Annual fibre crop systems

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Author: Steef J.J. Lips, Jan E.G. van Dam and Wolter Elbersen

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Agrotechnology & Food Innovations B.V.
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480084
E-mail: info.agrotechnologyandfood@wur.nl
Internet: www.agrotechnologyandfood.wur.nl

This report is authorised by: Rene van Ree

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Abstract

This report is the final report of WP26 on the annual fibre crops systems as studied in the EU ENFA project (SSPE-CT-2005-006581).
The ENFA project aims to develop a dynamic agricultural and forest sector model for the integrated economic and environmental assessment of non-food alternatives in European agriculture and forestry.
This report includes a description of fibre crop production chains of long and short fibres, as well as a market description of fibre crop products, with emphasis on flax, hemp and kenaf. Also environmental aspects of these chains and the regulations concerning fibre crops are addressed.
The technical data for the ENFA model (deliverable 24) are presented in this report in the appendices and they are send to the coordinating partner as excel worksheets as input for the model. An analyses of policy and innovation for non-food application of agricultural produce since the 1980s in the Netherlands was made (appendix 2). Based on the general outcome of this analyses specific examples of critical success factors of fibre crop systems are presented (deliverable 25).

Content

1 Introduction

1.1 Enfa project

The ENFA project aims to develop a dynamic agricultural and forest sector model for the integrated economic and environmental assessment of non-food alternatives in European agriculture and forestry. With this tool it will be possible to analyze market and environmental impacts from the adoption of non-food strategies.

1.2 Non-food crops and focus on fibre crops

Crop diversification has been one of the promises for European agriculture in the past decades. As a result of surpluses in the production of the major food crops, which has arisen from increased productivity in the seventies and EU pricing policy in the eighties alternative crops for non-food markets have received substantial interest. More recently, the establishment of a bio-based economy has been recognised as one of the key issues for sustainable development. Renewable resources as alternative for fossil based products seem to regain preference because of their inexhaustible availability and due to environmental considerations such as neutrality towards production of greenhouse gasses (closed CO_2 cycle) and potential carbon sequestration.

Transition to a more sustainable bio-based economy, as a political consequence of the Kyoto protocol on global climate change (UN, 1997), includes a shift of feedstock for energy and chemical industries from petrochemical to renewable resources. The use of non-food crops as major source for renewable resources, however, requires careful consideration of the environmental impact. Data on emission reduction of greenhouse gasses are to be combined with the projections for the year 2050 on the demand for food, energy, and raw materials. For instance the impact of a growing world population and more even distribution of resources have to be included (Boeriu et al., 2004; Van Dam et al., 2007 (submitted)). It is a good sign that also industries have by now recognised that the concept of "eco-efficiency" is an important way for businesses to contribute to sustainable development (Lawn, 2001).
The enhanced ecological performance of renewable products should, however, be demonstrated unambiguously by scrutinous comparative analysis of the total life cycle of products (LCA). This FP6 EU project ENFA aims to design decision tools for policy and (agro) industry. As an example of the non-food crops studied in this project the production chain and processing of fibre crops is worked out here.

1.3 Limited market penetration

As a major renewable resource lignocellulosic fibres derived from the structural plant tissues will play an important role in this transition towards a bio-economy. Fibre crops are – among the technical and non-food agricultural products – the commodities with the longest tradition. For example cellulosic fibres for textile (cotton) and paper pulp (soft wood) production are still major commercial non-food commodities. The markets for fibre crops such as flax, hemp, jute and sisal have seen substantial erosion since the introduction of synthetic fibres after WO II in textile industries (FAO statistics). However, still a market niche has been maintained and numerous new markets are currently emerging for fibre crops. Especially, the ecological 'green' image of cellulosic fibres has been the driving argument for innovation and development of products in the past decade, such as fibre reinforced composites in automotive industries, building and construction materials, biodegradable geotextiles and horticultural products (Van Dam et al. 1994). The assumed environmental benefits for the use of renewable materials are placed in the context of fibre crops use in industrial products and the various impact factors that have to be accounted for.

1.4 Purpose of this report

This report describes and compares in detail the agricultural production system and processing of various fibre crops other than cotton that can be grown in Europe. Quantification of the economical costs and the factors affecting LCA has been done by reviewing sources in literature and interviews with manufacturers and suppliers.

2 Methods

Most of the information on the cultivation of fibre crops is gathered by reviewing the literature and a search in the databases of FAO, Eurostat and WUR-PPO. The information on the processing of these crops to marketable fibres is collected through literature and individual contacts with processors and fibre line producers.

The focus has been on the traditional flax production and the production of new crops as hemp and kenaf. Flax is mainly grown for the production of long fibres for textile applications.

Hemp is grown for other applications in which cleaned short fibres can be used.

Kenaf, which can only be produced in Southern Europe, can be grown for the same applications as hemp is cultivated for. These fibres have to compete with each other in the market.

As kenaf is a very new crop in Europe no reliable data on large scale production are available. Recently a growth model has been developed within the EU Biokenaf project based on research in many South Europe.

Natural fibres can be used in different applications like textiles, paper, automotives and building materials. The producers buy there raw fibre materials on the market. The collection of processing data in study was focussed on the production of marketable long fibres for textiles and marketable short fibres for other applications.

The purity of the fibres determines the suitability for the different applications. The choice of production system, capacity and purity grade is entirely up to the processor leading to different systems and purity grades in the processing of these fibre crops. To facilitate the modelling within this project one reference systems for long fibres and one reference system for short fibres was chosen.

Environmental aspects are mainly gathered from literature, but also from the interviewed processors. A number of aspects could be quantified and are presented in the worksheets that can be used for further modelling.

3 Description of fibre crop production chains

3.1 Technical description of annual fibre crop production systems

3.1.1 Introduction

Natural organic fibres are used for many different applications. They can be of vegetable origin or produced by animals. Fibres of commercial interest of animal origin are hairs from mammals (sheep wool) and cocoons of insects (silk worms). Wool is mainly used for manufacturing of clothing because of the good insulation properties. Vegetable fibres are (ligno-)cellulosic fibres that can be divided in wood and non-wood fibres. Most of the wood fibres are relative short and used in the paper and fibre board industries. The long non-wood fibres are used in many different applications like paper, textiles, fibre boards, composites, non-woven mats, filters and absorbents. The non-wood fibres can be divided in the categories bast fibres (flax, hemp, kenaf and jute), leaf fibres (sisal) and seed hair fibres (cotton). This description focuses on the bast fibre category, which is the group with potential for industrial applications within Europe.
Flax (*Linum usitatissimum* L.) and hemp (*Cannabis sativa* L.) are fibre crops that have been cultivated in Europe for centuries for textile (flax) or ropes and sails (hemp). The development of cheap synthetic fibres after WWII resulted in a large decrease of cultivated area of both crops. Recently environmental legislation and public awareness resulted in a renewed interest for natural fibres.
Flax fibres are softer and more suitable for fashionable clothing than hemp fibres and due to high added values flax is mainly grown for textile. The flax fibres that are too short for textiles are used in other applications like paper and composites. Recently, a European project under the acronym HEMPSYS has been carried out within the QLK5 program. In this project the effect of growing conditions on the fibre characteristics was studied in order to produce a finer fibre from hemp that is suitable for textile applications (Amaducci, 2003).

A third fibre crop that has the potential of growing and application in Europe is kenaf (*Hibiscus cannabinus* L.), a tropical bast fibre plant that can be grown in Southern Europe. The fibre characteristics are very similar to those of jute. Like flax and hemp the stem of the plant exists of approximately $^{1}/_{3}$ of bast and $^{2}/_{3}$ of woody core. Kenaf fibres are very coarse and therefore not suitable for textile applications, but they can be used for other applications like composites for automotives. Currently, the crop production of kenaf in countries like Spain, Italy and Greece is studied within the European framework QLK5 under the acronym BIOKENAF.

With the above mentioned fibre crops, three main products can be produced. These products are; seeds, bast fibres and woody core. Seeds can easily be harvested after flowering and seed setting of the mature plants, but for the separation of the bast fibre fraction from the woody core fraction (decortication) much more effort has to be made. For all these crops storage after harvest is necessary to be able to process the fibres all year round.
Figure 1 shows a stained cross-section of a flax stem. The green part represent the woody core, with circular around it the bast layer. The bast layer consists of cellulose rich bast fibre bundles

(blue) and parenchyma tissue that forms the glue between the bundles and the core. For most applications the bast fibres have to be extracted from this layer. Other bast fibre plants are constructed similar by nature.

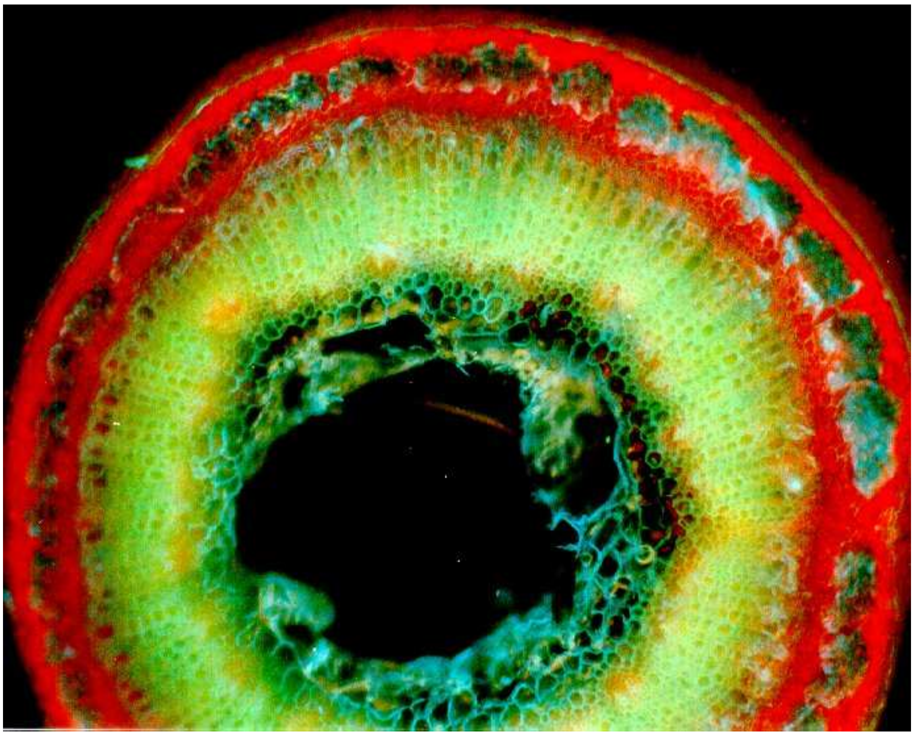


Figure 1: Cross-section of a flax stem; green is woody core, red is bast layer, and blue are the bast fibre bundles within the bast layer.

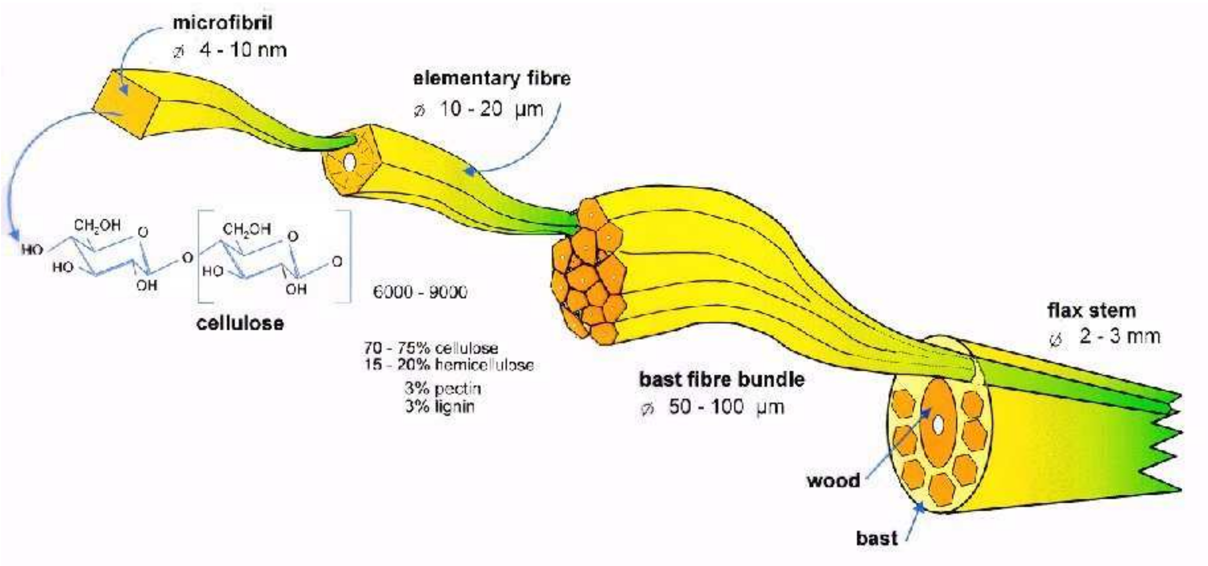


Figure 2: schematic view of the building blocks within a flax stem

3.1.2 Fibre production chain

The production chain for fibre crops can be divided into three main links: agricultural production – fibre processing – and utilisation (Scheme 1). Difficulties in organization of integrated production chains for innovative agro-industrial products, including storage and transport, marketing and sales, have been identified as major constraints in the successful commercial introduction of novel (ecologically enhanced) products on the market (Young, 1987; Berlo, 1993; Bos et al., 2008). Despite the interdependency of the different links in the chain, the interests of the various players with respect to quantitative and qualitative aspects may be divergent and contra-productive. The price and performance ratio of the products prevails in the competitiveness on the market, rather than quality or ecological benefits. Objective rating systems are a necessity to appreciate quality. Therefore it is important to develop certified fibre production chains, using instrumental and predictive methods as standards of qualification. This is especially relevant for the novel industrial end-uses like composites or building materials. Each application, however, will have specific demands on the performance of the raw material, which may be confidential industrial information. The quality control in the fibre production chain is requiring much attention and geared activities of all parties concerned (Van Dam et al., 2004a; Van den Oever et al., 2006). A number of aspects in quality control and improvement in the production chain of cellulosic fibres from agricultural produced fibres do need attention. In the whole life cycle of production and use - from breeding and primary production to combustion and disposal - the upgrading of quality and enhanced performance can be achieved by dedicated technology and logistic control systems.

Scheme 1. Agro-industrial chain of fibre crop production, processing and application. The interdependent links influence the end product price and performance.

• Breeding	genetics for yield and quality improvement
• Cultivation	agronomy: soil, climate, weed, disease and pest control, fertilisers
• Harvest / storage	moment of harvest, mechanisation, storage, transport and handling
• Fibre extraction	(controlled) retting, braking, decortication, degumming
• Fibre preparation	cleaning, hackling, carding, refining, extrusion, steam explosion, chemical / biochemical treatments, etc.
• Fibre processing	spinning, weaving, finishing; compounding; pulping, refining
• Use	performance
• Disposal	reuse and recycling, incineration / degradation / energy

The low-end market outlet for fibrous biomass is found in energy production. Promotion of renewable energy and biomass conversion plants by the various European governments is targeting for a multiplication of the contribution to the energy production in the coming decades.

3.2 Flax fibre production chain

The production and processing of annual bast fibre crops such as flax and hemp follow basically the same flow scheme. In the developed countries most of the agricultural processes are mechanised (Fig 3) and use of fertiliser and pesticides is common practice. Relatively, as compared to customary agricultural practice in growing of other crops, fibre crops have a low demand for nitrogen weed control and pesticide (see appendices). However, some fungi (especially Botyris cinera) may cause damage in fibre hemp to the lower part of crop. Chemical spraying of the tall crop is impractical and is considered economically and ecologically undesirable (De Mayer et al., 1995)

Flax growing is more demanding on the soil structure quality and drainage than hemp. To avoid pests and contamination of the crop, low amounts pesticides (parathion) and weed control agents (betazon, sethoxydim) are applied (Riensema et al., 1990). In Europe the agricultural production of flax is mechanised and special equipment is designed for harvesting and deseeding. Dew retting is still common practice in flax, which leaves the crop for some weeks on the field.

Flax is traditionally grown in the north of France, Belgium and the Netherlands where the agronomic conditions are optimal, resulting in good quality fibres. In 2003, 95% of the EU production area used for flax cultivation was found within the above mentioned countries. The highly specialised expertise of the growers in these countries results in high yields and good quality fibres. With the extension of the EU in 2004 new flax producing countries like Poland and Tsjech Republic entered the EU, resulting in an increase of the production area of about 20%.

3.2.1 Long flax fibres

In the EU, flax is almost completely cultivated for long fibres to be used for textile applications. In 2005 70% of the production of long flax fibres was exported, mainly to China (50%) (European Commission, 2006). As the costs of these process steps are increasingly high in Europe compared to countries like China, hackling is now mainly done in China. In the Netherlands only small special batches are still processed into sliver. Also the amount of flax yarn produced in the EU is decreasing. In 2006 less than 20% of the produced amount flax fibres in was converted into flax yarn within the EU-25 (Kasse, 2007a).
All the required production and processing steps for the flax textile chain are schematically presented in Figure 3.

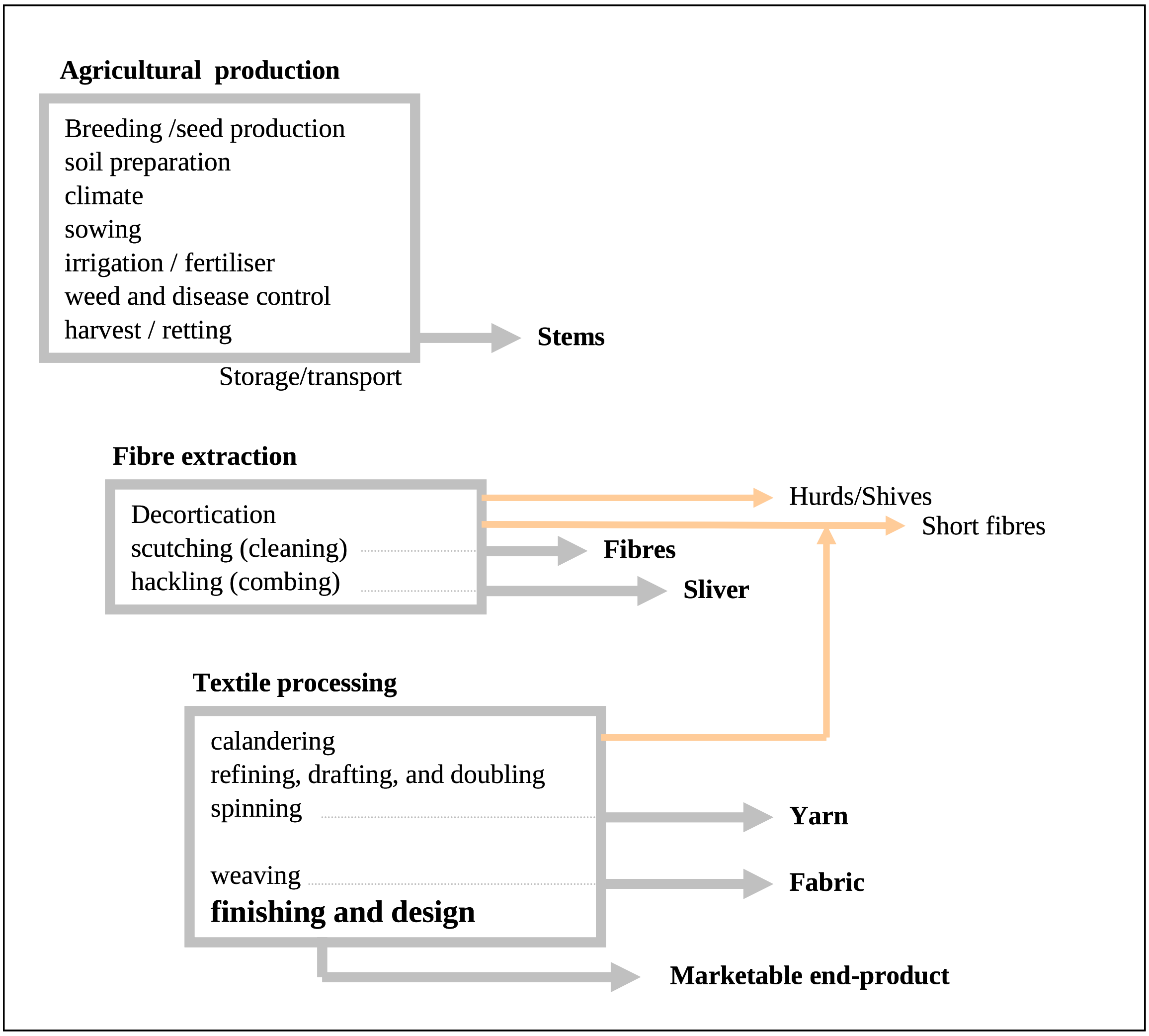


Figure 3: schematic overview of a flax textile production chain; source: (Van Dam et al., 2006)

Sowing seeds are produced in the same area as the flax cultivated for fibre production. In the Netherlands 80% of the area is used for the cultivation of flax sowing seed. The cultivation of flax needs fertilizer, but too much nitrogen is harmful for the fibre quality. Good weed control is necessary and is mostly done with chemicals. Chemical means are also used for prevention of diseases, and pests (Stokkers et al., 2004).

During the harvest, the flax plant is pulled and laid down in swath on the soil in rows of equal thickness (Figure 4). The flax is than left in the field for several weeks to undergo retting process (dew-retting) which is an uncontrolled microbiological treatment of the stems that removes the tissue between the fibre bundles and the core (red material in Figure 1). This retting process is crucial for the quality of the fibres and as the weather conditions influence the speed of retting a frequent control of the progress of this retting process is necessary. A too long period of retting results in a decrease of fibre strength. This can happen if the soil becomes too wet to be able to collect the retted flax with machinery. On the other hand if the retting is not completed, the fibres will be more contaminated with woody core particles. To get a good homogenous retted flax crop, the flax has to be turned at least once in the period of field retting. If the flax straw is sufficient retted and dry, it is baled and transported to a fibre processing mill.


Figure 4: harvest of flax

The collection of seed (rippling) can be done at the following points in the harvest and processing chain:

- simultaneously with the pulling of the flax;
- simultaneously with the turning of the flax or
- in the decortication mill.

If the flax is produced for sowing-seed, the collection of seed will be in the beginning of the chain. The seeds are ready for harvest in a later stage than the flax straw, therefore the harvest is late and the risk of over-retting the straw due to wet weather is higher than when flax is cultivated for the fibres. In the latter case the seeds are not fully ripe and used for the production of linseed oil.

The process of separation of the bast fibres from the core is called decortication. A mechanical device breaks the woody core into small pieces (hurds) from which the majority is instantly separated from the bast. After the breaker the bast still contains a significant amount of hurds and further cleaning of the bast fibres is necessary. This further cleaning is done by scutching, an additional step of combing (hackling) removes the last hurds and splits the bast into fibre bundles. After these processing steps the clean long fibres are aligned parallel and called sliver.

For application in textile, these fibres have to be further refined by drafting and doubling and finally a spinning process converts the fibres into yarns. Weaving, finishing and design of the yarns lead to a marketable textile end product (Figure 3).

3.2.2 Short flax fibres

During the processing of the bast fibres some losses of bast fibre are occurring in the form of short fibres or tow (fig3). These fibres are sold as a commodity on the short fibre market. Depending on quality aspects like cleanness and fibre length they can be used in applications like speciality papers, blended textile yarn, non-wovens and composites, with increasing prices in this order (Ernst & Young -AND International, 2005). The maximum price of these short fibres is approximately $^{1}/_{3}$ of the price of long fibres. Most of these short fibres are used for textile applications in for instance blends with cotton (40%). About 35% of the flax short fibres is used by the paper industry and about 25% is used in composites for the automobile industry (European Commission, 2006). The latter is the most advanced new market for fibres, which may create higher selling prices for short fibres since it demands the highest quality.
In the fibre preparation process for long fibre spinning the scutched fibres are hackled. About 30% of the fibres are combed out and discarded (hackling tow). These clean and fine fibres are sold as staple fibre for short fibre spinning at much higher prices than the short fibres produced during scutching.

3.2.3 Shives (woody core particles)

Approximately $^{2}/_{3}$ of the flax stems consist of a woody core. As described before, the shives are separated from the bast to get clean fibres without contamination of those particles. These shives form the biggest product stream in volume and weight leaving the decortication mill. Traditionally these shives are used for production of flax fibreboards and insulation products, but as an insulation material it is replaced by other materials. The price paid for shives is very low and as it is a very bulky material, transporting is very expensive. Some decorticators convert this material into baled bedding material for horse stables. This creates added value to the material, but a very good removal of dust and long fibre is a requirement. The lowest valuable application is to use the shives as fuel.

3.3 Hemp fibre production chain

Hemp is a traditional fibre source and was used for ages in ropes and canvas manufacturing for sailing ships. The narcotic use of hemp varieties with a high content of THC (tetra hydro cannabinol) is the reason that growing of fibre hemp can cause severe legislation problems. The hemp varieties that are selected and grown for fibre have a THC content lower than 0,2%, which makes the extraction of the drug unattractive. Even when all the permits are granted to grow fibre hemp, the grower might get problems with local authorities that are not familiar with this crop. The grower can also encounter the problem of illegal harvesters who mistakenly think they can use part of the plants as a THC source. Breeding and agronomy of new hemp varieties has been studied for high yield fibre and low THC contents. Experimental fields of fibre hemp have been established in many EU countries and commercial production has been introduced at some locations. Traditionally hemp fibre production in Europe was found and still is present in France for paper making and in eastern Europe (Hungary, Romania) for rope and twine manufacturing. New fibre production technologies for specific industrial utilization have been studied. Some products have entered the market successfully at a modest scale. Fibre hemp production of high quality for textile use has been studied and shows promise to become commercially successful (HEMP-SYS / HARMONIA projects). Imports from China and Korea of hemp textiles takes place at an increasing volume.

In a case study on the LCA of hemp for paper pulp production the energy demand for agricultural production is found to be low (1.2 GJ/ton pulp) as compared to the decortication (6.2 GJ/ton pulp) or the pulping processes (15.2 GJ/ton pulp) (Berlo, 1993; Kok, 2001).

3.3.1 Short hemp fibres

So far, hemp is not grown in EU for long fibre textile applications on large scales, but the efforts made in the EU HEMPSYS project might create better opportunities for this application in the near future. Up to now hemp fibres are marketed as short fibres, which have to compete with short fibres from flax and other fibre crops like jute and kenaf. Competition is difficult on the textile market with ready available and easier to clean short flax fibre. Only in the (small) niche market of trendy hemp textiles the relative high cost for hemp yarn manufacturing are compensated. In the non-textile markets for short fibres (paper, composites, non-woven) the competition is mainly on price. As the highest prices for short fibres are only $^{1}/_{3}$ of the long fibres, processing costs must be much lower than for long fibres. Fortunately far less processing steps are needed to produce these short fibres (Figure 5).

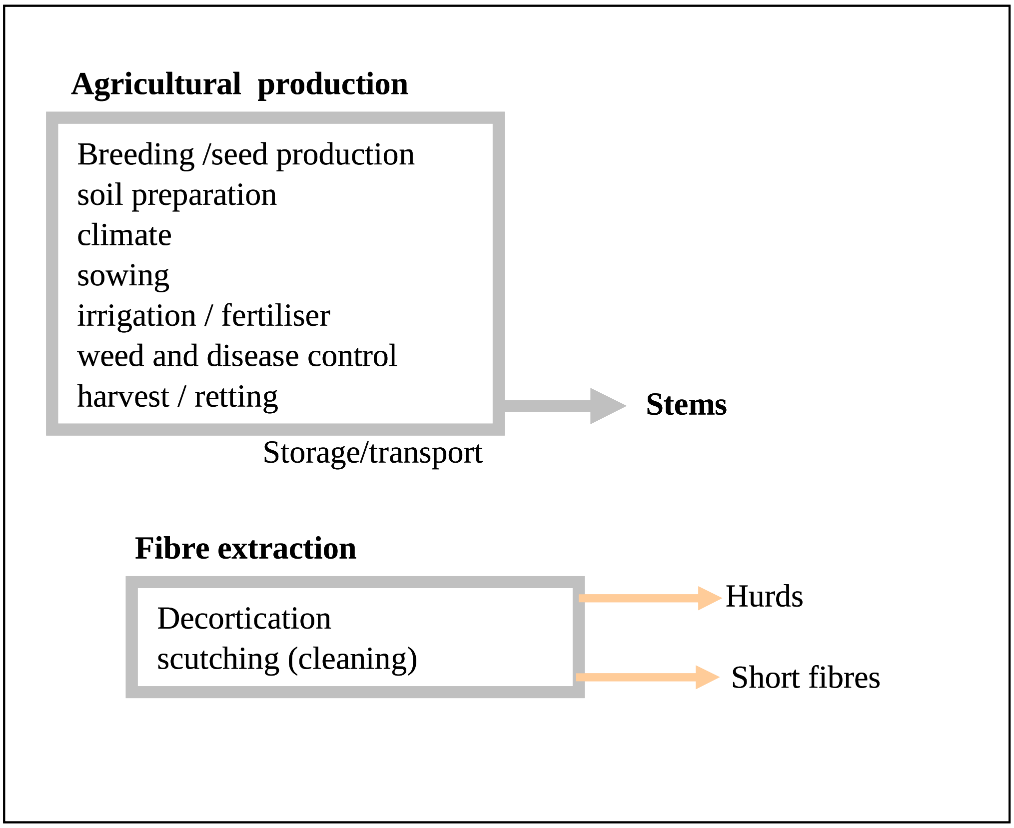


Figure 5: Hemp short fibre production chain

Different types of fibre processing lines can be used and depending on local situation the processors select the way of processing hemp stems into short fibres and woody core or hurds. As mentioned above the hemp short fibres find their outlet on the same market as other short fibres and the value increases with purity and quality. About 85% of the hemp fibres is used for papermaking. The use in composites is a growing market, which now utilises 12% of all the hemp fibres. The rest is used in non-wovens for building and insulation (European Commission, 2006).

3.3.2 Hurds

Known applications of hemp woody core or hurds as they are called are found in animal stable bedding, light weight particleboards and wall plasters. Especially horse bedding has proven to be an interesting and profitable market.

3.3 Kenaf fibre production chain

Kenaf (*Hibiscus cannabinus*) is a (sub)tropical bast fibre crop of which some varieties appear visually very similar to hemp. This sometimes leads to problems for the grower with local authorities that cannot distinguish the differences between the plants.

Figure 7: kenaf field

Figure 6: flowering kenaf

Besides this resemblance there are important differences between the plants. The elementary fibre cells, which form the building elements of the fibre bundles, are shorter than those of hemp. In contrast with flax and hemp, the kenaf plant has a spongy pith in the centre of the plant. To grow this crop successfully high temperatures are needed. Only in the most southern parts of Europe seeds can be produced. So the production of kenaf fibres is restricted to the Mediterranean countries. It is not yet grown much at a commercial scale in EU. In the EU project BIOKENAF a growth model, with a lot of inputs like geographical position, irrigation, fertiliser gift and climate and soil conditions, has been development with the data of trial fields.

The production chain of kenaf fibre is largely the same as that of hemp, but there exists a very important difference that can harm the quality or raise the production costs of kenaf fibres. Kenaf is very sensitive to frost (Kirby, 1963), therefore sowing in EU is done in late spring (even in the Southern European countries) when there is no more risk of frost. As the plant hardly grows at low temperatures there is also no advantage in early sowing. The plant will only develop strongly at average day temperatures of over 20 °C. The plant will continue growing until temperature drops in November. After this temperature drop the yield of stem material decreases.

3.3.1 Harvest scenarios

Storage of the harvested kenaf plants without microbial affection is only possible when the dry matter content of the stems is above 85%. In November at the peak yield, these plants only have a dry matter content of about 25%. To harvest dry plants, the died plants are dried naturally on the field, which will take a long time as the winter brings rains and especially the pith in the centre is very hydrophilic and difficult to dry. Depending on the local situation, the fields might be too wet to harvest the kenaf during winter. During this winter period the outer part of the stem, consisting of the bast fibres for which they are grown, is exposed to weathering during a long period leading to affection by micro-organisms. It is a kind of retting on stem, but it is far less controlled than dew retting of flax and hemp. With this crop, the dry matter content of the material and the soil condition determine the moment of harvesting and not the stage of the retting process.

An alternative way of ensuring the production of good quality of fibres is to harvest the still wet crop before the winter and dry the material artificially. Especially, with increasing energy prices this is a very costly process step. An additional retting step is still necessary, as decortication of dried unretted stems will result in much damaged fibres and a lot of contamination with hurds. As the crop is already harvested and stored dew retting is not possible anymore. Therefore water retting, enzymatic retting or chemical retting has to be applied. After retting the fibres have to be dried again. These extra steps will raise the production costs to a level that will make competition with other natural fibres very difficult when no other advantageous properties are obtained.

To reduce all these extra costs another alternative might be possible. In this process green decortication is applied within a few hours after harvest. The fresh and still wet stems are easy to decorticate and the bast can then be retted in an industrial way by enzymatic or chemical retting to remove the pectin that glues the fibre bundles together. A similar process was investigated in the HEMPSYS project and attempts are made to further explore this process.

4 Market description of fibre crop products and statistics

4.1 Fibre market developments

Traditional fibres crops flax (Linum usitatissimum) and hemp (Cannabis sativa), but also new crops for Europe such as kenaf (Hibiscus cannabinus), broom (Ginestra sp.) have intensively been studied, for non-traditional end-uses in compounds and fibre composites with numerous synthetic polymers (Van Dam et al 1994). Many novel end-uses for cellulosic fibres have been identified and demonstrated to be technically feasible. The lower qualities of fibre (flax tow, straw), which are produced as residue from agro-industrial production have to compete with cheap wood fibre on the market for paper and pulp, fibre board and composites. Both hard- and softwood fibres are utilised on large scales for refining and pulping. Only about 11% of the world's virgin cellulose pulp is made from non-wood sources (mainly straw, bagasse, and bamboo). In the EU, US and Canada practically no non-wood pulp is currently used (De Groot et al., 1999).

The use of cellulosic fibres as renewable raw material in fibre reinforced composite materials is receiving much attention in the automotive industry and shows much promise (Schlößer et al., 1997; Wötzel, 1999). Automotive industries have been the driving force for development of cellulosic fibres production for (thermoplastic) composite car parts. Flax and hemp non-woven find a growing outlet in compression moulded trim panels and dashboards, because of weight reduction and easier recycling by incineration (Karus et al., 2000; Karus et al., 2002; Karus et al., 2006)
Identified issues for sustainable developments and ecological building – apart from energy aspects – is the promising use of renewable resources as building materials. Fibre boards and panels and insulation materials for building applications have been developed based on flax, hemp, miscanthus or fibres derived from agro-residues (wheat straw, reeds, etc.). The production scale (and related costs) of established building materials is hindering extension of the market share for renewable building products. However, there is scope for these materials on the market for sustainable building and construction. The complex building regulations and standardisation in the different EU member states, combined with different legislation on the use of building materials at national levels, make the introduction of novel products on this scattered and conservative market difficult. Implementation of alternative renewable building products at large scale involves substantial commercial challenges that should be the driving force behind development of the production chain. This can only be achieved when the qualitative and quantitative aspects have been defined in detail for each specific end-use. It should be substantiated that especially in the case of building materials, the ecological advantages should combine with better comfort, health and safety aspects (indoor climate), without premature degradation or excessive maintenance costs or the need for hazardous chemicals for preservation (Van Dam, 2005).

The use of plant fibres as geotextiles in civil engineering and as horticultural substrates or biodegradable plant pots is increasingly receiving attention. The competing (synthetic or mineral) market products, however, hold a strong position.

With the extraction of the fibres from the plant stems, the woody inner part of the stems is broken into smaller pieces called hurds or shives. If they are sufficiently cleaned from dust and bast fibres, they can be sold as horse bedding material, the majority of the hemp shives are currently sold in this market.

4.2 Fibre quality and market

Profitable EU agricultural production of non-food crops, implies competitiveness with cheaper raw materials produced from other regions. The availability of bulk quantities of fibre products like jute and sisal, and the potential large scale production in Eastern Europe of flax or hemp is forcing the agro-industrial production in the EU into a specialized niche market. Traditionally, the flax fibre production in Western Europe for high quality linen textiles has been able to cope with competing imported raw materials, because of its high quality standard. The concentration in the past decades of the conventional linen promotion on the fashionable textile market has increased the dependency of the sector on a strongly fluctuating market segment. One way for EU agriculture to compete on the world market of lignocellulosic fibres is to supply high quality raw materials with added value for the user. Only when the qualitative aspects for each specific end-use have been defined in detail this can be achieved.

Innovations for fibre hemp (*Cannabis sativa*) and flax linen are promoting the use as feedstock for the production of soft and easy-care textiles. Flax linen is well know for its traditional use in haute couture textile, summer wear, bed linen, upholstery etc. Hemp fibre is coarser but tests in the textile industry have shown that certain processes allow improvement in the everyday-wear characteristics of hemp textiles. The characteristics of flax and hemp for textile and non-textile use have been studied in great detail. Recently, the potential of hemp as a feedstock in textile processing was investigated [HEMP-SYS]. Therefore, a detailed study on the effects of agronomical management systems and fibre extraction procedures on fibre properties and to make them suitable for textile processing has been carried out. Qualification and grading of the fibre feedstock has to be performed at various levels in the production chain.

4.3 Economics of fibre crop production

Minimum costs of production for fibre flax in the Netherlands [Kasse, 2002] by traditional methods of harvesting (pulling, dew retting) and processing for textile fibres, have been calculated to amount over € 3000 per ha. With an average yield per hectare of 8 tons straw, the minimum straw price for the farmer should then amount at least € 380 per ton in order to be profitable. Adding to the production costs of linen textile fibre are the different specialised tools and equipment designed for parallel aligned harvesting and processing of fibre flax. Per hectare the crop will be yielding on average 1 ton of long fibres, 1 ton of short fibres (tow), 3 ton of shives and 1 ton of linseed (Table 1) bringing globally an income below € 2000 per ha (including costs of deseeding and fibre extraction processes; scutching = € 115 /ton).

Table 1: Average yields of different quality fractions in fibre flax production per hectare in the Netherlands.

	Yield ton/ha	Market price € per ton
Flax straw	6-8	
Long fibre (scutched)	0.7 - 1.2	1.300 - 1.800
Short fibre uncleaned (tow)	0.4 - 1.0	130-230
Shives	3	20 – 40
Linseed	1.1 - 1.5	150 – 190

The gap between production costs and market value of the raw materials has been bridged in the past decades by EU financial support, but the EU support regulations for fibre production have been changed dramatically. The economic production of flax in the EU without subvention will become impossible if the yields and/or market prices do not increase. If this market is to be maintained, primary production has to shift to cheaper production areas. Stimulation of alternative market outlets with a more efficient production chain, however, could even enhance economic activities. These markets for fibre products then should be identified between the value added textile market and economic value of energy from biomass.

Reduction of EU subsidies and threat of cheap imported products from low-wage countries, prompted many farmers to abandon their business. Farmers would benefit from additional outlets, especially in novel industrial non-food applications. Therefore much attention has been given in the EU RTD programs to new markets for existing crops as well as to develop novel crops. Research and development activities have been directed towards valorisation of agricultural residues and product development for various "industrial" crops for specific oilseeds, proteins, starches, carbohydrates, or cellulosic fibre.

The EU policy for sustainable development promotes the use of renewable resources for production of alternative industrial products, which currently are derived from fossil petrochemical or mineral resources. The potential of agricultural production of a wide range of different industrial feedstock has been scrutinized for composites, plastics and polymers, resins and adhesives, building and insulation materials, energy and fuel feedstock, paints, coatings, and dyestuffs, soaps, detergents, surfactants, lubricants and waxes, agro-chemicals, pharmaceuticals and cosmetics. The development of the described fibre markets fits in this policy and may become more substantial since the costs for petrochemical resources are increasingly high. The production costs however also include the costs for energy (diesel fuel, electricity) that affects the ecological impact of the product. Therefore detailed cost calculations and LCA (see Chapter 5), including the consumption of fossil energy, CO_2 emissions etc. are required for rational decision for the better alternative. Since ecological arguments are not decisive for industries or consumers to choose for renewable products, legislative measures on the use of less sustainable products favours utilization of new crops.

4.4 Fibre crop production in EU and global competition,

The annual production data of fibre crops is monitored by FAO. The major fibre crop is cotton, while other crops grown for fibre production are relatively much smaller in comparison. Jute (including kenaf) and sisal are almost exclusively produced in tropical areas, while flax and hemp also can be produced in temperate zones.

The FAO statistical data (FAO, 2006) gives the production area and yields per year and country. The data of hemp are summarized in Table 2. This table represents the amount of fibres, the amount of hemp straw is 3 to 4 times the above mentioned numbers. Also the Eurostat database (Eurostat, 2006) gives information about crop production (Table 3) that are not in agreement with the FAOstat data. From these tables it can be concluded that today it is still even very difficult to obtain reliable quantitative data of hemp fibre and crop production. The hemp production data of Spain for example cannot be correct. So the differentiation in fibre quality is still far off. The poor quality of these figures might be the reason that hemp fibre and tow production is not present as a separate commodity in the FAO database after 2005.

Table 2: World Production data hemp fibre and tow (FAO stat) in metric tonnes

	2000	2001	2002	2003	2004	2005
Chile	4048	4095	4180	4290	4350	4385
China	17000	20186	30104	26000	26000	26000
France	370	260	360	700	700	700
Hungary	129	150	120	600	600	500
Italy #	437	221	1281	2986	1281	1281
Korea, Dem People's Rep	12500	12500	12800	12800	13000	13000
Korea, Republic of	263	235	224	224	224	224
Poland #	50	50	50	50	50	50
Romania #	1400	2800	5600	3200	2000	2000
Russian Federation	7100	5400	2900	1800	1500	1500
Serbia and Montenegro	30	20	20	20	20	20
Spain	7047	15000	15000	15000	15000	16000
Turkey #	1244	1000	900	800	800	800
Ukraine	2000	1000	1000	1000	1000	1000

values given are corresponding to whole stem yield data in Table 3.

Table 3: Eurostat data hemp production area and straw yields over the period 2000-2005

	2000	2001	2002	2003	2004	2005	
Spain	5.264	0.857	0.634	0.721	0.684	0.684	(1000 ha)
Spain	7.047	3.146	4.271	2.152	2.960	2.960	(1000 t)
Spain	**1.339**	**3.671**	**6.737**	**2.985**	**4.328**	**4.328**	(t/ha)
France	7.074	6.928	7.559	9.395	8.581	9.075	(1000 ha)
France	52.593	45.983	53.857	71.135	58.035	66.553	(1000 t)
France	**7.435**	**6.637**	**7.125**	**7.572**	**6.763**	**7.334**	(t/ha)
Italy	0.078	0.04	0.296	0.873	1.001	0.096	(1000 ha)
Italy	0.438	0.221	1.281	3.034	4.053	0.380	(1000 t)
Italy	**5.615**	**5.525**	**4.328**	**3.475**	**4.049**	**3.958**	(t/ha)
Hungary	0.058	0.068	0.925	0.332	0.495	0.463	(1000 ha)
Hungary	0.560	0.608	3.779	1.958	3.643		(1000 t)
Hungary	**9.655**	**8.941**	**4.085**	**5.898**	**7.360**		(t/ha)
Netherlands	0.792	0.981	2.079	1.461	0.031	0.100	(1000 ha)
Netherlands	4.651	5.134	14.349	10.905	0.230		(1000 t)
Netherlands	**5.873**	**5.233**	**6.902**	**7.464**	**7.419**		(t/ha)
Poland	0.089	0.145	0.083	0.101	0.476	0.162	(1000 ha)
Poland	0.040	0.660	0.036	0.031	0.063	0.075	(1000 t)
Poland	**0.449**	**4.552**	**0.434**	**0.307**	**0.132**	**0.463**	(t/ha)
United Kingdom	2.297	2.733	1.396	2.367	1.539	1.539	(1000 ha)
United Kingdom	9.46	9.566	6.003	15.149			(1000 t)
United Kingdom	**4.118**	**3.500**	**4.300**	**6.400**			(t/ha)
Romania	0.500	0.600	1.054	1.188	1.195	2.147	(1000 ha)
Romania	1.400	2.800	5.586	3.163	1.868	4.698	(1000 t)
Romania	**2.800**	**4.667**	**5.300**	**2.663**	**1.563**	**2.188**	(t/ha)
Turkey	0.883	0.700	0.659	0.65	0.375	0.065	(1000 ha)
Turkey	1.244	1.000	0.900	0.800	0.600	0.055	(1000 t)
Turkey	**1.409**	**1.429**	**1.366**	**1.231**	**1.600**	**0.846**	(t/ha)

The FAOstat production data for flax fibre and tow (Table 4) show that currently more than 50% of the production is found in China, followed by the traditional flax linen growing area of North West Europe including the coastal areas of Belgium (12.6%) and France (10.1%) and The

Netherlands (1%). Considerable production of flax fibre is also found in Eastern European countries where a long tradition of flax processing is maintained like Russia (6.8%), Belarus (5.6%), Ukraine (1.4%), Poland (1.2%) and Czech republic (1.5%). The production of flax in Spain and the UK is the result of crop diversification policy in the EU.

Fibre and tow yield of 0.7 and 1.0 tons per ha are common figures found for flax. However, careful analysis of these FAOstat data with respect to the harvested areas reveals that the productivity in Belgium amounts almost 6 tons per ha while in the rest of the countries like France (with similar productivity) this is substantial lower (1 ton per ha). This means that the Belgian data give straw yields while in France the bast fibre yield is accounted for. In China the yields of 3 tons per ha must concern the straw yields. The production data of the Netherlands, Poland and UK range between 1.5 and 2 tons per ha.

Table 4: World Production data flax fibre and tow (FAO stat) Mt

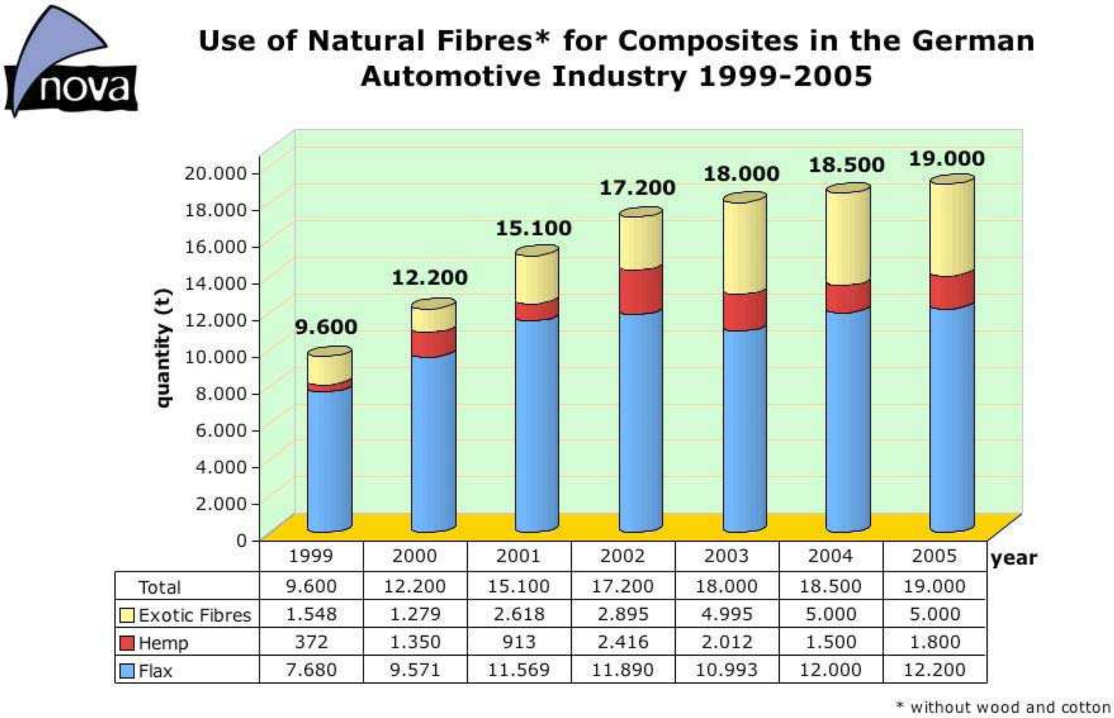
	2000	2001	2002	2003	2004	2005
Argentina	1900	1900	1900	1900	1900	1900
Belarus	37200	31500	26100	41300	56600	50000
Belgium*	90011	45288	108000	134605	123400	111953
Bulgaria	-	-	-	142	209	209
Chile	2100	2200	2250	2300	2400	2500
China*	214877	345675	524781	465500	470500	470500
Czech*	15100	17700	16000	12387	17801	13500
Egypt	14000	7110	7160	9000	9000	9000
Estonia	79	105	100	50	108	100
France	75000	75000	75000	86000	90000	90000
Italy	450	450	450	450	450	450
Latvia	1100	840	1400	800	1600	1000
Lithuania	7200	4000	6200	9900	5800	3400
Netherlands #	8100	5100	6200	8100	8200	8200
Poland #	7900	10200	10100	6200	10000	11000
Romania	900	400	800	700	300	300
Russian Federation	51000	58000	38000	55000	58000	60000
Slovakia	418	1812	904	1200	1160	1160
Spain	10022	11000	11000	11000	11000	12000
Turkey	7	17	50	55	55	55
Ukraine	8300	12300	11000	10900	16200	12000
United Kingdom #	28000	28000	28000	28000	28000	28000

* data of straw yields; # high fibre yields or low straw yield per ha

Comparative overviews on market prices of flax and hemp fibres and competing exotic fibres are scarce. No recent overview could be found, but a good overview was made by NOVA in 2000 (Karus et al., 2000). The data of this study are presented in Table 5. They show that for the application in composites sisal, jute and kenaf fibres transported from other continents to the EU can compete very well with short flax and hemp fibres produced in the EU. In a more recent NOVA study it is shown that the total amount of natural fibres composites used in automotives is slowly increasing (Figure 8). This graph also shows that high flax fibre prices in 2001 resulted in a shift from flax and hemp fibres to exotic fibres. Despite lower flax fibre prices in the last years, this shift appeared to be irreversible so far (Figure 9). The share of exotic fibres in this application increased from 16% in 2002 to 26% in 2005. This shows that if flax and hemp fibres do not have specific quality advantages for an application, they are in heavy competition with other natural fibres for the use in that application despite the long transport distances.

Table 5:Market prices of flax and hemp short fibres and competitive fibres (Germany 1999-2000): Source NOVA

Natural fibre and application	Price in €/kg
Flax from the EU, inferior quality, un-cleaned for commodity pulp (shives content up to 50%)	Starting at 0.10
Flax fibre from EU, for specialty pulp (shives content 10-25%)	0.25-0.30
Flax long fibre tow from Eastern Europe	Starting at 0.35
Flax fibre from EU for floor sound insulation	0.40-0.45
Flax fibre from EU for composites	0.45-0.53 02/2000: up to 0.65
Flax fibres from EU for thermal insulation materials	0.45-0.55 02/2000: up to 0.65
Flax long fibres from EU for apparel	1.28-2.30 (Some higher)
Hemp fibre from EU, for specialty pulp (shives content 10-25%)	0.28-0.35
Hemp fibre from EU for floor sound insulation	0.43-0.45
Hemp tow from Eastern Europe (good quality, 1998)	About 0.50
Hemp fibre from EU for composites	0.45-0.60
Hemp fibre from EU for insulation materials	0.45-0.60
Hemp long fibres from Eastern Europe (1998)	1.00-3.00 (Some higher)
Chemically and enzymaticaly retted hemp fibres for apparel industry (3 qualities, China 1998)	1.50-3.50
Jute fibres new (Bangladesh) for composites	0.55-0.60
Jute fibres new (Bangladesh) for specialty pulp	0.40-0.45
Sisal new (Africa and South America) for composites	0.55-0.73
Sisal new (Africa and South America) for specialty pulp	0.55-0.60
Kenaf fibres new (Bangladesh) for composites	0.58-0.60
Kenaf fibres new (Bangladesh) for specialty pulp	0.45-0.50
Abaca (Philippines) for specialty pulp	0.80-0.90
Cocos fibre for geotextiles	0.20-0.30
Cocos fibres premier quality	0.35-0.40



	1999	2000	2001	2002	2003	2004	2005
Total	9.600	12.200	15.100	17.200	18.000	18.500	19.000
Exotic Fibres	1.548	1.279	2.618	2.895	4.995	5.000	5.000
Hemp	372	1.350	913	2.416	2.012	1.500	1.800
Flax	7.680	9.571	11.569	11.890	10.993	12.000	12.200

Figure 8: Natural fibres use in automotives: Source NOVA

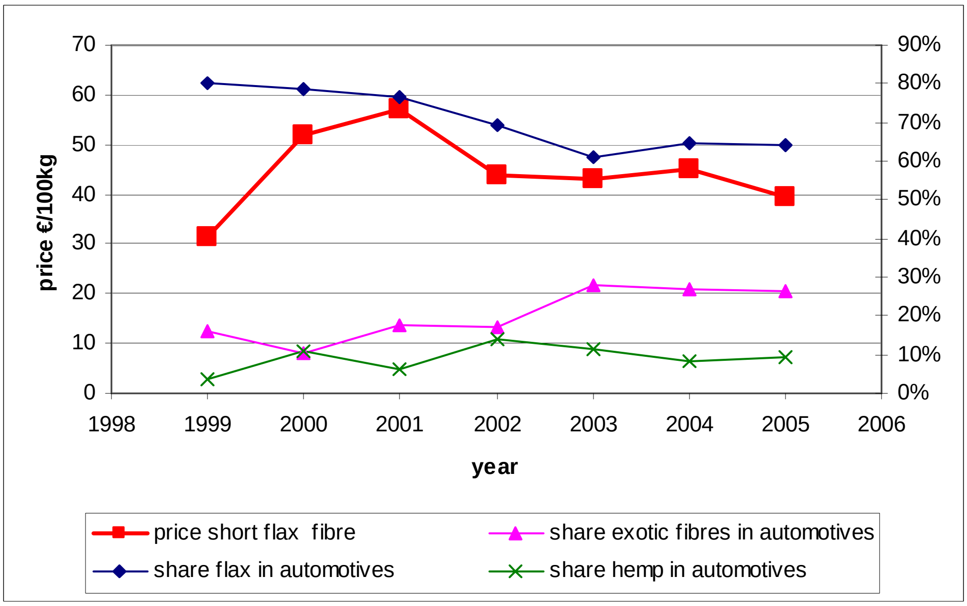


Figure 9: Flax short prices (France) and share in German automotives: Sources: NOVA and CELC

In the season 2006/2007 flax fibre price increased again since many years. Despite decreasing amounts sold and increasing stock, selling prices were about 14% higher for long fibres. For short fibres prices increased up to 40% at decreasing stock. The question is if these higher short flax fibre prices will again result in extra replacement of flax fibres by exotic fibres in the automotive industry.

4.5 Fibre classification systems

Traditionally fibre crop classification systems were based on organoleptic assessments. Attempts have been made to install instrumental quality measurements in the flax and hemp fibre production chain (Van den Oever et al., 2003; Van Dam et al., 2004b; Van den Oever et al., 2006). Flax trade for the linen textile industries is still relies on the assessment of quality by experts in grading. For the use in non-textile application these quality parameters are inadequate.

In many eastern European countries, where fibre hemp is grown in substantial amounts (Table 2 and Table 3) and processed for rope and twine production these classification systems are still in use. In China and North Korea the highest quantities of fibre are produced and also best qualities of hemp fabric are imported from Asia.

5 Environmental aspects of annual fibre crop chains

5.1 Introduction LCA of fibre crops

Fibres extracted from annual crops are advertised for their positive ecological performance because these are produced of a renewable and CO_2 neutral source. However, the amount of energy and fertilizers needed for its production needs to be accounted for. For the comparison of the environmental impact of processes and products quantitative data of the alternatives are required to select the most sustainable option. The environmental effect of products has been subject of systematic analysis since the 1980's. The Life Cycle Assessment (LCA) is one of the most common methods. LCA is a methodology that is developed to compare extremely diverse environmental effects. LCA focuses on the ecological implications of the entire life cycle of a product (and its by-products) from the raw material acquisition to end-product disposal (Heijungs, 2001; Pennington et al., 2004). However, standardisation of the weighing factors of environmental impacts and health effects are difficult and often based upon politics rather than science. Data collection is very difficult and insecure, due to dependency on confidential industrial figures and poorly definition of system limits. These days the debate on the emerging bio-economy is taking the "cradle to grave" or "cradle to cradle" scenarios into account.

Only limited quantitative information is available on comparative life cycle assessment of the industrial use of fibre crops. Industries can be reluctant to publish results of their LCA studies for competitive reasons. Another reason might be the relatively small economic importance of fibre crop products for Western industries, resulting in little interest from LCA performing groups. A literature review on this was published (Van Dam and Bos, 2004a). This report is an extended abstract of this publication.
The ecological performance of hemp cultivation was analysed (Van der Werf, 2004; Turunen et al., 2006; Van der Werf et al., 2008) recently and data from this analysis are included in the datasheets of this project. Most information was obtained on the primary crop production systems including the inputs of energy and agrochemicals. The post-harvest processing and use phases of the fibre derived products are more diverse and complicated, but some quantification and comparison is possible. Other impact categories such as eutrophication and acidification are often more difficult to quantify. The effects of by-products use and methods of end-product disposal may be critical (Venturi et al., 2003) for the impact of the use of renewable resources.

5.2 Fibre crop production

The production and processing of annual bast fibre crops such as flax and hemp follow basically the same flow schemes. In the developed countries most of the agricultural processes are mechanised and use of fertiliser and pesticides is common practice. Relatively, as compared to customary agricultural practice in growing of other crops, fibre crops have a low demand for nitrogen, weed control and pesticide (see Appendix 1.1-1.10). However, some fungi (especially *Botyris cinera*) may cause damage in fibre hemp to the lower part of crop. Chemical spraying of the tall crop is impractical and is considered economically and ecologically undesirable (De Mayer and Huisman, 1995). Flax growing is more demanding on the soil structure quality and drainage than hemp. To avoid pests and contamination of the crop, low amounts pesticides (parathion) and weed control agents (betazon, sethoxydim) are applied (Riensema et al., 1990). In Europe the agricultural production of flax is mechanised and special equipment is designed for harvesting and deseeding. Dew retting is still common practice in flax, which leaves the crop for some weeks on the field.

5.3 Impacts factors of fibre based products

The degree of positive environmental impact of natural fibre based products is partly depending on the substitution potential in industry of the various fibres and the energy requirement of the production process, the product performance and functional life time, including options for waste disposal.

5.3.1 Textiles

In the conversion process of raw fibres into yarns and fabrics, energy is used in the various steps for operating the machinery. Most of the processing steps from combing, drawing, spinning, to weaving are fully mechanised. The dyeing, bleaching and softening steps require input of chemicals and measures for effluent treatment. In industrialised countries strict rules are formulated on the use of dyestuffs and processing chemicals (Van Dam, 2002). The dyeing and bleaching of textile products are still contributing strongly to the ecological impact of products, but do not differ substantially for cellulosic fibre or the synthetic fibre products. In textile processing no dramatic differences in environmental impact between cotton and polyester are indicated. However, the use of fossil resources to produce the synthetic polymer substantially contributes to CO_2 emission. The assessment of the Life cycle inventory (LCI) of 100% cotton fabrics as compared to 50% polyester cotton fabrics showed that the functional life time of a blended fabric is better and also the energy required for laundering is in its favour (Kalliala et al., 1999). In the evaluation of the whole life cycle of a textile product it was stated that the phase of consumer use and maintenance has the largest ecological impact (AFMA, 1993). Pollution and energy use due to laundering was by far the largest impact factor for textiles.

Recently an eco-profile of the use of linen shirts was made by Bio Intelligence Service (Bio Intelligence Service, 2008). It was made by means of an LCA study according to the ISO 14020 standard. About 80% of the primary energy and water consumption is used by washing and ironing during the use phase. Compared to a cotton shirt the primary energy is about 15% higher due to longer ironing. Linen shows it advantages especially in the cultivation stage. The water consumption during the life time of a cotton shirt is 4 times that of linen shirt due to intensive irrigation. The eutrophication is about 18% more for cotton and the freshwater aquatic ecotoxity potential is for cotton almost 8 times as much as for linen. The global warming potential is about 130 grams of CO_2 for both type of shirts.

5.3.2 Ropes, twines, fishing nets

Price and performance of synthetic fibres has led to severe competition with natural fibre products on the market for ropes and binder twines. In many markets these have eliminated the plant fibre products. However, in some applications the biodegradability will have substantial advantages for the environment. For example in horticulture or shipping and fisheries. Nowadays synthetic fishing nets and hawsers are widely used because of their strength, but their persistence is causing severe damage to wild life. Furthermore, when the nets are washing ashore huge amounts of debris is accumulated at the beaches. In the calculation of the LCA of products such effects are generally not weighed or incorporated in the impacts of fish consumption.

5.3.3 Paper and board

In a case study on the LCA of hemp for paper pulp production the energy demand for agricultural production is found to be low (1.2 GJ/ton pulp) as compared to the decortication (6.2 GJ/ton pulp) or the pulping processes (15.2 GJ/ton pulp) (Berlo, 1993; Kok, 2001).
The paper and pulp applications of non-wood fibres in wood-free pulps as compared to wood based products have a negative image. This is mainly because the effluent treatment and chemical recovery systems are not fully integrated in the relatively small scale pulping mills in developing countries as is the case in the large scale wood pulping mills in Scandinavia and Canada. Only 10% of the worlds virgin pulp is made from non-wood pulp, and is largely produced in China from wheat and rice straw, bagasse and bamboo (Hurter, 2000). The requirement of energy for harvest, transport, chipping and refining of wood and the amount of chemicals needed to obtain high grade pulps could be advantageous for non-wood when the distance to the pulp mill is small (Berlo, 1993). Therefore small scale processing units for voluminous fibre crops is essential. However, the high costs for chemical recovery are preventing the downscaling of pulping industries, which makes competition with wood based pulping difficult. Only the niche market of the speciality pulps annual crops can compete because higher prices can be asked. Developments for valorisation of discarded by-products from cellulose production, such as lignin in adhesives, coatings and 'green chemicals', is providing a solution for more sustainable use of renewable resources (Gosselink et al., 2004).

5.3.4 Non-woven

Non-woven fabrics by dry-laid needle punching technology can be produced of most types of natural fibres. Each fibre yields a characteristic fabric, depending of the length and softness of the fibre used. In the conventional needle punching process, on a needle loom, dust formation is a point of concern even with cleaned fibre. Dust minimisation is important also to reduce excessive machine contamination. To enhance the coherence in the non-woven mat, for various applications cross-linking chemicals are used, or the fibres are blended with synthetic fibres, and consolidated and finished by subsequent calendering on hot rollers. Alternatively, a wet laid process can be used. With this technology high pressure water jets are used to entangle the fibres and - similar to paper making processes - the fibres form bonds at contact points upon drying, resulting in a strong web structure.

Non-wovens are applied in various forms and products:
- as tissues and hygienic products
- in filters,
- as sorbents in diapers and disposables,
- in building industries as insulation mats,
- as filling material in mattresses, furniture

• in floor covering and carpets,
• in laminates and composites,
• as horticultural substrate and weed control fleece,
• as geotextiles.

In each application the environmental impact of cellulosic fibre based products requires comparison with competing synthetic or mineral products. Especially in the end application the aspects of functional life time and waste disposal of the non-woven product need to be consistent. For single use disposable tissues and diapers, the persistence of synthetic fibres is in favour for the use of renewable and degradable fibres, provided that the technical performance is the same.

5.3.5 Geotextiles

Geotextiles are used as reinforcement for embankments and slopes to avoid erosion in civil engineering constructions. The natural biodegradation of the lignocellulosic fibres can be considered to be an advantage in temporary civil engineering applications. However, the functional life time of a geotextile should be sufficient under the applied conditions and give the required protection against erosion as long as the construction needs to be stabilised (Rao, 1994; Gosselink, 2000; Venkatappa Rao, 2002). In many cases on slopes and waterfronts, natural rooting of plants takes over the reinforcing role of the geotextile (Rickson, 1998). Biodegradation of the soil stabilising geotextile then is desirable (Hoefnagels, 1994). Geosynthetics that need to be removed after a period of time cause a considerable disturbance and is very costly. In general those geosynthetics are resistant to degradation and will remain in the soil for long periods of time.

5.3.6 Horticultural materials

Artificial substrates, synthetic binder twines, plastic clips and plant pots are extensively used in the modern horticultural production in greenhouses and nurseries. For the growers the plastics products and substrates for soilless production (e.g. mineral wool) are forming increasingly a problem of disposal. The mineral wool products are a concern for their effects on human health (Islam, 2002). Alternatively, the use of renewable growing media have been investigated and coir pith, the residue from coir fibre production, was introduced as renewable substitute for the disputed peat moss or artificial media. Also other fibrous materials and bark have been considered for conversion to ecologically sound alternatives in potting mixtures and substrates, with promising results. In the production and disposal these alternatives can be assumed to require less energy, but no quantitative data are yet available. The use of synthetic twines has been the result of too fast loss of strength and degradation of the sisal or jute twine under the moist conditions in a greenhouse. The increasing weight of the crops and the risk of damage due to failure of the twine has been the main reason for using the synthetic products.

Biodegradable plant pots based on plant fibres and different binders are on the market. Competition with the plastic plant pots on price is still very difficult, despite the fact that labour intensive replanting in nurseries will be unnecessary when the pots are biodegradable and roots are able to grow through the walls. The ecological advantage for using biodegradable products is not yet included in the product costs. Recently the UK has marked plant pots as packaging material which implies that an extra tax is put on these products. This has increased the interests of consumers and producers in alternative renewable material based plant pots.

5.3.7 Building materials

Building industries are contributing to a large extent to resource depletion, waste generation and energy consumption, while on the other hand the built environment is vital to economic development (Emmanuel, 2004). Promotion of the utilisation of renewable resources as CO2 neutral building materials can only be considered sustainable when it does not result in faster deforestation.

Apart from promotion of the use of FRC certified wood, the use of other renewable building products has received limited attention in the building industries. Fibre crops could play a more prominent role in building and construction applications as fibre board material (Van Dam et al., 2004c; Van Dam et al., 2004d), insulation materials, and as reinforcement or filler in many different products. In lightweight concrete, bricks and loam building blocks, cellulosic fibres have been known to provide good properties. In the production of substitutes for asbestos cement abaca fibres, were proven specifically suitable. However, the effects on ecological impact for renewable building materials have been poorly documented.

Thermal insulation materials based on natural fibres and cellulose have a good technical Performance (Valovirta, 2002). Also the ecological profile, as compared to the energy requirement for the production of mineral wool insulation or expanded polystyrene, can be assumed to be positive (Hoefnagels, 1994). However, in an publication of the stone wool industries those arguments are opposite (Schmidt, 2004) and lowest consumption of total energy is claimed for mineral wool insulation products.

Application of fibre crops in fibre boards for building has to compete with wood fibres. Substitution is only feasible when the fibres can be produced cheaper than wood chips. In most cases the amount of (synthetic) glue or resin, required for binding the fibres to form strong board materials, is higher in the case of non-wood fibres. This will have a negative impact on the economics of the board product and also on the ecological performance of the product. Coatings, paints and adhesives are necessary to increase the durability of renewable building products.

Presently, these are mainly based on petrochemical products. To increase the environmental performance of renewable building materials, varnishes, paints and coatings based on plant oils should preferentially be applied. Similarly, natural resins derived from plants (e.g. lignin, furans) should be developed for production on commercial scale and become available as binders for boards and as components in protective coatings.

A recent LCA study on the application of kenaf fibre in insulation panels for building applications shows that kenaf mats have lower impact than other products if the panels are incinerated after the service-life and the core fibres are incinerated as well(Ardente et al., 2008). Without these incinerations the impact of kenaf panels is less than from synthetic panels but higher than from mineral panels. In the analyzed production process 15% of polyester fibre is mixed with kenaf fibres. After heating, these polyester fibres support the structure of the panel by forming the bonds between the kenaf fibres. However about 50% of the total energy consumption originates from the production of these polyester fibres. Depending on the chosen scenario the energy savings during the life time of the panels is 50 to 150 times the energy consumption in the production of the panels.

5.3.8 Composites

The LCA of hemp and flax fibre reinforced synthetic polymer composites for automotive parts has been reviewed by several researchers (Wötzel, 1999; Patel, 2003; Bos, 2004). Comparison for automotive applications with glass fibre reinforced composite products were addressed also by manufacturing companies. Critical evaluation of the product flow from the primary production of the fibre crop to the end of the life cycle of a passenger car reveals that, within the system boundaries, the agricultural cultivation of fibre crops is insignificantly contributing to the ecological impact. The (non-renewable) energy requirements for the production of fibre glass or flax fibre mats (Diener, 1999) differ substantially (54.7 MJ/kg vs 9.6 MJ/kg). However, relative to the impact of the polymer matrix material, the overall improvements in the use of natural fibres were small.

Apart from the direct benefit of lower environmental impact of the constructive part which is in some cases reached, also during use a composite reinforced with agro-fibres could contribute to a lower environmental impact, especially when the part is used in transport applications. Due to the lower weight, fuel consumption of a transporting vehicle could be lowered when any glass fibre reinforced part is replaced by an agro-fibre reinforced part, as long as the part is designed for stiffness. If natural fibre composites are produced with higher fibre content for equivalent performance the amount of synthetic polymer can be reduced as well (Joshi, 2004). A hemp reinforced car part was compared with one from ABS (Acrylonitril Butadiene Styrene copolymer) using several methods, including the Eco-indicator 95 method (Wötzel, 1999). It was found that not only there is a minor environmental advantage of the hemp reinforced part during the production phase (only 8%), but also the weight saving due to the application of the hemp reinforced part leads to a (limited) energy saving and thereby further environmental advantage during the use phase.

The life cycle assessment of china reed (*Miscanthus sinensis*) fibre reinforced PP was studied as a replacement for glass fibre reinforced PP for the production of transport pallets (Corbiere-Nicollier et al., 2001). Various methods were used to estimate the environmental impact including the Eco-indicator 95 method. They report an environmental advantage of about 30% due to the use of the natural fibre reinforced material. The effect of a 20% recycling level of glass fibre pallets on all impact categories of the LCA was indicated to be insufficient to compensate for the lower impact of the natural fibre pallet. A significant reduction of energy consumption due to weight saving during the use phase was reported.

In data-sheets and appendices 1.1 to 1.12 quantitative information is presented on the natural fibre production chain related to environmental aspects. They can be used for further comparisons in the ENFA model.

6 Regulations relevant to annual fibre crop production chains

In most countries of the European Community a licence is needed to grow and transport fibre hemp and certified seeds are needed for crop production and to collect the EC subsidy for hemp. No licence is needed to grow and process flax, but of course EC and National regulations related to the use of permitted seeds or pesticides have to be followed.

With growing fibre crops, the farmer is entitled to receive support under the single area payment scheme according to the Council Regulation (EC) No 1782/2003. However when hemp is produced the varieties used must have a tetrahydrocannabinol content not exceeding 0.2 %. The granting of payments is subject to the use of certified seeds of certain varieties listed in the Commission regulation (EC) 796/2004 and to a declaration of areas on hemp grown for fibre. The single area payment is an individual support which can be applied differently in each Member State. In the Netherlands it is based on the historic production and rights of the farm.

In the past, the support on fibre crops resulted in supporting large areas of flax and hemp which were not further processed to fibre. The EC changed the regulations and now the EC council regulation (EC) No 1673/2000 is effective on the common organisation of the markets for flax and hemp grown for fibre. This regulation is developed to maintain the production of long flax fibre and to support the short flax fibre and hemp fibre production temporarily in such a way that potential outlet for new products reaches equilibrium.

At the moment there are two levels of EC subsidy available for fibre crop processors depending on the type of fibres that are produced. For long flax fibres (textile application) a support is given of € 160/ton of fibres and for hemp fibres and short flax fibres (textile or other applications) the subsidy is € 90/ton. In order to take account of the special status of traditional flax in certain areas of the Netherlands, Belgium and France additional transition aid is granted to the primary fibre processor in two areas. In the area of the Netherlands and part of Belgium this support is € 120/ha and in the other part of Belgium and France the aid is €50/ha.

In May the European Commission will present the proposal for the coming years. Probably the support for hemp fibres and short flax fibres and also the extra processor support will be stopped in the near future. Actually this change was already mended to be implemented in 2006, however the Council of Ministers decided to extend the present situation till 2008 (EC No 953/2006). There is no information available yet if the existing situation will be further extended.

Primary processors must submit applications for authorisation to the competent authorities. For each country and for both short and long fibres, the subsidy is limited to different national guaranteed quantities of fibres.

In 2007 the total of guaranteed national quantities of long flax fibres was about 81000 tons. With almost 56000 tons France is by far the country with the highest amount. France, Belgium and the Netherlands are the countries with the highest support together they receive 92% of the support on long fibres. The total of guaranteed national quantities of short flax fibres and hemp fibres is about 146000 tons and beside the above-mentioned countries also Spain and Germany receive substantial support. These five countries receive about 75% of the support of short flax and hemp fibres. Short flax fibres and hemp fibres are allowed to contain 7.5% of impurities and shives. However, the Member States may, with reference to traditional outlets, also decide to

grant aid to less pure short fibre to a maximum of 25%, but recalculation to impurity content of 7.5% is required.
If the total production for a type of fibre is higher than the guaranteed quantity, the subsidy for the processor is limited to a maximum number of tons/ha. However if the guaranteed quantity of one type of fibres is not reached than each Member State is allowed to transfer the not claimed support to the other type of fibres. Transfers are carried out on the basis of an equivalence of one ton of long flax fibre to 2.2 tons of short flax fibre and hemp fibre.
In the years 2000-2007 the long fibre production in the Netherlands was more than the guaranteed quantity however the short fibre production was not, which made it possible to fully support the total long fibre production nonetheless (Kasse, 2007b). Every EU Member State has a different ratio in the production of short and long fibres and different guaranteed quantities of both fibres have been assigned to every country. Within the scope of this project it is not possible to create an overview of the granted support in each country .

In the trade with third countries it is forbidden to levy any charge having equivalent effect to a customs duty and to apply any quantitative restriction or measure having an equivalent effect.
However if the Community market is threatened with serious disturbance appropriate measures may be applied in trade with third countries until such disturbance or threat thereof has ceased.
The Council will then define the circumstances and limits within which Member States may adopt protective measures. Import of hemp and hemp sowing seed is not allowed without a certificate that the tetrahydrocannabinol content is not exceeding 0.2%.

7 Technical data for the ENFA model -- Deliverable 24

Complete sets of technical production and processing data of commercial annual fibre crops could not be found. There are always important figures missing. The best data sets can be found in appendix 1.1 to 1.10. Based on literature, interviews and calculations two complete sets of data were composed with subsidies for the Dutch situation. They are available as data sheets and as appendix 1.11 and 1.12. In addition PRI was contracted to review data availability, this confirmed our own findings.

7.1 Production of flax

One of the most important factors is the harvest yield of the crops. Literature data of yield in the production of flax straw ranges from 1500 kg/ha in the UK to 7000 kg/ha in France (ADAS, 2005; Eurostat, 2006). In Belgium and the Netherlands the yield is about 6000 kg/ha (Eurostat, 2006). As France is the largest flax producer in the EU a yield of just below 7000 kg/ha of flax straw is probably the most appropriate number of yield. However growing flax in countries that are traditionally not growing flax, yields will be lower. In Eurostat a yield of 3000 kg can be found for Romania and 4000 kg for Italy. Also in Germany a yield of 4000 kg is more common (Karus et al., 2000). The necessary amount of fertiliser depends on the soil and different sources report different applications (Van der Werf, 2004; ADAS, 2005; WUR-PPO, 2006). Application of Nitrogen (N) is on a level of 40 kg/ha does not differ much. Application of P (P_2O_5) varies from 30 kg/ha in France to 80 kg/ha in The Netherlands and K (K_2O) ranges from 60 (Van der Werf, 2004) to a recommendation of 200 kg/ha in The Netherlands (WUR-PPO, 2006). The International Fertilizer Industry Association presents figures for present practices (IFA, 2006) (www.fertilizer.org) For Western Europe and a yield of 6 t/ha these figures are for deep loams N=0-20, P_2O_5=70, K_2O=70 and for light soils N=40-70, P_2O_5=70-100, K_2O=70-100. For crop protection different amounts and combinations of chemicals are practised (appendix 1.6 and 1.9)
The mentioned amount of fuel needed to grow and harvest this crop differs strongly from 68 litres (Van der Werf, 2004) to 184 litres (WUR-PPO, 2006). However a Dutch fibre processor and a Dutch farmer conclude that the figure mentioned by WUR-PPO is too high. In the INRA study the retting is carried out in a central mill with thermal water, so turning of the flax in the field is not accounted for.
In most literature the technical data available is not complete for the ENFA model and there is much variation between it. The price of the produced commodities strongly depends on the world market and quality of the products. Subsidies are different for the produced type of fibre (short or long) and the region.

Based on literature, interviews and own calculations a datasheet for long flax fibre production was composed (Appendix 1.11 and Flax A&F) that in our opinion can be a base case for further calculations in the ENFA model. For the cultivation most of the data of the "flax KWIN participation datasheet" was used. Some adjustments based on interviews were made. The flax fibre separation and cleaning is based on a modern production line with an average mill size. These data are based on an interview with a fibre producer. The second processing step (as can be found in the INRA sheets) to produce sliver (band of very fine fibres) has almost completely

moved to China. Only 20% of the sliver production is done in Europe and it is decreasing every year. So that processing step was not included in this datasheet
The long fibres are the most valuable fibres and are used in textile. The price depends strongly on fashion. Besides the long fibres also short fibres are produced. The price of those short fibres depend on purity and application and are often used in the same applications as short fibres from other sources. This is also the reason that flax production for short fibres only is not advisable as the specific quality of the flax fibre is not needed in those applications and the yields of hemp and other fibre sources are in general higher. Short flax fibres (not good or long enough for textile application) are normally produced as a side stream in the flax long fibre production.

7.2 Production of hemp

The yield of hemp found in literature varies from 5500 kg/ha (Karus et al., 2000; ADAS, 2005) to 8000 kg/ha (Van der Werf, 2004; WUR-PPO, 2006). Eurostat shows yields of around 7 tons/ha for France and the Netherlands. For the Netherlands this was confirmed in personal communications with a Dutch grower and producer (Veld, 2004). In the Netherlands 110 kg of N and no application of P and K is advised. However in the INRA study calculations are made with N=68, P=30 and K= 114 kg/ha.
No crop protection is advised in The Netherlands and the INRA study also does not include any crop protection (Van der Werf, 2004; WUR-PPO, 2006). Fuel use is reported between 52 to 65 litres.

Also for hemp short fibres a complete datasheet was composed (appendix 1.12 and Hemp A&F). For the cultivation the “hemp KWIN datasheet” was used but the fertilizers average of the ADAS, KWIN and INRA study was used in this case. For the industrial part data from a modern 10 /h production line obtained from an interview with a machinery producer were used.
Hemp fibre is a so called hard fibre and the production for textile as described in the INRA sheet is not yet competitive with flax. The fibres of hemp are still to course and cannot yet compete with flax or cotton for fine textiles. They can be used for jeans and similar thick clothing, but this is still a niche market. Most of the hemp fibres are used for composites and paper, but in these applications they have to compete with other so called hard fibres like jute and kenaf and of course the short fibres of flax.

7.3 Production of kenaf

As kenaf is a very new crop in Europe no reliable data on large scale production are available. For KEFI only uses N as fertiliser, they calculate with 200 kg urea (46%)/ha (K.E.F.I., 2006).
The yield figures of the research plots in the Biokenaf project are not yet published, but large scale trial fields in Triest showed yields from 6 to 10 tons/ha. The yields in small scale trial fields were higher than 20 tons/ha for a number of areas in Greece, Sicily and Spain, but irrigation was necessary to get the production at such a high level.

7.4 Decortication of fibre crops

Fibres are extracted from the plant in decortication mills. The production of long textile fibres from flax is carried out in the traditional way by breaking and scutching into in technical long fibre that can be used for different applications. Further treatment and refining (hackling) make these fibres suitable for spinning, weaving and textile applications. The production of fibres for new application like composites for automotives and insulation materials is often done in less traditional process steps. In contrast with other industries – as for example mechanical pulp mills for paper production – decortication mills may differ strongly from each other. These differences already start at harvest; sometimes the plants are harvested with a maize chopper already cut to small pieces of about 10 centimetres. There are also harvesting machines that cut the plants into pieces of 30 to 60 centimetres after which they are baled to big round or rectangular bales and also harvesting without cutting the stems is practised.

In not traditional decortication mills, where fibres are produced for other applications than for textile, the bales can be cut in pieces after which a bale opener opens them into loose stem pieces. These are then treated in a hammer mill that separates the fibres from the hurds. But there are also mills that do not include a hammer mill. In other mills chopped stems are received that are not baled. In these fibre lines there are no bale openers and hammer mills present.
Depending on the applications, different mills also produce different qualities. For application in pulp and paper specialties a hurd content of 25% is no problem, however for application in composites for automotives the fibres have to be very clean. Obviously a higher purity requires more cleaning steps and higher production costs. Due to all the differences in harvest and processing facilities it is not possible to calculate the mass and energy balance for an average mill. Therefore we have chosen for one well established system as a model for further calculations. In this fibre processing mill, the straw is not cut at harvest and pressed into bales. The straw is cut in the decortication mill and a hammer mill is used to break the bonds between the core from the fibres. The fibres are then cleaned to a hurd content of 10 to 15% (Remmery, 2007).

8 Analyses of critical success factors --Deliverable 25

8.1 Introduction

Market penetration of novel non-food agricultural products has been limited so far. This is also the case for annual fibre crops and fibre products.

8.2 Approach:

A general analysis of factors contributing to success or failure of non-food production chains has been made for The Netherlands with an outlook for Europe in general (Bos et al., 2008). Based on this analysis a specific analysis has been made for annual fibre crops following 7 general areas of interest.

8.3 General analysis of success factors and policy and innovation for non-food crops and applications.

The manuscript by Bos et al. (See Annex 2) analyses innovation policies for non-food application of renewable resources in the Netherlands since the 1980s (Bos et al., 2008). Based on stakeholder studies performed in 2000 the factors of success for innovations in the non-food production chain have been described. Recommendations for innovations and therefore market penetration have been derived. Furthermore, the developments have been analysed using the theory of Strategic Niche Management (SNM). The quality of the processes at regime level and at niche level has increased considerably in the last years. The trend towards a much wider use of renewable resources for non-food applications thus seems more robust than it was in the previous millennium. From the SNM analysis we derive a number of recommendations for policy makers active in this field.

8.4 Specific analysis of factors contributing to innovation success for annual fibre crops

8.4.1 Specific market demand for the product:

Crucial for a successful initiative is the existence of a specific market demand for the new product, but a market does not develop by itself, it needs to be created. Therefore it is important that the firm or entrepreneur who will market the new product takes the lead when market introduction comes into view.

Example:

In the last decade technology has been developed for the replacement of glass fibre by natural fibre in reinforced plastic composites. Replacing glass fibre by natural fibre can reduce weight and make plastic components easier to recycle or the product can be burned to generate energy. The automotive industry has been interested in using the product. And once the properties of the new products had proven their quality and shown that they could bring weight reduction in the cars, the demand has been growing steadily. Still, the impact on the market has been limited. The demand for this alternative to glass fibre composites has only developed when new laws were introduced (in Germany) which made companies responsible for recycling their products. This has led to a specific demand for recyclable fibre composites. Natural fibre plastic composites should benefit from this more specific market demand.

8.4.2 Technology has to be available

The development needs to be technologically feasible, but a successful new technology is in itself not enough to guarantee a successful market introduction, the market demand still needs to be created.

Examples:
A new process has been developed in which granules of natural fibres and plastic composites are produced. Numerous products can be moulded with this composite that are recyclable and can be used as fuel at the end of the life cycle. This half product creates new possibilities in the use of natural fibres composites. Once the first products are made with this composite the demand is expected to grow, however it takes an enormous effort for the company to create the demand for this product. In the above mentioned production of natural fibre composites for moulded products, the technology is ready but the market for this product needs to be created.

Kenaf is a promising crop for southern Europe and there is a demand for using the crop in several products. However, due to climate conditions dew retting of kenaf in the field is not possible. Retting on stem during the wet winter has to be applied, however this is an uncontrolled process. The standard fibre processing technology is available however new retting technology has to be developed to guarantee the quality of the fibres that enables the competition with other fibres.

8.4.3 Infrastructure

The availability of suitable infrastructure helps in bringing a new development to the market, the need for a large investment in infrastructure can be a serious barrier for new developments.

Example:
To be competitive large scale processing is necessary, however that requires large investments. The start of hemp fibre production in the Netherlands was made easier by installing a full-scale second hand fibre extraction line in existing buildings that had been used for other purposes. By installing this second hand line and using existing infrastructure for equipment and storage, the financial risks of starting this hemp fibre industry could be minimized without loosing the profits of economy of scale.

8.4.4 Spin-off from existing production chains

Many successful initiatives are spin-offs from existing agro-food production chains, setting up a completely new production chain, with new players, is much more difficult and costly.

8.4.5 Environmental benefits

Environmental benefits such as biodegradability and renewability and sustainability in general are by themselves not enough to sell a (biobased) product, unless these benefits provide specific functional advantages.

Examples:
Thermal insulation materials based on natural fibres and cellulose have a good technical performance (Valovirta and Vinha 2002). Also the ecological profile, as compared to the energy requirement for the production of mineral wool insulation or expanded polystyrene, are considered positive (Hoefnagels et al. 1994) though this has been disputed by the stone wool industries (Schmidt et al. 2004).
LCA claims are clearly very difficult to quantify and even when there are obvious environmental advantages, most of the consumers will make their choices on price and performance. In thermal insulation the natural fibres are thought to have the advantage over mineral and glass wool that they perform better in equalizing the humidity in living spaces by a better absorption of water. This selling point is much more relevant in the market as this is specifically demanded. A positive environmental impact is less relevant as this is not specifically required for in the market.

The use of new building materials based on renewable raw materials is slowly growing because these will have lower environmental impacts than the common mineral based building products. Faster developments of new techniques is prevented by the conservative attitude of many builders that want to avoid risks. Also consumers are aware of potential risks of new building techniques and will not readily buy these type of houses, unless it is proven that they are as durable as conventional houses. Only few people that are very concerned about their environment will accept the risks of new materials and techniques.

8.4.6 Regulations

Also, existing regulations can obstruct market introduction. Newly developed products can have much difficulty penetrating the market because laws, regulations and standards are made for existing synthetic products and regulations are not geared to biobased alternatives. On the other hand new regulations which forbid or discourage current products or directly promote or facilitate biobased products are often necessary to give an impulse to products based on renewable raw materials.

Examples:
Regulations of structural support and subsidies are important for the production of fibre crops in Europe. Without the present EU regulations on subsidies for the grower of fibre crops and the processing into fibres the balance for the grower and producer would be negative.

The strict German regulations on recycling of cars forced the automobile industry to decrease the amount of non-recyclable parts in their cars. It resulted in an gradually replacement of glass fibres by natural fibres.

Other regulations can have a counterproductive effect.
The Kyoto protocol and the public awareness results in higher demands for starch containing crops, resulting in higher prices for wheat. With the ongoing increment of wheat grain prices the supply of flax and hemp straw for the fibre processors is jeopardized. Due to the high wheat grain prices farmers are now switching to wheat. In the Netherlands the amount of flax that will be produced in 2008 is expected to be 20% lower than in the preceding years and for France this decline is expected to be 10%.
In general water retting results in a better quality fibre than dew retting. However water retting has become very expensive and has totally been replaced by dew retting. About ten years ago it was calculated that due to cheap thermal energy warm water retting and scutching in Iceland of flax produced in the EU would be profitable. The retted fibres could then be transported back for further treatment. However as Iceland was not a EU country, taxes on import of these retted fibres in the EU prohibited the actual implementation of this strategy.

8.4.7 Distinguish end-markets and raw material markets

The end market for biobased products and the raw materials market are very different. In the Netherlands (and Europe in general) the price of agricultural raw materials is often so high that raw materials are cheaper imported from abroad. Therefore the successful introduction of a new product based on agricultural raw materials does not automatically mean success for potential local producers of raw material.

Example:
The use of natural fibres in the automotive industry created an extra demand of natural fibres and supported the production of hemp in Europe and created an extra outlet for the short flax fibres. However when fibre prices of flax and hemp increased in the years 2001 and 2002, the growing demand in the automotives industry was largely covered by extra import of exotic fibres like jute and kenaf and not by locally produced hemp and flax fibres.
In Italy insulation materials are produced from local grown kenaf from which the fibres are extracted in a small mill. However the company has started to import kenaf fibres with less impurities from Asia which can be delivered at about the same price. Larger scale processing and higher growing yields are necessary to be competitive with the fibres Asia.
Cheap labour has moved the textile industry to China and India. For the same reason the processing step of hackling flax has largely been moved to China. Only the first steps of fibre extraction and removal of the core parts are still performed in the EU. So not only the growers, but also the processors of these raw fibres have to deal with the competition from other parts of the world.

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Appendix 1: Technical data of fibre crop systems

Appendix 1.1

source	**"vezelsector in opmars", LEI**				
cost calculations	**2004**				
Fibrecrop	**FLAX**				
country	Netherlands				
				selling contract no seed sepearation in field	participation contract seed separation in field
	amount	unit	price/unit	income/costs	income/costs
income					
stro+seed	7500	kg	0.14	1050	
fibre (long +short)	1600	kg	1.18		1888
seeds	1000	kg	0.68		680
gross income				***1050***	***2568***
costs					
sowing seed	115	kg	1.78		205
labor					
water					
crop protection					
bentazon	3	litre	26.93	81	81
mineral oil	6	litre	2.83	17	17
MCPA	0.5	litre	4.85	2	2
triallaat	3.5	litre	11.14	39	39
deseases and plagues					
deltamethrin	0.3		37.43	11	11
energy					
fuel	184	litre	0.35	64	64
fertilizer					
N	40	kg	0.55	22	22
P_2O_5 (tripelsuper)	80	kg	0.52	42	42
K_2O (Kali-60)	200	kg	0.31	62	62
other costs					
inspection costs	1	ha	182		182
interest	5.5	%			13
insurance	0.9	%	1050	9	
	0.9	%	2570		23
N-mineral samples	0.5	sample	36.32	18	18
harvest costs					948
scutching					662
Total costs				***368***	***2391***
Gross margin				***682***	***177***
subsidy					
EU ha (regio 1)	1	ha	446	446	446
seed	1000	kg	0.28		280
long fibre	1000	kg	0.16		160
short fibre	600	kg	0.09		54
EU processor	1	ha	120		120
total subsidy				**446**	**1060**
Processing					
input quantity	7500				
output fibres	1600				
output seeds	1000				
output core					
output dust					
emissions					

Appendix 1.2

source	**UK flax and hemp production, ADAS**			
cost calculations	**2004**			
Fibrecrop	**FLAX** short fibre			
country	UK			
	amount	unit	price/unit	income/costs
income				
straw	1500	kg	0.03	44.12
fibre (long +short)		kg		0
seeds	750	kg	0.25	187.5
gross income				*232*
costs				
sowing seed	50	kg	2.06	103
labor				
water				
crop protection				
insecticides	0.25	liter	4.41	1.10
herbicides	30	g	0.59	18
herbicides	0.5	liter	32.35	16
fungicides	0	liter	0	0
desicciation	3	liter	2.35	7
deseases and plagues				
energy				
fuel	not given			
fertilizer				
N	50	kg	0.49	24
P	60	kg	0.43	26
K	60	kg	0.43	26
other costs				
inspection costs				
interest				
insurance				
N-mineral samples				
harvest costs				??
haulage	1.5		17.65	26
Total costs				*247*
Gross margin				*-15*
subsidy				
EU ha (regio 1)	1	ha	360	**360**

Appendix 1.3

source	**UK flax and hemp production, ADAS**			
cost calculations	**2004**			
Fibrecrop	**HEMP** short fibre			
country	UK			
	amount	unit	price/unit	income/costs
income				
straw	5500	kg	0.147	809
fibre (long +short)		kg		0
seeds	0	kg		0
gross income				*809*
costs				
sowing seed	37	kg	4.71	174
crop protection				0
deseases and plagues				0
energy				
fuel	not given			
fertilizer				
N	110	kg	0.49	53
P	60	kg	0.43	26
K	60	kg	0.29	18
other costs				
inspection costs				
interest				
insurance				
N-mineral samples				
harvest costs				
contract cutting,turning,baling				109
haulage	5.5		17.65	97
Total costs				*477*
Gross margin				***332***
subsidy				
EU ha (regio 1)	1	ha	360	**360**

Appendix 1.4

source	**"markets and prices for Natural fibres", NOVA**			
cost calculation	**2000**			
Fibrecrop	**Flax** short fibres 6-8cm			
country	Germany			
	amount	unit	price/unit	income/costs
income				
straw	4000	kg		0
fibre short 6-8 cm card opener only	1200	kg	0.51	612
seeds		kg		
cleaned shives	2000	kg	0.21	420
gross income				***1032***
costs				
sowing seed	100	kg	1.52	152
soil preparation and seeding				125
crop protection				
Pesticides and application				145
deseases and plagues				0
energy				
fuel	not given			
fertilizer and application				90
N				
P				
K				
other costs				
inspection costs				
interest				
insurance				
N-mineral samples				
harvesting pulling,baling				220
haulage				80
storage				40
lease				125
Total cultivation and harvesting costs				***977***
Processing				
input quantity	4000			
output fibres	1200			
output seeds	0			
output core	2000			
output dust				
Processing costs (fibre processing facility)				
wages and salaries				200
administrative expenses				66
packaging				45
depriciation				185
other costs				60
electricity				50
outside capital interest				40
total processing costs				**646**
	profit before taxes			**-591**
subsidy	coupling with cereal subsidy			**685**
	inclusive subsidy			**94**

Appendix 1.5

source	**"markets and prices for Natural fibres", NOVA**			
cost calculation	**2000**			
Fibrecrop	**HEMP** short fibres (non woven grade)			
country	Germany			
	amount	unit	price/unit	income/costs
income				
straw	*6000*	*kg*		*0*
fibre short 6-8 cm card opener only	1500	kg	0.51	765
seeds		kg		
cleaned shives	3300	kg	0.18	582
gross income				*1347*
costs				
sowing seed	40	kg	4.06	162
soil preparation and seeding				125
crop protection				0
deseases and plagues				0
energy				
fuel	not given			
fertilizer and application				110
N				
P				
K				
other costs				
inspection costs				
interest				
insurance				
N-mineral samples				
harvesting cutting,baling				245
haulage				120
storage				60
lease				125
Total cultivation and harvesting costs				***947***
Processing				
input quantity	6000			
output fibres	1500			
output seeds	0			
output core	3300			
output dust				

Processing costs (fibre processing facility)		
wages and salaries		300
administrative expenses		90
packaging		65
depriciation		275
other costs		90
electricity		75
outside capital interest		65
total processing costs		**960**
	profit before taxes	**-560**
total subsidy		**663**
	inclusive subsidy	**103**

Appendix 1.6

source	**"Kwin", PPO**			
cost calculations	**2006**			
Fibrecrop	**FLAX**			**participation contract**
country	Netherlands			
	amount	unit	price/unit	income/costs
income				
straw		kg		0
fibre (long +short)	1600	kg	1.18	1888
seeds	1000	kg	0.68	680
gross income				***2568***
costs				
sowing seed	115	kg	1.78	205
labor	14	hour		
crop protection				
bentazon	3	litre	32.50	97.50
mineral oil	6	litre	5.00	30
MCPA	0.5	litre	6.50	3
triallaat	3.5	litre	15.20	53
deseases and plagues				
deltametrin	0.3	litre	37.00	11
energy				
fuel	184	litre	0.75	138
fertilizer				
N (kalkammonsalpeter??)	40	kg	0.83	33
P_2O_5 (tripelsuper)	80	kg	0.57	46
K_2O (Kali-60)	200	kg	0.40	80
other costs				
inspection costs	1	ha	182.00	182
interest	5.5	%		15.0
insurance	0.90	%	2560	23.0
productschapsheffing	1	ha	14	14
N-mineral samples	0.5	sample	45.4	23
harvest costs contract	1	ha	950	950
scutching	1	ha	662	662
haulage				
Total costs				***2565***
Gross margin				***3***
subsidy				
EU ha	1	ha	446	446
seed	1000	kg	0.22	220
long fibre	1000	kg	0.16	160
short fibre	600	kg	0.09	54
EU processor	1	ha	120	
total subsidy				**880**

Appendix 1.7

source	**"Kwin", WUR**			
cost calculations	**2006**			
Fibrecrop	**FLAX**			**selling contract**
country	Netherlands			
	amount	unit	price/unit	income/costs
income				
straw +seeds	7500	kg	0.140	1050
fibre (long +short)		kg	1.18	0
seeds		kg	0.68	0
gross income				*1050*
costs				
sowing seed		kg	1.78	0
labor	14	hour		
crop protection				
bentazon	3	litre	32.50	97.50
mineral oil	6	litre	5.00	30
MCPA	0.5	litre	6.50	3
triallaat	3.5	litre	15.20	53
deseases and plagues				
deltametrin	0.3	litre	37.00	11
energy				
fuel	184	litre	0.75	138
electricity				
fertilizer				
N (kalkammonsalpeter??)	40	kg	0.83	33
P_2O_5 (tripelsuper)	80	kg	0.57	46
K_2O (Kali-60)	200	kg	0.40	80
other costs				
inspection costs		ha	182.00	0
interest	5.5	%		15.0
insurance	0.90	%	1050	9.5
productschapsheffing	1	ha	14	14
N-mineral samples	0.5	sample	45.4	23
scutching		ha	662	0
haulage				
harvest costs		ha	950	0
Total costs				***553***
Gross margin				***497***
subsidy				
EU ha	1	ha	446	**446**

In a selling contract, harvesting, haulage and seed are delivered by the processor

Appendix 1.8

source	**"Kwin", WUR**			
cost calculations	**2006**			
Fibrecrop	**HEMP** short fibre			
country	Netherlands			
	amount	unit	price/unit	income/costs
income				
straw	8000	kg	0.077	617
fibre (long +short)		kg		0
seeds	0	kg		0
gross income				***617***
costs				
sowing seed	20	kg	3.36	67
labor	5	hour		
water				
crop protection				0
deseases and plagues				0
energy				
fuel	52	litre	0.75	39
fertilizer				
N kalkammonsalpeter	110	kg	0.83	91
P_2O_5 (tripelsuper)	0	kg	0.52	0
K_2O (Kali-60)	0	kg	0.31	0
other costs				
inspection costs	0			0
interest	5.5	%		4
insurance	0.36	%	617	2
productschapsheffing	1	ha	3.95	4
N-mineral samples	0	sample	36.4	0
harvest costs contract				500
mowing	1	ha	125	125
turning	1	ha	40	40
pressing	1	ha	235	235
haulage	1	ha	100	100
Total costs				***708***
Gross margin				***-91***
subsidy				
EU ha	1	ha	446	**446**

Appendix 1.9

source	**"LCA of Hemp Textile Yarn", INRA**			
data	**2006**			
Fibrecrop	**FLAX**			
country	France/Belgium/Netherlands			
	amount	unit	price/unit	income/costs
income				
straw	6000	kg	0.250	1500
fibre (long +short)		kg		0
seeds	600	kg	0.25	150
gross income				*1650*
costs				
sowing seed	115	kg		
labor		hour		
crop protection				
insecticide Phosalone	0.2	kg		
insecticide Lambda-C	0.00023	kg		
insecticide Parathion	0.13	kg		
herbicide Triallate	1.4	kg		
herbicide Linuron	0.2	kg		
herbicide Bentazon	0.6	kg		
fungicide Prochloraz seed treatment	0.046	kg		
desicciation	0	litre		
deseases and plagues				
energy				
fuel	68	litre		
fertilizer				
lime	666	kg		
N	40	kg		
P_2O_5	30	kg		
K_2O	60	kg		
Proces step 1			price €/kg	
input quantity	6000	kg		
straw after retting	5400	kg		
output fibres	972	kg	1.8	1750
output core	2970	kg	0.02	59
output scutching tow (short fibres)	594	kg	0.35	208
output rest	864	kg		
subsidy				120
			income	2137
Proces step 2			price €/kg	
input quantity	972	kg	1.8	
output sliver	632	kg	2.15	1358
output hackling tow	243	kg	1.3	316
output rest	97	kg		
subsidy				
			income	1674
			less than fibre value after step 1	

Appendix 1.10

source data	**"LCA of Hemp Textile Yarn", INRA 2006**			
Fibrecrop	**HEMP**			
country	France/Belgium/Netherlands			
	amount	unit	price/unit	
income				
straw	8000	kg		
fibre (long +short)		kg		
seeds		kg		
gross income				
costs				
sowing seed	55	kg		
labor		hour		
crop protection				
insecticide Phosalone	0	kg		
insecticide Lambda-C	0	kg		
insecticide Parathion	0	kg		
herbicide Triallate	0	kg		
herbicide Linuron	0	kg		
herbicide Bentazon	0	kg		
fungicide Prochloraz seed treatmer	0	kg		
desicciation	0	liter		
deseases and plagues				
energy				
fuel	65	liter		
fertilizer				
lime	666	kg		
N	68	kg		
P_2O_5	30	kg		
K_2O	114	kg		
Scenario water-retting with geothermal heath				
Proces step 1			price €/kg	
input quantity	8000	kg		
retted straw	6480	kg		
output fibres	583	kg	1.75	1021
output seeds		kg		0
output core	2592	kg	0.2	518
output scutching tow (short fibres)	1490	kg	0.75	1118
output rest	1814	kg		
subsidy				120
			income	2777
Proces step 2			price €/kg	
input quantity	583	kg		
output sliver	292	kg	2.15	627
output hackling tow	233	kg	1.3	303
output rest	58	kg		
subsidy				
			income	930
		is less than fibre value after step 1		

Appendix 1.11

based on participation contract "Kwin", PPO
corrected for fuel, fertilizer and inspection costs and yield
processing costs based on interviews and calculations

Fibrecrop	**FLAX**		**participation contract**	
country	Netherlands			
	amount/ha	unit	price/unit	income/costs
income				
straw	7000	kg		
fibre long	1200	kg	1.6	1920
fibre short	1000	kg	0.25	250
seeds	1000	kg	0.68	680
gross income				***2850***
costs				
sowing seed	115	kg	1.78	205
labor	14	hour		
crop protection				
bentazon	3	litre	32.50	97.50
mineral oil	6	litre	5.00	30
MCPA	0.5	litre	6.50	3
triallaat	3.5	litre	15.20	53
deseases and plagues				
deltametrin	0.3	litre	37.00	11
energy				
fuel	100	litre	0.75	75
fertilizer				
N (kalkammonsalpeter??)	40	kg	0.83	33
P_2O_5 (tripelsuper)	80	kg	0.57	46
K_2O (Kali-60)	200	kg	0.40	80
other costs				
inspection costs	1	ha	30.00	30
interest	5.5	%		15.0
insurance	0.90	%	2560	23.0
productschapsheffing	1	ha	14	14
N-mineral samples	0.5	sample	45.4	23
harvest costs contract	1	ha	950	950
scutching	1	ha	707	707
haulage	7	ton	35.00	245
output seeds	1000			
Total costs				***2640***
Gross margin				***210***
subsidy farmer	EU single area payment			
Processing	/ha			
input quantity	7000	kg		
output seeds	1000	kg	0.68	680
output fibres long	1200	kg	1.6	1920
output fibres short	1000	kg	0.4	400
output core	2500	kg	0.028	70
output dust	600	kg	-0.01	-6
labour	15	h		-355
electricity	600	kWh	0.12	-72
administration				-212
management				-139
depriciation				-89
interest				-26
payment to the farmer				-2850
costs scutching charged to farmer				707
Margin processor				28
Margin farmer and processor				**238**
Eu subsidy seeds and fibres in 2008				
seed	1000	kg	0.22	220
long fibre	1200	kg	0.16	192
short fibre	1000	kg	0.09	90
EU processor	1	ha	120	120
total subsidy in 2008				**622**

Appendix 1.12

based on	**"Kwin", WUR 2006**			
fertilizer corrected				
processing costs based on interviews and calculations				
Fibrecrop	**HEMP** short fibre			
	amount	unit	price/unit	income/costs
income				
straw	8000	kg	0.077	617
fibre (long +short)		kg		0
seeds	0	kg		0
gross income				***617***
costs				
sowing seed	20	kg	3.36	67
labor	5	hour		
water				
crop protection				0
deseases and plagues				0
energy				
fuel	52	litre	0.75	39
fertilizer				
N kalkammonsalpeter	110	kg	0.83	79
P_2O_5 (tripelsuper)	0	kg	0.52	17
K_2O (Kali-60)	0	kg	0.31	23
other costs				
inspection costs	0			0
interest	5.5	%		4
insurance	0.36	%	617	2
productschapsheffing	1	ha	3.95	4
N-mineral samples	0	sample	36.4	0
harvest costs contract				500
mowing	1	ha	125	125
turning	1	ha	40	40
pressing	1	ha	235	235
haulage	1	ha	100	100
Total costs				***735***
Gross margin				***-119***
subsidy				
EU ha	single area payment			
Processing	/ha		price €/kg	€/ha
input quantity	8000	kg	0.077	-616
output cleaned short fibres	1920	kg	0.4	768
output cleaned core (shives)	4880	kg	0.125	610
output dust	800	kg	-0.01	-8
waste for use as fuel	400	kg	0	0
labour	4	h	-15.5	-62
administration				-15
management				-31
depriciation				-79
interest				-79
electricity	780	kWh	-0.12	-94
Margin processing				**394**
EU processing subsidy 2008	**173**			

Appendix 2: Manuscript Bos et al., 2008. Review. Beyond agrification: twenty five years of policy and innovation for non-food application of renewable resources in the Netherlands.

Reference:

Bos, H.L., Slingerland, M.A., Elbersen, W., Rabbinge, R., 2008. Review. Beyond agrification: twenty five years of policy and innovation for non-food application of renewable resources in the Netherlands. Biofuels, Bioproducts and Biorefining. Volume 2 Issue 4, Pages 343 – 357. Published Online 25 Jun 2008.

http://www3.interscience.wiley.com/cgi-bin/abstract/120081416/ABSTRACT

Abstract:

The first part of this review describes policy developments in the Netherlands since the 1980s around innovations for non-food application of renewable resources. Next, these developments are analyzed using the Strategic Niche Management (SNM) theory. The drivers at the regime level and the quality of the processes at the niche level have increased considerably in the last number of years. The trend toward a much wider use of renewable resources for non-food applications thus seems more robust than it was in the previous century. From the SNM analysis, we derive a number of recommendations for policy-makers active in this field. We also present a previously unpublished stakeholder study performed in 2000 on the factors of success for innovations in this field, and derive from this study recommendations for innovators active in the field. © 2008 Society of Chemical Industry and John Wiley & Sons, Ltd