Review of products derived from fibre crops

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Biorefinery production chain for fibre crops

Platform
- textile
- technical
- energy

Process
- decortication
- milling
- degumming
- pulping
- Injection molding
- compression
- anaerobic digestion

Product
- yarn
- Paper pulp
- biopolymers
- Plywood
- biofuels

Market
- textile
- peper
- automotive
- aeronautic
- bio-building
- energy

Fiber-based products
Chemical products
Composite products
Energy products
## Hemp products

<table>
<thead>
<tr>
<th>Flax</th>
<th>Hemp</th>
<th>Kenaf</th>
<th>Ramie</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The best grades are used for linen fabrics such as damasks, lace and sheeting.</td>
<td>1. Hemp is used to produce rope, cloth, food, lighting oil and medicine.</td>
<td>1. The kenaf leaves were consumed in human and animal diets.</td>
<td>1. Despite its strength, ramie has had limited acceptance for textile use.</td>
</tr>
<tr>
<td>2. Coarser grades are used for the manufacturing of twine and rope.</td>
<td>2. Currently hemp fibres are used to manufacture bank notes.</td>
<td>2. The bast fibre was used for bags, cordage, and the sails for Egyptian boats.</td>
<td>2. Ramie is used to make such products as industrial sewing thread, packing materials, fishing nets, and filter cloths.</td>
</tr>
<tr>
<td>3. Various parts of the plant have been used to make fabric, dye, paper, fishing nets, hair gels, and soap.</td>
<td>3. These are valued hugely before the development of plastic fibres from petrochemicals.</td>
<td>3. The uses of kenaf fibre have been rope, twine, coarse cloth.</td>
<td>3. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, frequently in blends with other textile fibres (for instance when used in admixture with wool, shrinkage is reported to be greatly reduced when compared with pure wool.)</td>
</tr>
<tr>
<td>4. The use of flax fibre for manufacturing fabrics for garments dates back to Neolithic times.</td>
<td>4. Hemp hurds can be mixed with a hydraulic lime binder to act as an aggregate</td>
<td>4. Uses of kenaf fibre include engineered wood, insulation, clothing-grade cloth, soil-less potting mixes, animal bedding, packing material, and material that absorbs oil and liquids.</td>
<td>4. Shorter fibres and waste are used in paper manufacture.</td>
</tr>
<tr>
<td>5. Sprouts are used in salads.</td>
<td>5. Hemp fibres were added as a tensile reinforcement in a lime/hemp hurd mix.</td>
<td>5. It is also useful as cut bast fibre for blending with resins for plastic composites, as a drilling fluid loss preventative for oil drilling muds, for a seeded hydromulch for erosion control.</td>
<td>5. Apparel dresses, suits, skirts, jackets, pants, blouses, shirts, children wear, mixed with cotton in knitted sweaters</td>
</tr>
<tr>
<td>6. The oil from the seeds makes linseed oil, and can be used in cooking.</td>
<td>6. Kenaf can be made into various types of environmental mats, such as seeded grass mats for instant lawns and moldable mats for manufactured parts and containers.</td>
<td>6. Kenaf can be made into various types of environmental mats, such as seeded grass mats for instant lawns and moldable mats for manufactured parts and containers.</td>
<td>6. Home fashion curtains, draperies, upholstery, bedspreads, table linens, sheets, dish towels, Sewing threads, Handkerchiefs, Parachute fabrics, Woven fire hoses, Narrow weaving, Canvas Filter cloth.</td>
</tr>
<tr>
<td>7. Can be ground into a low carbohydrate meal for making breads and doughs.</td>
<td>7. Kenaf is also used for producing papers.</td>
<td>7. When used in a mixture with wool, shrinkage is reported to be greatly reduced when compared with pure wool.</td>
<td>7. When used in a mixture with wool, shrinkage is reported to be greatly reduced when compared with pure wool.</td>
</tr>
<tr>
<td>8. Are used in herbal teas.</td>
<td>8. Despite its strength, ramie has had limited acceptance for textile use.</td>
<td>8. Short waste fibres are used for the production of high quality papers, such as bank notes &amp; cigarette papers.</td>
<td>8. Short waste fibres are used for the production of high quality papers, such as bank notes &amp; cigarette papers.</td>
</tr>
<tr>
<td>9. The medicinal uses of Flax promote heart health, lowers cholesterol, protects against strokes, lowers blood pressure.</td>
<td>9. As ramie takes up phosphorous, it is potentially useful for cleaning up the Everglades. This region suffers from a nutrient overload from the sugar industry.</td>
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<td>9. As ramie takes up phosphorous, it is potentially useful for cleaning up the Everglades. This region suffers from a nutrient overload from the sugar industry.</td>
</tr>
</tbody>
</table>

### Chemical composition and properties of some common non-wood materials

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Density, mm</th>
<th>Length, mm</th>
<th>Diam., µm</th>
<th>Tensile modulus, GPa</th>
<th>Elongation, %</th>
<th>Cellulose, wt%</th>
<th>Hemicellulose, wt%</th>
<th>Lignin, wt%</th>
<th>Pectin, wt%</th>
<th>Waxes, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemp</td>
<td>1.4-1.5</td>
<td>5-55</td>
<td>25-500</td>
<td>23.5-90</td>
<td>1-3.5</td>
<td>68-74.4</td>
<td>15-22.4</td>
<td>3.7-10</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Flax</td>
<td>1.4-1.5</td>
<td>5-900</td>
<td>12-600</td>
<td>27.6-103</td>
<td>1.2-3.3</td>
<td>62-72</td>
<td>18.6-20.6</td>
<td>2-5</td>
<td>2.3</td>
<td>1.5-1.7</td>
</tr>
<tr>
<td>Kenaf</td>
<td>1.4</td>
<td>-</td>
<td>-</td>
<td>14.5-83</td>
<td>1.5-2.7</td>
<td>31-72</td>
<td>20.3-21.5</td>
<td>8-19</td>
<td>3-5</td>
<td>-</td>
</tr>
<tr>
<td>Ramie</td>
<td>1.0-1.55</td>
<td>900-1200</td>
<td>20-80</td>
<td>24.5-128</td>
<td>1.2-4.0</td>
<td>68.6-8.5</td>
<td>13-16.7</td>
<td>0.5-0.7</td>
<td>1.9</td>
<td>0.3</td>
</tr>
<tr>
<td>E-glass</td>
<td>2.5-2.59</td>
<td>&lt;17</td>
<td>70-76</td>
<td>1.8-4.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typical nutritional analysis of seeds/100g

<table>
<thead>
<tr>
<th>Property/constituents</th>
<th>Hemp*</th>
<th>Flax**</th>
<th>Kenaf***</th>
<th>Ramie****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy/100 g</td>
<td>567 kcal</td>
<td>534 kcal</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Protein</td>
<td>30.6</td>
<td>18.3</td>
<td>21.8</td>
<td>–</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>10.9</td>
<td>28.9</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Dietary fibre</td>
<td>6.0</td>
<td>27.3</td>
<td>13.6</td>
<td>–</td>
</tr>
<tr>
<td>Fat</td>
<td>47.2</td>
<td>42.2</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Saturated fat</td>
<td>5.2</td>
<td>3.7</td>
<td>25.8</td>
<td>–</td>
</tr>
<tr>
<td>Palmitic 16:0</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stearic 18:0</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monounsaturated fat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic 18:1 (Omega-9)</td>
<td>5.8</td>
<td>7.5</td>
<td>37.9</td>
<td>–</td>
</tr>
<tr>
<td>Polyunsaturated fat</td>
<td>36.2</td>
<td>28.7</td>
<td>36.9</td>
<td>–</td>
</tr>
<tr>
<td>Linoleic 18:2 (omega-6)</td>
<td>27.6</td>
<td></td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Linolenic 18:3 (omega-3)</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma-Linolenic 18:3 (omega-6)</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholesterol</td>
<td>0 mg</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>4.7</td>
<td></td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Ash</td>
<td>6.6</td>
<td>5.9</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Vitamin A (B-Carotene)</td>
<td>4.0 IU/100g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiamine (Vit B1)</td>
<td>1.4 mg</td>
<td>1.6 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riboflavin (Vit B2)</td>
<td>0.3 mg</td>
<td>0.12 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyridoxine (Vit B6)</td>
<td>0.1 mg</td>
<td>0.5 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td>1.0 mg</td>
<td>0.6 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin E</td>
<td>9.0 IU/100g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>9.0 mg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>74.0 mg</td>
<td>255 mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>4.7 mg</td>
<td>5.7 mg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*http://www.wcranchohemp.com/info.php
****Not relevant for ramie seeds. For some data on nutritional value of other ramie parts as feed, see www.feedipedia.org/node/179 and Gonto et al. (2011).
Fibre-based products
Kraft pulping
Wheat straw
Paper manufacturing
**Fibre flocculation**

**Fibre lengths**
- Hemp: 5-55 mm (bast)
- Flax: 5-900 mm (bast)
- Ramie: 900-1200 mm (bast)
- Softwood: < 3 mm
- Hardwood: < 1 mm
# The use of annual crop fibres in speciality papers

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Type of paper</th>
<th>Content of annual crop fibres in furnish</th>
<th>Complementary fibres in furnish</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hemp (bast fibres)</strong></td>
<td>Cigarette paper</td>
<td>50-100%</td>
<td>Wood pulp, bagasse, straw, kenaf bast or jute bast pulp</td>
</tr>
<tr>
<td></td>
<td>Condenser paper</td>
<td>20-60%</td>
<td>Wood pulp, flax or cotton pulp</td>
</tr>
<tr>
<td></td>
<td>Banknote</td>
<td>50-80%</td>
<td>Flax, cotton or wood pulp</td>
</tr>
<tr>
<td></td>
<td>Lightweight printing or writing</td>
<td>20-80%</td>
<td>Wood pulp, flax or cotton pulp</td>
</tr>
<tr>
<td></td>
<td>Security paper</td>
<td>50-80%</td>
<td>Flax, cotton or wood pulp</td>
</tr>
<tr>
<td><strong>Flax (bast fibres)</strong></td>
<td>Cigarette burning tube</td>
<td>20-100%</td>
<td>Wood pulp</td>
</tr>
<tr>
<td></td>
<td>Banknotes</td>
<td>50-80%</td>
<td>Cotton pulp or wood pulp</td>
</tr>
<tr>
<td></td>
<td>Lightweight printing &amp; writing</td>
<td>20-80%</td>
<td>Cotton pulp or wood pulp</td>
</tr>
<tr>
<td></td>
<td>Ultra lightweight (bible)</td>
<td>50-100%</td>
<td>Cotton pulp or wood pulp</td>
</tr>
<tr>
<td></td>
<td>Writing &amp; book</td>
<td>20-60%</td>
<td>Cotton pulp or wood pulp</td>
</tr>
<tr>
<td></td>
<td>Security paper</td>
<td>50-80%</td>
<td>Cotton pulp or wood pulp</td>
</tr>
<tr>
<td><strong>Kenaf (bast fibre)</strong></td>
<td>Bleached paperboard</td>
<td>50-100%</td>
<td>Wood pulp, bagasse or straw pulp</td>
</tr>
<tr>
<td></td>
<td>Cigarette paper</td>
<td>50-100%</td>
<td>Wood pulp, flax, hemp or abaca pulp</td>
</tr>
<tr>
<td></td>
<td>Lightweight specialty papers</td>
<td>50-100%</td>
<td>Wood pulp, flax, hemp or abaca pulp</td>
</tr>
<tr>
<td></td>
<td>Linerboard</td>
<td>50-100%</td>
<td>Kraft, bagasse, straw or waste paper pulp</td>
</tr>
<tr>
<td></td>
<td>Multi-wall sack</td>
<td>50-100%</td>
<td>Kraft, bagasse or straw pulp</td>
</tr>
<tr>
<td></td>
<td>Newsprint</td>
<td>20-30%</td>
<td>Wood pulp, or kenaf core mechanical pulp</td>
</tr>
<tr>
<td></td>
<td>Printing &amp; writing - mechanical</td>
<td>20-50%</td>
<td>20-40% wood pulp, balance mechanical pulp</td>
</tr>
<tr>
<td></td>
<td>Printing &amp; writing - woodfree</td>
<td>20-100%</td>
<td>Wood pulp, bagasse, straw, reed or bamboo pulp</td>
</tr>
<tr>
<td></td>
<td>Tissue</td>
<td>60-90%</td>
<td>Wood pulp, bagasse or straw pulp</td>
</tr>
<tr>
<td><strong>Kenaf (whole stalk)</strong></td>
<td>Bleached paperboard</td>
<td>40-50%</td>
<td>Wood pulp</td>
</tr>
<tr>
<td></td>
<td>Corrugated medium</td>
<td>50-100%</td>
<td>Waste paper</td>
</tr>
<tr>
<td></td>
<td>Linerboard</td>
<td>40-50%</td>
<td>Kraft pulp and waste paper</td>
</tr>
<tr>
<td></td>
<td>Multi-wall sack</td>
<td>20-40%</td>
<td>Kraft pulp</td>
</tr>
<tr>
<td></td>
<td>Newsprint</td>
<td>80-90% (chemi-mechanical)</td>
<td>Wood pulp</td>
</tr>
<tr>
<td></td>
<td>Printing &amp; writing - mechanical</td>
<td>20-50% (chemi-mechanical)</td>
<td>Wood pulp</td>
</tr>
</tbody>
</table>

Insulation material

Hemp

Kenaf

Use of hemp hurds

Hempcrete
### Fibre-based products, overview

<table>
<thead>
<tr>
<th>Product category</th>
<th>Nature (intermediate or final)</th>
<th>Product type</th>
<th>Derived from***</th>
<th>Further information, comments, etc.</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M*</td>
<td>S*</td>
<td>P*</td>
<td></td>
</tr>
<tr>
<td>Bank notes</td>
<td>Final</td>
<td>x</td>
<td></td>
<td>Stem</td>
<td>Sen et.al. 2011</td>
</tr>
<tr>
<td>Binder</td>
<td>Final/intermediate</td>
<td>x</td>
<td>x</td>
<td>Hurds</td>
<td>Sen et al., 2011</td>
</tr>
<tr>
<td>Nonwoven</td>
<td>Final/intermediate</td>
<td>x</td>
<td>x</td>
<td>stem</td>
<td>Hutten et al., 2007</td>
</tr>
<tr>
<td>Cordage</td>
<td>Final</td>
<td>x</td>
<td></td>
<td>stem</td>
<td></td>
</tr>
<tr>
<td>Hydraulic sealing</td>
<td>final</td>
<td>x</td>
<td></td>
<td>stem</td>
<td></td>
</tr>
<tr>
<td>Carded blended yarns</td>
<td>Final/intermediate</td>
<td>x</td>
<td>x</td>
<td>stem</td>
<td>Cierpuca et al., 1998. Cierpuca et al., 1993.</td>
</tr>
<tr>
<td>Seed mat</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>Haber, 1994.</td>
</tr>
</tbody>
</table>
Chemicals
Seed oil as a raw material for producing different chemical structures

(a) polyol, 
(b) triol, 
(c) fatty amide triol, 
(d) fatty amide diol, 
(e) monoglyceride, 
(f) polyesteramide, 
(g) polyetheramide and 
(h) alkyd

**Potential products**

- polyurethanes
- inks,
- plasticizers,
- lubricants,
- adhesives,
- coatings and
- paints

Use of lignin

- Phenolic resins
- Panelboard adhesives
- Thermoset resins for moulded products
- Friction materials
- Adsorbent materials
- Foundry resins
- Insulation materials
- Decorative laminates
- Rubber processing
- Antioxidant applications
- Printed circuit board resins
- Animal health applications
- Composites and biocomposites
- Carbon fibres (for vehicles and other uses)
- Synthetic lignosulphonates, with a large number of well-established uses
- Degradation to phenols and other aromatic compounds
### Chemical products overview

<table>
<thead>
<tr>
<th>Product category</th>
<th>Nature (intermediate or final)</th>
<th>Product type</th>
<th>Derived from</th>
<th>Further information, comments, etc.</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polyurethane</strong></td>
<td>Intermediate</td>
<td>x</td>
<td>Seeds</td>
<td></td>
<td>Sharmin et al., 2012</td>
</tr>
<tr>
<td><strong>Fatty acids, fatty alcohols, methyl esters, glycerine</strong></td>
<td>Intermediate</td>
<td>x</td>
<td>Seeds</td>
<td></td>
<td>Dunford, 2012.</td>
</tr>
<tr>
<td><strong>Lignin</strong></td>
<td>Intermediate</td>
<td>x</td>
<td>Stem</td>
<td></td>
<td>Ghaffar and Fan, 2014.</td>
</tr>
<tr>
<td><strong>Lignin adhesive</strong></td>
<td>Final</td>
<td>x</td>
<td>Stem</td>
<td></td>
<td>Forss and Fuhrmann, 1979.</td>
</tr>
</tbody>
</table>

* M, major current product; S, secondary current product; P, potential new product
Composites
Application fields of WPC in Europe 2012

- Decking: 67%
- Autointerior parts: 23%
- Siding and Fencing: 6%
- Technical Applications: 2%
- Furniture: 1%
- Consumer goods: 1%

Total production 260,000 tons, all production processes
Use of Natural Fibres for Composites in the European Automotive Industry 2012

- Wood: 38%
- Cotton: 25%
- Flax: 19%
- Kenaf: 8%
- Others (mainly Jute, Coir, Sisal and Abaca): 7%
- Hemp: 5%

Total volume 80,000 tonnes
## Use of biomaterials in cars

<table>
<thead>
<tr>
<th>Model(s)</th>
<th>Feedstock</th>
<th>Material</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadillac DeVille</td>
<td>Wood</td>
<td>Polypropylene</td>
<td>Seatbacks</td>
</tr>
<tr>
<td>Chevrolet Impala</td>
<td>Flax</td>
<td>Polypropylene</td>
<td>Trim, rear shelf</td>
</tr>
<tr>
<td>Ford Flex</td>
<td>Wheat straw</td>
<td>Polypropylene</td>
<td>Interior storage bins</td>
</tr>
<tr>
<td>Ford Focus BEV</td>
<td>Coconut</td>
<td>Polypropylene</td>
<td>Loadfloor</td>
</tr>
<tr>
<td>Ford vehicles (Multiple)</td>
<td>Soy</td>
<td>Polyurethane</td>
<td>Foam seating, headrests, headliner</td>
</tr>
<tr>
<td>GMC Terrain</td>
<td>Cotton, kenaf</td>
<td>Polyester</td>
<td>Acoustic insulator, ceiling liner</td>
</tr>
<tr>
<td>Honda Pilot</td>
<td>Wood</td>
<td>N/A</td>
<td>Floor area parts</td>
</tr>
<tr>
<td>Lexus CT200h</td>
<td>Bamboo, corn</td>
<td>Polyethylene terephthalate, Sorona</td>
<td>Luggage-compartment, speakers, floor mats</td>
</tr>
<tr>
<td>Mazda 5 Hydrogen RE Hybrid</td>
<td>Corn</td>
<td>Polylactic acid</td>
<td>Console, seat fabric</td>
</tr>
<tr>
<td>Mercedes-Benz A-Class</td>
<td>Abaca/banana, flax, other natural fibers</td>
<td>Composite material</td>
<td>Underbody panels, seatbacks, spare tire cover</td>
</tr>
<tr>
<td>Mercedes-Benz C- and A-Class</td>
<td>Flax</td>
<td>Polyethylene</td>
<td>Engine and transmission cover, underbody panels</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>Corn</td>
<td>Sorona EP</td>
<td>Instrument-panel, air-conditioning vent</td>
</tr>
<tr>
<td>Toyota Raum</td>
<td>Kenaf, starch</td>
<td>Composite material</td>
<td>Floor mats, spare tire cover</td>
</tr>
</tbody>
</table>

Emerging trends in the global natural fibre industry

Trend A: Increasing emphasis on recyclability

Trend B: Penetration of Wood Plastic Composites in North America

Trend C: Price-performance balance of Natural Fiber Composites

Trend D: Global concern towards global warming

Trend E: Asian Companies interest towards green electronics

Trend F: High demand of natural fiber composites by European Automotive Players

HempFlax products

Composites

HempFlax supplies to NPSP Composites, a company that processes hemp fibres in:

- ANWB ‘mushrooms’
- electric scooters
- radar units
- sinks

Hemp fibres require 10 times less energy to produce and require fewer chemicals to bind to the resin in comparison to fibreglass. They are also more biodegradable after the lifespan of the product has expired.

Electric scooter

ANWB ‘mushroom’

Sinks
Energy products
Production of ethanol and methane from hemp

Heat and power production from hemp

Hydrothermal carbonization (HTC) of biomass

## Energy products overview

<table>
<thead>
<tr>
<th>Energy products</th>
<th>Nature (intermediate or final)</th>
<th>Product type</th>
<th>Production capacity**</th>
<th>Derived from</th>
<th>Further information, comments, etc.</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td></td>
<td>M* x P*</td>
<td>2288</td>
<td>Whole plant</td>
<td>Pellets or briquettes for combustion</td>
<td>Carus et al., 2013.</td>
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<tr>
<td>Pellets or briquettes for combustion</td>
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<td>x</td>
<td></td>
<td>Hurds</td>
<td></td>
<td>Prade et al., 2011.</td>
</tr>
<tr>
<td>Bioethanol</td>
<td></td>
<td>x</td>
<td></td>
<td>Stem</td>
<td></td>
<td>Kreuger et al., 2010.</td>
</tr>
<tr>
<td>Biogas</td>
<td></td>
<td>x</td>
<td></td>
<td>Stem</td>
<td></td>
<td>Prade et al., 2012.</td>
</tr>
<tr>
<td>Biodiesel</td>
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<td>x</td>
<td></td>
<td>Seeds</td>
<td></td>
<td>Maher and Bressler, 2007.</td>
</tr>
<tr>
<td>Biochar, porous carbon</td>
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<td>x</td>
<td></td>
<td>Whole plant</td>
<td></td>
<td>Hoekman et al., 2010</td>
</tr>
</tbody>
</table>

* M, major current product; S, secondary current product; P, potential new product
Other products
### Other products, overview

<table>
<thead>
<tr>
<th>Product category</th>
<th>Nature (intermediate or final)</th>
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<th>Derived from</th>
<th>Further information, comments, etc</th>
<th>Key references</th>
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</thead>
<tbody>
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<td>Seeds</td>
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<tr>
<td>Animal feed</td>
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<td>Seeds</td>
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<tr>
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<td>Final</td>
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<td>Seeds</td>
<td>Hemp, flax, kenaf</td>
<td>Muir et al., 2003</td>
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<tr>
<td>Animal bedding</td>
<td>Final</td>
<td>x</td>
<td></td>
<td>Stem</td>
<td></td>
<td>Carus et al., 2013</td>
</tr>
<tr>
<td>Food</td>
<td>Final/intermediate</td>
<td>x</td>
<td></td>
<td>Seeds</td>
<td>Hemp, flax, kenaf</td>
<td>Muir et al., 2003</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Intermediate</td>
<td>x</td>
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<td>Stem</td>
<td>Hemp, flax, kenaf</td>
<td>Muir et al., 2003</td>
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<tr>
<td>Insulation</td>
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<td>Stem</td>
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<td>Kymäläinen et al., 2008</td>
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Other products, overview (cont.)

<table>
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<tr>
<th>Product category</th>
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<th>Derived from</th>
<th>Further information, comments, etc</th>
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<td>Seed</td>
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<tr>
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<td>Stem</td>
<td></td>
<td>Carus et al., 2013</td>
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<tr>
<td>Fertilizer</td>
<td>Final</td>
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<td>Dust</td>
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</table>

*M, major current product; S, secondary current product; P, potential new product
Thank you for your attention.
Awaiting future actions with excitement.