FINAL REPORT:
Technology Mapping for the Australian Industrial Hemp Industry

A Final Report from the Food Agility project:
Agriculture Production System Technology Mapping

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Technology mapping for the Australian industrial hemp industry

EXECUTIVE SUMMARY

This study addresses the Australian industrial hemp industry's technological constraints and opportunities. The current situation in the hemp value chain is mapped to actual and potential technologically based and organisational opportunities. A review of available literature on selected gaps and opportunities is accompanied by field-level consultation to present practical aspects of the value chain, and the production and marketing system. Readiness of technologies are assessed with the CRAM tool. Using a simple 2-stage model of the value chain, disaggregated to capture diverse scale, cost structures and farm types, projections of financial implications of change in the value chain are made. The focus of the review aspects of the study is hemp fibre, rather than hemp grains and the hemp food value chain. The analytic emphasis is the whole-of-chain view of hemp industry development opportunities, as they are influenced by technologies and organisational changes needed. The main conclusions are:

1. a significant number of technologies are in use in related industries or applications, but require last-mile additional research and development to achieve readiness for hemp
2. several organisational models were identified in the literature and from discussion with stakeholders, and these are suited to further research by means of trials
3. a lack of information flows along the hemp value chain constrains developments in product differentiation, in exposure of the industry to carbon markets, and in the advance towards a modernised digitally based THC testing regime to replace current procedures
4. engagement with regulators should extend to researchers, particularly to advance recommendations about deployment of technology in regulatory compliance
5. productive and profitable hemp fibre value chains require a high-capacity utilisation for processors. This is most pronounced for small scale processors, but for all sizes a network-type effect can be identified whereby producers benefit from recruitment of additional producers to the processor they supply.
6. product descriptions and quality standards are lacking for bast fibre, which bodes poorly for possible oversupply conditions
7. current THC testing procedures impose significant costs on producers and are unsustainable in a growing hemp industry
8. relocation of some fibre processing to be close to farms can generate cost savings which potentially raise prices paid to producers and save the industry large sums on aggregate transport costs
9. scope exists for sharing of costs and cost savings between processor and producer so as to maintain processing viability
10. scope exists for recruitment of committed producers to ownership of processing plant, to mobilise industry expansion.

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1. INTRODUCTION

1.1 Background

Industrial hemp – which for current purposes excludes medicinal and drug-related end uses - comprises three inter-related value chains:

- Food, centred on grain production
- Hurd fibre
- Bast fibre

Australian hemp production patterns have generally featured geographic separation of grain and fibre production. Localities well equipped with handling facilities for grains and oilseeds more generally, and the machinery and irrigation infrastructure associated with their production, have produced hemp grain. Planted areas have been small. Isolated claims are heard, of producers sowing hemp crops with no thought to markets.

Production requirements are in general no more demanding than those of any cash crop, although producers profess a learning process which must accommodate the somewhat "wild"[1] (varying in phenotype and genotype, with varying responses to management action) nature of the crop. Adequate water and fertiliser are recognised as essential, with some localised conditions requiring chemical inputs. Reliable access to reliable seed represents two other constraints mentioned by producers, and is linked to the problems of variation within the crop and between crops.

All hemp production faces costs and potential disruption due to licensing, product testing, and a short list of crop and product management regulations. Regulatory action is the responsibility of state agricultural authorities, who in general enjoy excellent and productive relations with producers. This reflects a strongly positive view of the prospects for hemp as an earner of farm income, a contributor to regional development, as a natural and/or compostable ingredient or input to industrial processes, and as a carbon sink both in production and use. A certain populism in politics, reflecting negative views on the cannabis plant, remains a constraint to marketing and hence further development.

Grain production utilises well established technology and practice at production, harvest and processing stages. Problems persist on topics such as exacting and timely grain drying needs associated with oil quality. The state of the retail market, variously described as vibrant, yet slim, is a cause of fluctuations precipitating a link to hurd and bast supply. Active research areas include plant breeding and agronomic improvements targeting better varieties; defined variously as locally and climatically adapted, providing whole-of-plant use, and dual purposes.

Fibre production encounters technological barriers. Cutting and harvest equipment has needed to be developed which is specific to the crop, and the machines tend to be home-made in Australia. Procedures for retting straw are still in development, and although not dependent on a technology, do address timing of operations and the role of dual purpose crops. Baling faces issues of cut stem, and so bast fibre, length. Fibre extraction takes two general alternate forms, using either a hammer mill or a roller-based decorticator, with implications for hurd and bast form and characteristics. These capital intensive technologies, in association with geographically diffuse production volumes, call for technological-organisational solutions referred to below as aspects of "business models", rather than purely technological solutions.

Market demand is termed here localised for hurd, but internationalised for bast. Hurd quality parameters are then internalised between buyer and seller in the value chain, while for bast the

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[1] This term was used by a number of stakeholders, and is supported by research (Schluttenhofer & Yuan, 2017).

quality criteria are unclear pending large scale market uptake of Australian fibre by international buyers. Opportunities for bast processing for apparel textiles include use of existing wool and cotton spinning equipment, and this is under investigation in on-going research. The current absence of a ready market for bast calls for its being stockpiled, which in turn requires a compact, compact and readily tradeable product form which can be transported at a reasonable cost. Downstream potential uses including industrial applications have been examined rather little for the financial viability. The many uses of hurd fibre call for consideration of the value being added and the potential for downstream technological advance to reduce costs and/or improve productivity.

By-products or quasi-waste materials are in general not discarded along the value chain due to their widely recognised inherent usefulness. Harvest, processing and handling technologies deliver these in varying quantities and qualities, and grazing is being examined by researchers as a productive use of crop residues. The share of value associated with the main hemp products remain unclear at the time of writing, but these will need to be reconciled with the economics of processing to pursue an optimum product mix and reduced volumes of by-products destined for low valued uses.

Hemp's status as a somewhat environmentally friendly and sustainably-produced crop has been little exploited in marketing, nor in policy and community dialogues on climate change. Potential Australian differentiating factors – such as non-use of chemical retting for fibre, and ploughing in of residues – have to date not been identified in product profiles and associated information flows.

1.2 Purpose of the study

The current study addresses the Australian industrial hemp industry's technological constraints and opportunities. It maps the current situation in the industry's several value chains to actual and potential technologically-based improvements associated with tasks conducted by the value chain's actors. Technologies are selected for further analysis, and the associated state of knowledge is presented from literature review. Specific technologies are assessed for readiness for uptake, and for their apparent impact on producers. Particular attention is paid the structures and governance around transactions and asset ownership: the business models which might be applied.

Conclusions are drawn about selected technologies and their likely contribution, their readiness and the combinations in which they may be adopted, and the organisational arrangements which might accompany their adoption. The study identifies facilitating factors in delivery of enhanced adoption of desirable technologies, and priorities for research into new technologies and the supporting knowledge base.

1.1 Methods

The study entails a set of industry consultations with key stakeholders to identify the current value chain environment, and associated problems and opportunities. Its focus is on the tasks along various supply chains to add value to industrial hemp. Literature review is used to identify current and likely future technologies. Emphasis is given to task sets in the value chain which are not receiving intensive research attention: for this reason the current work on plant breeding and varieties is not reviewed in detail, but its central aspects are identified for analysis. The components are mapped together to designate particular technologies for further analysis. An assessment of technology readiness is conducted for the technologies designated for further analysis.

A financial model of the industrial hemp value chain up to primary processing is presented. Commentary is provided on hurd and bast value chains beyond this point. The analysis is driven strongly by assumptions about technical parameters that although informed by stakeholder consultation, remain the subject of active research. It employs yet more assumptions in projecting the impacts of technology, the components of which also are the subject of ongoing research. A number of organisational aspects of the industry are identified and discussed, and in some cases included in the analysis. Conclusions are drawn about desirability of the technologies, changes needed to facilitate adoption, and future research.

1.2 Outline of study

This report has seven sections. Section 2 addresses hemp production and technologies. As noted above, the intensively researched production-oriented tasks receive less attention in the review than other value addition tasks. Section 3 sketches the stages and value-adding tasks of the jackfruit value chain and section 4 maps these items together. Section 5 presents the gross margins calculated along the value chain as a base case and discusses the analysis of scenarios associated with technological changes. The results are presented in Section 6. Section 7 synthesises the study and draws conclusions about technology priorities and future research.

2 PRODUCTION AND TECHNOLOGIES

2.1 Production

2.1.1 Genetic basis

Genetic analysis has left some uncertainty surrounding the extent to which industrial hemp and cannabis are genetically distinct, due to the pronounced genetic variation seen in industrial hemp (Lynch et al., 2016; Rupasinghe, Davis, Kumar, Murray, & Zheljazkov, 2020). A dual DNA and hempseed embryo extraction process characterised successfully different Canadian varieties (Soler et al., 2016) according to type. Several laboratory-based tests are available for delineating the two plant types, several of which target the genetic basis for THC synthesis in the plant (Kitamura, Aragane, Nakamura, Watanabe, & Sasaki, 2017). However other research suggests that the genetic distinction may not entirely reflect plants' observed THC synthesis (Sawler et al., 2015).

2.1.2 Breeding of hemp for commercial purposes

A review article aligning breeding goals and methods with Canadian, European and Chinese hemp fibre industry contexts is available (Elma M. J. Salentijn, Zhang, Amaducci, Yang, & Trindade, 2015). Chinese and European production systems have also been compared in substantial detail with regard to crop husbandry and management (S. Amaducci et al., 2015).

Fibre quality, as represented fundamentally by structures observed in the harvested plant (Bonatti et al., 2004), have been mapped to specific quantitative trait loci, and a large number of hemp varieties have been classified according to this genetic potential (Petit et al., 2020). Genes associated with bast and hurd production have been identified (van den Broeck, Maliepaard, Ebskamp, Toonen, & Koops, 2008; Zhao et al., 2022). A protocol for RNA extraction from bast fibres has been developed (Guerriero, Mangeot-Peter, Hausman, & Legay, 2016). For research purposes, imaging technologies have been applied in relating quality-related fibre bundle and fibre characteristics to known genetic and agronomic variation, to predict fibre quality (Müssig & Amaducci, 2018). An extensive physical classification exercise has also aligned various hemp fibre characteristics and production traits to genetic markers (Amarasinghe et al., 2022).

A particular call for accelerated genetic research on hemp (Schluttenhofer & Yuan, 2017) addresses its relative lack of domestication. Hence these authors encourage molecular biological research and investigation of the potential for sex manipulation to improve yields and production characteristics. Sex differentiation research of hemp has included identification of polymorphism between X and Y chromosomes and amongst X (Rode et al., 2005). An updated status of biotechnological developments regarding industrial hemp has been prepared by Hesami et al (Hesami et al., 2020).

2.1.3 Seeds

Seed storage and preservation, and packaging methods, are known to have considerable influence on viability at sowing (Suriyong, Krittigamas, Pinmanee, Punyalue, & Vearasilp, 2015). Machine vision technology has been developed for assessing seed quality across several domains for hemp seeds for food uses, as well as in sowing applications (Ola, Mănescu, Cristea, Budde, & Hoffmann, 2013).

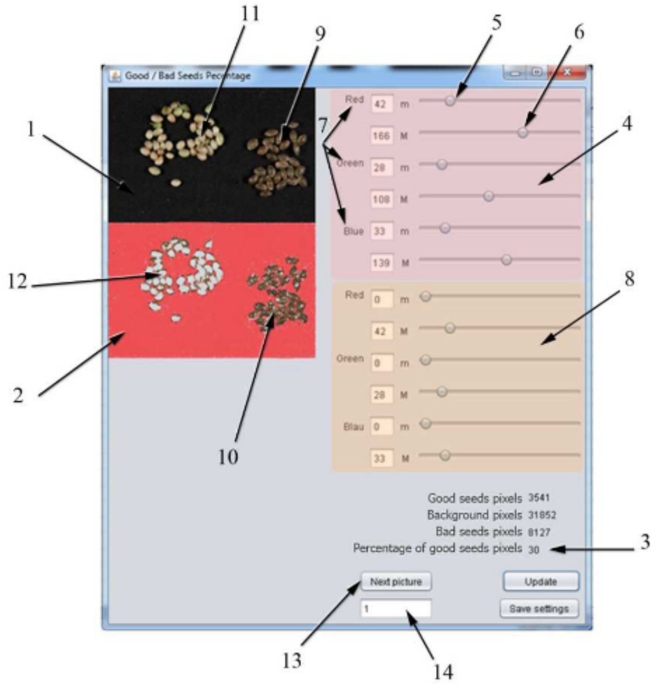


Fig.6. Graphic user interface for the software that analyzed the images acquired for the seed probes. 1 – original image of the seeds sample used for calibration; 2 – processed image with the filters active; 3 – percentage result for the quality evaluation of the probe; 4 – sliders used to define the values for the background pixel selection; 5 – minimum limit for the color of the pixels on the red channel; 6 – maximum limit for the color of the pixels on the red channel; 7 – the sliders of the RGB channels for the background selection; 8 - sliders used to define the values for the good seeds pixel selection; 9 – the good seeds as seen in the original image; 10 – the good seeds as seen when selected by the filter algorithm; 11 – the bad seeds in the original image; 12 – the bad seeds selected and highlighted with gray color by the selection algorithm; 13 – loading the next picture button; 14 – text field showing the picture number.

Figure 1. User interface for machine vision imagery on seed quality (Ola et al., 2013)

2.1.4 Agronomy

Farm management information is available from several recent reviews, and should be viewed alongside forthcoming Agrifutures' best practice manuals.[2] A predictive model for hemp crops' productive performance was developed by Baldini et al. for use in matching hemp varieties to localities (Baldini, Ferfuia, Zuliani, & Danuso, 2020). Management of nitrogen fertilisation of hemp is informed by the development of a nitrogen dilution curve and associated management guidelines adjusted for plant density (Tang et al., 2017). Fertilizer needs for US hemp production have been reviewed and synthesised by Wyllie et al. (Wylie, Ristvey, & Fiorellino, 2021). Initial examination of herbicides, specifically herbicide tolerance, for US hemp crops has been conducted (Flessner, Bryd, Bamber, & Fike, 2020). A listing of fungal pathogens of bast fibre crops based on their molecular biology, and associated management options, has been prepared (Cheng et al., 2020).

Interest in pest control for hemp centres on the pests' targeting of valuable plant parts (stems and flowers) and the tendency for stressed plants to increase THC levels. A US study lists the arthropod pests of hemp, and assesses the related threats posed to hemp crops by climate change, with a case study of corn earworm (Ajayi & Samuel-Foo, 2021). These authors also draw the reader's attention to studies showing that pest infestation is a factor in new or inexperienced growers' exit from the industry.

[2] Forthcoming at the time of writing.

Production and the value chain for hemp grains is largely able to use existing agronomic, field and logistics technologies, and adaptions of equipment such as mowers and harvesters are adopted either as farm workshop modifications or as imported machines. On-going agronomic research into new varieties and improved husbandry, increased scale of operation and numbers of producers, and a more general standardisation of the plant within and between crops, are all likely to align existing machinery to the necessary tasks.

Dual purpose hemp crops have been found to yield fibre and seed in ratios related to sowing dates, and performance is also influenced by the plant sex (Faux et al., 2013). Timing of harvest for fibre, particularly in relation to flowering date, is important many fibre performance measures and have implications for value of dual use varieties (Burton, Andres, Cole, Cowley, & Augustin, 2022; Musio, Mussig, & Amaducci, 2018; Vandepitte et al., 2020). Particular attention to the link between flowering and fibre quality, and its implications for plant breeding are summarised by (E. M. J. Salentijn, Petit, & Trindade, 2019). The timing of harvest with respect to flowering has been the subject of modelling effort to optimise fibre yield and quality, with models' performance being satisfactory overall, but less so at extreme latitudes (Stefano Amaducci et al., 2012). Dual use hemp crops are also more constrained in the timing and duration of retting, due to adherence to the flowering timetable (Mazian, Bergeret, Benezet, & Malhautier, 2019).

2.1.5 Retting

Bacteria and fungi present and functioning during retting, and their proportions, have been recorded and attributed to local growing conditions (Ribeiro et al., 2015). Metagenomics of the retting microorganisms have been compiled (Djemiel et al., 2020). Scanning electron microscopy has been used to characterise the changes undergone by hemp stems during field retting and the implications for microbial populations and their actions (Fernando, 2019).s

The role of micro-organisms in retting, and potential manipulation of the paddock environment and the plant's microbiome, have been examined as a means of establishing retting regimes to improve the consistency of fibre quality in processing (Law, McNees, & Moe, 2020; Valladares Juarez et al., 2009). Some research suggests that effective control of the retting process enhances the usefulness of short bast fibres in composites' uses (Réquilé, Duigou, Bourmaud, & Baley, 2019). Retting's microbial growth may discolour and otherwise affect hurd quality (Kymalainen, Koivula, Kuisma, Sjoberg, & Pehkonen, 2004), including its CO_2 fixing properties (Butkutė et al., 2015). Problems posed by the presence of immature flower heads in the retting process for cut stems have led to the proposed use of pre-harvest removal of flower heads using an elevated mower (Bruce, Hobson, White, & Hobson, 2001).

Various forms of retting have been compared, with dew retting a generally favoured option despite the large number of variables not under management control. Opinion is divided as to the length of time dew retting might last, with literature spanning 7-28 days. Stand retting has been advocated for areas less suited to dew retting (for example where microorganism growth is excessive for straw quality), and where field days can be saved in the rotation, and where forage-harvesting equipment can be diverted to hemp (Assirelli, Dal Re, Esposito, Cocchi, & Santangelo, 2020). Inoculation of a harvested crop with selected microbes has been used to enhance retting where conditions do not favour natural microbial development and growth (Candilo, 2000). Non-destructive tests for monitoring the retting process and its bacterial growth have employed various approaches to measuring volatile organic compounds (B. Mazian et al., 2019) emitted by hemp during retting.

Chemical retting is reported to be widely used in some countries, and trials offer a mixed evaluation of its effectiveness in influencing fibre quality (Strazds, Reihmane, & Bernava, 2015). At least one study finds few differences in bast fibre quality and processing performance, between retted and unretted fibre (Hobson, Hepworth, & Bruce, 2001). Chemical retting has employed electrolytic-type processes which also deflocculate and treat waste water (Sun, Li, Yu, Chen, & Fan, 2022). Nonchemical alternatives to in-paddock retting, including crop rotation benefits and the reduction of weather-related uncertainty, are reported by (Gusovius, Lühr, Hoffmann, Pecenka, & Idler, 2019), particularly addressing advanced material uses such as composites' production. Other authors have extended anaerobic retting principles to harvesting hemp straw as silage. Microwave treatment of straw, in association with retting, has been shown to improve the quality of fibre generated in terms of the distribution of fibre diameter (Nair, Lyew, Yaylayan, & Raghavan, 2015).

Stages of retting, expressed as management guidelines, are available from colour spectroscopy studies of dew retted straw (Bleuze, Lashermes, Alavoine, Recous, & Chabbert, 2018). Research on flax's dew retting has yielded multi-modal modelling tools to assist industrial decision-making (Chabbert et al., 2020). A Ukrainian innovation involves use of a belt thresher on a combine harvester, to accumulate and roll hemp stems for appropriate retting (Sheichenko et al., 2022). Optimisation of retting has been addressed by simulation modelling of the biological and bacterial processes, targeting the bast fibre outcomes with respect to the nature of fibre bundles (Lashermes et al., 2020).

2.2 Harvest and logistics

The reported demanding requirements for hemp grain crops' cleaning and drying appear to be able to be met with existing technology and supply chain logistics and relationships. Discussions revealed no shortage or imbalances of capacity.

Rationalisation of the discussion of harvest and transport through to processing for bast fibre crops is presented by Pari et al. (Pari, Baraniecki, Kaniewski, & Scarfone, 2015), and their review summarises social and technological change in both China and Europe. These authors conclude that hemp can be harvested and presented for processing using equipment and procedures used for flax, with the exception of the cutting task due to the height and toughness of the hemp stems, and their variability.

2.3 Processing

Equipment for oil and cake extraction, and for protein extraction, is reported to be readily available and not specialised to hemp grain processing.

Evidence points to considerable variation amongst hemp varieties in most aspects of processing performance for fibre, including fibre yield and the distribution of fibre length and diameter (Musio et al., 2018; Vandepitte et al., 2020; Zimniewska, 2022). A comprehensive review of factors affecting hemp fibre and yarn performance, and the array of treatments and processes available to improve it, is available (Shuvo, 2020).

Decortication is viewed by some as a process not employing retting (Zimniewska, 2022), but a larger review of interaction between retting and processing technologies is also available (Lyu, Zhang, Wang, & Hurren, 2021). Studies of the influence of hemp variety, and variation of morphologies within a variety, on the effectiveness and cost (particularly energy use) of decortication have progressed to the development of a lab-based methodology, but not for assessment at an industrial scale (S. Wang et al., 2018).

Success is reported in using flax/linen processing plant for producing hemp yarn (Vandepitte et al., 2020). The spinning system is viewed as a bottleneck in the European hemp value chain (Zimniewska, 2022), particularly for processing short fibres (hackling) which although part of the flax/linen processing line, is absent from other textiles' systems (Zimniewska, 2022). Hemp fibres aligned using flax processing equipment have performed well in incorporation into composites (Gabrion et al., 2022). Hemp yarn has also been spun using both wool and cotton systems (Zimniewska, 2022).

2.4 Alternative uses and sustainability

A summary of studies of hemp products' use as animal feeds is provided by Rehman et al., which details resulting changes in products' fractions and animal's response and productivity change (Rehman et al., 2021). The use of hempseed cake is reported to be constrained by its high fibre content, and this was the subject of a separate study on dairy cattle (Bailoni, Bacchin, Trocino, & Arango, 2021). As part of an experiment on array of forages, vibrational spectroscopy has been used to effectively predict feed content and quality in hempseed cake (Tassone, Masoero, & Peiretti, 2014).

Pelletised hemp biofuels have been produced which satisfy local calorific requirements for marketed fuels (Streikus, Jasinskas, Zukaite, & Soucek, 2020). Crossovers between canabanoid products and industrial hemp have been identified, notably in using canabanoid-origin resins in coatings for hemp fabrics which offer some benefits to users' skin health (Zimniewska et al., 2021).

Use of hemp in phytoattentuation of heavy metal pollutants, and subsequent productive use of fibre, has been reported (De Vos, Souza, Michels, & Meers, 2022). This knowledge has been extended to examination of the genetic and biochemical mechanism for hemp's tolerance of lead (Xia et al., 2019), chromium (Raimondi, Rodrigues, Maucieri, Borin, & Bona, 2020), and cadmium (Huang et al., 2019). Production of hemp fibre on saline soils for use in composites (Batog, Bujnowicz, Gieparda, Wawro, & Rojewski, 2021) and hemp fibre production from landfill sites, or on waste ground (Panoutsou et al., 2022), and effluent sites (Eerens, 2003) have also been the subjects of research.

Hemp's suitability for production systems focused on sustainability has been emphasised by (Sorrentino, 2021). Its application in Europe, particularly in relation to support programs for organic or production and use of low levels of chemical input, has also been promoted in this regard. One example is farmer support under the multi-faceted the European Green Deal centred on sustainability (Zimniewska, 2022).

Notwithstanding the advantages offered by hemp's compostibility, and overall natural perception, it can also generate its own environmental externalities such as water absorption and GHG emissions' mitigation. An example of the former is presented for its use as a substrate for greenhouse tomato production (Nerlich, Karlowsky, Schwarz, Förster, & Dannehl, 2022). Amongst agricultural crops, hemp is highly effective in sequestering atmospheric CO_2 even when fed with organic fertilisers, and its production system lends itself to emissions' abatement by displacement of fossil fuels' use (Finnan & Styles, 2013). A widely-publicised statistic is that growing hemp absorbs 22 tonnes/ha of CO_2, with greater storage possible in fibre crops and residues (Adesina, Bhowmik, Sharma, & Shahbazi, 2020), with multiple hemp crops offering some potential multiplication of this figure.

Hemp crops' long term contribution to CO_2 abatement has been modelled in a dynamic 100-year analysis, and its impacts are found to be encouraging, but vary according to hemp variety, to agronomic practice, and to fundamental soil conditions such as CN balance (Z. Shen, Tiruta-Barna, & Hamelin, 2022). A number of positive reviews of hemp products' environmental contributions are available in life cycle analyses. Examples include hemp concrete (Scrucca et al., 2020), hemp fibre insulation (Zampori, Dotelli, & Vernelli, 2013), use in composites for automative parts (Wötzel, Wirth, & Flake, 1999), and as a feed source for biochar (Bartocci, Bidini, Saputo, & Fantozzi, 2016).

3 ASPECTS OF THE INDUSTRIAL HEMP VALUE CHAIN

3.1 The hurd value chain

The form and performance of hemp hurd-based building materials are described by Ingrao (Ingrao et al., 2015) in relation to building standards for energy efficiency, and other aspects of the construction industry. Mathematical modelling of hemp material's use in fibre board manufacture (Radosavljevic, Hoffmann, Pecenka, & Fürll, 2009), and tabulation of failure and fatigue tolerances (Shah, Schubel, Clifford, & Licence, 2013) have provided industrial guidelines. A comprehensive guide to factors affecting performance and suitable uses for hemp masonry and hempcrete has been compiled (Brümmer, Sáez-Pérez, & Suárez, 2018). Technology applied to quality evaluation and control for hemp masonry products has extended to 2-D image analysis focused on pore and surface features, and acoustic analysis (Brás et al., 2019).

Hemp hurd's performance in buildings has further been examined with regard to the type and industrial origin of binders, mixers and fillers used (Ingrao et al., 2015). Heat and alkaline treatments are used to modify hurd to improve its thermal stability and other attributes for construction suitability (Stevulova et al., 2014). Although the behaviour of the products was not in general affected by mixer choice, environmentally significant variables such as carbon fixation during curing, were found to be influenced (Arehart, Hart, Pomponi, & D'Amico, 2021; Stella mary, Nithambigai, & Rameshwaran, 2021). Factors affecting the extent and form of curing of hempcrete have been researched, notably that fillers and moisture affect quality (M. Paz Sáez-Pérez, Brümmer, & Durán-Suárez, 2021). The pre-treatment of hurd with water, and re-use of the water with cement, was shown to detract from setting performance of cement/hurd concrete mixes (Diquélou, Gourlay, Arnaud, & Kurek, 2015), and these authors' work also contributes a method for hurd performance measurement in concrete, and a summary of fibre quality implications.

A review of research into factors affecting hemp masonry performance, and an explanation of recent trends, is provided by (M. P. Sáez-Pérez, Brümmer, & Durán-Suárez, 2020).

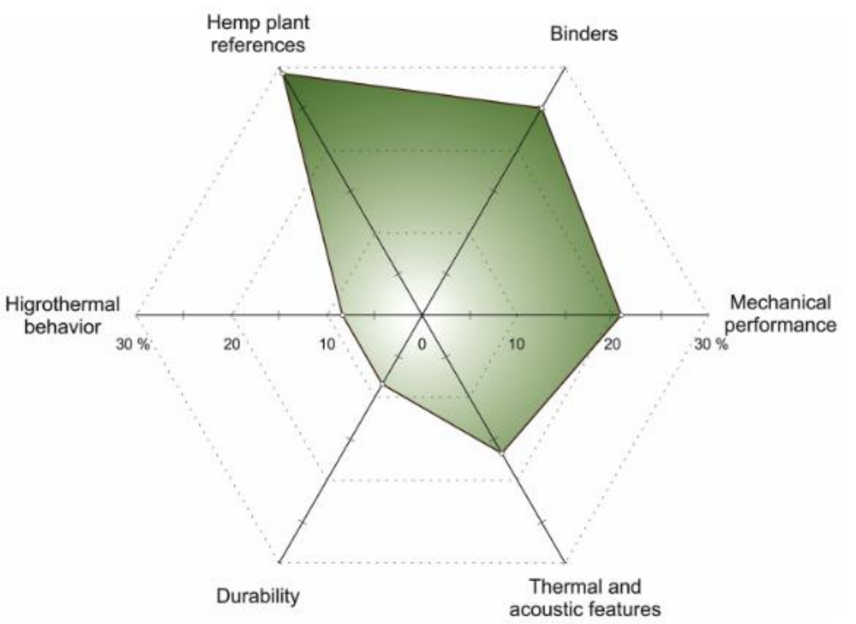


Fig. 14. Interest in particular aspects of this subject as shown by the percentage of publications on each topic.

Figure 2. Distribution of research subjects associated with hemp concrete and masonry (M. P. Sáez-Pérez et al., 2020).

At a more *ad hoc* level, use of limited volumes of hemp hurd as additives to conventional building materials has also produced benefits in the absence of organised hemp masonry production and using limited fabrication technologies (Charai, Sghiouri, Mezrhab, & Karkri, 2021). In non-hemp fibre, tensile strength of concrete mixes has been found to be strongly related to particle dimensions, specifically the (length to diameter) Aspect Ratio (Manniello, Cillis, Statuto, Di Pasquale, & Picuno, 2022). Hemp bast shives' performance in CO2-fixation as a hempcrete constituent may be affected by the retting procedure used during harvest (Butkutė et al., 2015). Further chemical processing of hurd to exploit additional high value uses (textiles and paper), primarily through its reduction to a useable pulp, have also been reported (Muangmeesri et al., 2021; Serra-Parareda et al., 2020).

3.2 The bast value chain

Several technical overviews of current and potential uses of bast fibre – including hemp - and possible future development pathways, have been compiled (Deyholos & Potter, 2014; Sadrmanesh & Chen, 2018). Four constraints are identified (Deyholos & Potter, 2014): the variability of properties in available fibres; their poor adhesion when used with conventional resins; their moisture absorption properties; and their cost of production and processing through to a useable fibre product.

A trial of hemp varieties, with variation in key agronomic management variables, has provided insight into performance of bast fibres in composites (Musio et al., 2018). Appropriate retting in association with processing pre-treatment has been shown to improve adhesion and water-related behaviour in composites (Liu, Thygesen, Summerscales, & Meyer, 2017; Mazian, Bergeret, Benezet, & Malhautier, 2018), but certain other treatments have been less successful (Rytlewski, Moraczewski, Malinowski, & Żenkiewicz, 2014). Blending of hemp with other natural fibres such as coir (Lakshmanan, Naveen, Saravanan, Nivitha, & Vathana, 2020), and synthetic fibres have been shown to improve performance of hemp in composites (Corbin, Ferreira, Labanieh, & Soulat, 2020).

As pointed out in a detailed engineering analysis of industrial uses of corn stover, the viability of such uses depend on the cost and convenience of supply relative to the cost of existing and potential alternatives (Delgado-Aguilar et al., 2018). Despite evidence of performance advantages of hemp bast fibres in many settings over hydrocarbon-based materials, cost disadvantages and lack of year-around availability persist in limiting uptake (Papadopoulou et al., 2015). Other authors have addressed the value chain for hemp bast fibre in composites on a more holistic basis, specifically looking at delivery of ready-prepared composite for injection, rather than an using intermediate phase of pelletized raw material (Gusovius et al., 2016). An alternative strategy for use of bast fibres in such applications has been examined by Graupner et al., in that less well-sorted bast fibres can deliver most of the their available benefits but at considerably lower manufacturing cost (Graupner et al., 2022). Creation of a pulp from bast has also been developed and promoted as a trademarked method for production of high value yarns (Jürgen Paulitz, 2017). A variety of treatments have been applied to "cottonise" bast fibre, with some authors' giving due consideration to the environmental effects of waste materials (Sahi, 2022). Further examination of sourcing of bast fibres in a non-specialist context (essentially from by-products within the bast processing value chain, such as dust) is conducted by Mussig et al. (Müssig, Haag, et al., 2020).

Fibre length, and particularly the avoidance of short fibres for particular processing applications, has been found to be linked to the material's height-location on the stem, and the size and weight of the hemp plant at harvest (Liu et al., 2015; W. Westerhuis & Stomph, 2009; Westerhuis et al., 2019), which in turn relate to sowing density and harvest date (W. Westerhuis & Stomph, 2009), and to internodal length and plant density (Livingstone, Ang, Yuan, Swanepoel, & Kerckhoffs, 2022). Manipulation of fibre diameter by fertiliser regime applied to hemp plants of separated sexes has also been demonstrated (Cerri, Reale, Roscini, Fornaciari da Passano, & Orlandi, 2022). Agronomic and crop management factors are then influential in achieving fibre quality and textile applications, as well as yield, targets (Stefano Amaducci, Zatta, Pelatti, & Venturi, 2008; Gabrion et al., 2022).

Rapid, and potentially in-field, methods for determining fibre quality at specific marker locations on plants in commercially relevant quantities has included infrared spectroscopy (Vârban et al., 2021).

The performance of a number of natural fibres, including hemp bast, in housing insulation is examined using standardised tests heat conductivity and diffusivity, as well as moisture accumulation and toxicity (Volf, Diviš, & Havlík, 2015).

3.3 The hemp food value chain

Detail of the technologies applied in extraction of oil, protein and other fractions from hemp grains, and their use existing food and beverage products, is seen to utilise known and available technologies which are widely applied to other agricultural products in Australia (Burton et al., 2022). Hempseeds' dietary composition is well documented, although some studies identified significant differences between hemp varieties (Vonapartis, Aubin, Seguin, Mustafa, & Charron, 2015). Certain dietary proteins have attracted significant interest, and been examined for differences amongst varieties (Abdollahi, Sefidkon, Calagari, Mousavi, & Fawzi Mahomoodally, 2020).

The array of hemp seed food and beverage products able to be produced is summarised by Burton et al. (Burton et al., 2022). The dietary profile of hempseed and its desirable features in the diets of humans and livestock are reviewed by Xu et al (Xu et al., 2021). The acknowledged presence of desirable fractions in foods of hempseed origin has led to the development of technologies for magnifying or extracting them. An example is in the use of membrane ultrafiltration to boost the supply of heart-health associated amino acid arginine (Malomo & Aluko, 2015). Xu et al.'s review includes a list of oil extraction methods, conditions, and oil recovery performance.

Table 3 Hempseed oil yield and tocopherol content from different extraction methods

Extraction methods	Extraction conditions	Oil recovery/ yield (%)	Tocopherol content (ppm)	References
Screw press	8 mm nozzle size, 70°C, rotational speeds of 32 rpm, no thermal pretreatment	73[a]		Crimaldi *et al.* (2017)
Hexane extraction	Seed-to-solvent ratio of 10%, 70°C, 10 min	29[b]		Kostić *et al.* (2013)
Hexane and isopropanol (3:2, v/v) extraction	Seed-to-solvent ratio of 5% (w/v), 20°C, 1 h	98[a]	746	Grijó *et al.* (2019)
Pressurised n-propane extraction	100 bar, 60°C	98[a]	974	Grijó *et al.* (2019)
Ultrasound-assisted hexane extraction	24 kHz, 400 W, seed-to-solvent ratio of 10% (w/v), 6 h	37[b]		Devi & Khanam (2019)
Microwave-assisted hexane extraction	450 W, 7.19 min, seed-to-solvent ratio of 10% (w/v)	34[b]	930	Rezvankhah *et al.* (2019)
Liquid carbon dioxide extraction	150 bar, 20°C, 195 min, <1 mm particle size, 10 mL min^{-1} CO_2	68[a], 28[b]	813	Aiello *et al.* (2020)
Supercritical carbon dioxide extraction	300 bar and 40°C, or 400 bar and 80°C	72[a], 22[b]		Da Porto *et al.* (2012a)
Supercritical carbon dioxide extraction	300 bar, 40°C, 0.71 mm particle size	22[b]		Da Porto *et al.* (2012b)
Supercritical carbon dioxide extraction	300 bar, 60°C	98[a]	877	Grijó *et al.* (2019)
Supercritical carbon dioxide extraction	300 bar, 40°C, 195 min, <1 mm particle size, 10 mL min^{-1} CO_2	93[a], 31[b]	810	Aiello *et al.* (2020)
Ultrasound extraction	200 W power, 25 min; acting on–off ratio of 20:20 (s/s), solvent-to-solid ratio of 7 to 1 (v/w)	91[a]		Lin *et al.* (2012)
Ultrasound-assisted supercritical carbon dioxide extraction	10 min of ultrasonic pretreatment prior to supercritical carbon dioxide extraction at 40°C, 300 bar, and 45 kg CO_2/kg seeds	24[b]		Da Porto *et al.* (2015)
Cold press and supercritical carbon dioxide extraction	60°C, 20 Hz frequency, 6 mm nozzle size; 250 bar, 45°C, 1.2 kg h^{-1} CO_2, 3.5 h	100[a]		Aladić *et al.* (2014)

[a]Oil recovery is equal to the amount of extracted oils divided by the amount of oil in hempseeds used for oil extraction.
[b]Oil yield is equal to the amount of extracted oils divided by the amount of hempseeds used for oil extraction.

Figure 3. List and comparison of oil extraction methods, including performance (Xu et al., 2021)

Fortification of conventional flours with hemp flour to boost various dietary components has been demonstrated (Rusu et al., 2021), along with applications to the broader baking industry (Radočaj, 2014). Hempseed-based drinks have been developed which deliver quality attributes across a range of quality attributes, with the research also delivering categorisation and analytic methods for industrial use (Nissen, Demircan, Taneyo-Saa, & Gianotti, 2019).

Trials of nutritional improvement and consumer acceptability of hemp foods are widely reported, particularly where foods derived from hemp are combined with, or added to, known foods such as meat (Zając et al., 2019; Zając & Świątek, 2018) or grain products (Korus, Gumul, Krystyjan, Juszczak, & Korus, 2017; Merlino et al., 2022; Švec & Hrušková, 2016). Replacement of meats with hemp products has also met with success in terms of consumer acceptance (Augustyńska-Prejsnar, Ormian, Sokołowicz, & Kačániová, 2022), as have butter replacements in baking (Gutiérrez-Luna, Ansorena, & Astiasarán, 2020).

Education of the consumer is identified as a key development stage for hemp for food, ranging from dispelling THC-related fallacies through to information provision about beneficial food fractions and recipes for preparation at home (Burton et al., 2022). The existing variation within Australian supermarket lines of food is little known to the consumer, but spans a considerable range of health-relevant variables even for simple flour (Hughes, Vaiciurgis, & Grafenauer, 2020). More precise identification of valuable and exploitable fractions, and documentation of their health benefits, are called for (Bono, Le Duc, Lozachmeur, & Day, 2015; Rupasinghe et al., 2020). Relevant profiling (structure, content, flavour) of hemp proteins has recently emerged, with projections for future use in foods (P. Shen, Gao, Fang, Rao, & Chen, 2021), that can inform manufacturers.

3.4 Whole of chain issues and business models

Examination of social and economic impacts of hemp cultivation and development of associated value chains has been limited. A US study and comparison of economic costs and sustainability along the entire supply chain for hemp bast fibre with cotton, indicated an advantage for hemp based on its lower use of inputs – including water - and higher yield in terms of weight per hectare. This study (Duque Schumacher, Pequito, & Pazour, 2020) did not consider the revenue side of the ledger. Prospects for use of waste ground in the European union to serve identified markets were rated poorly in comparison with other crops, both in terms of opportunity and risk (Panoutsou et al., 2022). However, that study identified basic uses of hemp as having desirable features such a general readiness of technology for processing and use in the value chain (in this case, use in insulation material).

Across all US hemp value chains, industry development requirements and recommendations have been provided by Horner et al. (Horner, 2019). These authors sketch a rapidly-expanding industry in the US state of Missouri, identifying difficulties in adjustment dynamics such as a “sellers’ market for inputs”, depressed producer prices due to oversupply, constraints imposed by processing capacity and logistics, and institutional and policy uncertainties (in that case, including CBD markets and regulation). Key transitional enabling features identified include regular publication of indicative and benchmark prices (of CBD and hemp biomass), and secondary services such as online marketplaces (e.g. https://kush.com/, https://www.hemptraders.com/Default.asp) and analysis which lists unsold inventory. These authors offer useful insight into grain and fibre processing margins, and provide directions to machinery manufacturers and the basic capital investment costs. Amongst companies listed are those providing a mobile processing plant (https://formation-ag.com/). An indicative gross margin for industrial hemp (combining grain and fibre) and estimates of its social economic impact in Missouri, are provided.

A model of technical, organisational and logistics aspects of hurd and bast processing – and specifically its logistic connection to production – is provided by Pecenka (Pecenka, Lühr, & Gusovius, 2012), which is useful in examining sensitivities to variables such as distance and parameters such as fibre yields. These authors contrast traditional decortication-based bast processing lines (characterised as long, with low mass flows, and many operational problems) with (what they described as "modern") hammer mill-based technologies with higher straw throughput. Variables examined include such industry-development items as delivery distances, and shares of local acreage in hemp. A notable strong result related to these variables is that processing profitability requires around 4 tonnes/hour throughput.

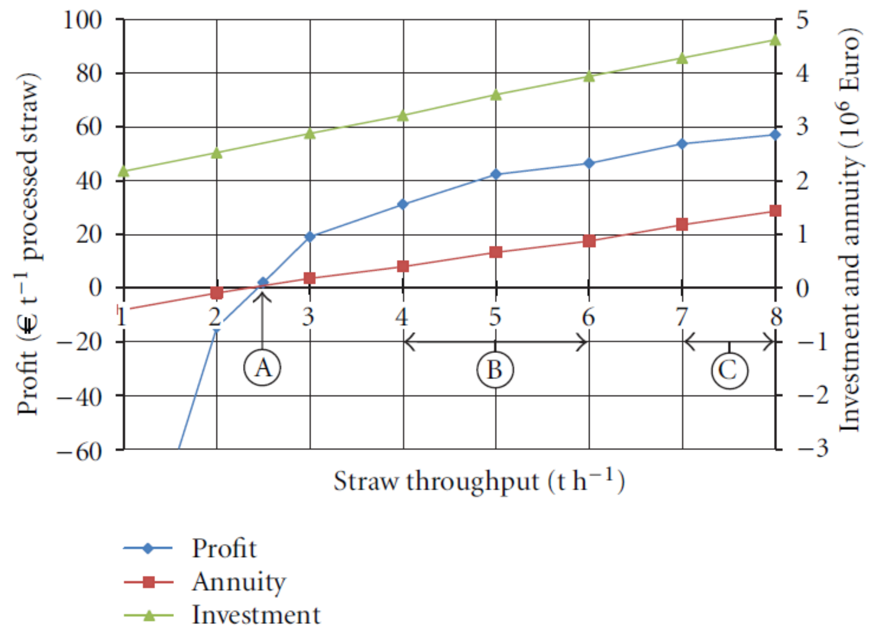


FIGURE 6: Profit for hemp processing with the ATB-processing plant in dependence to straw throughput. A: break even B: optimum relation between plant investment, straw logistic costs and profit C: increased profit at higher investment and straw logistic costs.

Figure 4. Logistic analysis of hemp fibre processing (Pecenka et al., 2012)

A study on agronomic conditions suitable for the supply of hemp to the Australian newsprint industry is instructive in terms of value chain alignment of capacities and logistics (Lisson & Mendham, 2000). A review of extraction rates at various points in the bast fibre processing line appears in (Zimniewska, 2022). A whole-of-value-chain exercise on hemp-based composites was conducted to draw inference for the redesign of the bast fibre value chain, including all aspects of breeding, production and processing (Müssig, Amaducci, Bourmaud, Beaugrand, & Shah, 2020). This reverse engineering research emphasised the need for each stage of the value chain to achieve end use orientation, despite the gaps knowledge gaps for actors along the chain.

At the input level, seed production has been questioned as a commercial venture due to producers' (and in some cases processor's) preference for certified imported seed. Recent Australian market developments, particularly the recent demise of canabanoid industries and a current market glut for hemp grain, have seen a shift toward fibre production. Some producers with confidence in their own ability to produce and handle seed have retained it for sowing. At least one grain processing business is reported to have also shifted to a fibre orientation: notably with the new venture exploiting strong producer-processor linkages developed as experience with hemp grain crops.

Research into agronomic aspects of hemp production is receiving considerable attention, particularly in development of commercial varieties and attention to crop husbandry. Although these advances embody technology, the subjects will not be pursued further here. Dual purpose varieties may be suited to limited geographic areas, and their financial viability has not been investigated. Demands on equipment of differing hemp phenotypes (particularly crop height and stem diameter and hardness) are still becoming apparent.

Consideration of programmatic expansion of hemp in Australia has addressed insertion of its insertion into sophisticated multiple crop rotations, such as cotton (Kumar, 2022). Hemp generally fits an annual crop planning window, but tropical regions and selected crop rotations (e.g. sugarcane) allow for multiple crops, and inter-cropping and cover-cropping. Areas may be limited by overlapping considerations such as centrepivot area availability.

Australia's well developed grain production and harvest, drying, milling and processing industries employ technologies suited to hempseed. Producer-processor relations and procedures for grains, seeds and small seeds production are apparently applicable to hemp grain production both for food and seed.

Hemp straw destined for fibre extraction is treated, in general, in a manner opposite to hay. Leaves and small branches, and seed and flower material, are not legally useable in fibre processing. Hence straw drying and retting, and in the case of a dual crop windrowing behind a header, will ideally remove all additional plant material and leave only a stem.

Limits on the stem length (see below), and the potential for stems to be gathered into sheaves, also may dictate the handling of straw at harvest. Experience suggests that design and use of hay rakes, and straw curing protocols more generally, may be specific to hemp. The height of the crop and the strength of the stem may require specialised hay mowers, some of which have been developed by farmers in their own workshops.

Hurd, along with bast, is extracted either by a decortication process which splits stems by pressure within a roller system, or a hammer mill process which breaks up the stems. As straw is presented to a hammer mill generally by rotating drums, the process is sensitive to length of material. In turn, this is derived from plant height and dictates harvest practices and technologies. Hammer mills also produce short bast fibres, and some evidence suggests damage to fibres. Decortication is less sensitive to plant height and produces, in principle, long bast fibres.

The uses of hurd vary substantially both in sophistication and value. It is variously promoted as a packing material, pet bedding for example, as well as a in hemp houses and hempcrete. Its carbon-sequestering production and use in building, its end-of-use compostibility, its resistance to the pests of, and its fire resistance are all acknowledged as desirable and usable in promotion.

For construction, several successful supplier-builder relationships have emerged around Australia, particularly for hand-packing of frames . These do not feature formal objective measures of hurd quality, but rather an iterative process where feedback on quality and suitability are discussed or successive end uses. Quality variables such as shive size and colour are reported to be able to be included in unique housing characters which are appreciated by customers.

The production and delivery of hurd to building sites for blending with mixing agents, and the current practice of hand-packing formed wall spaces, mean that hemp houses are expensive to build. Localised production and supply channels based on areas sown to fibre crops have resulted, and in principle these can grow as demand for hemp houses grows. Alternatives to the burnt lime-based mixers currently used for creating hemp housing material, may be available.

Bast yield per area of crop is substantially affected by crop characteristics such as crop height and stem diameter. This adds significance to the choice variety, as well as seeding rate and desirable plant spacings for fibre and dual purpose crops.

Processing of bast - essentially the extraction of fibre from the waxy stem covering – is enhanced by retting. Retting practice is not well established nor standardised in Australia, but nonetheless is well suited to utilisation of dew and/or the use of irrigation equipment. Both offer an environmentally preferable method to those involving chemicals or immersion in bodies of water as reported in some other countries' bast processing systems.

Bast's actual and potential use in textiles – as individual fibres, as mats of fibres and as spun yarn – are numerous and in evidence across a range of industries and applications. An enthusiastic discussion surrounds these end uses, particularly involving substitutions for synthetic components in manufactured products as diverse as car bodies and electronic circuits. Hence, global markets exist for bast fibre, but prices and associated quality specifications are not readily identified, and certainly not to the extent that the more familiar cases of wool and cotton are observed and acted upon in Australian industries.

Processing and spinning of bast fibre is under active research in Australia for its facility for use in cotton spinning equipment, and in New Zealand is reported to be already in use in wool spinning mills. In both cases the bast may be blended with these textiles and others, to provide a yarn and finished garment with a range of characteristics, particularly feel.

Broad commercial application of bast fibres in composites (of hemp and other origins) is discussed in detail by Deyholos and Potter (Deyholos & Potter, 2014), who identify four constraints: the variability of properties in available fibres; their poor adhesion with conventional resins; their moisture absorption properties; and their cost of production and processing to a useable fibre product.

4 MAPPING OF TECHNOLOGIES TO INDUSTRIAL HEMP FIBRE APPLICATIONS

4.1 Approach

The forgoing information on the industrial hemp value chain, its technical and organisational functions, and its technological gaps and opportunities, are assembled as a map. The following table lists and describes the components of the map, applied to the fibre value chain.

Table 1. Components of the technology map

	Definition	Interpretation/use
Technology theme	Term encompassing tasks	Generally aligned with supply chain stages
Target tasks	Tasks that offer potential for value generation	An identifiable task in production or along the value chain
Value generation mechanism	The mechanism by which either costs or revenue are affected	Identifies the variables which change as immediate consequence of a technology change, in association with the tasks identified
Technologies implicated	Technologies associated with the value generation mechanisms, selected from the literature review and stakeholder consultations	Components of the technology are reflected in changes to the baseline financial analysis as a package of inter-related shifts in specification from the baseline
Technology readiness	Evaluation conducted according to readiness guidelines	Not explicitly included in the analysis, but enters the discussion of results
Technology link to organisation	Cost and benefit changes imposed, which reflect organisational changes as part of technology uptake	Acknowledgement that many technologies are co-dependent on organisational change at the business or value chain level
Other notes	Clarification and additional points	Enables links to specification pf baseline and scenarios, and interpretation

Table 2. Mapping of technology theme to technologies and value generation

Technology theme	Target tasks	Value generation mechanism	Technologies implicated	Technology readiness (Possible 36)	Technology-organisation	Notes
Hemp grain value chain	Seed quality improvement	Farm productivity	Seed testing and certification process	25	Exploits existing infrastructure	Links needed to georeferenced seed use
Hemp fibre production, harvest and post-harvest	Targeting varieties at end uses and agro-ecological zones	Farm productivity	On-going plant breeding and agronomic research			Variety trial results available
	Retting	Processing productivity Fibre quality	Swathe/windrow structure Irrigation use Monitoring of colour, moisture	9	Baling schedule Sensors Database access on straw status	Concepts and technologies entirely familiar. Subjects not researched
	Curing of straw	Machinery use Processing productivity Carbon sequestration efficacy Cost of regulatory compliance	Monitoring of moisture Monitoring of spillover products	9		
	Crop residue management		Monitoring of swathe composition, bale composition Monitoring of regrowth	9	Databases on straw status Remote sensing of regrowth	
Fibre processing	Fibre processing: Hammer mill	Fibre processing cost Fibre quality	Equipment in place and at high capacity utilisation	21	Ownership model Possible mobile plant	Lease-lend at small scale
					Transport and location model	Capacity utilisation
					Supporting equipment Labour supply	Stalk length, feed-in and storage
	Fibre processing: Decorticator	Fibre processing cost Fibre quality	Equipment in place and at high capacity utilisation	20	Ownership model	
					Transport and location model	Capacity utilisation
					Supporting equipment Labour supply	Stalk length, feed-in and storage
Hurd value chain	Processing	Fibre quality and price	Fibre quality measurement and implementation	Not assessed	Buyer feedback Product descriptors	Currently negotiated internally in supply chain
		Processing costs and value	Alternative fillers and mixers	Not assessed	Sourcing of alternatives Database on materials' content	Reference to Carbon sequestration in building materials
	Downstream construction	Construction costs	Materials and construction processes for walls	Not assessed	Investment in mechanised space packing	Supply chain requirements not examined
		Cost of building code compliance			Alignment with guidelines for building code	[ongoing]

Table 2. Cont'd

Technology theme	Target tasks	Value generation mechanism	Technologies implicated	Technology readiness (Possible 36)	Technology-organisation	Notes
Bast value chain	Processing	Fibre price	Fibre quality measurement Calibration of machinery	24 Not assessed	Alignment with global textiles industry	Technology familiar in other industries No known calibration of processing machinery
	Downstream value	Market access	Access to alternative users Definition and dissemination of fibre and product specifications	Not assessed	Information flows Standardised measurement methods	
	Inventory management		Baling and storage procedure and facilities for bast fibre	Not assessed	Quality demarcation Bale content and branding conventions	
Dual use hemp crops	Production	Production costs	Elevated headers	23	[available and in use]	Ownership and distribution models are not tested
			Multi-level mowers		[available and in use]	
			Mowing for tough stems		[available and in use]	
Integration of hemp with other crops and agricultural products	Production planning	Cost of production Market access	Utilisation of land, water and infrastructure	18	Initial studies done	Applications vary according to crop rotations
			Utilisation of cotton textile marketing channels and markets	17	Collaboration with cotton and sugar cane industry actors	Differing marketing mechanisms prevail
	Social and community participation	Employment creation	Labour utilisation	Not assessed	Social organisation Locations need assessment with regard to product delivery	An ownership model required
Hemp registration and testing	Rationalising registration	Cost of compliance	Enhanced information flows on seed certification	27	Data flows regarding seed recording and geo-referencing farms	Seed certification as a basis for registration In place for numerous other industries
			Certification of self-produced or retained seed	(see also above)	[existing systems]	
	Modernising THC testing	Cost of compliance	Hand-held NIR sensors + geolocation	23	Regulatory change required Ownership model for devices Data security Calibration tasks	THC testing technology widely used for drug-related tests Research supports in-field crop application but has not developed a product

Table 2. Cont'd

Technology theme	Target tasks	Value generation mechanism	Technologies implicated	Technology readiness (Possible 36)	Technology-organisation	Notes
Environmental services, including C-sequestration	Evidence for C-sequestration	Product differentiation	Data-driven records on crops and value chain Calibration mechanism Linkage to standard databases Tracing technology	25	Development of CER methods and ACCU models Establishment and marketing of offset offering Value addition model Data sharing arrangements Calibration mechanism	Place of Carbon in product differentiation, income generation and environmental profile of industry to be established
Product differentiation on low emissions products	Evidence for end-of-life product profile		Tracing technology Information transparency	Not assessed	Value addition model Data sharing arrangements Calibration mechanism	Life Cycle Analyses are available in literature
	Alternative fillers for hemp masonry		Tracing technology Linkage to database on environmental scores	Not assessed	Proof of concept on fillers Guidelines for filler selection Collaboration with builders + Building Code	Promotional model and its funding to be developed between building industry and production and processing base
Social and economic development associated with hemp	Value retained in community	Local economic benefits Social value	Data-based co-ordination of labour demand and supply	Not assessed	Partnerships between processors and community organisations	Direct link needed between end products, producers and community
Organisational aspects of hemp value chains	Established flexible and replicable business models	Value chain performance	Transaction arrangements Ownership models Market access	Initial modelling done	Insight into margins and returns along the entire supply chain	A range of models can be identified, for each of which technology parameters may differ

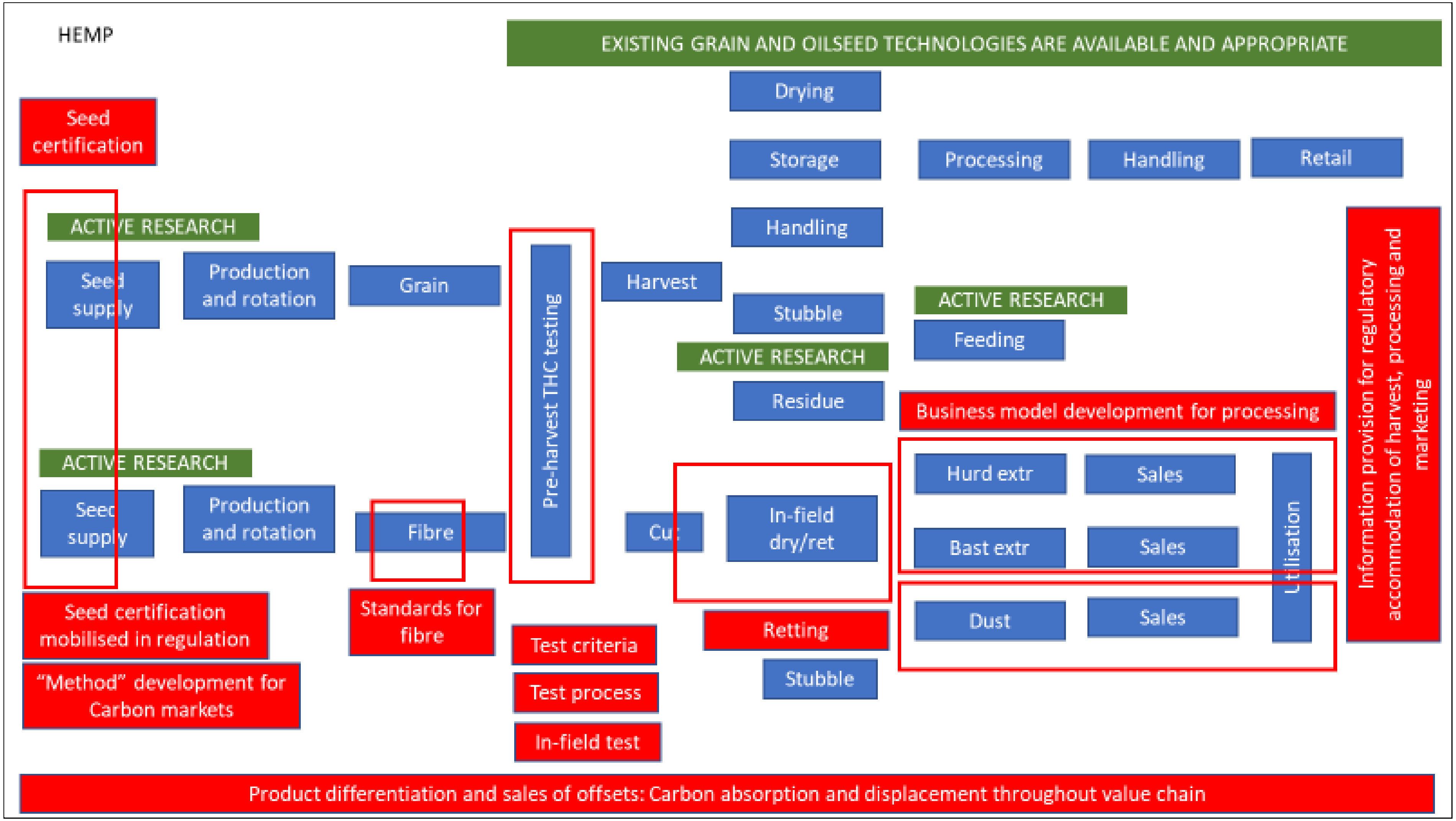


Figure 5. Sketch of industrial hemp value chain, with superimposed technology gaps and opportunities

4.2 Technology themes

4.2.1 Hemp grain production, harvest and post-harvest

Technologies for production, harvest, cleaning and drying and storage are available from existing Australian grain and seed industries and the machinery supply industry. Persistent problems in seed certification are within the scope of existing seed technologies and arrangements (score TRM of 25). Opportunities exist for extension of seed certification to crop recording, and registration and licensing.

4.2.2 Hemp fibre production, harvest and post-harvest

Agronomic research continues on agronomic and plant breeding, particularly matching varieties to production environments. Issues with seed certification are as for hemp grains.

Mowing and handling of the tall hemp fibre crops – and dual purpose crops - presents challenges to conventional mowing and hay raking equipment due its wrapping around working parts, the tensile strength of the green material, and – dependent on variety – the toughness of large diameter stems. Farmers' own modifications to mowing equipment, and specialised adaptations of header carriages for mowing tall dual crops have also appeared.

The length of stems, and configuration of cut stems into stooks or buddles, offers opportunities for fibre processing: both directly and as a facilitator of retting. Along with swathe configuration (such as a windrow deposed behind a header in dual purpose crops), these actions take on cost implications. Returns in terms of processing and handling cost reduction, and improved hurd and bast production and quality, are likely to be affected although evidence in Australian contexts has been slow to appear. Harvest action on these subjects can utilise existing equipment.

Fig. 3. Tebeco Clipper 4.3 MMH—the stems sections are left onto the ground occupying the full field area.

Figure 6. Multiple level cutting machine, cited in (Pari et al., 2015).

Retting is firmly established in non-Australian settings. Informal reports suggest that Chinese and certain other Asian production systems employ chemical retting or immersion in ponds or waterways. A process with a reduced environmental impact (using natural due or irrigation water) offers a market differentiation option for the Australian industry and is light on technological requirements – primarily being timing and duration of a curing process that is familiar to producers' hay crops.

The curing process, as outlined earlier, provides scope for removal of leaves and flower material, in a somewhat reversed-quality criteria setting to that for hay. Raking and drying – spaced to accommodate retting – would then use existing farm equipment although some there are some reports of the need to avoid PTO driven tedding and raking implements with regard to the tangling of long fibres. Stakeholders suggest that the most desirable technology would enable a rake-type turning process while incorporating sufficient contact and vigour to break off and shake loose non-stem plant material. Producers and contract service providers are familiar with these considerations.

Collection of straw for processing necessarily involves conventional baling, unless some sheaf and stook-type accumulation is being used, requiring a stick-rake type of implement, again familiar to producers. The breaking of bales for feeding into decorticator or hammer mill would ideally be mechanised and use conventional equipment (forklift and bale feeder). Round bales may offer an advantage over square ones in this regard, but introduce a trade-off against logistics costs. Round bales offer well widely acknowledged advantages in terms of preservation and water repulsion. These technological considerations are well known to producers and contract service providers.

Harvest and collection methods, stubble grazing procedures, and ploughing of stubble and residues can all contravene hemp licenses due to contamination of one product with another, non-specified uses, and regrowth from discarded grain.

Overall, technical solutions to these fibre crop and product handling and treatment are available as imported machinery or already have been developed by stakeholders in Australia. Although well developed in some cases, there has not been a commercial trial or development process. Hence TRM score is at 9.

4.2.3 Fibre processing

Hemp straw processing equipment is either a hammer mill (TRM 21) or a decorticator (TRM 20). These can be compared for a number of operational and product quality attributes, although this information is not readily available. Processing equipment is capital intensive, which obviates plant owners' need to maximise capacity utilisation by matching crop volumes to processing capacity. Such a match can be achieved by machine size selection, varying shift number and duration, varying the number of suppliers and volumes supplied, and by matching production to the delivery rate required by buyers of processed fibres: in addition to choosing location. Location has further implications for delivery costs.

A scan of available hemp fibre processing machinery reveals significant presence of hand-feeding for the feed stock into the intake. This is accompanied by (somewhat simultaneous) manual removal and replacement of sacks or bags as product accumulates, along with packaging and storage. The manual task then requires 2-3 persons operating the hand-fed plant. Larger machines incorporate bale opening, loader-compatible elements, automated bagging, and product pressing equipment.

		
Hand-fed decorticator (Hurdmaster https://hurdmaster.com/)	Hand-fed hammer mill (ABM Equipment https://abmequipment.com/hemp-mills/)	Mechanised decorticator intake (Greenfield https://canadiangreenfield.com/hemptrain/)

Figure 7. Hand-fed and mechanised fibre processing equipment

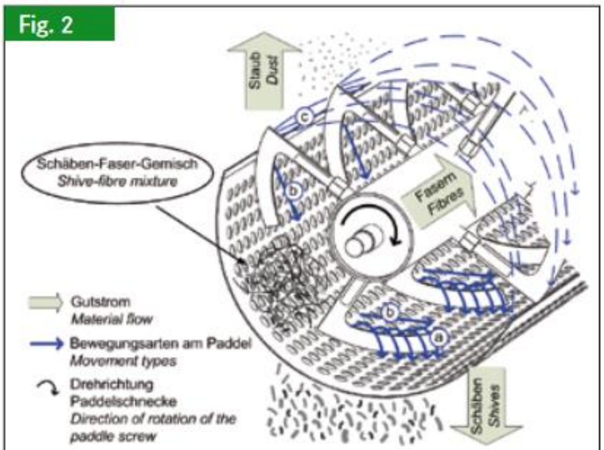
Accompanying choices surrounding the degree of automation is consideration of volume (and hence capacity utilisation), available supplies of labour and appropriate electric power, availability of suitable multi-purpose machines, and access from farm and to road transport. The impact of scale on cost structures affects the flow-through of price and cost developments to producers.

4.2.4 Hurd value chain

Metrics and standards for hemp quality are not currently in use. Consistency, convenience in packaging, shive size and colour, shape distribution, and freedom from impurities including bast and other straw remnants, are all mentioned in discussion of desirable hurd features.

Currently there are no technologies in use for quality measurement and sorting for sale and delivery, nor for calibrated settings on processing machines beyond some adjustable screens. Technology for separation of hurd from straw material, and then sorted for shive size, when delivered as a bast by-product from some versions of decortication, of offered by Luhr (Lühr, Pecenka, Fürll, & Hoffmann, 2012).

Fig. 2



Material flow and straining process of a shive-fibre mixture in the axial fractionator
a) flow over the paddle; b) flow along the paddle;
c) dropping from paddle

Figure 8. Hurd shives extraction technology (Lühr et al., 2012)

Targeting or improvement in hurd quality is thought to be achieved in iterative communications between user and supplier. Existing high value uses of hurd (e.g. hurd houses) entail considerations of rates and routes of delivery of hurd to buyers. Hurd has been promoted as a raw material in 3D printing for construction for individual homes as well as large scale office space (Luhar et al., 2020): a fundamental shift in supply chain arrangements, volumes, packaging and handling, delivery co-ordination and quality requirements.

Hand packing in hemp house construction

3-D printing

Figure 9. Contrasting hemp house construction methods (Source *Futurition* news item)[3]

Address to this market, and expansion of hemp houses more generally, will be dictated by hurd availability, quality and reliable delivery within a given transport network which is matched to demand for hemp houses. These contexts are in contrast to a commodity market approach driven by price-quality linkages as historically seen in cotton and wool, and explains the absence of explicit quality standards in those industries. Technology, and long term industry planning, is not currently oriented to this purpose for hurd.

Although there are privately-established standards and certifications for hemp house construction overseas[4], Australian hemp masonry requirements appear to be centred on the National Construction Code, notably the Australian Standard AS1684 ("Residential timber framed construction"). Developments in that code and associated standards can be expected to influence aspects of the practices and material requirements for hurd. These can be expected to affect costs and prices, although the role of technology in this process is unclear.

Less schedule-driven uses of hurd (e.g. hemp crete) and mass market uses (pet litter, packing filler) are likely to generate hurd quality guidelines, but these also may be subject to the iteratively established arrangements between buyer and seller seen for hemp house construction. Mass uses (bulk sales for packing of fragile products) are likely to differ from branded uses by multiple competing buyers (pet litter), with the latter likely to occasion objective quality standards.

4.2.5 Bast value chain

Despite the significant history of bast fibres in textile uses, and Australia's leadership in use of objective quality measures in wool and cotton (see TRM of 24), few quality metrics appear to be in

[3] https://www.youtube.com/watch?v=7cbUP95mwLw

[4] https://www.hempbuildmag.com/home/hempcrete-approved-for-us-residential-building-code-update

use for bast in Australia. Fibre length and integrity is discussed by producers, as well as purity (freedom from hurd shives, and from hemp processing dust as well as dirt and other contaminants). Unlike hurd, bast fibre is connected to international markets, featuring competition with foreign hemp bast and other textile fibres. This means that objective quality measures are likely to be, and become more, important. Bast's bulky nature means that its accumulation during fibre processing requires storage facilities. Baling of bast requires a baler and bale handling equipment, as well as appropriate storage. Bales, more so than bags of product, need to be described for quality. These features of the bast product and its trading environment mean that quality standards will be required, and quality measurement and sorting technologies be employed in processing, packaging and marketing the product.

The measurement of hemp bast fibre yield and quality during processing and as a guide to use following processing has been addressed by the development of a processing kit used at various points in the decortication process (S. Wang et al., 2018). Hemp bast fibre diameter lend itself to measurement by Optical Fiber Diameter Analyzer systems, as well as with conventional image analysis and the airflow tests (H. M. W. a. X. Wang, 2004). Standardized specifications for the design and performance of ceiling tiles made from hemp bast fibre material have been developed in Latvia (Gaujena, Tihana, Borodinecs, & Agapovs, 2018). Standardized measurement of hemp bast fibres has been the subject of a trial using Russian cotton-based descriptions, specifically the Spinlab HVI 900 equipment, with success in terms of spinning performance, user interpretation, and repeatability (Illarionova, Grigoryev, & Asfondiarova, 2019).

There is on-going research regarding bast fibres' extraction efficiency, and performance using cotton spinning equipment, for Australian contexts and in comparison with those seen overseas. A further application of hemp bast fibre is a New Zealand company's reportedly spinning bast into blends with wool and other fibres. Currently there is no specialist hemp spinning equipment present in Australia or New Zealand, and three factors select against this investment on shore in the short term: the small volumes of bast available and their geographic dispersal; the absence of a differentiated product initiative for Australian bast fibres' products; and a history of wool and cotton processing taking place overseas following sale of a high quality commodity defined by recognised objective standards aligned to textile industry requirements for international consumer markets.

A great variety of special uses of bast fibre have been discussed in media. Notwithstanding the high profile of hemp's use in a range of industrial and consumer settings, the means of access to these uses and users is not clear. The transaction mechanisms, quality requirements, volumes required, prices to suppliers, and conditions or compliance of both products and delivery systems, are all opaque particularly to the producer. This will provide insight into the technologies enabling these aspects of bast use.

4.2.6 Dual use hemp crops

Crop height associated with fibre production requires elevated headers for grain harvest from dual use varieties. Further, harvest of the crop in one pass for fibre production as well requires that straw length is kept within certain limits. Multiple-height mowers are already in use for fibre-only production (TRM 23). Issues regarding the stem numbers, diameter, and strength/hardness are influential of choices of harvest technology and its application, but these are under active consideration in ongoing agronomic and genetic research so will not be discussed further here.

As noted above, registration and testing-based compliance with industrial hemp regulation presents challenges for production and marketing of a mix of products or end uses. These issues may involve explicit mixing (dual products) or more incidental or accidental mixing (e.g. leftover seed or flower material in straw destined being processed for fibre). No specific management procedure currently addresses this problem, and appropriate technologies are likely to centre on location-based data submission similar to crop husbandry notifications.

4.2.7 Integration with other crops: production and supply chain management

One study (Kumar, 2022) has looked intensely at hemp's integration into a regional cotton production system, as a new entrant in crop rotations. This research remains at investigative level but many fundamental questions have been answered (hence TRM of 18). Integration into cotton supply chain operations (e.g. out-of-season use of transport and product handling facilities; more general access to global textile markets) has received less practical consideration (TRM 17). Ownership and governance models for hemp production and harvest in association with other crops' resource base (particularly water allocations) and commercial arrangements, have not been examined.

Sugarcane offers a further opportunity for integration with hemp. In that case the specific interaction with sugar production and harvest logistics and governance – for which many issues dictate crop rotations – would need to be established. Ownership of hemp-specific equipment, use of industry-owned roads, electricity infrastructure and railways would need to be negotiated.

4.2.8 THC measurement technology

For functioning markets, harmonised specification of hemp seed quality, and standardised tests for THC content have been called for (Burton et al., 2022). Classification of hemp types with regard to canabanoid content has employed real time mass spectrometry, in approaching real time. In association with cluster analysis of sampled varieties, this was successfully used in typing of plants (Dong et al., 2019). Near Infrared Spectroscopy (NIR) has been used to measure Canabanoid content in a laboratory environment (Callado, Núñez-Sánchez, Casano, & Ferreiro-Vera, 2018). Differentiation of drug-type and industrial hemp plants has successfully been achieved with an application of Raman spectroscopy is presented by Sanchez et al. (Sanchez, Filter, Baltensperger, & Kurouski, 2020). This technology is based on rapid turnaround of samples, rather than application to standing plants.

Recent research work has targeted hand-held field-level measurement of THC content, specifically for hemp growers. However, the literature does not present a ready-to-use technology (TRM 23). Harpaz presents a review of portable biosensor technologies employed in THC detection, characterisation and quantification (Harpaz, Bernstein, Namdar, & Eltzov, 2022). The large number of devices (optical, electrochemical and acoustic) developed reflect the various needs of regulatory and policing agencies in on-site testing of products, people and various residues in real time. These are however based on samples rather than standing plants. Also based on samples, Jaren's work with NIR measures CBD concentrations in plant material for the purposes of marketing CBD products (Jarén et al., 2022). The training and calibration of the model was based on certified laboratories' database of recorded measurements on CBD content of samples collected. In Yao's work (Yao et al., 2022) FT-NIRS methods were used, and the training and calibration were conducted on an array of samples taken from farms, research stations and online sellers.

A major potential contribution of a hand-held THC testing device, used in association with a georeferenced record of tests on crops already georeferenced and registered for use of certified low THC varieties' seeds, is the saving on costs and uncertainty surrounding existing procedures. This change requires significant change in compliance procedures and regulatory expectations, as well as the technological advances needed to bring a suitably calibrated tool to market.

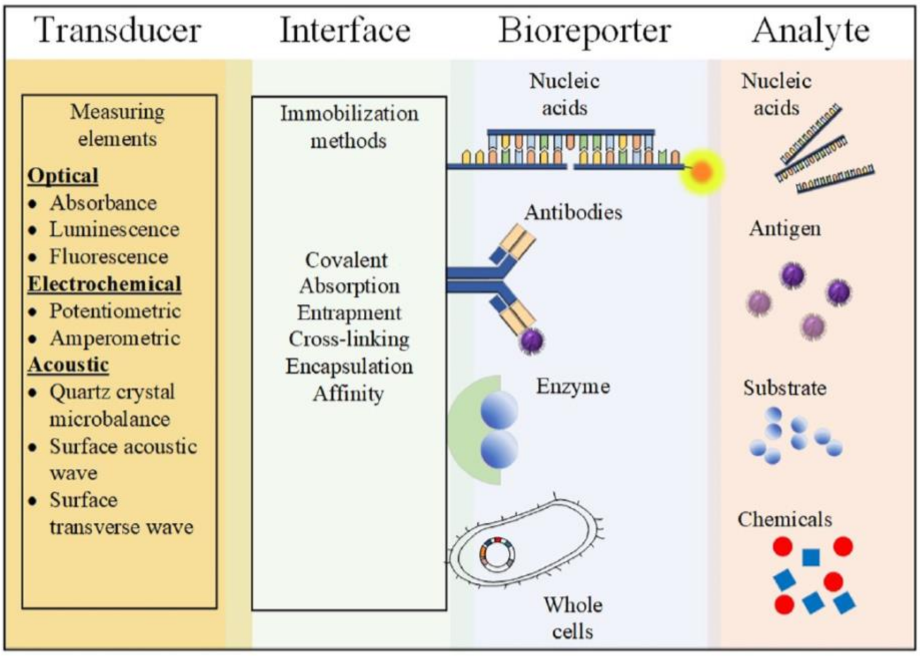


Figure 10. Portable biosensors' makeup (Harpaz et al., 2022)

4.2.9 Environmental services, including Carbon sequestration

A hemp production method is currently not registered with the Australian Clean Energy Regulator to enable sales of ACCU. Further, no formalised structure is in place for sales of offsets related to hemp crops. Supporting procedures and services for operation of such methods and the associated verification are in development in many production contexts around Australia, and are readily applicable to hemp (TRM 25).

The contribution of hemp to Carbon sequestration at production level, and in downstream products such as hemp houses and hemp concrete, provide marketable product attributes that are not currently presented to the consumer.

Existing technology based around tracking of products' provenance and physical contents along the supply chain are suitable for this purpose and are readily available. Hemp products' compostibility offers an end of life story which is highly marketable but not currently utilised. These offer opportunities in product differentiation across food and fibre products, which although not assessed here for TRM, are readily applied to other products in Australia.

For hemp housing and hemp concrete, alternative fillers to existing burnt-lime-based products may be able to utilised, with an environmental consequence that adds value to hemp. Wastes from mining or industrial processes offer an opportunity, and these are materials for which technologies already exist for handling and transport to suitable sites. In addition to waste reduction (by use of the material), and end of life recycling (as part of a compostable material), this option may reduce the need for industrially-intensive production of the existing mixers.

4.2.10 Hemp in social development roles

Several aspects of hemp value chains offer drivers for community development which favour localised employment and value retention, short delivery distances and opportunities for small businesses. Hurd supply for hemp housing has been cited as one example, with a generalised ratio of one hectare of hemp crop being sufficient for one hemp house providing a direct link between production and end use. Models of this kind require a matching of processing capacity and location to seasonal harvest and cashflow requirements at the locality, and the availability of sufficient labour. Where a particular social group has access to appropriate land and water supplies, various ownership models might be developed for land use, input and service provision, crop ownership, processing input and product sales.

4.2.11 Organisational aspects of hemp value chains

The hemp industry already features organisational strengths. These include advocacy bodies, linkages to international groups, an integrated set of state and national communication channels, dedicated research initiatives, and a nascent CRC. Within value chains, and to a degree between value chains, there are also commercial and personal linkages which offer inherent strengths and implicit agreed codes of practice. There are also productive links between regulatory bodies (which tend to double with technical and extension advisory services) and producers. These strengths lend themselves to productive industry development in several respects.

First, they provide information conduits which can be adapted to collection and use of data as an industry resource. These linkages also assist in industry actors' seizing and understanding business opportunities and formulating business models to exploit them. The information also is the enabling factor in accessing carbon markets and verifying environmental claims. A whole-of-chain blockchain implementation has been described and demonstrated as a proof of concept (Ferrández-Pastor, Mora-Pascual, & Díaz-Lajara, 2022), complete with technical and organisational requirements.

Second, these linkages encompass experience in industries' value chain upgrading. This enables transition from commodity marketing, to high value markets and consumer oriented organisation. Third, these linkages access government and regulatory experience, to be applied in industrial hemp's emergence from THC-related prohibitions.

4.3 Summary of Technology Readiness level assessment

Technology readiness scores (referred to above) were compiled from the authors' assigned scores across some 36 items in four categories, being Technology Readiness, Market and Customer Knowledge, Supply, Manufacturing preparedness, and the availability of supporting Financial analysis. The scoring matrix is presented in Appendix B, and reproduces materials developed by Agrifutures[5]. Of a possible aggregate score of 36, nine of the ten hemp-related technologies considered scored better than 50%. The one scoring below this level is arrangements around retting of crops, which seems to be at a stage of *ad hoc* communications.

Several technologies are widely applied in other industries or contexts, but not yet in hemp. This includes NIR technology for THC measurement, carbon-related tracing of marketable products, and seed certification. For these three technologies and accompanying arrangements, there are both significant cost savings available to the industry and a key new evidence base to present to government.

I general, the TRM scores are highest on the left side of the table, covering technology and the customer base. They are weaker on the right hand side, as few technologies have been costed and readied for investment in the context of hemp. The scores vary for the remaining column, in that some of the technologies feature well known or established supply chains but others do not.

Table 3. Technology Readiness (CRAM) assessments

Value addition mechanism	**Technology**	**Score (poss. 36)**	Technology Readiness Level (T)	Market & Customer Knowledge (M)	Supply, Manufacturing & Distribution Knowledge (S)	Financial, Revenue and Cost Models (F)
Seed quality improvement	Seed testing and certification process	25	9	7	3	6
Crop quality improvement	Retting, curing and related technology and management	9	5	2	1	1
Hemp processing	Hammer mill	21	8	5	5	3
Hemp processing	Decorticator	20	8	6	5	1
Hemp fibre value	Bast fibre measurement	24	6	6	7	5
Hemp harvest	Mowing and heading equipment	23	8	6	5	4
Production efficiency	Hemp integration with other crops	18	6	7	4	1
Hemp marketing	Other crops' marketing channels	17	7	6	4	0
Hemp production licensing	Information flows on seed certification	27	9	7	6	5
Hemp production THC compliance	NIR hand held THC test	23	7	6	6	4
Product differentiation + alt income for hemp	Carbon sequestration evidence	25	7	7	6	5

[5] Thanks to Agrifutures' Peter Vaughan.

5 Financial analysis along Industrial Hemp value chain

5.1 Approach

A whole of chain analysis for production, harvest and processing of industrial hemp fibre was assembled in an MS Excel® spreadsheet. Three arbitrarily-defined size based models for processing are depicted, each with associated supply arrangements based on a farm type. These are used to establish a baseline. Scenarios are imposed that entail changes to selected input variables. Scenarios can entail single or multiple changes, and in the context of technology are set up accordingly as combinations imposed. The baseline is not targeted at 100% accuracy, but rather at indicative values with inference to be drawn from departure of those values from the baseline. Approximations i the model are immediately apparent, particularly in the processing part of the model. Some indicative results are presented at the end of this this section, with the analysis related to technology mapping deferred to the following section.

The analytic tool developed[6] accommodates hemp grain production, with options to specialise at farm level or produce dual use crops. This analysis focuses entirely on hemp fibre, for three reasons. First, technology for hemp's food value chain – both extractive and for more direct use of dehulled seeds – is both well understood and available in the realm of seed and grain processing. Second, few attempts have been made to examine empirically the linkages between production and processing in an Australian context. Third, the organisational models of oilseed production and processing are well understood, and there is limited benefit little from examination using such a scenario-based approach. Processing is limited to primary activities generating hemp, bast and dust products.

5.2 Production setting

The analysis depicts three production units, based on figure 11. A 20 ha area on a diversified cropping farm is depicted, with minimal specialised equipment and 20% use of multiple use farm equipment. Detail by way of *Southeast Farmer* survey of contract rates for 2019[7], updated and extrapolated using a multipurpose guide to 2022 crop gross margins,[8] a 2022 growers' guide,[9] and a GM estimate (Kumar, 2022).

Production system	HEMP								
FIXED COSTS									
Land	20	ha					0		
Spec farm equipment	35,000		10%	deprn			3,500		
Generalised farm equipment	350,000	20%	10%	deprn			7,000		
Perm labour	120,000	1 FTE	10%	allocated			12,000		
Admin	30,000		20%	allocated			6,000		
ALL FIXED COSTS									28,500
Casual labour	20%	FTE	48.00	$/hr					
Grain yield	0	T GRAIN/ha							
Straw yield	10.0	T STRAW/ha							
								Totals/ha	Totals
Total straw production	200	T Straw	350	kg bales					
			28.6	bales/ha					
	%	T or kg	Prices						
Grain 1	90%	0	3.00	$/kg				0.00	0
Grain 2	10%	0	2.50	$/kg				0.00	0
Straw		200.00	492.47	$/T				4,924.74	98,495
		0		$/kg				0.00	0
		0		$/kg				0.00	0
							Totals	4,924.74	98,495

Figure 11. Fixed costs in production

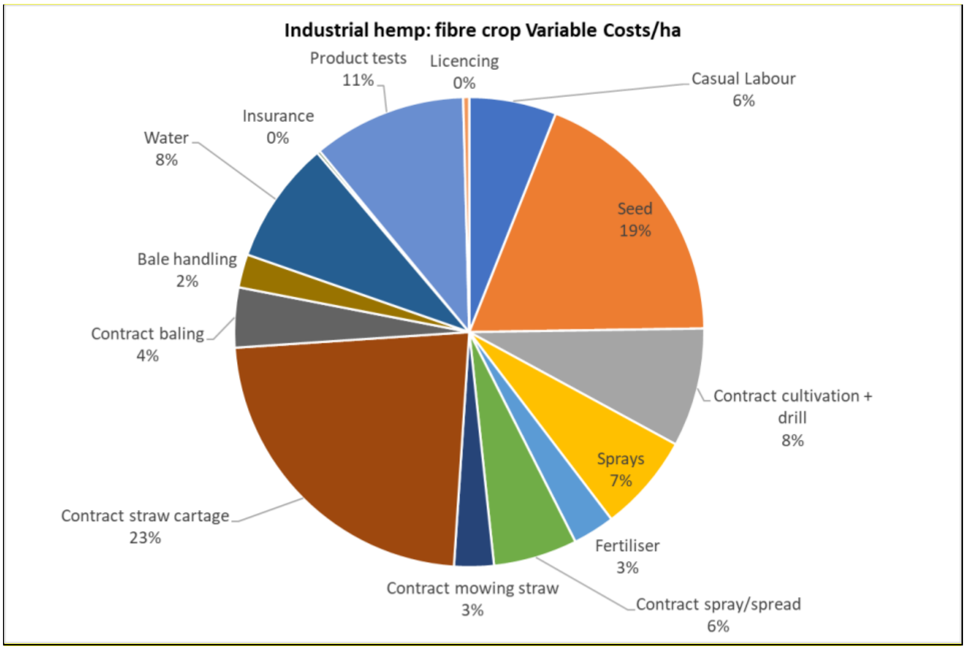
[6] Contact the author for a copy of the analysis and further information on its specification.
[7] https://www.southeastfarmer.net/section/news/new-naac-contracting-prices-2019
[8] GRDC Gross Margin Guide
[9] WA DPIRD growers' guide

Variable costs are set up as shown in figure 12, with flexibility maintained to accommodate grain production as a dual or specialised crop. Cells are colour-coded to reflect specifications, which are sensitive to items such as dual used crops (e.g. seeding rates and cultivation requirements) and presence/absence of irrigation. Contract rates have been used where available. Detail of hemp specific items such as crop testing[10] are approximations of specified arrangements. The GM arrived at (for which variations are shown for different processing-production linkages) is close to the results obtained by others (Kumar, 2022).

VARIABLE COSTS									VC $/ha	VC total
Casual Labour	78	hrs	48.00	$/hr				6.0%	187.20	3,744
Seed	45	kg seed/ha	13.00	$/kg seed				18.8%	585.00	11,700
Contract cultivation + drill	3		85	$/ha				8.2%	255.00	
Sprays	3		70	$/ha				6.7%	210.00	4,200
Fertiliser	0.75		120	$/ha				2.9%	90.00	1,800
Contract spray/spread	3	passes	60	$/ha				5.8%	180.00	3,600
Contract mowing straw	1		85	$/ha				2.7%	85.00	1,700
Contract harvest grain	0		210	$/ha				0.0%	0.00	
Contract grain cartage	0		11.25	$/ha				0.0%	0.00	
Contract straw cartage	100	km	0.25	$/bale/km				22.9%	714.29	14,286
Contract baling	28.6	bales/ha	4.50	$/bale				4.1%	128.57	2,571
Bale handling	28.6	bales/ha	2.50	$/bale				2.3%	71.43	1,429
Water	3	ML/ha/yr	88	$/ML		$/year		8.5%	264.00	5,280
Drying										0
Insurance	1		2.5	$/$1000				0.2%	6.46	129
Product tests	1	tests/ha	265	$/test				10.6%	329.50	6,590
Other testing costs	165	$/hr	6	hrs	300	accomm				0
Licencing	1300	per license	5	years				0.4%	13.00	260
All VC costs/ha									3,119.44	
All Rev/ha									4,924.74	
GM/ha									1,805.29	
GM										36,106

Figure 12. Variable Costs in production

The resulting distribution of variable costs is shown in figure 13. The interested reader's attention is drawn to the 23% of variable costs associated with an assumed 100 km delivery of baled hemp straw.



[10] https://pir.sa.gov.au/__data/assets/pdf_file/0018/427050/industrial-hemp-faq.pdf

Figure 13. Distribution of variable cost items in hemp fibre production

5.3 Fibre processing

Three analytic models are established, generally referred to as small, medium and large. The small model is shown as figure 14. The assumptions regarding capacity are based on stakeholder conversations and specifications of commercial equipment[11] posted online. Prices are drawn from stakeholder conversations and validation from international sources.[12]

Processing system			CAPACITY					upgrade	
INTAKE	1.5	round bale/hr	525	kg straw/hr				0%	
			220	days/year MAX					
			1	shifts/day					
			866	T straw/year MAX					
			3.9	T straw/day MAX					
PURCHASES									
	2	farms @	762	HOURS WORKED/yr					
	40	ha @	20	ha			46%	CAP UT	
	400	T straw @	10.00	T/ha					
SALES									
		T straw		T product			Price in $/T	Revenues	
Yield of hurd	65%	260		260			1,650.00	429,000	
Yield of bast	25%	100		100			850.00	85,000	
Other	10%	40		40			300.00	12,000	
Totals		400		400					
						Ave price rec/T products	1,315.00	All revenues	526,000
						Ave price rec/T Straw	1,315.00		

Figure 14. Processing volume and capacity specifications (small scale)

Specialised and generalised machinery and labour are specified along with other fixed costs. Variable costs are specified based on stakeholder interviews and technical specifications. Casual labour and electrical power requirements are extrapolated from the small model to the medium and large models using scale adjustments. The cost and price specifications are used to construct a mechanism for an adjustable price which is transmitted to production level.

A simple markup pricing model is employed where the processor retains 40% of the sales value per tonne, and subtracts off machinery depreciation and non-straw variable costs to arrive at a farm level price for straw. The inclusion of the (non-volume dependent) depreciation amount in the pricing equation enables the differential price transmission mechanisms for the three processing models.

The processing models are connected to separate farm production models according to different value addition mechanisms. Figure 15 presents the small scale model, and table 4 presents the specifications of the three value chains.[13]

[11] For example, Greenfield's Hemptrain® https://canadiangreenfield.com/hemptrain/

[12] For example, UNCTAD price and cost reports. https://unctad.org/system/files/official-document/ditccom2022d1_en.pdf

[13] The degree of simplification is apparent from large returns on capital for the processing stage of the chain

COSTS AND PRICE FORMULATION									
				Non-straw Variable Costs/T straw			211.53		
Markup from sales price	40%			Markup/T straw			572.00		
Depreciation	34,000			Price paid /T straw			433.97		
				Payment equivalent per ha			4,339.74		
				ADDITIONAL PRODUCT VA			39,000		
FIXED COSTS									
		Cap value	SHARE	Depreciation				Cost	
Decorticator value		240,000	100%	10%				24,000	37%
Machinery		200,000	50%	10%				10,000	15%
Insurance								10,000	15%
Admin								4,600	7%
Perm labour			25%	200,000				50,000	77%
All fixed costs									64,600
VARIABLE COSTS									
Purchases of straw									
Markup on costs									
								Variable costs	
Purchases of straw	400	tonnes	433.97	$/T				173,589	67%
Electricity	30	kVA	24	kW	1	Motors		5,851	2%
	0.32	$/kW hr							
Cas labour	48.00	$/hr	1.0	scale factor				36,571	14%
Building rent								0	
Loader fuel	15	l/hr		2.30	$/litre			26,286	10%
Outwards freight	0.13	$/Tkm	100	km	400	T products		5,200	2%
R&M	8%	of other VC						5,913	2%
Misc	6%	of other VC						4,789	2%
All Variable costs									258,200
							NET		164,200
							Margin		228,800
							Margin after FC		164,200
							RET on PROCESSING CAPITAL		48%

Figure 15. Processing volume specifications and pricing mechanism (small scale)

Table 4. Specification of three hemp fibre processing value chains

	Small	Medium	Large
Processing machinery ($)	240,000	1,800,000	10,000,000
Other machinery ($)	100,000	450,000	3,000,000
Rented building space (m2)	0	250	1,500
Max capacity/year (T straw/year)	866	5,775	34,650
Number of suppliers	2	13	16
Yield of straw (T/ha)	10	10	10
Farm Variable Cost/T straw ($/T)	311.94	311.94	290.77
Areas/farm (ha)	20	20	100
Total area (ha)	40	260	1,600
GM/ha at farm ($)	1,220	3,028	3,857
Price paid for straw ($/T)	433.97	614.77	676.44
Non-straw Variable Costs / T straw ($/T)	211.53	87.69	31.31
Share of straw in VC	67%	88%	90%
Capacity utilisation assumed	46%	45%	46%
Profits assumed @ 40% of sales price	228,800	1,592,600	9,716,000
Margin after Fixed Costs	164,200	1,330,100	8,821,000
Return on Capital (%)	48%	59%	68%

5.4 Validation and sensitivity to specifications

The margins along the three value chains are presented in figure 16. These are assembled from sources cited above and subjected to adjustments to fit observed price margins and enable a workable model of price transmission processes.

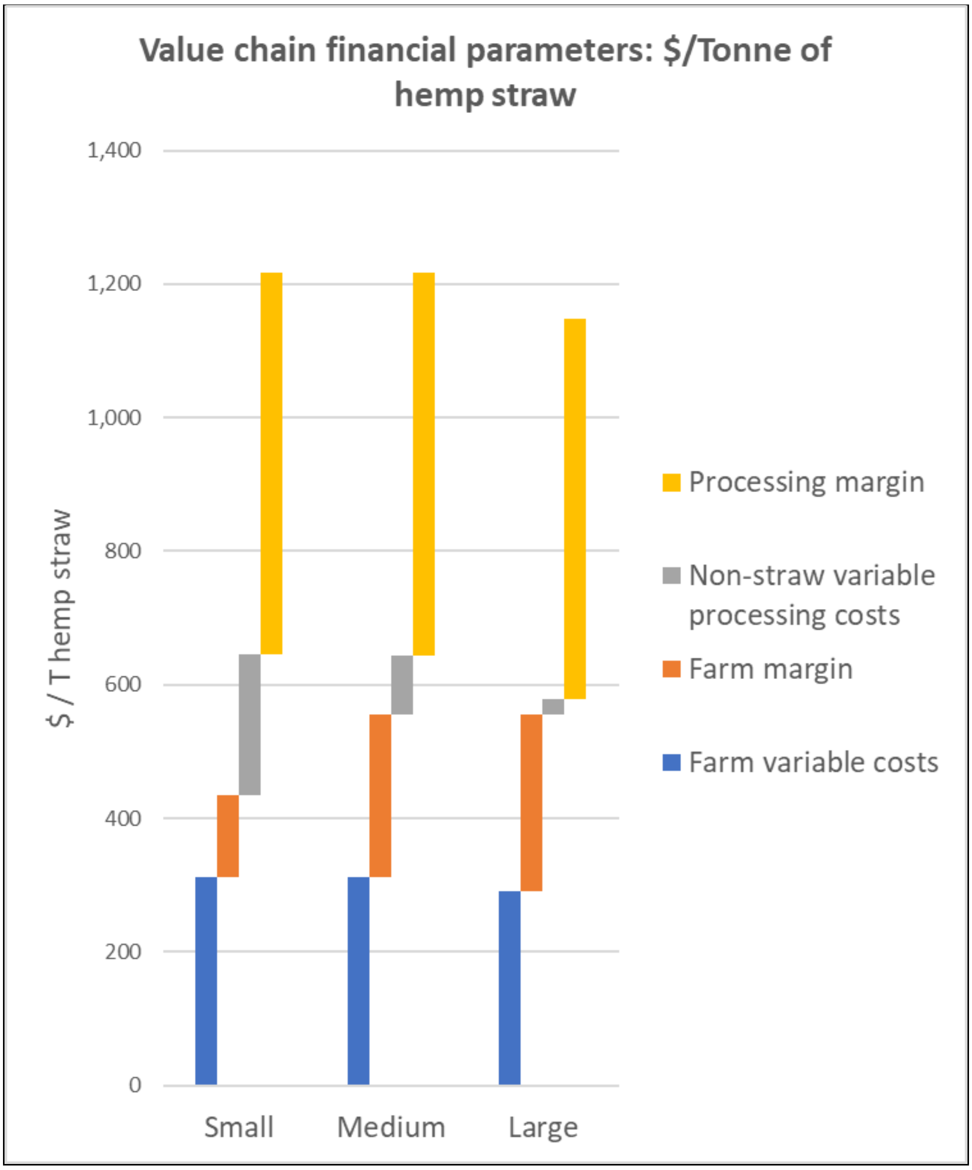


Figure 16. Assembled margins in hemp processing value chains

The three models were subjected to a series of imposed external changes and their responses recorded. The changes included variation in planted area per farm, crop yield, and the number of farms supplying a processor. Projected changes along the value chain, in response to these shocks, are shown in figure 17 as sensitivity analysis. Three rows of diagrams appear, each offering projections from one of the size-based models.

An overarching theme of the sensitivity analysis is that processing capacity utilisation is influential in pricing in the value chain and so flows through to farm financial indicators. For all models, farm gross margins rise with such volume-enhancing change such as area increase, yield increase and numbers of farms. Connections to farm level costs are not so direct due to the prevalence of straw transport costs in the farm variable cost calculation: a reduction in volume subtracts from variable costs per tonne and so partially offsets other effects. Projected farm Gross Margin is particularly sensitive to crop yield assumptions, reflected in the importance attached to plant breeding and agronomic research. Processors' return on capital (baselines are 50-70%) tend to reflect utilisation of processing capacity and the factors that affect it.

The transmission of shocks from processing through to the farm level are projected to be larger for the small model, reflecting its lower baseline and more simplistic connection to producers (just 1-3 farms supplying the small scale processing unit).

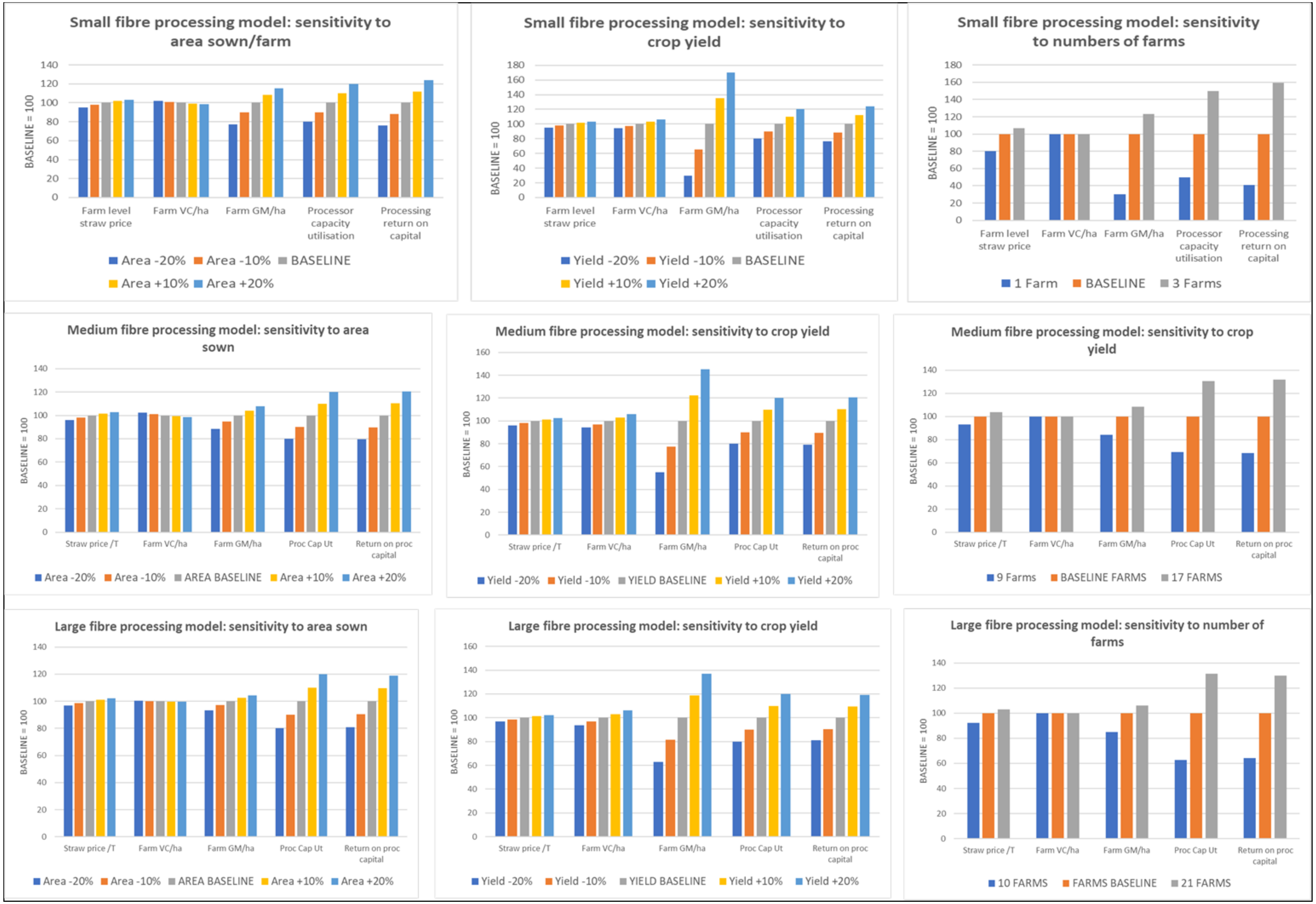


Figure 17. Sensitivity of analytic model to assumptions

6 PROJECTIONS AND ANALYSIS OF TECHNOLOGY ADOPTION

6.1 Approach

From the spreadsheet-based baseline analytic framework as described, scenarios entail:

1. Examinations of the presumed response in cost and/or benefit, to a presumed change induced by adoption of a technology and related changes
2. Examinations of changes in selected elements or patterns of cost or revenue, due to presumed changes due to technology or organisational change

The analysis is based on limited data and hence a set of assumed values for technical parameters. As far as possible, reliable data sources for crop production and cost parameters were used. Extensive use of non-hemp arable products was however necessary. The parameters are however varied in some scenarios, and are set up in a flexible fashion to increase the numbers of possible enterprise types (e.g. dual purpose crops). The author's best attempts have been made in employing data, and the specifications and results obtained are tested for sensitivity to key assumptions.

Projections of analysis conducted using the model developed – generally disaggregated across the three size-related versions of the model. In the first stage, a set of results based on aspects of the cost calculations are presented. In the second stage, the analysis involves more complex scenarios.

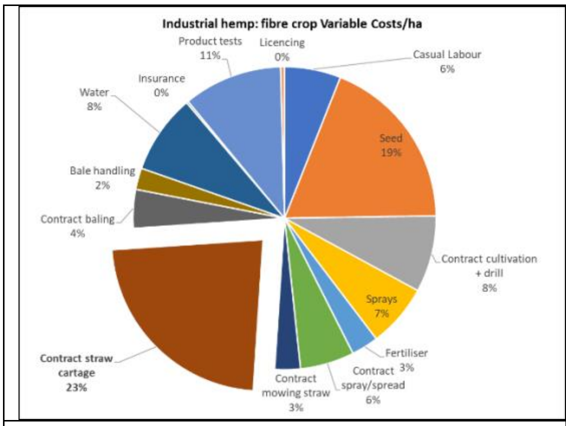
Scenario analysis is not conducted as an attempt to replicate reality, but rather to examine the projected effects of one or a few changes, relative to a baseline. This approach minimizes the analytic impact of the errors inherent in the baseline: the same errors are included in both the baseline and the scenario. Improvements to the baseline are of course to be welcomed, but do not distract from central results.

6.2 Projections arising from cost compilation

6.2.1 Fibre processing location

Transport occupies 23% of farm costs. Baseline conditions depict a 100 km delivery from farm to processor, and a further 100 km delivery from processor to market. Although the processing operation delivers no reduction in weight (all products are utilised), the transport mode and form and packaging of products is changed after processing, but are equally shelf stable as the straw bales transported from the farm.

A shift of the processing plant so that its distance from farms averages 10 km, and its delivery distance from processed products is 190km, is examined. In total, transport costs for the entire value chain are reduced by 42%. Additional costs assumed by the processor result in a 3% decline in straw prices paid. The reduced transport costs increase farm GM/ha by 42%, and a significantly expanded farm margin.



	change
Straw price	-3%
Farm GM/ha	42%
Non-straw processing costs	6%
Total transport costs	-62%

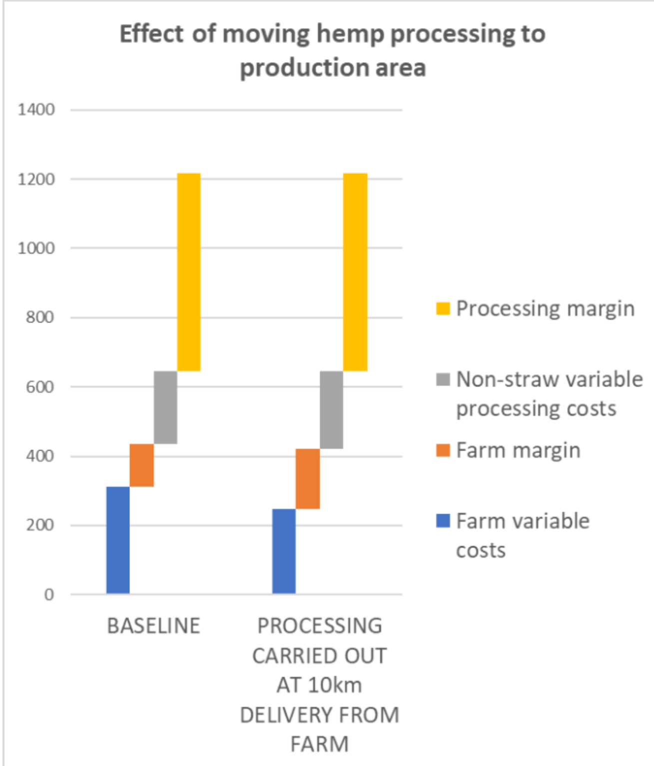


Figure 18. Effects of shifting processing plant closer to farm

6.2.2 THC testing costs applied across the producer-processor interface

THC tests for standing crops feature costs associated with laboratory changes, and government staff travel, accommodation and time. Assuming one test per hectare and one crop per year, and rationalised travel arrangements, costs amount to 8-11% of variable costs for the farm level models presented here. The small, medium and large models serve a producer base of 2, 13 and 16 farms respectively. The sum of these costs is then around $12,000 for the producer base of the small processor, $70,000 for the 13-farmer producer base for the medium sized processor and over $400,000 for the 16 farms (each with 100 ha of hemp) delivering to the large processor. These costs can be expressed per tonne of product processed, and related to straw prices. This latter indicator is between 4.3 and 7.1%. This is to say that an innovation which removed, or largely removed, this cost from the system would have a larger positive effect on farm income than would a 20% increase in crop yield (projected at 4%).

Table 5. Analysis of whole-system costs of THC testing

Model	No. of farms	Farm areas	Cost per farm ($)	Aggregate cost ($)	cost/T straw ($)	% of straw price
SMALL	2	20	5,945	11,890	29.73	7.1%
MED	13	20	5,386	70,023	26.93	4.8%
LARGE	16	100	26,586	425,370	26.59	4.3%

6.2.3 Ownership in lieu of income

The large scale processor is depicted as having a capital base of $13 million, which is an approximation of the costs of processing equipment and supporting machines that are associated with the volumes produced. The generally low labour cost per unit of operation enables a higher price per tonne of straw paid to producers, than do the other two models. The analysis here examines a potential exchange of reduced straw price for shares in the ownership of the processor. Using conveniently round numbers, a 10% reduction in straw price paid to an individual farmer with a 100 ha hemp crop would reduce GM/ha by around 19% and cost around $62 thousand in lost income. This amount represents around 0.5% of the value of the processing plant (a book value approximation) and this might denote a share owned by the farmer in lieu of full payment. This approach would free up cashflow for other expenditures by the processor, particularly where recruitment of new suppliers could be achieved as a means of raising capacity utilisation.

Table 6. Indicative share in lieu of full straw price payments

Single producer	
Straw price ($/T)	617.94
Volume straw delivered/farm (T)	1,000
Shares in lieu rate of price reduction	10%
Straw price reduction ($/T)	61.79
Change in GM/ha	-19%
Farm income foregone ($)	61,794
Farm income foregone as % of processor capital	0.5%

6.3 Scenario analysis

6.3.1 Expanded numbers of farmers

The sensitivity analysis demonstrated the sensitivity of the model to changes in numbers of farms. The effect of this change is to raise the capacity utilisation of processing, thereby lowering variable costs, which precipitates a price paid to producers for straw. This was examined as a sensitivity test or the models. The scenarios here examine changes in numbers of farmers at the margin: a single additional farmer supplying straw. The relative changes to farm numbers are presented for each model: 50% for the small model as its baseline is just two farmers and is increased to three. One additional farmer for the medium and large models are 5% and 6% respectively, and note that the large model is supplied by farms with 100 ha hemp crops. Capacity utilisation is seen to rise by the same proportion as numbers of suppliers. Straw price and farm GM/ha are seen to rise, as does return on capital for processors. Overall transport costs rise as new suppliers join the network for each processing plant. This result emphasises the importance of capacity utilisation in processing, in this case improved by recruitment of additional farmers. However, the less obvious impact is on producers: price and income rises by virtue of recruitment of additional suppliers, and small starting numbers mean that the effect of an additional supplier is large.

Table 7. Analysis of numbers of farmers supplying hemp to processors

Changes in variables	SMALL		MED		LARGE	
	FARM	PROC	FARM	PROC	FARM	PROC
Number of farms	50%		8%		6%	
Capacity Utilisation		50%		8%		6%
GM/ha	23%		3%		1%	
Casual labour costs	0%	50%	0%	8%	0%	6%
Return on Capital		59%		9%		6%
Straw price/t	7%	0%	1%	0%	1%	0%
Transport cost total	0%	50%	0%	8%	0%	6%

6.3.2 Benefits of adaptation to changing product prices

Table 8 presents first, projected responses to a 10% increase in the price of hurd. Unsurprisingly these are positive: across the production and processing system: 9-13% increases in straw price which delivers an 18-48% increase in farm GM/ha (dependent on the starting base). However a significant further benefit is achieved if the processing action can deliver a 10% shift from other products to hurd. Despite differences between the models, this delivers substantial gains in terms of farm GM/ha and also substantial increases in processors' return on capital. This scenario highlights the benefits to be gained from flexibility and precision in production and processing, and in capacity to select hemp crops which yield heavily in hurd to respond to maker opportunities.

Table 8. Analysis of processing composition adjustment

Changes in variables	SMALL		MED		LARGE	
	10% rise in hurd price	10% rise in hurd yield from processing + 10% rise in hurd price	10% rise in hurd price	10% rise in hurd yield from processing + 10% rise in hurd price	10% rise in hurd price	10% rise in hurd yield from processing + 10% rise in hurd price
Straw price	13%	26%	11%	20%	9%	18%
Farm GM/ha	48%	91%	24%	45%	18%	34%
Processor return on capital	10%	18%	8%	16%	8%	14%

6.3.3 Benefits of labour input to processing

Reductions in labour costs for processing generate benefits throughout the producer-processor system. The magnitude of the effect differs across the models examined. In the large scale case 50% reduction in labour costs is barely passed on to producers as a change in straw price, due to the small share of costs occupied by labour. In the small scale case the effect is very strong on straw price and GM/ha, and in the medium case there is an intermediate result. A proposed 50% reduction in labour input might be associated with labour reducing technology, but equally – and particularly in the small scale case – may be due to a labour sharing arrangement between producer and processor.

Table 9. Analysis of reduced processing labour costs

	SMALL		MED		LARGE	
	FARM	PROC	FARM	PROC	FARM	PROC
Farm GM/ha	43.2%		5.1%		0.4%	
Casual labour costs		-50%		-50%		-50%
Straw price	12.1%		2.3%		0.2%	

7 Synthesis and Conclusions

7.1 Overview

The current study maps the current situation in the hemp value chain to actual and potential technologically-based and organisational opportunities. It offers a review of available literature on selected issues and the associated technologies. It employs field-level consultation to present practical aspects of the value chain, the production and marketing system, and the relevant research underway. Using a simple 2-stage model of the value chain, disaggregated to capture diverse scale, cost structures and farm types, projections of financial implications of change in the value chain are made.

The focus of the review aspects of the study is hemp fibre, rather than hemp grains and the hemp food value chain. This should not be interpreted as bias, nor as an assignment of priority. Rather, the technology, marketing and industrial organisation associated with the hemp food value chain is to an extent accommodated by current conditions. To that extent, producers, processors, retailers and end users have some clarity on investment and market opportunities. Notwithstanding current market conditions for hempseed oil, this is a very different context for a consideration of technology in contributing to industry growth, than is the case for hemp fibre. The analytic tools developed can accommodate hemp grain crops' production and dual crops, and analysis of that context is deferred to further work.

This study sets out to contribute to a whole-of-chain view of hemp industry development opportunities, as they are influenced by technologies. The study has recognised the need to analyse organisational opportunities and problems in the hemp industry, particularly around the focal point in the value chain occupied by processors and the technologies they employ. Further, there are several strands of current research into Australian hemp which are contributing substantially to the scientific and farm management knowledge base, as well as examining bast fibre processing opportunities. This study has accordingly treated those subjects somewhat lightly and only in contexts related to value chain development.

Substantial enthusiasm surrounds the hemp industry. This reflects exciting market prospects for food and fibre, both in traditional and exciting new products and market segments. Hemp's sustainability and carbon-related credentials, its short crop life, and its general capacity for fitting into existing farm systems and technology are also attractive. Hemp is emerging from what some term "prohibition", and notwithstanding the cost and uncertainty of regulatory regimes and some ill-informed consumer resistance, there is enthusiasm about growing and use of hemp in Australia.

Hemp is however faced with constraints on its expansion in areas sown and on its development as a value adding industry. These two forms of constraints are strongly linked due to the role played by capacity utilisation and economies of scale in processing. Processing is a requirement for market access, and markets are poorly developed so do not deliver strong price signals. This in turn discourages large scale uptake by producers, who in any case are short of key inputs such as appropriate varieties and good quality seed. Technology, and the organisation of transactions, in the industry are the target of this study.

7.2 The research literature on the hemp value chain

This study's review of the research literature sketches the knowledge base of the hemp value chain, particularly as it relates to technologies being used and Australia's developmental context. Plant breeding is addressing productivity, but is having to do so for a diverse set of agro-climatic settings and across grain, fibre and dual purpose systems. Key findings on genetics and plant breeding include the difficulties in separating genetically the drug-type from industrial hemp, and the extreme variety reported in plant characteristics, productivity and product characteristics between the cultivated varieties available. The absence of genetic tests suggests that alternative approaches are needed in both promoting identified varieties for desirably low THC content, and developing new compliance arrangements for the standing crop to replace expensive lab-based testing of crops.

In addition to contributions to farm management, literature identifies production aspects of hemp and its product life cycles as relatively sustainable, useful in actions such as populating contaminated soils, and as a significant weapon in carbon emissions reductions. Existing technology and organisational capacities in Australia can largely accommodate the demands of production and harvest, but commonly in the nature of commodity production rather than as value added products. There are exceptions: producers have developed their own marketing to hemp house and hemp concrete producers; vertically integrated operators have established successful brands for hemp oil and value added hemp food products. A significant amount of research supports these efforts and offers guidelines on productivity and quality. Particularly for fibre, such localised developments have meant that quality standards have received little attention. A current lack of any market for bast fibre is resulting in a multi-season glut of unsold product which will eventually enter markets without information about its fibre characteristics. The entire hemp fibre value chain is short of information. Marketing of hemp’s sustainability story, and more direct access to carbon markets, remain elusive due to the lack of product information. Intermittent market operations by processors, and the absence of processors from large geographic areas, contribute to poor information flows.

Processors are a multifunctional stage of the hemp fibre value chain, as they also supply into end user markets. Stakeholders consulted during this study suggested that many such marketing actions were strongly localised: hemp house building providing several examples. Large scale domestic markets such as pet bedding require significant volumes of standardised product, and the retail chains can alternatively source cheap imported product. Negotiating such markets in the presence of fluctuating capacity utilisation and variation in varieties supplied has constrained processors’ market development progress. The research literature provides guidance on advanced uses of hemp fibre, particularly bast in composites and organic alternative to metals and plastics, for which many of the same requirements (uniformity, known quality attributes, regular supply) apply.

The research literature addresses the several contact points between the hemp industry and regulation. Although technologies exist for THC detection and content measurement in plant material, on clothing, and in human saliva all using hand held mobile equipment, this has not yet led to the development of a device for in-field assessment of a standing hemp crop. Building regulations have not fully addressed hemp houses and hemp concrete, although the literature tests and promotes an array of performance measures in structural strength, and moisture and temperature mediation. Despite substantial promotion of knowledge about hemp food products and their beneficial uses, hemp related foods face continued regulatory scepticism and the international press reports extreme anti-hemp regulation abroad.

Few whole-of-chain analyses have been conducted which measure or project costs and benefits of change in the hemp value chains. Just one of these provided detailed projection about processing technology, logistics and spatial issues, and prices. A number of life cycle analyses of hemp appear in the literature, most frequently on carbon. These tend to be trial based and do not illuminate information pathways by which product attributes - like sequestered carbon - can be identified and traced through to a paying consumer.

7.3 The hemp value chain mapped to technologies

This study provides a mapping of the three main hemp value chains to technologies, and identifies gaps. Contributions to filling those gaps are made from the literature review, where technologies and organisational arrangements are identified. Beyond scientific contribution, the study illuminates the suitability of these technologies for adding value in the hemp value chain, and identifies the mechanism by which value might be added. These technologies – sometimes loosely defined - are then assessed for their readiness, using the Agrifutures' CRAM analytical tool.

TRM assessments were mixed: generally high in terms of technical development but generally low in commercial or suitably applied commercial development. Legal and regulatory barriers play a part in this disparity. The development of hand-held in-paddock THC measurement devices has not advanced anywhere in the World, probably due to resistance from regulators of hemp cultivation. Seed certification for hemp would receive substantial impetus if it was promoted as the central indicating element of low THC production on a farm. Product quality metrics are in existence for most fibres, but have not progressed so that they are in use in Australia.

Processing equipment is apparently fit for purpose, but its widespread introduction is delayed due to low capacity utilisation: too few farmers with two few hectares each; or both. This means that the CRAM's criteria regarding testing of commercial arrangements and commitment from supply chain actors cannot be met. It is also clear that different sized models of processing are emerging, and the form in which each of them approach their supplier and customer bases will also differ. Hence, the nature of the testing of commercial arrangements will also vary.

7.4 Central results from the analysis of value chains

The analytical tool developed is a spreadsheet representation of two stages of the hemp fibre value chain. It is simplistic in its representation of cost and revenue items at both stages, and has a simple two-stage farm price formation process based on an assumed % of markup. The analytical tool is not intended to be entirely accurate in its representation of enterprises' costs and performance. Its farm level budgets however have much in common with similar published work, and so some statements about apparent farm level costs can be made, and each of these has a strong bearing on technology and organisational priorities for the industry:

- transport of bales of hemp straw constitute a significant (23%) share of variable costs and to this should be added baling, bale handling and storage
- costs of TCH testing are a significant item in the farm budget, and this is not surprising given their inherent travel, accommodation and use of professional time
- seed is expensive, and represents a large cost item despite its parsimonious use because of a desired low plant density.

The representation of cost and revenue flows at the processor is greatly simplified and no claim is made that cost and profitability levels mimic reality. However, the analytical tool offers some compliance to principles associated with shares of costs allocated to labour and raw material. Conclusions available from the processor budgeting process are:

- capacity utilisation is attributable primarily to capacity utilisation
- different models of processor, based on scale of operation, are necessary to reflect the diversity of producers' participation in hemp fibre value chains
- mechanisms exist by which costs sharing, or ownership transfer in lieu of payment, might be used to release cash for the processor's use in the context of industry development and expansion.

The analytic tool provides a means by which technological and organisational changes can be analysed for their effect on two stages of the hemp fibre value chain. Three overriding themes emerge from the analysis:

- capacity utilisation is the key to ensuring reasonable price levels passed to producers
- cost structures associated with processors' size affect the transmission of changes to producers, with the three models (representing different scales of operation) providing different transmission
- opportunities exist for shared actions between processors and producers, impacting costs directly by changed roles, or indirectly by influencing capacity utilisation.

The predominance of processing capacity utilisation is responsible for one of the interesting results projected using the model: that producers benefit when additional producers enter the same processing arrangement. This network-type effect provides incentives for both expansion of the production base and durability of supply arrangements. Additions to areas sown have similar network-type effects, but face constraints such as the crop rotation or availability of a suitable irrigated area.

The spatial configuration of the fibre processing industry is a crucial component of its efficiency, and hence its capacity to support suitable farm incomes. Significant benefits are projected from locating processing plant near to farms and distant from markets. Despite a reduction in straw price, farm GM/ha rises significantly. An additional result is the substantially reduced aggregate transport cost for the industry. In addressing the final customer or end user, there is scope for processors and producers to progress these organisational changes with an explicit benefit sharing agenda. This forms the basis for vertical integration or other whole-of-chain ownership structures.

The analysis demonstrated benefits available from production co-ordination around variety selection and processing machine settings. A benefit is generated along the value chain due to changes in relative product prices. However, these benefits can be magnified by changing the ratios of products to reflect, or partly reflect, the new price regime. Implementation of this co-ordination requires significant information exchange, and a mutual understanding between processor and producer, that is lacking to date.

Beyond the whole of chain analysis, potential benefits of new technologies and organisation remain unexploited. Not directing NIR technology to THC testing is imposing a cost on producers of a magnitude that will, for example, offset available benefits from years of advance due to improved varieties. When aggregated to the scale of a large processor, the costs of on-farm testing are alarming: although in reality government officials will lack the time and laboratory resources to test the associated areas using current technologies and procedures.

Orientation of the hemp industry to carbon markets requires the development of information flows for validation, which would also be written into a method for approval by the CER. One hectare of hemp is thought to sequester 22 tonnes of CO_2 which in the presence of a recognised method, at a conservative value[14] of $20/T would be worth $440 per hectare. This represents an addition of 19, 12 and 10% of GM/ha respectively for the farms associated with the small, medium and large models of processing operations depicted here. For a farm producing two crops per year, these numbers can be increased, and appropriate specification of the method would ensure that they are doubled. Further benefits await the successful product differentiation of hemp as an

[14] https://www.cleanenergyregulator.gov.au/Infohub/Markets/Pages/qcmr/september-quarter-2021/Australian-carbon-credit-units-(ACCUs).aspx

environmentally friendly product, and this step also requires the development of information systems which would extend to standard quality descriptions.

7.5 Further research

This study has identified several technologies or organisational changes that are on the brink of application to hemp, and are vital to its development. Matching of selected hemp varieties to agroclimatic zones is one such task: this is in progress at the time of writing and is not within the main remit in the current study so it is noted here for completeness. Last-mile type investments in the following technologies are recommended:

- NIR technology for THC assessment in a standing hemp crop, to reduce costs and avoid overloading of government services
- supply of seed certified for low THC content, as an adjunct to existing genetic research and in terms of improved certification and supply
- applications of data georeferencing for crop data to assist initially with regulatory compliance and later to enable information systems for carbon marketing and product traceability.

Transfer of existing knowledge to Australian hemp processing is also underway in terms of commercial links to other countries' industries, and trials for bast fibre in various textile processing systems at home and abroad. In terms of whole-of-chain development, priorities include:

- product quality descriptors and metrics for hurd, bast and useful dust products
- a registered method for access to carbon markets.

The significance given to the need for new organisational models for hemp fibre value chains prompts a recommendation for trial activities. These would deploy technologies in pursuit of accumulating product volumes for improved processing capacity utilisation. Trials would ideally include:

- a small scale processing unit located near to a production base
- alternative ownership models including hire, co-operative membership, rent-to-own or ownership in lieu of payment
- alternative payment and delivery models which might extend to land-only contributions by farmers, with production activities undertaken by the processor and an area-based payment made to land owners
- community based projects for hemp which offer a commercial advantage such as connection mining waste, integration with other crops, or proximity to buyers of final products.

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Appendix. Commercial Readiness Assessment Matrix (CRAM) used in Technology Readiness Assessment

The Commercialisation Readiness Assessment Matrix (CRAM)					
TECHNOLOGY			max score = 36		
USE					
CRAM SCORE	0	0	0	0	0
Development Stage	**Score**	**Technology Readiness Level (T)**	**Market & Customer Knowledge (M)**	**Supply, Manufacturing & Distribution Knowledge (S)**	**Financial, Revenue and Cost Models (F)**
Early Stage/Research		The basic principles have been observed and reported.	The target end-user and market are clearly understood and described (including segments).	Initial manufacturing and supply chain stages to deliver the technology have been identified.	The total costs to develop and commercialise (extension) the technology have been documented.
	0				
		Competing technology and/or technology applications have been formulated or reviewed and compared.	Secondary research has been undertaken and included in the project materials.	The supply chain requirements have been identified, including the types of partners or manufacturers.	Revenues for the next 36 months have been modelled for the initiative and documented.
	0				
		Preliminary analytical, experimental, or proof-of-concept functions have been demonstrated.	Primary market research has been undertaken and insights applied.	The roles and responsibilities have been defined for the types of supply chain partners who will need to deliver the technology, products or services.	Cost of production and delivery have been validated by direct discussion with suppliers/manufacturer/ distributors.
	0				
Proof-of-Concept		The component and/or prototype approach has been validated in a laboratory or 'in-house' environment.	The value proposition has been validated against competing approaches (products/services or practices).	Specific supply chain partners have been identified, including the role/s within organisations to approach regarding the deal.	The costs of distributing and supplying the product or service have been verified.
	0				
		Validation in a relevant industry operating environment has occurred.	A prototype has been sold, or a collaborative project initiated, with a partner.	Supply chain processes have been discussed with initial customers and critical partners have demonstrated their ability to meet needs.	The revenue model has been tested with at least one customer.
	0				
Development		System/subsystem model or prototype demonstration in a relevant environment has occurred.	End-user/customer sales pitches have been developed for the technology, product or service.	All supply chain partners have been engaged. Key back-ups have been identified.	The costs of production and distribution have been validated across multiple markets and regions.
	0				
		A system prototype has been used by target end-users in an operational environment.	Marketing collateral has been developed using the results of market research for each target customer/region.	The supply chain has been trialled with at least one customer in each target market.	Revenue and cost models have been verified based on the final product or service over 6 months.
	0				
Application/Adoption		Actual system has been completed and qualified through early use with 10 end-users.	The technology has been sold to 10 unique customers (or used by 0.5% of end-users if the technology is incorporated into other products or services).	Post-sales support has been tested and verified to be effective for each target region.	Cost models have been validated across multiple batches or sales over 12 months (or multiple countries if applicable).
	0	0	0	0	0
		Actual system has been proven through successful operations. 50 end-users paying for access.	Over 50 sales have been made or demonstrated sales across multiple regions (or the technology been used by 5% of the target market).	The robustness of the supply chain has been validated across all customer types, target markets and regions.	Revenue models have been validated with a minimum of 50 sales (or 5% of a target market) over 12 months.
	0	0	0	0	0

Source: Agrifuture