Identification and review of the downstream options for the recovery of value from fibre-producing plants: Hemp, Kenaf, Bamboo

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Post-mining industrial development from fibre-rich plants
Key Processing Stages

Cultivation

Harvest

Pre-treatment

Product recovery

Conversion

Manufacturing

Biorefinery

Water  Seed

Plant biomass

Fibrous-Part

Non-Fibrous-part (twigs, leaves, seeds etc)

Conversion

By-products

Lead product

Additional product(s)

High-end by-products
Bast fibre plants

*Hemp*

*Kenaf*
Bast fibre plants

Bast fibre plant

Bast fibre plant cross section

Epidermis or bark

Bast fibre

Woody core or hurd
Different bast plants have a different ratio of bast to woody core

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hemp</th>
<th>Kenaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bast fibre (% in stalk/stem)</td>
<td>25-30</td>
<td>35-40</td>
</tr>
<tr>
<td>Fibre fineness (um)</td>
<td>25 to 40</td>
<td>20 to 35</td>
</tr>
<tr>
<td>Fibre length (mm) – long fibre</td>
<td>16 to 40</td>
<td>8 to 18</td>
</tr>
<tr>
<td>Cellulose (wt%)</td>
<td>70 – 74</td>
<td>45 - 57</td>
</tr>
<tr>
<td>Hemicellulose (wt%)</td>
<td>18 -22</td>
<td>21- 23</td>
</tr>
<tr>
<td>Lignin (wt%)</td>
<td>4-6</td>
<td>8-13</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>550-1000</td>
<td>195-700</td>
</tr>
</tbody>
</table>
Bast fibre crop-to-product profile

**ENTIRE PLANT**

Energy

Example - Bioethanol

**STEM**

Fibre + Woody tissue

Example: Hemp

**SEEDS**

Seeds or Oil

**LEAVES**

Leaves or Medicine

Example - Bioethanol

Example - Bioethanol
Bast fibre stem cross-section

- Bast Fibre: 25-40%
- Hurd: 60-75%

Intermediates

- Long Fibre: 70-90%
- Short Fibre: 10-30%

End-products

- Conventional textiles
- Bio-composites
- Cordage
- Paper Pulp
- Shives
- Construction materials
Bast fibre plant multi-product profile

- **Whole plant**
  - or
  - Stem
  - &
  - Woody tissue/core fibre
  - &
  - Seeds
  - or
  - Whole seed
  - &
  - Leaves

- **Long fibre**
  - Bast Fibre

- **Short fibre**
  - Bast Fibre

- **Chemical extracts**
  - Edible oil (e.g. hemp seed oil)
  - Personal products
  - Paint/varnish
  - Animal Fodder
  - Food
  - Human food
  - Medicine

- **Oil**
  - Edible oil (e.g. hemp seed oil)
  - Personal products
  - Paint/varnish
  - Animal Fodder
  - Food

- **Protein**
  - Edible oil (e.g. hemp seed oil)
  - Personal products
  - Paint/varnish
  - Animal Fodder
  - Food

- **Energy (e.g. bioethanol, biogas)**
  - Conventional textiles
  - Bioplastics
  - Biocomposite textiles
  - Cordage
  - Paper pulp
  - Construction composites
  - Insulation boards
  - Paper pulp
  - Bioethanol/biobutanol
  - Shives (animal bedding etc)

- **Paint/varnish**

- **Animal Fodder**

- **Food**

- **Human food**

- **Medicine**

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*Bast fibre plant e.g. hemp*
Conventional textiles

- Hemp and kenaf fabrics are breathable, warm, moisture-wicking, antibacterial and biodegradable.
- Bast fibres can be easily blended with other fibres such as cotton to make lightweight softer fabrics.
Fibre composites are made by embedding plant fibres in synthetic or biodegradable resins.

PFRCs are being incorporated into thermoplastic matrix composites and are gaining traction in the automotive and aerospace industries.
Hemp and kenaf construction products range from insulating panels, non-woven felts for acoustic damping or levelling from woody tissue/hurds to fibre reinforced polymers for façade panels and concrete.

The most commonly applied product in the building and construction sector is hempcrete.
Paper products

- Paper pulp can be made either from short bast fibre or woody tissue.
- Paper made from kenaf bast fibre is reported to be comparable to paper from some softwoods and most hardwoods.
- Paper from core fibre or woody tissue (hurd) is not as strong, but is easier to manufacture as well as softer, adsorbent and more suitable for hygienic products.
Hemp and kenaf seeds can either be used as a whole or crushed and pressed to produce oil and a residual seed cake.

Hemp seeds contain 30% oil by weight, whereas kenaf seeds contain 20% oil.

Hemp flowers or leaves can be used to make cannabidiols which have low THC levels and are used for medicinal purposes.
Bast fibre processing

- Stems are pre-treated to soften them through retting or degumming, which can be chemical, mechanical or high-pressure/temperature processes.
- Bast fibre is separated from woody tissue, into long & short fibre through a process known as decortication.
Bast fibre multi-product flowsheet options

Plant → Harvest → Stem → Pre-treatment → Stem → Product recovery → Fibre

Long → Spinning → Textiles → Composites → Conversion → Cordage → Carding → Cordage → Pulping → Paper → Conversion → Shives → Pulping → Construction materials → Sorting → Paper

Short → Carding → Cordage → Pulping → Paper → Conversion → Shives → Pulping → Construction materials → Sorting → Paper

Woody tissue → Pulping → Conversion → Shives → Pulping → Construction materials → Sorting → Paper

By-products → Seeds → Cleaning → Whole seeds → Seed oil → Compression → Whole leaves → Medicine → Leaves → Cleaning → Whole leaves → Medicine

Fibre products → Spinning → Textiles → Composites

Woody tissue products → Carding → Cordage → Pulping → Paper → Conversion → Shives → Pulping → Construction materials

By-products → Seeds → Cleaning → Whole seeds → Seed oil → Compression → Whole leaves → Medicine → Leaves → Cleaning → Whole leaves → Medicine

Bast fibre multi-product flowsheet options
Environmental & socio-economic impacts

Implications of the various product options

<table>
<thead>
<tr>
<th></th>
<th>Energy inputs</th>
<th>Water inputs</th>
<th>Job Creation potential</th>
<th>Skills level requirement</th>
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</thead>
<tbody>
<tr>
<td>Conventional textiles</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Fibre-reinforced composites</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Construction materials</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Paper</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
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</table>
Bamboo
Bamboo plant structure

- Culm
- Twigs
- Leaves
- Node
- Internode
- Rhizome
- Shoot
- Roots
- Exodermis
- Fibre
- Endodermis
Bamboo crop-to-product profile

**ENTIRE PLANT**
- Energy
  - Example - Biochar

**STEM/CULM**
- Wood or Fibre or Pulp

**BRANCHES**
- Household wood products

**SHOOTS**
- Vegetable
Bamboo culm/stem

Intermediates
- Wood
- OR
- Pulp
- OR
- Fibre

End-products
- Poles
- Wood products
- Cardboard
- Paper Pulp
- Natural
- Rayon
Bamboo multi-product options

- Whole plant
  - Pulp
  - and/or
  - Strips
  - and/or
  - Poles
  - or
  - Whole leaves
  - or
  - Chemical extracts

- Culm
  - and/or
  - Rayon fibres
  - Natural fibres
  - Woven products
  - Engineered “wood-based” composites

- Branches
  - and/or
  - Sticks
  - Mat, blinds, chopsticks

- Leaves
  - and/or
  - Whole leaves
  - or
  - Chemical extracts
  - Fodder (Manure)

- Shoots
  - Food

- Internode
  --twigs
  - Node
  - Rhizome
  - Shoot
  - Roots

- Culm
  - Energy; biofuels
  - Paper & cardboard
  - Textiles
  - Polymer composites
  - Handicrafts
  - Furniture/Decor
  - Flooring
  - Sporting equipment
  - Construction materials

Part of plant
Raw products
Intermediate products
End-products
Wood-based products

- Bamboo has many applications in the construction and building industries due to its woody nature and similar properties to timber.
- The culm is either used whole as poles or split into strips to make woven products or engineered bamboo wood-composites.
There are two types of bamboo textiles – bamboo linen (also called “natural bamboo fibre”) extracted by mechanical or microbial processes.

Bamboo rayon made through chemical treatments similar to the manufacturing of rayon viscose.
Fibre reinforced composites

• Similar to bast fibre composites, bamboo fibres can be used to reinforce natural or synthetic polymer matrices.

• Bamboo-fibre reinforced plastic (BFRP) composites’ tensile strength is comparative to mild steel and have a lower density, making them ideal for structural applications.
Energy-based products

• Bamboo has a number of desirable characteristics as a fuel for combustion, such as a low ash content and alkali index compared to other bioenergy feedstocks.

• Bamboo culm can be processed into pellet form or other forms of fuels, such as biogas, bioethanol and charcoal.
Bamboo processing

- Each product type requires a separate treatment or processes.
- Bamboo processing is more intensive and extensive than bast fibre processing.

```
Plant
  ↓
Harvest
  ↓
Conversion
  ↓
  Leaves
  Shoots
  Branches
  ↓
  By-products

Culm
  ↓
Splitting
  ↓
Fibre recovery
  ↓
Conversion
  ↓
Poles

Conversion
  ↓
Pulping/Conversion
  ↓
Paper products

Conversion
  ↓
Energy-based products

Conversion
  ↓
Whole plant

Conversion
  ↓
Fibre-based products

Conversion
  ↓
Wood-based products
```
Bamboo multi-product processing scenarios

1a. Fibre recovery - High quality stems
   - Natural fibre

1b. Board-making - High quality stems
   - Plybamboo/Strand woven boards

2a. Weaving - Medium quality stems
   - Bamboo mats

2b. Board making - Medium quality stems
   - MDF boards/Bamboo mat boards

3a. Pulping - Low quality stems/wastes from options 1 and 2
   - Paper pulp

3b. Board making - Low quality stems/wastes from options 1 and 2
   - Particle board

3c. Burning - Low quality stems/wastes from options 1 and 2
   - Energy
## Environmental & socio-economic impacts

### Implications of the various product options

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<td>High</td>
<td>Medium</td>
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<tr>
<td>Energy products</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
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</table>
Potential metal recovery
Potential integrated metal recovery process

Cultivation

Water \rightarrow Soil \rightarrow (metals)

Harvest

Plant

Fibrous-Part

Pre-treatment

Fibrous-Part

Fibre-recovery

Manufacturing

Lead products

Non-fibrous parts

Leachate \rightarrow (metals)

Plant-synthesised nano-catalysts

Ashing

Bio-ore

Hydrometallurgical/pyrometallurgical extraction

Metals

Additional products
Summary

• All the fibre-producing plants can generate multiple products however, the range of products and targeted markets differ for the different plant types.

• There appear to be few holistic or systemic studies on the selection of products and processing of fibre-rich plants.

• This review shows that the selection of product recovery and treatment processes is highly dependent on desired product types and output of low-end vs high-end value products.
The exploitation of fibre-based plants will depend on….
Bast fibre plants appear to be the best downstream option for the production of “green” textiles and high-end niche products such as fibre-reinforced composites.

Bamboo is more suitable as a replacement for conventional timber in the production of functional products such as wooden flooring and construction materials and paper.

Further studies will be required to investigate the effect of contaminants on products and processing options.