which improves soil health and biodiversity. Field-based soil analysis, including DNA profiling of soil microbes and elemental analysis including carbon, will be led by ecologists at UoY. The impact on industrial hemp as a break crop on arable land soil composition will focus on a dedicated 3-year trial site designed and operated through STC. The Game and Wildlife Conservation Trust (GWCT) will deliver (1) project management for biodiversity surveying; (2) baseline assessments of pollinator and natural pest enemy communities in hemp crops and (3) trial and develop pollinator monitoring methods that are suitable for future use by farmers in anticipation of ELM payments requiring farm-based data on biodiversity.

WP5 will explore innovations to maximise hemp yield/hectare. Evaluation of the use of novel seed and plant treatments will be undertaken to maximise biomass and specific plant components such as fibre, seed, shiv and leaf quantities. In addition, the project will evaluate and develop industrial hemp harvesting technology, building upon innovations that already exist on farm.

Azotic Technologies Ltd (ATL) will evaluate their N-Fix® technology, based on the bacteria *Gluconacetobacter diazotrophicus* to assess yield performance in industrial hemp. ATL will undertake plant growth cabinet-based assessments and in-field testing following well defined methodologies used in a range of other crop plants both in the UK and globally. The Hemp-30 project sites available through STC, KJV and ESL, will be used to provide in field environments and the BDC facilities (where ATL shares a site) will be available for growth cabinet-based experiments.

In parallel with this work, the project team will explore opportunities to improve and more widely disseminate hemp harvesting technology. This will be delivered in part through an evaluation of innovative harvesting technology developed by subcontractor NVS on the East Yorkshire Hemp farm and also through a broader assessment of global hemp harvesting technologies and the creation of information sheets to communicate this information to interested parties.

OBJECTIVE 3 Demonstrate innovative on-farm processing technologies that increase farm incomes and reduce environmental impacts

WP6 will evaluate and further develop hemp processing innovations.
Evaluation of before the farm gate innovation opportunities including decortication fibre cottonisation technology, use of on farm anaerobic digestion (AD), biochar production and on farm pelleting of biomass.

The BDC has open access pilot scale biomass processing and analysis facilities as well as vacant warehouse space that will be used to assess a series of hemp processing innovations that have the potential to be used on farm.

Three hemp product categories will be investigated – (1) textiles; (2) construction; and (3) bioenergy, as these appear to offer the greatest level of demand for increased UK-grown hemp biomass.

Industrial hemp is an excellent source of fibre for woven and non-woven textile products. BDC facilities will be used to evaluate fibre processing technologies including those developed by TEL and SFL project subcontractors.

BDC warehouse space will be used to assemble and showcase hemp-based construction materials including hempcrete, building boards and insulation. SYL will undertake an evaluation of these materials, as part of their pipeline of building development projects, in terms of functionality, cost and access to supplies at scale.

BDC pilot scale AD facilities will be used to assess biogas and hydrogen production using hemp biomass. Access to biomass for AD plants can be a limiting factor and the performance of UK-grown hemp will be evaluated for its biomethane potential.

BDC pelleting facilities will be used to assess hemp-based pellets for use in bioenergy generation and downstream biochar production using subcontractor University of Nottingham's BioChar Demonstrator facility.

BDC also has access to facilities and expertise for evaluating bioethanol production from lignocellulosic material. The potential of hemp as a biomass source for bioethanol production will be assessed using BDC 5 and 30 litre hydrolysis and bioreactor facilities.

WP7 will represent an environmental, economic and social impact assessment. Analysis of the sustainability (economic, environmental and social) of products and processes that rely on hemp as a raw material eg for construction, textiles, biofuels.

The life cycle greenhouse gas emissions balance of hemp-derived products will be assessed through comprehensive carbon accounting, considering 1) trial data on hemp cultivation in UK, including soil carbon change; 2) manufacture of hemp-composite construction materials, energy products, and biochar; and 3) use of hemp-derived products to sequester biogenic carbon and displace incumbents. This activity will link through all work packages, providing an evolving view as data becomes available of the role of UK manufactured hemp-derived products in contributing to net zero progress through generation of on-farm carbon credits, sequestration of biogenic carbon in construction materials and biochar, and displacement of fossil fuel use.

Growing trial data generated during the project, including fertiliser and agrochemical input rates, yield, and soil carbon impacts, will be key inputs to quantifying impacts of hemp cultivation. This data will be supplemented with literature values to estimate variability and longer-term soil carbon impacts of hemp as a break crop. Anticipated yield improvements will be incorporated in future-looking scenarios. Manufacture and use of hemp-composite construction materials will be assessed with production process data from project partners, accounting for utility and material inputs and generation of hemp residue materials, and scenarios for their use in place of conventional materials. Results will be validated with existing studies of similar materials in other markets (Arrigoni 2017). Residual materials will be considered for fuel pellet and biochar markets. Pellet production and use will be assessed by adapting existing models (McKechnie 2011 and 2017) and consider potential for biogenic CO_2 sequestration, while net carbon sequestration with biochar will be

assessed with tools from the Biochar Demonstrator (UKRI GHG Removal Demonstrator), led by UoN.

OBJECTIVE 4 Connect and share knowledge across industrial hemp supply and innovation chains

WP8 Supply Chain Development Programme. A comprehensive programme of networking and information sharing will address disconnects between stakeholders in the industrial hemp value chain. Better knowledge sharing will accelerate adoption of industrial hemp, speed up innovation and enable better regulation. Acting as an "honest broker", the Hemp-30 project team will catalyse connections between potential large-scale users of hemp, investors and the growing community to release investment in both growing and processing the crop. The BDC subcontractor will work with the other project participants to create a voice for the industrial hemp community to connect with policy makers and to promote its products and expertise internationally. UoN will undertake life cycle analysis of hemp cultivation, harvest and processing to enable potential access to Voluntary Carbon Markets (VCMs) and the Environmental Land Management Scheme (ELMS).

4.2 Risks and risk management

A Risk Assessment table for the Hemp-30 P2 project is attached separately as Annex 6 summarising the key project risks and the mitigation steps in place. This covers COVID-related risks to the project as well as a range of other technical, financial and stakeholder engagement risks and mitigations.

4.3 Phase 2 project team, controls and governance

The Hemp-30 P2 project will be led by UoY with the BDC as the main project subcontractor. A strong consortium of UK-based participants has been assembled, covering the entire hemp industry supply chain to deliver P2 of the Hemp-30 project. This group will collectively deliver a series of connected innovations that drive a step change in hemp biomass production in the UK leading to reduction in greenhouse gas emissions and commercialisation in hemp-based textiles, construction and bioenergy markets alongside growth in food-based products. The project Gantt chart (Annex 3) provides a list of all P2 project participants and a short code for each one. The project will be governed by a Project Management Group (UoY and BDC) that will meet monthly and a Project Operations Group that will meet quarterly. In addition, an Industrial Advisory Group will be established involving representatives from all of the major hemp-product supply chains. Annex 5 provides an overview of the Hemp-30 P2 project management and governance arrangements.

5 Commercialisation Plan

Industrial hemp is a multi-billion dollar global industry with growing levels of planting, product development and major investment across much of the world. In 2019, the global hemp market was valued at £3.5bn and is expected to increase significantly with a CAGR of 34% taking it to £19.6bn by 2025, and continuing to £26bn by 2030, which is over 7-fold growth of market value.

The ambition for the 10-year Hemp-30 programme is 100-fold growth from 800 to 80,000 hectares, 14 times faster than the predicted prevailing world growth of industrial hemp cultivation. This accelerated growth will ensure that the UK will dramatically improve its share of the market from 0.3% in 2020 to c5% in 2030. In achieving this, the UK industrial hemp market value will climb from £11.4m in 2020 to £1.3bn in 2030.

P1 of the Hemp-30 project has engaged with business and other stakeholders throughout the hemp supply chain from seed, through growing, harvesting and end users as well as regulators, policy makers and researchers – see Annex 7 for a summary of these discussions. Building on the relationships and insights gained from this work, the P2 project will co-develop research and demonstration activities with stakeholders, ensuring that the innovations address real needs, that they progress rapidly though technology and business readiness levels and are widely disseminated to appropriate audiences. The Hemp-30 P2 Industrial Advisory Group will be an important sounding-board and source of connections and guidance for commercialisation.

The financial growth plan model developed during the P1 project for Hemp-30 (Annexes 8 and 9) has been built to reflect the impact of the work that will be done during the Hemp-30 P2 project itself, and for the following five years.

The model will be developed and refined during the P2 period as additional data becomes available. The model shows 5-year sales growth to £800m pa achieving cumulative sales of £1.7Bn over the period. The Net Present Value of the UK Hemp Industry in 2030 forecast is £4.7Bn.

A modest £5m Capex is assumed at the very early stages as we anticipate most infrastructure and plant used will be repurposed from existing uses with only minor modification required.

Sales grow from £149m in year 1 to £799m in year 5 (Annex 8 Fig 4 & 5) with an increasing growth curve based on a final area under planting of 80kha (Annex 8 Fig 1), based on rising Biomass and Seed Production due to work undertaken in Phase 2 (Annex 8 Fig 2).

The sales mix contributing to income matures and develops over the five years following the project moving from more of a reliance on streams with existing markets (eg biofuels) to those higher value sectors requiring market development (eg healthcare products) as time progresses (Annex 8 Fig 3).

Opex is forecast to increase from £87M to £542M over the timescale and will fluctuate depending on the sales mix achieved and margins attributable to the differing income streams (Annex 8 Fig 6).

The model is based around differing expected margins between the income streams and will require further refinement as the project progresses.

Overall profitability is forecast to rise from £62M to £258M over five years (Annex 8 Fig 6) as the industry benefits from greater scale and development of the sales mix.

The model will be developed to maximise the margin attainable through the sales mix, and the existing data represent a midpoint / average return we hope would improve.

Key to effective commercialisation will be the Hemp-30 P2 communications campaign which aims to join up the fragmented hemp supply and value chains and support development of an Industrial Hemp Trade Association. This will act as a voice for the UK hemp industries, advertising, educating, publishing, lobbying, and enabling collaboration between companies through conferences, networking and collaborative pre-commercial research.

The Hemp-30 P2 communications campaign will be guided by a communications strategy that will be drawn up in the first three months of the project detailing key messages, stakeholder groups and routes through which to reach these audiences as well as metrics for analysing the effectiveness of the campaign. A programme of networking events, exhibitions, open days and on-farm demonstrations will be developed supported by digital and print media and articles in relevant trade press. In addition to growers and contractors, the campaign will reach out to mainstream end users in the construction, textile, fuel and bioenergy sectors as well as food and feed manufacturing.

Importantly, the evidence base that is developed for the environmental impacts of Industrial Hemp will be shared with investors and agencies who are developing products for voluntary carbon markets as well as those in Defra who are working up standards for support under the Environmental Land Management Scheme, opening new potential opportunities for income from these sources.

The individual pre-farm gate innovations proposed in P2 will be commercialised within the overarching framework described throughout this report. Annex 1 provides a roadmap of how the industry will develop over the coming ten years and how the activities in the three-year P2 project will accelerate and support this development.

5.1 New plant varieties

UoY has already gone through the entire UK registration process to obtain UK Plant Breeders Rights and register a new hemp variety (CNAP1HOH) with a modified seed oil profile. Other new varieties are also in the UoY pipeline including a high Gamma Linolenic Acid (GLA) variety with double the amount of GLA compared to current commercial hemp seed oil. Through P1 of the Hemp-30 project, UoY has developed a collaboration with Elsoms Seeds, the UK's leading independent seed specialist and

plant breeder. Through this collaboration, the Hemp-30 project aims to have conducted multisite field trials cross the UK and have verified seed ready for farmer use in 2025 - consistent with the 10-year roadmap. In this way, outputs from this strand of the project will be delivered to the wider UK market and the project team will also explore opportunities for export sales for the verified seed. The P2 project will engage with food manufacturing companies to test the seed oil in their products and establish the oil in their supply chains.

Proving to UK growers that this UK-developed variety provides them with a good commercial return will establish a strong platform from which to launch follow-up varieties, expanding the area devoted to hemp growing and reducing reliance of the UK on imports of biomass, fibre, oils, and seeds.

5.2 New technologies to increase yield per hectare

East Yorkshire Hemp is home to farm-based business KJV that has developed a unique series of hemp harvesting technologies that have thus far been used only on the KJV farm. The P2 project will explore opportunities to further develop this technology in collaboration with the agricultural engineering company TEL and then demonstrate and seek to commercialise these capabilities to other hemp farmers across the UK and internationally.

ATL has developed a series of bacterial treatments to increase crop yield. This technology has been field trialled in the UK and the US using crops such as maize, rice and potatoes. The P2 project will investigate the potential for ATL technology to be used to increase the yield per hectare of industrial hemp. Working in controlled plant growth environments and through field trials, the potential of ATL technology will be explored and, if successful, will be demonstrated to UK farmers and potentially on an international basis following similar roll out procedures already being used by ATL for other crop treatments.

5.3 New processing technologies

Decortication

In addition to innovative harvesting facilities, KJV has developed a unique hemp downstream processing facility through collaborations with TEL and a range of other agricultural machinery companies. The P2 project will explore opportunities to further develop this technology in collaboration with TEL and then demonstrate and seek to commercialise these capabilities to other hemp farmers across the UK and internationally.

The Hemp-30 team has engaged extensively through P1 of the project with businesses involved in hemp supply chains linked to all of the major hemp-based products. Through this work, 3 key product supply chains have emerged as areas where further processing innovation and demonstration can be most impactfully applied. The BDC has existing scale up and demonstration facilities and access to additional warehouse space that can be used to develop and demonstrate innovations linked to (1) Bioenergy; (2) Construction (3) Textiles-based hemp supply chains.

Bioenergy

- **PELLETS** Industrial hemp represents a potentially important new UK bioenergy crop that can be used to support the transition away from fossil-based power generation. This potential has been recognised by Drax Group, the largest bioenergy power generator in the world with its main facilities based in North Yorkshire, and by growing consortia such as Rare Earth Global (REG). The BDC has facilities that will be used to assess the processing of hemp biomass into pellets and subsequent analysis. Working with Drax and REG, the BDC will evaluate hemp as a mainstream biomass crop.
- **BIOGAS** P2 will also explore hemp as a biomass feedstock for anaerobic digestion or, via dark fermentation, the production of hydrogen. The BDC has existing AD research and demonstration capabilities up to 1,000 litres and an extensive network of AD operators to work with and explore this potential route to hemp-based bioenergy.
- **ADVANCED AVIATION FUELS** UoY, supported by BDC scale up capabilities, is world leading in the development of second-generation bioethanol and related platform chemical production. The P2 project will explore hemp as a raw material in this process. UoY leads two of the UK's 6 Networks in Industrial Biotechnology and Bioenergy – BBNet and HVB Net – each with over 500 academic and industrial members. These two networks will provide an excellent route to engaging with the wider market for all three of the areas discussed above.

Construction

The Hemp-30 project team has engaged extensively with the hemp construction materials sector. Advanced plans have been developed by Hempcrete Ltd working with the Unyte Group to establish a series of hemp farming and construction material production centres across the UK. The BDC team also collaborates with Adaptavate Ltd, a UK-based SME, focused on developing and commercialising bio-based materials that disrupt the construction market. These include Breathaplasta, a hemp-based plaster and Breathaboard, a hemp-based plasterboard alternative. The BDC works closely with SYL a Yorkshire-based building and fit-out company that is exploring the use of bio-based building materials across a series of UK development sites. The P2 project will work with these businesses to broker connections and opportunities to showcase new developments and also demonstrate and showcase innovative hemp-based products at the BDC site to other interested construction companies.

Textiles

The Phase 1 project team has worked closely with SFL, a Yorkshire-based business developing an innovative process for modifying the properties of hemp fibre to produce a softer more 'cotton-like' material for use in woven and non-woven textiles. SFL has interest from major clothing companies such as Levis and Burberry and will work with the P2 project team to explore the potential for the deployment of 'Seff Technology' as an on-farm processing capability.

The global trend to move away from plastics-based textiles has driven strong interest in the development of hemp-based non-woven fibres such as wipes used across a broad range of sectors. Working with TEL, the P2 project team will explore opportunities for on-farm innovations, using the BDC site as a testbed for this development and demonstration work.

6 Summary of analysis

The P1 Stakeholder Engagement involved conversations with over forty organisations from the full range of industries in the Industrial Hemp supply chain. The findings from these interviews are summarised in Annex 7 which provides up to date information from key stakeholders to support development of the Hemp-30 roadmap (Annex 1) and guide the activity proposed in the Hemp-30 P2 application.

Assumptions underlying the projected growth of the industrial hemp industries are summarised on pages 20 and 21 of the roadmap in Annex 1. The financial growth plan has been created using a granular approach to all financial captions, with income modelled based on increasing forecast areas grown, likely yields of both seed and fibre and nine separate income lines to represent the product mix. For each year, reasonable growth within each caption and a maturing sales mix were included.

For operating expenses, the model includes estimates of field establishment costs, ongoing costs for cultivation and harvest, and a granular forecast margin for each sales caption to represent anticipated operating expenses. Operating expenses also include costs incurred for the establishment of a hemp trade association.

Capital expenses have been estimated based on modest initial setup costs. Our early enquiries suggest modifications to existing plant and machinery rather than investment in entirely new equipment will be required.

Other assumptions include forecast income (and cost) annual inflation of 3.0%.

7 Annex List

Annex 1 – 10-Year Hemp-30 Roadmap
Annex 2 – Hemp Breeding Strategies
Annex 3 – Hemp-30 Phase 2 Gantt chart
Annex 4 – Hemp-30 Phase 2 Deliverables and Milestones spreadsheet
Annex 5 – Phase 2 Project Management and Governance
Annex 6 – Phase 2 Risk Register
Annex 7 – Stakeholder engagement findings
Annex 8 – Hemp-30 Commercialisation Summary
Annex 9 – Hemp-30 Business Model
Annex 10 – References cited in the Phase 1 Final Report

Annex 1

hemp-30

Phase 1 | BFI Project

Industrial Hemp 10-Year Roadmap

CONTENTS

Vision	1
Background and Context	2
Market opportunities	3
Projections for hemp 2022–31	4
Priorities for UK hemp	5
Overview of hemp industries 2022–2031	6
Timeline for hemp cultivation and use	7
Activities to develop UK hemp	9
Breakdown of actor roles	10
Industrial hemp by 2030: Industry vision	11
Annex 1: Priority 1 – Roadmap for new varieties	12
Annex 2: Priority 2 – Roadmap for hemp cultivation	15
Annex 3: Priority 3 – Roadmap for hemp industries	17
Annex 4: Commentary on projections	20
Abbreviations	22

Partners:

University of York

Biorenewables Development Centre

LUCID INSIGHT

Kepier & Company Limited
Business and Management Consultants

VISION

Our vision is for a thriving ecosystem of hemp-based industries that adds 700 million pounds to the UK economy and sequesters or displaces a million tonnes of CO_2 each year.

Farmers will plant hemp on at least 80,000 hectares of UK arable land as a profitable and soil-friendly break crop in cereal rotations with many growers adding value through on-farm processing of the crop at regional hubs.

With excellent connectivity between growers, end users, researchers and regulators, the crop will be used as raw material in diverse markets to displace more carbon intensive resources within food, feed, construction, biofuel and bioenergy industries as well as textiles and high value health and wellbeing products.

Founded on a robust evidence base, UK hemp-based products will be sought after in voluntary carbon markets and will play an important role in decarbonising the construction industry.

The UK will be recognised world-wide both as a leader in fast-track breeding of optimised hemp cultivars and as innovator in hemp processing.

BACKGROUND AND CONTEXT

Industrial hemp is currently grown on a few hundred hectares in the UK. It has potential both as a low input break crop in cereal rotations and as a sustainable raw material for a range of industries, however, it faces a number of barriers:

- Growers suffer from limited availability and expense of certified seed together with poor evidence on the performance of different varieties under UK conditions. The effectiveness of hemp in rotation with cereals for suppression of weeds and disease as well as sequestering CO_2, improving soil organic carbon and enhancing biodiversity need demonstration and analysis so that growers can select the best variety for their purposes and access the opportunities arising from "carbon farming".
- Current use of hemp products is niche rather than industrial in scale. Potential large scale users will not invest in hemp as a raw material because supply is insecure with limited numbers of producers. Producers will not grow at scale until the markets for their product are secure - Catch 22.
- Connections are lacking between potential large scale users of hemp and the growing community as well as with research groups. Poor knowledge sharing means that opportunities for adding value before the farm gate are not adopted and innovation is slow.
- Whilst the industry agrees regulation is important, the current licensing process is unwieldy, untimely and expensive for growers as well as limiting opportunities for UK processing of high value extractives.
- The UK is world leading in the use of hemp in construction as well as the genetics of hemp secondary metabolism and seed oil composition but could lose this first mover advantage.

MARKET OPPORTUNITIES

Productive break crop
Hemp can meet a pressing need for new break crops in cereal rotations, reducing the need for pesticides, suppressing weeds and enhancing yields of cereal crops. A conservative estimate suggests production of 100kt seed and 600kt biomass from 80,000 ha in 2031.

Carbon farming
Hemp can fix up to 22t CO_2 per ha in above ground biomass whilst enhancing soil carbon and biodiversity. Hemp biochar for soil amendment or as co-feedstock for AD or heat and power can help farms achieve net zero and income from ELMS or VCMs.

Value before the farm gate
Processing of hemp at regional on-farm facilities for construction raw materials or food/feed/health products can capture value before the farm gate, enhancing farmer incomes and growing the rural economy across the UK.

Food & feed
The healthy profile of hempseed oil and protein is attractive for human and animal diets. Hempseed meal is well placed to meet exponentially growing UK markets for plant based 'meat' products, replacing imported soy as raw material.

Construction
Some 5% of the UK's carbon emissions arise from new construction and there is an urgent need to retrofit existing homes. Construction applications of hemp have been proven over twenty years and now need investment to scale up and fulfill their potential to decarbonise construction, displacing or sequestering over 0.5 mt CO_2 whilst adding over £200m to the UK economy by 2031.

Textiles
Hemp, with its strong but biodegradable fibre, is well positioned to replace plastics in non-woven products such as wipes. New technology to cottonise hemp fibre will open markets in woven textiles, avoiding the social and environmental drawbacks of cotton.

Composites
The excellent weight and elasticity of hemp fibre together with a strength comparable to carbon is driving the use of hemp in the body work of cars. With some technology development, the wind industry could use hemp fibre in turbine blades

Health & wellbeing
The UK is home to a thriving CBD industry generating sales worth £700m in 2021; oil from imported hempseed is already widely used in personal care products and pharmaceuticals founded in cannabis have UK markets of £1bn by 2025.

Bioenergy
Whilst a low value application, bioenergy supplied by pelletted hemp biomass can be an accessible market that will drive increased acreage of hemp cultivation whilst displacing or sequestering CO_2 from 2027.

Biofuel
Hemp offers an opportunity to establish 2G ethanol production in the UK for use in sustainable aviation fuel.

PROJECTIONS FOR HEMP 2022–31

80,000 ha

of arable land growing industrial hemp

Displacement or sequestration of

1 m

tonnes CO_2 pa

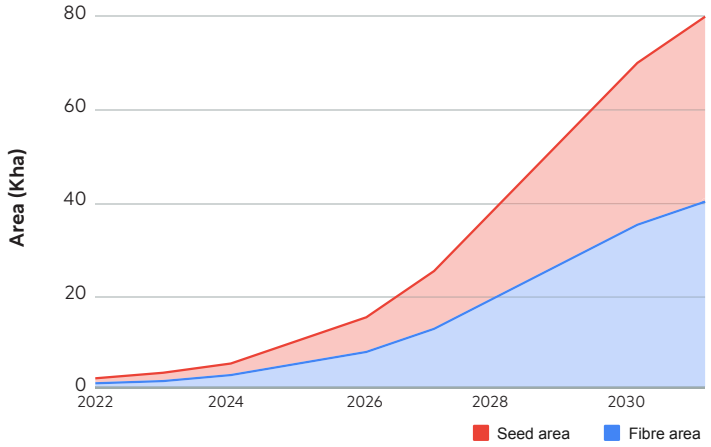
Contribute

£700 m

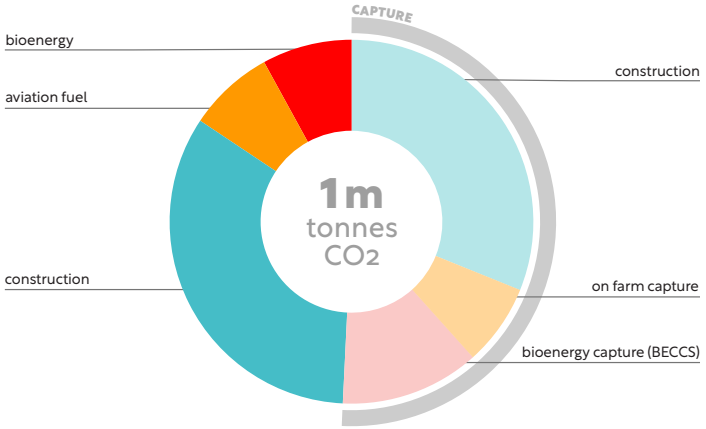
to the UK economy

See Annex 4 for commentary on projections.

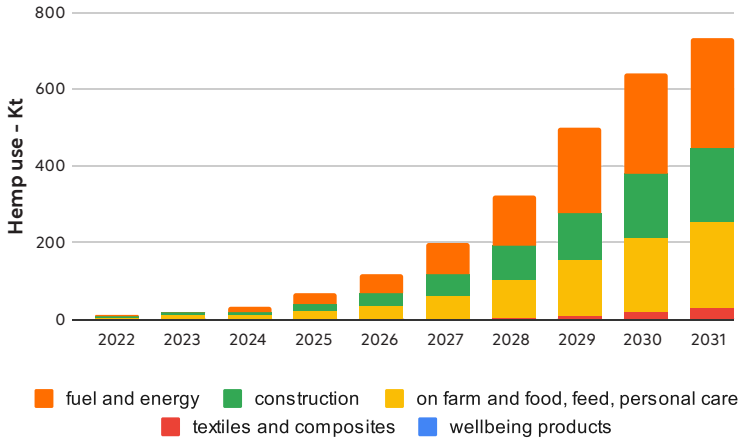
80,000 ha under hemp in the UK by 2031



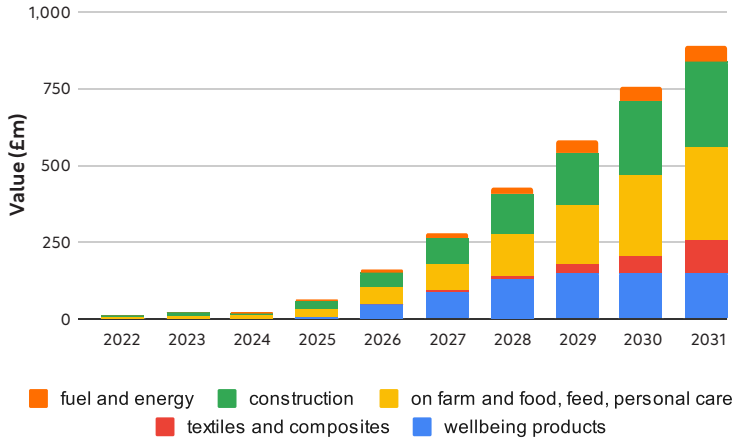
1 mt CO_2 displaced or sequestered by hemp products by 2031



Mass of hemp used in different markets 2022–31



Value of hemp in different markets 2022–31



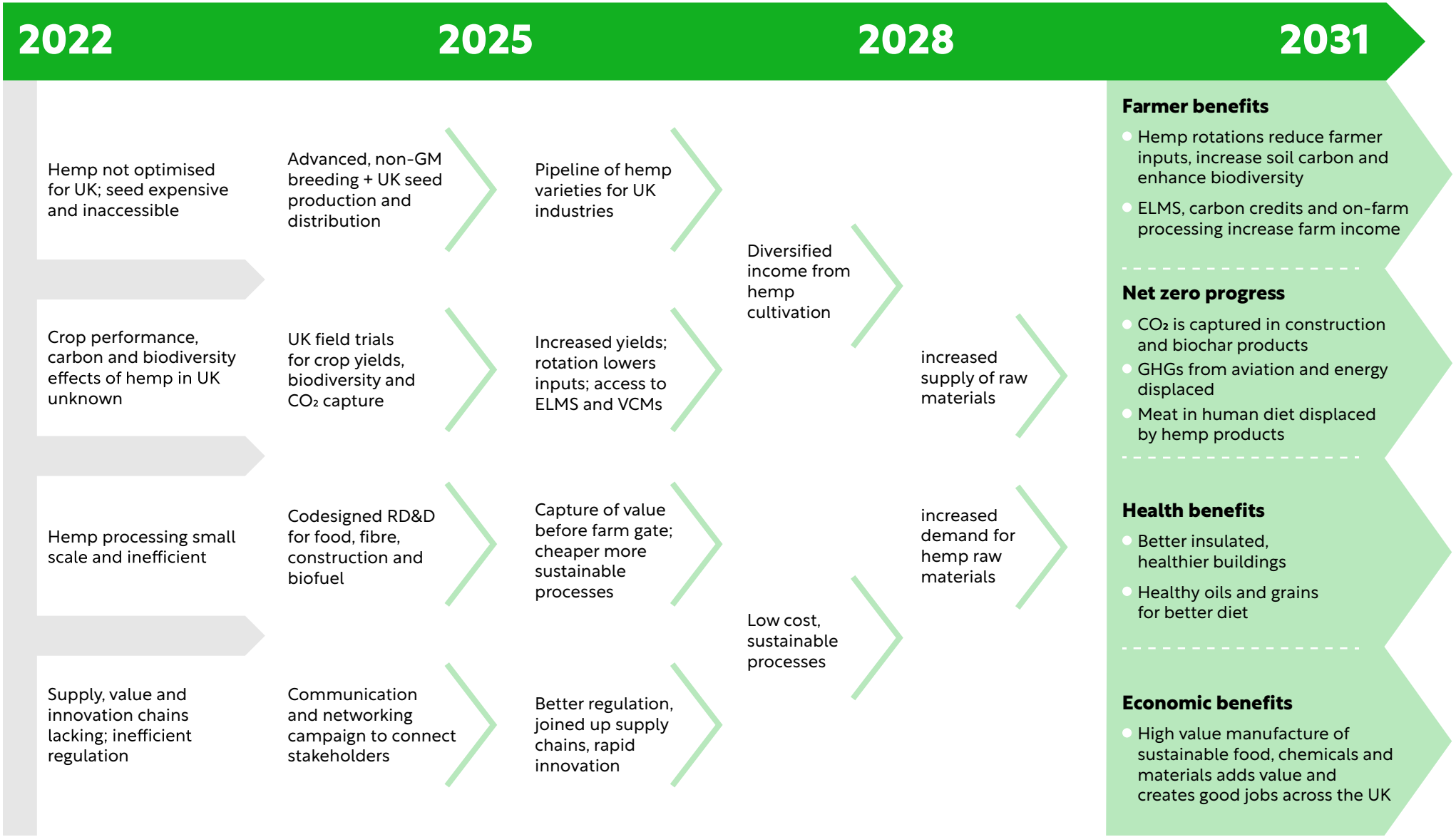
PRIORITIES FOR UK HEMP

Develop hemp varieties for a range of markets for instance dual purpose food & fibre crops to increase income for farmers; hempseed oil that is more stable and suitable for more food industry applications; reduce losses that arise from retting in the field; optimise levels of various secondary metabolites including THC and CBD; address emerging threats of pests and disease. **Farmers need reliable access to affordable seed** for existing varieties and sources of seed for new varieties as they are developed.

Expand the area of land used for hemp cultivation which is held back by lack of evidence for performance of hemp under UK conditions, its nutritional needs & effectiveness as a break crop as well as data on its carbon and biodiversity impacts; crop establishment also requires optimisation. Key to expansion of hemp as a break crop is streamlining regulation of its cultivation.

Develop supply chains and processes for hemp products On-farm process development is needed for retting and decortication to release fibre and for fibre cottonisation as well as pelletting of biomass for bioenergy and use of biomass in AD & biochar. Lack of reliable carbon accounting is hindering access to the opportunities offered by Voluntary Carbon Markets (VCMs)and Environmental Land Management Scheme (ELMS). Poor connectivity between stakeholders leads to small scale supply, value & and innovation chains together with inefficient regulation.

Overview of hemp industries 2022–2031



Timeline for hemp cultivation and use

Barriers	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
	Hemp30 Phase 2 activity									
Varieties	**Priority 1: Develop hemp varieties for a range of markets**									
• Need for dual purpose food & fibre variety • Seed oil unsuitable for many food industry applications • Losses from poor retting, establishment & seed scatter • THC, CBD & 2°ry metabolites not optimised • Emerging threats of pests & disease	• **WP 2:** UK-bred varieties with seed oil suitable for broad food industry applications registered • Building on York's existing advanced genetics platform, develop hemp germplasm with variation in genes controlling key traits (disease resistance, dual purpose crop, retting, THC/CBD, seed oil & protein)			• Hemp lines with variation in key traits identified; initial trials to pick best performers to take forward to registration • Varieties with new seed oil profiles registered				• Registration trials for varieties with enhancements in key traits (eg dual purpose, disease resistant, Zero-THC &/or high CBD, ease of retting)	
• Insecure seed supply with reliance on imported seed • No hemp seed multiplication in the UK • No route to market for new varieties bred in the UK	• **WP3:** Establish hemp seed production in UK • Multiply seed for UK-bred variety with oil suitable for new uses in food industry • Improve seed supply of existing varieties with best traits for UK growers			• Certified seed from UK-bred varieties with novel seed oil profiles available to farmers • Availability within UK of varieties with best traits for UK growers & end users				• UK-bred seed available to farmers for new varieties with enhancements in key traits • More varieties suited to UK become part of the program to multiply seed in UK	
Low acreage	**Priority 2: Expand the area of land used for hemp cultivation**									
• Hemp is a niche crop, unfamiliar to many farmers & limited information available on agronomy • Evidence is lacking for performance of hemp under UK conditions, its nutritional needs & effectiveness as a break crop • Inefficient regulation inhibits hemp cultivation	• **WP4:** Field trial existing varieties in UK • Characterise hemp as a break crop for cereals • **WP8** Collaborate widely to disseminate results; engage with regulators to improve regulation			• Variety selection and agronomy guidance is available to growers • Mainstream farmers adopt hemp as a break crop • Experience of growers increases yield of seed and biomass				• Widespread optimised cultivation of hemp for a range of food, feed, materials and energy markets	
• Crop establishment not optimised • Carbon sequestration & biodiversity effects under UK conditions not characterised, limiting access to ELMS support and voluntary carbon markets	• **WP5:** Evaluate novel seed and plant treatments to maximise yield and minimise inputs • **WP4&7** Characterise soil carbon sequestration and biodiversity effects of hemp			• New agronomic methods increase yields and decrease inputs. • Evidence base for biodiversity and carbon sequestration offers new sources on income to growers from VCM & ELMS				• Increased yields, optimised inputs and VCM or ELMS income enhance returns to farmers whilst enabling soil carbon and biodiversity gains	

Timeline for hemp cultivation and use (cont...)

2022	2023	2024	2025	2026	2027	2028	2029	2030	2031

Barriers	Hemp30 Phase 2 activity		
Supply chains	**Priority 3: Develop supply chains and processes for hemp products**		
• Retting inefficient and unreliable • Decortication to separate fibre and fibre cottonisation suboptimal. • Pelleting of biomass & its use in AD and biochar require optimisation	• **WP6** Collaborative research, development and demonstration to deliver new processes for retting and on-farm decortication, fibre cottonisation, use in AD, biochar and on farm pelleting of biomass	• New regional on-farm processing hubs scale up hemp supply. • Capture of value before the farm gate delivering new sources of income and carbon savings for farmers • Use of innovations later in supply chain delivers more sustainable products	• Technology and knowledge for processing hemp on farm is being exported world-wide • Farms are well integrated into supply chains and capture value with multiple end-markets
• Evidence base lacking for carbon & biodiversity impacts of hemp in UK, hindering access to ELMS and VCMs • Environmental, economic and social impacts of hemp not understood	• **WP7** Develop evidence base for use of hemp in VCMs and ELMS and guidance on best practice to maximise carbon sequestration and biodiversity impacts of hemp on farm and in products • Evidence base allows agreement on criteria for sustainability reporting in hemp products and business case releases investment	• Income from VCMs and ELMS improves price competitiveness of hemp in construction & other markets • Agreed sustainability criteria accelerate adoption of the best innovations • Investment is released in sustainable processing creating value and jobs • Policy makers and regulators use analysis for better policy and regulation	• Demand for UK hemp products drives up value through the whole supply chain. • Reputation of UK hemp products for reliable sustainability claims increases demand in export markets • Improved soil carbon, biodiversity and carbon negative products accelerate UK progress to net zero • Good jobs in the net zero economy
• Supply, value & and innovation chains are lacking / small scale • Inefficient regulation inhibits hemp cultivation and processing • Poor connectivity between stakeholders • Seed is expensive and difficult to obtain • Low international awareness of UK expertise in hemp technology • Perception of industrial hemp as marijuana	• **WP8** Works as an "honest broker" connecting stakeholders (regulators, investors, growers, end users) to initiate and strengthen hemp supply and innovation chains, collaborating with stakeholders to co-design and disseminate research, connecting with regulators, supporting farmers in seed buying co-operatives, promoting UK hemp internationally & raising awareness with large scale end-users.	• Industrial hemp trade association established • Industrial hemp 'normalised' as a UK crop and in products • Improved connectivity & knowledge sharing enables supply chains, investment, accelerated innovation before and after the farm gate and regulation that is responsive to the needs of different sectors	• Vibrant hemp ecosystem with established supply and value chains responsive to market demand in the UK and internationally; rapid innovation arising from excellent knowledge sharing; policy makers and regulators support sustainable development of the hemp-based industries

ACTIVITIES TO DEVELOP UK HEMP

WP1 PROJECT MANAGEMENT

Management team to include all delivery partners and advisory board reflecting primary producers and end users, existing and potential.

Priority 1 – New variety development

WP2 HEMP BREEDING PROGRAMME

- Development of varieties adapted to UK conditions with characteristics needed by end users. In the first instance this will build on the York advanced breeding platform to develop varieties of hemp with desirable characteristics in their seed oil. Longer term targets will include a range of additional industrial hemp traits such as disease resistance, retting time, seed scattering, and secondary metabolite profile. This WP will take target traits from idea through to field trials and registration of new varieties.

WP3 SEED MULTIPLICATION

- Key to successful deployment of new varieties is timely, reliable and resilient bulking of seed.

Priority 2 – Expand area of land used for hemp cultivation

WP4 HEMP CROP CHARACTERISATION PROGRAMME

- Field trials of existing varieties under UK conditions
- Characterisation of hemp as a break crop for cereals.

WP5 HEMP YIELD MAXIMISATION PROGRAMME

- Evaluation of the use of novel seed and plant treatments to maximise biomass and specific plant components such as fibre, seed, shiv and leaf quantities.
- Characterisation of carbon sequestration above and below ground and biodiversity effects of hemp.

Priority 3 – Develop supply chains and processes for hemp products

WP6 HEMP PROCESSING INNOVATION PROGRAMME

- Evaluation of before the farm gate innovation opportunities including decortication, fibre cottonisation technology, use of on farm anaerobic digestion, biochar production and on farm pelleting of biomass.

WP7 ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACT ASSESSMENT

- Analysis of the sustainability (economic, environmental and social) of products and processes that rely on hemp as a raw material eg for construction, textiles, biofuels. This WP will include establishing hemp and its products for carbon credits.

WP8 SUPPLY CHAIN DEVELOPMENT PROGRAMME

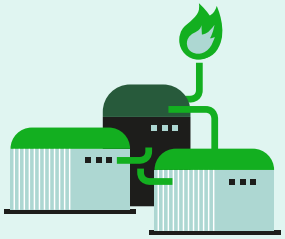
- This will focus on building supply, value and innovation chains for hemp through connecting end users with the primary producers and research providers.

Breakdown of actor roles

Stakeholder	Role
Phase 2 project participants	
University of York	Project Lead, Plant Breeding, Field Trial Studies
The Biorenewables Development Centre Ltd	Hemp processing development / Stakeholder engagement / Project Management
Lucid Insight Ltd	Stakeholder Engagement
Kepier & Company Limited	Commercialisation
K J Voase & Son	Hemp Growing Trials
Seff Fibre Limited	Fibre Production
UK Hempcrete Ltd	Construction Materials Production
Azotic Technologies Ltd	Yield Development
Elsoms Seeds Limited	Seed Production
Stockbridge Technology Centre Limited	Growth Trials
University of Nottingham	Life Cycle Analysis
Tatham Limited	Processing Equipment Design
Simpson (York) Limited	Construction Industry
NNFCC Ltd	Biomass Feedstock Trends and Bio-based Product Development Advice
Game and Wildlife Conservation Trading	Biodiversity surveying
Phase 2 Industrial Advisory Group	
DRAX Group	Bioenergy
NFU	UK Farmers
IndiNature	Hemp-based insulation
Rowett Institute	Nutrition and Human Health
Nestle	Food and Drink
Industrial participants from Hemp-30 Phase 2 project	Textiles / Construction / Seed production / New Variety Development / Bioenergy

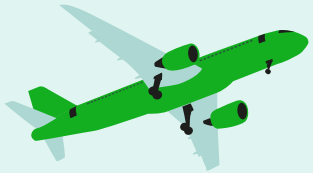
Stakeholders beyond phase 2	
Defra	Farming support policy, ELMS support for hemp
Home Office	Regulation & licensing of hemp cultivation and processing
BEIS	Use of hemp to reduce GHG emissions & grow the economy
UKRI	Funding innovation in use of hemp
	Promotion of UK hemp industries to export markets
Farmers	Cultivation and on-farm processing of hemp; use to decarbonise agriculture
Investors	Funding scale up of hemp industries and use in VCMs
RD&D community	Development and demonstration of hemp technology
Construction industry	Use of hemp to decarbonise & construct healthy buildings
Bioenergy industries	Use of hemp to make sustainable energy
Aviation	Using hemp biofuels to deliver sustainable aviation fuels
Personal care industries	Use of hemp products in personal and wellbeing products
Food industry	Use of hemp oils and protein in healthy low carbon food
Animal feed	Integration of hemp into pet food, aquaculture & farm animal diets
Textile industry	Integration of hemp into woven and non-wovens to replace plastics and cotton

Industrial hemp by 2030: industry vision



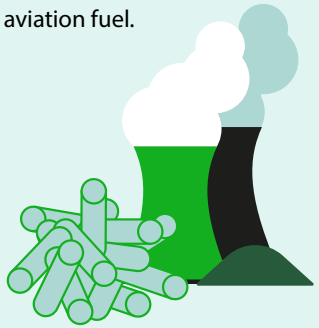
Biogas

Hemp biochar as a co-feedstock for anaerobic digestion can help farms achieve net zero and earn extra income.



Biofuels

Opportunities to establish 2G ethanol production in the UK for use in sustainable aviation fuel.

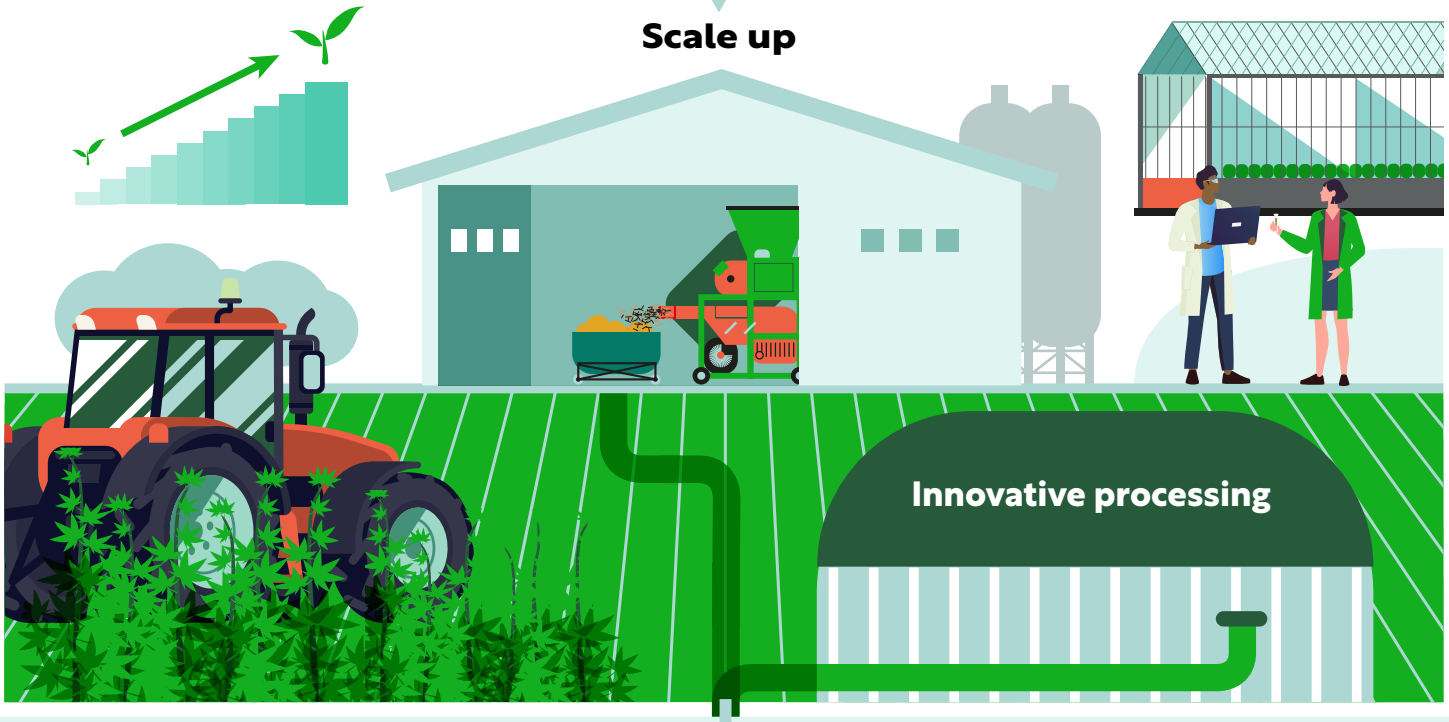


Bioenergy

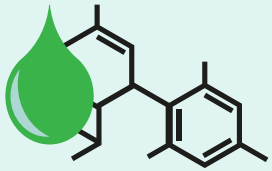
Pelleted hemp biomass will drive increased acreage of hemp cultivation whilst displacing 200 kt CO_2 from 2027.

Growth trials ⟷ **Plant breeding**

Scale up



Increase products on the market

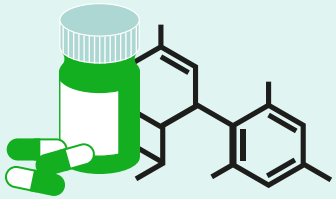


Oils and Proteins

Novel food products using hemp proteins and oils are displacing a range of high carbon food products.

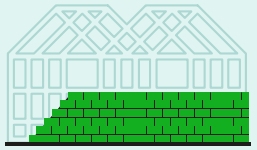
Textiles

New technology to cottonise hemp fibre will open markets in woven textiles, avoiding the social and environmental drawbacks of cotton.



CBD and Medicines

Oil from imported hempseed is already widely used in personal care products and pharmaceuticals, the UK market is estimated to be worth £1bn by 2025.



Construction

Hemp building products are predicted to have a value of >£200m and displace 1.3m tonnes of CO_2.

Automotive

The weight and elasticity of hemp fibre together with a strength comparable to carbon is driving the use of hemp in the body work of cars.

Annex 1:

Priority 1 – New variety roadmap

Date seed from HEMP-30 breeding programme available to farmers	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Seed oil profile			●		○		●		◆	
Varieties with no THC and/or high CBD available										■
Range of disease resistant seed and fibre varieties available										■
Rettability										■
Seed scattering										■

● HOH in Finola background ○ HGLA in Finola Background ● HOH in new background suitable for evolving UK markets ◆ Other novel oilseed profiles

Priority 1 – New variety roadmap

Trait	Present day	2024	2028	2031
Germplasm	• Finola widely cultivated seed variety, suitable for UK; short life cycle and height • UK bred high oleic variety approved for UK National Listing in 2021, and gaining traction internationally for its utility in the food industry • No UK commercial hemp seed production • Limited understanding of performance of hemp varieties under UK conditions • Hemp populations with increased genetic variation being developed for trait improvement using established fast-track breeding pipeline	• UK hemp certified seed production established • Better understanding of the performance of a range of varieties under UK growing conditions • New backgrounds suitable for breeding for UK conditions identified • Germplasm with variation in genes controlling key traits available	• Additional UK-bred varieties which perform better around a range of key traits undergoing registration trials • New traits being introgressed into a range of hemp backgrounds suitable for cultivation in the UK	• UK-bred varieties which perform better on a range of key traits available for farmers to grow in the UK
Oil profile	• Hemp oil profile attractive but unstable and unsuitable for use in many food industry applications • High Oleic Hemp (HOH) registered and ready for bulking • High GLA variety ready to enter registration trials	• HOH seed bulked and ready to be cultivated by UK farmers for use in the UK food industry • High GLA variety registered and ready for bulking • Germplasm with novel oil profiles available for development as the market demands • Introgression of HOH trait into other desirable hemp varietal backgrounds in progress	• High GLA certified seed bulked and ready to be cultivated by UK farmers for use in personal care & food industries • Seed available for farmers for HOH trait in different hemp backgrounds	• Seed for hemp varieties with a range of seed oils suitable for a different dietary and processing requirements
Disease resistance	• Evidence for disease problems (Sclerotina and downy mildew) emerging in Canada • Genes for broad spectrum disease resistance known	• Lines altered in disease susceptibility genes characterised • Laboratory assays for disease resistance in progress • Row trials starting	• Disease resistant varieties undergoing registration field trials	• Seed for disease resistant varieties available
Secondary metabolite profile	• Genes controlling CBD and THC well understood. • Entourage effects poorly understood but focus of research • Track record at York in manipulating biochemicals in range of species • Levels of THC and CBD not ideal for use of industrial hemp in a range of markets	• Zero THC and high CBD lines identified • Research starts to uncover effects of hemp metabolites beyond CBD and THC	• Zero-THC &/or high CBD varieties undergoing registration field trials	• THC-free seed and fibre varieties available
Rettability	• Some genes affecting rettability characterised	• Lines altered in genes controlling rettability characterised and assessment initiated	• Easy retting varieties undergoing registration field trials	• Easy retting varieties on the market
Seed scattering	• Inconsistent maturation leads to loss of seed in soil and through bird attack • Some genes known to control seed loss known in other species	• Lines altered in candidate genes controlling seed scatter identified • Assessment of lines initiated	• Reduced seed scatter trait introduced into elite varieties	• Reduced seed scatter trait available to the market in elite variety background

Timeline for introgression of novel trait into a new variety

	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
Establishment of M2 hemp population with variation in key target genes										
Screening and crossing for lesions in target genes										
Four generations of crossing between variant and (new) parental background										
Row trials of promising hemp lines										
Small scale bulking of seed for use in field trials										
Field trials benchmarked against parental varieties										
Distinctiveness, Uniformity & Stability (DUS) field trials for UK variety registration										
Value Cultivation and Use (VCU) field trials for UK National Listing										
Bulking of seed for use by farmers										
Seed enters market										

Annex 2:

Priority 2 - Roadmap hemp cultivation

Parameter	Present day	2024	2028	2031
Hemp cultivation	• 800 ha under cultivation • Niche crop grown at a small scale by innovative enthusiasts • A few mainstream farmers testing hemp on a limited acreage • Seed is difficult to get hold of, almost all imported and expensive	• 5,000 ha under cultivation • Some farmers are adopting hemp as a break crop • More mainstream farmers testing hemp on a larger acreage • New varieties with different seed oil expand markets for hemp seed products • Growers can access UK sources of certified seed & best practice for hemp cultivation	• 30,000 ha under cultivation • New dual purpose varieties and better fibre varieties enter the market • Hemp is widely grown by forward looking farmers as a break crop • Up to half UK growers are buying UK sources of certified seed	• 80,000 ha under cultivation • Hemp is seen widely as a viable alternative to OSR as a break crop • Cultivation is still mainly to-contract but spot markets for hemp are emerging • Majority of UK growers are buying UK sources of certified seed
Crop performance	• Nutritional requirements for UK conditions not characterised • Performance as break crop poorly understood • Varietal performance under UK conditions poorly understood • No UK adapted varieties available	• Multi-site field trials provide evidence base for performance and nutritional requirements of several hemp varieties under UK conditions • Trials demonstrate effectiveness of hemp as a break crop in rotations of cereals	• Experience with hemp cultivation increases yields of both seed and biomass • Risk of development of disease and pest problems are mitigated through diversified rotations, breeding and monitoring • New agronomic methods eg seed coating, decrease inputs and increase yields	• Increased yields and optimised inputs enhance returns to farmers whilst maintaining soil carbon and biodiversity • New varieties with UK adapted traits eg maturity, yield, establishment, pest/disease resistance start to become available
Carbon performance	• Carbon sequestration under UK conditions not characterised • Potential in soil carbon enhancement not well understood	• Trials have demonstrated performance of hemp in sequestering CO_2 both above and below ground • ELMS and Voluntary Carbon Markets (VCM) view hemp as an element in decarbonisation strategies • Farmers testing technology for hemp in anaerobic digestion, bioenergy and biochar	• Widespread use of hemp cultivation and hemp products in VCMs increases markets for hemp and reduces their cost • ELMS supports hemp as a means to mitigate agricultural emissions and improve soil health • All farmers can access biomass processing facilities for shiv and/or fibre markets, leading to long term sequestration in products	• Hemp is a key contributor to decarbonisation of UK agriculture

Priority 2 - Roadmap hemp cultivation (cont...)

Parameter	Present day	2024	2028	2031
Harvesting	• Harvesting machinery available but requires optimisation and skills development • Retting inefficient and unreliable • Seed processing facilities (drying and pressing) not easily available	• Several standardised robust fibre and stalk harvesters become available • Farmers collaborate/contract-out to source specialist equipment locally • Novel efficient retting options are developed, which are tailored for specific end uses • Easy-retting varieties are trialled	• Widespread availability of robust harvesting machinery • Easy-retting varieties become available • Novel retting options are in use • Specialist hemp harvesting contractors are established	• Novel harvesting options are emerging eg that allow harvest of seed and fibre, reducing costs and losses • New varieties with limited seed scatter become available reducing losses and increasing yields
Communication	• Information on variety performance is not widely available • Connections between hemp growers and end users ad hoc and insecure	• Results from field trials widely disseminated and partnerships established with key trade, networking and levy boards • Growing network of hemp users contract directly with growers • Growers can easily find out what specifications are required by buyers for different applications	• Up-to-date information on varieties and best agronomic practice is available to growers • Vibrant networks connect growers to their end markets • UK seed is widely available • Growing international connections enhance markets for hemp growers	• UK is seen internationally as a key source of agronomic innovation and best practice for hemp cultivation • The market supports an effective network supporting hemp growers
Regulation	• Regulatory regime is slow, expensive and not aligned with growers needs	• Licensing administration has transferred to Defra and streamlining prevents delays • Review of THC limit is undertaken and decision made on whether to change the limit	• Home Office and DEFRA maintain regular contact with growers and processors to ensure effective oversight that is responsive to industry needs	

Annex 3:

Priority 3 – Roadmap for hemp industries

Sector	Present day	2024	2028	2031
Food, beverage, pet and animal feed	• Raw materials mainly imported • Excellent science base for optimisation of seed oil • Connections between primary producers and end users are poor • Seed oil profile attractive but unsuitable for some food industry applications	• Facilities for processing hemp seed available • Speciality markets for hemp oil have expanded • Mainstream food manufacturing initiates use of the stable hemp oils produced from new varieties bred and grown in the UK • Protein from hemp meal starts to be incorporated into vegan meat and be used in mainstream food & beverage • Residual meal used as desirable ingredient in pet, animal & fish feed	• The stable hemp oils produced from new UK varieties are in widespread use in food manufacturing • UK hemp oil is in demand internationally because of its quality, provenance and sustainability • Protein from hemp meal is widely used in vegan meat and as an ingredient by mainstream food & beverage manufacturers • Residual meal displaces soy & animal protein as high quality ingredient in pet, animal & fish feed	• High value hemp oils with novel fatty acid profiles designed for different dietary requirements are entering the market • Export markets for UK hemp oil are well established and growing • Novel food products using hemp proteins and oils are displacing a range of high carbon foodstuffs • Hemp seed residues command high prices in animal feed sectors
Construction	• Hemp construction products are proven and demand market is huge but investment needed for scale up • UK is a global leader in hemp construction but risks losing this first mover advantage • Awareness is low amongst mainstream companies and consumers • UK manufacturing is small scale and products are expensive because carbon and other benefits are not accounted for • Artificially inflated prices of imported hemp construction products & post-brexit supply chain problems	• One large construction company has taken on hemp products as a means to reduce the emissions from construction • Widespread workforce training in hemp-based construction established • Architects further engaged in specifying hemp products in their designs • Investors engaged to develop scale processing of hemp for UK construction, lowering costs	• Large scale processing of hemp for construction in place; potential integration with production of aviation fuel and speciality chemicals • Hemp insulation and hemcrete are widely used across the construction industry and benefit from carbon credits	• Range of novel, carbon negative building products that use hemp are on the market • UK has built on its leading position to become the go-to place for expertise and innovation in hemp-based construction • Innovation, economies of scale, integration with production of materials, chemicals and fuels together with carbon credits make hemp-based construction low cost and high performance

Priority 3 – Roadmap for hemp industries (cont...)

Sector	Present day	2024	2028	2031
Textiles	• Most hemp textile grade fibre is imported and expensive • Low awareness of advantages of hemp vs cotton & synthetics • Innovation is needed for adoption of hemp into mainstream products	• Technology for cottonisation of fibre from UK-grown hemp commercialised • Hemp starts to replace plastics in non-woven products eg wipes • UK woven and non-woven companies and designers engaged.	• Technology for production of high quality, sustainable textile fibre established in the UK and being exported • Sustainable textile brands founded on UK hemp are establishing	• Improved varieties and technology development make fibre cheaper and improve quality • UK hemp brands known internationally
Composites for automotive and wind energy	• Connections with UK automotive manufacturing absent • Potential in wind turbines appreciated but innovation needed to overcome technical barriers	• Fibre from UK-grown hemp being incorporated into UK-manufactured automotive panels • Collaboration on development of hemp fibre in high performance composites for a range of applications	• Fibre from UK hemp widely used in UK automotive manufacturing • Commercialisation of hemp fibre in high performance composites for automotive and other sectors	• Light weight, strong hemp-based biorenewable composites contribute to efficient, low impact aviation, automotive and wind energy industries
Speciality chemicals	• No UK production of CBD because of regulatory hurdles; international competitors ahead in technology and commercialisation • CBD markets overheated and volatile • Excellent science base in plant biochemicals able to optimise balance of metabolites • UK is second largest market for CBD in the world	• More appropriate regulation of hemp allows processing of leaves and flowers and establishment of industries using hemp 2°ry metabolites • CBD products being manufactured from UK-grown hemp • Characterisation of the effects of new hemp 2°ry metabolites	• Hemp varieties with zero THC simplify regulatory status of hemp speciality chemicals • New products on the market from hemp metabolites based on CBD and other molecules • Better understanding of the effects of multi-component pharmaceuticals increases demand for whole hemp products and products with defined profiles	• Thriving high value UK industry based on hemp secondary metabolites exporting products worldwide
Biofuel	• Innovation needed to allow use of biomass in on-farm AD • Supply chains and investment absent in the UK for hemp-based aviation fuels	• Hemp biomass in use as a feedstock for on farm AD • Collaboration to demonstrate hemp as an aviation fuel feedstock	• Commercial production of hemp aviation fuel started, potentially integrated with manufacture of construction materials and speciality chemicals	• Commercial production of hemp aviation fuel established, supply chains integrated with manufacture of construction materials, bioenergy and speciality chemicals
Bioenergy	• Small scale briquette manufacture from hemp dust for domestic heating fuel	• On farm or regional facilities for large scale manufacturing of pellets for heat and power generation that are aligned with bioenergy sustainability criteria	• Hemp for bioenergy production has stable markets with ongoing monitoring of sustainability, acting as an “insurance policy” for use of hemp biomass	• Stable UK bioenergy markets supplied by sustainably produced hemp raw materials
Carbon credits	• Evidence base inadequate for use of hemp products in carbon credit markets	• Carbon credits on construction products and biochar from UK-grown hemp available on well regulated and respected platforms	• Further expansion of the carbon credit market for construction and biochar • Reputation of UK hemp based carbon credits drives demand by companies aiming for net zero by 2030	• Steady markets for carbon credits from construction and biochar products • Novel composites and building materials benefitting from carbon credits.

Priority 3 – Roadmap for hemp industries (cont...)

Sector	Present day	2024	2028	2031
Cross cutting support from the Hemp 30 innovation programme that catalyses product development and growth				
Hemp on-farm processing innovation programme	• Hemp30 WP5 supports RD&D to deliver new process for on-farm decortication & fibre cottonisation, use in AD, biochar, on farm pelleting of biomass	• Innovation programme enables capture of value before the farm gate delivering new sources of income and carbon savings • Innovations are used further up the hemp supply chain to deliver sustainable products	• Hemp processing and use on farm is an established part of the agricultural economy delivering value and carbon savings • Ongoing innovation, knowledge sharing	• Technology and knowledge for processing hemp on farm is being exported world-wide • Farms are well integrated into supply chains and capture value
Supply, value & and innovation chain development	• Hemp30 WP7 communication programme connects end users with primary producers, research providers & policy makers to initiate and strengthen hemp supply chains	• Connections established between primary producers and the end users in different sectors enabling integration of supply chains and investment in large scale facilities • New connections established between researchers and policy makers with the hemp supply chains accelerating innovation • Industrial hemp trade association established and servicing a wide range of industries and primary producers	• Hemp supply and value chains are established and responsive to market demand in the UK and internationally • rapid innovation arising from excellent knowledge sharing • Regulation that is responsive to the needs of different sectors	• Vibrant hemp ecosystem where businesses are aware of the complementary or competing interests in adjacent sectors, researchers are accessible and engaged in hemp product development, policy makers and regulators are aware and support sustainable development of the hemp-based industries
Environmental, economic and social impact assessment	• Hemp30 WP8 provides evidence base for use of hemp for carbon credits and sustainability in food, fuel and material markets	• Markets in carbon credits, food, construction, energy, materials and fuel use the sound evidence base to guide their product development and marketing • Policy makers and regulators use the social environmental and economic analysis to make better policy and regulation • Uses of hemp for applications that are not sustainable are avoided	• UK hemp products have an excellent reputation for reliable sustainability claims, which increases demand for UK products in export markets • Criteria for sustainability reporting in hemp products are agreed • UK perceived internationally as the go-to place for understanding of sustainability in hemp supply chains	• Demand for UK hemp products drives up value from hemp to farmers, manufacturers and the UK more widely. • Innovations are rapidly assessed according agreed criteria for the sustainability impact accelerating adoption of those that have a positive impact

Annex 4:

Commentary on projections

1. Area under cultivation of hemp

- 250ha of seed crop being grown, accounting for >30% of the estimated 800ha hemp cultivated currently. Interviews suggest plans 1,000 ha for seed in 2022 with licenses for 3* this area
- 2024 Increase *4 as HEMP30 field trial results come out, availability of seed increases and the High Oleic Acid variety becomes commercial available
- 2025, doubles again to 10 kha as farmers who have dipped their toe in 2024 increase their planting, knowledge on the effects on the soil emerges and markets for hemp increase and diversify
- 2026 - 2030 15kha added each year driven by increasing markets for hemp and carbon markets.

2. Yield – biomass

- 2022 stakeholders estimated average retted straw yield of 5.5t/ha. This is conservative because a substantial proportion of the biomass is lost during retting.
- 2023 -24 added a small yield increase of 0.5t/ha based on increasing experience of farmers combined with better knowledge and evidence from field trials
- 2025–30 increases of biomass yield of 1t every 3 years, getting 8t/ha in 2030. This might seem ambitious, but there are several reports of yield of >15t/ha now. Set against this, however, I'm estimating that 50% of the crop is dedicated to oilseed and biomass yield from the seed crop will be lower and of lower quality.

3. Yield – seed

- 2022 - 23: estimate oilseed yield average of 1.5t/ha. This year growers in the North East of the UK have achieved 2t/ha so the estimate is conservative
- 2024 - 30 assumed yield increases of 0.2/ha every two years achieving 2.4 t in 2030 through a combination of improved agricultural practice and new varieties entering the market

4. Area cultivated fibre vs oilseed %

- 2021 30% of 800ha is cultivated for oilseed
- 2022 - Lukie's interviews suggest 1,000 ha hemp planned for 2022 will be harvested for oil.
- 2023 This increases to 50% as markets for hemp food and feed products increase sharply - for instance, if good hemp sourced their seed from the UK, that would create an instantaneous market. And new HOA oilseed variety is available for farmers
- 2025 onwards, 50% of the are under hemp is cultivated for oil with the residual biomass being used for lower value applications such as biochar, biogas, bioenergy and biofuel
- 50% of the area cultivated is fibre crop used in construction textiles and composites

5. Yield of oil, protein, fibre and shiv

- Seed - assume 30% of the dry weight is oil, 30% protein, 30% carbohydrate, 10% insoluble fibre-
- Fibre represents 25% of the dry weight of biomass (estimates in the literature vary and this is a conservative estimate)
- Shiv represents 60% of the biomass
- Dust from processing is 10%

6. Hemp used in food, feed and personal care

- Assumed that 100% of the oilseed is used in food and feed markets. Note that seed products may also be used in non-food markets - eg as drying oil or in personal care.

7. Hemp used in bioenergy

- 2022–23 assumed that just the dust is used in bioenergy ie 15% of the biomass available
- 2024–27 50% of available biomass is used for bioenergy because this is a readily available market which requires little technical innovation to satisfy
- 2028 - 31 this reduces to 25% of the available biomass as higher value applications become available. Note that the total amount of biomass used in bioenergy continues to rise gently, it is only the that % reduces

8. Hemp used to manufacture bioethanol to be used in aviation fuel

- This does not start until 2027 when a small amount is used for demonstration purposes. This rises to 25–30% from 2029 as a small biorefinery becomes operational. This is based on the beta renewables plant in crescentino, Northern Italy, which produced 40,000 t ethanol from 200,000 t biomass (mainly grass). You would expect a hemp based biorefinery to produce more ethanol per ton because it is richer in cellulose and hemi-cellulose and lower in lignin. Note that the plant will produce a range of byproducts - biogas, bioenergy and CO_2.

9. Hemp in used in construction

- Insulation and hempcrete are being manufactured at a small scale already. Based on industry estimates, 40% of the hemp that is grown is going into construction and will continue to do so until 2023. From 2024 the absolute mass of hemp used in construction will grow steadily but it will drop as a proportion of the biomass available. This is because bioenergy, which will have shorter lead times for deployment, will take up a large proportion of the biomass that is available from 2024. Construction will pick up to remain steady at around 30% of biomass from 2025 onwards
- It was estimated that 20% of the hemp that is used in construction is insulation batts/boards and 80% is hempcrete - this is because around 25% of the biomass is bast fibre and 60% shiv. The fibre will have other higher value uses, at least in the long term.
- Commercial figures, were used to calculate the mass of hemp needed to deliver the current insulation requirements.

10. Hemp used on farm

- Estimate that about half of the hemp biomass that is produced in 2021 is used on farm, mainly for animal bedding.
- This % drops until 2025 (but the absolute tonnage grows gently), where it stabilises at 20% of the crop.
- Three main uses for hemp on farm are envisaged from 2025 - anaerobic digestion (AD) (35%) animal bedding (30%) and conversion to biochar for carbon markets and soil improvement(35%).

11. Hemp used in textiles

- Estimate that it will take five years to fully commercialise cottonised yarn production from hemp so production will start in 2027. Yield of yarn is likely to be low but the residues can be used for other purposes. Therefore the % of biomass used in yarn is quite low growing from 0.5% in 2027 to 2.5% in 2031.

12. Hemp used in high performance composites

- Use of hemp in high performance composites requires innovation which will take time. A similar growth trajectory and amount used as for textiles has been projected.

13. Hemp used in wellbeing products

- Based on FSA and industry data on quantities and numbers of people using CBD, UK consumption has been estimated at approx 150t pa
- Using CBD as a typical wellbeing product
  - assume regulation allows processing of UK grown hemp in 2024
  - it takes three years to ramp up production to this level

14. Calculations of value of products in different markets

- The price of products from hemp were estimated from interviews and prices advertised on the internet eg spot market prices and value calculated from the mass of hemp used in each market.
- Where a product is made entirely from hemp - eg seed oil, the whole value of the product has been used. Where the product contains only a percentage of hemp, the value was multiplied by the % of hemp in the product on a mass basis eg hempcrete, is approx 30% hemp by weight so the value of hempcrete was multiplied by 0.3
- Where products sequester CO_2, eg building markets, an extra £100 was added for each ton of hemp used from 2025 onwards.

15. Displacement and sequestration of CO_2

- The basis of these calculations is very simple and needs the attention of a proper carbon accountant in Phase 2
- For displacement,
  - the carbon footprint of the hemp product is subtracted from the carbon footprint of the existing product for a given functional unit (eg an amount of energy or a square metre of insulation). Where no figures are available for hemp, a similar material is used as a proxy eg flax for hemp insulation. The mass of hemp used for that functional unit is worked out and the CO_2 saved through use of the hemp product rather than the competing product calculated.
- For sequestration
  - 1 ton Biomass typically contains 0.4 t carbon and 1 ton carbon represents 4 ton CO_2 so each ton of biomass sequesters approximately 1.6 ton CO_2
  - The mass of hemp that is used in the building product is multiplied by 1.6 to give the tons of CO_2 that are sequestered
  - Note that this does not take account of GHGs that are emitted during cultivation and processing of the hemp

Abbreviations

AD	anaerobic digestion
CBD	cannabidiol
ELMS	Environmental Land Management Scheme
GHG	Greenhous Gas Emission
GLA	gamma linlolenic acid
HOH	High Oleic Acid Hemp
THC	Tetrahydrocannabinol
VCM	Voluntary carbon market

Annex 2 Hemp Breeding Strategies

Figure 1 Experimental workflow for development of new hemp varieties

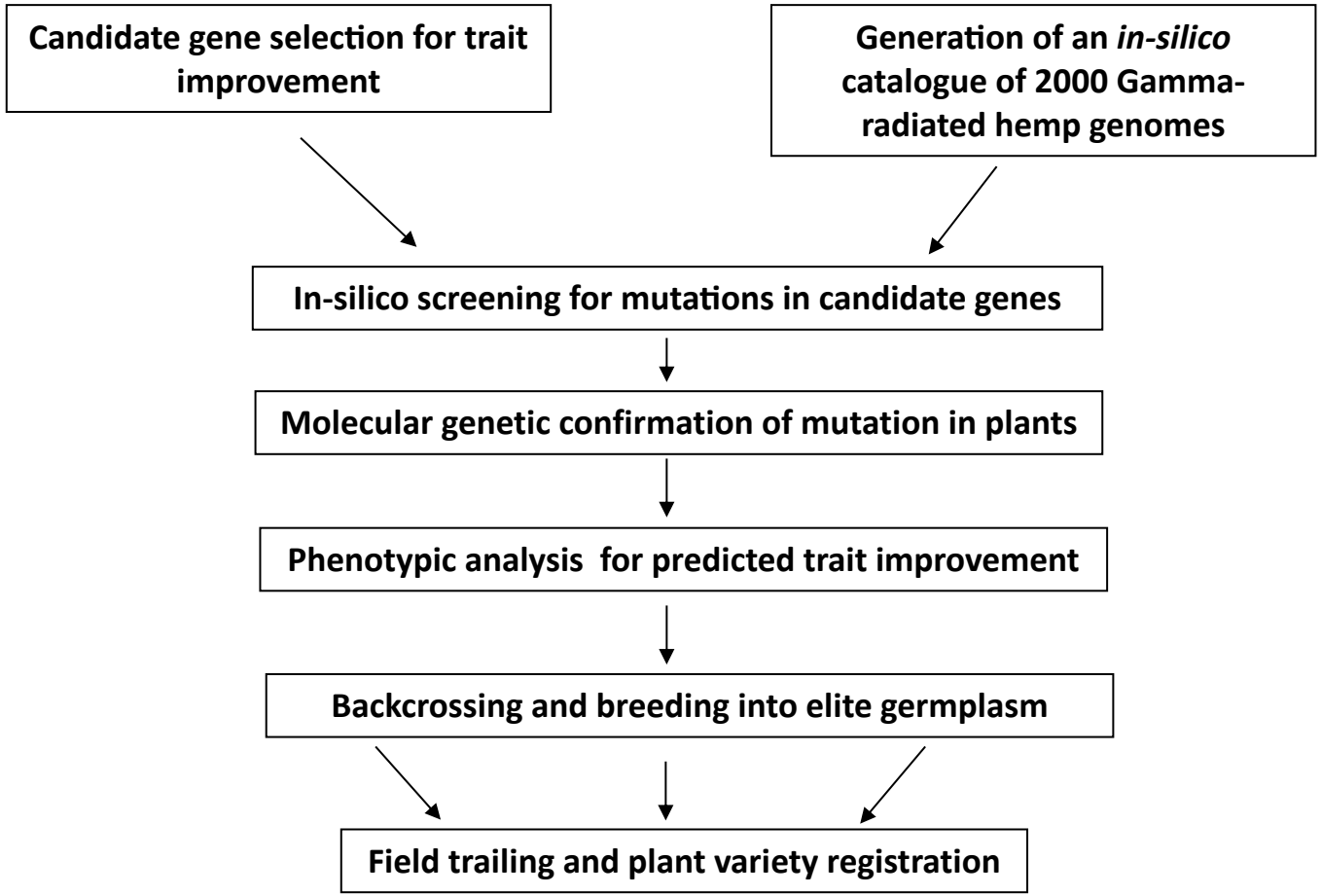
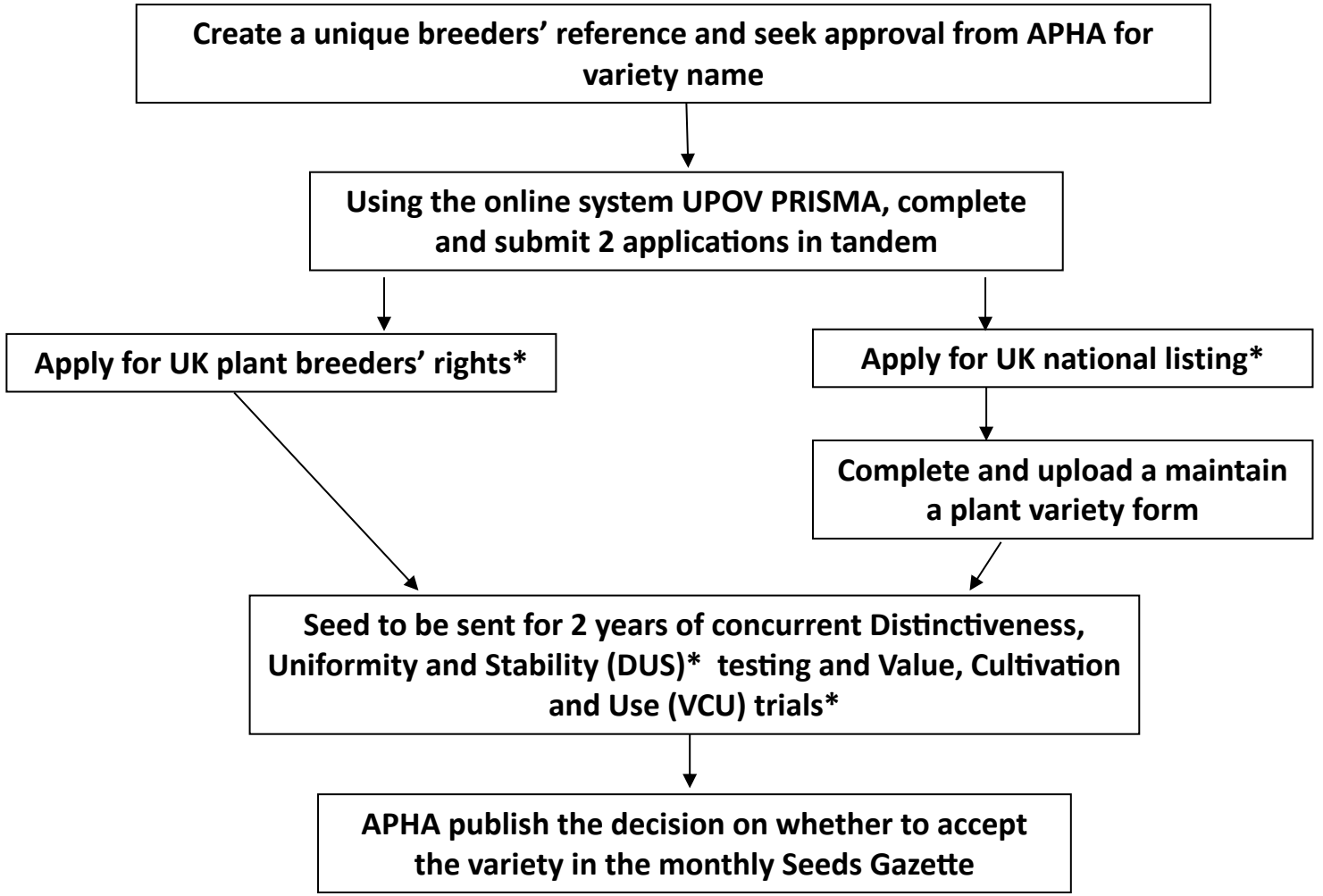


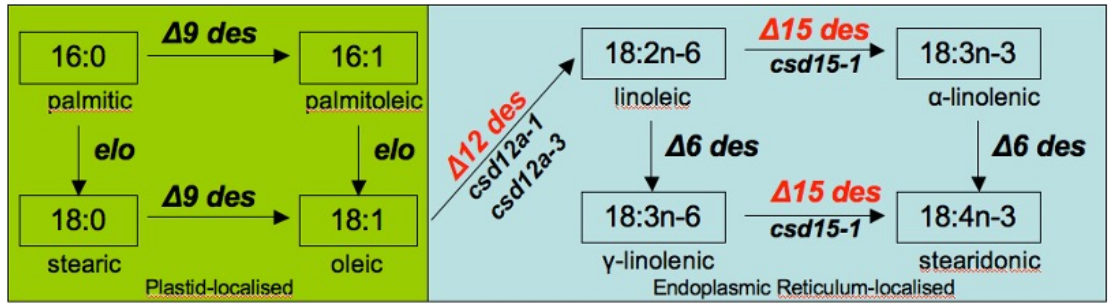
Figure 2 Plan for UK plant variety registration and national listing of the High GLA hemp variety



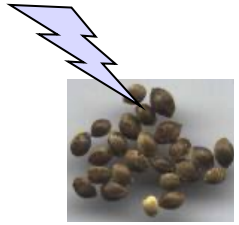
**Fees payable at this point*

Figure 3 Successful mutation breeding of industrial hemp: seed oil fatty acid composition

1. Biosynthesis of the different types of fatty acids present in the seed of commercial variety Finola involves desaturase (**des**) enzymes.



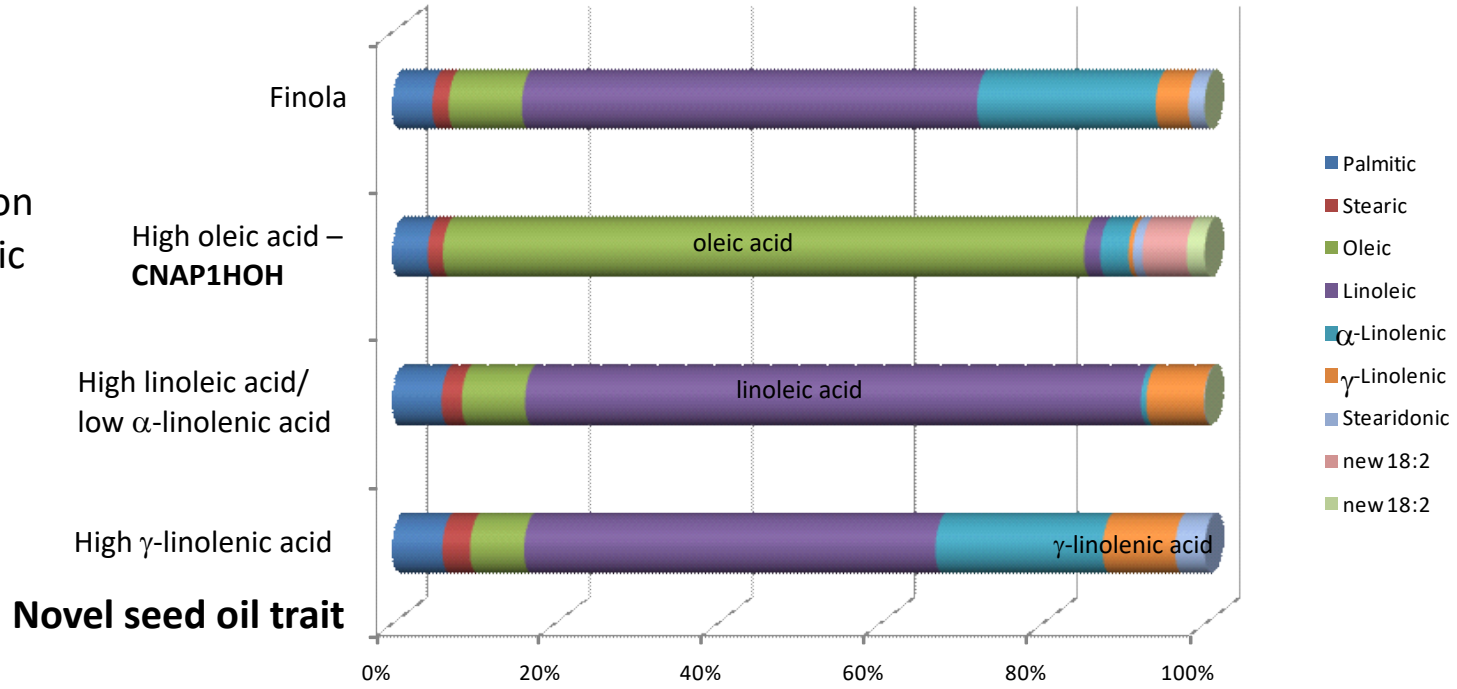
2. Mutation breeding uses chemicals or radiation to randomly alter the DNA of thousands of plants



3. Genomics-led Predictive Breeding methods can identify mutations in candidate genes

4. Mutation of a single ***Δ12 des*** gene results in accumulation of oleic acid to 80% total fatty acids in seed oil - the genetic basis of the new UK registered variety CNAP1HOH variety

5. Other novel seed oil traits have been developed for industry by targeting ***Δ15 des*** and ***Δ12 des*** genes



Annex 3 Hemp-30 Phase 2 3-Year Plan

		PROJECT ACTIVITIES	PROJECT PARTICIPANTS	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
	WP1	**WP1 PROJECT MANAGEMENT**																																				
		Monthly Management Team Meetings	UoY/BDC																																			
		Quarterly Project Team Meetings	ALL																																			
		Industrial Advisory Group Meetings - twice each year	NNFCC																																			
		Quarterly Project Reports to BEIS SICE Team	UoY/BDC																																			
		BEIS Stage Gate Reviews - twice each year	UoY/BDC																																			
Priority 1 - Hemp variety breeding and seed multiplication	WP2	**WP2 INDUSTRIAL HEMP BREEDING PROGRAMME**																																				
		Generation of Gamma-radiated M2 (GRM) Industrial Hemp Population	UoY																																			
		Candidate gene selection	UoY																																			
		Generate *in-silico* low-coverage genome catalogue of 2,000 M2 individuals	UoY																																			
		Genomics-led Predictive Mutation Breeding: target 1: cannabinoid content	UoY																																			
		Phenotyping, backcrossing and breeding for target 1: cannabinoid content	UoY																																			
		Genomics-led Predictive Mutation Breeding: target 2: Biomass yield and retting	UoY																																			
		Phenotyping, backcrossing and breeding for target 2: Biomass yield and retting	UoY																																			
		Variety Registration and National Listing of High (8%) GLA hemp variety	UoY																																			
	WP3	**WP3 SEED MULTIPLICATION**																																				
		3x Polytunnel based certified seed multiplication of CNAP1HOH at ESL	ESL																																			
		Germination, storage and molecular marker based quality assurance assays	ESL																																			
Priority 2 - Hemp crop characterisation and hemp yield maximisition	WP4	**WP4 HEMP CROP CHARACTERISATION PROGRAMME**																																				
		Field Trials over 3 year ramping up from 2 to 5 to 10 locations	ESL																																			
		Farmer/Grower Pre-Commercial Demonstrator trials	ESL/STC/KJV/UoY																																			
		Crop Rotation Experimental Field Trial	UoY/STC																																			
		Agri-environmental analysis - soil carbon and microbial composition	UoY																																			
		ESL relevant Biodiversity analysis	GWCT																																			
		Soil Impact Analysis - contextual data gathering	UoY/LIL																																			
		Soil Impact Analysis - surveys and data analysis	UoY/LIL																																			
		Biodiversity surveys and analysis	GWCT/KJV																																			
		Final survey analysis	GWCT/KJV																																			
	WP5	**WP5 HEMP YIELD MAXIMISATION PROGRAMME**																																				
		Inoculate hemp cultivators with G.diazotophicus and assess colonisation, localisation and distribution	ATL/BDC																																			
		Inoculate hemp cultivars and assess effect of treatments in growth cabinets	ATL/BDC																																			
		Replicate small-plot testing - evaluater yield and quality of biomass and seeds	ATL/BDC																																			
		Grower trials at recommended application rates	ATL/BDC																																			
		Field Study Preparation	ESL/STC/UoY																																			
		Field Studies and Analysis	ESL/STC/UoY																																			
		Harvesting Equipment - review of current market	BDC/LIL/KJV																																			
		Harvesting Equipment - showcasing	BDC/LIL/KJV																																			
		Harvesting Equipment - on farm evaluation	BDC/LIL/KJV																																			
Priority 3 - Develop supply chains and processes for hemp products, EES assessment and supply chain process development	WP6	**WP6 HEMP PROCESSING INNOVATION PROGRAMME**																																				
		BDC warehouse space set up for hemp processing activities	BDC/SYL/UoY																																			
		Textile processing evaluation - identify and locate equipment to evaluate	BDC/SFL/TEL/KJV																																			
		Textile processing evaluation - hemp processing evaluation and showcasing to stakeholders	BDC/SFL/TEL/KJV																																			
		Construction processing evaluation - identify materials and processing equipment	BDC/HCL/SYL/KJV																																			
		Construction processing evaluation - materials preparation and showcasing to stakeholders	BDC/HCL/SYL/KJV																																			
		Bioenergy processing evaluation - set up of additional AD and hemp preprocessing facilities	BDC/UoN/KJV																																			
		Bioenergy processing evaluation - carry out hemp based bioenergy trials for AD, pellets, fermentation and biochar	BDC/UoN/KJV																																			
		Economic, Environmental and Social assessment of hemp processing innovations	UoN/LIL/KCL/KJV																																			
	WP7	**WP7 ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACT ASSESSMENT**																																				
		Report on preliminary hemp cultivation and end products LCA	UoN/LIL/KCL																																			
		Update report with available project data on hemp cultivation and end products LCA	UoN/LIL/KCL																																			
		Update report with available project data on hemp cultivation and end products LCA	UoN/LIL/KCL																																			
	WP8	**WP8 SUPPLY CHAIN DEVELOPMENT PROGRAMME**																																				
		Create communication strategy, project website and initial dissemination materials	BDC																																			
		Programme of Hemp Special Interest Group events held every 6 months	BDC																																			
		Programme of Hemp Special Interest Group events held every 6 months	ALL PARTNERS																																			

Project Participant and Code

UoY	**University of York - Project lead**
BDC	Bioronewables Developmenct Centre - Project main contact
ATL	Azotic Technologies Limited
ESL	Elsoms Seeds Ltd
HCL	Hempcrete Ltd
KCL	Keiper & Co. Ltd
KJV	K J Voase & Sons
LIL	Lucid Insights Ltd
NNFCC	National Non-Food Crops Centre
SFL	Saff Fibre Ltd
SYL	Simpson York Ltd
STC	Stockbridge Technology Centre
TEL	Tatham Engineering Ltd
UoN	University of Nottingham
GWCT	Game and Wildlife Conservation Trust

BEIS Project Plan Tables

Annex 4 Hemp-30 Phase 2 PROJECT - Milestones and Deliverables

Project Workpackage Table

Workpackage ID	Workpackage Name	Project Partner Lead	Description (inc. Key tasks)	£ Cost exc VAT (*sum of all deliverables for selected workpackage from deliverables table)*	Project ID (Internal Use Only)
1	**Project Management**	UoY/BDC/ALL	**Hemp30 Project Management** The HEMP-30 project will be managed through a series of monthly Management Team meetings involving UoY and BDC senior staff involved directly with the project. Project management will also involve quarterly project team meetings involving representatives from all 15 project participants. The Industrial Advisory Group will meet twice yearly. BEIS Stage Gate Reviews will take place twice each year and quarterly project reports will be submited to BEIS SICE Team.		
2	**Industrial Hemp Breeding Programme**	UoY	**Industrial Hemp Breeding Programme** Generation of Gamma-radiated M2 (GRM) Industrial Hemp Population Candidate gene selection Generate in-silico low coverage genome catalogue of 2,000 M2 individuals Genomics-led Predictive Mutation Breeding: target 1: cannabinoid content Genetics and phenotyping for Target 1 heritability and trait imporvement Genomics-led Predictive Mutation Breeding: target 2: Biomass yield and retting Genetics and phenotyping for target 2: heritability and trait improvement Variety registration and National Listing of High (8%) GLA hemp variety		
3	**Seed Multiplication**	ESL	**Seed Multiplication** 3x Polytunnel based certified seed multiplication of CNAP1HOH at ESL Germination, storage and molecular marker based quality assurance assays		
4	**Hemp Crop Characterisation Programme**	ESL/UoY/STC/GWCT/LIL/NVS	**Hemp Crop Characterisation Programme** Field Trials over 3 year ramping up from 2 to 5 to 10 locations Farmer/Grower Pre-Commercial Demonstrator trials Crop Rotation Experimental Field Trial Agri-environmental analysis - soil carbon and microbial composition ESL relevant Biodiversity analysis Soil Impact Analysis - contextual data gathering Soil Impact Analysis - surveys and data analysis Biodiversity surveys and analysis Final survey analysis		
5	**Hemp Yield Maximisation Programme**	ATL/BDC/ESL/STC/UoY/NVS	**Hemp Yield Maximisation Programme** Inoculate hemp cultivators with G.diazotophicus and assess colonisation, localisation and distribution Inoculate hemp cultivars and access effect of treatments in growth cabinets Replicate small-plot testing - evaluate yield and quality of biomass and seeds Grower trials at recommended application rates Field Study Preparation Field Studies and Analysis Harvesting Equipment - review of current market Harvesting Equipment - showcasing Harvesting Equipment - on farm evaluation		
6	**Hemp Processing Innovation Programme**	BDC/SYL/UoY/SFL/TEL/NVS/UoN/LIL/KCL	BDC warehouse space set up for hemp processing activities Textile processing evaluation - identify and locate equipment to evaluate Textile processing evaluation - hemp processing evaluation and showcasing to stakeholders Construction processing evaluation - identify materials and processing equipment Construction processing evaluation - materials preparation and showcasing to stakeholders Bioenergy processing evaluation - set up of additional AD and hemp preprocessing facilities Bioenergy processing evaluation - carry out hemp based bioenergy trials for AD, pellets, fermentation and biochar Economic, Environmental and Social assessment of hemp processing innovations		
7	**Environmental, Economic and Social Impact Programme**	UoN/LIL/KCL	Report on preliminary hemp cultivation and end products LCA Update report with available project data on hemp cultivation and end products LCA Update report with available project data on hemp cultivation and end products LCA		
8	**Supply Chain Development Programme**	BDC/ALL PARTNERS	Create communication strategy, project website and initial dissemination materials Programme of Hemp Special Interest Group events held every 6 months Programme of Hemp Special Interest Group events held every 6 months		

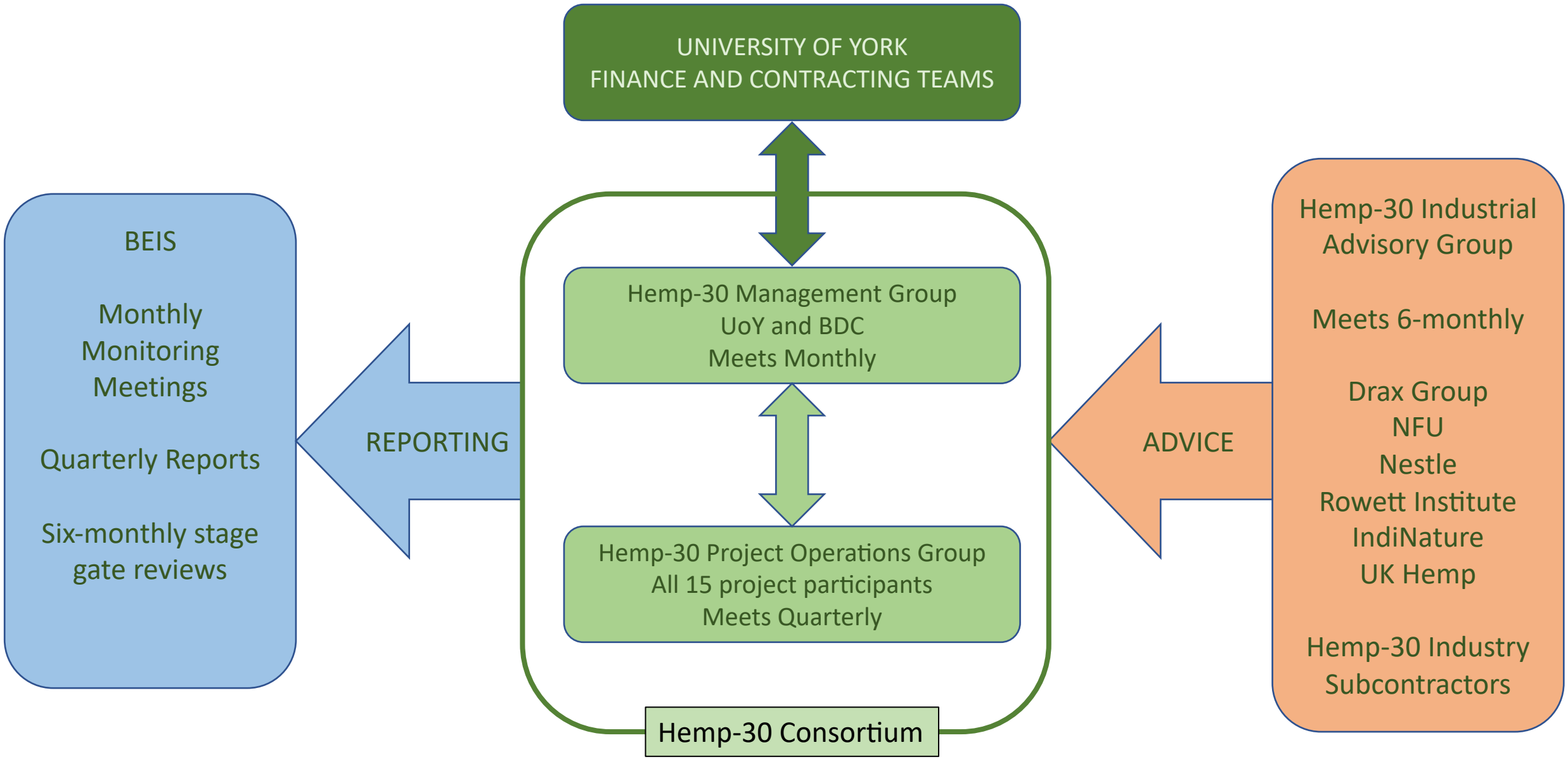
Project Deliverables Table

Workpackage ID	Deliverable ID *(for example workpackage ID followed by a letter: 1A,1B,1C, 2A, 3A, 3B)*	Deliverable Name	Description (inc. outputs)	£ Cost (exc VAT)	£ Cost (inc VAT)	Baseline Due Date *dd/mm/yyyy*	Duration *(in days of activity)*	Evidence Required *(evidence required to support an invoice submission for this deliverable)*
1	1.1	Hemp-30 Project Management	Hemp-30 Management Team meetings Hemp-30 Project Team meetings			31/03/2023	365	Minutes of HEMP-30 Management Team meetings Minutes of Project Team meetings
1	1.2	Hemp-30 Project Management	Hemp-30 Management Team meetings Hemp-30 Project Team meetings			31/03/2024	365	Minutes of HEMP-30 Management Team meetings Minutes of Project Team meetings
1	1.3	Hemp-30 Project Management	Hemp-30 Management Team meetings Hemp-30 Project Team meetings			31/03/2025	365	Minutes of HEMP-30 Management Team meetings Minutes of Project Team meetings
2	2.1	Gamma-readiated M2 population generation	Generation of Gamma-radiated M2 (GRM) Industrial Hemp Population			31/10/2022	210	Gamma-readiated M2 population
2	2.2	Candidate gene selection	Genes to target during breeding programme identified			31/12/2022	270	Database of candidate genes created
2	2.3	M2 plant catalogue	Generate in-silico low coverage genome catalogue of 2,000 M2 individuals			31/03/2023	180	Database of cataloguedM2 plamts
2	2.4	Breeding population for cannabinoid content	Genetics and phenotype of cannabinoid content population established			31/12/2024	630	Cannabinoid content breeding population
2	2.5	Breeding population for plant cell wall properties	Genetics and phenotype of plant cell wall properties population established			31/03/2025	630	Plant cell wall breeding population
2	2.6	Variety registration and National Listing of High (8%) GLA hemp variety	High GLA hemp varieties listed			28/02/2025	900	Successful listing of high GLA varieties
3	3.1	Certified seed multiplication	2022 certified seed multiplication			31/10/2022	180	Certified seed collection generated
3	3.2	Certified seed multiplication	2023 certified seed multiplication			31/10/2023	180	Certified seed collection generated
3	3.3	Certified seed multiplication	2024 certified seed multiplication			31/10/2024	180	Certified seed collection generated
3	3.4	Germination, storage and molecular marker based quality assurance assays	2022 Germination, storage and molecular marker based quality assurance assays			31/12/2022	60	Assay database generated from 2022 analysis
	3.5	Germination, storage and molecular marker based quality assurance assays	2023 Germination, storage and molecular marker based quality assurance assays			31/12/2023	60	Assay database generated from 2023 analysis
3	3.6	Germination, storage and molecular marker based quality assurance assays	2024 Germination, storage and molecular marker based quality assurance assays			31/12/2024	60	Assay database generated from 2024 analysis
4	4.1	Field Trials	2022 field trials at specific UK locations			31/10/2022	180	Database of information from 2022 field trail study
4	4.2	Field Trials	2023 field trials at specific UK locations			31/10/2023	180	Database of information from 2023 field trail study
4	4.3	Field Trials	2024 field trials at specific UK locations			31/10/2024	180	Database of information from 2024 field trail study
4	4.4	Biodiversity and soil impact study	2022 biodiversity and soil impact investigantions			31/12/2022	270	Database of information from 2022 biodiversity/soil study trail study
4	4.5	Biodiversity and soil impact study	2023 biodiversity and soil impact investigantions			01/01/2023	270	Database of information from 2023 biodiversity/soil study trail study
4	4.6	Biodiversity and soil impact study	2024 biodiversity and soil impact investigantions			02/01/2023	270	Database of information from 2024 biodiversity/soil study trail study
5	5.1	Bacterial treatment of hemp	Bacterial treatment of hemp - innoculation and growth cabinet testing			30/04/2023	390	Dataset of performance of hemp following bacterial treatment
5	5.2	Small scale plot testing with ATL technology	Replicate small-plot testing - evaluate yield and quality of biomass and seeds			30/04/2024	360	Dataset of performance of hemp following bacterial treatment
5	5.3	Grower trials with ATL technology	Grower trials at recommended application rates			31/03/2024	360	Dataset of performance of hemp following bacterial treatment
5	5.4	Field study preparation and testing	2022 field study preparation and testing			30/11/2022	240	Database of information from 2022 field trail study
5	5.5	Field study preparation and testing	2023 field study preparation and testing			01/12/2022	270	Database of information from 2023 field trail study
5	5.6	Field study preparation and testing	2024 field study preparation and testing			02/12/2022	270	Database of information from 2024 field trail study
5	5.7	Haverting equipment review, evaluation and showcasing	2022 Haverting equipment review, evaluation and showcasing			31/12/2022	120	Report on hemp harvesting 2022
5	5.8	Haverting equipment review, evaluation and showcasing	2023 Haverting equipment review, evaluation and showcasing			01/01/2023	120	Report on hemp harvesting 2023
5	5.9	Haverting equipment review, evaluation and showcasing	2024 Haverting equipment review, evaluation and showcasing			02/01/2023	120	Report on hemp harvesting 2024
6	6.1	Hemp texiles process innovation programme	Hemp textiles processing - evaluation of innovative technology			31/03/2024	1080	Report on textiles hemp processing
6	6.2	Hemp construction process innovation programme	Hemp construction processing - evaluation of innovative technology			31/03/2024	1080	Report on construction hemp processing
6	6.3	Hemp bioenergy process innovation programme	Hemp bioenergy processing - evaluation of innovative technology			31/03/2024	1080	Report on bioenergy hemp processing
6	6.4	Economic, environmental and social assessment of hemp process innovation programme	Detailed LCA and EES analysis of hemp processing for textiles, construction and bioenergy products			31/03/2024	1080	LCA and EES assessment on hemp processingg report
7	7.1	Preliminary hemp LCA analysis	Report on preliminary hemp cultivation and end products LCA			31/03/2022	360	Preliminary LCA report on hemp cultivation and products
7	7.2	LCA report at Yr 2	Update report with available project data on hemp cultivation and end products LCA			31/03/2023	360	Y2 LCA report on hemp cultivation and products
7	7.3	LCA report at Yr 3	Update report with available project data on hemp cultivation and end products LCA			31/03/2024	360	Y3 LCA report on hemp cultivation and products
8	8.1	Hemp-30 Communication Strategy	Create communication strategy, project website and initial dissemination materials			20/09/2022	180	Hemp-30 Communication Strategy document
8	8.2	Hemp Special Interest Group events	Programme of Hemp Special Interest Group events held every 6 months 2023			31/03/2023	180	2 Hemp-SIG events
8	8.3	Hemp Special Interest Group events	Programme of Hemp Special Interest Group events held every 6 months 2024			31/03/2022	180	3 Hemp-SIG events

Payment Milestone Schedule			
Payment Milestone ID	**Invoice Due Date** ***dd/mm/yyyy***	**Planned Deliverables** ***(Please provide the deliverable ID here. Use a comma seprated list if there are multiple entries)***	**Invoice Amount (exc VAT) VALUES TO BE AGREED WITH BEIS DURING CONTRACTING**
1	31/03/2023	1.1	
2	31/03/2024	1.2	
3	31/03/2025	1.3	
4	31/10/2022	2.1	
5	31/12/2022	2.2	
6	31/03/2023	2.3	
7	31/12/2024	2.4	
8	31/03/2025	2.5	
9	31/12/2024	2.6	
10	31/10/2022	3.1	
11	31/10/2023	3.2	
12	31/10/2024	3.3	
13	31/12/2022	3.4	
14	31/12/2023	3.5	
15	31/12/2024	3.6	
16	31/10/2022	4.1	
17	31/10/2023	4.2	
18	31/10/2024	4.3	
19	31/12/2022	4.4	
20	01/01/2023	4.5	
21	02/01/2023	4.6	
22	30/04/2023	5.1	
23	30/04/2024	5.2	
24	31/03/2024	5.3	
25	30/11/2022	5.4	
26	01/12/2022	5.5	
27	02/12/2022	5.6	
28	31/12/2022	5.7	
29	01/01/2023	5.8	
30	02/01/2023	5.9	
31	31/03/2024	6.1	
32	31/03/2024	6.2	
33	31/03/2024	6.3	
34	31/03/2024	6.4	
35	31/03/2022	7.1	
36	31/03/2023	7.2	
37	31/03/2024	7.3	
38	20/09/2022	8.1	
39	31/03/2023	8.2	
40	31/03/2022	8.3	

Annex 5

Hemp-30 Phase 2 Project Management and Governance



Annex 6

Hemp-30 Phase 2 Risk Register

Risk (Identify and describe all key project risks, including: financial, technology, supply chain, regulatory, etc)	**Overall risk rating:** (Probability x Impact) High, Medium or Low	**Mitigation actions** (Describe the actions taken or planned responses to reduce the impact and/or probability of the risk)	**Residual risk rating, after mitigation applied:** (Probability x Impact) High, Medium or Low
Covid associated risks across the project team including the risk of catching and transferring COVID-19 between, to, or from members of the project team	Medium	The University of York and the BDC have detailed Covid Risk Assessments in place which are reviewed regularly in line with government and University of York guidance. UoY and BDC will be the two principle locations for face to face meetings and excellent meeting room and workshop spaces are available allowing safe social distancing as required. It is anticipated that a significant part of the Phase 2 work involving stakeholder engagement and partner project meetings will be carried out using online technology such as Zoom and Teams. In the event of a return to a complete lock down the Hemp30 Phase 2 project communications will be managed using the now widely used video call technologies that all project participants have become familiar with.	Low
Failure to engage with relevant stakeholders across the industrial hemp supply chain and the broader bioeconomy sector in academia, industry and local and national government	Low	The project team is exceptionally well connected with relevant university, industry and government contacts providing excellent access to researchers, seed producers, farmers, processors and downstream hemp-based product companies. In particular, UoY hosts two of the six Networks in Industrial Biotechnology and Bioenergy (HVB and BBNet) which together have well in excess of 1000 members. The BDC also hosts the BioVale cluster which has a further 700 members from across the bioeconomy sector.	Low
Inability to provide qualified and experienced staff to deliver the project resulting in delays to project initiation	Low	All project partners have the staff already in place to deliver the Phase 2 project. This includes expert technical staff at UoY and BDC and highly experienced business facing employees across the other 13 project participants. No recruitment is required for the project and all of the necessary financial, managerial, reporting and governance systems are in place meaning there will be no delay in the project starting.	Low

Hemp-30 Phase 2 Risk Register

Risk (Identify and describe all key project risks, including: financial, technology, supply chain, regulatory, etc)	**Overall risk rating:** (Probability x Impact) High, Medium or Low	**Mitigation actions** (Describe the actions taken or planned responses to reduce the impact and/or probability of the risk)	**Residual risk rating, after mitigation applied:** (Probability x Impact) High, Medium or Low
Financial difficulties within individual partners prevent specific aspects of the Phase 2 project from progressing.	Low	All project partners are financially secure. In particular, UoY as the project lead is a large higher education institution with very low risk of financial difficulties during the 3 year project period.	Low
Lack of engagement from sub-contractor causing delays or non-delivery of activities	Low	All sub-contractors have confirmed their commitment to Phase 2 in writing through a Letter of Commitment. The Project Management Group are experienced in delivering projects with multiple partners and are already engaged with all the sub-contractors through other activities and projects.	Low
Project is not well managed leading to limited impact and poor financial control	Low	A highly experienced Project Management Group and Project Delivery Group is already in place to ensure good practise will be followed in term of all aspects of project management.	Low
Project schedule is not clearly defined or understood causing delays in delivering proposed activities	Low	A detailed project plan has been discussed and agreed with all project participants and will be reviewed regularly to reflect the project progress	Low
Technology strategies to develop new hemp seed varieties fails	Low	A highly experienced team is already in place within UoY to deliver the hemp breading programme with a strong track record in breeding new plant varieties including industrial hemp. A strong partnership has also been established with Elsoms Seeds to facilitate certified seed production and bulking up.	Low
Delays in obtaining a licence to grow industrial hemp at the BDC facilities which would limit the opportunities to demonstrate before the farm gate innovation opportunities	Medium	BDC is working closely with the Home Office to agree the details of a hemp growing and processing licence. UoY, STC and ESL all have hemp licences in place allowing activities to switch to another project organisation if licencing for BDC is delayed.	Low
Change to the regulatory policy on hemp prevents the project developing as planned	Medium	The UK government as a whole has commissioned the TIGGR report that recommends reducing hemp regulatory requirements. It is therefore very unlikely that any change in policy will increase the stringency of hemp farming, processing and product development	Low

Annex 7

HEMP-30
Phase I BFI Project

Industrial Hemp

Report of Interviewee Insights

28/02/2022

Interviews conducted by the HEMP-30 consortium team

Biorenewables Development Centre

LUCID INSIGHT

Kepier & Company Limited
Business and Management Consultants

Contents:

Sources	Numbers of interviews by type and list of interviewee organisations
Varieties Opportunities	Insights regarding hemp breeding, traits and varieties
Cultivation Opportunities	Insights regarding agronomy and growing, including licensing
Product Opportunities	Insights regarding hemp products and markets, including carbon credits

Sources: Interviewees

Interviewees by Type

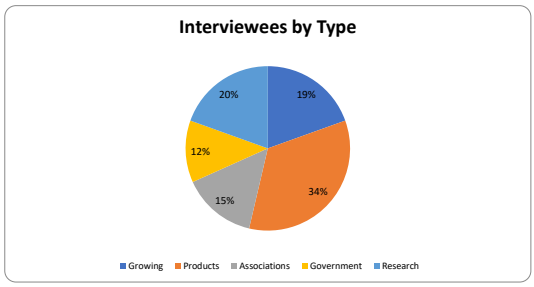
Total Approached: **55**

Total Interviewed: **44**

Interviews by main activity:

Growing	8
Products	14
Associations	6
Government	5
Research	8

NB: several interviewees cross-over between these categories. They have been categorised according to their main hemp related activity.



Interviewee Organisations

Key Activity	Organisations
Association	British Hemp Alliance
Association	NFU Combinable Crops
Association	NFU East Anglia
Association	NFU Renewable Energy
Association	Cannabis Trade Association
Association	National Brownfield Forum, Sustainable Remediation Forum
Government	Amanda Lyons, DEFRA Arable Team
Government	RPA
Government	AHDB
Government	Sam Dovey, DEFRA ELMS Team
Government	Harriet Cooper, DEFRA Soil Health Team
Growing	Whole Hemp Foods
Growing	Ashby Farms Ltd
Growing	Hemp North
Growing	FWAG
Growing	Margent Farm
Growing	Hempen
Growing	Lawson Farm
Growing	Matthew Fletcher, Agronomist
Products	East Yorkshire Hemp Company
Products	British Hemp Company/UK Hemp Ltd
Products	Hemp Block Company
Products	UK Hempcrete
Products	SPG Innovation
Products	Natural Building Systems
Products	Drax
Products	Oscar Cooper
Products	Luke Middleton, The Carbon Farm
Products	Harrison Spinks
Products	Rare Earth Global
Products	Kerfood Oils
Products	Tatham
Products	Unyte Hemp
Products	Gaia Farms
Products	Yelo
Products	IndiNature
Research	Lynda Deeks, Cranfield University
Research	Lydia Smith, NIAB
Research	Stefano Amaducci, Università Cattolica del Sacro Cuore di Piacenza, Italy
Research	Leonardo Gomex, CNAP
Research	Simon McQueen-Mason, CNAP
Research	Neil Bruce, Biology Department, University of York
Research	Phil Longhurst, Cranfield University
Research	Thorunn Helgason, Soil Biologist, York University

Additional Expert Events

Canadian Hemp Trade Alliance Conference, November 2021
BHA Hemp Hub, Carbon Sequestration, November 2021
Clarion Hemp Round Table, October 2021
Architechs Climate Action Network (ACAN) Natural Materials Masterclass – Building with Hemp, December 2021

Interview Insights: Variety Opportunities

Priority	Work Package	Opportunity/Barrier	Overview	Additional Quotes
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Tight THC regulations limit access to varieties	Interviewees highlighted the limited number of varieties that could be grown in the UK due to the 0.2% THC upper limit. In the USA the limit is 0.3% which would cover 68 varieties according to one interviewee. Other countries have a higher limit e.g. Switzerland at 1%.	"1% would open up many more varieties, even a small % increase would open it up [significantly]" "1% THC would really help"
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Limited access to UK adapted varieties	Traditionally grown UK varieties are not being utilised. It seems these have been lost to history, and work is required to develop UK adapted varieties to maximise yield, optimise for UK climates and reduce potential pest/disease vulnerabilities. 'Farmer friendly British varieties' were requested with attributes such as: grow shorter (for seed harvest); grow quicker; early maturity; best yield; improved establishment, improved retting/decortication.	"A major obstacle is that we don't have UK adapted landrace" "We need to build british genetics" "Even 1hr extra daylight hour requirement in a variety makes a huge difference in the UK" "Henola can achieve up to 2t/ha of seed, but in the UK no-one reaches that. 1.2t/ha is more realistic" "NIAB is trying to identify the varieties not yet listed that would be suited to the UK"
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Limited work on potential pest and disease issues for UK growers	Potential increases in pest and diseases could occur with increased acreage. This could be mitigated by breeding for resistance.	"Breeding is always an ongoing process. Hemp diseases are likely to increase with increase in crop area. It is susceptible to many diseases, particularly mildew and root impacting diseases"
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Opportunity to develop varieties that require less or no retting for fibre/shiv separation	Retting is currently a problematic stage in the process of fibre/shiv separation, and so there is great interest in the potential for varieties that do not require this stage. There is some work on non-retting varieties of hemp, but this is currently very limited, and no adapted varieties are available in the UK.	"We are looking to try out a non-retting variety" "Farmers are often put off by the risks attached with the retting stage, and the potential to lose a whole crop based on the vagaries of the weather during baling."
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Harvesting in time for sowing a winter crop	Time of flowering and seed maturity is significant in terms of being able to sow a winter crop subsequent to harvest. Some seed varieties may not mature until December if sown late. Work could be conducted to optimised varieties for the UK season, particularly frost tolerance to enable earlier sowing, and drought tolerance for later season growing.	"Can do anutumn barley [after hemp crop] but can be problem if Henola sown late then can be December before it is ready!"
P1: Variety Opportunities	WP3: HEMP SEED MULTIPLICATION	Limited access to seed suppliers	Interviewees highlighted the challenges in sourcing varieties, with many using the same supplier in France, Hemp-IT. UK Hemp Ltd distributes Polish varieties to UK growers. Some seed processors are planning on distributing other imported seed varieties for farmers to grow. Varieties grown include Henola, Finola, Futura, Ferimon, Fedora 17, USO 31 (oilseed/dual) and Futura 75, Felina 32, Bialbrzeskie (fibre).	"We took guidance from French hempseed supplier, Hemp-IT, that was recommended by another UK farmer" "We aim to start distributing seeds of other varieties from other [non-UK] companies"
P1: Variety Opportunities	WP3: HEMP SEED MULTIPLICATION	High cost of seed	Seed purchase is a significant cost to farmers for this crop	"The seeds were very expensive"
P1: Variety Opportunities	WP3: HEMP SEED MULTIPLICATION	Hemp seed consortium	An industry representative believes that a hemp seed consortium would greatly benefit the UK industry, in terms of building UK supply chain and security of supply of seed for growers	
P1: Variety Opportunities	WP2: HEMP BREEDING PROGRAMME	Varieties may impact fibre and shiv quality, but require further investigation	UK Hempcrete has used hemp from all over europe and hasn't seen difference between varieties in terms of quality or impact on building materials. However it seems this is not fully understood and it could be that there are differences that could be harnessed. This would require further investigation.	

Interview Insights: Cultivation Opportunities

Priority	Work Package	Opportunity/Barrier	Overview	Additional Quotes
P2: Cultivation Opportunities	WP4: HEMP CHARACTERISATION PROGRAMME	Need for a Varieties Selection Tool	There is limited data on the available current varieties for growers in the UK. They are often relying on word of mouth from colleagues or advice from suppliers with data from outside the UK. A tool to help growers select and know how best to grow varieties to suit UK conditions would be hugely beneficial.	"We need a handbook of which varieties perform and optimised agronomy guides"
P2: Cultivation Opportunities	WP4: HEMP CHARACTERISATION PROGRAMME	Limited UK data on environmental impact of the crop	The interviewees strongly believe there is an environmental benefit of growing hemp. There are studies from North America and continental Europe to support this view. However, they recognise the need for data to demonstrate these benefits of growing hemp in the UK, and to align with with roll out of ELMS programs. This includes carbon sequestration, soil health, biodiversity benefits, lower crop inputs, subsequent crop benefits etc.	
P2: Cultivation Opportunities	WP4: HEMP CHARACTERISATION PROGRAMME	Hemp as an ELMS recommended environmentally beneficial land management practice within arable rotations	The Farming and Wildlife Advisory Group (FWAG), along with a consortium of over 40 organisations are exploring land management options that enhance biodiversity and natural capital metrics, providing ecosystem services to be supported by ELMS and private investors e.g. via mitigation or credits. Practices such as use of cover crops and herbal leys within arable systems are being recognised for the value they deliver. There is an opportunity for hemp to be recognised in line with these other practices, given the soil, biodiversity and carbon sequestration benefits that it delivers for farmers.	
P2: Cultivation Opportunities	WP4: HEMP CHARACTERISATION PROGRAMME	Hemp as a driver of carbon sequestration in soil	Interviewees want to measure carbon capture/release. One interviewee mentioned work by Marcell Valderos, Leeds University on Eddy covariance flux towers to capture carbon above ground. These carbon flux systems are designed to measure CO2 and CH4 gas exchange between the biosphere and atmosphere. Glyn Mitchel in his Hemp Hub talk claimed 22t CO2/acr for seed crop. This requires verification. Work which is underway as part of a Soil Association field lab led by Linda Deeks at Cranfield University should provide some initial indicative data in this area, but more detailed studies are required. In addition, the Soil Carbon Code project (a forum of 46 organisations) is develping standards for carbon markets and deliver ELMS on soils, with a focus on the carbon impact of land management changes, initially looking at integration of herbal leys into arable rotations. It is feasible that integration of hemp break crops could be investigated. FWAG SW and Sustainable Soils Alliance are leading this work.	"We aim to make soil carbon part of a suite of blended finance [for farmers]"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Hemp as a short cycle biomass crop for tenanted farmers	There has been a huge increase in contract farming and tenancies. 1990's ended the Agricultural Holding Act tenancies AHAs, so now there are no more multigenerational tenancies. They were replaced with Farm Business Tenancies of up to 10-15yr, but in reality lots are on short term, often 2-5yr. This makes perennial crops unsuitable. 30% of all farmland, including uplands and grasslands is tenanted. Means that annual breakcrop for bioenergy could be attractive.	

P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Growing has been demonstrated by several successful players in the last few years	UK Hemp Ltd, under the brand British Hemp, stated operations in 2020, and is now processing seed from various growers across 240 hectares, and aim to expand that to 1000ha in 2022. Whole Hemp Foods described their journey as "gone from nothing to re-writing the book on hemp in their business in four years" Nick Voase at East Yorkshire Hemp have industrial scale fibre processing facilities on-farm, delivering products to multiple end-users from construction to bedding to textiles. Harrison Spinks have 300 acres of hemp and flax to make matresses at their own factory. Adnams' hempcrete distribution centre locked up 100-150t CO2 and saved over 450t CO2 in conventional materials. John Barrett has 20 acres under cultivation (2021) in Norfolk and plans to increase to 200 acres in 2022.	Scaling up hemp is "so within our grasp" "Proven the crop at farm level, we have good business models to present" "Harrison Spinks is a real success"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Major issues around break crop pests means farmers are looking for low input, low risk alternatives and greater diversity in rotations	Farmers are turning to hemp due to issues with increasing failure of standard break crops, such as oilseed rape (OSR) and sugar beet, due to pests and disease, such as OSR flea beetle and nematodes, and sugar beet aphid. Currently hemp in the UK suffers very low incidence of pests and disease, with some reports of fungal infections in some damper conditions. Farmers are also looking for crops that deliver soil health and benefits to subsequent crops, which have been reported for hemp. There is also some evidence that hemp reduces nematode load in the soil, whereas OSR can increase, and be susceptible to, nematodes.	Why did you choose to grow hemp? "We are big grower of sugar beet and OSR. Both are suffering diseases and increasingly restricted use of sprays are allowed" "Everyone is looking at other crops" "The industry needs more crop rotation options, not just from a business perspective but an environmental one too." "All the alternative [break crops] have issues so need as many tools in the box as possible" "We see hemp as a good break crop and replacement for OSR" "Hemp also has nematicidal properties so can potentially be used in rotation as part of an IPM programme."
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Expert hemp growing service model	One grower is partnering with landowners to provide a complete hemp cultivation service model (aka contract hemp growing service). This means he can provide all the specialist expertise, skills and equipment needed for the crop across multiple sites. He has found that he can grow at £500/acre cost inclusive from seed to delivery to buyers. He will share 50% of profit with the farmer.	
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Some other break crops are very unreliable and variable in yield	Peas and beans, as well as linseed can be very variable in yield, again driving farmers to seek alternatives.	
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Major issues with blackgrass weed combined with regulations on herbicide usage means farmers are looking for other ways to suppress blackgrass growth	Hemp can help suppress blackgrass growth due to its dense vegetative canopy, and can therefore be used as part of a rotation to reduce prevalence in arable systems.	"[We grew hemp because] we lack options for blackgrass herbicides" "We saw the potential of hemp, particularly…the sustainable side of weed shading, particularly as we have bad blackgrass"

P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Optimisation of growing systems in UK	Very few farmers have experience of growing hemp, and there is a limited bank of knowledge. Currently farmers are sharing knowledge from connections they are making or through the few hemp networks e.g. the British Hemp Company grower community. Growers requested baseline data for aspects such as seed rate, inputs, expected yields, soils, to provide a base model to then trial in their context	"Wanted dual use variety but deciding was difficult because there is no UK field data" "We have a whatsapp group for farmers to share learnings" "Henola can achieve up to 2t/ha of seed, but in the UK no-one reaches that. 1.2t/ha is more realistic" "In reality if you tell farmers to sow at 35kg seed/ha they plant 20-25kg seed /ha, so yield lower and they get weeds growing!" [seed varieties] "Lack of clear agronomic advice for UK on varieties, such as for optimal drilling and establishment" "Min till was big in the 60s but it didn't work for some so it got a bad name - we didn't know enough to do properly. It could be same with hemp if not done well, but now we know a bit more, able to get it right"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Optimisation of fertilizer inputs required	It is known that hemp generally requires nitrogen inputs to optimise performance. However, there is little data on UK fertilizer requirements for the different varieties available, and guidance is generally supplied from the country of origin, which may not translate to UK growing conditions.	"It is a myth that it doesn't need fertiliser. 120kgN/ha as general rule [for seed varieties]" [NB: Finola is higher] "Lack of clear agronomic advice for UK on...fertilizer rates"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Price paid to farmers for British grown seed is up to 3 times the price paid for imported Chinese seed	Imported Chinese seed can be bought for around £500 per tonne, but some seed processors are paying up to £1500 for traceable British grown hemp seed of known origin. Some larger UK hemp oil brands are currently using imported Chinese hemp seed, whereas other UK brands are selling premium British grown hemp products into East Asia.	
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Optimisation of agronomic practices required to minimise the risk of development of hemp pest and disease issues, and thus maintain hemp as a low input crop	Hemp does not currently require pesticide or herbicide inputs in the UK. One interviewee stated that despite extensive growing in Canada they have not seen problems develop. However, other agronomist interviewees stated that this could become an issue in the UK, particularly if dropped into conventional limited rotation diversity or grown as monoculture. Growing hemp as part of a diverse rotation is likely to limit this, but there is still a risk of problems with pests and diseases, particularly fungal infections to which hemp is prone.	"Hemp diseases are likely to increase with increase in crop area. It is susceptible to many diseases, particularly mildew and root impacting diseases" "Mould and blight can be an issue into october" "Towards harvest time [the crop] started to show signs of Sclerotinia sclerotiorum (white mold), but other than this no pesticides or herbicides were needed" "Hemp shouldn't become a monoculture, but part of rotation" "Some signs that cabbage white might like hemp leaves"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Opportunity to use hemp crop to build soil health	The deep rooting nature of hemp lends itself to be an excellent soil health crop, due to potential for soil exudates, root penetration improving infiltration, aggregate development. Further work is required to quantify these benefits, but the interviewees felt strongly that the crop had good attributes and potential for soil health building.	"Once it rains the rooting is terrific"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Licenses issued too late for sowing means farmers lose a season's crop	The timeliness of issuing licenses was highlighted as a key barrier, with several farmers reporting missing a season's growth themselves, or colleagues having the same issue, due to licenses being issued too late for sowing a hemp crop	"[The application] took longer than anticipated and we missed the 2020 season" "had to abandon growing in 2020 as the license arrived too late to sow"

P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Farmers do not find the licensing guidelines very clear, and so high level of rejected applications	Farmers and stakeholders commented that the guidelines for submitting an application for a license are not very clear, and cause confusion as to what the criteria are for granting or refusing an application. There is a perception that the appraisal and licensing is not being applied consistently. Restrictions around public access make it particularly challenging in more densly populated regions such as the South East.	"We failed first time then got it when someone helped us with the application" "We asked for the HO to help us select suitable fields but were told we just had to submit for each until the HO approved" "Our initial sites were rejected due to being on public access, but [the process is] not consistent as other farmers have been granted licenses on roadways or rights of way" "It makes it difficult to find sites in the South East where it is densely populated - not many field without some access" "We ended up [growing hemp] on poorer soil than we would have selected, so the crop was less productive"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	The licensing process could be made smoother: Home Office is not joined up with the RPA and DEFRA farm systems	Several interviewees believed that DEFRA might be more suited to management or overseeing the licensing administration, but with the HO still conducting the appropriate checks and tests. DEFRA already has systems in place for working with farmers which could make the process more streamlined. A suggestion was for a panel of reputable and proven hemp businesses to develop a strategy with government.	"Now is the time to present an alternative strategy to improve [the licensing] process but still keep the checks and controls in place" "My key recommendation is to transfer licensing to Defra" "It would be better if issuing and the basics of licenses could be delt with by Defra, with HO checks" "HO reps are asking for postcodes but then not matching sites of [the correct] fields" "I have not heard of problems with theft or public perceptions - we have had a very positive response" "[Farmers are] banging heads on licensing where a crop offtake market does exist but stymied by administration"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Opportunity for improved 'off-the-shelf' harvesting machinery	For seed crops existing machinery can be used, although some will cope better with the fibrous nature, especially those without so many rotating parts, such as straw walkers. For fibre crops, modified machinery that cuts the stem at several points of greater length than a forage harvester, is required for high quality fibre cropping. Forage harvesters can also be used if the longer fibres are not required. Small scale producers cannot afford specialist machinery, and so some are sharing equipment. As a rule, harvesting takes much longer, therefore is more costly, than for other crops, particularly if machinery has not been adapted.	Seed varieties: "Conventional machinery can be used but some combines are more robust than others" "My neighbour grew 30 acres for seed. He didn't find it easy combining." Fibre crop: "We designed and made our own harvester" "It took two days to harvest with forage harvester, when a normal crop would take a couple of hours, due to strong fibres causing problems, wrapping, so we had to unravel it" "Some have given up growing hemp because of wrapping issues" We used a [commercial] adapted header strip seed head, but it broke when we trialled it."

P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Innovation around retting is required for consistent fibre separation	The traditional approach of retting hemp stalks in the field to start the process of separating the fibres from the inner woody shiv is challenging for farmers. It is weather dependent, with the retting process requiring moisture for microbial activity, but dry enough conditions for machinery to work in the field without damage such as compaction. With less reliable weather patterns this process becomes even more risky. It also is time consuming, up to 5 weeks, delaying seedbed preparation and sowing of subsequent winter crops. Innovations include: microbial acceleration treatments, ensiling, and physical treatments such as ultrasound. NIAB are working on various on-field and off-field options, demonstrating UK knowledge in this area. Retted baled hemp straw is bought wholesale at £180 - 200 per tonne, but this was considered to be unattractive to farmers as the sole value from a hemp crop. It was emphasised that they will want a share in the added value streams, for higher value products.	“The risks are the retting time, which could suffer a wet season and reduced yields and quality, which means farmers are taking all the risk”. "[retting is] best suited to lighter soils, well draining fields" "Retting will be ‘learn on the job’" "We did not rett as another farmer did and it was a disaster two years running due to wet weather preventing drying and baling. The current big machinery cannot cope with the wet conditions" "It would help to find treatments to speed retting, like bacterial or fungi to breakdown the lignin, like in the paper industry" "We forage harvested so chopped up and clamped under plastic cover...like silage." On clamped hemp: "it will ret really well, fibres just come away. Can dry and decorticate. You can bale and silage it"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Lack of accurate biomass yield data available	There appear to be some descrepancies between reports of biomass yields and it is not clear as to the current level of biomass obtainable from the field from differing crops. 8-12t/ha seems reasonable for fibre varieties. It is likely that there is scope to increase with optimised systems such as around agronomy, variety understanding and UK adapted breeding.	"The range I have seen is 8-12t/ha for baled retted stalks" "Dry yield of biomass is 30t/ha" [fibre variety] "10ha henola [seed variety] gave 14t seed plus about 120t stalk"
P2: Cultivation Opportunities	WP5: HEMP YIELD MAXIMISATION PROGRAMME	Phytoremediation to reclaim contaminated land	It is an attractive crop for phytoremediation due to the long roots, fast growth and high biomass. This opens the opportunity for utilising non-arable land to produce biomass. However, there does not seem to have been any UK trials of growing hemp on contaminated land. [Context: May 2015 UK Government reported: "The legacy of the industrial revolution is over 400,000 hectares of contaminated land." Twenty-six open cast coal mines still remained in operation at the end of 2015, and Environment Analyst’s market data reported contaminated land/remediation consulting in UK worth £244m]	"There has been a lot of research undertaken internationally looking at the efficacy of hemp to remediate contaminated soils." "There is significant potential for hemp (low THC fibre, seed or dual-purpose hemp) grown in typical arable rotations to bio-remediate soil structure and sequester carbon to depth with the soil profile."

Interview Insights: Product Opportunities

Priority	Work Package	Opportunity/Barrier	Overview	Additional Quotes
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Use of whole plant would be ideal	Interviewees agree that it would be ideal to get a true dual purpose crop, and use the whole plant. Most seed crop growers are not utilising the stalks currently, apart from ploughing it back into the soil. The lower yield of stalk from a seed crop means that either more efficient fibre-shiv separation is required, or development for uses for less stringent quality fibres making it more economical to harvest the stalks. Alternatively, use of whole stalks after seed harvesting could include biochar, which at least two interviewees are already producing, or bioenergy.	Seed processor: "Our [seed] suppliers are not using the stalk. They are ploughing it back in"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	The UK hemp stalk processing lags behind France, where investment has improved quality and consistency of products	The facilities in France are more advanced in terms of delivering highly consistent, graded shiv products, controling for dust, mould, coloration, particle size distribution and low fibre content. UK facilities would benefit from improving these aspects to compete against French imported materials, which have had heavy investment. These properties have significant performance impacts, such as in spraying and creating composites. UK is lagging behind some other countries in terms of standardising hemp construction materials, such as in France there is an equivalant to BSI standard for hempcrete.	"France have put in place big infrastructure and had investment" "The classic standard is the french building shiv." "[France has] a £20m processing plant versus the UK £2m processing plant"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity to develop more regional fibre/seed processing facilities	Interviewees agree that regional processing facilities are required. Currently the only significant fibre processing centre is in East Yorkshire Hemp (https://eastyorkshirehemp.co.uk/) and at Harrison Spinks (https://www.harrisonspinks.co.uk/). Similarly for seed, there are a few regional facilities such as UK Hemp and Hempen, with others processing their own seed. Several organisation such as Natural Building Systems (https://naturalbuildingsystems.com/) in East Anglia; Whole Hemp Foods (https://hempwholefoods.co.uk/) in the Midlands, UK Hemp Ltd (https://ukhempltd.co.uk/) in the West, Hempen (https://www.hempen.co.uk/) in the South and Ashby Farm in the South East are seeking support and collaborative opportunities to set up regional hubs to cater for both seed processing as well as shiv/fibre products.	"We don't need another Cargills, farmers want to be part of the value creation chain, which will ultimately benefit rural economies. Having regional process centres will support this, farmers will take the risk if they have a share in the value-added benefits". "We need regional hubs of processing facilities that can be shared by growers" "We have put in grant application with another local farmer for [fibre] processing facilities, for Kent and the South East" "We are developing a hemp hub for the South for innovation and processing" "East Anglia has lots of drying capability... producers need regional [fibre] processing. " "eHempHouse is an example of a modular $1m system complete processing on-site container 'smart box' from the USA" Just fibre processing: "We have not invested huge money in machinery at all, because it is actually all very basic simple, just needs to be robust."
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity to take the lead internationally and export hemp consultancy and technologies globally	The UK has world class knowledge and expertise in hemp in construction, which has been active since the Hemcor facility scaled up hempcrete in the 1990s. One interviewee highlighted that the USA hemp construction industry is at a much earlier stage, due to only recent changes in legislation. Currently UK experts are consulting in the USA and there is a risk that without sufficient investment and development of the crop provision and support for the materials development then countries such as the USA will utilise UK know-how and then overtake the UK.	"Construction and bioenergy will drive increased growth in UK" "[The USA] could catchup and overtake our market"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp straw and/or pellets for distribution to heat and energy plants	Several interviewees are exploring pelletising options to supply biomass fed burners. At least one interviewee hemp farmer has a forage drier and pelletising facility on-farm. Others are exploring the potential of regional pelletizers or supplying baled biomass directly to straw burner facilities. Interviewees stated that the economics are such that baled straw is only viable to transport on a ~50 mile radius, whereas pelletized material increases this scope significantly due to increased density. One interviewee suggested that a yield of 6t/acre would be required to make pelleting economically feasible, and it was highlighted that the cost of baling hemp at all for bioenergy might not stack up given the challenging wrapping and blade blunting issues of harvesting. It may require a higher price nearer £80/t, than wheat or miscanthus to justify the costs. Another suggested that at current energy prices growing hemp for pellets 'was not a [economically] sustainable option'. There appears to be little work on pelletising hemp in the UK so far, but at least three interviewees are investigating this. One company stated they have off-take agreements for around 50,000T of pellets with '1st tier companies' and are seeking to grow in Yorkshire and Lincolnshire to generate pellets starting in 2022. They say they have machinery customised and mapped out to pellet hemp in the UK.	"We've pelleted various cultivars of hemp in different stages of moisture/storage and run commercial tests that covered the analysis (NCV, fines, ash etc.) of these samples. We also have machinery customised and mapped out to pellet hemp in the UK." "looking at putting [stalks] through a hammer mill, and extruding in a pelletiser to use as biomass for CHP" "It would be easier to send Heston bales direct to local burners [than pelletising]" "The biomass in hemp briquettes is much better than willow" "We would need £300 /t for pellets to be worthwhile"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp is a gateway into diversified farm businesses, generating natural biorenewable materials	One interviewee noted that hemp can act as an important entry point for farmers to diversify beyond food products, and start to supply natural materials into new markets, helping spread the risk and also improve the health of their farms through increased diversity, as well as replacing synthetic and petrochemical derived materials with local natural resources.	
P3: Product Opportunities	WP8: COMMUNICATIONS PROGRAMME	Marketing board	Several interviewees felt that a dedicated marketing board would be beneficial to bridge the gap with larger end-user markets, enable more communication from end-users on their needs and demonstrate the current and future potential of hemp products.	"We need a marketing board to sell the case to industry...Germany has increased hemp 900%"
P3: Product Opportunities	WP8: COMMUNICATIONS PROGRAMME	Co-operative model	Some stakeholders expressed a need for a co-operative or similar model in the UK industry to pool resources and collaborate at scale.	"The French model of co-operatives works really well" "It would be a better model to have regional co-operatives"
P3: Product Opportunities	WP8: COMMUNICATIONS PROGRAMME	Hemp Brand: Legitimate Industry Messaging	There is frustration amongst the industry around the continued stigma, feeling that concerns around industrial hemp providing a route to illegal activities are overstated. The feeling is that with increased acreage the crop would become normalised and no longer associated with illegal activites.	"There is a lot of myth around the potential for industrial hemp to segway into illegal CBD, medicinal and recreational uses " "We want to operate completely within the law, not lobbying for changes, not interested in bioactives side, be totally transparent and build a trusted reputable industry"
P3: Product Opportunities	WP8: COMMUNICATIONS PROGRAMME	Lack of trade organisations for hemp products	There is a lack of co-ordinated effort in terms of organisations to promote UK hemp applications to trade sectors.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp biomass CHP co-sited with on-farm solar to feed into grid	One interviewee thought there was opportunity to co-site hemp fed CHP with on-farm solar, where there is already infrastructure and a connection into the grid.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	On-farm anaerobic digestion feedstock to balance C:N ratio	One interviewee highlighted that a problem with on-farm AD feedstocks can be an overly high nitrogen content e.g. from animal slurry/manures, and therefore a high carbon feedstock, such as hemp could be useful to balance the ratio.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Fibreglass and rock wool alternatives	Some industries need top quality material but others "think they do but probably don't". Fibreglass and Rockwool replacement may only need rough fibres that can be just a few inches long rather than very long. Standard forage harvesters produce fibres around 10-13cm compared to 80 cm lengths for higher quality fibre harvester.	"Need to do trials to demonstrate [these applications]"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Insulation materials	UK hemp growers are providing fibre for insulation material of various thicknesses. It is possible to make natural product by using biodegradable PLA as the binder rather than plastics. A facility in Scotland, IndiNature (https://www.indinature.co/), is developing IndiTherm flexible insulation, UK origin, light weight, hemp fibre insulation/ thermal envelope products, at 45kg/m3, using a non-plastic bio-based binder. Thermofleece Natrahemp is 25kg/m3 which is similar to typical lightweight insulation, but uses plastic PE binder, costing £13.98/m2 for 100mm thick. Natural Building Systems' production facility in Suffolk, for up to 5000 panels per year, will produce modular system thermal envelopes, render boards, blocks and plaster boards using their patented quick drying HempSil technology, which uses an alternative binder to lime (https://naturalbuildingsystems.com/).	

P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hygrothermal properties of hempcrete gives moisture control and air quality properties	Hemp is highly hydrophilic structure, like a sponge of pores, so the lime absorbs moisture and this condenses inside the shiv pores, which then releases as the air heats up again and this buffers humidity making a very pleasant environment.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Unusual combination of thermal mass and insulating properties of hempcreate gives added benefits above normal insulating materials	Hempcrete combines benefits of thermal mass and insulation. The phase shift is the time which energy takes to pass through the envelope of the building - for 200mm hempcrete this is 12h, giving a diurnal cycle keeping the temperature very consistent in the building day and night BUT it doesn't meet the industry standard U value, which is based on insulation properties at 200mm. So even though it performs better in regulating temperatures than insulation standards you have to build the wall thicker to meet those standards.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Biochar opportunities	Biochar is being explored by several interviewees for applications in: soil amendments; carbon markets; and conductive ink, which can be used in printed circuit boards. Biochar represents a significant opportunity for carbon capture and truly long term sequestration. One interviewee has worked with the BDC on biochar production under different conditions.	"I am working on viability testing" Biochar based soil amendments system: "On my farm I can reduce mineral fertilizers by about 25% which equates to £9000 saving on his 320ha farm (£28/ha)"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Horticultural matting	Horticultural matting is being produced by the East Yorkshire Hemp Company, as well as a company in Essex.	"I am using Nick Voase's fibre matting for microgreens"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Corrugated card packaging	The British Hemp Alliance mentioned the opportunity for use of hemp stalks as a material for corrugated card packaging.	"We are in the process of putting in an InnovateUK bid, but it needs a big R&D push"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Layer hen bedding	Opportunity for producing high value bed for hatching hens, which needs to be sterile, antimicrobial and antibiotic, which hemp naturally is.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Horse bedding	Larger shiv produced by the East Yorkshire Hemp Company is used as horse bedding. Due to its antimicrobial properties, high absorbency and low dust, it is ideal for stabled animals.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Aviation fuel	The future potential for use of hemp in aviation fuel was mentioned by the British Hemp Alliance, but as a more distant opportunity.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hempcrete and other hemp-lime combinations are high in embeded carbon but also offers unique, and highly benefitical hygrothermal and insulating properties across the life of the building	It is recognised that lime has an environmental footprint in its manufacture, but it is a material that can be manufactured from local UK resources and it does confer a huge benefit across the lifetime of a building. In particular the combination of hemp in the lime matrix give the material a unique balance of thermal mass, vapour openness and hydrophilic properties that delivers a highly stable environment in terms of humidity and temperature, if constructed correctly. UK Hempcrete have monitored temperatures in hemp builds and found it to be stable at 16-18degC in all weathers without any heating due to the thermal mass and passive solar gain through windows. In addition, the lime binder protects the plant material and does not suffer any pests and is fire resistant, and so does not need any additional chemical treatements. This benefits the air quality and health of residents. Various projects are underway to reduce the footprint of lime manufacture, as outlined in the British Lime's Sustainable Development Report (https://hub-4.com/news/british-lime-s-sustainable-development-report-highlights-importance-of-lime-to-national-resilience).	"There are thousands of hempcrete buildings across the UK" "The Science Museum Archive is a hempcrete panel box to store artifacts because it can regulate the humidity and temperature" [This zero carbon storage building won the GreenBuild Award]
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	The UK has a long and strong history in hemp construction, which continues to grow	Lime Technology Ltd and Hemcore were the first to scale hempcrete in the UK using a licensed binder from France. Today UK Hempcrete and Unyte aim to build 10 regional hemp processing facilities in the UK and Northern Ireland, each utilising up to 6,000ha of locally grown hemp, and each capturing up to 121,000T CO2 equivalant per year in biomass, and generating a range of products to displace more carbon intensive products. Hemp build examples include: - William's Den East Riding, Yorkshire hempcret blocks, indoor outdoor activity ctre wood fiber insulation - Native Architects office S Yorkshire - Wrap around bungalow extension South Milford - Yoga studio Crag vale, internal solid wall insulation - Renewable House Program, Triangle swindon, 40 houses cast on site - Pringfield Meadow, Oxon, 25 house development with Greencore - University Bradford Sustainable Enterprise Centre is the tallest hemp, cast on site with hempcrete - M&S flagship cheshire Oaks	"UK has had 35 years of use of hemp shiv as a construction aggregate"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Recent changes are driving low carbon construction industry in both public and private sectors	As of 2021 the Construction Playbook now requires public works projects and programmes to provide a Whole Life Cycle Assessment, and this movement, which has taken place over several years, has been a key driver for the construction industry to seek low carbon alternatives. In addition to Brexit making supply chains uncertain, and so increasing interest in locally sourced materials, and more public awareness of the contribution of construction industry to carbon emissions, there has been a general trend over the past 4 years towards local, low carbon construction opportunities. Hempcrete was said to be one of the most carbon negative materials because: - Captures more carbon than forests due to speed of growth & conversion - Growing is low input and increases carbon in soil - Ability of lime to reabsorb carbon whilst drying to negate emissions of manufacture to some degree UK is lagging behind some other countries in terms of standardising hemp construction materials, such as in France there is an equivalant to BSI standard for hempcrete.	"There has been a perfect storm of the pandemic, brexit, and the build up to COP26 and climate change" "The challenge for industry is to scale up to respond to demand" "We need to get to carbon negative to really make a difference"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Ambitious private investment schemes underway by several hemp construction & bioenergy players	UK Hempcrete and Unyte Bioconstruct have formed a JV to invest £250m to build 10 regional facilities, using hemp from rotations on 5,000ha of land each, over the next 5-7years. They have a cohort of farmers willing to grow, but licensing is still a major hurdle. UK Hempcrete has seen "overwhelming demand" since the updated construction Playbook was published in january. Any public projects over £10m have to supply whole life carbon assessment. That's led to all commercial developers and architects looking at whole life costs. The key now is scaling the supply chain to match demand. UK Hempcrete have a network of contractors across the country and the JV is now focussed on parnerting with larger companies to allow construction at scale. REG plan to scale up to processing 15,000ha by 2026, and claim they have secured £18-20m recurring revenue contracted with multinational buyers by 2027. They plan in 2023 to set up processing, including decortication. IndiNature has attracted £4M+ of investment to set up their premium hemp insulation products business, at their site in Jedburgh, on the Scottish borders. Once installed their fibre processing equipment will process 2,600 ha equivalent of fibre (~1.6 tonnes fibres per ha), > 4000 tonnes fibre / year for their non-woven Airlay process.	One player suggested that "within 1-2 years we will be at capacity to consume all of East Yorkshire Hemp fibre, Shiv and flax supplies"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp modular low cost social housing	Several groups, such as Natural Building Systems, and Oscar Cooper are developing modular off-site social housing solutions using hemp materials.	

P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp buildings have been demonstrated in affordable housing schemes and in commercial builds	BRE and suffolk housing association built some hemp houses and BRE hemp house on their site. Total cost of building a hemp house is around £2,000 /m2 which is comparable with other materials. But this ignores the additional insulation benefit. Now scale house builders are beginning to think about hemp builds for 2025. In 2017-18 UK Hempcrete saw a huge increase in enquiries from the commercial sector : hospitals, schools. Springfield Meadows is a multi award-winning project of 25 Climate Positive homes, including 9 affordable houses, located in Southmoor, Oxfordshire by Greencore Construction, awarded One Planet Living Global Leader status, using Biond - an off-site manufactured, closed panel timber frame construction, insulated with Lime-Hemp and natural fibre insulation.	"In next 10 to 20 years selling a house that you don't have to heat will be the issue, not just the price of the house."
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp has cost and health advantages over Passivhaus standards	According to some interviewees Passivhaus, which is often used as the low carbon model for sustainable housing, contains a lot of high tech materials, as well as high embodied energy/carbon to make it operate efficiently. It creates a sealed system, making air quality an issue. Also there can be failures in the materials within a relatively short life span. In hemp based buildings the technology is relatively simple and resilient, and therefore believed to have a long viable lifespan, and the breathability, natural antimicrobial and fire resistant properties, and moisture control inherent to the system results in very high air quality, low chemicals, with low mould and good ventilation.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity for hemp construction products to contribute to retrofitting exsting building stock insulation for carbon efficiency and fire protection	Hemp based natural building products could play a huge role in retrofitting to improve carbon efficiency of existing housing stock, using materials that are both better for the environment and the health and wellbeing of residents. An EU Horizon project, Renofit, including UK partners, plans to develop 3D printed hempcrete to re-insulate high rise buildings with non-flamable material.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp lime plaster: external self-healing render	3mm shiv can be used for hemp lime plaster to render the outside of buildings and is 'self healing'. One interviewee mentioned Ty-Mawr, Wales, who are producing Lime Hemp Plaster made from a high calcium lime (also known as a fat/air/putty or non-hydraulic lime) blended with the hemp fibres and a pozzolan to aid the set.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity for UK manufactured hemp blocks	Hemp blocks are currently all sourced from outside the UK. Hemp Block Co. imports from Senini, N Italy. H G Matthews had attempted to make hemp blocks by hand but it was not economically viable at small scale. Currently there is no lime binder being produced in the UK. The Hemp Block Co. Chesham are experiencing high demand from architects (x 10) for the supply of hemp and natural fibres for house building. The Hemp Block Co, currently import their hemp blocks from Senini N. Italy. They supply three forms of hemp building materials: hempcrete blocks, formed hemp for use in timber and steel framed buildings, and sprayed hemp crete. Hempcrete is a non-structural building material, with excellent breathability and thermal mass. The Hemp Block Co suggest they are well placed with investment to set up and operate a hemp block production plant at their site in Chesham. They would need government or investor support to cover the infrastructure outlay.	"Biggest carbon [sequestration] gains are in hempcrete"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hempcrete spray offers an alternative to hempcrete blocks, giving a solid surface with no gaps.	The solid surface offers the benefit of no gaps for water ingress.	"Biggest carbon [sequestration] gains are in hempcrete"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	UK fibre processing needs support to scale up	The removal of the fibre processing aid program set the fibre market back considerably. To scale up its use it needs to be incentivised, whether through end-user net zero targets and 'green materials' incentives or through supporting UK fibre processing facilities directly to compete against imported, higher footprint materials.	"Removal of the fibre processing aid was a huge problem" "Lots of people want to grow and process hemp, but need to get end market demand"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Marine rope applications to eliminate microplastic risk	There is marine application demand for replacing PP materials, such as ropes, with biodegradable alternatives, such as hemp, especially with the emerging knowledge of microplastic pollution.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Soil Carbon Credits	There was great interest from farmers and researchers in the potential for hemp for carbon sequestration in the soil. Data is being gathered by Cranfield University, but further trials are required to establish the level of carbon sequestration. New soil carbon standards are being developed in the UK. Gentle Farming (https://www.gentle-farming.co.uk/) was mentioned by one interviewee. Also The Carbon Farm (https://carbonfarm.je/) is specifically working on hemp as a soil carbon credit crop with a carbon credit product due to be launched in 2022, and FWAG (Farming and Wildlife Advisory Group) working on a UK Farm and Soil Code for 2022.	"We lack data on exudates, but Gentle Farming group working towards it" "We need to consider 'onward crop benefits' like payment for carbon credits"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Hemp Materials Carbon Credits	There was general consensus that the biggest carbon benefit from hemp would be achieved through capturing hemp shiv and fibres long-term in construction materials. Carbon markets are likely to emerge relating to these carbon negative materials.	"Carbon markets will be important to future farming" "Loft insulation machinery being investigated in Scotland. They have done carbon LCA and found carbon negative even with all farming and processing inputs"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	On-farm compost generation	The increasing interest in organic matter in soils means there is likely to be increasing demand for organic amendments for soils in agriculture. On-farm organic residues from livestock are often are overly rich in high nitrogen matter and can lack carbon, so mixing with stalks of high carbon hemp makes a perfect combination for high quality compost.	"[Can be used to make] compost especially if you add nitrogen rich farmyard manure"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunties around hemp oil in cosmetics, food and feed	Kerfoot Group import hemp seed oil at volume from several countries, but buy from only one UK processor currently. 80% of their hemp seed oil is sold into personal care in the UK e.g. to Stephenson Personal Care, Boots, Body Shop for example, the rest is split between food oil and animal feed/care. Three types of hemp seed oil is supplied - 1. organic cold pressed (seed imported from NZ, Canada and China for processing in EU), 2. Refined (NZ, Canada, China, processed in Netherlands), 3. Unrefined (NZ, Canada, and one UK location tbc). There are several smaller hemp seed growers that are pressing themselves, such as Whole Hemp Foods, North Hemp, and also one larger facility at UK Hemp Ltd that has a capacity of 1000t/year processing, and aim to process 400 tonnes this year. Seed from china was said to be bought at £500 per tonne whereas UK Hemp pay up to £1500 to their UK growers.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	UK textiles industry could be primed for rapid development	The WRAP UK sustainable textiles roadmap is working with organisations across the clothing and textiles sector to collaborate on making rapid, science-based progress on climate action. This fits perfectly with the hemp fibre processing innovations underway, with Harrington Spinks proving the model, and the final pieces being put in place by other players such as East Yorkshire Hemp (https://eastyorkshirehemp.co.uk/) and Seff Fibre (http://seff-fibre.com/seff/), to develop a fully integrated UK textiles market, including manufacturing the processing equipment. This is a clear opportunity for the UK to make a significant reduction in consumer and industry environmental footprints, but the sector needs support from government and engagement from the big brands. An example of industrial use includes Camira, who have used hemp and wool mix for train seat material and other furnishings (https://www.camirafabrics.com/us/fabrics/contract/hemp).	"Seff Fibre has Future Fashion Factory support"

P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Manufacture of light weight high performance structural components for aerospace and rail (mass transport sectors), also the corrugated hemp panels used for exterior cladding on houses.	Cecence manufacture the light weight, high performance seat backs used in aircraft and rail, some made with recycled carbon fibre, blended with hemp fibre. They take the woven or non woven hemp matting and impregnate it with a bioresin made from sugarcane bagasse. They would like to make a bioresin from the sugars in hemp straw, but this needs development trial work. They are exploring with Tatham a machine to produce hemp fibre matting. Cecence made the exterior cladding panels for Margent Farm, using a thermo compression former and bioresin (which is 30% of the overall product). Green Boats is making a fibre glass replacement materials from flax and an epoxy resin used in small sailing boat hulls. They have also used for the Nascelle casing on wind turbines. They have been awarded an I-UK Women in Innovation award to design a natural fibre tray (for aerospace and rail) using hemp fibre. She is part of a network of 10 Women in the sustainable materials space.	"The main barrier is the lack of suppliers to produce woven and non woven materials to the required standard. The handful of natural fibre processers that exist in the UK are not up to the same standard as those in France and Poland". "The other real barrier is the cost of certification of the hemp fibre materials and resins to meet the standards set by BREEAM. Companies like Kingspan can afford the certification costs, so as long as this continues we'll always get the high carbon option that is non breathable".
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity for UK to be the key decortication and fibre producing equipment leaders	Tatham (https://www.tatham-uk.com/) and Wilson Knowles (http://www.wilsonknowlesandsons.co.uk/) manufacture hemp processing technology and infrastructure equipment, established in the UK. Tatham is the only UK decorticator equipment provider in the UK and is one of the leading global suppliers.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunity for hemp fibres in the wet wipe market	A significant market for non-woven hemp fibre could be wet wipes. Tatham (https://www.tatham-uk.com/), Bradford, a leading global non woven equipment supplier, has seen a steep rise in interest for hemp fibre in the non woven wipes market, driven by the recent plan to ban plastics in wet wipes. This market is searching for biodegradable materials. The Canadian Hemp Association also see this as a key market for hemp to replace plastics. UK has active non-wovens expertise with players including John Cotton (https://johncotton.co.uk) in Yorkshire and Warren Non-wovens (https://www.warren-nonwovens.co.uk). The wipe sector falls between the nonwoven and cotton route as it is necessary to soften the fibres ('cottonisation') so they are suitable for wipes.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Significant higher value for seed than fibre	Currently the seed market delivers significantly higher value and margins than stalk materials, but the volumes are lower for seed. It is also harder for growers to access the fibre markets without local processing facilities due to inefficiencies in transporting the bulky raw material	"We are selling seed to processors for around £1000/t (varies). It is much less for fibre"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Seed meal products for livestock or pet feed	Hemp seed meal is being fed to livestock directly on-farm by Whole Hemp Foods or being sold as high fibre animal feed e.g. by UK Hemp Ltd	"Our protein by product is being fed to our livestock"
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunities around hydrogenated oil products	Whole Hemp Foods (https://hempwholefoods.co.uk/), is sending seed oil to Sweden to process it to hydrogenated products for cosmetics and other applications. There is an opportunity to develop this hydrogenation processing in the UK, which they believed is currently absent, to serve soy alternatives markets: e.g. candle wax, soaps, skin balms. The wax product is also good for many other applications e.g. waterproofing. This would replace imported soy derivatives.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	It is not easy to drop-in hemp seed into existing OSR oilseed processing facilities in UK	The lower crop yield (1.5t/ha hemp seed vs >3t/ha rapeseed (OSR)) and lower oil content of seed (25-30% hemp vs 42% rapeseed) makes the economics of hemp very different to OSR. OSR does not require dehulling, so this would be an extra step for any OSR crushing facilities (Cargill in Hull is similar size and also does not have dehulling facilities). Switching between seed types can be done, but a facility would need sufficient seed to make it worthwhile, and that would also depend on the margins etc. OSR rape is also processed at approx. 85degC so not suitable for current hempseed (which is cold press is below 49degC and not heat stable), [Note: the high oleic variety from University of York CNAP may be able to withstand this temperature]	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Development of hemp milk	Gaias Farming has launched a hemp milk product with £200k investment, using a mixture of Canadian, French, Chineses and UK seed. The hemp milk process is: - dehulled to get hearts - shred seeds - mix with water and pasteurise - decant and centrifuge to get liquid (milk) and solid (protein) fractions - Combine with oats/other ingredients and 'bonding agents': sunflower lecithin, acidity regulator, salt, plant oils	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Opportunities for plant based vegan protein	Several interviewees are investigating opportunities around hemp protein for meat alternatives to replace soy. Victory Hemp, UK, has developed V-70™ Hemp Heart 70% Protein, containing all 9 essential amino acids.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	Everyday lifestyle household items can be made using hemp fibre	The Home of Sustainable Things sells hemp products such as coasters, lamps and earrings.	
P3: Product Opportunities	WP6: HEMP PROCESSING INNOV. PROGRAMME	The issue of British produced CBD	There are a handful of specially licensed pharmaceutical CBD sites in the UK, the largest is probably at the British Sugar site in East Anglia. Some interviewees feel that the ability for UK farmers to produce consumer CBD would make a significant diffrence to the industry. However, it was noted by expert growers that generally the process for producing quality CBD crop is very specific, usually involving propogation of individual plants to extend the growing season to get 2 or 3 crops in one season, depending on the regional climate, and then harvesting the flower on the stalk, drying upside down inside to concentrate the CBD before extraction process. If the crop is not managed optimally then the CBD levels will be significantly reduced, making it less economical for extraction. Several experts also felt that imported CBD is too cheap for British growers to compete against. However, others believe that there would be a market for validated premium British branded CBD products of known provenance and quality. UK Extraction companies include: Draganfly, farms and extraction facilities in romania then import to UK (https://dragonflycbd.com/) and Setiva, similar but extraction in Poland (https://www.sativagold.co.uk)	"It is frustrating because Europe have sorted out CBD production but still tricky in UK" "Being able to brand as British would be a bonus"

Hemp30 Phase 2 Work Packages

Priority 1 - New variety development

WP2 HEMP BREEDING PROGRAMME

Development of varieties adapted to UK conditions with characteristics needed by end users. In the first instance this will build on the York advanced breeding platform to develop varieties of hemp with desirable characteristics in their seed oil. Longer term targets will include a range of additional industrial hemp traits such as disease resistance, retting time, seed scattering, and secondary metabolite profile. This WP will take target traits from idea through to field trials and registration of new varieties.

WP3 SEED MULTIPLICATION

Key to successful deployment of new varieties is timely, reliable and resilient bulking of seed.

Priority 2 Expand area of land used for hemp cultivation

WP4 HEMP CROP CHARACTERISATION PROGRAMME

Field trials of existing varieties under UK conditions
Characterisation of hemp as a break crop for wheat

WP5 HEMP YIELD MAXIMISATION PROGRAMME

Evaluation of the use of novel seed and plant treatments to maximise biomass and specific plant components such as fibre, seed, shiv and leaf quantities. Characterisation of soil carbon sequestration and biodiversity effects of hemp

Priority 3 New product development and growth

WP6 HEMP PROCESSING INNOVATION PROGRAMME

Evaluation of before the farm gate innovation opportunities including decortication fibre cottonisation technology, use of on farm anaerobic digestion, biochar production and on farm pelleting of biomass.

WP7 ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACT ASSESSMENT

Analysis of the sustainability (economic, environmental and social) of products and processes that rely on hemp as a raw material eg for construction, textiles, biofuels. This WP will include establishing hemp and its products for carbon credits.

WP8 COMMUNICATIONS PROGRAMME

This will focus on building supply, value and innovation chains for hemp through connecting end users with the primary producers and research providers.

Annex 8

Forecast increase in planted land area and production output as yield improves

Fig 1

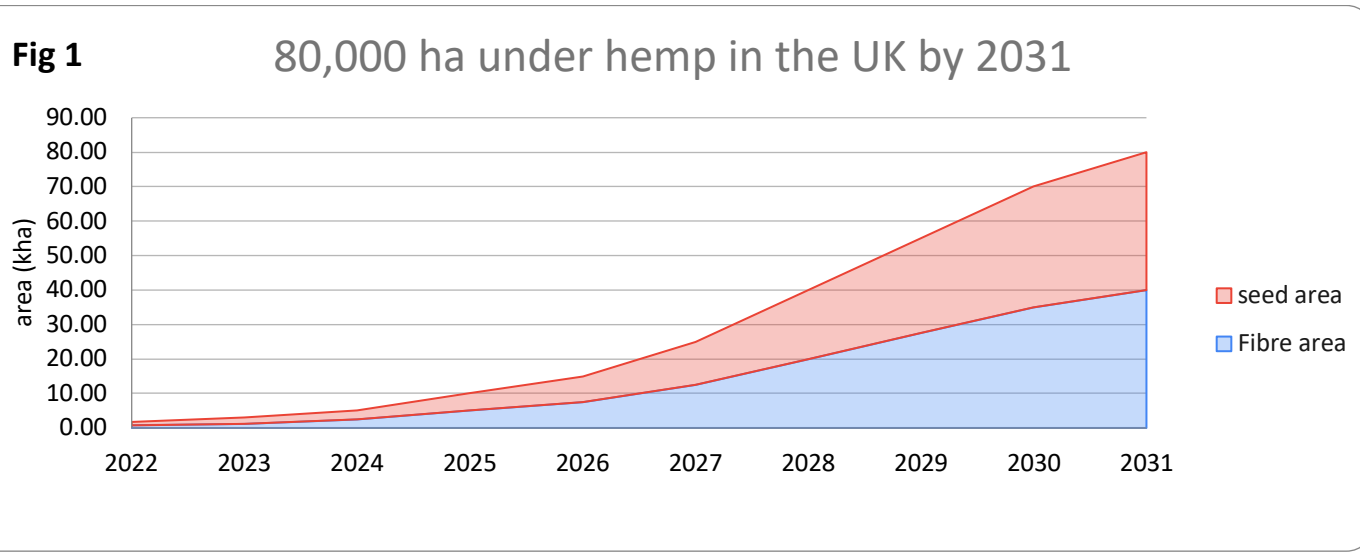
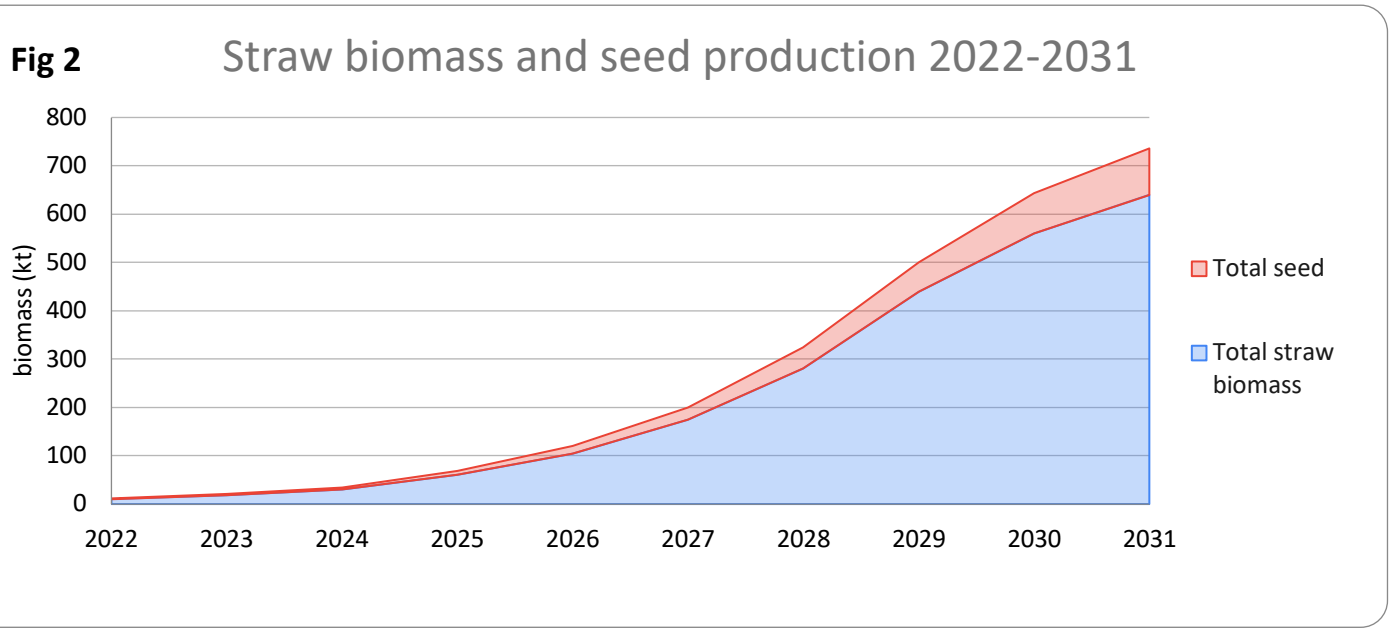
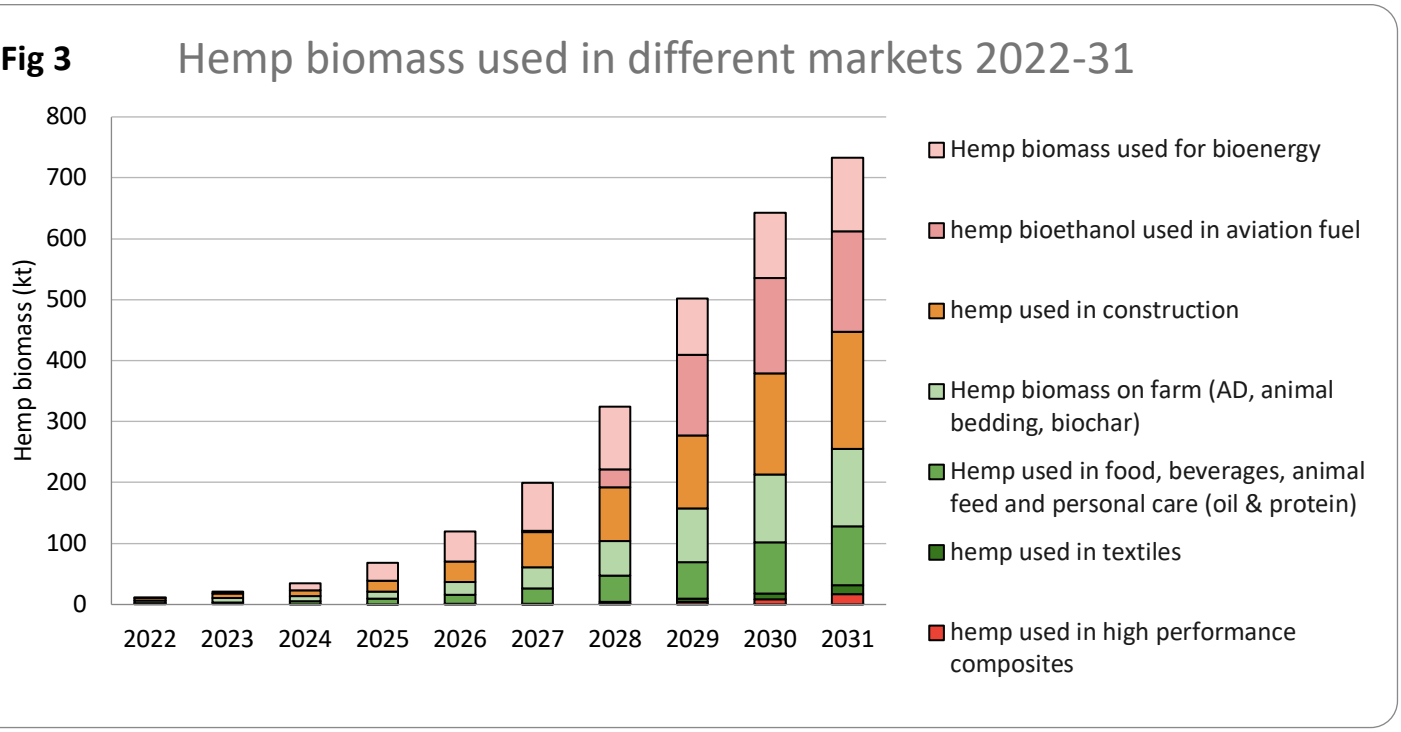


Fig 2



Use of produced hemp

Fig 3



Forecast sales and sales mix detail

Fig 4

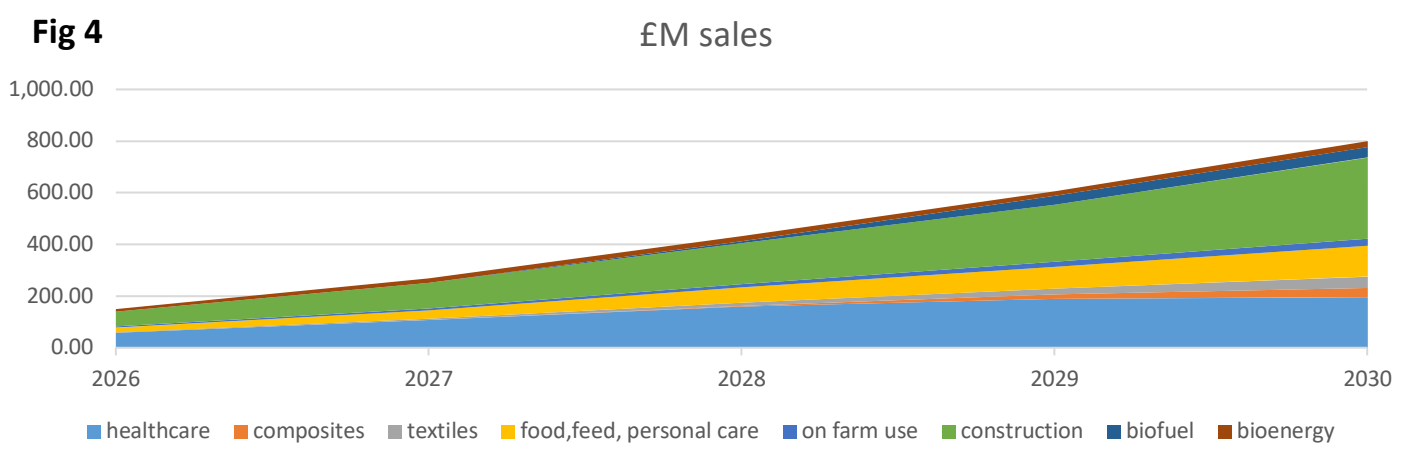


Fig 5 **Overall sales £M**

Caption	2026	2027	2028	2029	2030
Healthcare	57.96	107.46	159.88	190.02	195.72
Composites	0.00	0.73	2.41	15.61	35.80
Textiles	1.28	3.66	12.05	23.41	43.48
Food, feed, personal care	19.04	32.69	59.26	83.92	120.01
On farm use	4.52	7.75	12.78	20.68	27.11
Construction	56.88	99.46	157.90	219.87	313.75
Biofuel	0.00	0.53	7.23	33.60	41.02
Bioenergy	9.44	15.52	21.02	19.31	22.91
Total	**149.11**	**267.79**	**432.53**	**606.41**	**799.79**

Commercialisation Result

Fig 6

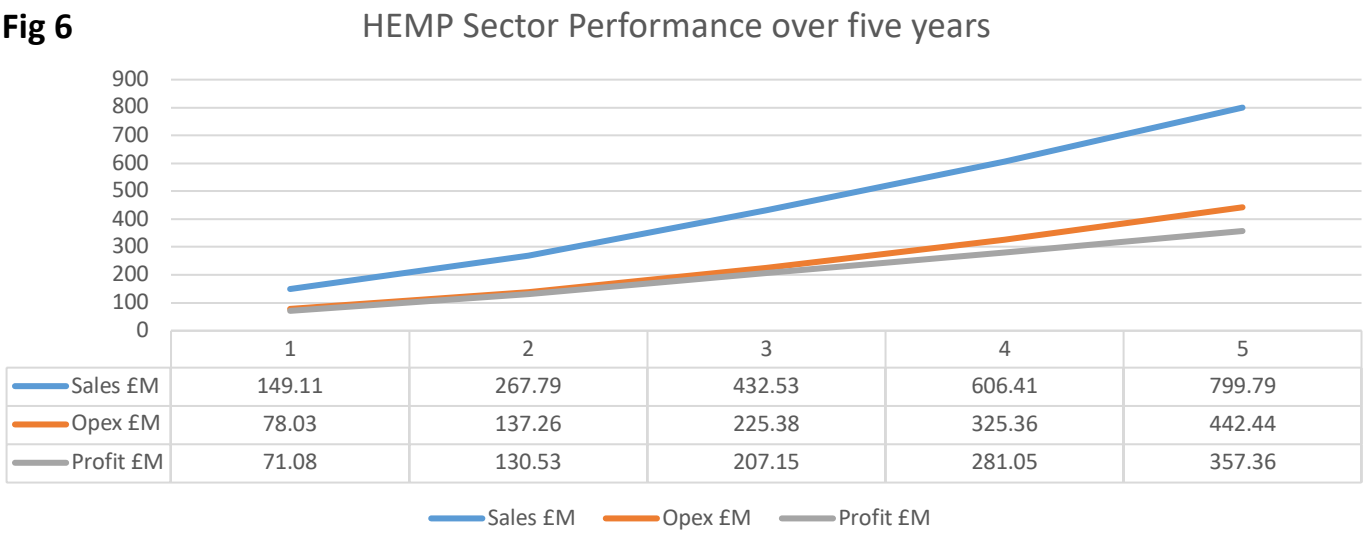


Fig 7 **Assumptions**

Production
Area of land under cultivation grows to 80Kha
Biomass yield increases from 7 to 8 t/ha as efficiencies are realised
Sales
Sales mix matures from bioenergy / fuels emphasis to higher value product emphasis
Per-Kg value of sales mix captions increases only by 3% annual inflation

Opex
Crop establishment, ongoing and harvesting costs based on known existing similar crop costs
Establishment of trade association during phase II work.
Assumed opex margin per sales mix individually assigned per caption.
Opex margin stays constant throughout model.
Capex
Capex is based around a £5M investment at the start of phase II adapt existing plant / facilities.

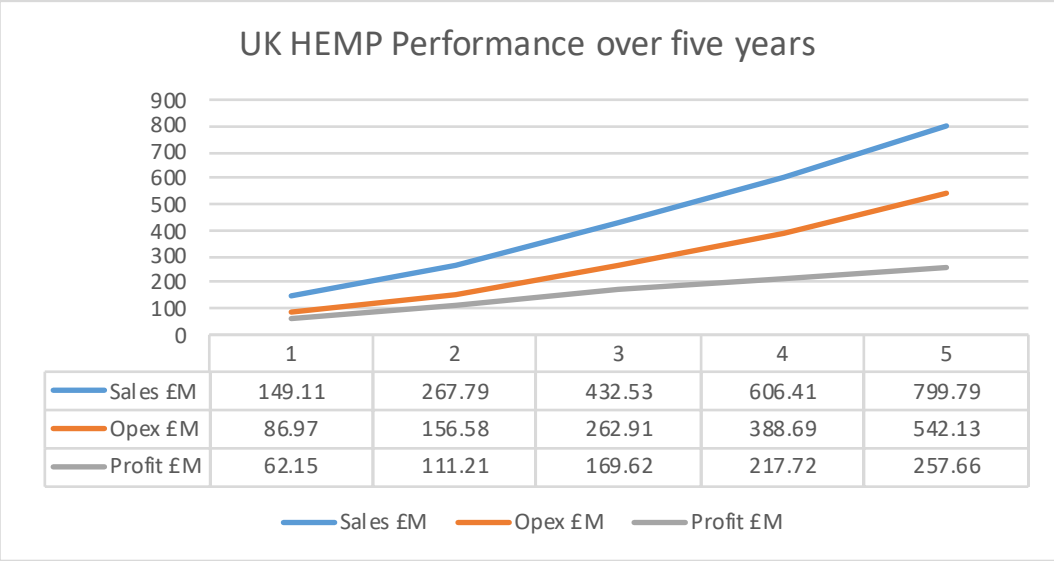
Annex 9 Hemp-30 Business Model

hemp-30

Business Model

UK Hemp Cashflow

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Sales	7.12	14.48	23.80	54.65	149.11	267.79	432.53	606.41	799.79
Opex	5.68	11.42	19.19	42.38	86.97	156.58	262.91	388.69	542.13
Result	1.44	3.06	4.61	12.27	62.15	111.21	169.62	217.72	257.66
Tax Patent	-0.07	-0.15	-0.23	-0.61	-3.11	-5.56	-8.48	-10.89	-12.88
Tax non	-0.14	-0.29	-0.44	-1.17	-5.90	-10.56	-16.11	-20.68	-24.48
Deprec protection	0.21	0.44	0.67	1.78	9.01	16.13	24.59	31.57	37.36
Cashflow	**1.4**	**3.1**	**4.6**	**12.3**	**62.1**	**111.2**	**169.6**	**217.7**	**257.7**



Terminal value
7,390.3

NPV	£4,671	M
Capex	5	M
Final NPV	£4,666	M

UK Hemp Sales

Inflation	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%

	1	2	3	4	5	6	7	8	9
	2022	2023	2024	2025	2026	2027	2028	2029	2030
healthcare	0.00	0.00	1.09	5.63	57.96	107.46	159.88	190.02	195.72
composites	0.00	0.00	0.00	0.00	0.00	0.73	2.41	15.61	35.80
textiles	0.00	0.00	0.00	0.47	1.28	3.66	12.05	23.41	43.48
food, feed, personal care	1.77	3.14	5.38	11.09	19.04	32.69	59.26	83.92	120.01
on farm use	0.00	0.00	1.82	2.51	4.52	7.75	12.78	20.68	27.11
construction	5.10	10.87	13.33	29.49	56.88	99.46	157.90	219.87	313.75
biofuel	0.00	0.00	0.00	0.00	0.00	0.53	7.23	33.60	41.02
bioenergy	0.25	0.47	2.16	5.46	9.44	15.52	21.02	19.31	22.91
Total	**7.12**	**14.48**	**23.80**	**54.65**	**149.11**	**267.79**	**432.53**	**606.41**	**799.79**

UK Hemp Opex

	1	2	3	4	5	6	7	8	9
K Hectares	1.8	3.0	5.0	10.0	15.0	25.0	40.0	55.0	70.0
Inflation		3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%	3.00%

	1	2	3	4	5	6	7	8	9
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Establishment (£M)	0.70	1.25	2.14	4.41	6.81	11.69	19.26	27.28	35.76
Ongoing (£M)	1.26	2.23	3.83	7.89	12.19	20.93	34.49	48.84	64.03
Harvest (£M)	0.31	0.54	0.93	1.91	2.96	5.07	8.36	11.84	15.53
healthcare	0.00	0.00	0.24	1.27	13.44	25.66	39.33	48.14	51.07
composites	0.00	0.00	0.00	0.00	0.00	0.44	1.48	9.88	23.36
textiles	0.00	0.00	0.00	0.21	0.59	1.75	5.93	11.86	22.69
food, feed, personal care	0.71	1.33	2.35	4.99	8.83	15.61	29.15	42.52	62.64
on farm use	0.00	0.00	1.00	1.41	2.62	4.63	7.86	13.10	17.68
construction	2.55	5.77	7.28	16.60	32.97	59.38	97.10	139.26	204.69
biofuel	0.00	0.00	0.00	0.00	0.00	0.31	4.45	21.28	26.76
bioenergy	0.15	0.30	1.42	3.69	6.57	11.12	15.51	14.68	17.93
Trade Association	0.25								
Total	5.68	11.42	19.19	42.38	86.97	156.58	262.91	388.69	542.13

EXPANSION OF CULTIVATION

Area under hemp 2022 - 2031

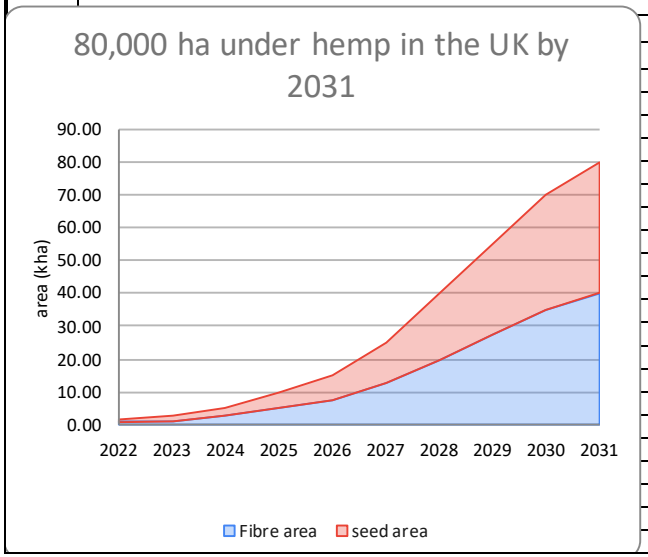
Unit	year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
kha	Total area	1.80	3.00	5.00	10.00	15.00	25.00	40.00	55.00	70.00	80.00
kha	Fibre area	0.72	1.20	2.50	5.00	7.50	12.50	20.00	27.50	35.00	40.00
kha	seed area	1.08	1.80	2.50	5.00	7.50	12.50	20.00	27.50	35.00	40.00

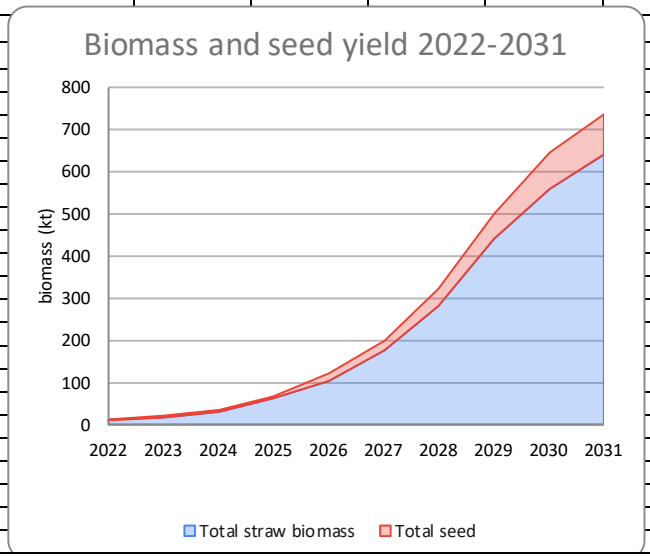
Biomass and seed yield 2022 - 2031

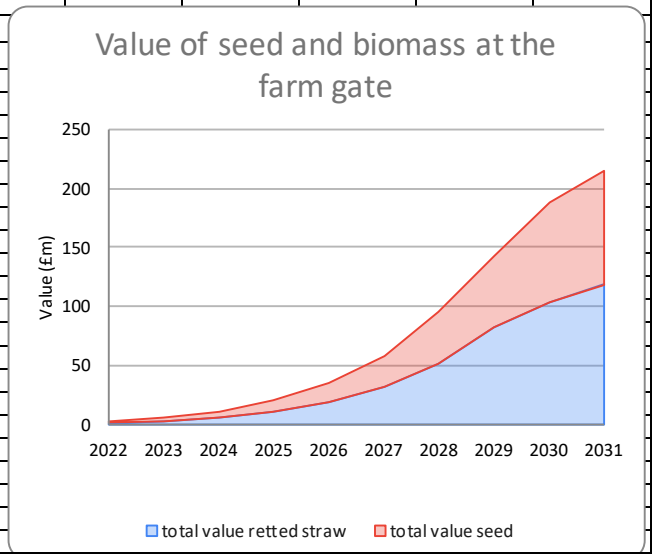
		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
t/ha	*biomass yield/ha*	*5.5*	*6*	*6*	*6*	*7*	*7*	*7*	*8*	*8*	*8*
kt	Total straw biomass	9.9	18	30	60	105	175	280	440	560	640
t/ha	*seed yield/ha*	*1.5*	*1.5*	*1.8*	*1.8*	*2*	*2*	*2.2*	*2.2*	*2.4*	*2.4*
%	*% hemp cultivated for seed production*	*60%*	*60%*	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*
kt	Total seed	1.62	2.7	4.5	9	15	25	44	60.5	84	96

Value at the farm gate

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
£k/t	seed	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
£k/t	retted straw or pellets	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186
£m	total value seed	1.620	2.700	4.500	9.000	15.000	25.000	44.000	60.500	84.000	96.000
£m	total value retted straw	1.841	3.348	5.580	11.160	19.530	32.550	52.080	81.840	104.160	119.040



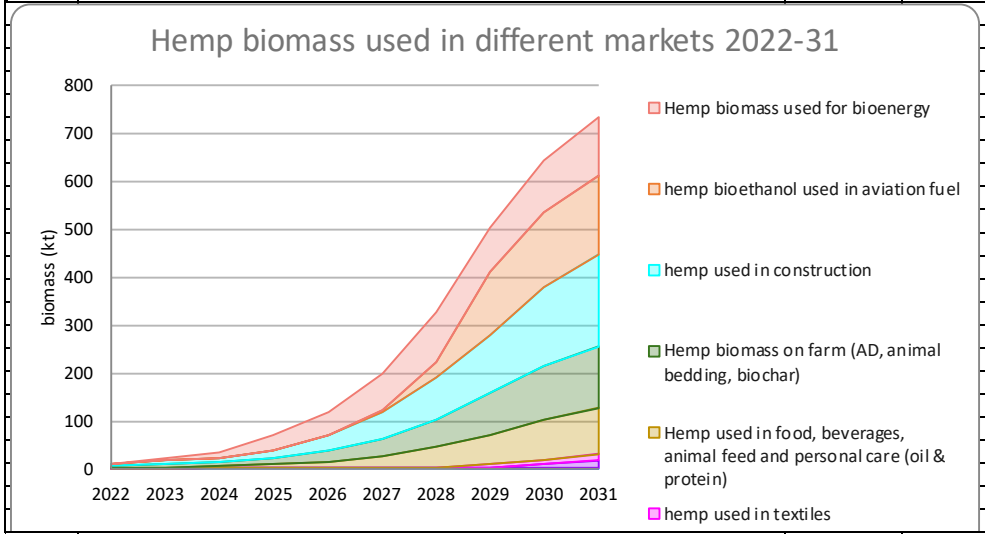


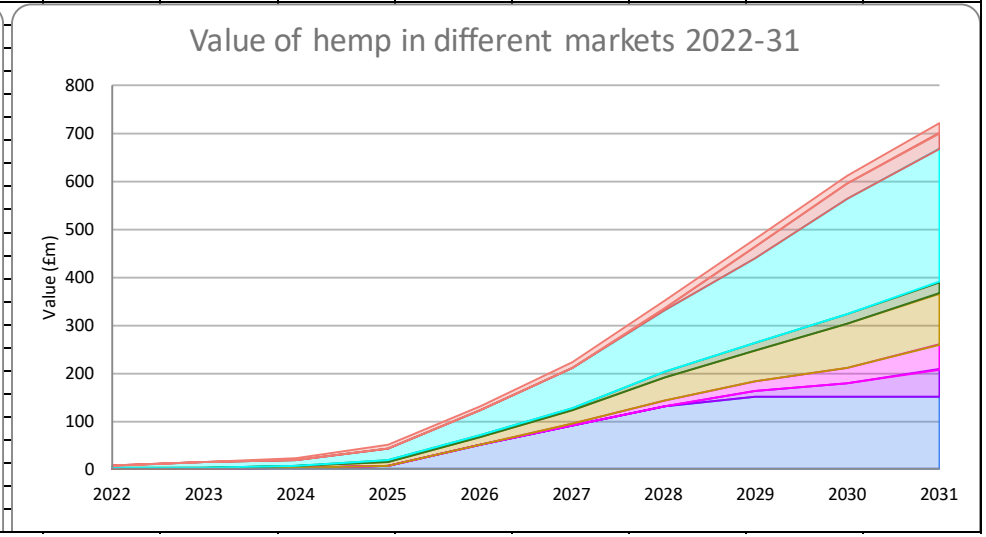


EXPANSION OF MARKETS FOR HEMP

	Biomass used in different markets 2022 - 2031	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Unit	**Hemp cultivation (kha)**	**1.8**	**3**	**5**	**10**	**15**	**25**	**40**	**55**	**70**	80
kt	hemp used in healthcare products	0	0	0.001	0.005	0.05	0.09	0.13	0.15	0.15	0.15
kt	hemp used in high performance composites	0	0	0	0	0	0	1	4	8	17
kt	hemp used in textiles	0	0	0	0	0	1	3	5	10	15
kt	Hemp used in food, beverages, animal feed and personal care (oil & protein)	2	3	5	9	15	25	44	61	84	96
kt	Hemp biomass on farm (AD, animal bedding, biochar)	5	8	9	12	21	35	56	88	112	128
kt	hemp used in construction	4	8	9	18	34	57	88	119	165	192
kt	hemp bioethanol used in aviation fuel	0	0	0	0	0	2	29	133	157	164
kt	Hemp biomass used for bioenergy	1	3	12	29	49	79	104	92	106	122
kt	Total Biomass used	10	18	30	60	104	174	281	441	558	638
kt	*Biomass used minus yield of biomass from ha grown (kt)*	*0*	*0*	*0*	*0*	*-1*	*-1*	*1*	*1*	*-2*	*-2*

	Value of hemp in different markets 2022-31	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
£m	healthcare	0	0	1	5	50	90	130	150	150	150
£m	composites	0	0	0	0	0	1	2	12	27	58
£m	textiles	0	0	0	0	1	3	10	18	33	52
£m	food,feed, personal care	2	3	5	10	16	27	48	66	92	105
£m	on farm use	0	0	2	2	4	6	10	16	21	24
£m	construction	5	10	12	26	49	83	128	174	240	279
£m	biofuel	0	0	0	0	0	0	6	27	31	33
£m	bioenergy	0	0	2	5	8	13	17	15	18	20

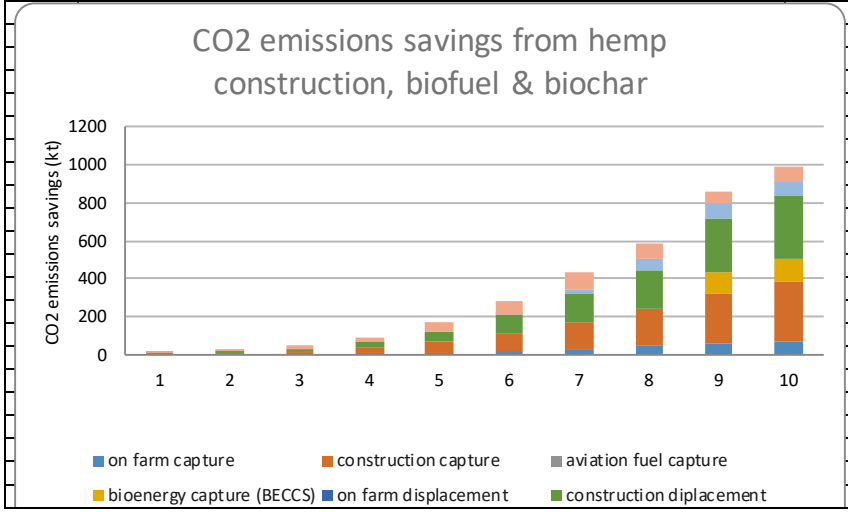


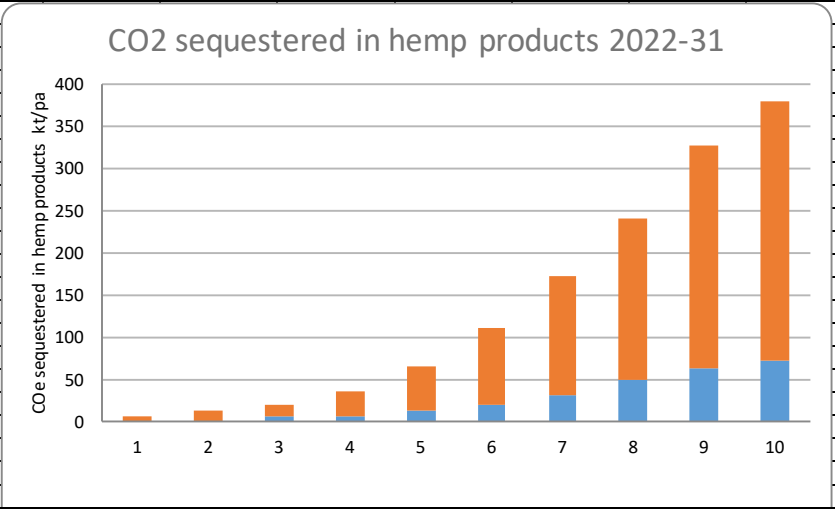


	CO2 displaced by use of hemp products	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
	healthcare										
	composites										
	textiles										
	food,feed, personal care										
	on farm use										
kt	construction	7	13	16	31	58	99	152	206	285	332
kt	biofuel	0	0	0	0	0	1	14	61	72	76
kt	bioenergy	1	2	11	26	43	69	91	81	69	79

	CO2 sequestered in hemp products	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
t	healthcare										
t	composites										
t	textiles										
t	food,feed, personal care										
kt	on farm use			5	7	12	20	31	49	63	72
kt	construction	6	12	14	29	54	92	141	191	264	307
kt	biofuel										
kt	bioenergy										

	CO2 displaced and sequestered by construction, biochar, fuel and bioenergy										
	CO2 displaced and sequestered by construction, biochar, fuel and bioenerg	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
kt	on farm capture	0	0	5	7	12	20	31	49	63	72
kt	construction capture	6	12	14	29	54	92	141	191	264	307
kt	aviation fuel capture	0	0	0	0	0	0	0	0	0	0
kt	bioenergy capture (BECCS)									107	123
kt	on farm displacement	0	0	0	0	0	0	0	0	0	0
kt	construction diplacement	7	13	16	31	58	99	152	206	285	332
kt	aviation fuel displacement	0	0	0	0	0	1	14	61	72	76
kt	bioenergy displacement	1	2	11	26	43	69	91	81	69	79





	% biomass used in different markets (this feeds figures for "biomass used in different markets")										
%	hemp used in healthcare products										
%	hemp used in high performance composites	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	0.20%	0.80%	1.40%	2.60%
%	hemp used in textiles	0.00%	0.00%	0.00%	0.20%	0.30%	0.50%	1.00%	1.20%	1.70%	2.30%
%	Hemp used in food, beverages, animal feed and personal care (oil & protein)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
%	Hemp biomass on farm (AD, animal bedding, biochar)	47.00%	43.00%	30.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%
%	hemp used in construction	38.00%	42.00%	30.00%	30.00%	32.10%	32.70%	31.50%	27.10%	29.50%	30.00%
%	hemp bioethanol used in aviation fuel	0.00%	0.00%	0.00%	0.00%	0.00%	1.26%	10.50%	30.14%	28.07%	25.69%
%	Hemp biomass used for bioenergy	15.00%	15.00%	40.00%	49.00%	47.00%	45.00%	37.00%	21.00%	19.00%	19.00%
	checking % add up	*1.00*	*1.00*	*1.00*	*0.99*	*0.99*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
unit	Seed components - oil, protein, protein, carbohydrate										
%	*Seed oil content*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*
kt	Total seed oil	0.486	0.81	1.35	2.7	4.5	7.5	13.2	18.15	25.2	28.8
%	*Seed protein content*	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
kt	Total seed protein	0.486	0.81	1.35	2.7	4.5	7.5	13.2	18.15	25.2	28.8
%	*seed carbohydrate*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*	*30%*
kt	*seed carbohydrate*	0.486	0.81	1.35	2.7	4.5	7.5	13.2	18.15	25.2	28.8
%	*seed fibre*	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
kt	*seed fibre*	0.162	0.27	0.45	0.9	1.5	2.5	4.4	6.05	8.4	9.6
	Checking seed components add up	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
unit	Stem components - fibre hurds an dust										
%	*fibre yield (% of biomass)*	*25%*	*25%*	*25%*	*25%*	*25%*	*25%*	*25%*	*25%*	*25%*	*25%*
kt	total fibre	2.475	4.5	7.5	15	26.25	43.75	70	110	140	160
%	*hurds (% biomass)*	*60%*	*60%*	*60%*	*60%*	*60%*	*60%*	*60%*	*60%*	*60%*	*60%*
kt	total hurds	5.94	10.8	18	36	63	105	168	264	336	384
%	*dust (% biomass)*	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*
kt	total dust	1.485	2.7	4.5	9	15.75	26.25	42	66	84	96
	checking biomass adds up	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Unit	Value of products from 1 ton hemp	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
£/t	healthcare	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
£/t	composites	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
£/t	textiles	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
£/t	food,feed, personal care	1,095	1,095	1,095	1,095	1,095	1,095	1,095	1,095	1,095	1,095
£/t	on farm use			186	186	186	186	186	186	186	186
£/t	construction	1,356	1,356	1,356	1,456	1,456	1,456	1,456	1,456	1,456	1,456
£/t	biofuel	200	200	200	200	200	200	200	200	200	200
£/t	bioenergy	165	165	165	165	165	165	165	165	165	165

Annex 10

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