Life Cycle Assessments of Natural Fibre Insulation Materials

Final Report

February 2008

Study funded by Defra

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Foreword

This study was undertaken at the instigation of the National Non-Food Crops Centre (the NNFCC), with funding provided by the UK Department for Environment, Food and Rural Affairs (Defra). The study examines the 'environmental profile' of insulation materials for construction that are based on the use of natural fibres using Life Cycle Assessment (LCA) methods. A specific element of the study is an evaluation of the potential for optimisation of the environmental profile of natural fibre insulation material(s). The LCA results obtained for the natural fibre insulation materials are placed in context by reference to available LCA information on example existing insulation products.

The project team consisted of Dr Richard Murphy, Mr Andrew Norton and Miss Sheau Tyun Tai of Imperial College London. Grateful thanks are extended to Mr Gary Newman of Plant Fibre Technology, Christine Armstrong of Second Nature, Mike Duckett of Hemcore, Jean-Pierre Buisson of Buitex, Nick Ralph of Rockwool, Stephen Wise of Knauf and Chris Foster of EuGeos Limited for supplying data and information used in this report.

Summary

The use of non-food crops has potential to be a route to delivering environmental and sustainability benefits and support for the UK government's objectives for sustainable development within the construction sector. In many cases, the production of non-food crop products can require low consumption of fossil fuels and other resources and generate fewer overall environmental impacts than alternatives. However, these aspects need to be examined objectively and on a case-by-case basis. The current lack of reliable, independent data regarding the environmental impact of Natural Fibre Insulation (NFI) materials was the overall reason for this study. The goal therefore, was to develop a scientific and transparent basis on which the environmental impact of natural fibre insulation materials could be evaluated.

The NFI materials investigated in this study were Isonat, a hemp/recycled cotton based material and Thermafleece which is produced mainly from waste sheep wool. The NFI materials were selected on the basis of their current UK market availability but are at relatively early stages of their product development. Thus, in addition to establishing LCA profiles for these NFI products, a major motivation for the study was to explore the potential for ongoing improvements to these profiles that may be possible in the near future.

Existing LCA information on the current market-leading materials produced by Knauf Insulation Ltd and Rockwool Ltd was kindly supplied by these manufacturers. This

has provided guidance in the present study on the levels of environmental impact associated with well established insulation products that have been awarded an A rating in the BRE Green Guide to Specification.

It is stressed by the authors that this research and its reporting was conducted solely with regard to the objectives in the preceding paragraph and must not be construed as a direct, comparative LCA study between the different 'types' of insulation materials (NFIs, mineral and glass wool products). As such, the LCA findings presented on NFI materials have not been subject to a peer review process as would be required for compliance with the ISO 14040 series of LCA standards when the purpose of a study is to develop comparative public assertions between alternative products fulfilling an identical function. The views and perspectives in this report on the LCA findings for the NFI materials are, thus, solely those of the authors.

The Functional Unit (FU) chosen for the study was for the insulation of a one square metre 'unit' area within the 'cold roof' space of a house:

"The manufacture, installation, use and disposal of insulation material for a 1 m^2 area of the central part of a first floor plasterboard/timber ceiling in a UK domestic house to a U-value of 0.16 W/m^{2}k for a period of 60 years service"

Specific process descriptions and data were obtained directly from NFI manufacturers and suppliers from which the specific life cycle inventories for the NFI materials were produced. Manufacturers of the Knauf Crown Loft Roll 44 and Rockwood Rollbatt materials supplied aggregated Life Cycle Inventory (LCI) data sets for their UK products. As data from selected databases have been used in part in the preparation of our NFI inventories, we have been careful to consider the potential for inconsistencies when drawing conclusions about the environmental profiles of NFI materials.

The environmental profiles for the NFI materials have been found to be similar to those of the BREEAM A rated materials in many impact categories. Impacts for the NFI products in areas of toxicity are linked to the use of the comprehensive Ecoinvent datasets. This is considered to be a source of inconsistency amongst the LCI data available across the range of insulation materials in the study and is explored further in a sensitivity analysis.

The impact of the NFI hemp/cotton product (Isonat) was found to be marginally higher than for other insulation materials in this study in several impact categories. This is largely attributable to the transportation required to take material to the current production facility in France and for the return journey to the UK for the finished product.

The sequestration of CO_2 into the NFI raw materials and its retention during the service life of these relatively long-lived insulation products was highlighted as being particularly beneficial in terms of their overall impact on Global Warming Potential (GWP_{100}).

Marginal analysis of the LCA data for the NFI products indicated several promising and feasible opportunities for continuous improvement of their environmental profiles. Many of these optimization opportunities are also the logical next steps for this nascent industry. NFIs have the potential to deliver an overall reduction in GWP_{100} because they can sequester atmospheric CO_2 in the fibre and binder materials and store it throughout the service life. Feasible improvements to the current NFIs indicate that net negative GWP balances for NFIs over a whole life cycle may be achievable. The main factors limiting the environmental performance of the *current* NFIs are inefficiencies in manufacture (consumption of fossil energy sources) and use of additives i.e. the flame retardants and polyester-based binders.

The LCA work has indicated that the main areas for near-future improvement in the environmental profiles of NFIs are:

- Replacement of the bi-component polyester binder in both of the natural fibre products is relatively straightforward using, for example, an available bi-component PLA (Polylactic acid) materials derived from crops. Trial runs using this replacement with hemp based product have demonstrated technical feasibility but economic constraints exist.

- Reduction in density of both NFI products is possible, especially with Isonat as its density is considerably higher than other insulation products (35 kg/m^3 vs 10-25kg/m^3). It should be noted that the current Isonat product offers additional functionality as a sound insulator and that this is in part a function of its higher density. It is thought that a wider range of products, including optimized ‘single-function’ products (e.g. thermal only) for the basic functional need of simple loft insulation materials as modelled here will be produced by NFI manufacturers and, like established products, take advantage of a low density to reduce resource consumption and environmental impact.

- A reduction in flame retardant use also constitutes an optimization route due to its substantial contribution to the overall environmental impact. The fibres for both NFI products are presently dipped in an aqueous solution of flame retardant and then dried. Whilst this gives a very consistent distribution it is understood that alternative application approaches e.g. a surface coating with reduced drying requirements *could* suffice to meet the necessary standards.

- Scaling up production, even using relatively unrefined non-woven textile machinery, would significantly reduce the energy requirements for plant fibre production. This energy reduction has obvious beneficial effects in terms of environmental impact reduction.

- The production of Isonat in France imposes a transportation requirement to deliver UK gown hemp fibre to Lyon and finished product back to UK for installation. The introduction of a production facility in the UK therefore would yield reductions in environmental impact, notably in reducing global warming potential.

- New technology is being patented by Plant Fibre Technology (the importers for Isonat) that involves very low energy inputs to blend fibres with thermoset binders and the fire retardants. Further development in terms of scaling up prototypes and binder development could well yield large environmental and commercial advantages through energy and material reduction.

Several of the above developments are likely to deliver benefit through reduced production costs. This could also transfer to the price of NFIs and enhance their market share. In order to gain these benefits, investment in optimising the products is required.

Targeted research funding and government procurement could strongly influence the development of NFIs in the UK, raising their environmental profile and helping to boost their market capture. The present LCA study has shown that NFIs have the potential to offer positive contributions to the issue of global warming through the sequestration of CO_2 and that UK has good potential for increased production. Focussed R&D, commercial development and promotion of optimized NFIs is recommended in order to help release this potential and contribute towards satisfying climate change goals.

Recommendations are also made for further work to improve understanding of the behaviour of insulation materials. These include:

- Studies of long-term performance of materials in use, for example the risk of sagging occurring and the implications if it does.

- Research to obtain material-specific data on the results of putting NFIs through municipal composting and Energy from Waste.

- Work to ascertain suitable mixing ratios and acceptable concentration levels of boron and its compounds for situations where large-scale, concentrated disposal of treated insulation may be contemplated through municipal composting or Energy from Waste.

TABLE OF CONTENTS

List of Figures

List of Tables

Introduction

The UK thermal insulation market in 2006 was estimated to have reached £1074.8 million at contractors' prices. Growth of the thermal insulation market has accelerated since 2002 due to changes in the Building Regulations and Government initiatives, with a peak increase of 11% in 2003. Continued strong growth is expected over the next five years with the value of the market being forecast to increase by a further 23% by 2011 (MBD, 2007).

Life Cycle Assessments (LCAs) have been conducted on many insulation materials and positive results have been used in product promotion by manufacturers. In some cases, LCA results have also been used to challenge perceptions of particular materials. One such example of this is an LCA commissioned by Rockwool to compare Rockwool stone wool insulation material with flax and paper fibre alternatives. The report concluded that the example of flax-based insulation material in the study had a poor environmental rating. This finding was used subsequently in an unsuccessful lawsuit by the insulation industry association of Germany (the FMI) against the EU Commission for endorsing the German government's decision to subsidise flax based insulation. It is clear from this example that LCA data and its interpretation can have an important role to play in evaluating the environmental 'pros and cons' of insulation products.

There is currently a lack of reliable data regarding the environmental impacts of natural fibre based insulation materials relevant to the UK. The NNFCC believes that appropriate use of non-food crops can provide a route to delivering environmental and sustainability benefits and support for the UK Government's objectives for sustainable development. Non-food crops are renewable industrial feedstocks and in many cases their production can require lower levels of energy inputs, consumption of fossil and other resources and generate fewer overall environmental impacts that alternative materials. However, these aspects need to be examined objectively and on a case-by-case basis. The overall purpose of this study, therefore, is to develop a scientific and transparent evidence base on which the environmental impact of natural fibre based insulation materials for construction can be evaluated. Natural fibre insulation materials cannot simply be presumed to have 'superior' environmental credentials.

Goal and Scope

Goal of this study

The goal of this study is to conduct a cradle to grave life cycle assessment (LCA) of natural fibre insulation (NFI) materials for construction use. The NFI products studied are still in the relatively early stages of product development. Thus, in addition to establishing their LCA profiles, a major motivation for the study was to explore the potential for ongoing improvements to these profiles that may be possible in the near future.

Existing LCA information on the current market-leading materials produced by Knauf Insulation Ltd and Rockwool was included in the study to provide guidance in the present study on the levels of environmental impact associated with well established insulation products that have been awarded an A rating in the BRE Green Guide to Specification. The co-operation of those manufacturers in supplying such information is appreciated. It is also stressed by the authors that this research and its reporting was conducted solely with regard to the objectives in the preceding paragraph and must not be construed as a direct, comparative LCA study between these different ‘types’ of insulation materials (NFIs, mineral and glass wool products). The purpose of the study is not to develop comparative public assertions between alternative products fulfilling the same function. The views and perspectives in this report on the LCA findings for the NFI materials are solely those of the authors.

The results of this project will primarily be relevant to the NNFCC and Defra and to suppliers to and developers of NFI materials. The results are expected to be of interest to various bodies in the context of sustainable development and to potential users of natural fibre products in meeting their environmental and sustainability goals.

Scope of the study

The scope of this study is a cradle to grave assessment of NFI materials following the principles of ISO 14040 series of international standards for LCA. The LCA includes each stage of the raw material collection, processing, manufacturing, maintenance and final disposal of the insulation materials chosen for the study.

Determining the environmental profile of NFIs over the various stages of their whole life cycle is undertaken to identify the key factors that give rise to significant environmental impacts and to assess opportunities for potential improvements. Consideration of the NFI results with regard to similar life cycle information available for low environmental impact conventional materials provides further important context to the NFI results. Analysis of predicted future advances in NFI product formulation and manufacture (for example, through production scale-up and the replacement of higher impact components) in consultation with their manufacturers has enabled a wider picture to be developed of how NFI products could develop in the insulation market.

The study concentrates on two NFI materials as summarized in Table 1.

Table 1 Summary of NFI products studied from information supplied from the manufacturers' data sheets.

	Natural Fibre Insulation (NFI) Materials		Conventional Insulation Materials	
Material	**Sheep wool**	**Hemp and Cotton**	**Mineral wool**	**Glass fibre**
Product name	Thermafleece	Isonat	Rockwool Rollbatt	Crown Loft Roll 44
Production Address	Mirfield, Bradford	Cours la Ville, nr. Lyon, France	PenCoed, Bridgend, Wales	Cwmbran, Torfaen, Wales
Length(mm)	1200	1200	1200	1160
Width(mm)	400,600	400,600	400,600	386,580
Thickness(mm) available	50,75,100	50,75,100	100,150,170	100,150,170, 200
Thermal Conductivity	0.039 W/m^{2}k	0.039 W/ m^{2}k	0.044 W/ m^{2}k	0.044 W/ m^{2}k
U value (W/m^{2}k)	0.16	0.16	0.16	0.16
Density (kg/m^3)	25	35	25	10
Thickness (mm) achieving U value 0.16W/m^{2}k for loft	225 (50+75+100)	225 (50+75+100)	270 (100+170)	270 (100+170)

The LCA data collection was representative of relevant geographical locations for a UK usage with current technology. Data for the NFI materials was acquired from site specific sources for natural fibres and their manufacture into insulation, from generic databases e.g. for transport, energy generation etc. and from published/available information. Aggregated system LCI data were obtained from the manufacturers of the mineral and glass wool insulation materials

Thermafleece

Second Nature UK Ltd was incorporated as a limited company by its Directors, Christine Armstrong and David Baldry in 2000. The Company officially launched Thermafleece in early 2001 with a targeted PR and marketing campaign. The launch followed two years R & D in conjunction with Leeds University. Thermafleece was developed as a renewable and sustainable insulation product to offer consumers an alternative to existing insulation products.

Second Nature invested in achieving British Board of Agrément (BBA) certification in 2002 for loft, sarking and timber frame wall applications. This allows the product to be specified when it is required to meet building control regulations.
Second Nature UK achieved The Queen's Award for Sustainable Development in 2004. The popularity of the product has also increased through projects featured on the Grand Designs TV programme having been specified by an individual or an architect due to its perceived environmental and health credentials. Thermafleece has

been purchased by a wide audience from National Trust properties, schools, universities, local authority, housing associations, visitor centres to residential premises. This has ensured that the company has grown over the last six years with turnover now reaching £1 million.

Thermafleece is sold through a network of merchants and distributors throughout the UK. These range from the largest building product suppliers in the world to small retail outlets supplying a range of natural building products, such as natural paints. The company still also sells direct to areas that are not serviced by active merchants

Second Nature UK buys time for Thermafleece's manufacture on a production facility owned by The John Cotton Group based in Mirfield, Bradford (Christine Armstrong, pers. comm.). The Group primarily produces non-woven bedding textiles such as pillows and mattress protectors. The John Cotton Group company was initially founded in 1918 and is still owned by the Cotton family with a turnover of circa £80 million. Since 1980 its home textiles sales have grown from £1m to approximately £45m today.

Farming

Upland sheep are in general grown for their meat rather than for their wool. As part of good animal husbandry however, upland sheep are sheared to maintain the health of the animal. As soon as wool is sheared on-farm, it is insured by the BWMB (The British Wool Marketing Board) against any damage or loss. Having been transported to one of the 17 wool depots across the UK, in this case Bradford, the wool passes through a series of steps before entering the manufacturing process. Wool is packed into standard sized bales. The farmer will be paid for the graded wool according to style, colours and quality of wool. It then later packed into bales suitable for local and international transportation. The bales weigh in the region of 340 kg, and are made up into sale lots of approx 8 tonnes (24 bales) of raw or "greasy" wool. The wool used in the production of Thermafleece is considered to be a 'waste' product of sheep rearing and husbandry and its production is not included within the system boundary of the study. The reasoning for this is explained in more detail within the data collection section of the study later in this document.

Scouring and rinsing

The fleece is sent to one of two scouring plants in bales from collection depots after auction in Bradford. The fleece is either sent to Haworth Scouring Plant in Bradford (see Figure 1) or Thomas Chadwick and Sons in Dewsbury. It is often dirty and contaminated with natural substances that must be removed before processing can be carried out in the scouring process.

Figure 1 View of Haworth Scouring Plant in Bradford

Wool scouring involves: blending the wool; de-dusting it; washing it in a series of 4 hot detergent bowls; followed by passage through a series of 4 rinsing tanks to remove lanolin, dirt and sweat from the greasy wool. The main product from the greasy wool contains 70% of wool worth less than £1 per kg and about 1% of lanolin which will be sold at 50 pence per kilo (Tim Whitaker, pers. comm.). Within the scouring process the fleeces receive a treatment with disodium octaborate tetrahydrate to protect it from fire and insects (Christine Armstrong, pers. comm.). It is then dried to about 20% moisture content.

The wastewater from the scouring and rinsing process passes to Yorkshire Water for effluent treatment (Neil Sagar, pers. comm.). The cleaned wool can be transferred pneumatically by overhead conveyors straight to the blending bins. Typically the bins holds 3-5 tonnes of scoured wool before packing commences (Haworth Scouring Company, 1999). For packing, there are presses which are equipped with weight-box devices to give consistent bale weights to be sent to the insulation material manufacturer - the John Cotton Group. Figure 2 shows a flow chart to represent the primary wool processing that produces the clean raw wool used in the insulation manufacture.

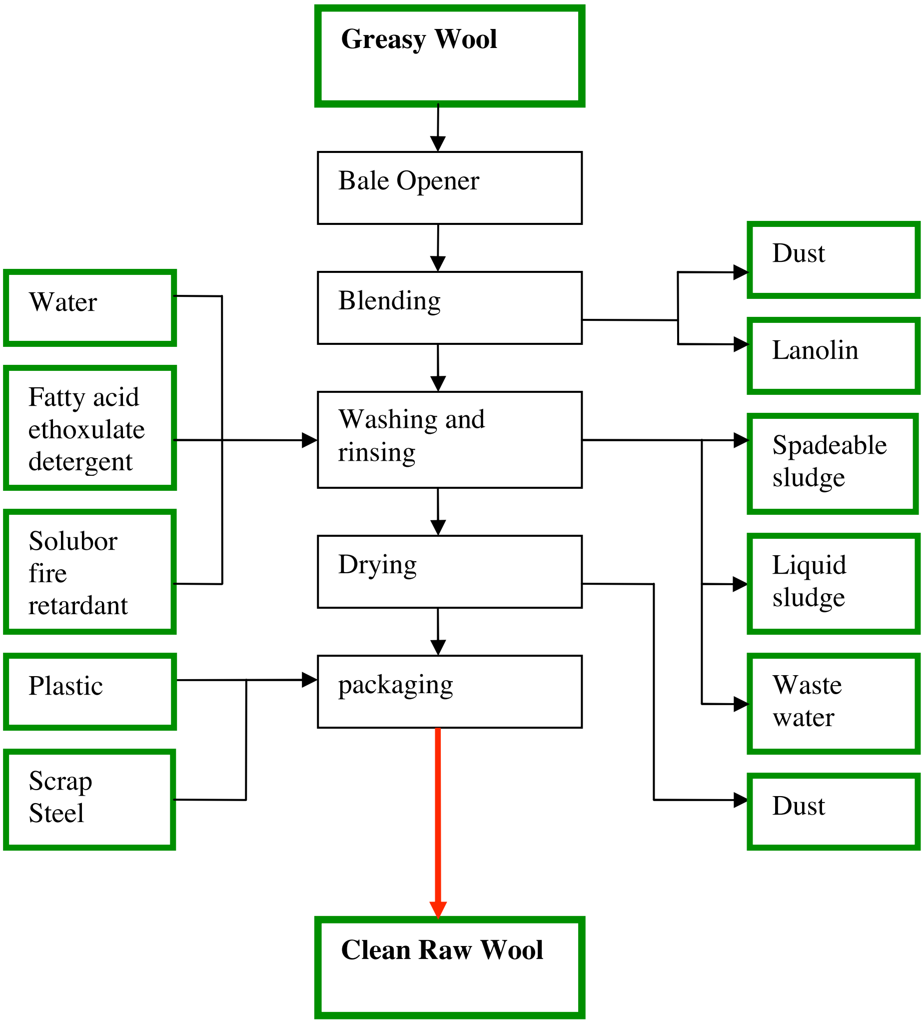


Figure 2 Flow Chart of Thermafleece Primary wool processing at Haworth Scouring

Manufacturing

The manufacture of Thermafleece involves blending, air-laying and thermal bonding processing. Thermafleece is produced by metering a blend of wool and binding fibre (a bi-component polyester), which is then formed into a three dimensional web to a specific density. This web is then held together through carding, and by use of "through air" bonding which forces the binder to cross link with the wool fibres. Any process or trimmed waste is reused in Thermafleece products. The cut and trimmed batts are then packed in polypropylene bags bearing the product name, grade, number of batts and the BBA identification mark. A flow chart of the insulation production stage is shown in Figure 3.

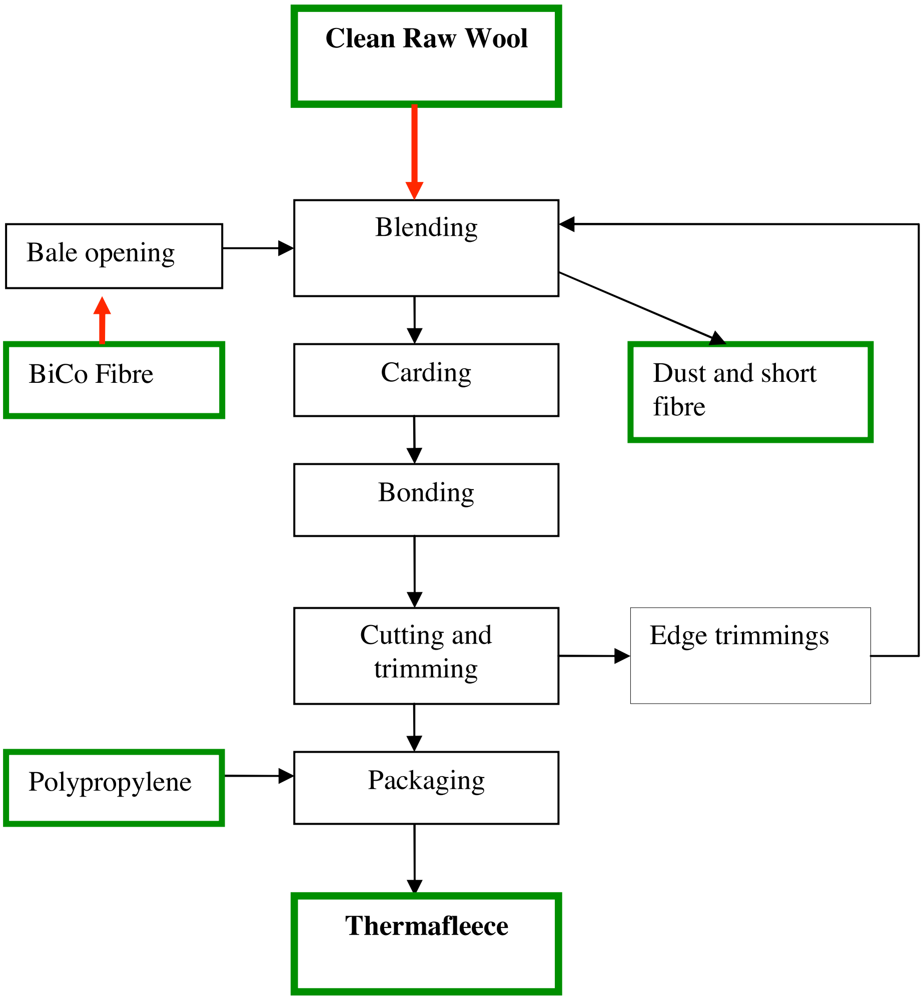


Figure 3 Flow Chart of Thermafleece Secondary Processing at John Cotton Manufacturing

Isonat

The Isonat insulation material is originally a French product based on non-woven textile technology originally produced using waste cotton from the nearby apparel industry for Saint Goban. A very similar product was then sold directly from the manufacturer, Buitex (at Cours le Ville, near Lyon) to the French construction market. The product studied in this project is a variation of this but is still produced by Buitex. It incorporates UK grown and processed hemp fibre blended with the French recovered waste cotton fibre. The use of the cotton fibre in this case was to keep the final cost down rather than for technical requirements. The final blend of materials is 35% hemp fibre, 35% recovered waste cotton fibre, 15% bi-component polyester fibre and 15% fire retardant.

The material importation into the UK is managed by Gary Newman of Plant Fibre Technologies and is sold by select building outlets such as NBT (Natural Building Technologies) and EnergyWays. The current annual sales value of Isonat is around £500k (Gary Newman, pers. comm.).

Hemp Farming

Hemp is a highly productive industrial crop and yields of up to 12 tonnes/ha have been reported in the UK though 6 tonnes/ha is more representative of current production. Hemp is fairly tolerant to pests and diseases and is self-weeding so requires relatively low agricultural inputs compared with other fibre crops. Dual variety crops of hemp can produce seeds for oils and food as well as fibre and shive. However these varieties are not generally used where fibre production is important due to the low yield and reduced quality of the fibre. As hemp grows, as with all plants, it absorbs CO_2 from the atmosphere and such carbon remains locked in the fibres throughout their use phase.

The hemp for the product is grown in the south east of England for primary processing at Hemcore, near Bishop’s Stortford, Hertfordshire. Most of the crops are currently grown within 100 km of the factory, generally in East Anglia. Though the specifics of cultivation can vary from farm to farm due to the different soil requirements and machinery available, the basic processes remain the same.

Prior to planting, land is sprayed with herbicide then the crop is sown and a fertilizer applied. After the crop has grown it is then cut and spread out in the field order to allow the crop to ret. The crop is then raked in and baled and stored on farm until it is required for delivery to the processing plant (Mike Duckett, pers. comm.). A flow chart for hemp production is given in Figure 4.

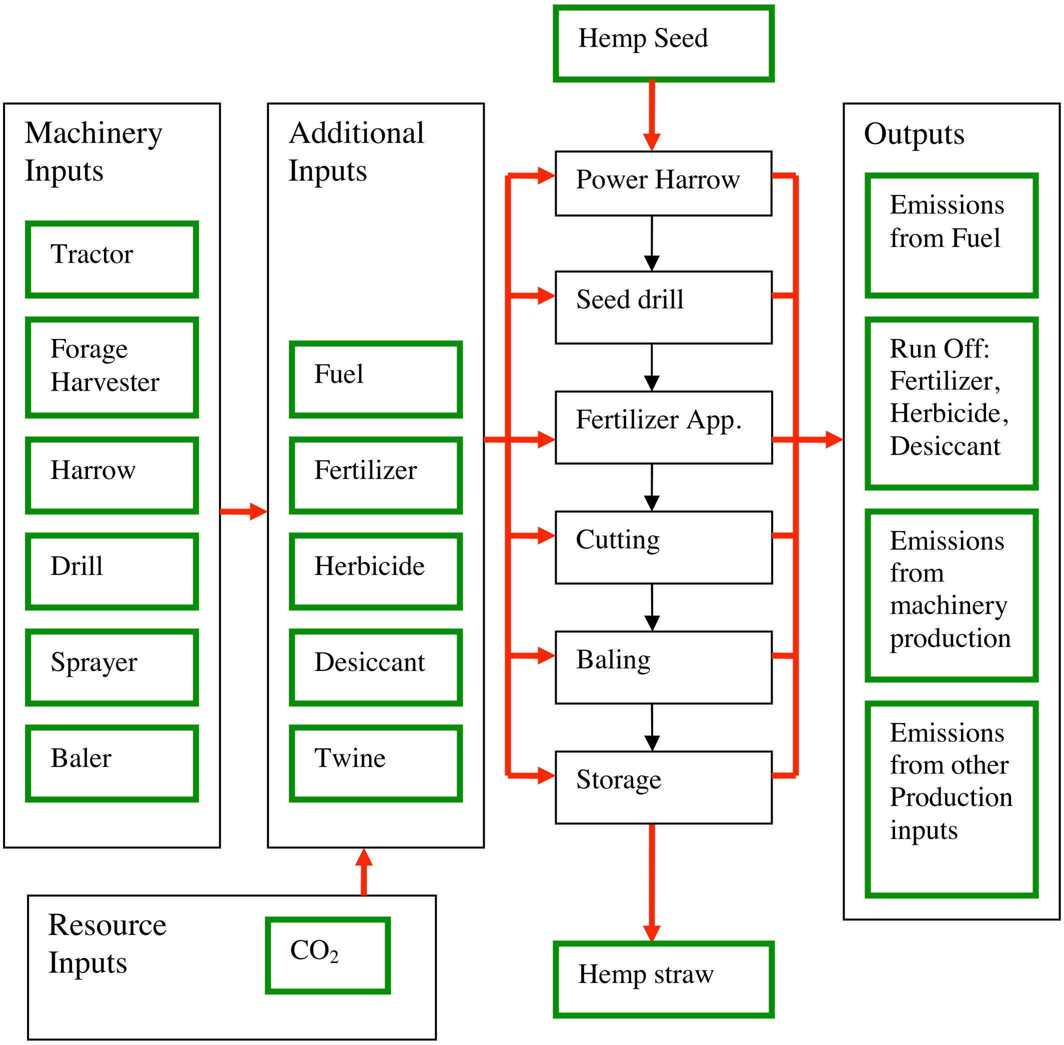


Figure 4 Flow Chart of Hemp Farming for Isonat product

Primary Processing

The primary processing carried out by Hemcore removes the shive, dust and any other major impurities from the harvested hemp straw and produces a baled fibre for transportation to France. The main unit of the processing plant is a scutcher, which loosens the fibre from the shive working on the principle that the shive will break and fall away from the fibre as it is worked between reciprocating plates that "crimp" the stem. The fibre and shive fractions represent the economic outputs of the crop and both have good current markets. The dust produced from the process is currently taken away for free and mixed with chicken manure and used as a fertilizer. In future it is likely be compacted into briquettes and sold as a bio-fuel.

The total energy used in the factory is 810 kWh at an average throughput of 1.5 tonnes/h of hemp straw, at an average of 16% moisture content. A more streamlined unit is currently being planned which would require twice the energy but would process around 7 tonnes/h of hemp straw. Figure 5 shows a flow chart for primary hemp processing that delivers the hemp fibre used in the Isonat insulation manufacture.

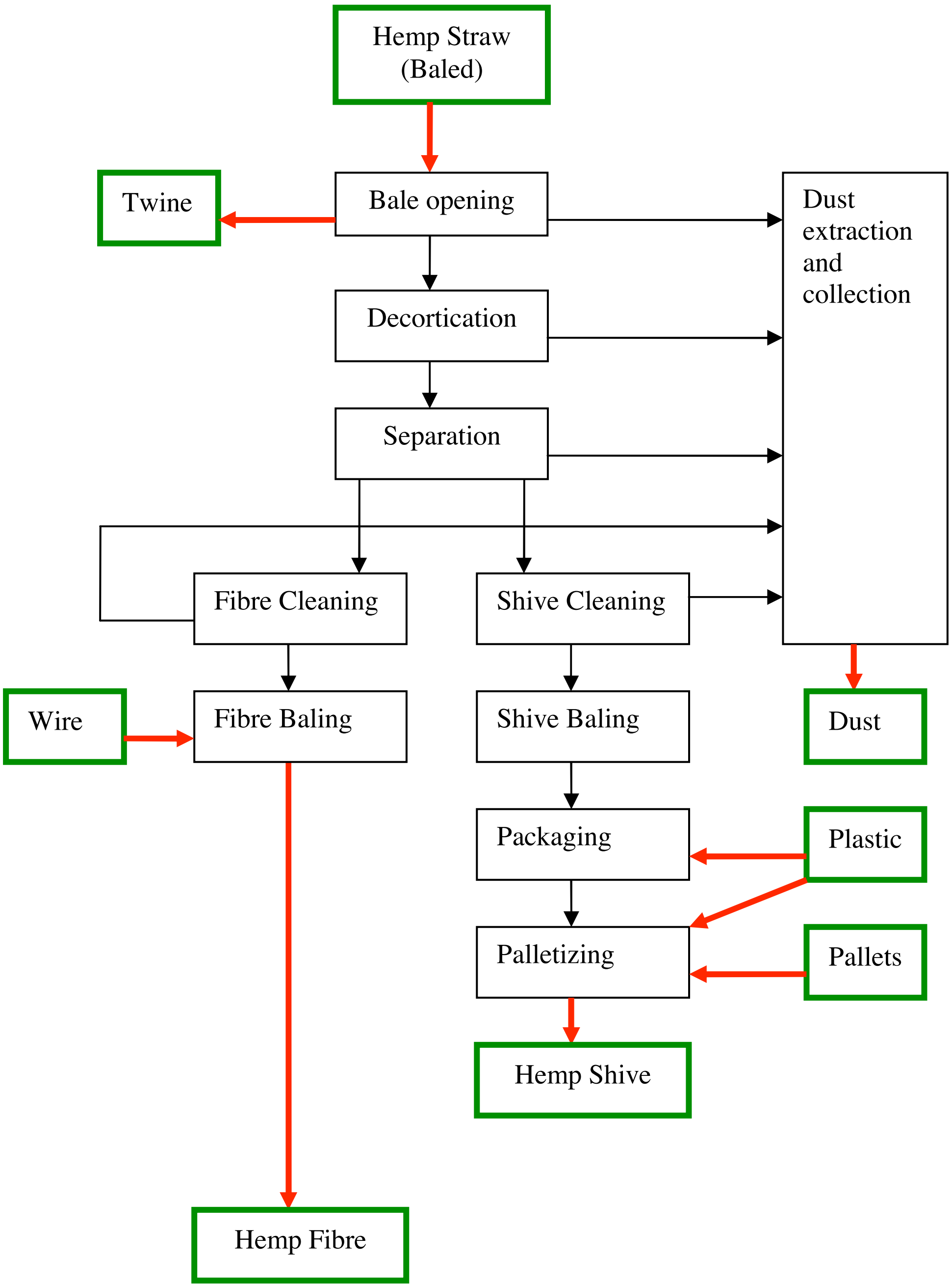


Figure 5 Flow Chart of Hemp Primary Processing at Hemcore for the Isonat product

Insulation Manufacture

At Buitex in France the fibre is blended with the recovered waste cotton fibre, a bi-component polyester fibre and a fire retardant and then air laid and bonded to produce the Isonat Product. The hemp and the recovered waste cotton fibre is initially dipped in an aqueous solution that contains the ammonium phosphate based fire retardant and then dried. The fibres are then blended with the bi-component polyester fibre and then pass through the processes of air laying, thermal bonding and trimming and packaging. The finished and packed product is transported back to the UK by road. A flow chart of the insulation production stage in France is shown in Figure 6.

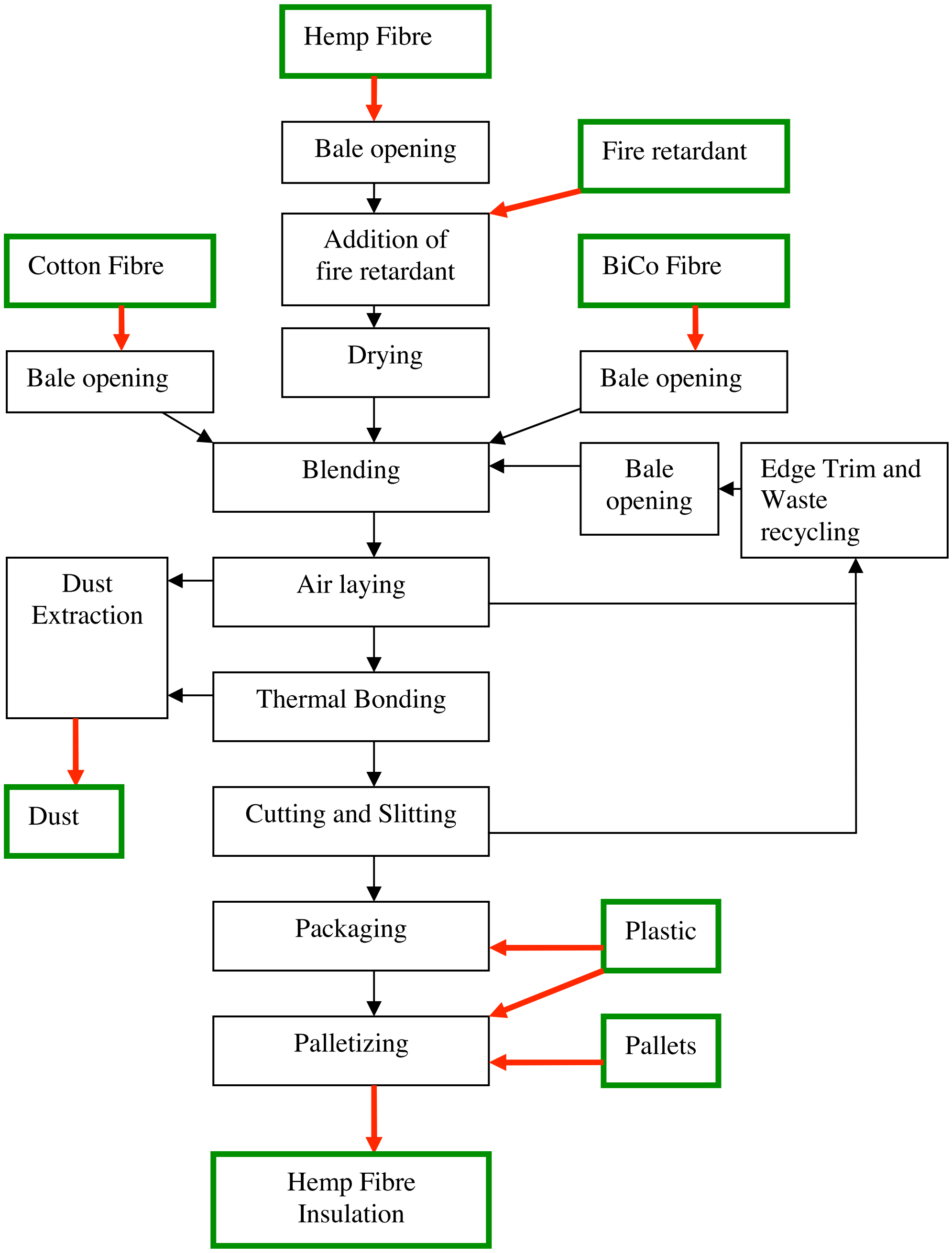


Figure 6 Flow Chart of Isonat insulation production at Buitex, France.

End of life scenarios for natural fibre insulation products

Potential end-of-life scenarios open to both the NFI products studied are shown in Figure 7. These are discussed in more detail in the scenarios section.

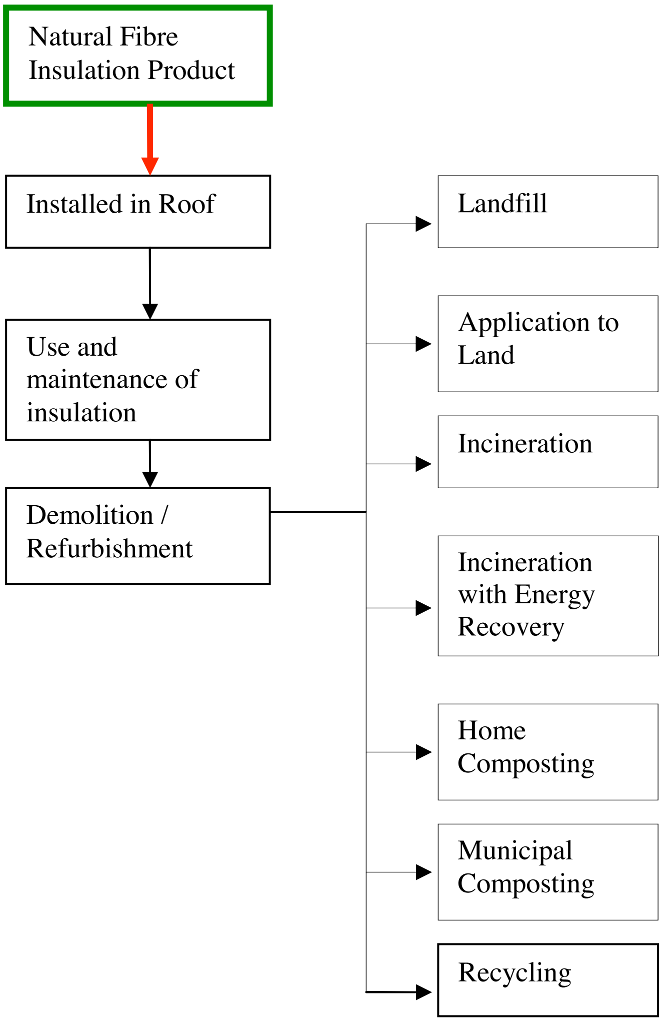


Figure 7 Flow Chart of the use and potential end of life scenarios for NFIs

Knauf

Knauf Insulation Ltd has three mineral wool insulation plants in the UK (one stone wool and two glass wool) and one extruded polystyrene plant, however this study concentrates on the Cwmbran, glass fibre plant. Knauf was founded in 1932 by the brothers Karl and Dr. Alfons N. Knauf. Today their sons and managing partners Baldwin and Nikolaus Knauf, still steer the corporation. Knauf has more than 100 production plants in over 30 countries worldwide. With an annual turnover in excess of 3 billion Euros, it is one of the largest independent European building materials groups and is the market leader in the UK for glass mineral wool. Formed in 1946 as Fibreglass Insulation it has been previously known as Pilkington Insulation and Owens Corning before the involvement of Knauf with Knauf Alcopor before finally becoming known as Knauf Insulation. In 1999 when the company was owned by Owens Corning the site produced a turnover of £75M, employed around 650 people with about 10% of their product being exported mainly to European countries. It is expected that these figures will have risen in line with the thermal insulation market growth during the period 2000 to 2006.

Glass fibre typically contains around 95% inorganic material, made from ingredients like molten sand and recycled glass (“cullet”) together with limestone and soda ash. Cullet includes bottles, windows, automotive plate glass as well as recycled off cuts from the insulation production process. This recycled fraction generally accounts for 30-60% of the raw material input though up to 80% can be used. Soda ash and limestone are generally used to lower the melting temperature. Glass fibre insulation often has the addition of boron to improve its moisture tolerance. It is also commonly made using a formaldehyde based resin as a binding agent to prevent the material from sagging during use.

Glass fibre insulation production

The production process of glass fibre insulation is very similar to mineral wool (see page 26), with the main difference being the use of a melting furnace as opposed to a cupola. Similar temperatures are achieved, generally around 1500-1550ºC. After heating the molten glass is then spun in rapidly rotating spinners shaping it into fibres. The fibres are then coated in the binder resin and then cured in a lower temperature oven at around 200ºC. The resulting wool is then cut to the required shape and packaged. This may include some compression for more efficient transportation and storage. A schematic diagram of glass wool insulation production is shown in Figure 8 and a flow diagram of the Knauf system in Figure 9.

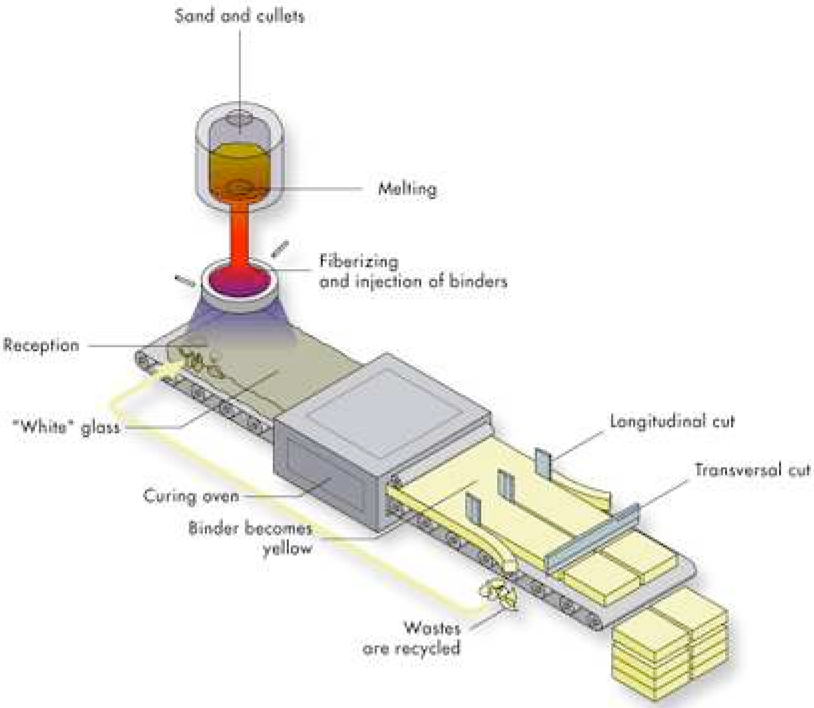


Figure 8 Diagram of glass fibre insulation production (from Eurisol UK)

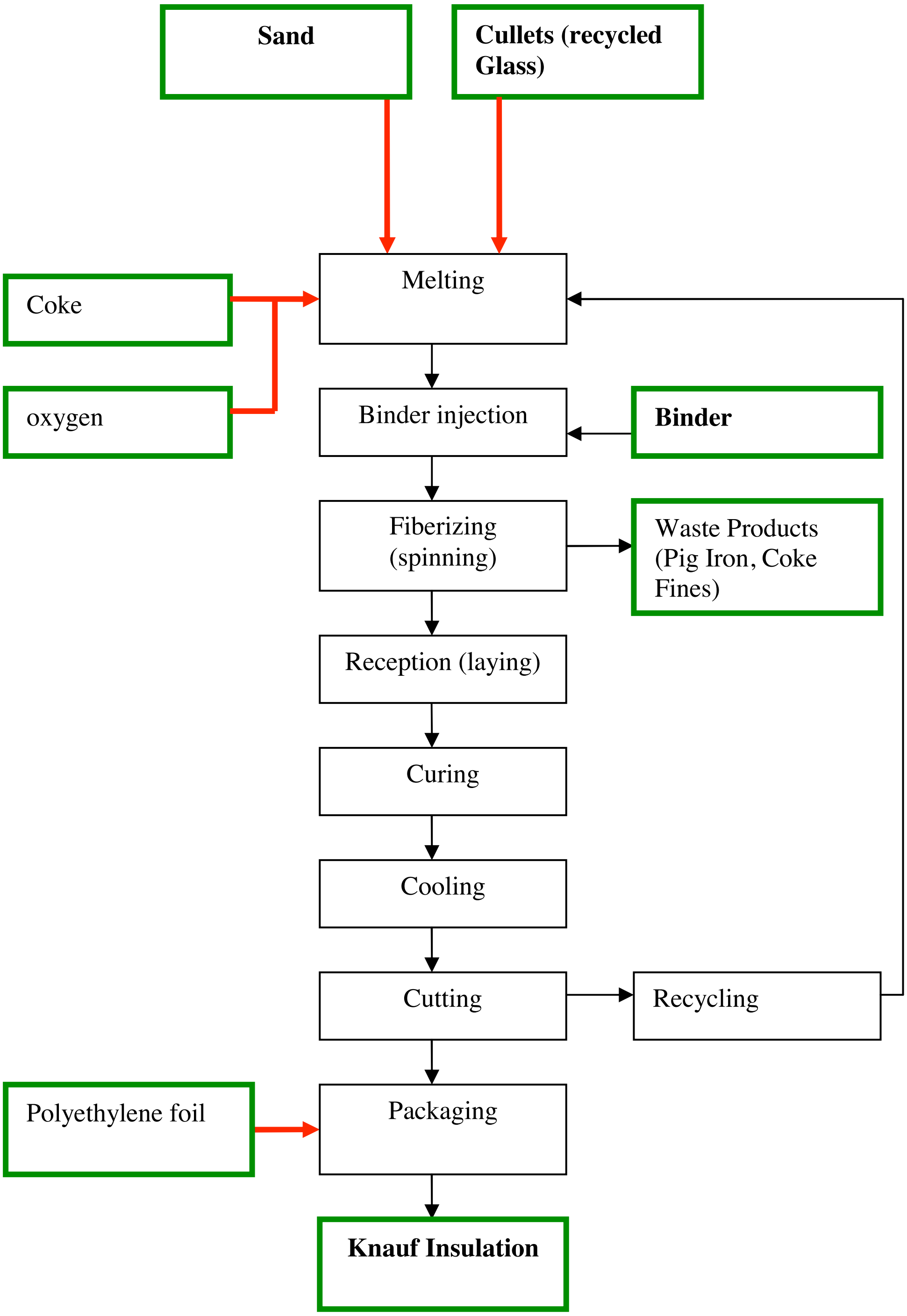


Figure 9 Flow Chart of Knauf processing (adapted from Eurisol UK (2006))

Rockwool

Rockwool Ltd has 22 factories, 19 of these are in Europe. The one UK manufacturing site is at Bridgend in south Wales, producing stone wool. Rockwool is the UK's leading manufacturer of mineral wool insulation for thermal, fire and acoustic protection. In 1999 Rockwool had a turnover of £52M and employed 460 staff (MBD 2001 market report). It is expected that these figures will have risen in line with the thermal insulation market growth during the period 2000 to 2006. The material itself is in essence a blend of various stones that are melted at high temperatures then spun, and cured into a low density fibrous mat.

Rockwool Rollbatt is a medium density insulation product of 25kg/m^3 and has a thermal conductivity of 0.044 W/mK. According to Rockwool, the Rockwool Product is 77% virgin raw material mainly in the form of diabase, Gotland stone, lime stone, cement and bauxite. The remaining 23% are classed as waste materials. In terms of the UK product the 77% virgin material is entirely UK sourced diabase rock (Nick Ralph, pers. comm.) though Rockwool also consists of a small amount of a synthetic thermosetting binder (8%) to stabilise the fibres and make them water repellent. 0.3% of mineral oil is also added to seal the surface against dust production.

Production

Rockwool is made by melting the quarried diabase rock and recycled slag briquettes with the other raw materials in a coke heater cupola furnace at 1500ºC, then drawing out the minutely thin fibres by means of a spinning unit. With the increase in coke content the swelling and the slag formation increases as coke improves the reduction kinetics of the briquettes. The molten stone cools rapidly as it is spun into fibrous Rockwool. The binder and oil are added during this process and it is subsequently reheated to around 200ºC to cure the binder and stabilise the material before it is trimmed and cut to the required size ready to be packed.

The phenol-formaldehyde binders used generate emissions including carbon monoxide, formaldehyde and phenol during the melting process and binding process respectively. The release of these into the environment is minimised through the use of an afterburner.

A flow diagram of the Rockwool process is presented in Figure 10.

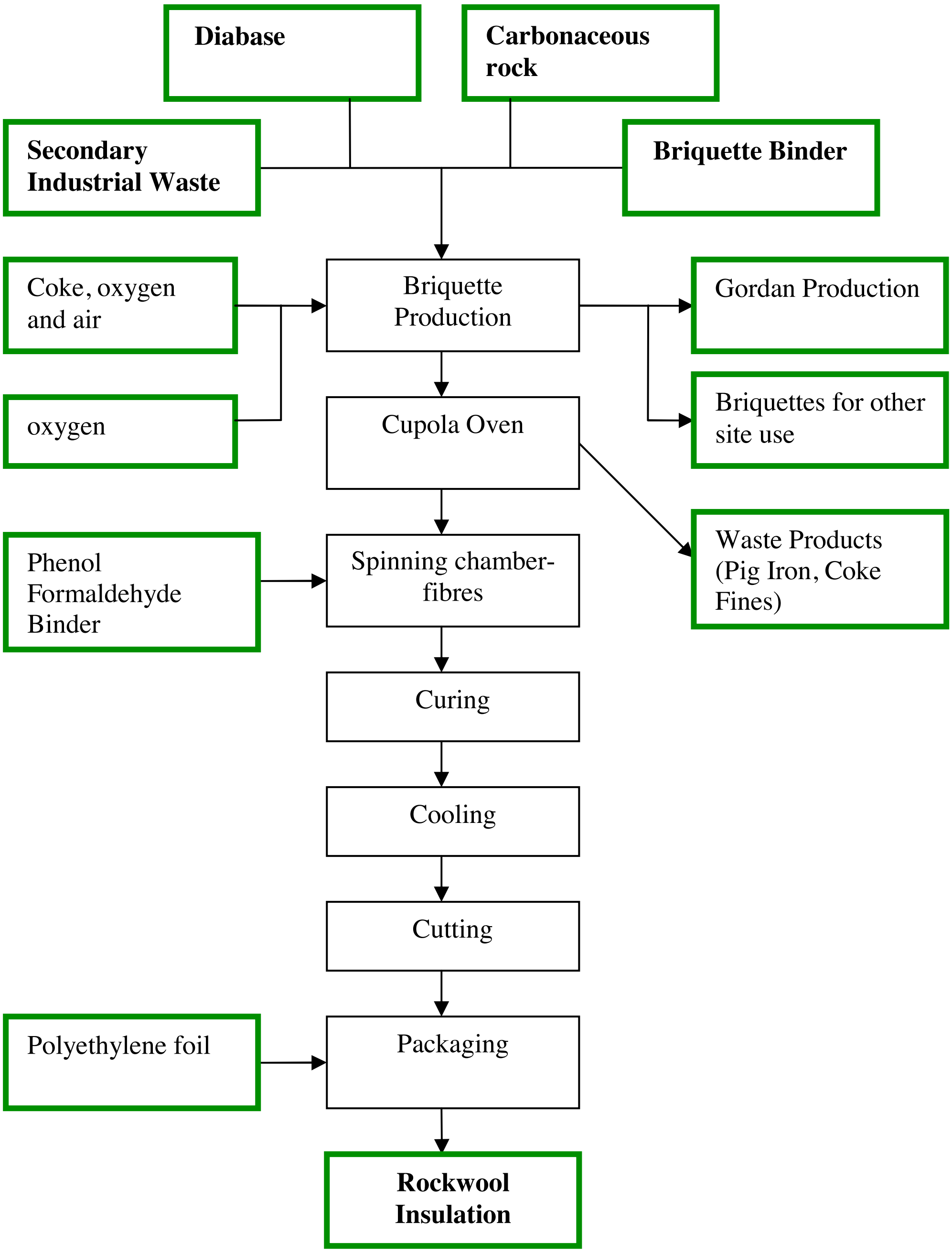


Figure 10 Flow Chart of Rockwool Processing adapted from Schmidt *et al.*, (2003)

Functions of the product systems

The insulation materials all serve the same purpose - to improve the thermal and energy efficiency of buildings. As much as 20% of a buildings' energy requirement can be saved by effective loft insulation (DTI, 2003).

This study focuses on the loft part of a domestic building. A base-line thermal conductance (U-value) of 0.16 W/m²k is used as this is the requirement stated by UK Building Regulations Document Part L (see Figure 11).

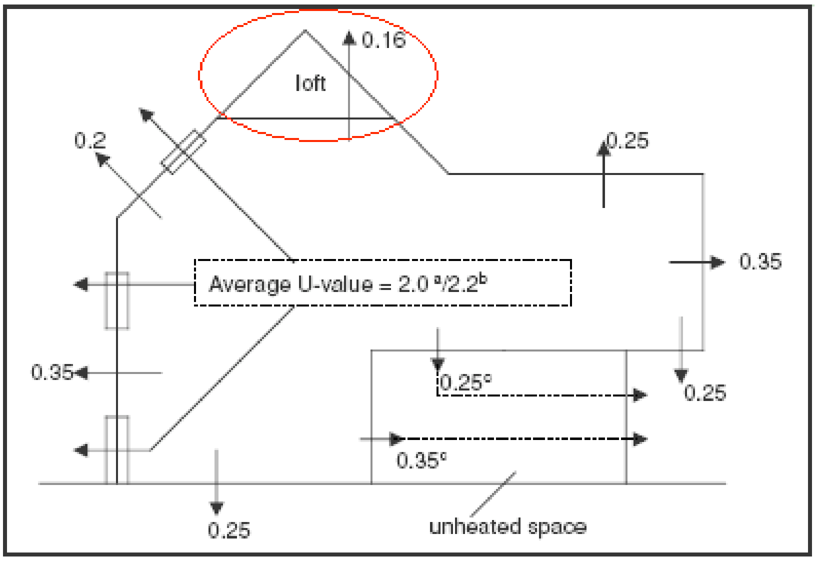


Figure 11 Summary of Elemental Method as outlined in Building Regulation (loft insulation circled)

The functional unit

The functional unit of the LCA is the quantified performance of a product system for use as an essential reference unit for the study. The amount of a given product required to perform the insulation function will depend upon the specific material characteristics such as thermal conductivity, density, etc. in order to achieve the U-value (thermal conductance) of 0.16 W/m²k within the specified application. In this case the application is modelled on the insulation of a first floor ceiling of plasterboard suspended on timber rafters into an open roof void, shown in Figure 12.

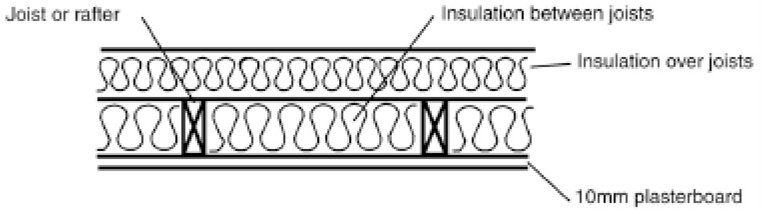


Figure 12 Pitched roof with insulation between and over ceiling joists

The functional unit concept also encompasses attributes such as durability, stability, maintenance and replacement. The time horizon for the assessment is 60 years after which it is assumed that the building is demolished or substantially changed, so that the insulation material is sent to disposal after this period of service.

The Functional Unit for the study was for the insulation of one square meter within the cold roof space of a given dwelling described as:

"The manufacture, installation, use and disposal of an insulation material for one square meter of the central part of a first floor plasterboard/timber ceiling in a UK domestic house to a U-value of 0.16 W/m²k for a period of 60 years service"

The properties and quantities required to fulfil the functional unit for each of the NFI products being examined is presented in Table 2 together with their equivalents in Knauf Crown Loft Roll 44 and Rockwool Rollbatt.

Product name	K value (w/mk)	Density kg/m^3	Thickness (mm) to achieve U-value*	Functional Unit (kg)
Isonat® Batts	**0.039**	**35**	**225**	**7.875**
Thermafleece Batts	**0.039**	**25**	**225**	**5.625**
Rockwool Rollbatt	**0.044**	**25**	**270**	**6.75**
Crown Loft Roll 44	**0.044**	**10**	**270**	**2.70**

Table 2 The reference flow for each insulation material required to meet the same functional unit of 1m^2 of loft insulation to achieve 0.16 W/m²k

Allocation procedures

Allocation is the partitioning of input or output flows of a unit process to the product system under study, as stated in ISO 14040 (BSI, 1997). Allocation procedures are needed when dealing with systems involving multiple products. Allocation within this study was conducted on a mass allocation basis, as recommended in ISO 14041 (BSI, 1998) except where stated.

Impact assessment categories and methodology

The LCA Institute of Environmental Sciences (CML) of Leiden University, NL has established the well recognised CML Impact assessment method for LCA. This is used in the present study. The CML impact categories used and their abbreviations and units used are as follows:

ADP = abiotic depletion potential (kg antimony eq.)
GWP_{100} = global warming potential, 100 year time-frame (kg CO2 eq.)
ODP = ozone layer depletion potential (kg CFC-11 eq.)

HTP = human toxicity potential (kg 1,4-dichlorobenzene eq.)
FAETP = freshwater aquatic ecotoxicity potential (kg 1,4-dichlorobenzene eq.)
TETP = terrestrial ecotoxicity potential (kg 1,4-dichlorobenzene eq.)
POCP = photochemical oxidant creation potential (kg ethylene eq.)
AP = acidification potential (kg SO2 eq.)
EP = eutrophication potential (kg PO4 eq.)

The definition of these impact categories of CML 2000 are defined by Guinée, et. al, (2001) as the following:

- **Abiotic resource depletion potential:** Non-living resources like minerals, coal or crude oil. The debate on the characterisation of depletion categories is not yet settled. In this method, characterisation is based on ultimate reserves and extraction rates. The unit of indicator result is kg of antimony equivalent.
- **Global warming potential (GWP_{100}):** This category refers to the impact of emissions on the atmosphere radiation heat adsorption, also known as greenhouse effect. Emissions are characterised as the global warming potential for a 100-year horizon. The units of indicator result for this method are kg CO2 equivalent.
- **Ozone depletion potential:** This refers to the deterioration of the stratospheric ozone layer that stops solar UV-B radiation from entering the atmosphere. The units of indicator result are kg of CFC-11 equivalent.
- **Human toxicity potential:** This category is related to the harmful effects of substances on human health. Emissions are characterised as human toxicity potential in an infinite time horizon, in kg 1,4-dichlorobenzene equivalent.
- **Ecotoxicity potential**: Ecotoxicity is divided into two categories depending on the environmental sub-compartment: freshwater aquatic ecotoxicity and terrestrial ecotoxicity. The ecotoxicity impact categories refer to the potential toxic effects of substances in the natural environment. Ecotoxicity potential is considered to happen on a global scale and an infinite time horizon. As such there is much debate over its importance and interpretation. For example a farm dependant product will often have a high apparent impact in these categories but this impact will be dispersed over a larger geographical region than a single factory outfall. Results are expressed in kg 1,4 dichlorobenzene equivalent.
- **Photochemical oxidant creation potential:** Also known as photo-oxidant formation. Sunlight in the presence of NOx causes some emissions like VOCs and CO to form chemical oxidising compounds such as ozone. Photo-oxidant formation is also known as summer smog. Characterisation results are expressed in kg ethylene equivalent.
- **Acidification potential:** This category is related to the acidification of the environment by pollutants such as SO_2 and NOx. These emissions react with water in the atmosphere and form acids that have several effects on the natural and man-made environment. Emissions are characterised as the acidification potential in kg SO_2 equivalent.
- **Eutrophication potential:** When there is an excess of nutrients in the environment changes in species distribution and excessive production of biomass may occur. This is commonly associated with loss of fertilisers from agricultural land. This impact category characterises emissions of nutrients such as N and P into kg PO_4 equivalent.

Normalisation

Although normalisation is an optional element of LCA, it can show to what extent an impact category has a significant contribution to the overall environmental problem. It compares the absolute score for impact in each specific category with the profile of an average Western European citizen's emission in that category in the given year (reference year 1995 used). Normalisation is used within the study to provide perspective on the relative scale of environmental impacts reported.

Data quality requirements

Detailed information on the processing stages was obtained in consultation with the NFI manufacturers and their suppliers (Second Nature Ltd, Isonat) and from provided information (Knauf, Rockwool). The manufacture and disposal of common elements within the ceiling/loft unit have been excluded from the assessment (e.g. ceiling joists, plasterboard). As far as possible, primary data describing the quantities of materials, co-products, by-products and wastes and emissions from current processes for NFI insulation material was used. In the case of the NFI products this was largely as disaggregated unit process data obtained in co-operation with the manufacturers and suppliers. In the case of the non-NFI materials these were aggregated cradle-to-gate whole system datasets supplied by the manufacturers.

Assumptions and Limitations

NFI systems were evaluated using the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, and decision rules on evaluating inputs and outputs and impact assessment. The following specific assumptions were used:

- The meaning of "loft" is of a ventilated space with exposed ceiling joists and no boarding.
- The dwelling is assumed to be in the city of Coventry – this location is used for all transport calculations.
- The roof is assumed to be a "cold" roof i.e. one were the insulation is laid directly between and over the ceiling joists.
- The loft ceiling joists assumed are 150 x 50 mm, evenly spaced at 400mm centres - 140 mm thick roll insulation can be fitted into the space between the joists equally and a further 100mm roll placed cross-hatched on top of the joists
- The study area is 1m square, 400mm in width between joists (different thickness may be required for different types of insulation materials)
- It is assumed that there is no need to clear spaces around cables, light fittings etc in the 1m^2 studied.
- No pins or sheets are needed.
- Service life for insulation material is 60 years with no maintenance required or loss of performance due to 'settlement' etc.

Further assumptions and limitations made regarding the individual products studied are discussed in the data collection section.

LCA Inventory Analysis

The life cycle inventory analysis is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of the product.

Data Collection Process

Primary data

Primary data regarding the NFI products studied were obtained through consultation with manufacturers. An initial questionnaire was sent out to NFI manufacturers concerning insulation production process with data on: proportion and origins of main raw materials and co-products, by-products, transport types and distance, energy used, manufacturing process; location of production and manufacturing and dimensions of the products in available sizes. The data collection process is summarised below.

- **Thermafleece** – Primary data regarding the Thermafleece product were obtained from factory visits and from Christine Amstrong at Second Nature Ltd, Neil Sagar and Tim Whitaker at Haworth Scouring Company and Carl Rushton at John Cotton Manufacturing.
- **Isonat** – Primary data regarding the Isonat product were obtained from factory visits and from Gary Newman at Plant Fibre Technologies, Jean Pierre Buiton at Buitex, and Mike Duckett at Hemcore.
- **Rockwool** – Primary date regarding the Rockwool RollBatt product were based on aggregated data provided by Nick Ralph of Rockwool (GB) Ltd, and from the report by Anders Schmidt *et al* (2003)
- **Knauf** – Primary data regarding the Knauf Crown Loft Roll 44 product were based on aggregated data of several factories provided by Stephen Wise of Knauf Insulation (UK)

Secondary data

It was not possible within the scope or resources of the study to acquire site-specific primary data for all unit processes involved within the system boundary for the products. As such, generic data and on occasion surrogates within recognised databases were used and referenced accordingly. Secondary data from databases (BUWAL, Ecoinvent) was examined for its structure and relevance to the products and processes under examination. The BUWAL 250 database was used for transport and disposal processes and Ecoinvent data was used for all other processes and materials. Both are internationally recognised datasets and represent mainly EU or UK specific cases. A separate independent dataset was used for a potential Polylactic acid (PLA) based binder. This database was developed at Imperial College London from primary PLA manufacture data.

Thermafleece

Description of the inventory for Thermafleece is given below.

Sheep Farming

A ***mass allocation*** was not used for the fleece supplied from upland sheep farming with one important exception (explained below). This is because the fleece used for insulation is categorised as a waste by-product from the main function of sheep farming for meat production and it is of extremely low economic value or possibly even of negative 'value' due to the costs of regulated disposal (Williams *et al*, 2006; consultation with farmers supplying wool for Thermafleece manufacture). Therefore, allocation of upstream interventions between the high value meat and livestock breeding outputs and the low or negative wool value was implemented on an ***economic allocation*** basis. The sheep wool was assigned a zero allocation and the meat/breeding stock maintenance component a 100% allocation of the ***upstream*** interventions of sheep farming.

The exception to this economic allocation basis concerns the tracking of carbon from the raw material production stage (agriculture) and onward throughout the life cycle. We have taken the view that it is informative to be able to track the accumulation and subsequent release of carbon (in its various forms e.g. CO_2, polymeric, CH_4) across the life cycle of NFI products in order to be able to identify those stages where such carbon impacts positively or negatively on GWP_{100}.

A limitation of economic allocation approaches in LCA (which otherwise represent 'cause and effect' for techno-economic processes) is that the economic values of products and co- or by-products are not directly coupled to their specific carbon contents and so allocation on economic value of these products distorts an accurate representation of the stoichometric 'carbon budget' when a carbon containing material such as sheep wool is formed, transformed into product/by- and co-products and is finally disposed. Yet it is this stoichometric carbon content that, as sequestration from the atmosphere or release back to the environment (for example on disposal), is responsible for the degree of GWP_{100} that occurs.

In view of this, we have maintained tracking of carbon atoms on a purely stoichiometric basis (equivalent to mass allocation) in order to maintain an accurate 'carbon budget' over the life cycle. We consider that this procedure facilitates observation of the consequences of carbon movement and contribution to GWP_{100} from natural fibre agriculture and subsequently through the whole life cycle whilst economic allocation accurately reflects the 'cause and effect' driver for all other material and energy inputs to (e.g. feed, fertilizers) and outputs from (e.g. methane) the agricultural system.

Scouring

0.25 kWh of electricity, 0.8 kWh of gas and 5 litres of water per kilo of greasy wool is used during the scouring and rinsing process (Tim Whitaker, pers. comm.). Raw wool is washed or scoured in tanks filled with hot water containing detergent to remove contaminants. The raw wool is passed through the first scouring bowl, then squeezed between rollers and carried into the 2nd bowl. It passes through four bowls until eventually it is rinsed in another bank of four bowls containing clean water. The Haworth facility can process 3.5 tonnes an hour of crossbred wool (Haworth Scouring Company, 1999).

Bonding

Energy used during the thermal bonding stage is an estimated 0.58 kWh of electricity and 0.94 kWh of gas per kg of Thermafleece (Carl Rushton, pers. comm.).

Summary of Thermafleece data

A summary of data for the materials and processes (Table 3) and transport (Table 4) for the Thermafleece product is presented below.

Table 3 Materials and processes in the Thermafleece system - functional unit basis

Process name	Value	Unit	Processes / materials involved	Value	Unit
Manufactured Thermafleece	1	kg	Clean, Raw Wool	0.85	kg
			PP packaging film	0.0286	kg
			Bi component Polyester	0.15	kg
			Electricity/heat		
			Heat gas	0.94	kWh
			Electricity, medium voltage, production GB	0.58	kWh
			Emissions to air		
			Particulates, SPM	0.1	kg
			Waste to treatment		
			Plastic waste	0.0286	kg
Clean, Raw Wool	1	kg	Scouring, Rinsing and Cleaning	1	kg
			Polypropylene, granulate	0.00084	kg
			Extrusion, plastic film	0.00084	kg
			Steel 50% scrap	0.004	kg
			Greasy wool	1.15	kg
			Waste to treatment		
			Plastic waste	0.00084	kg
			Steel waste	0.004	kg
Bi component Polyester	1	kg	Polyethylene terephthalate, granulate, amorphous	0.5	kg
			Polyethylene terephthalate, granulate, bottle grade	0.5	kg
			Extrusion	1.5	kg
Scouring, Rinsing and Cleaning	1	kg	Electricity, medium voltage, production GB	0.288	kWh
			Heat gas	0.92	kWh
			Fatty alcohol sulfonate, petrochemical	0.01	kg
			Borax, anhydrous, powder	0.085	kg
			Resource depletion		
			Water, process, drinking	7.14	kg
Greasy wool	1	kg	Polyethylene, HDPE, granulate	0.002	kg
			Extrusion, plastic film	0.002	kg
			Emissions to air		
			Carbon dioxide (50% C content of greasy wool)	-1.83	kg
			Waste to treatment		
			Plastic waste	0.002	kg

Table 4 Transport data in the Thermafleece system - functional unit basis

Process name	Value	Unit	Processes / materials involved	Value	Unit
Transport Clean Raw Wool to Factory	1	p	Truck 16t	0.037	tkm
Transport Fleece to Scouring	1	p	Truck 16t	1.19	tkm
Transport of Binder	1	p	Sea ship	3.61	tkm
			Truck 28t	0.47	tkm
Transport of PE fibre	1	p	Sea ship	14.07	tkm
Transport thermafleece	1	p	Truck 16t	1.28	tkm
Scouring, Rinsing and Cleaning	1	p	Truck 28t	0.00001	tkm

Isonat

Description of the inventory for Isonat is given below. The carbon content of hemp fibre is taken as 45.7% on a dry mass basis (Energy research Centre of the Netherlands, 2007) and that of the recovered waste cotton fibre as 40%. Allocation of carbon content in hemp fibre and recovered waste cotton fibre in the Isonat product was made on the same basis as for wool fibre (stoichometric 'carbon budget) to facilitate observation of the consequences of carbon movement and contribution to GWP_{100} from natural fibre agriculture and subsequently through the whole life cycle.

Hemp Farming

The hemp for the product is grown in the south east of England for primary processing at Hemcore, near Bishop's Stortford, Hertfordshire. 70% of the crops are currently grown within 100 km of the factory, generally in East Anglia, whereas the final 30% is grown an average of 190 km away elsewhere across the UK. The farming of UK hemp requires the following stages, this methodology has been built up as an average process utilized by the majority of the supplying farms.

After the previous crop has been harvested the field is de-cultivated with a 4m wide deep cultivator. Prior to sowing the ground is then sprayed with 3 l/ha of Round Up, a glyphosate based contact herbicide, and a foaming agent from a 24 m wide boom sprayer. The crop is then sown using a 4m wide combination drill and then rolled with a 9 m wide roller. The crop is then fertilized with NPK fertilizer with a formulation that provides on average 100 kgN/ha, 30 kgP/ha and 30 kgK/ha from a 24 m wide boom sprayer and left to grow. The amount of P and K fertilizer varies between farms but in general usage is very low, just sufficient to maintain levels in soil. Depending on soil type none may be used for at least three years (Mike Duckett pers. Comm.). At the end of the growing season the crop is then harvested using a 6m wide forage harvester and then tedded, i.e. spread out to dew ret, with a 6 m wide tedder. The retted crop is then raked up, square baled (both 6m wide) and then stored on farm before being transported to the factory by lorry or by tractor and trailer in cases where the farm is particularly near the factory. The 550 kg delivered bales require 289 g of polyester twine. As an average and reliable figure each farm yields around 6 tonne dry straw per ha (Mike Duckett pers. Comm.).

It was found that there were some discrepancies between the best available secondary data used and the actual on farm processes. For example many of the Ecoinvent farm processes based on Swiss farming methods assume smaller machinery than that used on the comparatively large scale hemp farming in East Anglia. For example, the de-cultivating process used assumes a 2.5 m wide cultivator rather than a 4m wide cultivator. The farming processes were used unadjusted as farming in general has a low impact on the overall product LCA.

Primary Processing

The primary processing carried out by Hemcore removes the shive, dust and any other major impurities from the harvested hemp straw and produces a baled fibre for transporting to France. This process involves a bale opener followed by a schutcher type decorticator and separator, from this the fibre is air cleaned to remove any further dust. The clean fibre is then baled using 774 g of wire per 100 kg bale and sold to Buitex. It is transported 872 km by road and 40 km by ferry across the English Channel, to Buitex in Cours le Ville, France in 25 ton trucks.

The shive fraction is sold once bagged and put on pallets. The dust is currently taken away and mixed with chicken manure and used as a fertilizer. In the future it is possible that it could be compacted into briquettes and sold as a fuel source. The total energy used in the factory is 810 kWh at an average throughput of 1.5 ton/h of hemp straw (at an average of 16% mc). This varies dependant on crop quality. During the current process there are no major components replaced on a regular basis, only the occasional knife sharpening.

Insulation Manufacture

At Buitex the fibre is blended with the recovered waste cotton fibre, a bi-component polyester fibre and a fire retardant and is then air laid and bonded to produce the Isonat product.

The UK hemp fibre is initially dipped in a solution that contains the fire retardant and then dried. The fire retardant is an ammonium phosphate based material purchased from THOR in Germany. The material is most likely to contain mono and poly phosphates but the exact European formulation could not be obtained (Robert Nelson (Technical director at THOR UK, pers. Comm.). The fibre is then blended with the recycled cotton fibre and the bi-component polyester fibre. The blended fibre then goes through the processed of air laying, thermal bonding and then trimming and packaging, with the waste trimmings re-blended in to the blending process.

The cotton fibre is purchased from the local textiles industry and transported around 5 km in the form of wire bound 100 kg bales. The bi-component polyester is currently purchased from Korea, where it is shipped approximately 25,000 km to Marseille and transported 400 km to Cours la Ville by truck. It is packaged with one wrap of 100 g/m^2 of PP per bale. The 0.56 g of PP/kg of fibre is shredded and used in other products within the factory. The 5% by weight of dust that is removed during the manufacture is compacted into briquettes and given away for domestic heating. The final product is packaged using 3.5 kg/m^2 of finished product of PLBD plastic wrap and placed on wooden pallets before being shipped back to the UK on 25 tonne trucks.

The initial drying of the fibre after the fire retardant is added and the thermal bonding are possibly the most energy intensive parts of the process as together they require 2.32 kWh/kg of finished product of piped gas, whereas the whole factory uses only 0.15 kWh/kg of finished product of national grid electricity. There is generally no replacement of any parts required.

Summary of Input data

A summary of all input data for the materials and processes (Table 5) and transport (Table 6) for the Isonat product is presented below.

Table 5 Materials and processes in the Isonat system studied - functional unit basis

Process name	Value	Unit	processes/materials involved	Value	Unit
Isonat production at Buitex, France	1	kg	Hemcore Hemp fibre production	0.35	kg
			Cotton fibres recycled	0.35	kg
			Bi component Polyester	0.15	kg
			Flame retardant (ammonium phosphate surrogate used)	0.15	kg
			Paper, unbleached	0.00001	kg
			Polyethylene, HDPE, granulate	0.028571	kg
			Extrusion, plastic film	0.028571	kg
			Electricity/heat		
			Electricity, high voltage, production France	0.15	kWh
			Heat gas	2.32	kWh
			Waste to treatment		
			Steel waste	0.008463	kg
			Packaging waste, paper and board	0.00001	kg
			Plastic waste	0.00084	kg
			Plastic waste	0.028571	kg
Bi component Polyester	1	kg	Polyethylene terephthalate, granulate, amorphous	0.5	kg
			Polyethylene terephthalate, granulate, bottle grade	0.5	kg
			Extrusion	1.5	kg
			Polypropylene, granulate,	0.00084	kg
			Extrusion, plastic film	0.00086	kg
Cotton fibres recycled	1	kg	**Electricity/heat**		
			Electricity, medium voltage, production France	0.0125	MJ
			Heat diesel	2.5	MJ
			ECCS steel 50% scrap	0.004232	kg
			Emissions to Air		
			Carbon dioxide	-1.47	kg
Hemcore Hemp fibre production (29%)	1	kg	Hemcore Farming hemp straw production	3.448	kg
Shive co-product (66.7%)	2.3	kg	steel 50% scrap	0.004232	kg
Dust co-product (4.3%)	0.15	kg	Electricity, medium voltage, GB	1.862	kWh
			Polyethylene, HDPE,	0.002	kg
(% by mass)					
			Waste to treatment		
			Plastic waste	0.000173	kg

Hemcore Farming hemp straw production	6	ton	Tillage, rotary cultivator	1	ha
			Application of plant protection products by field sprayer	0.625	ha
			Sowing	1	ha
			Haying, by rotary tedder	1	ha
			Haying, by rotary tedder	1	ha
			Baling	8.57	p
			Combine harvesting	1	ha
			Tillage, rolling	1	ha
			Ammonium sulphate, as N, at regional storehouse	100	kg
			Ammonium nitrate phosphate, as P2O5	30	kg
			Potassium chloride, as K2O	30	kg
			Polyethylene, LDPE, granulate	0.000173	kg
			Emissions to air		
			Carbon dioxide	-10.054	ton

Table 6 Transport data in the Isonat system - functional unit basis

Process name	Value	Unit	Processes / materials involved	Value	Unit
Transport - Cotton fibre to Buitex	1	p	Truck 28t	0.0175	tkm
Transport - fire retardant to Buitex	1	p	Truck 28t	0.07	tkm
Transport - hemp fibre to Buitex	1	p	Truck 28t	3.052	tkm
Transport - hemp straw bales to Hemcore	1	p	Sea ship	0.14	tkm
			Truck 28t	0.35	tkm
Transport - Isonat to Coventry	1	p	Sea ship	0.35	tkm
			Truck 28t	8.75	tkm
Transport - PE fibre to Buitex	1	p	Truck 28t	1.4	tkm
			Sea ship	32.8	tkm
Transport - waste wire from Buitex	1	p	Truck 28t	1.75	kgkm

Knauf

Available data for the Knauf Crown Loft Roll 44 product was provided as an aggregated system dataset for the production of 1000 kg of the glass wool insulation LD (packed) based on UK production in 2005. Consultation with the LCA practitioner was also undertaken.

Rockwool

Available data for the Rockwool Rollbatt product was provided as an aggregated system dataset, complemented with the report of a study conducted by dk-Teknik Energy & Environment on behalf of Rockwool (Schmidt *et al*, 2003).

Life Cycle Impact Assessment (LCIA)

The potentially diverse end-of-life scenarios for all the insulation products (especially considering the 60 year expected service life) make direct comparisons difficult. Thus, for reasons of simplicity, the results from the LCA are first considered for the ***cradle to installation*** part of the analysis only, i.e. the whole production process and transport functions used for each product studied from raw materials to delivery to installation in the dwelling. This is a natural and equal cut off point for all the products studied and is not thought to introduce any bias. The results of the full ***cradle to grave*** analysis are presented and discussed later in this section.

Generalised results

The results on a ***cradle to installation*** basis for the two NFI products (together with those for the glass and mineral wool materials studied basis are presented in Figure 13 using the CML impact assessment method.

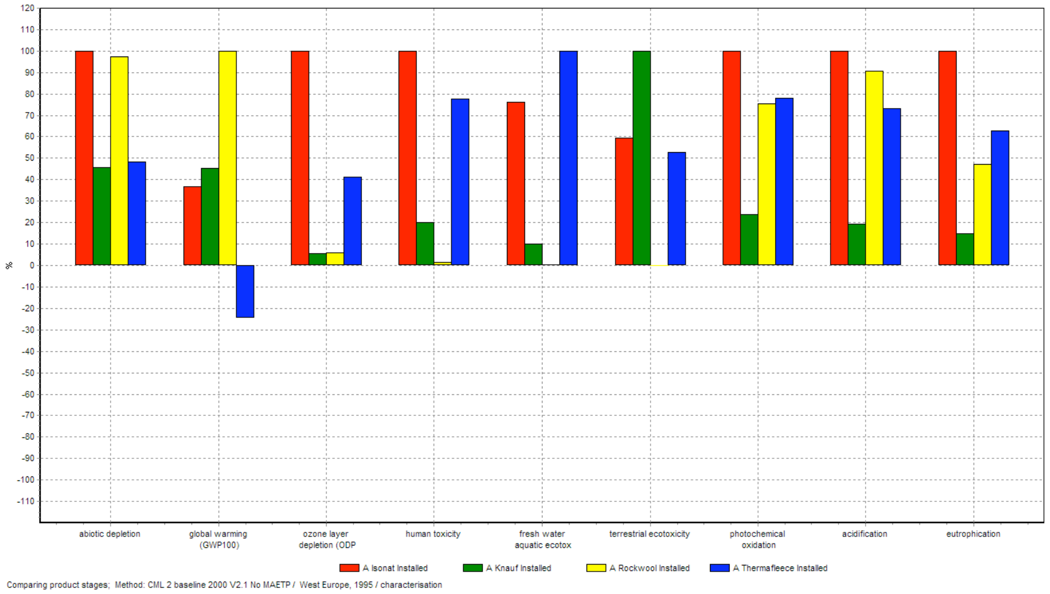


Figure 13 Environmental impact for NFI products and conventional insulation materials (CML baseline)

In general terms, Figure 13 indicates that the impact of Isonat tends to be greater than that of Thermafleece in most impact categories. This is a result of the greater density of Isonat, its longer transportation chain and its fire retardant treatment process. Of particular interest is the finding that Thermafleece offers a net negative GWP_{100} profile at this stage of the life cycle. This suggests that, up to the point of its installation and use, its material composition sequesters more $CO_{2\ eq}$ than has been released by the energy and materials consumed in its processing and transportation.

The results for the mineral and glass wool datasets when applied to the Functional Unit of this study suggest that the low density of the Knauf Crown Loft Roll 44 (~10 kg/m^3, the lowest of all the materials examined) enables it to exhibit a somewhat lower impact than that of the Rockwool Rollbatt. Furthermore, across the range of environmental impact categories it is observed that the NFI materials did not exhibit consistently lower levels of environmental impact than the glass or mineral wool products. Equally, NFI materials did not exhibit a consistently poorer performance across the environmental categories. We conclude from these results that the environmental profiles of these NFI products generally falls within the range that is exhibited by existing insulation products rated "A" in the BRE Green Guide to Specification. The net negative GWP_{100} of Thermafleece is a possible exception to this general picture in that it suggests that its material composition offers a potential mitigating effect on this particular impact category through the manufacture and use phase of the life cycle. This is discussed further in relation to the inclusion of disposal phase and NFI product optimisation options.

The relative importance of the impacts in the different impact categories following the normalisation procedure is indicated in Figure 14.

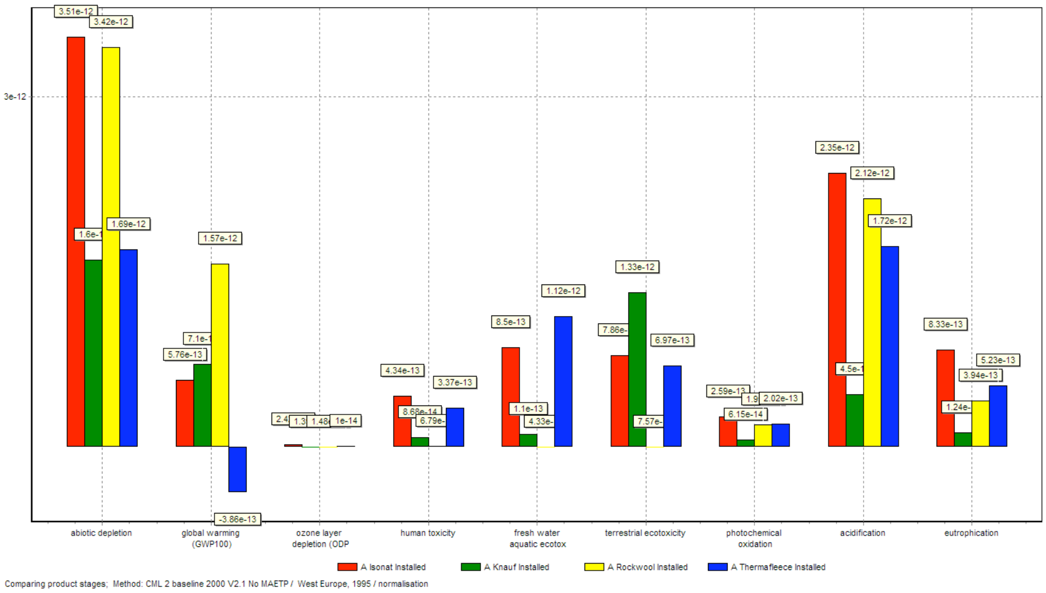


Figure 14 Normalised environmental impact of NFI materials and conventional insulation materials (CML baseline)

The normalised data more clearly indicates the importance of the impacts over these stages of the life cycle relative to the impacts in the other impact categories. This means that, where all materials have low impacts in a category, the significance of the greatest of these impacts is not mistakenly viewed as equal to a high impact in another category. For example, the impact of the Isonat product in ozone layer depletion (ODP) could be perceived as an important finding based on the non-normalised representation in Figure 13. In Figure 14 it can be seen, perhaps more realistically, that the impacts in this category overall are of relatively low significance when compared with the ozone-depletion impact of "the average West European citizen".

The results from the normalised data also emphasize the lack of a clear "winner", as each NFI product exhibits some relatively good and some relatively poor performance depending upon the impact category in question. The relatively more important ***high*** impacts are listed below:

Thermafleece	Acidification and Fresh Water Aquatic Ecotox
Isonat	Abiotic Depletion, Acidification and Fresh Water Aquatic Ecotox
Knauf	Terestial Ecotoxicity, Abiotic Depletion and GWP_{100}
Rockwool	Abiotic Depletion, Acidification and GWP_{100}

The NFI results are derived from disaggregated datasets and those for the glass and mineral wood insulation materials were calculated in this study from aggregated data sets. It is thus only possible to undertake marginal analysis for the NFI materials and this is done in a later section of this report (p53 on). The commentary below is restricted to those issues and the level of detail that we believe is justified by the data quality and resolution available.

The low density of the Knauf product is likely an important factor in generating its relatively low environmental impact across the categories (it had the lowest impact of all materials examined in 5 of the 9 categories, albeit in some cases by a very small margin). The Isonat product, for example, is nearly 50% denser than the Thermafleece and Rockwool products, with the Knauf product barely more than one quarter (2/7ths) the density of Isonat. This low density means that the product requires less material and thus provides a simple and effective method of reducing the product's environmental impact.

The present study has assumed that all the different insulation products will perform at their design level over the 60 year service life modelled. This assumption is made against a significant shortage of independent, published data on the long-term insulation performance, potential to 'sag' etc available for any insulation products. Peuportier (2001) states, for example, that a 25% variation of the conductivity, i.e. from 0.04 to 0.05 W/(m K), led to a 2.4% increase of the heating load (equivalent to more than the energy needed to produce the insulation) and a 2.3% increase of the overall CO_2 emissions over the 80 year period considered. Future studies on long-term insulation behaviour would be most welcome.

CO_2 sequestration of natural fibres

GWP_{100} impacts in general stem from the use of carbon emitting fuel sources and are thus strongly linked with the energy consumption of most products. It is noted, however, that although the GWP_{100} reported for the natural fibre products is lower than that of the conventional materials, the processing energy requirements may be higher

For the natural fibres, this lack of a simple coupling of energy consumption to make a product with its Global Warming Potential results from the removal of CO_2 from the atmosphere via photosynthesis and its conversion in the plant into the ligno-cellulosic fibres and other components of the plant body. In the case of sheep wool, the carbon sequestered by plants goes through a further conversion step in the animal into the proteins of wool. Thus, the 'sequestration' of atmospheric CO_2 into the basic raw material in the natural fibre products exerts a strong 'negative' GWP_{100} effect (removal of CO_2 from the atmosphere) and, in many cases, this is of sufficient magnitude to more than counterbalance the GWP_{100} emissions from energy consumption in the manufacture of the natural fibre product.

Two critical components in assessing the overall GWP_{100} balance over the life cycle of natural fibre materials and products are 1) their longevity in use (in this case assumed to be 60 years in a building) and 2) the end-of-life disposal method. It is in the disposal phase of the life cycle that some, or all, of the carbon 'sequestered' into the product may be returned to atmosphere, this being highly dependent upon the specific disposal route followed. This is reported in the End of Life section that follows.

End of life scenarios

There are many potential end of life scenarios for each of the studied products after the 60 year in-use period. During this assumed 60 year in-use period it is highly likely that legislation and practice surrounding the disposal of construction waste will change and as such it is very difficult to assume any one particular scenario will be used (Tony Roberts, Environment Agency Wales, Pers. comm.). A range of potential scenarios for NFIs are displayed in Figure 15, those studied are shown in blue. These were to chosen primarily to indicate the effect that a range of different options might have on the LCA outcome as a whole rather than as a prediction of those most likely to be adopted in the future.

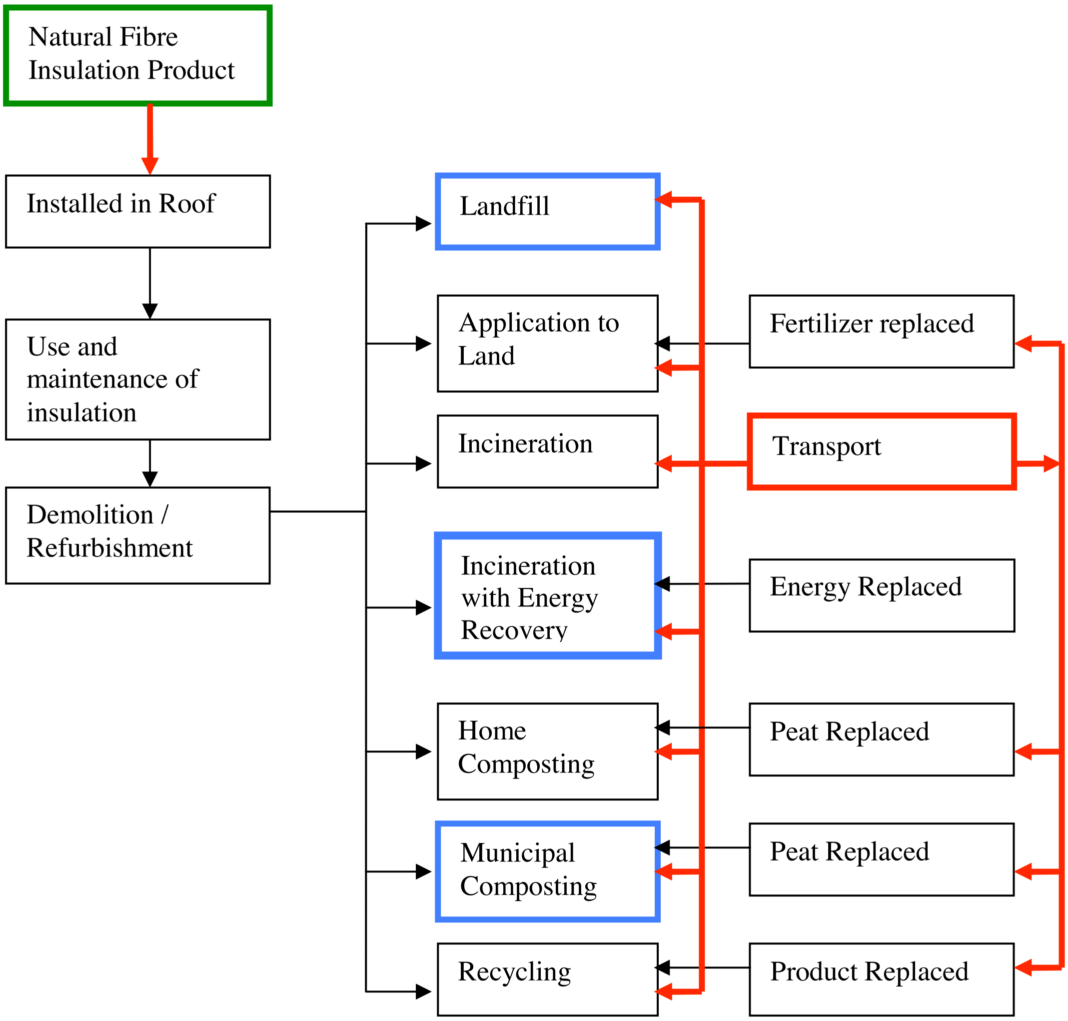
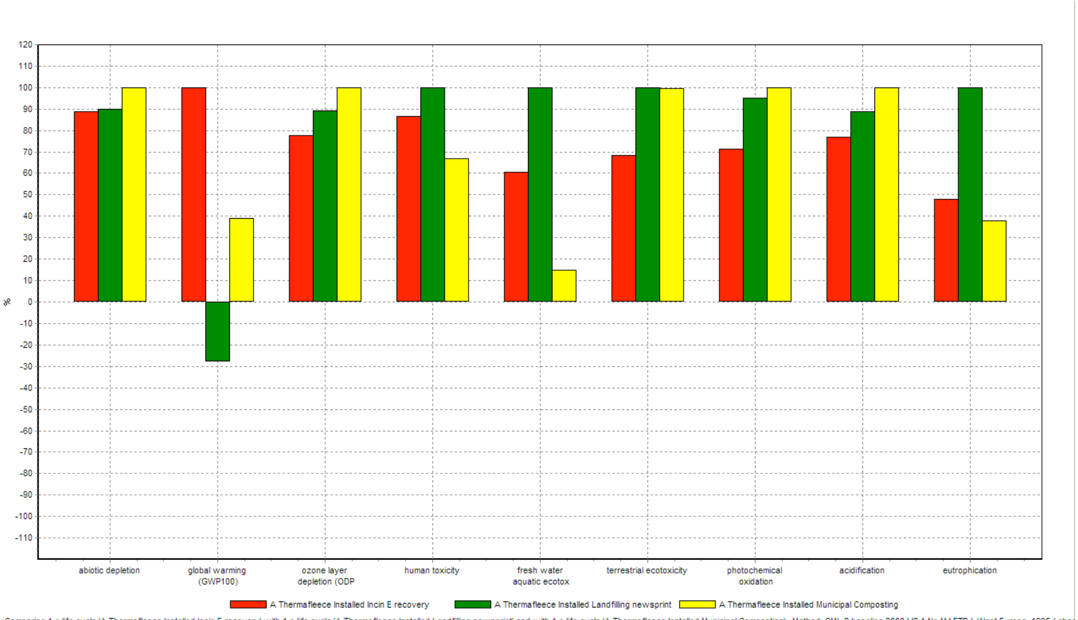


Figure 15 Potential End of Use Scenarios for the NFI Materials with individual scenarios selected for further study highlighted in blue

End of Life Scenario Results

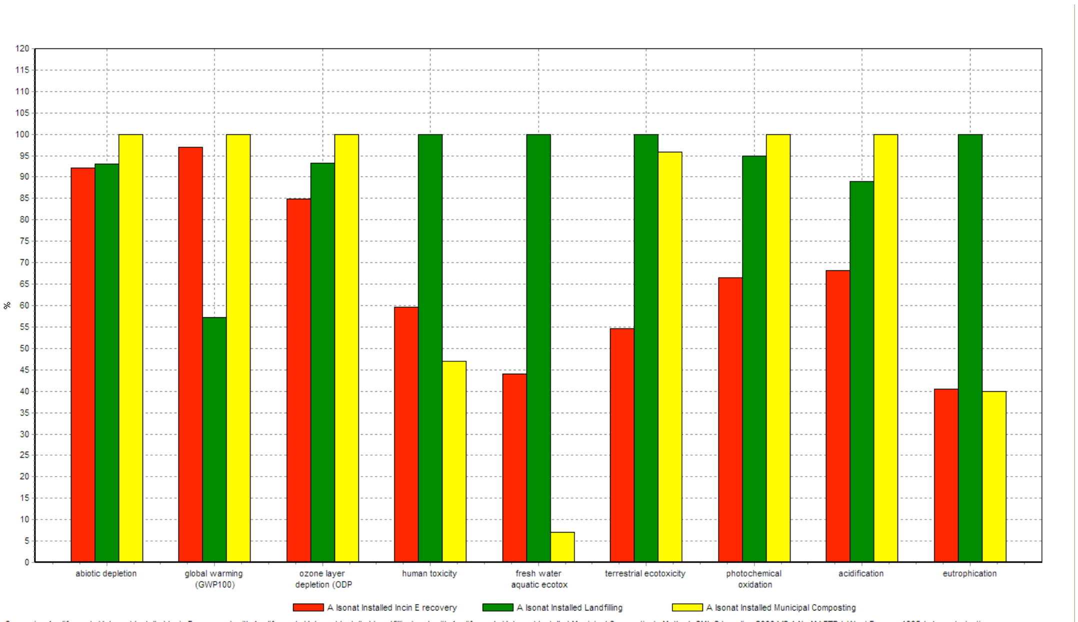
Thermafleece and Isonat

The results of the various end of life scenarios selected are given in Figure 16 and Figure 17.



Comparing 1 p life cycle 'A Thermafleece Installed Incin E recovery' with 1 p life cycle 'A Thermafleece Installed Landfilling newsprint' and with 1 p life cycle 'A Thermafleece Installed Municipal Composting'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / char

Figure 16 Effect of end of life scenarios on the Thermafleece life cycle



Comparing 1 p life cycle 'A Isonat Installed Incin E recovery' with 1 p life cycle 'A Isonat Installed Landfilling' and with 1 p life cycle 'A Isonat Installed Municipal Composting'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 17 Effect of end of life scenarios on the Isonat product

Landfilling emerged from this analysis as the best option for both NFI products in terms of GWP_{100}. This was particularly marked for the Thermafleece product, which maintained its capacity to reduce GWP_{100} when landfilled. This results from sequestered CO_2 remaining in the products due to a predicted slow breakdown in the landfill scenario. Conversely, the composting and incineration options investigated show release of much of this sequestered CO_2 and consequently a higher impact in this category. It is important to note that not all of the sequestered CO_2 is released by the composting scenario as the final compost product (containing around 50% of the original material's mass), will still retain a portion of the sequestered CO_2.

In most other categories the impacts are relatively similar for the examples chosen, except for eutrophication and fresh water aquatic ecotoxicity where the landfilling option presents a relatively larger impact.

Within the composting and incineration options, some benefits accrue from substitutions for a) grid electricity generation in the incineration option (approx. 4 MJ net power per kg disposed insulation was assumed for a mixed waste incineration) and b) peat replacement in the composting option.

Current most likely disposal option – Landfilling

Landfilling has been used as a 'default' end of life option Figure 18 as it is thought to be the most likely current option for an insulation material removed from a building during refurbishment or demolition. It is also thought to display similar results to low grade recycling options such as use in road surfacing (both involve some transportation to a facility, infrastructure and operational energy for the facility and the final fate of the product is return to land as a solid).

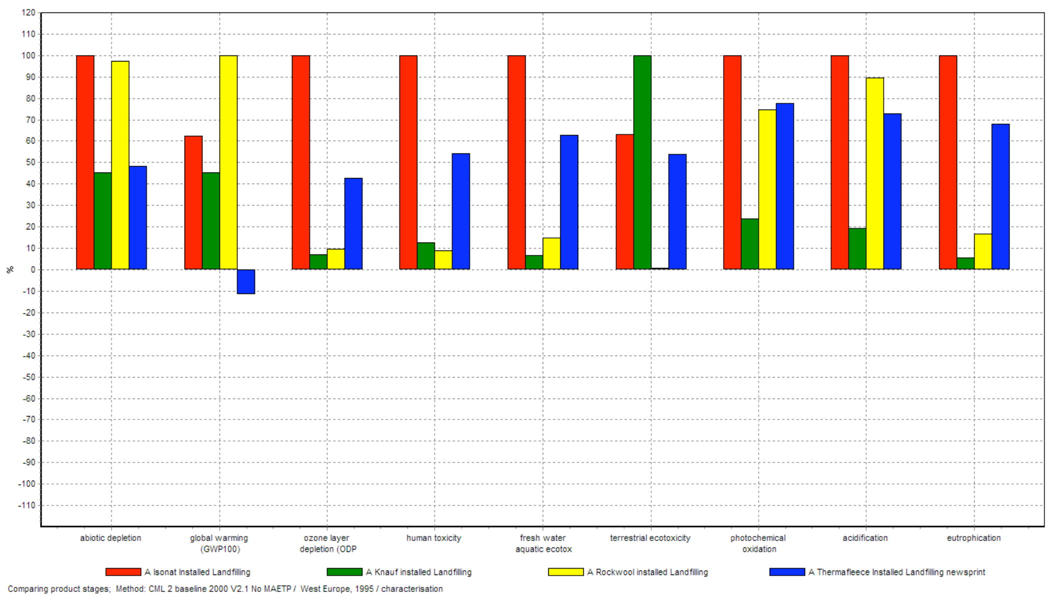
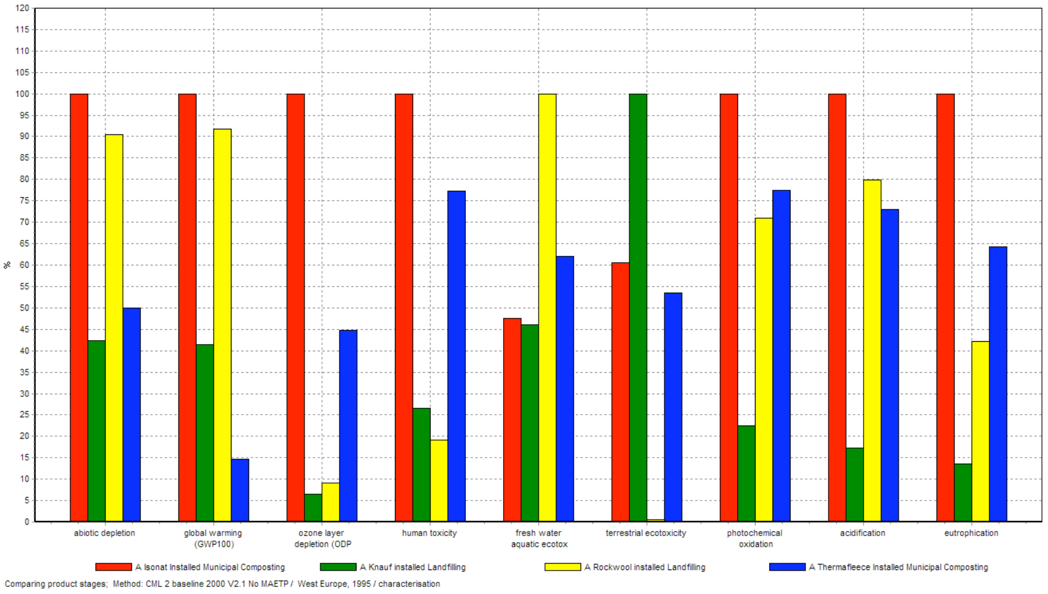


Figure 18 NFIs and glass and mineral wool insulation products - Landfilling disposal scenario

The lower density of Thermafleece and relatively slow degradation rate assumed for wool in landfill results in it exhibiting a lower environmental impact than Isonat and retaining its net negative GWP_{100} over the life cycle. The low density of the Knauf remains a highly beneficial attribute of this product when the end of life scenario of landfilling is included in the life cycle.

Example future disposal option – Composting

It is assumed here that as legislation and commercial considerations progressively restrict landfilling, the disposal of natural fibre products by this route will become less likely. As such, the option of composting is displayed here in Figure 19. As the glass and mineral wool products are not compostable they are displayed here using the landfilling option shown previously. This was chosen partly for continuity reasons and also as landfill is believed to display similar results to low grade recycling possibilities such as use in road surfacing that may be a future option for these products.



Comparing product stages; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 19 Example of a possible future disposal option, showing composting for NFI products and landfilling for glass and mineral wool insulation products.

Thermafleece has a lower impact than Isonat. However, as noted previously, the latter suffers from its high mass which is not fully offset at end of life by compost manufacture and an avoided peat extraction credit. In the future, municipal composting is likely to become a more common waste management system in the UK and, assuming that reliable product identification for NFIs can be achieved on disposal, they would have properties appropriate for this disposal route.

It is noted that Thermafleece uses a boron-based fire retardant treatment. Boron compounds can inhibit microbial and insect growth as well as being an essential element for plant growth. Work to ascertain suitable mixing ratios and acceptable concentration levels is recommended for situations where large-scale, concentrated disposal of treated insulation may be contemplated through municipal composting or alternative waste management options such as Energy from Waste (the NFIs are appropriate for Energy from Waste (EfW) disposal systems with a renewable ‘fibre’ content of ~85% or better (see later) and higher heating values likely to be approx 18 MJ/kg). Research to obtain material-specific data to characterise the performance of the NFIs in municipal composting and EfW systems would be valuable.

Conclusions from end of life scenarios

The end of life scenarios studied showed a release of some sequestered CO_2, but only a portion of the total amount was assumed to be released in landfilling and composting. As a result, the NFIs perform well in terms of GWP_{100}. The issue of CO_2 sequestration in renewable materials has been highlighted as an important area of study. It has been shown that LCAs that do not include this quantity of CO_2 could be missing large positive contributions in the area of GWP_{100}.

It is important to bear in mind that all the insulation products will, in use, save similar and substantial amount of energy and will recoup the energy needed for manufacture (and the environmental impacts of the energy production) several times over. This, however, is only true if the assumption that they will perform the same task during the product's life is correct. The issue of a product sagging and thus reducing the products thickness and thermal insulation property has been highlighted as a functional property that would benefit from further work and information. The reason for this is that any small change in the product's performance will affect heat and thus energy loss from the studied dwelling. Throughout the product's service life this could, if it is a variable property between different insulation products, have a much more significant effect than the initial production energy and, as such, alter the product's overall life cycle impact.

This aspect of functional performance over an extended time period of decades could not be examined in depth due to a paucity of information – the study is therefore based upon an assumption of no change in insulation performance over the 60 year *in situ* period modelled. Research into the issues regarding the long term performance of insulation products *in situ* will be valuable to develop more accurate, comparable LCAs.

Sensitivity Analysis

Secondary dataset usage

Data from Ecoinvent and other inventories have been used in the preparation of the NFI inventories. The Ecoinvent datasets act to accumulate certain impacts, for example in the toxicity and ozone depletion categories. These accumulations of impacts result from the “tree algorithms” used in the production of Ecoinvent databases. The inclusion of an Ecoinvent dataset in SimaPro will (by means of a “tree algorithm”) call up data from other databases on materials and processes it requires (e.g. the electricity required to make the material requested). In turn these will call up further datasets and so on (for example a portion of materials required in making the power plant that produced the electricity etc.).

Although this method does not necessarily take data from outside the system boundary, it does require some caution when assessing these data and those for the total aggregated system datasets (as provided for the glass and mineral wool products) which may not include as many branches or layers in their background data.

It was therefore considered appropriate to examine the data for the glass and mineral wool materials in the context of datasets, including Ecoinvent datasets, for similar products.

Knauf Data Set

Figure 20 presents the data for the Knauf UK insulation with an existing Ecoinvent data set for glass wool. This is for the same functional unit and covers the life cycle up to installation but not disposal.

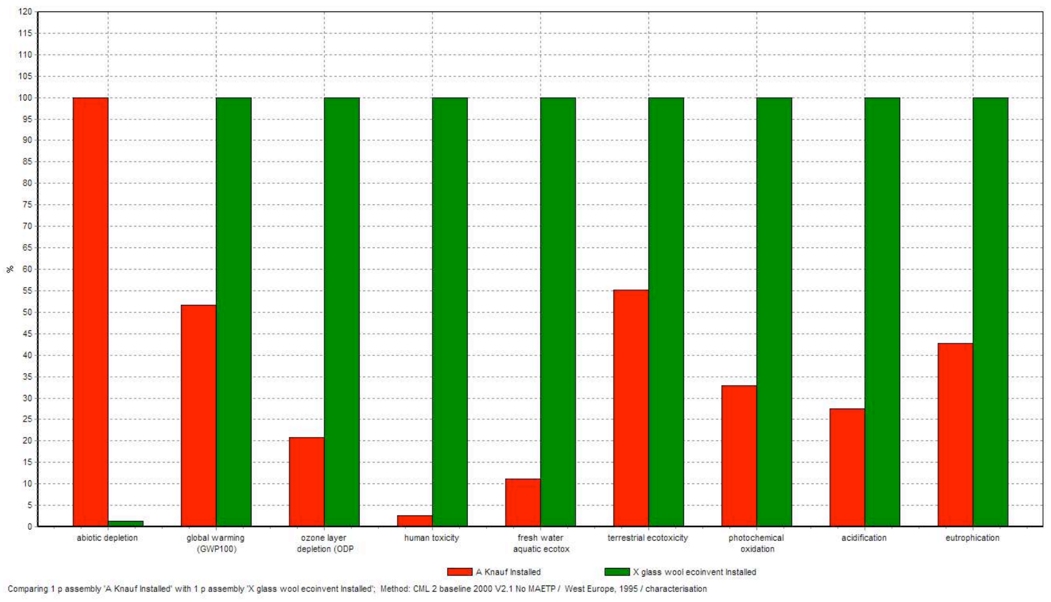


Figure 20 Supplied data from Knauf and Ecoinvent data on Glass wool production

The Ecoinvent dataset was produced by ESU (Energie - Stoffe - Umwelt or energy - materials - environment), of Switzerland. The dataset includes gate to gate inventory for the production of glass fibre. Identical transport data has been added to match the functional unit of the Knauf Product

The inventory is based on a “state of the art report for the European glass manufacturing industry covering 26 recuperative or oxy-fuel fired furnaces, operating at 12 sites in Europe, Using the average production volume of 475000 t/a”. This is assumed to be comparable to the large scale Knauf product UK manufacture.

All reported impacts (except abiotic depletion) for the Ecoinvent dataset appear higher than that reported for the Knauf product. There is no reason to believe that there are any significant missing data points from the Knauf data. As such it can be assumed that either the Knauf product is produced more efficiently, or that the glass wood production represented in this Ecoinvent dataset is not of a type appropriate for the application in question here. In the case of abiotic depletion, the Ecoinvent data under-represents impact and only a small impact from the added (BUWAL database) transport data is shown

Rockwool data set

As shown in the previous results section there appeared to be a lack of ozone depletion and toxicity impacts in the Rockwool datasets. The following presents the results of various other inventories available regarding stone wool products for an identical functional unit to the Rockwool UK data set.

Ecoinvent data set

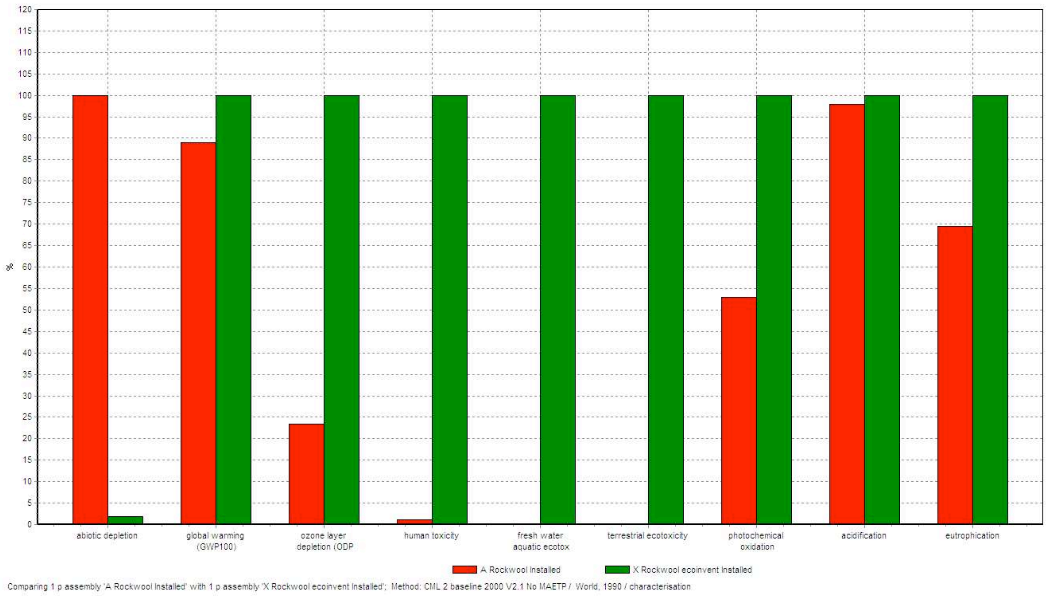


Figure 21 Rockwool UK supplied data and an Ecoinvent data set based on a Flumroc AG rock wool production plant in Switzerland

The Ecoinvent inventory suggests that the Rockwool dataset used for this study exhibited lower or absent values in some environmental impact categories. This Ecoinvent data set was produced by EMPA-DU (Centre for LCI, Dübendorf, Switzerland). An ESUs dataset is presented separately below. The Ecoinvent dataset presented here includes mechanical packing and the administration of the Flumroc AG rock wool factory in Switzerland though transportation from Switzerland has not been added for the above comparison. It is noted that the company Flumroc AG works on a technically high level producing a comparable 112500t/a, with an automated packing and loading process.

The results of the Ecoinvent dataset have some similarities with that of the data for UK Rockwool. These similarities are seen in GWP_{100} and acidification and to a lesser extent eutrophication and photochemical oxidation impact categories. The impact categories of ozone layer depletion and those concerning toxicity are far higher in the Ecoinvent database than that provided by Rockwool UK. In general, all of the Rockwool UK results are lower except in the impact category of abiotic depletion where the Ecoinvent database under-represents likely impact.

ESU data set

The Rockwool UK dataset is presented with data from ESU, Switzerland in Figure 22 below.

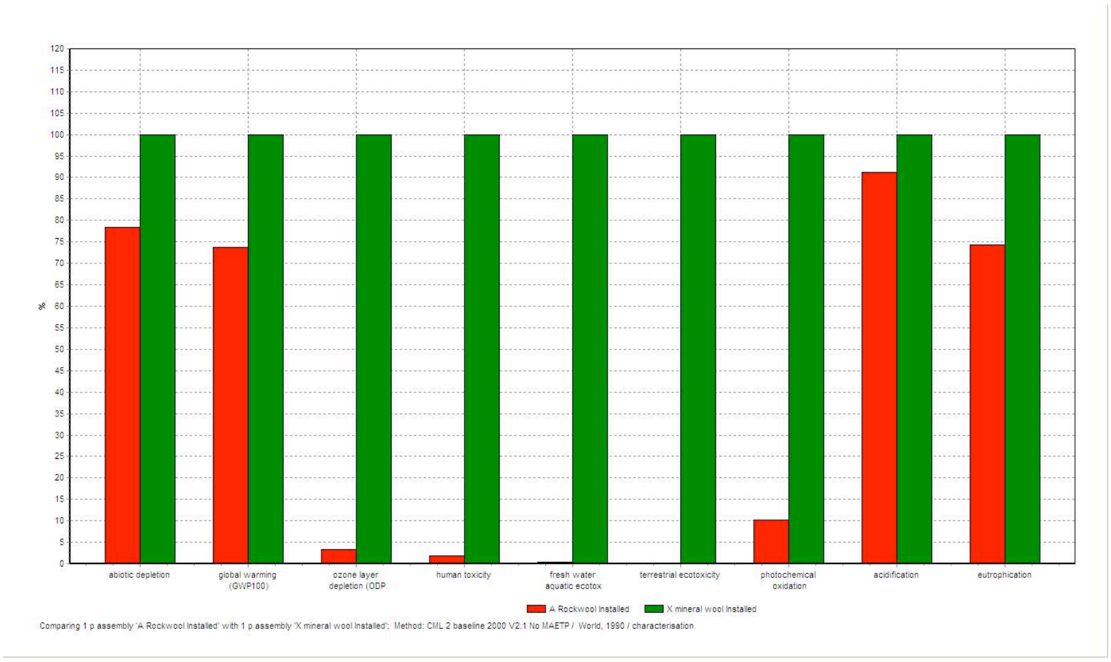


Figure 22 Rockwool UK data and ESU rock wool (Flumroc AG) dataset.

The Mineral wool ESU database is a total aggregated system inventory. The data is based on the Swiss production of a Flumroc rock wool product. It is not known if this is based on the same Flumroc product as described in the Ecoinvent data. The energy and emissions are taken from BUWAL (1995). The production is described as taking place in an oven at 1600°C, where various rock types (limestone, diabase), cokes and briquettes are melted. The molten mass is mixed with resin and spun to a mineral wool. The wool is cured in an oven and further treated for final delivery. Though the scale is not mentioned in this inventory summary it is assumed to be the same or on a similar scale to that described in the Ecoinvent database as it is assumed the same factory has been studied.

In general, the data is very similar to the Ecoinvent data and shows higher toxicity impacts than the Rockwool UK dataset. The ETH-ESU database however, appears to also include data leading to a similar impact in abiotic depletion to that provided by Rockwool UK.

Schmidt *et al* dataset

The Rockwool UK dataset is shown together with that in the previously discussed Schmidt *et al*. (2003) dataset produced by DK-teknik in Figure 23.

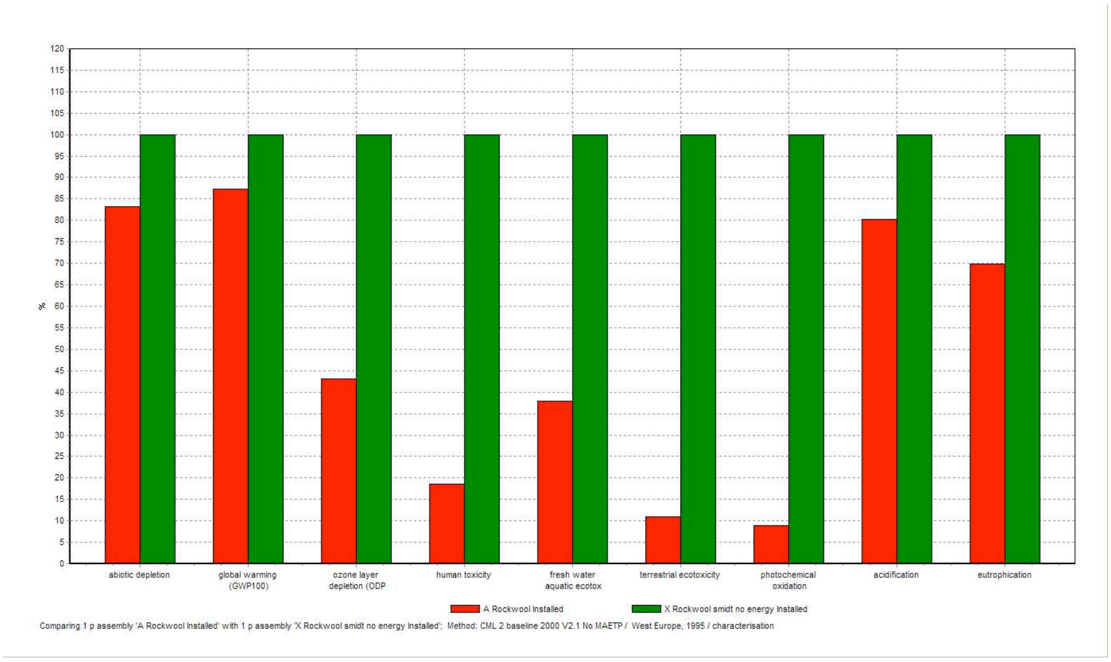


Figure 23 Rockwool UK data and dataset produced by DK-teknik in Schmidt et al. (2003).

It is noted that the Rockwool UK data set appears to be similar to that presented by Schmidt *et al*. (2003) in some categories, though again lower impact is shown in the ozone depletion, toxicity and photochemical oxidation categories.

Sensitivity Analysis Conclusions

As found with both of the Ecoinvent rock wool and glass wool datasets the Ecoinvent library under-represents impact in the abiotic resource depletion category. From this sensitivity analysis it has been shown that both the Knauf and Rockwool databases were almost certainly not constructed using Ecoinvent data (or similarly formatted datasets) and, as such, caution is needed in comparisons with the NFIs in the abiotic depletion impact category.

In general, the impacts reported by Rockwool UK in the toxicity and ozone depletion categories appear low. It is impossible to say if this is a result of different processing or lack of reported data and, thus, comparisons of toxicity and ozone depletion impact categories must be made with this potential inconsistency in mind.

Overall, the rock wool datasets presented in this section appear similar in GWP_{100} which would suggest comparable amounts of "embodied energy" reported by all the examined stone wool datasets. It is noted that the different fuel mixes used for electricity generation in the different countries studied may have an effect on these data.

Marginal Analysis

Marginal analysis is applied here to identify the principal causes of impact for each NFI product by impact category. Both the negative and positive contributions to each impact category are assessed by contributing process or material. Due to the uncertainty over potential end of life scenarios and for reasons of simplicity, the results displayed here are only for the *cradle to installation* portion of the LCA. The aggregated nature of the datasets provided for the benchmark products precludes this type of analysis on the Rockwool and Knauf products.

Thermafleece

The CML baseline impacts of the contributing processes and materials for a ***cradle to installation*** analysis of the Thermafleece product is presented in Table 7 below.

Table 7 Table of CML baseline impacts by described units for the Thermafleece product

Impact category	**Abiotic depletion**	**Global warming (GWP100)**	**Ozone layer depletion (ODP)**	**Human toxicity**	**Fresh water aquatic ecotox.**	**Terrestrial ecotoxicity**	**photochemical oxidation**	**acidification**	**eutrophication**
Unit	*kg Sb eq*	*kg CO2 eq*	*kg CFC-11 eq*	*kg 1,4-DB eq*	*kg 1,4-DB eq*	*kg 1,4-DB eq*	*kg C2H2 eq*	*kg SO2 eq*	*kg PO4--- eq*
Total	**0.00451**	**-0.323**	**1.48E-07**	**0.453**	**0.1**	**0.00584**	**0.000296**	**0.00835**	**0.00116**
Clean, Raw Wool	0.0017	-1.53	0	0.106	0.0332	0.00107	0	0.00141	0.000145
Packaging film	0	0.0681	0	0.0106	0.00294	0.000398	0	0.000666	0
Bi-component Polyester	0.00065	0.455	0	0.182	0.0312	0.00283	0.000124	0.00325	0.000595
Heat gas	0.00182	0.205	0	0.0221	0.000173	0.00019	0.000011	0.000229	0
Electricity, medium voltage	0	0.333	0	0.0897	0.0298	0.00111	0	0.00122	0
Transport total	0.000906	0.145	1.22E-07	0.0356	0.00231	0.000113	0	0.0017	0.000277
Recycling PP	-0.00056	0.00123	0	0.00695	0.000426	0.000133	0	-0.00012	0

Presented below are graphical representations of the contributing processes and materials in each of the CML impact categories. They are displayed as a percentage of the total impact for the product in Figure 24, and as a normalised representation in Figure 25.

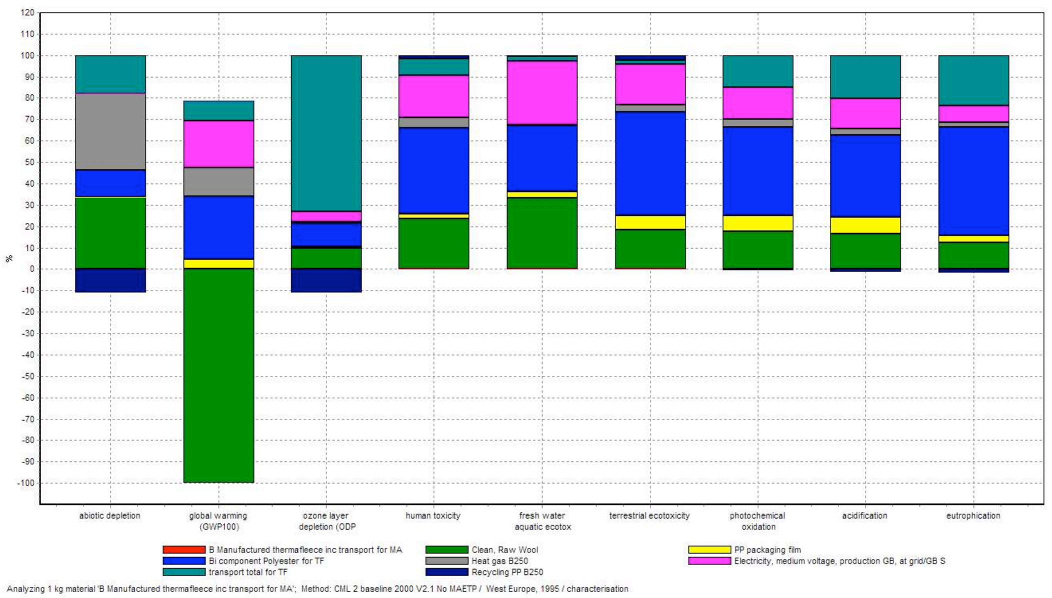


Figure 24 Marginal Analysis of the current Thermafleece product

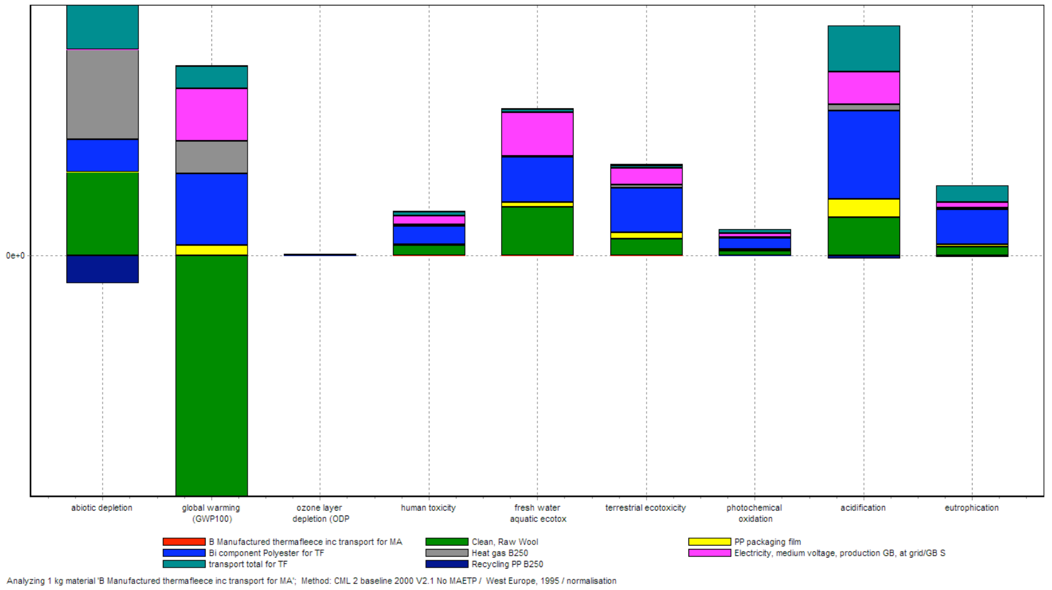


Figure 25 Marginal Analysis of Thermafleece with Normalisation

From Figure 24 and Figure 25 the following observations have been made:

- In terms of abiotic depletion, a large portion of the product impact is derived from the use of natural gas both in the final product production (used to melt the binder material) and as part of the scouring process within the production of clean wool.
- The use of grid electricity in the final production (pink) produces an impact in most categories (associated often with the use of coal).

- The use of diesel fuel in the transport of raw materials and finished product also gives an impact in most categories.
- A large negative contribution (i.e. environmental benefit) in terms of GWP_{100} is attributable to the renewable material fraction of the product, in this case wool.
- Figure 24 shows a large impact across most impact categories from the bi-component polyester fibre (light blue). For example, even though the fibre constitutes only 15% of the material input it is responsible for 38% of the GWP_{100} impact.
- The large contribution to ozone depletion (shown in Figure 24) from transport is almost entirely due to two fire suppressing “Halon” chemicals. This is pulled through from their use in oil refineries as reported in the database used. Normalisation of the data (Figure 25) indicates impacts in the ozone depletion category to be comparatively minor factors in the life cycle.

A flow chart to show the GWP_{100} impact contribution by each sub-process or material is given in
Figure 26 in order to give a visual appreciation of the relative contribution to this impact category of the various life cycle components.

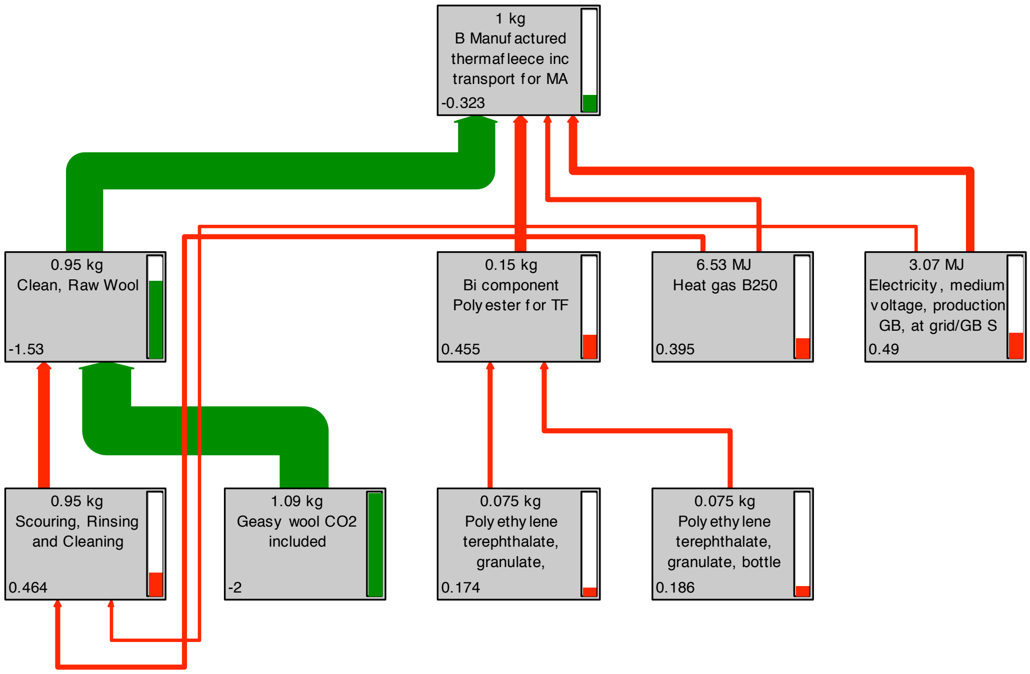


Figure 26 Flow chart to show the process and material contribution the overall product impact in terms of GWP_{100}. Impacts of less than 8% of the total have been omitted from the flow chart for clarity.

In
Figure 26 the negative impact on GWP of the scouring process is apparent but is compensated by the positive effect of the wool (due to carbon sequestration) in the product “clean, raw wool”.

Isonat

The CML baseline impacts of the contributing processes and materials for a ***cradle to installation*** analysis of the Isonat product is presented in Table 8 below.

Table 8 Percentage contributions to impact category by Isonat process

Impact category	**abiotic depletion**	**global warming (GWP100)**	**ozone layer depletion (ODP)**	**human toxicity**	**fresh water aquatic ecotox.**	**terrestrial ecotoxicity**	**photochemical oxidation**	**acidification**	**eutrophication**
Unit	*kg Sb eq*	*kg CO2 eq*	*kg CFC-11 eq*	*kg 1,4-DB eq*	*kg 1,4-DB eq*	*kg 1,4-DB eq*	*kg C2H2 eq*	*kg SO2 eq*	*kg PO4-- eq*
Total	0.00669	0.345	2.56E-07	0.418	0.0545	0.00471	0.000272	0.00814	0.00132
Hemp fibre production	0	-0.486	0	0.0708	0.01	0.000421	0	0.000437	0
Cotton fibres recycled	0	-0.511	0	0.000432	0	0	0	0	0
Bi-component Polyester	0.00065	0.455	0	0.182	0.0312	0.00283	0.000124	0.00325	0.000595
Flame retardant	0	0.0426	0	0.0332	0.00431	0.000391	0	0.000155	0
Kraft paper, unbleached	0	0	0	0	0	0	0	0	0
Packaging film	0	0.0648	0	0.01072	0.003076	0.000364	0	0.000695	0
Electricity, medium voltage	0	0.0139	0	0.00755	0.00176	4.10E-05	3.12E-06	8.82E-05	6.51E-06
Heat gas	0.00448	0.506	0	0.0546	0.000428	0.000469	2.70E-05	0.000565	6.37E-05
Transport total	0.00164	0.263	2.21E-07	0.0599	0.00411	0.000157	7.40E-05	0.00297	0.000534
Recycling ECCS steel	0	-0.014	0	-0.00112	-0.00053	0	0	0	0
Recycling PP	0	0	0	0.000204	0	0	0	0	0
Landfill PE	0	0.0123	0	0	0	0	0	0	0

Presented below are graphical representations of the contributing processes and materials in each of the CML impact categories. They are displayed as a percentage of the total impact for the product in Figure 27, and as a normalised representation in Figure 28.

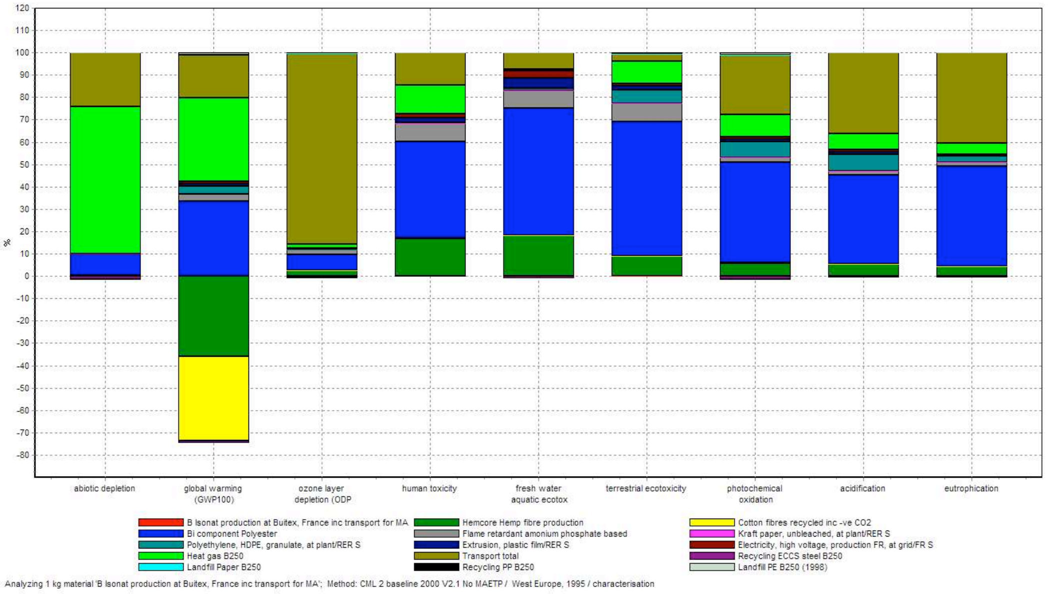


Figure 27 Marginal Analysis of the current Isonat product

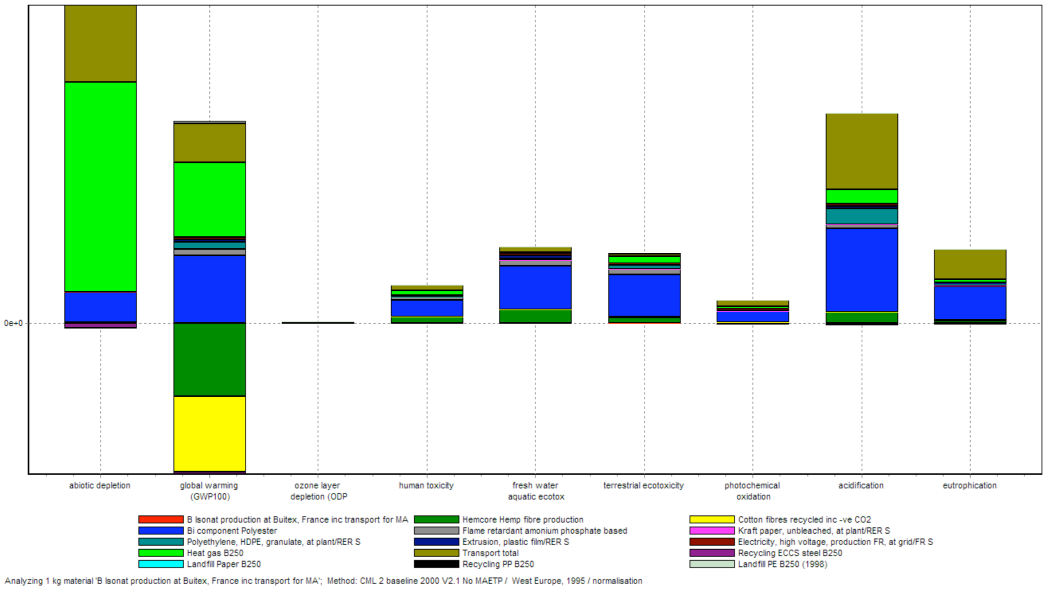


Figure 28 Marginal Analysis of Isonat normalised to the West European average citizen impact.

The results in Figure 27 and Figure 28 indicate:

- A large negative contribution (i.e. environmental benefit) in terms of GWP_{100} is provided by the renewable material fraction of the product, i.e. the hemp and recycled cotton fractions
- The relatively large quantity of gas used for drying and bonding the product (light green) contributes significantly to abiotic depletion and to GWP_{100}

- The bi-component polyester fibre (blue) contributes a large detrimental impact across most impact categories even though the fibre constitutes only 15% of the material input
- The total transport (olive green) also contributes highly in many categories. A large proportion of this is due to the transportation of materials to and from France.

An example flow chart to show the GWP_{100} impact contribution by each sub-process or material is given in Figure 29.

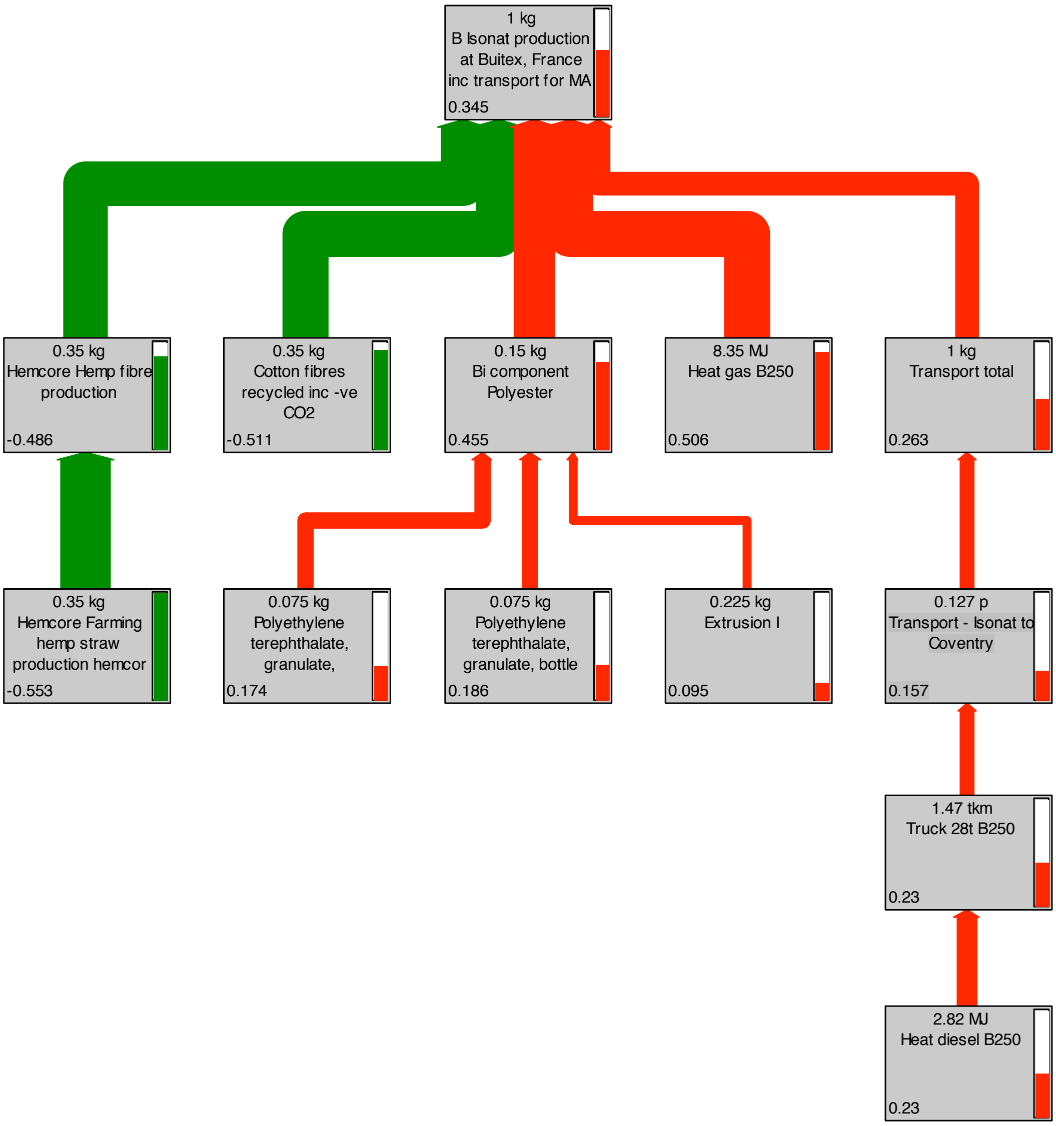


Figure 29 Flow chart to show the process and material contribution the overall product impact in terms of GWP_{100}. Impacts of less than 16% of the total have been omitted from the flow chart for clarity.

A notable observation from Figure 29 is that the impact of the specific transport function is visible exceeding the cut off at the 16% contributing impact limit. This particular transport function shown is that of the final delivery by truck of the Isonat material from the factory in France to the final installation in Coventry, with the majority of the impact stemming from the diesel used in the truck. The ferry journey taken as part of this function is of low overall impact.

Optimization Study

Optimization of Insulation Materials

The marginal analysis of the NFI products has identified the sub-processes and materials that carry the most significant impacts. In this section, potential improvements to the products that may reduce their overall environmental impact are explored.

NFI materials are currently produced on a very different scale to that of the benchmark products. From approximations based on the respective companies' turnovers and product sales values, it would appear that both of the benchmark products are produced on a scale some hundred times larger than either of the NFIs. As such there are likely to be large economies of scale that can be exploited, as discussed in the first part of the following section.

Economies of Scale

It is well known that an economy of scale characterizes a production process in which an increase in the number of units produced enables process improvements and efficiencies that reduce the average economic cost and the energy used for each unit. Rockwool and Knauf are long-established companies that operate successfully at large scale making their product as efficiently and economically as possible. This enables them to offer highly competitive pricing in the marketplace. Both manufacturers have reduced their unit energy consumption by producing large quantities at high efficiency.

Taking the production of glass products as an example, it is possible to see the effect that scaling up production has on the energy usage for a furnace-based production industry. This example is shown in Figure 30.

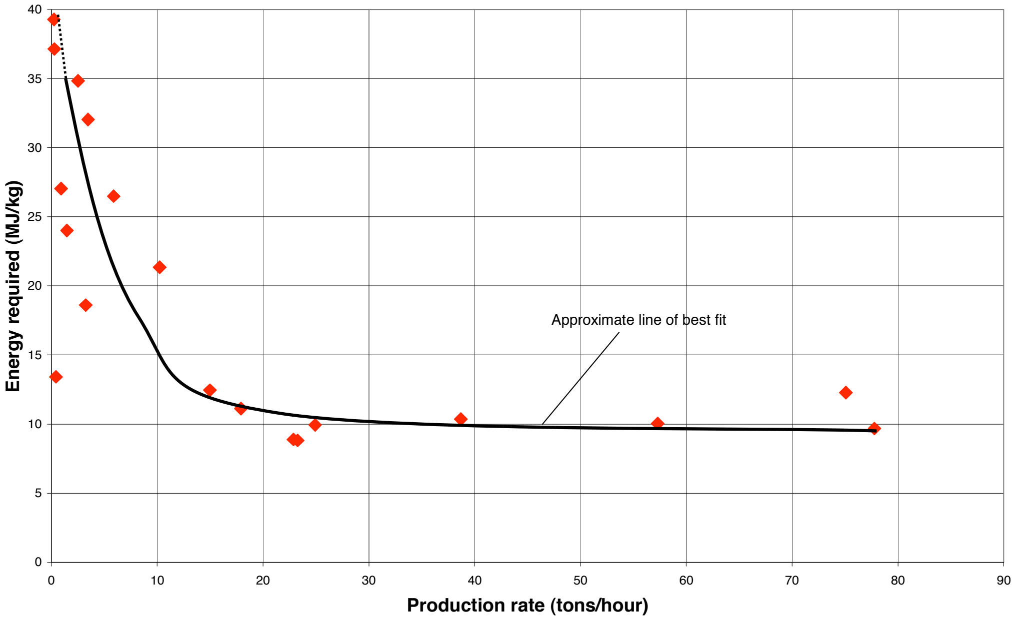


Figure 30 Energy usage (MJ/kg) of different glass product manufacturers against, productivity (tons/hour).

Figure 30 demonstrates the marked decrease in energy requirements per ton of product produced when moving from production capacities of 1tonne/h to 15tonnes/h. However, little or no decrease in energy appears to occur from 20tonnes/h to 80tonnes/h. This ‘bottoming out’ of the ‘economy of scale’ shown by the glass product industry is thought to be similar to that of glass and mineral wool. Both the glass and mineral wool products studied here are produced at large scale and thus are likely to have limited scope for significant further energy savings in manufacture. For example, Rockwool has reduced its energy consumption per unit of output by 50% from 1975 to 2000. Over the period 1996 to 2003 the calculated embodied energy has only decreased from 18.2MJ/kg to 17.3MJ/kg (Rockwool, 2006a), i.e. 4.9%. This advanced status of manufacturing efficiency suggests that opportunities for further substantial efficiency gains and their associated environmental improvements are limited.

Optimization studies

Due to the range and uncertainty over potential end of life scenarios and for reasons simplicity, the results displayed here for improvement analysis for the NFIs are only for the ***cradle to installation*** portion of the LCA.

Every effort has been made to model optimization stages that could be commercially feasible for manufacturers of these materials. The intention is to gain an understanding of the scale of effect of such operations. It is not in any way implied that the optimization stages modelled will be adopted and the results of the analysis are, equally, ***not*** an estimation of the ***best possible*** products made from natural fibres.

Optimization of a Sheep wool fibre based product

Shown here is a selection of potential “optimization” methods for a sheep wool product. These include the replacement of the binder material, a reduction in the use of fire retardant and a reduction in density. There are other optimization stages that could be considered for a new product. However, due to a lack of data and/or commercial sensitivity, they have not been considered here.

Replacement of binder material

It was identified in the marginal analysis that the polyester based bi-component fibre was a relatively high impact component in most categories. The replacement of the current bi-component fibre used to bind the fibres is a very near-future option for product improvement. A potential bio-derived replacement is that of poly-lactic acid (PLA) based fibres. Bi-component PLA fibres are available “off the peg” currently and show potential for environmental impact reduction. Modelled here is a direct replacement of the existing polyester fibre with the same quantity of PLA based fibre in the standard Thermafleece product. The PLA dataset used was produced at Imperial College London.

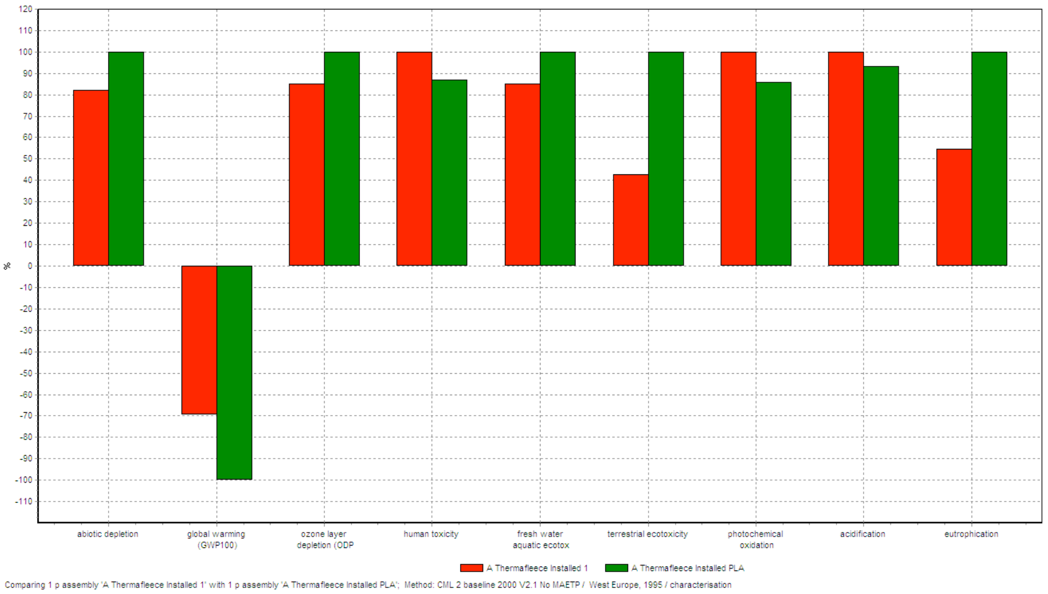


Figure 31 Effect of producing the current Thermafleece material with a PLA based binder

Using a PLA binder improves the product's impact in some categories while generating more impact in others. The following observations from Figure 31 can be made:

- GWP_{100} in particular is reduced further through the use of the PLA material. This is attributed to the additional sequestration of CO_2 by the PLA fibres.
- Other impact categories are made worse due to the maize feedstock and high energy requirements currently incorporated in the production of the material. The latter has potential for reduction for some PLA based products as production scales increase.

Borax salt usage reduction

A reduction in the current quantity of Borax solution is a potential improvement to the Thermafleece product as such levels may be acceptable to satisfy the relevant fire safety standards. Modelled here is a 30% reduction in the quantity used in the standard product. This has been estimated as an attainable reduction.

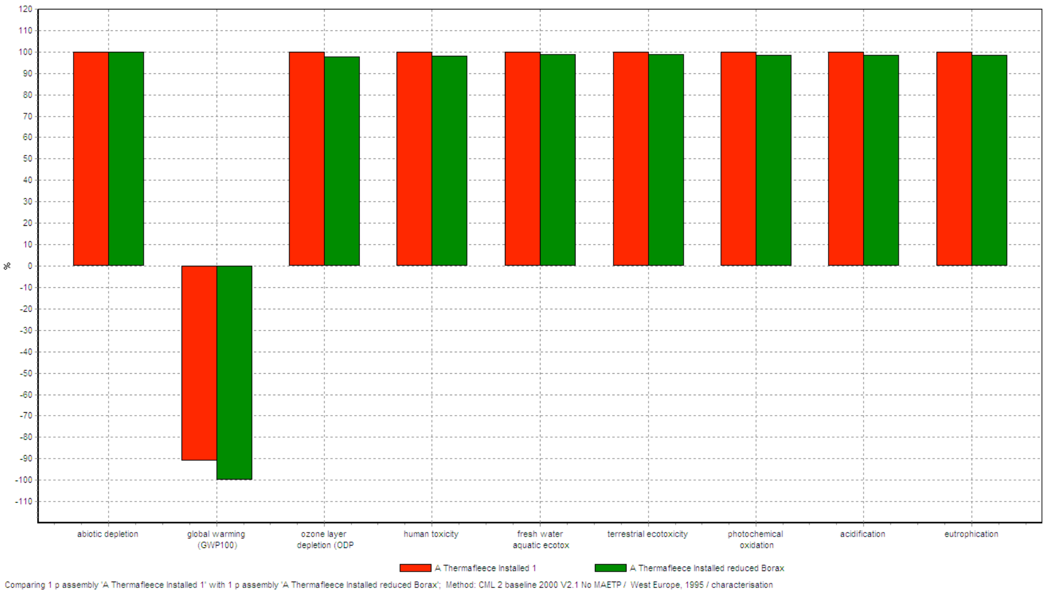


Figure 32 Graph to show the effect of a reduction in Borax usage in the current Thermafleece product

The reduction in Borax usage has a small impact on most impact categories, the greatest impact reduction being in GWP_{100} due to a reduction in the burden carried through from the energy required to produce the borax salts.

Density Reduction

In previous discussion it has been shown that a lower density product will carry a lower environmental burden if it fulfils the same functional unit. It has been calculated by the producers of the Thermafleece product, Second Nature, that a reduction in density from 25km/m2 to 22kg/m2 could be possible without any notable change in production requirements or performance. The implications of this (approximately 10%) reduction in functional unit weight are presented in Figure 33.

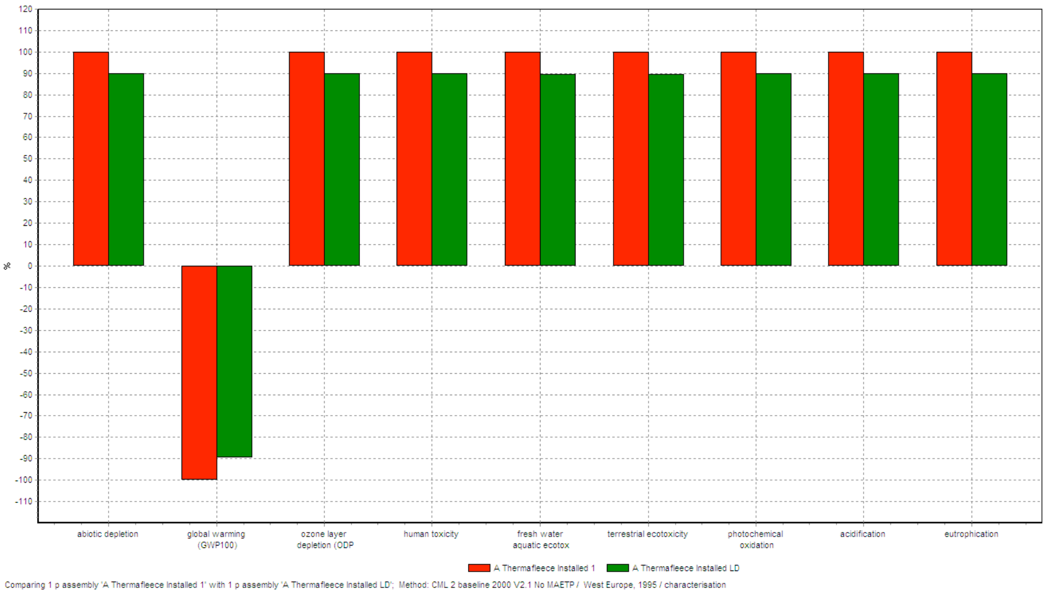
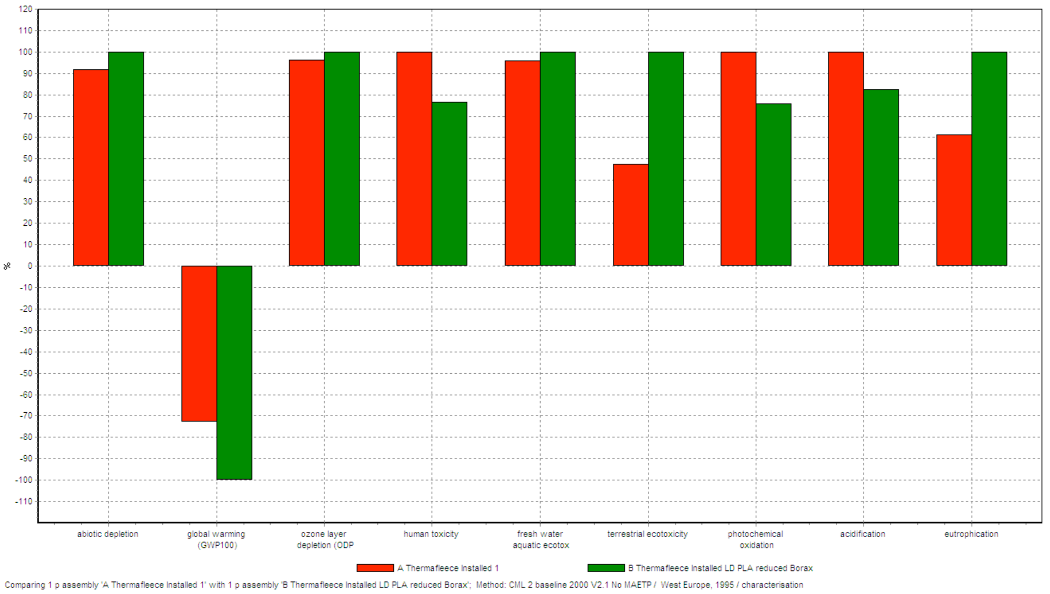


Figure 33 Graph to show the effect of a reduction in density in the current Thermafleece product

As can be seen from Figure 33 the positive and negative environmental impacts of the product have been proportionately reduced across all categories. In reality there ***may*** be a minor fluctuation caused by transport as it has been assumed here that the lower density product can be delivered with the same ***weight*** of product on the delivery truck.

Effect of all example optimization changes

The combination of all the studied stages of optimization reveals the potential for a possible near future product. It should be noted, however, that this represents a "potential product" and is not intended to represent a commercial development line. It is merely an example given to show potential development opportunities and 'headroom' for continued product improvement via selected production alterations.



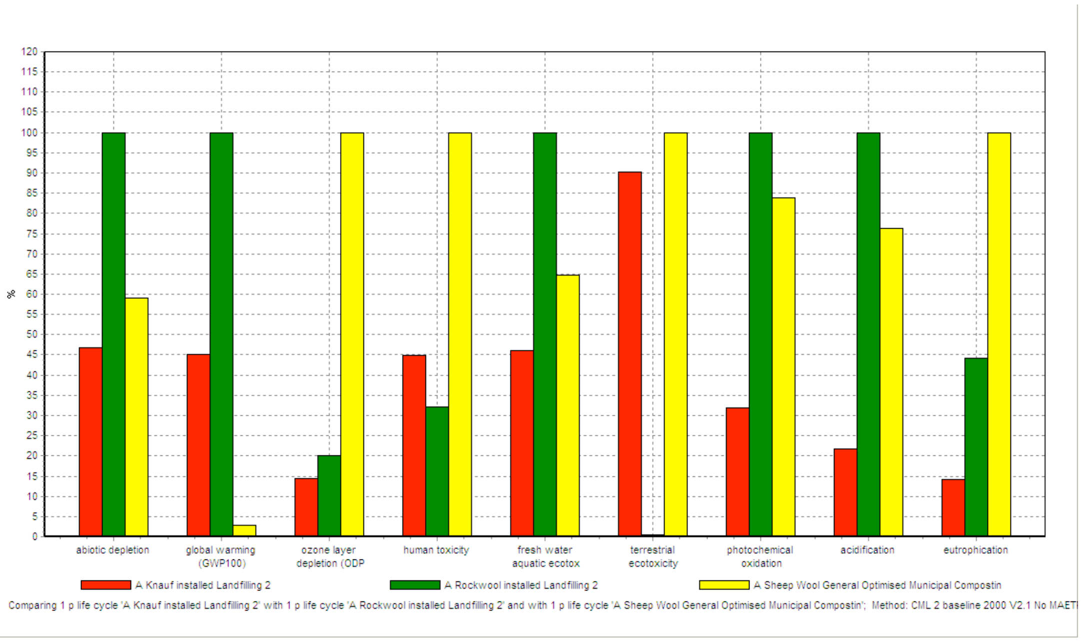
Comparing 1 p assembly 'A Thermafleece Installed 1' with 1 p assembly 'B Thermafleece Installed LD PLA reduced Borax'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 34 Effect of a reduction in borax, a density reduction and switch to PLA binder

It can be seen from Figure 34 that a sheep-wool based product, if produced with all of the optimisation stages discussed previously, shows both positive and negative environmental effects when compared with the current Thermafleece product. The combination of optimization stages increases the product's negative GWP_{100} by over 25%. The use of PLA causes the negative impacts in some categories as discussed previously.

End of Life example of sheep wool product with minimal optimization

Figure 35 below compares the example future scenario of a composted sheep wool product with landfilled benchmark products.



Comparing 1 p life cycle 'A Knauf installed Landfilling 2' with 1 p life cycle 'A Rockwool installed Landfilling 2' and with 1 p life cycle 'A Sheep Wool General Optimised Municipal Compostin'; Method: CML 2 baseline 2000 V2.1 No MAETI

Figure 35 Example future scenario of a composted NFI sheep wool product showing data calculated for glass and mineral wool insulation products with landfill disposal

The minimal optimization is shown (through the use of PLA) also to have some negative impacts compared with the current Thermafleece product. However, the example "optimized" product shown here still performs comparably against the "A" rated benchmark products. This is in no way a suggestion as to the best possible sheep wool based product as it is only provided to display the effects of the example minimal alterations.

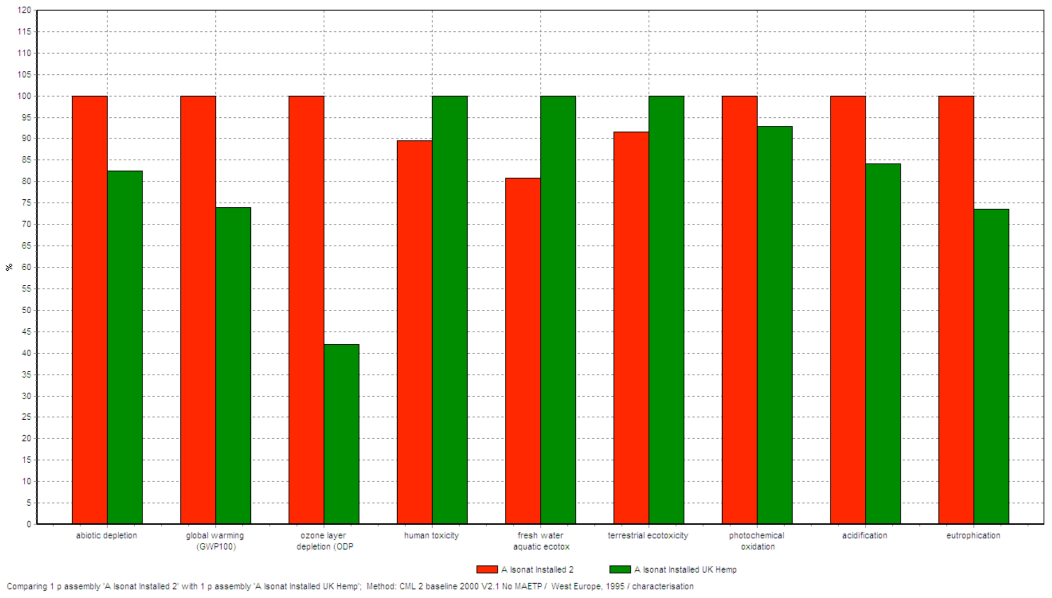
Optimization of hemp fibre based product

There is great scope to reduce the environmental impact of the current Isonat product. A wide selection of potential improvements that have been identified from the marginal analysis is studied here together with a discussion on the potential demand for land for hemp cultivation for NFI production.

UK Production

UK Production of an Isonat or a similar Hemp based product is seen as a likely scenario given the current increase in demand from the UK market, though the timing of such an operation is uncertain. As well as improved supply logistics which may result in a more reliable product for the UK market, the obvious reduction in transportation is of real benefit to the product's environmental profile as shown in Figure 36.

We have studied the effect of transport reduction resulting from assumed production in the UK on the basis that such production is located close (~10km) to the current hemp primary production facility. Also studied here is the effect of removing the recycled cotton fraction as this is likely to be replaced by hemp fibre if such a site change were to happen. The cotton fraction is currently used due to the close proximity of the French production site to large quantities of usable recycled cotton.



Comparing 1 p assembly 'A Isonat Installed 2' with 1 p assembly 'A Isonat Installed UK Hemp'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 36 Current Isonat production by Buitex in France and a UK hemp NFI production scenario (recycled cotton fraction replaced by an increase in hemp fibre usage).

An insulation production facility in the UK would substantially reduce the amount of transport required for the UK market, which has a large beneficial effect on the installed material's GWP_{100} and also to ozone layer depletion potential.

Some negative effects are produced (mainly in the toxicity impacts) due to the switch from French to GB electricity mixes. This is mainly caused by France’s high generation of nuclear derived electricity that in general has low impacts in these categories. The effective doubling of the scale of hemp farming will also contribute to these negative impacts.

Density reduction

As previously discussed with regard to the Knauf benchmark product, a large reduction in environmental impact can be gained through lowering the density of the product. This reduces the quantity of material needed to produce the same volume of product. Natural fibre insulation materials have been made with far lower densities but with the same thermal conductivity value, for example a previously available flax based product (Natilin) had a density less than 60% of the density of the current Isonat product. The effect of a reduction in density from 35kg/m^2 to 20kg/m^2 is shown in Figure 37 below as calculated by a reduction in functional unit.

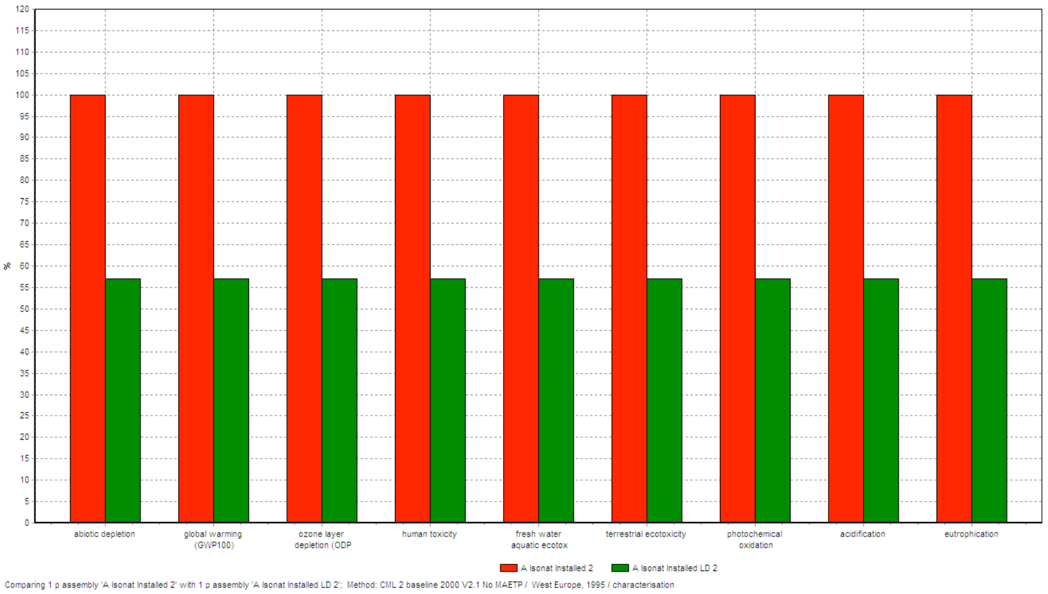


Figure 37 Current Isonat production by Buitex and a reduced density (20kg/m^2) scenario equivalent.

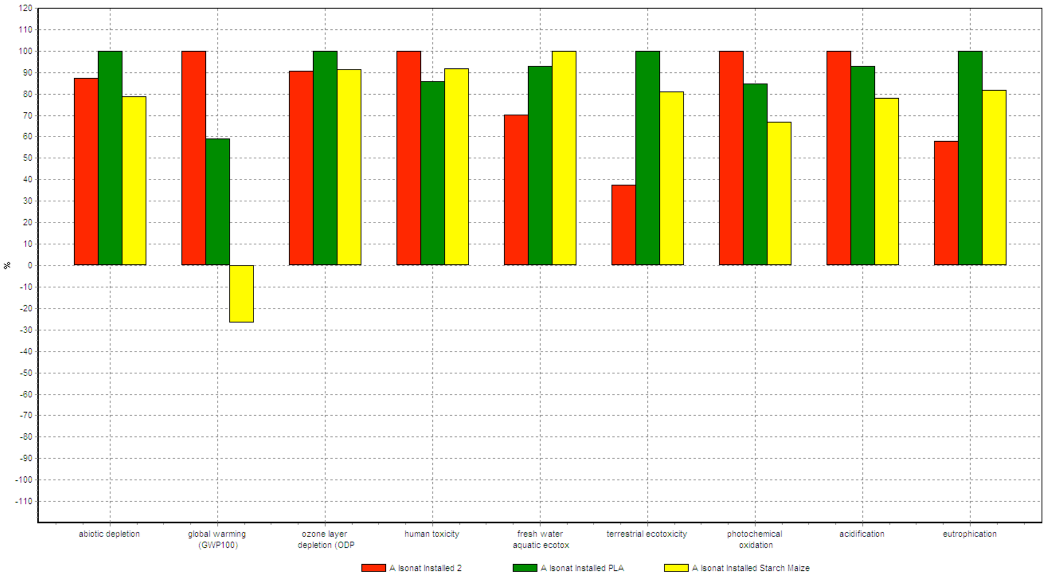
As can be seen from Figure 37 a lower density product reduces the product’s impact by a proportionate amount (i.e. just over 40%) when no change in transport impact is assumed.

Binder Material Replacement

The marginal analysis identifies that material replacement provides scope for environmental impact reduction, especially in the area of energy use. This large energy saving comes mainly from replacing the bi-component polyester binder as it is a very energy intensive material to produce and based on a fossil reserve. Omitting the purchase of a material from Korea, where the polyester material used in the Isonat product is made, would further reduce the energy used in transportation.

FIT (Fibre Innovation Technology) in America produce a bi-component fibre which has been trialled by Buitex with only minor technical issues, such as a requirement for a tighter temperature range in the curing process. It is the higher cost, however, that currently prevents its usage, as it has been identified as an almost direct replacement for the polyester based binder.

Starch based binders have been tried by other natural fibre insulation manufacturers. In a German hemp product (no longer in production) the starch used was found to be too brittle after long periods to be a reliable material. It is, however, possible that other more reliable starch based thermoplastics that are currently being developed may provide an alternative binder and so an estimate of their impact has been studied here and their effect is shown in Figure 38. The PLA binder was modelled using a data set produced at Imperial College, London and the starch binder was modelled by using existing Ecoinvent starch and extrusion datasets. Both were modelled as a direct replacement for the current polyester fibres with appropriate adjustments made to the transport, for example to include shipping from the USA.



Comparing 1 p assembly 'A Isonat Installed 2' with 1 p assembly 'A Isonat Installed PLA' and with 1 p assembly 'A Isonat Installed Starch Maize'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 38 Effect of replacing the current binder with a PLA or Starch based binder in current Isonat

Both the starch and a PLA based binder were found to give a large reduction in GWP_{100} over the Isonat product. This is due to the alternative binder materials sequestrating CO_2. In the case of the starch binder the lower energy inputs than for PLA will also reduce GWP_{100}. However a commercially viable starch binder may (or indeed may not) require more extensive processing to make a reliable product than was modelled in the estimate here.

The negative impacts that are developed in other categories, such as eutrophication, fresh water aquatic ecotoxicity and terrestrial ecotoxicity, derive from the farming inputs required for both alternatives.

Fire Retardant reduction

It is thought that through further development and testing a reduction in the amount of fire retardant (FR) currently used may be achieved. A surface treatment may be a technically feasible route to meeting the required standards. A surface treatment method would also mitigate the need for drying the fibre after it has been dipped in the FR solution.

A 30% reduction in FR chemical consumption has been modelled as an estimate to show the material's impact but it is uncertain how much of a reduction may be expected in the absence of specific testing. The assumption shown here also includes the use of half the current gas consumption in the final product processing as very little drying would be required. The remaining gas used is assumed here to continue being consumed in the thermal bonding stage.

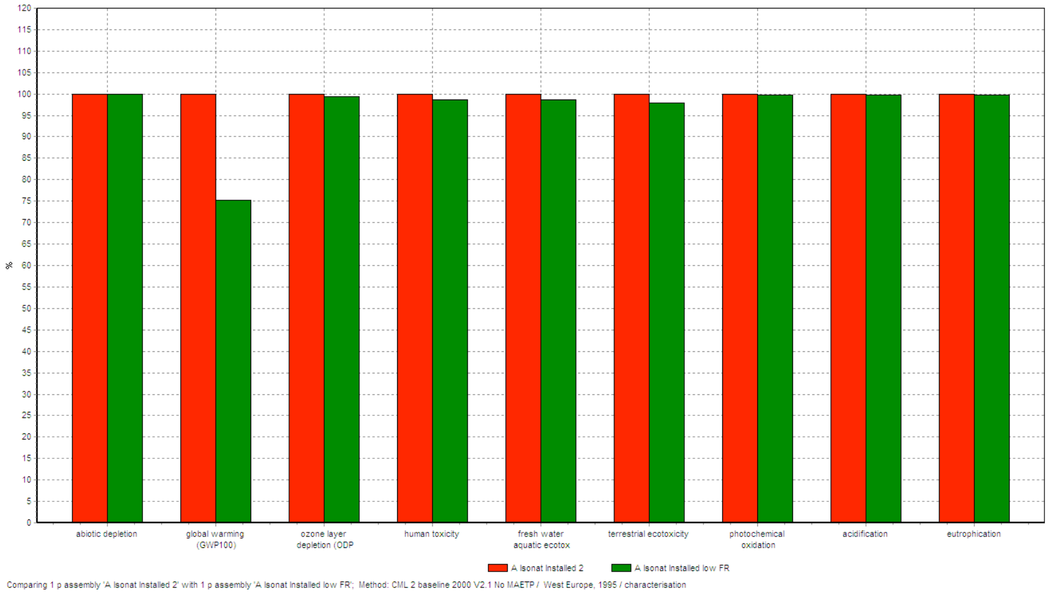


Figure 39 Effect of reduced fire retardant usage i.e. 33% reduction in FR and reduced energy use from lack of drying requirements

- A reduction in GWP_{100} of some 35% accrues from reducing the FR quantity due to high consumption of energy in the production of the ammonia (poly) sulphate material.
- Reduced energy usage from the reduced gas usage in drying also contributes to the reduced GWP_{100}.

Primary processing

The current energy usage for the primary processing of hemp is rather high due to the low throughout. Higher throughput machinery is available and is a logical next step for a growing fibre processor. Studied here is the effect of two stages of increased throughput with their associated reduction in energy usage which in turn results in reduced environmental impact. Figure 40 shows the effect of the increased primary production throughput both on the current product formulation and on a hemp only material (i.e. with no recycled cotton fraction). The data used was derived from consultation with industry, though the exact energy and throughput figures are withheld for reasons of confidentiality. They have been modelled by reducing the primary energy usage accordingly within the traditional Isonat product formulation and a hemp-only based product (i.e. with the cotton fraction replaced with an increase in hemp fibre usage).

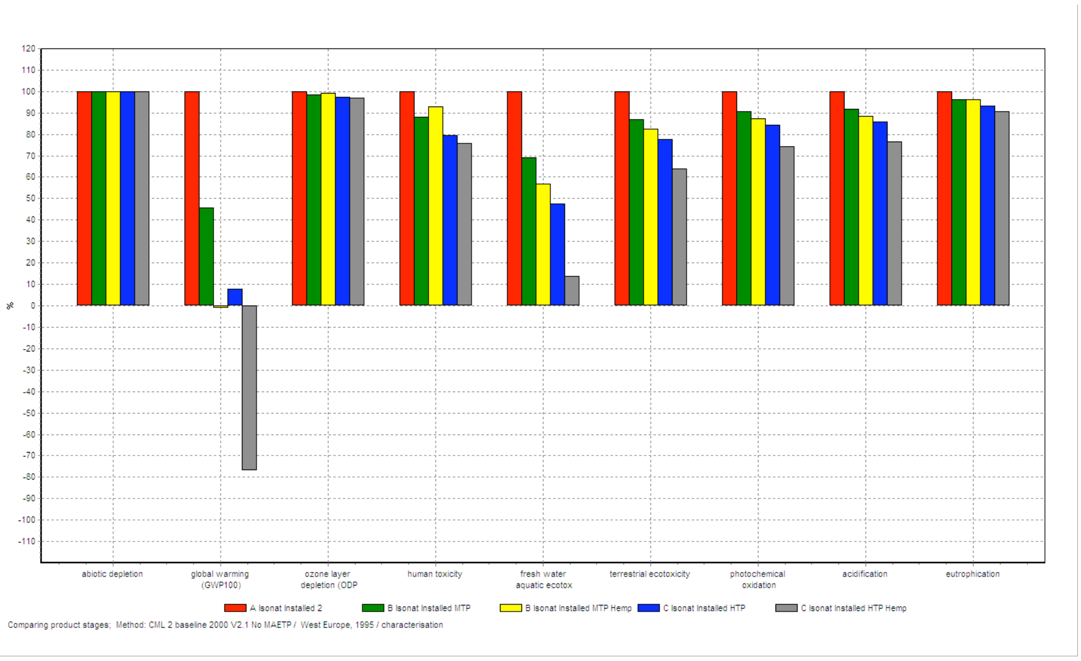


Figure 40 Effect of a 2-stage increase in primary production throughput on the current Isonat product formulation and on a hemp-only material

It is apparent from Figure 40 that large reductions in GWP_{100} occur as the scale of operation is increased due to the reduction in processing energy per unit produced. This is based on a GB national grid mix of electricity and so the fossil fuel based impacts, such as acidification and toxicity, are also seen to reduce.

The effect of a hemp only material increases the effect of scale up in most cases, except for some of the toxicity based scores where the benefit is outweighed by the increased hemp farming inputs.

Farming

From the marginal analysis of the Isonat product it can be seen that farming only contributes to a very small fraction of the total impact of the product. As a potential product is optimized, however, this figure is likely to become a more 'visible' component as the impacts from other processes and materials are reduced. There is less 'headroom' for improvements in this aspect of the life cycle due to the inherent processes involved with good farming practice (e.g. hemp uses relatively little fertiliser, no pesticides etc). It is thought, however, that the figures used in this study are conservative and the relatively large scale farming that is used in East Anglia to produce the hemp straw is probably more efficient than is displayed here. For example, no reduction in tractor usage has been accounted for even though wider farming tools are used that will reduce the amount of distance travelled by the tractor from the examples used in the data sets. Also included in the Ecoinvent data sets are the manufacture of the farm machinery and the farm buildings. As such it is thought that further studies into specific farming practices would most likely show somewhat lower impacts than are represented here.

If a hemp-based product became popular through increased market demand, the land area under hemp farming would increase. This raises a question regarding how much hemp fibre could be supplied by British farming. For example, in order for hemp-based insulation products to supply the whole of the UK loft insulation market (approx. 6.2Mm^3/year), it is calculated that this would require an 80 tonnes/h straw processing line fed using approximately 12,000 ha of land. This represents only 0.064% of all UK agricultural land. This land use figure also assumes that the insulation product would be produced at the same relatively high density that is supplied currently. The production of a lower density product would require a proportionately reduced amount of crop and land area.

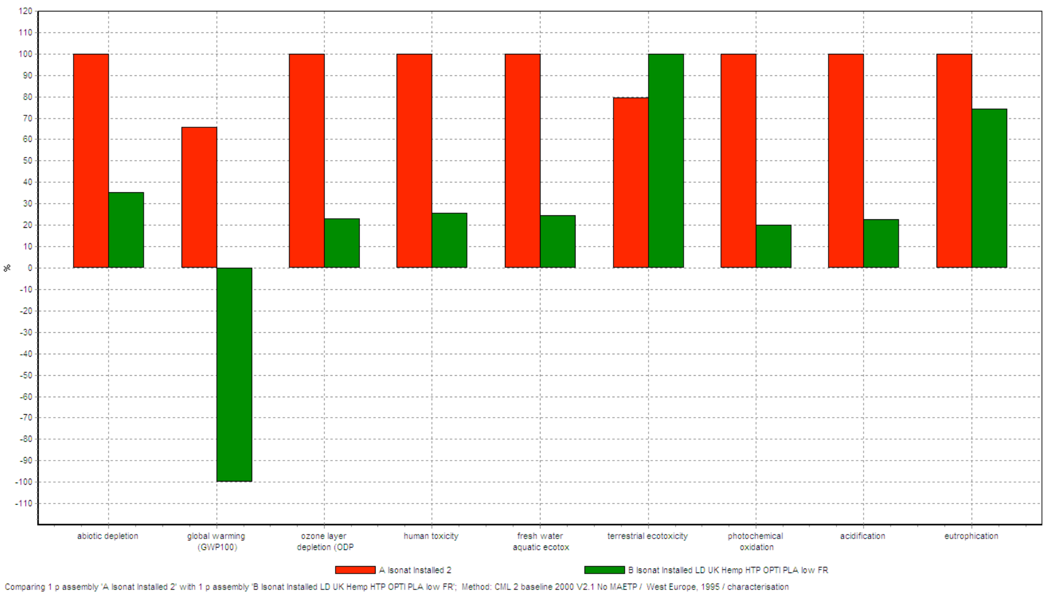
The quantity of fibre produced would also provide some 40,000 tonnes of shive annually. With efficient and economically competitive production, this could provide a notable supply of biomass for local heating and energy plants in line with Government targets for renewable energy. Alternatively it could be utilized in hemp-lime construction techniques which are increasingly popular.

Combination of most likely optimization

A combination of the optimizations described above has been selected to represent the near future potential of a logically optimized product. The optimizations combined are:

- Reduction in product density from 35kg/m^2 to 20km/m^2
- Production in the UK
- A hemp only product, omitting the recycled cotton fibre portion
- Reduced fire retardant usage with consequently reduced drying requirements
- A switch to a PLA-based bi-component binder.
- An increased throughput in primary processing

The result of a combination of the optimizations described above is a very strong environmental profile, see Figure 41.



Comparing 1 p assembly 'A Isonat Installed 2' with 1 p assembly 'B Isonat Installed LD UK Hemp HTP OPTI PLA low FR'; Method: CML 2 baseline 2000 V2.1 No MAETP / West Europe, 1995 / characterisation

Figure 41 Graph to show the effect of a near future combination of optimisation processes

Particularly noticeable in Figure 41 is the very large reduction in GWP_{100} and the product's potential to have a substantial GWP_{100} 'benefit' in this area. This effect is only possible with renewable resources as the carbon locked up in the product is a direct reduction in atmospheric CO_2 . This aspect of long-life NFI materials could prove to be a very strong positive factor in favour of their selection, both by the public and via government procurement schemes seeking to specify products with the lowest possible GWP_{100}. It is not usually possible to achieve this effect with a 'synthetic' material.

Further reductions in impact categories are very apparent across the whole profile with the exception of terrestrial ecotoxicity. This is small increase in this category is caused by the PLA based replacement binder derived from the initial maize farming needed for its production. It is noted, however, that PLA polymer manufacturing processes are currently in a process of intensive modification and optimisation with a view to reducing their environmental profiles.

End of Life Example of near future optimized hemp product

Figure 42 below presents the example future scenario of a composted hemp NFI product alongside those from results with glass and mineral wool insulation materials disposed of by landfilling.

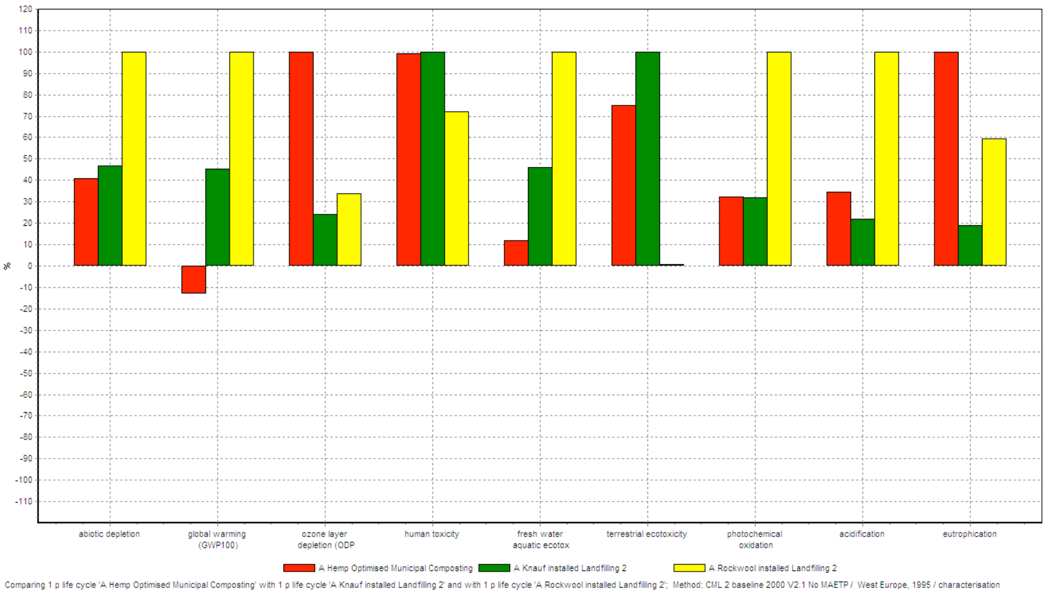


Figure 42 An example future scenario of a composted NFI hemp product and data calculated for glass and mineral wool products with landfilling end of life disposal

A very notable effect shown here is that the "optimized" product still retains its negative GWP_{100} impact as was shown in the cradle to installation results previously (Fig. 41). The example product still performs comparably against the "A" rated benchmark products in most other impact categories.

This is also not intended to suggest that the example modelled here is the 'best' possible hemp fibre based product - it is provided to demonstrate the effects that reasonable processing and product improvements can be expected to have on the overall LCA profile of this type of insulation material. The final choice of which optimisation routes may be adopted in practice will be influenced by a diversity of factors including economic costs, regulatory and market factors, investment and technical development.

Other Comparable Functional Units

Although they are commonly used in cold roof type installations, both Isonat and Thermafleece are supplied in the form of a semi rigid “batt”. This allows them to be used in a number of different applications, including sarking, timber frame stud walls and lining “warm roof” spaces. It is thought that around 50% of the Isonat product is used for wall insulation rather than in cold roof situations (Gary Newman pers. comm.). This is based on the figure that half of all Isonat sales are in the form of 60cm widths as opposed to the 40cm widths commonly used in “between rafter” roofing situations.

Equivalent batts are produced by both Knauf and Rockwool and are much higher in density than their “roll” equivalents. As such, a comparison using the functional unit of a batt will no doubt have an effect on the impact of the conventional materials. This calculation was not however undertaken as it was outside the Functional Unit chosen in the present comparison for which the selected NFI materials represent current practice. This issue has been raised here to stress the importance of clearly recognising limitations imposed by the assumptions and system boundary decisions made in this and indeed any other LCA study.

Final Conclusions and Recommendations

This LCA study has found environmental advantages from the NFI materials in some areas when compared with the provided benchmark data. The main area in which the NFI materials perform well against the benchmarks is that of GWP_{100} due to the renewable carbon sequestered in the material that reduces the amount of CO_2 in the atmosphere. The current Thermafleece product fares comparably to the benchmark products in most other environmental impact categories, except where those products' datasets have little or no impact (as discussed in the sensitivity analysis). It is clear that the higher mass of the Isonat NFI hampers its environmental performance in comparison with the other insulation materials. Conversely, the very low density of the Knauf glass wool insulation material provides it with advantage with regard to its LCA profile.

Marginal analysis has identified that substantial environmental improvements could be realised by limited and reasonable further optimisation of NFI products. Many of these optimizations represent the next logical development steps for this nascent industry as volumes grow. The largest area of environmental impact that NFI can make beneficial contributions to is that of climate change (GWP_{100}). The reason for this is the materials' sequestration of atmospheric carbon dioxide. With certain improvements to the current product, a negative impact (benefit) can be achieved in this impact category. The reason the current products do not deliver this benefit in full is due to present limitations in their manufacture (relying on fossil fuel energy sources) and energy intense additional materials, i.e. the flame retardants and polyester based binders. The main areas for near future improvements are outlined below:

- Replacement of the bi-component polyester binder in both of the natural fibre products is relatively straightforward by using "off the peg" bi-component PLA (Polylactic Acid) materials derived from corn starch (or other carbohydrate sources e.g. sugar cane). Trial runs using this replacement with the hemp based product have been successful technically but the current high cost prevents it from being used in the existing product.

- Reduction in density of both NFI products is possible, especially with Isonat, as its density is much higher than its competitors (it can also be used as a sound insulator). It is thought technically feasible for both NFI 'types' to develop possible additional 'single function' variants optimized on density and with this they will be able, like the Knauf material, to reduce the resources required and their environmental impact.

- The reduction in flame retardant use is also seen as a possible optimization stage. The fibres for both NFI products are dipped in a flame retardant solution and then dried. This gives a very even distribution but for the standards required a surface coating may suffice. Due to the energy intense manufacture of the flame retardants, relatively large environmental impact reduction can be achieved with relatively small reductions in quantities used.

- New technology is being patented by Plant Fibre Technology, the importers of Isonat, that involves very low energy inputs to blend fibres with thermoset binders and the fire retardants. Further development in terms of scaling up prototypes and binder development could well yield large environmental advantages.

- Scaling up production, especially in the UK to supply the UK market, can halve the energy requirements for every doubling in throughput. This can be achieved even using relatively unrefined non-woven textile machinery. This energy reduction has obvious beneficial effects in terms of environmental impact reduction.

R&D support, promotion and government procurement could see great benefits for the NFI materials, not only in technical terms to further enhance their environmental profile but also by boosting their market presence and economic position within it. As with all renewable materials, they have the potential to offer a positive contribution to the issue of global warming through the sequestration of CO_2. As such, further work is recommended to help realise this potential.

All insulation materials are beneficial to the environment because they save energy and reduce global warming potential. However, NFIs have the added benefit that they sequester CO_2, making a further contribution to reducing global warming potential. The authors therefore consider it worthwhile to take advantage of the scope to develop the environmental profile of the NFI materials and to boost their market presence. A range of tools, including R&D support, promotion and Government procurement, are available to this end.

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[N.B. where a reference has been accessed from a web site the date provided is the date accessed rather than the date published.]

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