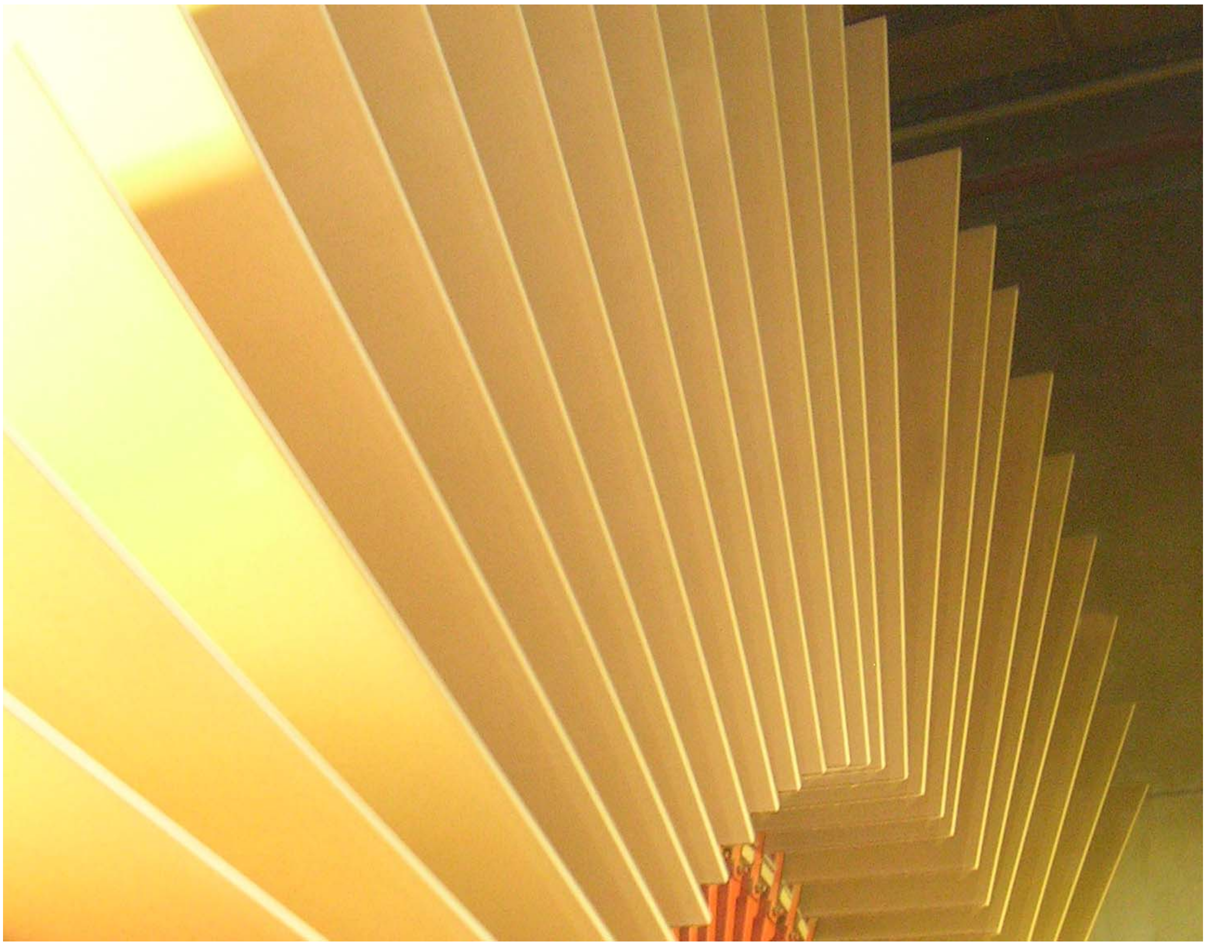
Final Report

Life Cycle Assessment of Closed Loop MDF Recycling: Microrelease Trial



A Life Cycle Assessment of Closed Loop MDF Recycling using the Microrelease Process to Produce Recycled Wood Fibre from MDF Waste

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Written by: Amy Mitchell and Gary Stevens (Gnosys Report number: GR185)

Front cover photography: MDF manufacture, Topan 1 line, Glunz, Meppen, Germany

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Executive summary

In the UK, as in Europe, there is a large demand for wood based panel board materials in many industries, such as construction and furniture manufacture. The annual production tonnage of these materials is significant as is the amount of waste produced during board and furniture manufacture.

The furniture industry consumes 90% of MDF produced in the UK and a great deal of MDF waste is produced, in the form of process waste from MDF production and off-cuts from use in furniture manufacture. This is estimated to be around 18% of all MDF used.

There is an opportunity to undertake recycling of some or all of this waste MDF. The recycling technology considered here is the Microrelease process, which recovers wood fibres from MDF waste using microwave technology. The fibres produced through this technique could be used in a number of added value applications but this report considers their use in closed loop recycling where the recovered fibres are put back into the MDF manufacturing process.

This report presents the results of an environmental life cycle assessment study of the environmental performance of alternative waste management routes and the effects of diverting waste MDF to the Microrelease process. Further, the study examines the effects of using recovered wood fibres on the MDF production process, relative to the case where virgin fibres is exclusively used.

Goal

This study sought to evaluate the environmental impacts of waste MDF in each of the primary waste management routes of energy from waste onsite and offsite and landfill compared with recovered fibres from MDF waste utilising the Microrelease process to supply recovered fibre to new MDF board production, with a recycled content of 10 – 20% by weight.

A large scale MDF manufacturer, Sonae Indústria at Meppen in Germany, has run trials incorporating recovered MDF wood fibre into their MDF production line and data has been taken regarding their plant processes to model this trial and propose the environmental effects of replacing a proportion of virgin fibre, produced in the plant, with recycled fibre. While this trial was carried out in Germany, this study considers the MDF manufacturing process operating in the UK and it therefore uses a UK fuel mix for electricity generation.

Also, bench scale studies, by C-Tech, have been made of the Microrelease process and data from these trials was used to evaluate the small scale process which, with appropriate assumptions, enables larger scale processing to be assessed.

Functional Unit

As the aim of this study was to evaluate whether diversion of waste from current disposal practices to Microrelease and recycling into MDF board manufacture is of benefit to the environment, the functional unit chosen was 1tonne of MDF waste.

However, in order to effectively compare the environmental impact for different approaches to the production of MDF board and recycled Medium Density Fibreboard (rMDF), the study also used a production unit of 1tonne of MDF and rMDF board, where rMDF has been shown to be a technically comparable product in terms its mechanical properties.

Conclusions

This life cycle assessment has examined the environmental impacts of current MDF production and particularly waste disposal routes in an attempt to evaluate the opportunity of diverting MDF waste from landfill and incineration with energy recovery to recovery of the wood fibres for reintroduction into MDF production.

In virgin MDF board manufacture, the fibre production stage has the highest environmental impact. This stage of the process is the most environmentally damaging due to high energy use, chemical additive production and transportation burdens. This suggests that reducing the total requirement for virgin fibres should reduce environmental impacts even though much of the internally generated MDF waste is used to support the production of process heat allowing gas combustion to be significantly reduced or avoided.

In terms of disposal of the MDF waste arising from the manufacturing process, disposal by landfill has the highest environmental impact of all of the waste management options. Energy from waste onsite has the lowest environmental impact of all the disposal routes, as this route may be treated as providing a biogenic fuel source that produces process energy to support the manufacturing process. As this avoids the use of fossil gas, the most common alternative fuel source, a benefit can be claimed in relation to the avoided environmental impacts arising from fossil use to provide the equivalent process energy. Similarly, using onsite facilities to recover energy from waste reduces the transportation burden required to transport the waste to offsite facilities.

On consideration of the Microrelease process for recycled fibre generation, when the avoided processes are not considered, the environmental impacts calculated for the process are higher than that of the 100% landfill option. This is due to the energy consumption of the process. However, if the avoided processes are included, which include avoidance of disposal of the MDF through conventional routes and avoidance of the production of virgin fibre, then over the majority of impact categories the Microrelease process has a smaller environmental impact than any of the other disposal options.

These findings indicate that diversion of MDF waste from incineration and landfill to the Microrelease process will have a beneficial effect in reducing the majority of the environmental impacts arising from MDF manufacture, where the wood feedstock used for MDF production is felled specifically for this purpose. For global warming potential this could amount to a saving of 0.4 tonnes of CO_2 equivalent for each tonne of waste MDF produced.

When the same systems are compared on the basis of the production of one tonne of MDF board, the rMDF 10 and 20% board production, the 10% recycled content MDF board shows reductions in environmental impacts for some impact categories such as global warming potential, eutrophication and the ecotoxicity categories. The majority of impact categories are reduced when the recycled content is increased to 20% rMDF. In this case up to 0.52 tonnes of CO_2 equivalent may be saved for each tonne of finished MDF board produced.

A sensitivity analysis investigated the energy efficiency of offsite energy from waste MDF as a biofuel based on combined heat and power (CHP) in comparison with a similar installation within an MDF manufacturing plant for onsite process heat generation. The CHP scenarios examined included use of waste to produce only heat or only power and also a combination of the two at a notional co-generation level recommended by the European Commission. The results of these scenarios suggested that true CHP producing both heat and power from waste MDF can produce a greater environmental benefit than producing only heat. Producing only electricity from waste MDF combustion shows the highest environmental impacts as this process has lower energy efficiency and also does not include the benefits of avoided gas combustion alongside avoided power generation. On comparison with diversion of waste to the Microrelease process, the scenario for heat and power co-generation from CHP has a marginally lower environmental impact in most impact categories. In contrast, when considering only heat or only power the Microrelease option produces a better environmental performance.

Some possibilities for improvement of the rMDF manufacturing process were also investigated for a variety of options within a sensitivity analysis.

Process Developments and Optimisation

Future developments that could be made to rMDF board manufacture may include reduction of the resin content (typically 11% to 12% was added during the trials to ensure good wetting of recycled fibres) and addition of the recycled fibres as a wet slurry, i.e. removal of the drying stage from the Microrelease process. It was found that there is a positive effect of reduction of the resin content to 10% by weight on environmental impacts; however, it is not large in relation to other production impacts and may be deemed insignificant. A similar effect was seen with the Microrelease changes where removal of the drying stage had the effect of lowering the environmental impacts of the process, however not to a particularly large degree.

Waste Split

The waste split is important as this determines the availability of post-industrial waste MDF for use as a biofuel for process energy production for either the MDF production process or other applications. If all of the waste produced is diverted to the Microrelease process then there would be none available for use as a fuel source and therefore gas combustion would need to be used to produce an equivalent amount of heat.

Three scenarios were considered:

1. 100% of all waste diverted to Microrelease;
2. All of the waste being sent to landfill diverted to Microrelease – with the energy from waste fraction used as a biofuel for onsite incineration;
3. A portion of the waste remains onsite for use as a biofuel (25%) with the remaining going to the Microrelease process for fibre recovery.

The findings indicate that there is likely to be an environmental advantage to diverting MDF waste to the Microrelease process for fibre recovery. Although the economics are not considered in this LCA report, there will be a trade-off between recycling material and using the MDF waste for energy production in off-site co-generation of for on-site process heat production for MDF manufacturing plants, where capital investment in energy from waste infrastructure already exists. Further, there is merit in considering what proportion of this waste should be diverted in order to optimise the environmental performance of individual MDF manufacturing plants.

Disclaimer:
The results contained in this LCA report were generated using bench scale trial data for the Microrelease recycling process.

MDF manufacturing data was supplied, under a confidentiality agreement, from a large scale MDF production plant based in Germany. We believe that the data contained in this report and the results generated are appropriate for application to a similar scale plant based in the UK taking its feedstock from logs felled from sustainable forests specifically for the purpose of MDF manufacture.

This report also notes that waste MDF arises from both MDF board manufacture and from the furniture industry; no account is taken of MDF waste streams arising from other sources, such as construction.

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1.0 Introduction

In the UK, as in Europe, there is a large demand for wood based panel board materials in many industries, such as construction and furniture manufacture. The annual production tonnage of such materials is in the region of 940,000tonnes in the UK[1], and the amount of waste arising is significant at approximately 284,000tonnes per year, produced during board and furniture manufacture.

Medium density fibreboard (MDF) is particularly popular due to the stable, flexible and homogeneous nature of the product. The furniture industry consumes 90% of MDF produced in the UK and a great deal of MDF waste is produced, in the form of process waste and off-cuts. This is estimated to be around 18% (equivalent to 153,000 tonnes) of the MDF purchased[1, 2].

Current waste disposal practices differ with the source of waste, however it can be split into three end fates, which are (i) incineration onsite with energy recovery, (ii) incineration off-site, or (iii) landfill. Each of these disposal practices has associated environmental impacts. There is an opportunity to avoid these impacts through diversion of MDF waste from these disposal options to material recovery and recycling. One option for recycling this MDF waste is through use of the Microrelease process, which recovers the wood fibres from board waste using microwave technology. Although the fibres produced through this technique could be used in a number of added value applications, their being used in closed loop recycling back into the MDF manufacture process was considered to be the most promising application and was therefore chosen for the LCA study. A number of the other possible applications have been investigated and reported on[3].

This report presents the results of an environmental life cycle assessment study of the environmental performance of alternative waste management routes and the effects of diverting waste MDF to the Microrelease process. Further, the study examines the effects of using recovered wood fibres on the MDF production process, relative to the case where virgin fibres is exclusively used.

2.0 Goal

This study aims to evaluate the environmental impacts of waste MDF in each of the primary waste management routes of landfill and energy from waste onsite and also in offsite facilities compared with recovery of fibres from MDF waste utilising the Microrelease process to supply recovered fibre to new MDF board production, with a recycled content of 10 – 20% by weight.

A large scale MDF manufacturer, Sonae Indústria at Meppen in Germany, has run trials incorporating recovered MDF wood fibre into their MDF production line and data has been taken regarding their plant processes to model this trial and propose the environmental effects of replacing a proportion of virgin fibre, produced in the plant, with recycled fibre[3]. While this trial was carried out in Germany, this study considers the MDF manufacturing process operating in the UK and it therefore uses a UK fuel mix for electricity generation. The Sonae plant is considered to be representative of large MDF production plants within the UK, where the feedstock used is sourced from trees felled specifically for this purpose from sustainable forests.

Also, bench scale studies, by C-Tech[4], have been made of the Microrelease process and data from these trials is used to evaluate the small scale process which, with appropriate assumptions, enables larger scale processing to be assessed.

3.0 Scope

3.1 Product system

In this study, a closed loop system of recycling MDF waste back into MDF production, via the Microrelease process, will be evaluated. The current disposal practices will be examined to assess the effect of diversion of MDF waste to such recycling via the Microrelease process.

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[1] *Personal correspondence with Wood Panel Industries Federation (WPIF) (numbers from 2006)*

[2] *Personal correspondence with Furniture Industry Research Association (FIRA) (numbers from 2007)*

[3] *WRAP Report: Demonstration of end uses for recovered MDF fibre, WRAP project: MDD005, March 2008*

[4] *"Final Report: Investigation of Dielectric Processing for Recycling of MDF",* C-Tech Report (Number CT1176), August 2007

3.2 Functional unit

As the aim of this study is to evaluate whether diversion of waste from current disposal practices to Microrelease and recycling into MDF board manufacture is of benefit to the environment, the functional unit chosen is 1tonne of MDF waste.

It is assumed that the waste is generated from either the MDF manufacturing process or from furniture manufacture and therefore consists of untreated board which has not been painted or varnished. The study does not include post-consumer or post-construction waste.

In order to effectively compare the environmental impact for different approaches to the production of MDF board, the study also uses a production unit of 1tonne of MDF board.

3.3 System boundary

The systems included in this study are shown in detail in Figure 1.

The MDF manufacturing process is split into two stages, the first of which is the wood fibre generation and preparation stage. In this stage logged trees are the raw material supply to the process. These are felled from sustainable forestry sources specifically for MDF manufacture. They are transported to the manufacturing plant where they are chipped, washed and converted into wood fibres. This is followed by drying and sifting before moving onto the second stage of board production.

Stage two involves board production by first forming the fibres into a uniform mat followed by two compression stages to produce a defined density and thickness of board material. Finally, the board is sanded as a finished product and cut to size for distribution. These two stages have been integrated by aggregating the process data involved to protect the confidentiality of Sonae's process information. This particular split has been chosen as it falls naturally where the insertion of the recycled fibres will take place, after fibre sifting.

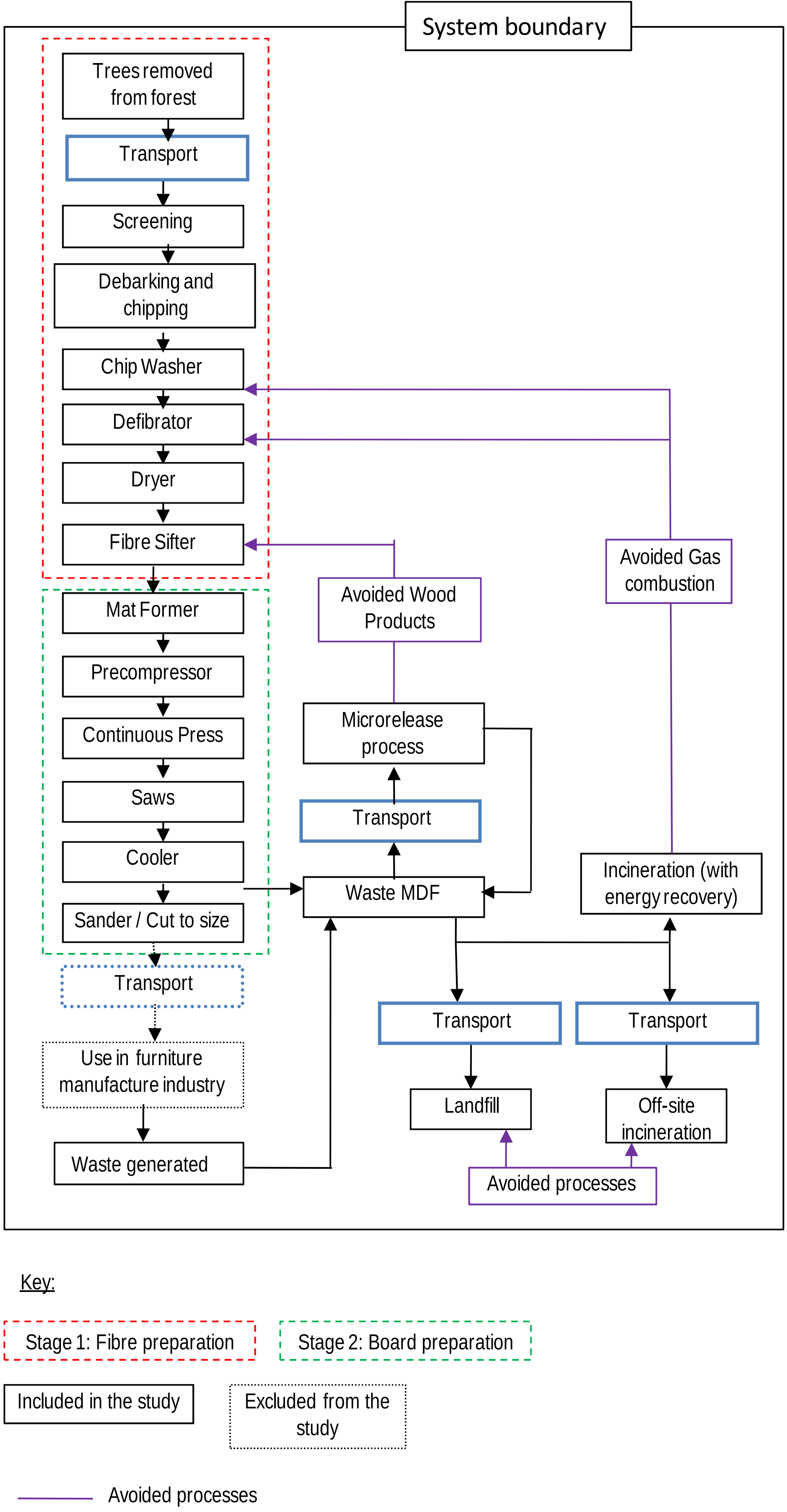
Included in the system boundary is the waste generated by MDF production and the current and proposed disposal routes, including diversion to the Microrelease process and subsequent reintroduction of recovered fibres into MDF manufacture.

This study excludes all activities related to the use of the MDF board in the furniture manufacture industry. Any transportation of finished board from the MDF plant to its customers is excluded from this study. However, transportation of waste MDF from the furniture manufacturing site to a site of disposal is examined in Section 6.4.

These stages are discussed in more detail in Sections 4.1 and 4.2.

The avoided processes are also outlined in the system boundary diagram, which includes avoidance of gas combustion for heat generation where MDF waste is used as a fuel source. An additional avoided process is the generation of fibres through the virgin MDF manufacture route, i.e. through chipping trees and subjecting these chips to defibration, where recycled fibres are being introduced to the production line.

Figure 1 System boundary for MDF manufacture and waste management.



3.4 Allocation

Allocation is used to designate environmental loads between different parts of a system, which, ideally, should be avoided through closer scrutiny of the system or through system expansion. However, in some cases this may not be practical, for example, when a sawmill produces lumber and bark as products from a single piece of wood, the energy use must be distributed (or allocated) between the two products. In this example, the bark may not be a product, but a waste and so in this case it may be appropriate to allocate all impacts to the lumber.

While in some cases of smaller MDF manufacturing plants the raw material input into the process may be waste wood or wood by-products from other processes, the large scale MDF board manufacturing examined in this study sources the majority of its raw wood from trees cut for purpose. Raw material supply is primarily logs, which may be debarked and then chipped on-site as part of the process but it may also consist of some pre-chipped wood. One of the processes involved in MDF production is the debarking of soft wood logs prior to chipping. This produces a by-product in the form of bark. This is more valuable as a resource, rather than a fuel source, and so it is not used in energy from waste but is sold for agricultural uses. The impacts of the debarking processes, in this study, are allocated 100% to the MDF process, this is due to the confidentiality agreements in place which do not allow for disaggregation of the fibre preparation processes. However it is believed that the debarking process is a low energy processes and so the impacts of this stage are considered to be relatively small.

Allocation is also of relevance to the use of recycled materials. Several methods are commonly used to deal with recycling, such as the avoided burdens approach, the cut-off approach, and consequential studies. In this report the avoided burdens and processes approach is used.

There are a number approaches towards the allocation and management of carbon when conducting an LCA study utilising biomass/wood. These methods may include detailed options accounting for carbon sequestration and storage and also carbon management. Due to the relative youth of large scale MDF production and the management of forests in relation to tree growth ratios these evolving methodologies were purposely omitted from this study for the sake of simplicity. Future work in this area might investigate these methods further where appropriate.

The waste MDF examined in this study comes from two sources, (i) The primary focus of MDF board production process – usually supplied as waste from the production process, and (ii) the furniture manufacturing industry. These industries contribute differing amounts to the total MDF waste produced annually and these details are shown in Table 1 and Table 2.

Table 1 Breakdown of waste streams in the UK for MDF manufacture and use in furniture industry per annum[5]

Total tonnage of MDF manufactured in UK	941,666tonnes
Market for MDF board in the UK furniture industry [a]	847,500tonnes
Waste generated from MDF board manufacture (at 14% of board produced)	131,336tonnes (46% of total MDF waste)
Waste generated from furniture manufacture (at 18%, minimum, of board used)	153,000tonnes (54% of total MDF waste)
Total waste generated	284,336tonnes

Table 2 shows the details of the current MDF waste disposal routes for these two industries in the UK.

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[5] "*Evaluation of waste production, utilisation and brokerage potential within the UK furniture industry*" FIET (Furniture Industry Environment Trust) (2002)

Table 2 Breakdown of disposal routes in the UK for the MDF waste coming from differing waste streams

	Waste stream		
Disposal route	MDF manufacture	Furniture manufacture	Total
Landfill	36,774tonnes [a]	107,100tonnes [b]	143,874tonnes
Incineration (with no energy recovery)	0tonnes [a]	36,720tonnes [b]	36,720tonnes
Incineration (with energy recovery)	94,562tonnes [a]	9,180tonnes [b]	103,742tonnes

[a] Source: WPIF (2006) and FIRA (2007)

[b] Figures estimated using split of 70% waste to landfill, 24% waste to incineration offsite, 6% waste to incineration with energy reclaim onsite, from WRAP report[6]

The furniture industry generates the highest proportion of waste MDF at ~54%, while the remaining 46% comes from MDF manufacturing industry.

The functional unit of this study is 1tonne of MDF waste and the waste disposal options are considered as the environmental impacts of sending 100% of this waste to landfill, energy from waste (onsite and offsite) and also of diverting 100% of this waste to the Microrelease process.

It is also appropriate to consider the aggregated position for the disposal of 1 tonne of MDF waste, which reflects current disposal practices using an allocation of ~540kg with furniture manufacture and ~460kg with MDF manufacturing is appropriate and the differing end fates for the waste from these producers, as shown in Table 2. This is important as the waste disposal routes for these two industries are different and so the relative contribution to each waste management route can be correctly assessed.

3.5 Assumptions

This study is based on MDF fibre recycling trials carried out at Sonae Indústria, at Meppen in Germany. The scale of these trials was small, utilising 2tonnes of recycled fibres to produce 20tonnes of rMDF (recycled MDF) board with a 10% by weight recycled fibre content. The recycled fibres were added manually to the production line, i.e. no additional processing equipment was required. These conditions are used in this study as no information exists for mechanical or automated feeding of fibre at this point in the manufacturing process.

Also while the study was carried out at Sonae, a German facility, the data collected from Sonae during the trials is used but "translated" to the UK, i.e. the process requirements are assumed to be the same as would be found in a larger UK facility but the energy sources come from the UK energy mix, rather than that in Germany. The actual energy mix used in this report is broken down and shown in **Table 3**[7].

Table 3 Energy mix for the UK

Energy source	Percentage contribution
Hard coal	33.42
Oil	1.15
Natural gas	40.09
Industrial gas	0.99
Hydropower	1.99
Nuclear	19.59
Wind	0.52
Cogeneration	0.99

For the Microrelease process there are a number of process possibilities for releasing the wood fibres from waste board material according to the trials run by C-Tech[4]. The trials were performed on a laboratory scale, leading to the production of approximately 2tonnes of recycled fibre, so the amounts of raw material used were not large

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[6] *"Evaluation of the market development potential of the waste wood and wood products reclamation and reuse sector"* WRAP (2004)

[7] *EcoInvent database, Version 2.0*

however the “immerse then Microwave” process was the lowest energy option, and had the highest efficiency and best ease of use – this process involves immersion wetting of the MDF prior to microwave processing of the wet MDF. An alternative method investigated in the C-Tech study was the “Immerse and Microwave” method, which involves immersing the MDF waste in water and then Microwaving the MDF whilst submerged, i.e. microwave heating of the water which contains the MDF. While this method may be useful for future process developments, it was found to have a much higher energy demand, so the more energy efficient “Immerse then Microwave” route was chosen. Due to the scale of the process and the general efficiency of conversion of MDF board to recycled fibres there is no reported mass lost in the process. This may be different in a pilot and full scale plant where larger tonnages processed may lead to greater waste burdens, however no data currently exists to model this and it is the authors opinion that the losses would be insignificant, as waste material would be recycled into the process, so it is assumed in this study that no process losses occur.

In this study, the data used was taken from the “Immerse then Microwave” Microrelease process.

Incineration of waste MDF for energy recovery, in the form of heat rather than electricity, is used as a waste disposal option and it is necessary to know the amount of energy available per unit of waste. The heat value of wood varies with species, however on average it is 15MJ/kg. This value is the amount of heat generated for complete incineration of wood with a 100% heat conversion efficiency[8]. The MDF board being considered as a fuel source does contain a small, 10%b.w., fraction of formaldehyde resin which also has a calorific value to contribute to the energy recovered from combustion of this waste. However, it is assumed that at these low concentrations, the contribution would be minimal and so is not taken into account in this study.

In many incinerators a 100% heat conversion efficiency is not achieved. An 80% conversion efficiency is at the top end of wood burning incinerator efficiency and will be used as standard in this study[9]. If the incinerator is operating at 80% efficiency then the energy available for use is assumed to be 12MJ/kg of waste MDF. This energy can be used in place of the combustion of gas or oil resulting in a benefit through “avoiding” the combustion of fossil fuels. For energy from waste facilities both onsite and offsite it will be assumed that the heat produced will replace an equivalent amount of heat produced through gas combustion. A sensitivity analysis will be undertaken to investigate the types of energy recovery available for wood and biowaste, from incineration with heat recovery to combined heat and power cogeneration (CHP).

Another important assumption made in this report is that MDF waste is treated as a biogenic fuel source. Wood and other biomass fuels are seen as preferential renewable options to fossil fuels due to the nature of the CO_2 emitted on combustion. For biogenic fuels this CO_2 is classified as biogenic-CO_2 and is treated as though it has zero global warming potential impact. This is because it is assumed that these fuels are sourced from sustainably managed forests or farms and that the CO_2 emitted through combustion of the fuel is the same amount as that taken-up during tree growth[10,11]. Further, as the MDF waste is considered clean, then hazardous waste treatment requirements do not apply.

A final assumption made in this study relates to the water content of the recycled fibres produced by the Microrelease process. It has been found in the Microrelease trials that the fibres produced through the process contain a higher water content, relative to the normal water content of MDF board ~8%b.w. For simplicity, it is assumed that 1tonne of recycled fibre can be used to displace 1tonne of virgin fibre in rMDF board production as it is possible that during the time between production of recycled fibre and it being fed into the production line, the excess moisture in the recycled fibre may be lost.

3.6 Limitations

An imposed limitation in this study is the source of the waste being used. It has been assumed that all the waste being used is post-board manufacture and post-industrial, but the latter coming only from the furniture industry. This waste is assumed to be completely untreated, with no surface coatings as was used in the C-Tech trials. It is

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[8] Renewable energy holdings website: http://www.reh-plc.com/projects_bioenergy.asp and Hearth .com articles: *“Heating value of common wood species”* http://hearth.com/econtent/index.php/articles/heating_value_wood, date accesses 24/09/08

[9] *“Benchmarking wood waste combustion in the UK furniture manufacturing sector”* , February 2005, BFM Ltd.

[10] *“UK Biomass Strategy”,* Defra/DTI/DFT report, May 2007

[11] *“Waste Wood as a Biomass Fuel”,* Defra report, April 2008

feasible that some of the waste that would be imported to large scale Microrelease plants would be uncoated – coming from furniture manufacturers that use uncoated MDF in their production. In the future it is anticipated that the Microrelease process could be used to recover fibre from MDF waste that is coated and also sourced from the construction industry and other sources. In this case it is likely that there would be an additional waste fraction from the Microrelease process, however as no data currently exists for this, and what the fate of any waste arising due to coatings would be, it has not been included in this study.

A further limitation of this study is the data available from the C-Tech trials on the Microrelease process. As previously mentioned the scale of the trials was small laboratory sized samples. Larger scale fibre production was carried out to produce feedstock for the Sonae trials, however this data was not recorded. As a result, the data used for this life cycle assessment came from small scale trials it is therefore unlikely to be representative of a pilot or large scale Microrelease process. It could be assumed that after scaling up the process to pilot scale there will be optimisation of the process to reduce energy use and waste outputs, however as no data for this exists currently this cannot be accurately modelled except as part of a sensitivity analysis.

Due to lack of data on the decomposition of MDF waste there is no information on the emissions produced through landfilling this waste, with regards to the chemical additives and their effect, in addition to that of the wood component. As such it was necessary to use Ecoinvent database information on the decomposition of generic untreated wood in landfill, which includes landfill gas (LFG) recovery, in place of decomposition of MDF waste.

As with any LCA, the impacts described are potential impacts. A prime example is the category “acidification potential”. In this case, the magnitude of the impacts are dependent on the source – pathway – receptor relationship. If the receiving environment is not susceptible to acidification, the impact will be different to an environment which is sensitive to this.

3.7 Data and data quality requirements

The ISO 14044 (2006) standard sets a range of data quality requirements for any life cycle assessment study.

3.7.1 Technology and Geography

While the Microrelease process is a developing technology, primary data was taken directly from laboratory trials, which were performed in 2007. In contrast, MDF production is a developed technology and the Sonae plant in Meppen represents a very efficient process which produces very little waste and utilises waste incineration for energy production onsite. Data for MDF manufacture was provided by Sonae, gathered specifically for this study in 2007 and it represents this particular modern plant located in Germany. It is assumed that the process would be the same for large scale MDF producers in the UK and so the energy requirement and material input data is assumed to come from the same source, however the energy mix used will be that in the UK not Germany.

Where necessary, secondary data from the databases within SimaPro was used, where the data is no older than ten years or has been updated within the last ten years.

3.7.2 Timescales and data sources

Information on the UK production volume and waste disposal position was taken from industry sources including the Wood Panel Industries Federation (WPIF) and FIRA.

Industry data has been collected during the course of this work and so represents the most up-to-data position possible for 2007 to 2008.

Data for the disposal of waste are taken from a variety of credible sources including published literature and life cycle inventory databases such as the Ecoinvent database.

Data for transportation calculations have been taken from the EcoInvent database and the specific vehicles used are specified in the text as identified by Sonae as to the load delivered of each material. For the transportation database entries used, the Euro IV emissions limits have been applied.

In terms of transportation involving waste vehicles at landfill sites, the EcoInvent database entry specifies a number of transportation burdens which have also been applied.

3.7.3 Completeness and Representativeness

Where there are concerns about specific datasets, the study will assess these and draw comparisons with literature and databases as appropriate. All data used meets the preceding criteria and reflect the situation in the UK. The method and data are described in sufficient detail to allow an independent practitioner to reproduce the results contained in this report.

3.8 Inventory analysis

The life cycle inventories compiled for this study are built up from the inputs and outputs of the processes shown in the system boundary schematic, Figure 1. These inputs may be material or energy and all have environmental relevance, as do outputs (emissions) and waste. The flow of these materials is recorded, for each process in the system, and summarised across the entire system to form the life cycle inventory.

3.9 Impact assessment

SimaPro 7.1 LCA software has been used to model environmental impacts in this study and to generate the life cycle inventories and impact assessments on which the conclusions are based. Datasets used in the course of this work include the EcoInvent processes database, which has also been used for the energy mix for the UK and transportation impacts.

In this study the CML 2 baseline-method characterisation factors have been applied and the following impact categories have been assessed:

- Abiotic depletion potential
    - This is the use of non-renewable resources, such as oil, natural gas, coal, and metals
- Global warming potential (GWP)
    - This is the measure of how much a given mass of greenhouse gas is estimated to contribute to global warming relative to the same mass of Carbon Dioxide
- Ozone layer depletion (ODP)
    - This is a measure of the release of chemicals that are thought to reduce the amount of ozone in the stratosphere
- Human toxicity
    - This is a measure of the effect of the emissions of a life cycle or product on human health
- Ecotoxicity – in terms of fresh water aquatic, marine aquatic and terrestrial
    - This is a measure of how chemicals affect the environment and the organisms living in it, specific to different environments (i.e. land based and water based)
- Photochemical oxidation
    - This is a measure of the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems, and which may also damage crops
- Acidification potential
    - This is a measure of the ability of certain substances released to build and release H+ ions which have a damaging effect on the environment
- Eutrophication potential
    - This is a measure of the impacts to the environment due to excessive levels of macronutrients caused by emissions of nutrients to air, water and soil.

These impact categories are midpoint impacts and are determined through aggregation of data on emissions to potential impacts in various categories. An example of this is in the case of global warming potential. It is measured in terms of CO_2 tonne equivalents and is contributed to by a number of air borne emissions. Carbon dioxide itself is a contributor as is carbon monoxide and methane. The impact factor weight assigned to these chemicals depends on their impact on global warming relative to the impact of CO_2 emissions, i.e. CH_4 has a higher impact than CO_2 by a factor of 25.

Using the midpoint impacts does not provide any insight into assessing the endpoint impacts of the process. These are typically grouped in terms of loss of biodiversity, damage to human health *etc*. but these are not examined in this study.

3.10 Critical review panel

The critical review reported in the annexes was performed by a panel comprising:

- David Fitzsimons, Oakdene Hollins (chair);
- Bernie Thomas, ERM

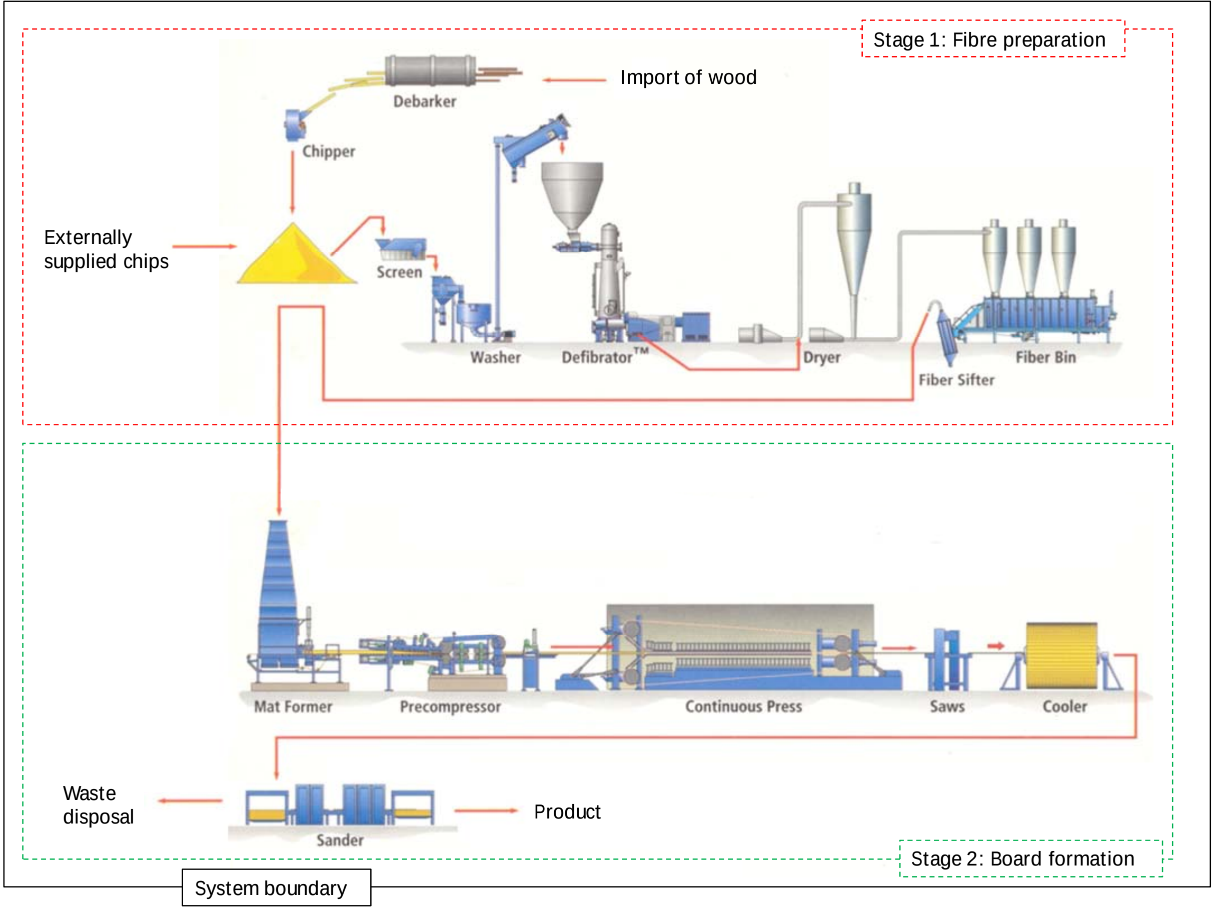
4.0 Inventory analysis

4.1 Virgin MDF (vMDF) production

It is important to examine the current position with regards to MDF manufacture and waste disposal and to have a benchmark to compare the case of utilising recycled wood fibre against current end of life fates.

Figure 2 shows a more detailed schematic of the MDF production process. This process is broken down into two stages as described previously, the fibre preparation stage and the board formation stage.

Figure 2 MDF production process



4.1.1 Stage one: Fibre preparation

As previously discussed and detailed in Figure 1 and 2, the fibre preparation stage begins at import of the raw material into the production plant. This is imported typically as logs, felled specifically for MDF production or as pre-chipped timber.

The logs imported to the plant are both hardwood and softwood. Softwood logs, such as pine, spruce, fir and larch make up 66% of the wood input into the process and are debarked prior to chipping. The removed bark is sold for agricultural use rather than used as a biofuel as it more valuable for sale as a by-product than as a fuel. Hardwood logs, such as poplar, make up 25% of the wood input and these logs are not debarked prior to chipping. Already prepared imported wood chips make up the remaining requirement for timber, 10% of the total required, for fibre production on-site. The impacts of forestry by-products are not included in the life cycle, only the felled logs are used[12]. The energy requirements for felling the trees is included and also the burdens associated with transporting the felled trees the short distance from the site at which they are felled to the forest road for collection and transportation to the MDF manufacturing plant.

All of the wood (logs and chips) imported comes from a radius up to 150km around the plant at Meppen with an average distance travelled of 75km.

The debarking process involves large electric motor driven rotating drums knocking the bark off the softwood logs. The hardwood logs are not debarked as this is more difficult and requires more energy, which is thought not to be cost effective. After debarking all of the logs imported are chipped. These chips are added to the stock of chips coming from other sources and these are then fed into the screen to remove contaminants, such as grit, prior to defibration. A small amount of metal is removed from the chip, which is sold to scrap merchants for reuse.

The chips are washed and then introduced to the defibration process. This involves initial pre-steaming to soften the chips, followed by heating and softening and then mechanical breakdown of the chips to produce wood fibres. The energy requirements for all steps described in these paragraphs are shown in Table 3 as an energy input into the life cycle. The energy used is grouped together and displayed as energy requirements from electricity use, and gas or wood waste combustion.

As the fibres travel to the dryer from the defibrator, additives are introduced into the process. The additives used for the MDF board trial were urea/formaldehyde resin (UF resin) and paraffin. The UF resin is added at 11% solid material by weight of fibre, the resin is introduced as an aqueous solution, 65% solid in water. The paraffin is similarly diluted and is supplied to the plant at 60% concentration and is introduced to the fibres at 0.75% solid paraffin by weight of fibre.

The additives imported to the plant are tankered to the site; the UF resin travels 76km from the Netherlands and the paraffin travels 245km from Hamburg, Germany in 40tonne trucks.

After addition of the additives to the fibres the treated fibres are dried in a hot air vortex, some of the heat for which is supplied by incineration of waste MDF onsite, and sifted into fibre storage bins prior to use in board formation.

Table 4 shows the inputs and outputs of these first stages of the MDF manufacturing process.

Table 4 Inventory data used in assessment of environmental burdens of Stage 1: Raw material supply for production of 1tonne of virgin MDF fibre

Inputs			
Materials (kg):		**Transportation:**	
Softwood logs	589.54	Wood components	75km
Hardwood logs	220.63	UF resin (at 65% b.w. conc.)	76km
Softwood wood chips	88.25	Paraffin (at 60% b.w. conc.)	245km
Urea/formaldehyde resin	110	**Energy required (kWh):**	
Paraffin	7.5	In the form of electricity	389.5
		From gas combustion	773.3
		From wood waste combustion	466.7
Outputs			
Materials (kg):		**Avoided process (kWh):**	
Prepared fibres	1000.0	Gas combustion	466.7
Bark (for agricultural use)	15.92		

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[12] *Information gathered through personal communication with Sonae*

Water use in the fibre preparation stage has not been included in the impact assessment as, from the data gathered from Sonae, water used in all the processes is recovered through filtration and water cleaning, and reused. This is an efficient process, however some top-up is required to make up for evaporative losses and this additional water requirement is sourced from near-by rivers. On breaking this down to water required as a top-up per tonne of fibre prepared, the amount is minimal and has not been included in the analysis.

4.1.2 Stage two: Board formation

The second stage in the process uses the pre-treated fibres and produces, through a mat former and a sequence of presses, the MDF board.

Initially the dry fibres are allowed to settle gravitationally into a mat in the mat former. The mat produced is introduced to a precompressor, where pressure is applied without heat. This presses the fibres into a more board-like structure. The next stage is pressing the board under heat to activate the resin to bind the fibres together – the compression applied controls both the density and the thickness of the board.

This stage in the process is less complex than the fibre preparation stage with only one input, the dried fibres, and simple processing. Included in this stage of production are the emissions and waste streams, which are limited. Waste is generally in the form of dust particulates produced in the processing of the fibres and boards and ash from the incinerators, which is disposed of in landfill. An additional waste stream considered is the treatment of the waste water, which is treated internally and then disposed of to the local sewage system.

UK estimates for waste MDF produced for disposal in the production of MDF board amounts to 140kg per tonne of MDF manufactured and this waste is incinerated onsite for energy production primarily for process heat with a small amount sent to landfill.

Table 5 shows the inputs and outputs of this stage in the manufacturing process.

Table 5 Inventory data used in assessment of environmental burdens of Stage 2: Board formation, for the production of 1tonne of virgin MDF board

Inputs			
Materials (kg):		**Energy required (kWh):**	
Fibres prepared	1000	In the form of electricity	106.7
		From gas combustion	266.6
Outputs			
Materials (kg):		**Waste for disposal:**	
MDF boards (750kg/m^3)	860	Ash/particulates/dust for landfill	1.8g
		Wood sludge for land farming	24g
		Waste water	0.318m^3
		Waste MDF	140kg

4.1.3 Stage three: Waste disposal

Waste disposal is the third stage in the life cycle of virgin MDF production.

The environmental impacts of the disposal options for MDF waste arising from MDF production, will be considered in terms of comparing the impacts when 100% of the waste is sent to landfill or energy from waste options, both onsite and offsite.

The effects of the current waste disposal options for MDF production plants will also be considered. Table 2 shows that 72% of waste produced from MDF manufacturing in the UK goes to onsite incineration with energy recovery and 28% goes to landfill. The portion used for energy recovery is assumed to avoid gas consumption for the amount of energy produced. With regard to the amount going to landfill, the transportation burden is included in the assessment and the distance to the landfill site is assumed to be 30km from the process plant. The waste is transported to landfill utilising a 28tonne lorry and similarly the same vehicle type is used to transport MDF waste to offsite energy from waste facilities at a distance of 60km.

When utilising energy from waste there is the opportunity to use the energy provided to displace another method of energy production. In this report it is assumed that energy from waste replaces heat production through combustion of gas. As stated in the Assumptions section of this report, it is assumed that combustion of 1kg of waste MDF will result in the production of 12MJ of energy. Therefore combustion of 1kg of waste MDF will result in the avoidance of production of 12MJ of heat energy through gas combustion.

The impacts of disposal of the waste arising from the furniture manufacture industry will be considered in a sensitivity analysis, to examine the effects of the additional transportation burden.

4.2 Microrelease process

The Microrelease process provides an alternative route to the use of waste MDF. It utilises microwave heating to assist in the recovery of wood fibre from MDF. The fibres reclaimed can then be utilised in various applications, including being used to produce MDF boards containing a portion of recycled fibres. In the future it may be possible to produce wholly recycled boards.

The Microrelease process under consideration consists of the following stages:

- Shredding and separation of waste MDF board

After receipt of the waste MDF by the Microrelease plant, the first stage includes shredding and sorting of the feedstock. Shredding the waste MDF board to manageable size releases dust and also frees any metal contaminants from the MDF. These cannot be used in the Microrelease process and are currently disposed of to landfill. Unfortunately, information on the processes included in this first stage does not exist as the scale of the trials was too small to require automated or mechanical shredding and did not produce large quantities of waste.

An estimate of the energy requirements for the shredding stage can be made by examining equipment currently available which is able to perform this function and operate at the scale-up capacities required. One such example is a shredder with the capability to process enough waste wood that is more than adequate for this application. It would be driven by a motor utilising diesel as a fuel with an approximate consumption of 1.33kg of fuel per tonne of MDF waste shredded[13]. In an integrated MDF manufacturing plant this technology might be replaced with an electric drive shredder.

- Immersion

Waste MDF board fragments are immersed in water to allow water uptake prior to microwave heating. The temperature of the water prior to immersion is 98°C and the board is immersed for 300seconds. Energy requirements for this immersion in hot water are 159kWh/tonne. Water uptake has been found to be 93kg per tonne of waste MDF board. The water used in the immersion stage will be cleaned and recycled within the process. Any slurry or solid residue removed from the water will be disposed of, to landfill.

- Microwave Release

This stage involves heating the wet board fragments in a microwave field which causes the board section to swell and the fibres to be separated for reclaim. The temperature in the microwave cavity has been measured as 101.5°C and the electrical energy consumption for the microwave process has been measured at 303kWh per tonne of waste MDF board. In the trial production carried out by C-Tech, 2480kg of wet MDF material was taken from the immersion stage (including the water soaked up during immersion) and this yielded 1000kg of notionally dry fibre – note: even when dried the fibre will retain 8%b.w. or more of water under ambient conditions.

- Separation and drying

Separation of the fibres after immersion and microwaving is achieved through mechanical separation of the fibres in a way that the fibres are not damaged or broken. The fibres are then dried. This is the most energy consuming stage in the process, requiring 963kWh/t of board input. Any water collected from the drying process will be cleaned and recycled in the immersion stage and the dried fibres are collected ready for shipping to the end user. After drying 1093kg of dried products are produced, this is expected to contain a greater percentage of water than the MDF waste fed into the process, and is estimated to be 16% in excess of the water contained in the MDF waste fed into the process. Due to the small scale nature of these trials and the laboratory apparatus used, there is no data available for the evaporative losses incurred through these activities. On a large scale it is assumed that appropriate facilities would be in place to minimise water losses through evaporation and to recycle

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[13] Data taken from correspondence with recycling equipment providers, November 2008

as much, if not all, of the water back into the process. For the purposes of this study, it is assumed that there are no evaporative losses.

This data is based on small scale trials to find the best and most efficient process for fibre reclamation. The trials were run with the objective of proposing the best procedure for use in the pilot plant, where this process will be scaled up to produce 2 to 6tonnes of reclaimed fibre per day.

The inventory data for the Microrelease process is shown in Table 6 where the data is taken from the laboratory trial results but scaled up to utilise the 1000kg of waste MDF produced.

Table 6 Inventory data used in assessment of environmental burdens of the Microrelease process; based on C-Tech trial data, scaled up to utilise 1tonne of MDF waste

Inputs			
Materials (kg):		**Energy required:**	
MDF waste	1000	from Gas (kWh):	
Water, process	1478	Heating of water for immersion stage	159
Transportation:		Fibre drying	1052
16 tonne Lorry (km)	30	From National Grid (kWh):	
Fuel (kg):		Microwave separation of fibres	331
Diesel for fuelling the shredder	1.33		
Outputs			
Materials (kg):		**Pollutants (mg):**	
Microreleased fibre	1000	Suspended solids	482
		Formaldehyde	67
		Waste water (m^3)	1478
Avoided Processes			
Waste disposal by incineration*	720kg	Fibre preparation stage (production of virgin fibres in MDF board manufacture)	1000kg
Waste disposal by landfill*	280kg		

* This position reflects the current practice for disposal of MDF manufacture waste

4.3 Recycled MDF (rMDF) production

rMDF board is produced using essentially the same production process used in virgin MDF board production. The differences are the material inputs and the process energy sources. In rMDF manufacture the recycled fibres produced by the Microrelease process are used to replace a portion of the virgin prepared fibres. Therefore to produce the same volume of board there is lower requirement for virgin fibre preparation, so this can be treated as an avoided process. The second difference between vMDF and rMDF manufacture is the source of the energy or heat used. In vMDF manufacture there is a proportion of the process heat requirement which is met by waste MDF incineration. In rMDF manufacture it is assumed that all of the MDF waste produced is diverted to the Microrelease process and so is not available for incineration for heat recovery. As such the portion of energy provided by waste incineration in vMDF is replaced with gas combustion in rMDF production. This is investigated further in a sensitivity analysis, Section 6.2, as the diversion of 100% of MDF waste to the Microrelease process may not be optimal for reduction of the environmental burdens of MDF or rMDF production as this would remove the relatively “environmentally friendly” fuel source from the process because MDF waste can be treated as a biofuel, in comparison with fossil gas combustion.

Similar to the processes detailed in Sections 4.1.1 and 4.1.2 the inventory data for the fibre preparation and board formation stages are shown in the Tables 6 and 7 below.

During the trials at Sonae it was decided to add an additional 1% mass fraction of the urea/formaldehyde resin to ensure thorough wetting of the recycled fibres and therefore good mixing with the virgin fibres and production of a homogeneous board.

The environmental impacts of using the recycled fibres in MDF board production are considered in terms of 1tonne of displaced virgin fibre.

Table 7 Inventory data used in assessment of environmental burdens of raw material supply for production of 1tonne of rMDF without use of energy from waste MDF

Inputs			
Materials (kg):		**Transportation:**	
Softwood logs (at forest road)	524.68	Wood components	75km
Hardwood logs (at forest road)	196.36	UF resin (at 65%b.w. conc.)	76km
Softwood wood chips	78.54	Paraffin (at 60%b.w. conc.)	245km
		Energy required (kWh):	
Urea/formaldehyde resin (@12% weight)	108	In the form of electricity	389.5
Paraffin	6.75	From gas combustion	1240
Outputs			
Materials (kg):			
Prepared fibres	900		
Bark (for agricultural use)	14.3		

In the board production stage the recycled fibres from the Microrelease process are introduced, replacing a proportion of the virgin fibres produced in the fibre preparation stage. Table 8 shows the inventory data when using 100kg of recycled fibres to produce a 10% recycled MDF board. It is assumed that there is a direct replacement of 100 kg of virgin fibres with 100 kg of recycled fibres to produce 10% recycled MDF board which has the meets the same requirements for MDF board as the virgin board, i.e. has the same physical/mechanical properties and visual characteristics.

Table 8 Inventory data used in assessment of environmental burdens rMDF Board formation, for the production of 1tonne of virgin MDF board with 10% by weight recycled fibre

Inputs			
Materials (kg):		**Energy required (kWh):**	
Fibres prepared	900	In the form of electricity	106.7
Microreleased fibres	100	From gas combustion	266.6
Outputs			
Materials (kg):		**Waste for disposal:**	
MDF boards (750kg/m^3)	1000	Ash/particulates/dust for landfill	1.8 g
Avoided products (kg):		Wood sludge for land farming	24 g
Fibres prepared	100	Waste water	0.318m^3
		Waste MDF	140kg

5.0 Impact assessment

5.1 Virgin MDF Production and Waste Disposal

This case covers the production of virgin MDF and the disposal of both MDF production waste and also waste from the furniture manufacture industry. This case represents the current position and can be used as a benchmark against which to compare the case of production of rMDF, containing a known fraction of recycled wood fibres.

Table 9 shows the impact assessment for the generation of 1tonne of waste MDF from MDF manufacturing and disposal options for 100% of this waste sent to each waste disposal option, as well as the current disposal practice, which use a mix of energy from waste and landfill.

Table 9 Impact assessment results showing contribution from different process stages of virgin MDF manufacture for the generation of 1tonne of MDF waste and its disposal

Impact category	Unit	MDF Production process for the formation of 1 tonne of MDF waste		Disposal options for 1 tonne of MDF waste - 100% scenarios			Current disposal practice - 72% to Energy from waste onsite, 28% to Landfill
		Stage 1: Fibre preparation	Stage 2: Board formation	Landfill	Energy from waste - onsite	Energy from waste - offsite	
abiotic depletion	kg Sb eq	45.51	7.81	0.25	-7.29	-7.21	-5.18
global warming (GWP100)	kg CO_2 eq	16997.95	995.31	81.92	-882.99	-871.36	-612.82
ozone layer depletion (ODP)	kg CFC-11 eq	4.36E-04	7.66E-05	5.64E-06	-1.15E-04	-1.13E-04	-8.09E-05
human toxicity	kg 1,4-DB eq	1887.83	172.15	12.58	-111.17	-109.01	-76.52
fresh water aquatic ecotox.	kg 1,4-DB eq	251.49	13.51	11.05	0.50	0.95	3.46
marine aquatic ecotoxicity	kg 1,4-DB eq	2.01E+06	3.41E+05	1.30E+04	-7.11E+04	-6.96E+04	-4.76E+04
terrestrial ecotoxicity	kg 1,4-DB eq	22.32	1.96	0.36	-0.87	-0.85	-0.53
photochemical oxidation	kg C_2H_4	1.46	0.12	0.02	-0.10	-0.09	-0.06
acidification	kg SO_2 eq	17.58	2.11	0.16	-0.68	-0.62	-0.44
eutrophication	kg PO_4--- eq	2.33	0.17	2.63	0.20	0.22	0.88

For MDF board production the highest impact stage is fibre preparation, which involves the highest energy consumption and also includes transportation and addition of all of the raw materials to the process. This stage may be avoided, in part, through the addition of recycled fibres to displace virgin fibre.

In terms of disposal of the MDF waste produced through the manufacture process, disposal by landfill has the highest environmental impact over all of the impact categories. Energy from waste, on-site, has the lowest environmental impact of all the disposal routes as the entirety of the waste produced is used as a biogenic fuel source. This means that an alternative fuel source, in this case gas combustion, is considered to be avoided as it is not required to provide the equivalent process energy. Similarly, using onsite facilities to recover energy from waste reduces the transportation burden required to transport the waste to offsite facilities, as shown in energy from waste, offsite.

With regard to the current disposal practice for MDF manufacturers in the UK, the majority of the waste produced is used onsite for energy production at 72% of the waste produced. The remaining 28% of the waste currently is disposed of through landfill, and so the beneficial use of waste as a fuel source is balanced against the more damaging landfill option.

5.2 Microrelease process

As previously noted the functional unit of this study is 1tonne of MDF waste principally coming from MDF production. The previous sections in this report have examined the environmental impacts of the production of vMDF board and the disposal of waste produced. In this section the MDF waste produced is diverted to the Microrelease process. The Microrelease process will be considered to be onsite, as this is the most likely place for placement of the technology enabling it to be integrated into the MDF manufacturing process.

The impacts of the Microrelease process are shown in Table 10 in comparison with the other waste disposal options shown previously. The Microrelease option is shown both as a standalone process which produces the recycled fibres and also, as an option which includes the benefits accrued by not sending the MDF waste to current disposal options in addition to the avoidance of virgin fibre production.

Table 10 Environmental impacts of the waste disposal options and the Microrelease process, utilising 1tonne of MDF waste

Impact category	Unit	Disposal options for 1 tonne of MDF waste - 100% scenarios			Current disposal practice	Microrelease Process	
		Landfill	Energy from waste - onsite	Energy from waste - offsite		Without avoided processes	With avoided processes
abiotic depletion	kg Sb eq	0.25	-7.29	-7.21	-5.18	16.24	15.00
global warming (GWP100)	kg CO2 eq	81.92	-882.99	-871.36	-612.82	764.18	-1008.26
ozone layer depletion (ODP)	kg CFC-11 eq	5.64E-06	-1.15E-04	-1.13E-04	-8.09E-05	2.82E-04	3.01E-04
human toxicity	kg 1,4-DB eq	12.58	-111.17	-109.01	-76.52	267.17	78.70
fresh water aquatic ecotox.	kg 1,4-DB eq	11.05	0.50	0.95	3.46	25.35	-13.34
marine aquatic ecotoxicity	kg 1,4-DB eq	1.30E+04	-7.11E+04	-6.96E+04	-4.76E+04	3.15E+05	8.06E+04
terrestrial ecotoxicity	kg 1,4-DB eq	0.36	-0.87	-0.85	-0.53	2.05	-0.56
photochemical oxidation	kg C2H4	0.02	-0.10	-0.09	-0.06	0.24	0.10
acidification	kg SO2 eq	0.16	-0.68	-0.62	-0.44	4.10	2.08
eutrophication	kg PO4--- eq	2.63	0.20	0.22	0.88	0.39	-0.82

When ignoring the avoided processes through the use of the Microrelease the environmental impacts calculated for the process are higher than that of the 100% landfill option. This is due to the energy consumption of the process. If the avoided processes are considered, which include avoidance of disposal of the MDF through conventional routes and also the avoided production of virgin fibre, then over the majority of impact categories the Microrelease process has a smaller environmental impact than any of the other disposal options.

A potential weakness of diverting all of the MDF waste produced through MDF manufacture to the Microrelease process is that this waste would no longer be available as a fuel source. Therefore the production of process heat from waste MDF combustion would need to be replaced by combustion of an alternative fuel, such as gas. However, through use of the recycled fibres in the Microrelease process, rather than utilising the current disposal practice would lead to a saving of 0.4 tonnes equivalent of CO_2 per tonne of board diverted.

A breakdown of the various contributions to the impacts of the Microrelease process, including the avoided processes, is shown in Table 11.

This table shows that there is a clear positive effect on the environmental impacts of the process through the avoidance of virgin fibre production and avoidance of landfilling a portion of the MDF waste. The avoidance of incineration of the MDF waste, and the recovery of heat from it, paints a mixed picture. Some impact categories show large values, for example the global warming potential and marine aquatic ecotoxicity, and this is due to the fact that while avoiding the incineration of MDF waste avoids the production and release of a number of harmful chemicals, if the MDF waste is not incinerated for energy production, then an alternative fuel will be combusted to make up the difference. In this case we consider that gas combustion is the alternative to MDF waste combustion and so this is done, producing and releasing chemicals which are no longer avoided.

This effect is studied in more detail in a sensitivity analysis, which seeks to investigate the balance of sending waste to the Microrelease process and allowing a portion to remain as a fuel source for energy from waste.

Table 11 Breakdown of contributions to the total impact of the Microrelease process, including avoided processes

Impact category	Unit	Microrelease process	Avoided Processes			Total for Microrelease process with avoided processes
			Virgin fibre preparation (1 tonne)	Disposal by Landfill (28%)	Disposal by Energy from waste, onsite	
abiotic depletion	kg Sb eq	16.24	-6.37	-0.07	5.21	15.00
global warming (GWP100)	kg CO2 eq	764.18	-2380.05	-23.09	630.71	-1008.26
ozone layer depletion (ODP)	kg CFC-11 eq	2.82E-04	-6.10E-05	-1.59E-06	8.18E-05	0.00
human toxicity	kg 1,4-DB eq	267.17	-264.33	-3.55	79.41	78.70
fresh water aquatic ecotox.	kg 1,4-DB eq	25.35	-35.21	-3.12	-0.36	-13.34
marine aquatic ecotoxicity	kg 1,4-DB eq	3.15E+05	-2.81E+05	-3.66E+03	5.08E+04	80628.17
terrestrial ecotoxicity	kg 1,4-DB eq	2.05	-3.13	-0.10	0.62	-0.56
photochemical oxidation	kg C2H4	0.24	-0.20	-0.01	0.07	0.10
acidification	kg SO2 eq	4.10	-2.46	-0.04	0.49	2.08
eutrophication	kg PO4--- eq	0.39	-0.33	-0.74	-0.14	-0.82

5.3 rMDF production

The differences between rMDF production and vMDF production are the raw materials used, i.e. vMDF production utilises virgin fibres while the rMDF production uses recycled fibres from the Microrelease process to displace an amount of virgin. The second difference is that in the production of rMDF gas combustion is used for all of the process heat required in the process.

The environmental impacts of the displacement of 1tonne of virgin fibre by recycled fibre are shown in Table 12, where the rMDF board produced contains 10% or 20% by weight of recycled fibres. This means that a total of 10tonnes of rMDF board is being produced in the case of 10% recycled content, and 5 tonnes of rMDF board for the 20% case. Also shown is the reduction of this to a tonne of rMDF board produced for comparison with the manufacture of 1tonne of virgin board. The results are also shown graphically in Figure 3.

Table 12 Comparison of the environmental impacts of the displacement of 1tonne of virgin fibre with 1tonne of recycled fibre to produce MDF board and 1tonne production unit

Impact category	Unit	Displacement of 1 tonne of virgin fibres with 1 tonne of recycled fibres to produce:		Production of 1 tonne of MDF board as:		
		10% rMDF	20% rMDF	vMDF	10% rMDF	20% rMDF
abiotic depletion	kg Sb eq	100.41	51.38	7.47	10.04	10.28
global warming (GWP100)	kg CO2 eq	23763.07	9991.26	2520.06	2376.31	1998.25
ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-03	6.74E-04	7.17E-05	1.21E-04	1.35E-04
human toxicity	kg 1,4-DB eq	3061.19	1393.39	288.51	306.12	278.68
fresh water aquatic ecotox.	kg 1,4-DB eq	360.25	155.22	37.12	36.03	31.04
marine aquatic ecotoxicity	kg 1,4-DB eq	3.31E+06	1.54E+06	3.29E+05	3.31E+05	3.09E+05
terrestrial ecotoxicity	kg 1,4-DB eq	33.73	14.82	3.40	3.37	2.96
photochemical oxidation	kg C2H4	2.12	0.99	0.22	0.21	0.20
acidification	kg SO2 eq	28.33	13.83	2.76	2.83	2.77
eutrophication	kg PO4--- eq	2.18	0.49	0.35	0.22	0.10

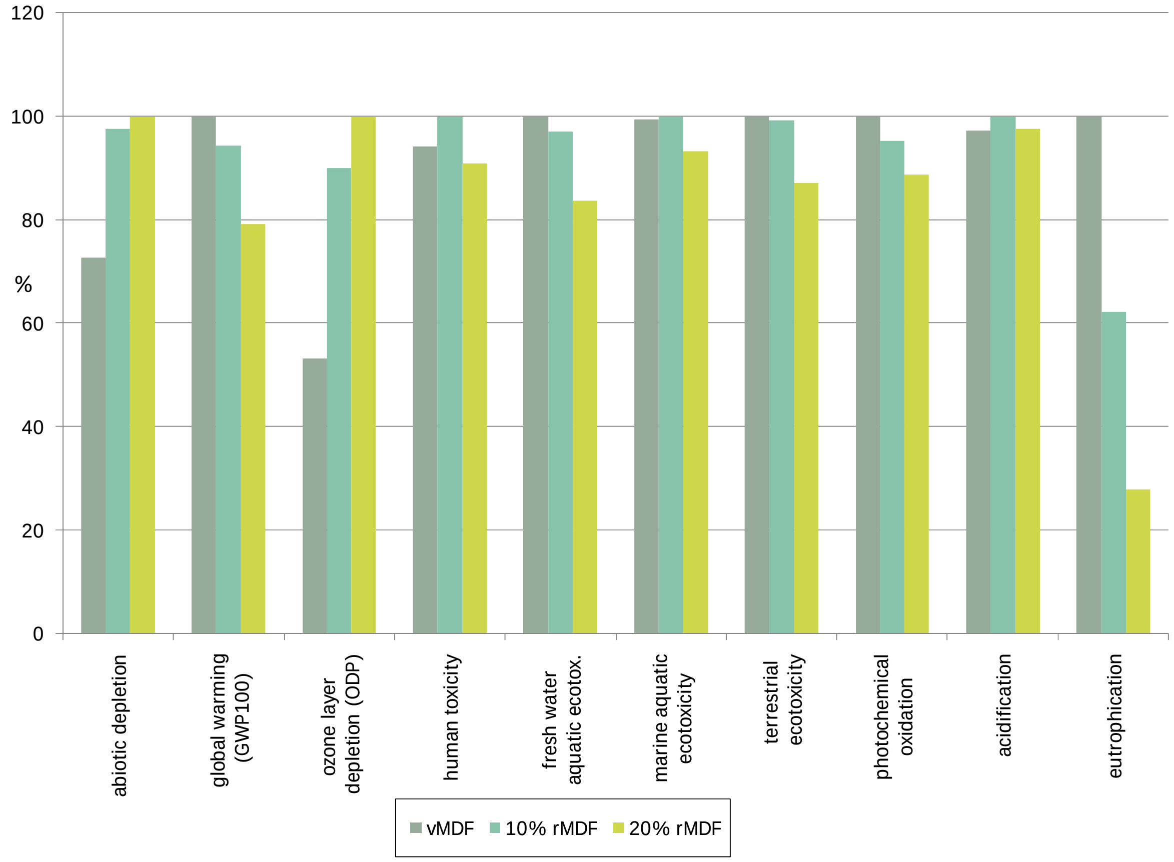
The results show that for different impact factors there is a mixed picture as the amount of recycled fibre in MDF board production is increased. There is clearly a reduction in many environmental impacts with increase in recycled fibre content when consideration is given to the displacement of 1tonne of virgin fibre with recycled to produce 10 and 20% recycled content board. In each case the total amount of board production is different - 1tonne of virgin fibre in 10% rMDF results in the production of 10tonnes of board while in the 20% case displacement of 1tonne of virgin fibre results in only 5tonnes of board. However, the 20% recycled content does not result in a 50% reduction in the environmental impacts over the 10% rMDF case.

It is also helpful to consider the impacts related to the production of 1tonne of finished MDF board product. Compared with virgin board production, the 10% rMDF board shows a reduction in some of the impacts categories relative to virgin board production such as global warming potential, eutrophication and ecotoxicity. This is matched by a further reduction in the majority of impact categories when the recycled content is increased to 20%. On consideration of the production unit, there is potential for a saving of 0.52 tonnes of CO_2 equivalent per tonne of rMDF board produced.

For some of the impact categories, the effect of addition of recycled fibre to MDF board causes the impact to rise initially with 10% addition, and then either fall below vMDF or close to its impact values when the recycled content increases to 20%. An example of this is abiotic depletion, which is the measure of the depletion of non-renewable resources. In this case the use of recycled fibres causes an increase in this category because use of waste MDF as a feedstock for the Microrelease process, leads to additional gas combustion to replace that from energy from waste MDF. This effect contributes to ozone layer depletion and acidification, where the emissions from gas combustion have a higher effect on these impact categories than waste MDF combustion; however, there is a reduction in these impact categories when the recycled fraction is increased to 20%, as a balance is struck between the harmful impacts of the gas combustion required and the avoidance of the energy used in virgin fibre production due to the use of recycled fibres.

It should be noted that the following environmental impacts for 1tonne of final MDF product are progressively reduced in going from virgin to 10% and then 20% recycled content: global warming potential, fresh water, marine and terrestrial ecotoxicity, photochemical oxidation and eutrophication - as shown in Figure 3.

Figure 3 Comparison of environmental impacts of production of 1tonne of vMDF and 1tonne of rMDF with 10% and 20% recycled fibre content



6.0 Sensitivity analysis

The scenarios examined in this sensitivity analysis are as follows:

- Scenario A: Is the baseline case as examined in the section above, of 10% rMDF manufacture, as studied in the Sonae trials
- Scenario B: Is an analysis of the baseline case with reduction of the resin content from 12% to 11%
- Scenario C: Is an analysis of the baseline case with reduction of the resin content from 12% to 10%
- Scenario D: Is an analysis of the potential for addition of the recycled fibres into the MDF production line as a wet slurry rather than a dried fibre – this allows the fibre recovery drying stage to be avoided
- Scenario E: Is an analysis of the waste split and the effect of varying the proportion of waste going to the Microrelease process with some remaining onsite for use as energy from waste. In this case the split is 75% of the waste being sent to the Microrelease process, with the remaining 25% being used as a fuel source
- Scenario F: Is an analysis of the effect of the proportion of waste being recycled or used as a fuel. This scenario reflects a nearly 50:50 ratio of waste to Microrelease and energy from waste. In this case all the energy required from waste MDF combustion is achieved with the remaining surplus waste being recycled by Microrelease
- Scenario G: Is an analysis of the opportunities for use of CHP to generate heat onsite, for the generation of process heat, replacing gas combustion
- Scenario H: Is an analysis of the opportunities for use of CHP to generate both power and heat from incineration of MDF waste
- Scenario I: Is an analysis of the use of waste MDF incineration to produce power
- Scenario J: Is an analysis of the impacts associated with the source of MDF waste. In this case the source of MDF waste is solely from the furniture manufacturing industry, and so is offsite, with a transportation burden of 50km
- Scenario K: Increases the transportation distance of the MDF waste from the furniture industry to 100km
- Scenario L: Is an analysis into the sensitivity surrounding the transportation of the other raw materials, i.e. the wood supplied to the MDF site and the chemical additives, in this scenario being locally sourced
- Scenario M: Is an analysis of raw materials sourcing, in this case being sourced from greater distances.

6.1 rMDF production options

While this study does not attempt to assess options for further development of the Microrelease process and fibre use in existing MDF production lines, some evaluation of the sensitivities can be made. Two examples of this are the resin content of the rMDF board and the potential for future developments in process alterations for optimisation of the introduction of the recycled fibre into the MDF production line. In addition, it is helpful to consider the effects of changing the amount of waste MDF diverted from energy from waste uses to fibre recovery by the Microrelease process. Variation in the conversion efficiency of energy from waste production and the effect of variation in the transportation distances of various materials is also considered.

6.1.1 Resin content

In the trials run at Sonae on the introduction of recycled fibres into MDF production, the resin fraction added to the fibres was increased to 12%. This was to ensure good wetting of the recycled fibres and good mixing of recycled and virgin fibre to ensure production of a homogeneous board. This may not actually be necessary in practice as current understanding suggests that this is not removed during the fibre recovery process and further trials are planned on varying the resin fraction to assess this. This sensitivity analysis will examine the environmental impacts of varying the resin content by ± 1% about the current production level of 11% used in vMDF production.

The scenarios examined in this sensitivity analysis are shown in Table 13.

Table 13 Scenarios examined in resin content sensitivity analysis for the utilisation of 1tonne of waste MDF

	Resin content (%b.w)
Scenario A	12%
Scenario B	11%
Scenario C	10%

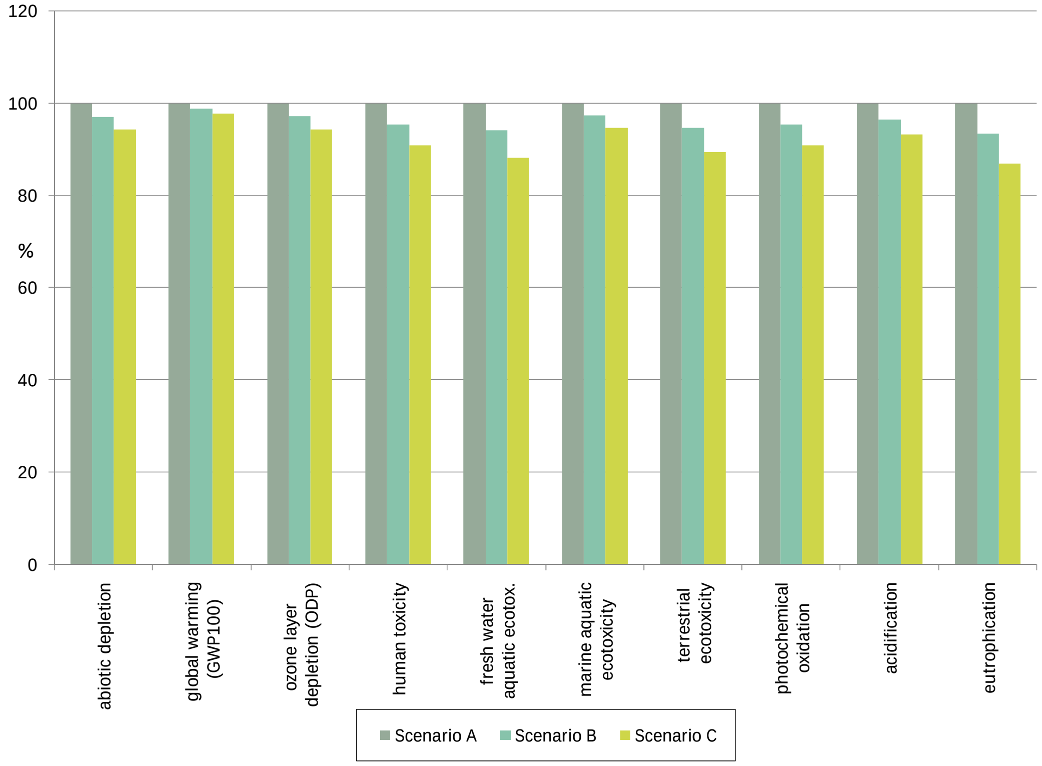
Table 14 shows the results of the life cycle impact assessments for the three resin content scenarios. Each scenario includes account of the first virgin MDF board manufacturing process, where the resin content is constant at 11%, followed by the Microrelease process for production of recycled fibres before going through the rMDF manufacture process where the variation in the resin fraction of the scenario is applied.

Table 14 Life cycle environmental impacts of scenarios utilising different resin content in rMDF production for the displacement of 1tonne of virgin fibre with recycled fibre

Impact category	Unit	Scenario A	Scenario B	Scenario C
abiotic depletion	kg Sb eq	100.41	97.54	94.67
global warming (GWP100)	kg CO2 eq	23763.07	23497.37	23232.84
ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-03	1.18E-03	1.15E-03
human toxicity	kg 1,4-DB eq	3061.19	2923.64	2786.23
fresh water aquatic ecotox.	kg 1,4-DB eq	360.25	339.09	317.93
marine aquatic ecotoxicity	kg 1,4-DB eq	3.31E+06	3.22E+06	3.13E+06
terrestrial ecotoxicity	kg 1,4-DB eq	33.73	31.96	30.20
photochemical oxidation	kg C2H4	2.12	2.02	1.93
acidification	kg SO2 eq	28.33	27.36	26.40
eutrophication	kg PO4--- eq	2.18	2.04	1.90

There is a decrease in all impact categories with decrease in resin content and Figure 4 shows a comparison of the relative effects of each scenario on a number of impact categories. The results suggest that the variation in environmental impacts is not significant, however there is a clear environmental benefit of using a lower resin content.

Figure 4 Comparison of sensitivity analysis for resin content



6.1.2 Future Options: Recycled Fibre Slurry versus Dry Fibre

In this study it is assumed that the Microrelease plant is situated on the MDF production site. This is the most appropriate place for the plant for easy feeding of recycled fibre into the MDF production line and it is assumed that the process would be optimised to reduce the economic and environmental impacts of production.

In this case the recycled fibres from the Microrelease process may be supplied as a wet slurry rather than as a dried fibre as used in the previous sections. This is possible as the Microrelease process uses an “Immerse then Microwave” method followed by a drying stage. Rather than drying within the Microrelease process it would be possible to utilise the drying stages within the MDF production line to dry the recycled fibre alongside the virgin fibre. This is likely to be beneficial as a superfluous drying stage in the Microrelease process is removed with attendant economic and environmental benefits, this will also likely confer a technical benefit by allowing the recycled fibres to mix more intimately with the virgin fibres to produce a more homogeneous final product.

Two scenarios are compared in this sensitivity analysis, the first (Scenario A) is the process as it has currently been trialled, i.e. the recycled fibres are supplied as a dry fibre, the second (Scenario D) examines the process with the removal of the drying stage from the Microrelease process.

Table 15 shows the variation in environmental impacts through removal of the Microrelease drying stage. This comparison of the Microrelease process does not take into account the avoided processes, so the virgin fibre preparation and avoided disposal routes.

Table 15 Comparison of Microrelease process for Scenario A and D, where the drying stage is removed from Scenario D

Impact category	Unit	Microrelease - Scenario A	Microrelease - Scenario D
abiotic depletion	kg Sb eq	16.24	14.11
global warming (GWP100)	kg CO2 eq	764.18	505.59
ozone layer depletion (ODP)	kg CFC-11 eq	2.82E-04	2.48E-04
human toxicity	kg 1,4-DB eq	267.17	226.71
fresh water aquatic ecotox.	kg 1,4-DB eq	25.35	23.00
marine aquatic ecotoxicity	kg 1,4-DB eq	3.15E+05	2.92E+05
terrestrial ecotoxicity	kg 1,4-DB eq	2.05	1.77
photochemical oxidation	kg C2H4	0.24	0.21
acidification	kg SO2 eq	4.10	3.84
eutrophication	kg PO4--- eq	0.39	0.36

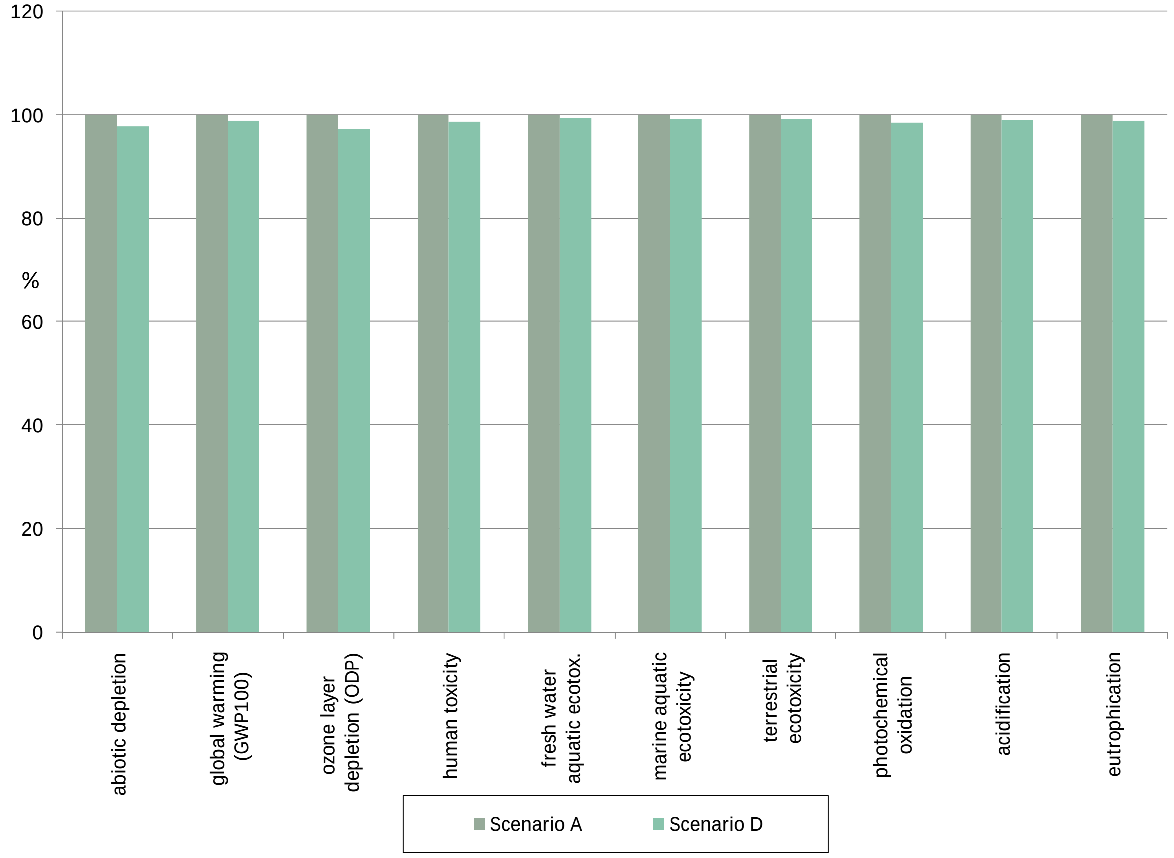
Table 16 and Figure 5 show the environmental impacts of the life cycle for the displacement of 1 tonne of virgin fibre with 1tonne of recycled fibre for the production of rMDF-10% for these two scenarios.

Table 16 Comparison of the impacts of displacing 1 tonne of virgin fibre with 1tonne of recycled fibre, in 10% rMDF production, utilising dry and wet recycled fibre

Impact category	Unit	Scenario A	Scenario D
abiotic depletion	kg Sb eq	100.41	98.28
global warming (GWP100)	kg CO2 eq	23763.07	23504.49
ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-03	1.18E-03
human toxicity	kg 1,4-DB eq	3061.19	3020.73
fresh water aquatic ecotox.	kg 1,4-DB eq	360.25	357.90
marine aquatic ecotoxicity	kg 1,4-DB eq	3.31E+06	3.28E+06
terrestrial ecotoxicity	kg 1,4-DB eq	33.73	33.45
photochemical oxidation	kg C2H4	2.12	2.09
acidification	kg SO2 eq	28.33	28.07
eutrophication	kg PO4--- eq	2.18	2.16

There is a reduction in all impact categories through removal of the drying phase in the Microrelease process, however it is not particularly significant. Further work is required in this area to identify areas for future optimisation in integrating the Microrelease and MDF manufacturing processes.

Figure 5 Comparison of the environmental impacts of displacing 1tonne of virgin fibre with 1tonne of recycled fibre, in 10% rMDF production, utilising dry and wet recycled fibre



6.2 Waste Split – varying the waste diverted to Microrelease

Current disposal options for MDF waste include both landfill and incineration of the waste. In the case of incineration there is the opportunity to recover energy from waste MDF to provide process heat or energy for other applications. This is of environmental benefit as it allows the producer to avoid utilising gas or oil combustion to generate an equivalent amount of energy.

In the cases above, when examining the fate of 1tonne of MDF waste by the Microrelease process, all of the waste included in the study was diverted from its normal disposal routes to the Microrelease process. This proved to be beneficial but it removes the economically and environmentally useful use of waste MDF as an energy source to support MDF production. Further, if this diversion was fully implemented most MDF production plants would have to invest in new capacity to maintain the process heat requirements.

In this sensitivity analysis the effects of diverting different quantities of waste to Microrelease from onsite energy recovery is examined and compared against the 100% case considered previously. The scenarios evaluated are shown in Table 17.

Scenario E represents a position where 75% of the total MDF waste generated is diverted to the Microrelease process with the remaining 25% being utilised for energy production during MDF manufacture. Of the 1tonne of waste being evaluated, 750kg is sent to the Microrelease process, with the remaining 250kg being used as a fuel source. This results in a smaller amount of recycled fibre being generated by the Microrelease process to displace virgin fibre in rMDF manufacture and so will produce a smaller amount of rMDF at 10% by weight recycled content – *in practice this would simply limit rMDF production volume if no other sources of rMDF were accessed.*

Scenario F represents a position where 52% of the total waste generated, is diverted to the Microrelease process with the remaining 48% being incinerated for energy recovery. The waste being used for energy recovery will provide enough energy for the production of 1tonne of MDF board plus a small amount of surplus energy, which may be utilised for other on site processes, such as other production lines or space heating. This scenario closely matches the current position at the Sonae plant.

Table 17 Waste split for sensitivity analysis

Scenario	Percentage of waste going to:		
	Incineration	Landfill	Microrelease process
Scenario A	0	0	100
Scenario E	25	0	75
Scenario F	48	0	52

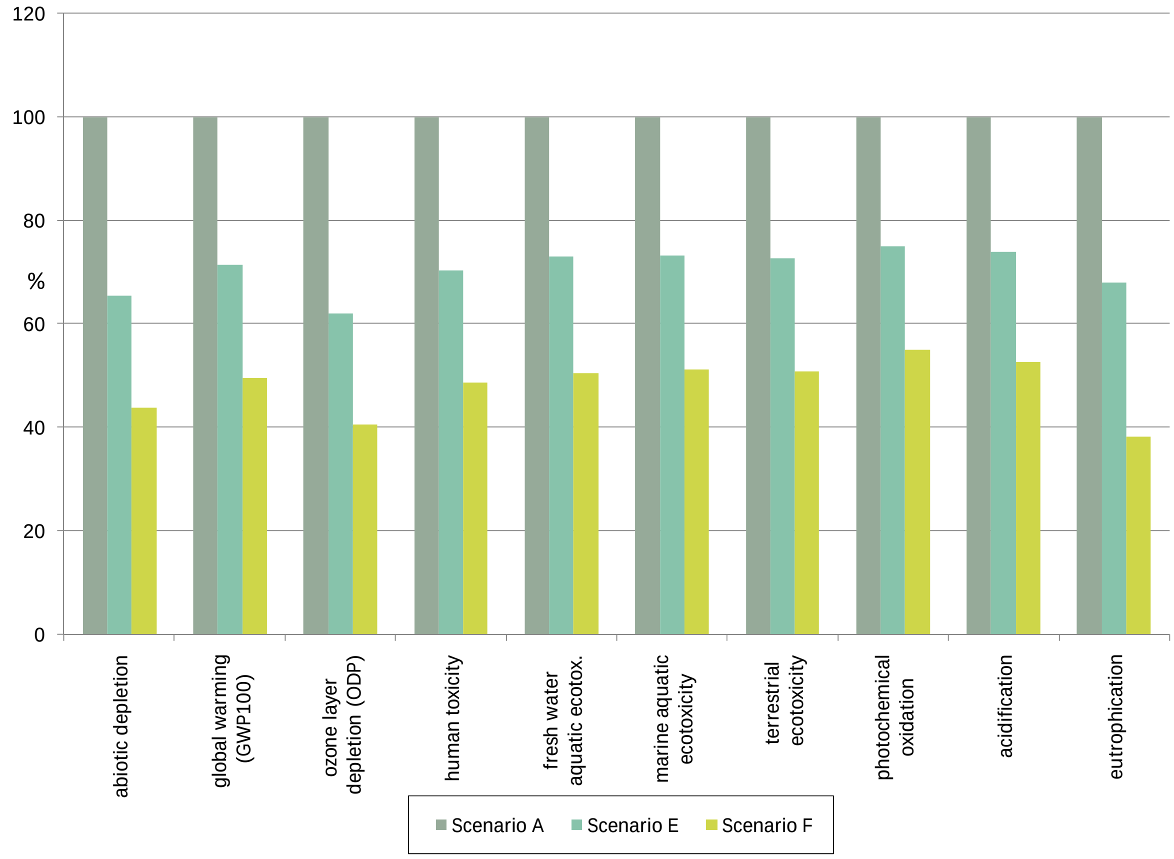
Table 18 shows the environmental impacts for the utilisation of 1tonne of waste MDF for the scenarios detailed above and Figure 6 shows the impact of each scenario over a number of separate impact categories, relative to the scenario with the largest impact.

Table 18 Comparison of environmental impacts of three scenarios where differing amounts of 1tonne of MDF waste are sent to either energy recovery or diverted to the Microrelease process for fibre recycling and used to displace appropriate amounts of virgin fibre

Impact category	Unit	Scenario A	Scenario E	Scenario F
abiotic depletion	kg Sb eq	100.41	65.76	44.07
global warming (GWP100)	kg CO2 eq	23763.07	16968.17	11804.36
ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-03	7.54E-04	4.93E-04
human toxicity	kg 1,4-DB eq	3061.19	2155.40	1490.69
fresh water aquatic ecotox.	kg 1,4-DB eq	360.25	263.04	182.28
marine aquatic ecotoxicity	kg 1,4-DB eq	3.31E+06	2.42E+06	1.70E+06
terrestrial ecotoxicity	kg 1,4-DB eq	33.73	24.54	17.16
photochemical oxidation	kg C2H4	2.12	1.59	1.16
acidification	kg SO2 eq	28.33	20.98	14.91
eutrophication	kg PO4--- eq	2.18	1.48	0.83

The results suggest that while there is an advantage to diverting MDF waste to Microrelease process for fibre recovery and there is merit in considering what precise proportion of the waste to divert. If 100% of the waste is diverted to Microrelease, then no waste MDF is available for use as a biofuel in MDF production. This results in a greater amount of energy from gas combustion which affects the environmental impacts of the process as a whole.

Figure 6 Relative environmental impacts of the three waste split scenarios for the use of 1tonne of waste MDF



In scenario E, the majority of the waste is diverted to the Microrelease process for fibre recovery, however a small proportion is left onsite for incineration and energy recovery. This allows the life cycle to benefit from both avoidance of some gas combustion through the combustion of a biofuel, and also the avoidance of an amount of virgin fibre production in comparison with the 100% diversion case (Scenario A).

In Scenario F, a similar effect is seen, as the environmental impacts are reduced further through using incineration of MDF waste to fuel plant processes, while still feeding recycled fibres into the process, via the Microrelease process.

Comparison on this scale shows a decrease over all impact categories, where the amount of MDF waste going to incineration and energy from waste is increased, with a large reduction in the environmental impacts where there is an approximately equal amount of MDF waste going to the Microrelease process as the amount of waste being used as a fuel source.

However, if these results are compared for the production of 1tonne of MDF board, then vMDF may be compared with rMDF-10% for each of the scenarios – this is shown in Table 19 and Figure 7.

In this comparison a more complex pattern is observed, with, in the majority of impact categories studied, the vMDF case is showing the highest environmental impacts. In these cases introduction of recycled fibres reduces the environmental impacts of board production, however, managing the waste split so that a greater amount of MDF waste remains for use in energy recovery from waste allows the process to benefit both from avoided production of an amount of virgin fibre production alongside some avoidance of use of gas combustion for heat generation.

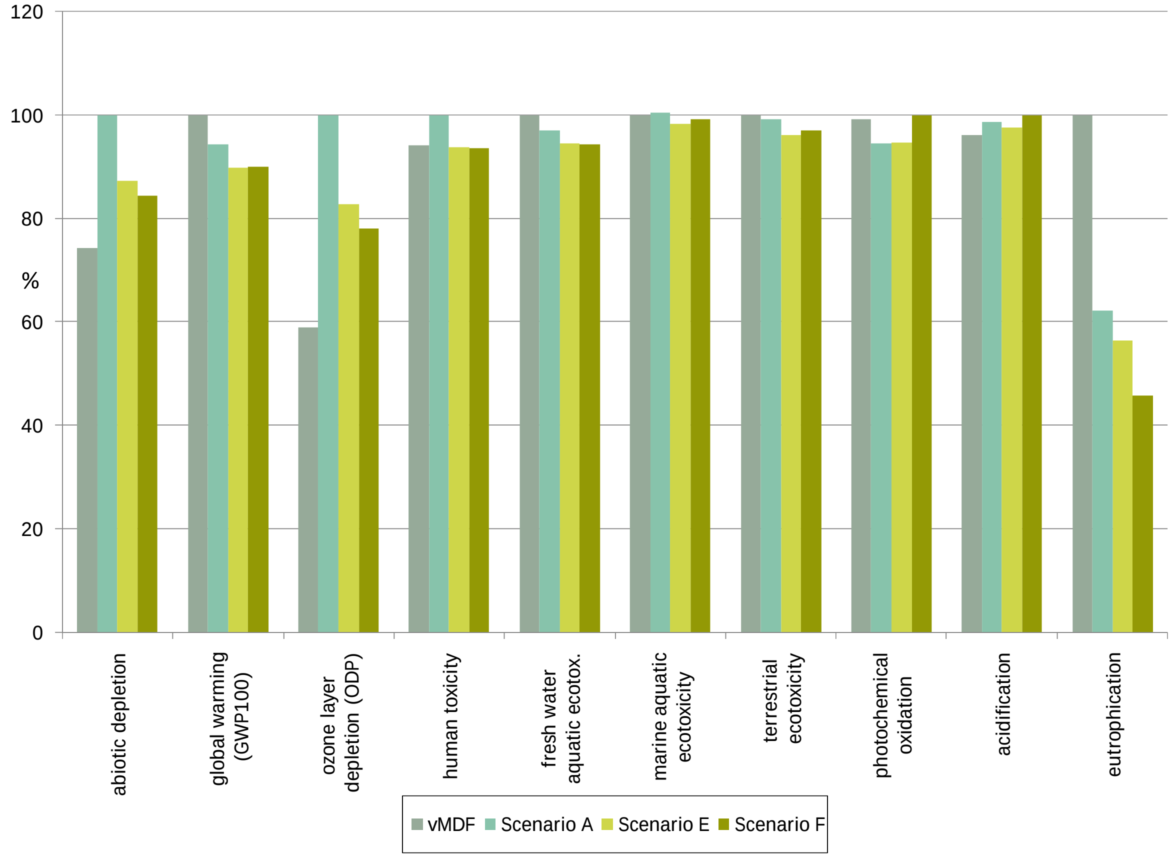
This complicated trade-off between the recycling of waste MDF and using it for energy production results in a mixed picture of the benefits of recycling over energy recovery and these findings reinforce the need for further investigation into the optimal split of waste MDF between these two fates. This is probably best done on a case-by-case basis where the individual MDF plant configuration and operational characteristics are considered. In the future, it is anticipated that the Microrelease plant could accept waste that is not contamination free, including treated and coated materials. Trials have already been done to assess the possibility of utilising sources of coated

MDF waste; it is certainly feasible but will result in the production of waste laminates, which need to be disposed of, or recycled, accordingly. As these trials have not been undertaken and reported in detail, they have not been included in this report.

Table 19 Comparison of the environmental impacts for rMDF with vMDF production utilising different waste split scenarios for the production of 1tonne of finished MDF board.

Impact category	Unit	vMDF	Scenario A	Scenario E	Scenario F
abiotic depletion	kg Sb eq	7.47	10.04	8.77	8.47
global warming (GWP100)	kg CO2 eq	2520.06	2376.31	2262.42	2270.07
ozone layer depletion (ODP)	kg CFC-11 eq	7.17E-05	1.21E-04	1.01E-04	9.49E-05
human toxicity	kg 1,4-DB eq	288.51	306.12	287.39	286.67
fresh water aquatic ecotox.	kg 1,4-DB eq	37.12	36.03	35.07	35.05
marine aquatic ecotoxicity	kg 1,4-DB eq	3.29E+05	3.31E+05	3.23E+05	3.26E+05
terrestrial ecotoxicity	kg 1,4-DB eq	3.40	3.37	3.27	3.30
photochemical oxidation	kg C2H4	0.22	0.21	0.21	0.22
acidification	kg SO2 eq	2.76	2.83	2.80	2.87
eutrophication	kg PO4--- eq	0.35	0.22	0.20	0.16

Figure 7 Relative environmental impacts for rMDF with vMDF production utilising different waste split scenarios for the production of 1tonne of finished MDF board.



6.3 Energy from waste options

Combined heat and power cogeneration is an additional option for bio-waste disposal, and is promoted by the European Commission and UK government bodies as an attractive means of waste disposal. A number of technologies exist for generation of energy as both heat and power (electricity), however steam driven turbines are the simplest when solid biofuels are used. In CHP technology it is possible to control the amount of energy directed to electrical power production via turbines and the amount converted to heat, either as process heat such as steam or local in district heating schemes based on hot water.

MDF waste is considered eligible for use in CHP, as it contains neither heavy metals nor halogen contamination, which might be released on combustion and affect environmental or plant performance[14].

Conversion of waste into heat through incineration is by far the most efficient form of energy reclaim, and on the MDF production site it may contribute to part or all of the process heat required. However, in off-site facilities heat generation may not be the most appropriate form of energy reclaim if there is less requirement for it locally. In off-site facilities electricity generation may be the more useful option, or an appropriate mixture of both heat and electricity suited to local needs.

There are guidelines and limits for the energy efficiency of CHP facilities which must be met[14, 15] and these are taken into account in the three scenarios chosen to represent different CHP options considered in this part of the sensitivity analysis; these are shown in Table 20. In all cases the CHP facility is assumed to be offsite at a distance of 60km from the origin of the MDF waste.

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[14] *Waste Incineration Directive: Directive 2000/76/EC, Article 2(2), (2000)*

[15] *Cogeneration Directive: Directive 2004/8/EC, Annex II, (2004)*

Table 20 Sensitivity analysis for type of CHP used to reclaim energy through the combustion of 1tonne of waste MDF

	Energy efficiency	Power to heat ratio	Heat from wood produced (kWh)	Electricity from wood produced (kWh)
Scenario G	80%	1	33333.3	0
Scenario H	65%	0.45	1489.58	1218.8
Scenario I	25%	0	0	1041.7

For these scenarios the offsite CHP based energy reclaimed from 1 tonne of MDF waste will be considered separately from the on-site reclaim to support MDF production process.

The first scenario (scenario G) represents a similar position to that used in the bulk of this report, where all of the MDF waste sent to incineration and energy reclaim is utilised in heat production, however in this scenario the CHP facility is assumed to be 60km from the origin of the waste. As production of heat only from incineration of waste allows for the highest efficiency and in this case 80% is used, which is in-line with the Cogeneration Directive.

The second scenario (scenario H) represents a position where CHP is utilised for production of both heat and power from the MDF waste taking place at an off-site CHP facility. In this scenario the overall energy efficiency will be 65%, the reduction due to the losses incurred through electricity generation. The power to heat ratio used in this case will be 0.45 as suggested in the Cogeneration Directive for CHP using steam driven turbines.

The third scenario (scenario I) represents a position where off-site power generation is taking place from MDF waste incineration. This scenario will have the lowest energy efficiency and in this scenario a value of 25% is used, which is in-line with the UK position, quoted as being between 19 – 27%[16].

In all cases the energy fuel source that is being replaced by MDF waste as the final source is considered. So for scenario A, heat is being produced and this is assumed to replace gas combustion; in scenario G, the energy produced is replacing a proportion of both gas combustion and also electricity taken from the UK national grid. In the third scenario (I) the power produced replaces electricity taken from the national grid.

Table 21 compares the environmental impacts of the disposal of 1 tonne of MDF waste through these CHP options and also with landfill and diversion to the Microrelease process as previously shown in Table 10.

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[16] *Fichtner Consulting Engineers Limited (2004) "The Viability Of Advanced Thermal Treatment Of MSW In The UK", ESTET, March 2004*

Table 21 Comparison of environmental impacts of three CHP options for different heat : power ratios and of other disposal options, including diversion to Microrelease

Impact category	Unit	Disposal options for 1 tonne of MDF waste - 100% scenarios				Current disposal practice	Microrelease Process	
		Landfill	Energy from waste CHP scenario G - offsite	Energy from waste CHP scenario H - offsite	Energy from waste CHP scenario I - offsite		Without avoided processes	With avoided processes
abiotic depletion	kg Sb eq	0.25	-7.22	-9.06	-4.93	-5.18	16.24	15.00
global warming (GWP100)	kg CO2 eq	81.92	-873.82	-1175.21	-662.56	-612.82	764.18	-1008.26
ozone layer depletion (ODP)	kg CFC-11 eq	5.64E-06	-1.13E-04	-6.86E-05	-1.45E-05	-8.09E-05	2.82E-04	3.01E-04
human toxicity	kg 1,4-DB eq	12.58	-109.40	-210.13	-126.10	-76.52	267.17	78.70
fresh water aquatic ecotox.	kg 1,4-DB eq	11.05	0.89	-17.82	-12.12	3.46	25.35	-13.34
marine aquatic ecotoxicity	kg 1,4-DB eq	1.30E+04	-6.99E+04	-5.09E+05	-4.05E+05	-4.76E+04	3.15E+05	8.06E+04
terrestrial ecotoxicity	kg 1,4-DB eq	0.36	-0.85	-2.69	-1.94	-0.53	2.05	-0.56
photochemical oxidation	kg C2H4	0.02	-0.10	-0.15	-0.09	-0.06	0.24	0.10
acidification	kg SO2 eq	0.16	-0.65	-2.96	-2.18	-0.44	4.10	2.08
eutrophication	kg PO4--- eq	2.63	0.21	-0.23	-0.16	0.88	0.39	-0.82

The results in Table 21 show that there is a definite benefit to utilising MDF waste in CHP whatever the ratio of heat to power and that this disposal route is much more preferable to landfill. The scenario which performs the best, i.e. has the lowest environmental impact over all of the impact categories measured is scenario H where both power and heat are co-generated through waste MDF combustion in CHP. When this best case scenario is compared with Microrelease recovery of fibre, the global warming potential is comparible. When taking into account that the data used for the Microrelease process came from laboratory bench scale trials and the uncertainties involved with them this value may approach the benefits accrued through use of CHP for power and heat generation; it is possible that process improvements to Microrelase would improve this performance further.

The large differences between the Microrelease process and CHP options can be explained by the increased use of energy for Microrelease in comparison to the savings accrued through biofuel combustion. The electricity used at its source will generate No_x and SO_x which are high contributors to acidification and will also have a knock on affect onto ecotoxicity results.

In some impact categories the CHP scenario G, with only heat generation, performs better than using the MDF waste for the Microrelease process. However, in terms of global warming potential particularly, the Microrelease process has a lower impact.

Out of the three CHP scenarios, the worst performing is the option where only power is generated through combustion of waste MDF (scenario I). This is due to the lower energy efficiency of this scenario and so the amount of electricity generated is low and while it is replacing electricity from the national grid, which is of benefit, it is a relatively small amount and there is no additional avoidance of gas combustion. In all impact categories, this scenario performs worse than the current disposal practice, which includes some proportion of the waste being landfilled and is, in most cases, performing poorer environmentally than the Microrelease process for fibre recovery.

The marginal differences between onsite and offsite facitilies can be seen on comparing the results in Table 21 with Table 10, where onsite facilities are considered for energy recovery from waste. If the CHP facility was moved or built onsite where the MDF production line could benefit from the energy produced a small increase in the reduction of environmental impacts would be observed inline with the omission of the transportation burdens.

The information gathered from the MDF producer, Sonae, suggested that there are additional considerations to take into account with regards to whether a plant would install and use CHP facilities in their process. These considerations are primarily economic as CHP plants are reported to require a large amount of capital investment.

6.4 Transportation

In this sensitivity analysis the transportation distances of various raw materials to the MDF production plant are analysed and the effects of these on the environmental impacts of the process assessed.

As mentioned in a previous section this is a good opportunity to assess the differences in environmental impact when considering MDF waste coming from furniture manufacturers rather than focusing only on MDF waste from MDF board production processes.

All of the materials used in MDF board production (both virgin and containing a recycled fraction) come from different sources geographically surrounding the manufacturing plant. The data used in these studies have been taken from information provided by Sonae for the operation of their plant in Meppen. As such the transportation data in particular is not representative of the position in the UK.

In the first set of transportation sensitivity analyses, the distance travelled by the MDF waste to the Microrelease process assume that the Microrelease plant is situated at the MDF production site and MDF waste is taken directly from the process waste and so no road transportation is involved at all. In contrast MDF waste sourced from furniture manufacture is transported. Table 22 shows a breakdown of the distances for the MDF waste to travel in each of the scenarios.

Table 22 Details used for transportation sensitivity analysis studying source of waste MDF

	Scenario A	Scenario J	Scenario K
Distance travelled by MDF waste (km)	0	50	100
Additional Comment	Microrelease process fed by onsite MDF production waste	All of the MDF waste sourced from the furniture industry	All of the MDF waste sourced from the furniture industry

The results of this sensitivity analysis are shown in Table 23 and they suggest that the source of the MDF waste will have very little impact on the environmental burdens associated with rMDF production. Increasing the distance travelled by the MDF waste marginally increases the environmental impacts over all of the impact categories studied, however it is not a significant increase.

Table 23 Comparison of transportation scenarios varying the source of the MDF waste, either MDF process waste onsite, or furniture industry waste with an additional transportation burden

Impact category	Unit	Scenario A	Scenario J	Scenario K
abiotic depletion	kg Sb eq	100.41	100.44	100.53
global warming (GWP100)	kg CO2 eq	23763.07	23767.15	23780.46
ozone layer depletion (ODP)	kg CFC-11 eq	1.21E-03	1.21E-03	1.22E-03
human toxicity	kg 1,4-DB eq	3061.19	3061.89	3064.00
fresh water aquatic ecotox.	kg 1,4-DB eq	360.25	360.40	360.82
marine aquatic ecotoxicity	kg 1,4-DB eq	3.31E+06	3.31E+06	3.31E+06
terrestrial ecotoxicity	kg 1,4-DB eq	33.73	33.73	33.76
photochemical oxidation	kg C2H4	2.12	2.12	2.12
acidification	kg SO2 eq	28.33	28.33	28.38
eutrophication	kg PO4--- eq	2.18	2.18	2.19

The second transportation sensitivity analysis examines the effect of sourcing the other raw materials from both shorter and further distances than examined in the cases above and will concentrate solely on the virgin MDF manufacture process. The scenarios examined are shown in Table 24, where the distances travelled by all raw materials are summarised.

Scenario A uses the data provided by Sonae and represents the position for a large MDF manufacturer in Germany. Scenario L represents a situation where all of the material inputs are locally sourced, no further than 50 km travelled for material inputs. The final scenario, Scenario M, represents a worst case situation where all inputs are being transported over long distances to reach the MDF plant.

Table 24 Scenarios examined in raw material sourcing transportation sensitivity analysis

	Material	Input into stage:	Distance travelled
Scenario A	Wood components	1	75km
	UF resin	1	76km
	Paraffin	1	245km
Scenario L	Wood components	1	50km
	UF resin	1	50km
	Paraffin	1	50km
Scenario M	Wood components	1	150km
	UF resin	1	150km
	Paraffin	1	245km

The results of the impact assessment are shown in Table 25. Scenario L represents local sourcing of materials and is shown to have the lowest environmental impacts, conversely Scenario M, which has the raw materials travelling greater distances, shows the highest environmental impacts.

On comparison of the results, however, there is very little difference in the impact categories with change in transportation distance for the raw materials.

Table 25 Comparison of environmental impacts of transportation scenarios

Impact category	Unit	Scenario A	Scenario L	Scenario M
abiotic depletion	kg Sb eq	53.33	52.92	53.97
global warming (GWP100)	kg CO2 eq	17993.26	17936.45	18081.92
ozone layer depletion (ODP)	kg CFC-11 eq	5.12E-04	5.03E-04	5.26E-04
human toxicity	kg 1,4-DB eq	2059.97	2049.08	2077.31
fresh water aquatic ecotox.	kg 1,4-DB eq	265.00	262.62	268.78
marine aquatic ecotoxicity	kg 1,4-DB eq	2.35E+06	2.34E+06	2.36E+06
terrestrial ecotoxicity	kg 1,4-DB eq	24.28	24.16	24.48
photochemical oxidation	kg C2H4	1.59	1.58	1.60
acidification	kg SO2 eq	19.68	19.47	20.05
eutrophication	kg PO4--- eq	2.50	2.46	2.57

7.0 Summary and Conclusions

This life cycle assessment has examined the environmental impacts of current MDF production and particularly waste disposal routes to evaluate the position of diverting MDF waste from conventional disposal routes of incineration and landfill to recovery of the wood fibres for closed loop reintroduction into MDF production.

The particular focus of this study is MDF waste from the MDF production process in the UK. The environmental consequences of recovering the fibres from this waste, utilising the Microrelease process, have been studied taking into account the effects of diversion of this waste from landfill and incineration with energy recovery both in on-site and off-site facilities.

In virgin MDF manufacture the fibre production stage, where the wood is fed into the process as felled trees and converted to fibres through a number of high-energy processes, has the highest environmental impact. This stage of the process is the most environmentally damaging due to high energy use, chemical additive production and use, and transportation burdens. This suggests that reducing the total requirement for virgin fibres should reduce environmental impacts even though much of the internally generated MDF waste is incinerated for heat production allowing reduced gas combustion.

In terms of disposal of the MDF process waste, disposal by landfill has the highest environmental impact of the impact categories considered. On-site energy from waste, has the lowest environmental impact of the disposal routes as the feedstock is considered to be a biogenic fuel source. This means that an alternative fuel source, in this case gas combustion, is avoided as it is not required to provide the equivalent process energy. Similarly, using on-site facilities to recover energy from waste reduces the transportation burden required to ship the waste to off-site facilities.

On consideration of the Microrelease process for recycled fibre generation, if the avoided processes are ignored, the environmental impacts are higher than that of the 100% landfill option. This is due to the energy consumption of the Microrelease process. If the avoided processes are included, especially the avoided production of virgin fibre but also the avoidance of disposal of the MDF through conventional routes, then over the majority of impact categories the Microrelease process has a smaller environmental impact than any of the other disposal options.

The displacement of virgin fibres by recycled fibres produces a clear reduction in environmental impacts with increasing recycled fibre content, as can be clearly seen when assessing the displacement of 1tonne of virgin fibre with recycled fibre to produce 10%b.w and 20%b.w recycled content board. For the processing of 1tonne of waste MDF it is possible to achieve a saving of 0.4 tonnes of CO_2 equivalent by using the Microrelease process.

When the same systems are compared on the basis of the production of one tonne of MDF board, the rMDF 10 and 20% board production, the 10% recycled content MDF board shows reductions in environmental impacts for some impact categories such as global warming potential, eutrophication and the ecotoxicity categories. The majority of impact categories are reduced when the recycled content is increased to 20% rMDF. In this case up to 0.52 tonnes of CO_2 equivalent may be saved for each tonne of finished MDF board produced.

In some of the impact categories the effect of adding a recycled content to MDF board causes the impact to rise initially with 10% addition, and then either fall below vMDF or close to its values for increase of the recycled content to 20%. An example of this is abiotic depletion, which is the measure of the depletion of non-renewable resources. In this case the use of recycled fibres causes an increase in this category because with use of the waste MDF as a feedstock for the Microrelease process rather than a fuel source, gas combustion is used as an alternative and being a non-renewable fuel, this causes an increase in this value. This effect contributes to ozone layer depletion and acidification, where the emissions from gas combustion have a higher effect on these impact categories than waste MDF combustion, however there is a reduction in these impact categories with increase of recycled fraction to 20% as a balance is struck between the harmful impacts of the gas combustion required and the avoidance of the energy used in virgin fibre production – which is avoided through the use of recycled fibres.

These findings indicate that diversion of MDF waste from incineration with energy recovery and landfill to the Microrelease process will have a beneficial effect for most impact categories considered in reducing the environmental impacts of MDF manufacture.

Some of the possibilities for alterations of the rMDF manufacture process have been investigated in a sensitivity analysis, for example the resin content of the rMDF board and the potential for future developments in process alterations to optimise the introduction of recycled fibre. These areas were highlighted as possible routes for improvement by Sonae during the rMDF production trials.

With regard to the resin fraction, typically 11% by weight of fibre is added in typical virgin MDF board production. During the trials 12% by weight was added to ensure good wetting of recycled fibres. However, the recycled fibres already contains a resin fraction as this is thought not to be removed during the Microrelease process so it is possible that less resin may be required. It was found that there is a positive environmental effect of reduction of the resin content to 10% by weight; however, it is not large in relation to other production impacts and may be deemed insignificant.

In relation to the possible future introduction of recycled fibre as a wet slurry, there is a reduction in all impact categories through removal of the drying phase in the Microrelease process, however it is not particularly significant. Further work in this area is required with more detailed studies and trials on a case-by-case basis to highlight areas for future optimisation.

The results of the sensitivity analysis of CHP options (power to heat ratio) and energy efficiency, show that there is a definite benefit to utilising the 1tonne of MDF waste considered in CHP whatever the ratio of heat to power and that this disposal route is much more preferable to landfill. The scenario which performs the best, i.e. has the lowest environmental impact over all of the impact categories measured in the CHP scenario where both power and heat are generated through waste MDF incineration.

In some impact categories the CHP scenario with only heat generation performs better than using the MDF waste for the Microrelease process and recycling of the wood fibres, even when taking into account the benefits accrued through avoidance of the fibre preparation stages in MDF manufacturing, which the fibres would be used in. However, in terms of global warming potential particularly, the Microrelease process shows itself to have the lesser impact.

Out of the three CHP scenarios, the worst performing is the option where only power is generated through combustion of waste MDF. This is due to the lower energy efficiency of this scenario and so the amount of electricity generated is low and while it is replacing electricity from the national grid, which is of benefit, it is a relatively small amount and there is no additional avoidance of gas combustion. In all impact categories, this scenario performs worse than the current disposal practice, which includes some proportion of the waste being landfilled and is, in most cases, performing poorer environmentally than the Microrelease process for fibre recovery.

The waste split is also an important factor for investigation as this determines the availability of waste MDF for use as a biofuel for process heat production for either the MDF production process or other applications. If all of the waste produced is diverted to the Microrelease process then there would be none available for use as a fuel source and therefore gas combustion would need to be used to produce an equivalent amount of heat.

Three scenarios were considered:

1. 100% of all waste diverted to Microrelease.
2. All of the waste being sent to landfilled diverted to Microrelease – with the energy from waste fraction used as a biofuel.
3. A portion of the waste remains onsite for use as a biofuel (25%) with the remaining going to the Microrelease process for fibre recovery.

The findings suggest that there is an environmental advantage to diverting MDF waste to the Microrelease process for fibre recovery. However, it is a complicated trade-off between recycling and using the MDF waste for energy production be it on-site process heat production or off-site co-generation. Further, there is merit in considering what proportion of this waste to divert in order to optimise the environmental performance of individual MDF manufacturing plants.

Appendix 1 Primary Data

The data used in the impact assessments in terms of primary data taken from information supplied by Sonae on their plant process is displayed in the tables below. Also included in this Appendix are the input data used for the Microrelease process and subsequent use of the recycled fibres in rMDF production.

Table 26 Raw materials for virgin MDF manufacture

	Type	Value	Travel distance	Comment
Wood Supply[*]	Softwood (pine, spruce, fir, larch)	65% [58%]	75km	Felled for use in MDF production
	Hardwood (poplar)	25% [22%]	75km	Felled for use in MDF production
	Softwood chips, sawmill by-product	10% [9%]	75km	
Fibre preparation	Urea/formaldehyde resin	11% (solids UF-resin based on dry fibres)	76km	Supplied as an aqueous solution (65% solids)
	Paraffin	0.75% (solids paraffin based on dry fibres)	245km	Supplied as a paraffin emulsion

[*] The wood supply data relates to the wood fraction only being input into the MDF production process and as such adds up in itself to 100%. The values shown in square brackets relates to their relative contribution to the mass of the MDF board produced also taking into account the chemical additives input into the fibre preparation stage

Table 27 MDF production process energy use

Stage in process	Fuel source	Unit	Value
Fibre preparation	Electricity (Grid)	kWh / tonne product	389.5
	Gas combustion	kWh / tonne product	773.3
	Wood combustion	kWh / tonne product	466.7
	Gas combustion avoided	kWh / tonne product	516
Board formation	Electricity (Grid)	kWh / tonne product	106.6
	Gas combustion	kWh / tonne product	266.6

Table 28 Microrelease process (Immerse then Microwave) inputs and outputs

Inputs	Unit	Value
MDF waste	kg	1000
Water, process	kg	1478
Truck, 16tonne	km	30
Heat Gas	kWh	1211
Electricity	kWh	331
Avoided Processes		
Disposal of MDF waste through incineration	kg	494
Disposal of MDF waste through landfill	kg	506
Outputs		
Microreleased fibres	kg	1000
Suspended solids	mg	482
Formaldehyde	mg	67
Waste water	m^3	903

Table 29 rMDF production inputs

Inputs	Value	Transport distance	Comment
Wood supply	90%	75km	Same split as with vMDF
Urea/formaldehyde	12%	76km	
Paraffin	0.75%	245km	
Microreleased fibres	10%	30km	
Avoided Process			
Fibre preparation	10%		See Table 26 and Table 27 for inputs

Table 30 rMDF production process energy use

Stage in process	Fuel source	Unit	Value
Fibre preparation	Electricity (Grid)	kWh / tonne product	389.5
	Gas combustion	kWh / tonne product	1240
Board formation	Electricity (Grid)	kWh / tonne product	106.6
	Gas combustion	kWh / tonne product	266.6

Appendix 2 Secondary Data

Table 31 Secondary data

Process	**Source**	**Geographic coverage**	**Year**
Logs, softwood, at forest	EcoInvent v2.0	Switzerland *	2003
Logs, hardwood, at forest	EcoInvent v2.0	Switzerland *	2003
Wood chips, mixed, u=120%, at forest	EcoInvent v2.0	Switzerland *	2003
Urea formaldehyde resin, at plant	EcoInvent v2.0	Switzerland *	2003
Paraffin, at plant	EcoInvent v2.0	Switzerland *	2003
Transport, lorry 16-32t, EURO4	EcoInvent v2.0	Switzerland *	2007
Diesel, at regional storage	EcoInvent v2.0	Switzerland *	2003

* Data assumed to be representative for Europe

Appendix 3 Life Cycle Inventories

This Appendix presents the life cycle inventories for the systems studied as the primary investigation, i.e. the production of 1tonne of MDF waste, from the MDF manufacturing industry, its potential end fates and its use in rMDF manufacture (both 10% and 20% cases) *via* the Microrelease process.

Table 32 Material emissions, output to atmosphere, kg/tonne MDF waste utilised

Substance	Production of 1 tonne of waste from MDF production	Disposal Options						Displacement of 1 tonne of virgin fibre with recycled to produce:		Production of 1 tonne of:		
		Landfill	Energy from waste, onsite	Energy from waste, offsite	Current disposal practice	Microrelease (without avoided)	Microrelease (with avoided)	rMDF 10%	rMDF 20%	vMDF	10% rMDF	20% rMDF
Heavy Metals												
Antimony	7.05E-06	2.15E-09	-2.14E-07	-2.14E-07	-1.54E-07	5.99E-07	-1.72E-07	1.05E-05	4.66E-06	9.87E-07	9.62E-07	8.54E-07
Arsenic	1.58E-04	1.39E-07	-1.12E-06	-1.07E-06	-7.70E-07	1.76E-05	-3.91E-06	2.31E-04	1.04E-04	2.22E-05	2.11E-05	1.90E-05
Cadmium	1.94E-04	4.06E-07	-6.63E-08	9.88E-08	6.59E-08	2.51E-05	-4.30E-06	2.85E-04	1.28E-04	2.72E-05	2.61E-05	2.34E-05
Chromium	2.07E-04	1.49E-06	-1.24E-06	-6.74E-07	-4.73E-07	2.15E-05	-7.30E-06	2.98E-04	1.32E-04	2.89E-05	2.73E-05	2.43E-05
Chromium VI	7.68E-06	4.98E-09	-6.65E-08	-6.47E-08	-4.65E-08	5.42E-07	-4.57E-07	1.08E-05	4.71E-06	1.08E-06	9.91E-07	8.63E-07
Cobalt	4.94E-04	2.53E-07	-1.90E-06	-1.80E-06	-1.30E-06	3.26E-05	-3.92E-05	7.00E-04	2.98E-04	6.92E-05	6.41E-05	5.46E-05
Copper	6.08E-04	9.69E-06	-3.03E-06	1.69E-06	5.33E-07	5.99E-05	-3.11E-05	8.77E-04	3.85E-04	8.51E-05	8.03E-05	7.04E-05
Iron	4.67E-03	1.26E-06	-3.90E-06	-3.35E-06	-2.45E-06	1.52E-04	-5.49E-04	6.42E-03	2.63E-03	6.53E-04	5.88E-04	4.82E-04
Lead	1.02E-03	1.08E-06	-2.30E-06	-1.84E-06	-1.36E-06	6.29E-05	-8.52E-05	1.01E-03	4.20E-04	1.42E-04	9.24E-05	7.70E-05
Manganese	2.51E-03	2.55E-07	-2.21E-06	-2.20E-06	-1.52E-06	2.26E-05	-3.53E-04	3.94E-05	-1.33E-04	3.52E-04	3.61E-06	-2.43E-05
Mercury	6.44E-05	2.01E-07	-1.81E-06	-1.76E-06	-1.24E-06	1.18E-05	5.13E-06	1.02E-04	4.91E-05	9.02E-06	9.30E-06	9.00E-06
Molybdenum	1.13E-04	1.23E-07	1.09E-06	1.14E-06	8.22E-07	1.43E-05	-3.23E-06	1.67E-04	7.52E-05	1.58E-05	1.53E-05	1.38E-05
Nickel	4.24E-03	4.95E-06	-1.48E-05	-1.27E-05	-9.30E-06	4.22E-04	-1.99E-04	6.14E-03	2.69E-03	5.94E-04	5.62E-04	4.93E-04
Platinum	4.34E-12	2.06E-13	-5.59E-13	-5.53E-13	-3.45E-13	5.85E-13	3.56E-13	8.00E-12	3.65E-12	6.08E-13	7.32E-13	6.68E-13
Selenium	1.86E-04	1.76E-07	-2.22E-06	-2.14E-06	-1.55E-06	2.27E-05	-6.70E-07	2.74E-04	1.25E-04	2.61E-05	2.51E-05	2.29E-05
Silver	2.70E-08	3.35E-13	4.69E-12	4.78E-12	3.47E-12	7.78E-11	-4.03E-09	3.64E-08	1.44E-08	3.78E-09	3.34E-09	2.64E-09
Thallium	1.31E-06	1.21E-10	6.47E-09	6.47E-09	4.69E-09	9.05E-09	-1.93E-07	1.76E-06	7.02E-07	1.83E-07	1.61E-07	1.29E-07
Tin	3.04E-06	1.71E-09	3.37E-10	4.67E-10	7.20E-10	5.81E-08	-3.97E-07	4.12E-06	1.67E-06	4.25E-07	3.77E-07	3.06E-07
Titanium	3.10E-04	4.65E-08	-1.91E-07	-1.90E-07	-1.25E-07	1.97E-06	-4.47E-05	4.18E-04	1.66E-04	4.34E-05	3.83E-05	3.05E-05
Vanadium	1.49E-02	6.27E-06	-4.18E-05	-3.90E-05	-2.83E-05	7.28E-04	-1.49E-03	2.09E-02	8.72E-03	2.09E-03	1.92E-03	1.60E-03
Zinc	3.83E-03	3.87E-05	-6.51E-06	2.01E-06	6.15E-06	1.24E-04	-4.50E-04	1.18E-03	3.53E-04	5.36E-04	1.08E-04	6.46E-05
Inorganic Emissions												
Aluminum	7.74E-02	9.20E-06	-5.79E-04	-5.77E-04	-4.15E-04	6.11E-03	-3.32E-03	1.09E-01	4.84E-02	1.08E-02	9.95E-03	8.86E-03
Ammonia	1.77E+00	1.72E-04	8.20E-03	8.55E-03	5.95E-03	5.76E-03	-2.71E-01	2.22E+00	8.69E-01	2.48E-01	2.03E-01	1.59E-01
Barium	3.73E-04	5.52E-08	-3.81E-06	-3.79E-06	-2.73E-06	2.77E-05	-1.78E-05	5.26E-04	2.33E-04	5.23E-05	4.82E-05	4.26E-05
Beryllium	1.11E-06	1.11E-10	-1.93E-09	-1.92E-09	-1.36E-09	1.52E-08	-1.49E-07	1.51E-06	6.10E-07	1.56E-07	1.39E-07	1.12E-07
Boron	6.45E-03	1.69E-05	-1.31E-04	-1.30E-04	-8.98E-05	7.55E-04	1.69E-05	1.04E-02	4.74E-03	9.04E-04	9.49E-04	8.68E-04
Bromine	1.85E-03	2.89E-07	-2.37E-05	-2.36E-05	-1.70E-05	1.83E-04	-2.45E-05	2.65E-03	1.21E-03	2.59E-04	2.42E-04	2.22E-04
Carbon dioxide	8.34E+01						-1.28E+01	9.90E+01	3.84E+01	1.17E+01	9.07E+00	7.03E+00
Carbon dioxide, biogenic	1.16E+02	1.57E+01	1.46E+03	1.46E+03	1.06E+03	9.84E+00	-1.15E+03	1.60E+02	7.19E+01	1.62E+01	1.46E+01	1.32E+01
Carbon dioxide, fossil	4.90E+03	1.94E+01	-7.82E+02	-7.72E+02	-5.58E+02	6.98E+02	6.86E+02	9.48E+03	4.40E+03	6.87E+02	8.68E+02	8.06E+02
Carbon disulfide	2.11E-03	2.15E-07	1.20E-06	1.28E-06	9.22E-07	2.27E-05	-3.01E-04	2.85E-03	1.14E-03	2.95E-04	2.61E-04	2.08E-04
Carbon monoxide	8.61E+00						-1.32E+00	-7.05E-01	-8.97E-01	1.21E+00	-6.46E-02	-1.64E-01
Carbon monoxide, biogenic	1.51E-02	1.19E-03	2.23E-01	2.23E-01	1.61E-01	7.99E-04	-1.76E-01	2.00E-02	8.57E-03	2.11E-03	1.83E-03	1.57E-03
Carbon monoxide, fossil	4.65E+00	8.43E-02	-4.57E-01	-4.43E-01	-3.05E-01	4.35E-01	1.10E-01	7.80E+00	3.45E+00	6.51E-01	7.14E-01	6.32E-01
Chlorine	3.07E-04	6.32E-07	5.17E-06	5.48E-06	3.90E-06	7.57E-05	3.01E-05	4.81E-04	2.41E-04	4.29E-05	4.41E-05	4.41E-05
Cyanide	1.81E-05	1.28E-06	8.88E-04	8.88E-04	6.39E-04	2.04E-06	-6.94E-04	2.67E-05	1.23E-05	2.54E-06	2.44E-06	2.25E-06
Fluorine	5.01E-05	4.03E-09	-2.10E-07	-2.09E-07	-1.50E-07	4.04E-06	-2.13E-06	6.89E-05	3.08E-05	7.02E-06	6.31E-06	5.64E-06
Helium	5.99E-04	1.42E-05	-4.40E-06	1.27E-05	8.12E-07	1.46E-03	1.37E-03	2.27E-03	1.78E-03	8.40E-05	2.08E-04	3.26E-04
Hydrogen	1.64E-03	4.29E-06	3.38E-05	3.53E-05	2.56E-05	4.33E-04	1.96E-04	2.79E-03	1.41E-03	2.30E-04	2.55E-04	2.58E-04
Hydrogen chloride	1.38E-01	2.13E-04	-1.74E-03	-1.73E-03	-1.20E-03	1.01E-02	-7.16E-03	1.74E-01	7.63E-02	1.93E-02	1.60E-02	1.40E-02
Hydrogen fluoride	3.19E-02	1.32E-04	-4.17E-04	-4.15E-04	-2.63E-04	3.12E-03	-5.52E-04	4.51E-02	2.05E-02	4.46E-03	4.13E-03	3.76E-03
Hydrogen sulfide	3.05E-02	8.37E-07	-9.72E-03	-9.72E-03	-7.00E-03	3.64E-03	7.42E-03	7.33E-02	3.34E-02	4.27E-03	6.71E-03	6.12E-03
Iodine	8.08E-04	1.47E-07	-1.30E-05	-1.29E-05	-9.29E-06	8.10E-05	-7.95E-06	1.17E-03	5.33E-04	1.13E-04	1.07E-04	9.76E-05
Nitrate	3.07E-06	3.73E-10	-2.63E-08	-2.62E-08	-1.88E-08	2.72E-07	-9.00E-08	4.34E-06	1.96E-06	4.31E-07	3.97E-07	3.59E-07
Nitrogen oxides	1.10E+01	1.72E-01	-1.88E-01	-9.04E-02	-8.69E-02	1.37E+00	-6.38E-02	1.52E+01	6.91E+00	1.54E+00	1.39E+00	1.27E+00
Ozone	1.88E-02	1.06E-05	-3.66E-04	-3.65E-04	-2.61E-04	1.92E-03	-1.04E-04	2.74E-02	1.25E-02	2.64E-03	2.51E-03	2.30E-03
Phosphorus	3.40E-04	9.52E-08	1.08E-04	1.08E-04	7.76E-05	2.41E-05	-1.04E-04	4.67E-04	2.06E-04	4.77E-05	4.28E-05	3.77E-05
Scandium	1.03E-06	1.17E-11	-5.75E-10	-5.72E-10	-4.11E-10	6.48E-09	-1.49E-07	1.39E-06	5.53E-07	1.44E-07	1.27E-07	1.01E-07
Silicon tetrafluoride	1.65E-08	9.19E-11	-1.29E-09	-1.24E-09	-8.99E-10	1.03E-08	9.02E-09	3.66E-08	2.11E-08	2.31E-09	3.35E-09	3.87E-09
Strontium	4.37E-04	3.99E-08	-3.73E-06	-3.71E-06	-2.67E-06	2.91E-05	-2.58E-05	6.13E-04	2.68E-04	6.12E-05	5.61E-05	4.91E-05
Sulfur dioxide	7.97E+00	2.71E-02	-4.48E-01	-4.38E-01	-3.15E-01	2.93E+00	2.24E+00	1.47E+01	7.80E+00	1.12E+00	1.35E+00	1.43E+00
Sulfur hexafluoride	7.11E-04	1.19E-07	-6.24E-06	-6.22E-06	-4.46E-06	6.94E-05	-1.18E-05	1.01E-03	4.60E-04	9.96E-05	9.21E-05	8.42E-05

Organic Emissions												
Acetaldehyde	1.17E-03	2.78E-07	-2.34E-05	-2.33E-05	-1.68E-05	5.53E-05	-9.51E-05	1.69E-03	7.12E-04	1.64E-04	1.55E-04	1.30E-04
Acetic acid	1.13E-02	2.68E-06	-1.86E-03	-1.86E-03	-1.34E-03	1.17E-03	1.13E-03	2.17E-02	9.78E-03	1.58E-03	1.99E-03	1.79E-03
Acetone	1.27E-03	3.98E-07	-1.61E-05	-1.59E-05	-1.15E-05	6.72E-05	-1.01E-04	1.81E-03	7.69E-04	1.79E-04	1.66E-04	1.41E-04
Acrolein	3.24E-07	1.97E-08	-6.71E-09	-6.36E-09	6.72E-10	9.37E-08	5.17E-08	5.33E-07	2.75E-07	4.53E-08	4.88E-08	5.04E-08
Aldehydes, unspecified	1.85E-05	3.17E-08	-5.41E-07	-5.32E-07	-3.81E-07	3.27E-06	1.37E-06	2.90E-05	1.40E-05	2.60E-06	2.65E-06	2.56E-06
Benzaldehyde	3.33E-08	1.02E-08	-2.82E-10	-1.13E-10	2.65E-09	3.47E-08	2.70E-08	7.84E-08	5.22E-08	4.66E-09	7.18E-09	9.55E-09
Benzene	4.34E-02	8.68E-04	-4.54E-03	-4.34E-03	-3.03E-03	7.13E-03	4.49E-03	5.95E-02	2.82E-02	6.08E-03	5.45E-03	5.16E-03
Butadiene	5.88E-11	1.33E-12	-2.91E-13	2.13E-13	1.64E-13	1.38E-10	1.29E-10	2.15E-10	1.68E-10	8.23E-12	1.97E-11	3.09E-11
Butane	7.94E-02	3.55E-04	-2.55E-02	-2.53E-02	-1.83E-02	4.72E-02	5.76E-02	2.28E-01	1.25E-01	1.11E-02	2.09E-02	2.29E-02
Butene	3.12E-04	8.03E-06	-1.72E-06	2.77E-06	1.01E-06	8.28E-04	7.81E-04	1.25E-03	9.94E-04	4.37E-05	1.14E-04	1.82E-04
Cumene	2.53E-05	4.21E-07	-1.23E-06	-1.01E-06	-7.65E-07	4.40E-05	4.13E-05	8.13E-05	5.91E-05	3.54E-06	7.44E-06	1.08E-05
Ethane	3.64E-01	1.26E-04	-1.34E-01	-1.34E-01	-9.64E-02	6.62E-02	1.28E-01	9.47E-01	4.46E-01	5.10E-02	8.67E-02	8.17E-02
Ethanol	2.15E-03	4.86E-07	-2.28E-05	-2.26E-05	-1.63E-05	9.17E-05	-2.04E-04	3.03E-03	1.27E-03	3.01E-04	2.78E-04	2.33E-04
Ethene	3.10E-03	1.64E-05	-6.13E-06	2.99E-06	1.84E-07	1.70E-03	1.23E-03	5.86E-03	3.35E-03	4.34E-04	5.37E-04	6.13E-04
Ethylene diamine	3.29E-10	4.28E-14	-2.86E-12	-2.85E-12	-2.05E-12	2.92E-11	-9.51E-12	4.64E-10	2.10E-10	4.61E-11	4.25E-11	3.84E-11
Ethylene oxide	4.58E-07	5.45E-09	-6.08E-08	-5.80E-08	-4.23E-08	5.86E-07	5.70E-07	1.38E-06	9.17E-07	6.42E-08	1.27E-07	1.68E-07
Formaldehyde	8.03E-01	9.66E-07	-1.24E-03	-1.24E-03	-8.95E-04	7.11E-04	-1.21E-01	1.09E+00	4.29E-01	1.12E-01	9.94E-02	7.85E-02
Heptane	3.10E-03	8.03E-05	-1.72E-05	2.77E-05	1.01E-05	8.28E-03	7.81E-03	1.24E-02	9.93E-03	4.34E-04	1.14E-03	1.82E-03
Hexane	1.80E-02	1.73E-04	-1.32E-04	-3.58E-05	-4.66E-05	1.88E-02	1.64E-02	4.26E-02	2.85E-02	2.52E-03	3.90E-03	5.22E-03
Hydrocarbons, aromatic	1.56E-02	1.00E-06	-2.24E-03	-2.24E-03	-1.62E-03	9.25E-04	4.83E-04	1.72E-02	7.30E-03	2.19E-03	1.58E-03	1.34E-03
Methane, biogenic	1.66E-02	2.31E+00	5.66E-03	5.66E-03	6.51E-01	1.40E-03	-7.17E-01	2.50E-02	1.11E-02	2.32E-03	2.29E-03	2.03E-03
Methanol	2.45E-01	1.68E-06	1.28E-06	2.12E-06	1.39E-06	2.22E-04	-3.72E-02	3.30E-01	1.30E-01	3.43E-02	3.02E-02	2.38E-02
Monoethanolamine	2.93E-06	2.49E-09	-7.24E-08	-7.21E-08	-5.14E-08	2.81E-07	-3.46E-08	4.32E-06	1.95E-06	4.11E-07	3.95E-07	3.58E-07
PAH, polycyclic aromatic hydrocarbons	6.20E-04	3.78E-06	-1.21E-04	-1.21E-04	-8.62E-05	7.01E-05	8.44E-05	1.23E-03	5.59E-04	8.68E-05	1.13E-04	1.02E-04
Pentane	7.66E-02	4.36E-04	-1.46E-02	-1.44E-02	-1.04E-02	5.18E-02	5.32E-02	1.97E-01	1.13E-01	1.07E-02	1.80E-02	2.07E-02
Phenol	1.81E-06	1.81E-10	1.47E-08	1.47E-08	1.06E-08	3.38E-08	-2.47E-07	2.42E-06	9.78E-07	2.53E-07	2.21E-07	1.79E-07
Propane	1.36E-01	3.59E-04	-5.13E-02	-5.11E-02	-3.68E-02	5.73E-02	8.15E-02	3.90E-01	2.01E-01	1.91E-02	3.57E-02	3.68E-02
Propene	1.25E-03	1.63E-05	-7.51E-06	1.57E-06	-8.42E-07	1.70E-03	1.52E-03	3.37E-03	2.37E-03	1.75E-04	3.09E-04	4.34E-04
Propionic acid	9.23E-04	2.13E-08	-2.41E-04	-2.41E-04	-1.73E-04	1.09E-04	1.84E-04	2.05E-03	9.37E-04	1.29E-04	1.88E-04	1.72E-04
Propylene oxide	5.59E-07	1.28E-08	-2.59E-09	3.05E-09	1.72E-09	1.32E-06	1.24E-06	2.06E-06	1.62E-06	7.84E-08	1.89E-07	2.96E-07
Styrene	2.18E-07	7.76E-11	-5.18E-09	-5.16E-09	-3.70E-09	2.28E-08	2.72E-11	3.21E-07	1.47E-07	3.05E-08	2.94E-08	2.69E-08
Toluene	1.20E-02	3.99E-04	-1.57E-03	-1.47E-03	-1.02E-03	6.52E-03	6.08E-03	2.96E-02	1.62E-02	1.68E-03	2.71E-03	2.97E-03
Xylene	1.44E-02	3.83E-04	-1.99E-04	-1.05E-04	-3.61E-05	4.86E-03	3.08E-03	2.41E-02	1.28E-02	2.01E-03	2.21E-03	2.35E-03
Particulate Emissions												
Aluminum	7.74E-02	9.20E-06	-5.79E-04	-5.77E-04	-4.15E-04	6.11E-03	-3.32E-03	1.09E-01	4.84E-02	1.08E-02	9.95E-03	8.86E-03
Particulates	1.61E+00		1.57E-04	1.57E-04			-1.23E-04	-2.00E-01	-1.98E-01	2.25E-01	-1.84E-02	-3.63E-02
Particulates, < 2.5 um	1.13E+00	1.66E-02	-4.36E-03	2.08E-05	1.52E-03	1.08E-01	-5.46E-02	1.63E+00	7.19E-01	1.59E-01	1.49E-01	1.32E-01
Particulates, > 10 um	2.23E+00	1.37E-02	-2.06E-02	-1.59E-02	-1.10E-02	1.95E-01	-8.28E-02	3.17E+00	1.42E+00	3.12E-01	2.90E-01	2.60E-01
Particulates, > 2.5 um, and < 10um	3.81E-01	3.27E-03	-1.13E-03	1.04E-05	1.06E-04	2.10E-02	-3.54E-02	5.33E-01	2.25E-01	5.33E-02	4.88E-02	4.11E-02

Table 33 Material emissions, discharged to waste effluent, kg/tonne MDF waste utilised

Substance	Production of 1 tonne of waste from MDF production	Disposal Options						Displacement of 1 tonne of virgin fibre with recycled to produce:		Production of 1 tonne of:		
		Landfill	Energy from waste, onsite	Energy from waste, offsite	Current disposal practice	Microrelease (without avoided)	Microrelease (with avoided)	rMDF 10%	rMDF 20%	vMDF	10% rMDF	20% rMDF
Heavy Metals												
Antimony	1.71E-04	1.68E-06	-1.10E-05	-1.10E-05	-7.48E-06	2.12E-05	6.71E-06	2.80E-04	1.28E-04	2.40E-05	2.57E-05	2.35E-05
Arsenic, ion	7.11E-04	4.23E-04	4.04E-04	4.04E-04	4.09E-04	7.72E-05	-4.61E-04	1.08E-03	4.90E-04	9.96E-05	9.86E-05	8.97E-05
Cadmium, ion	4.00E-05	2.01E-04	1.63E-07	3.08E-07	5.63E-05	9.84E-06	-5.76E-05	6.72E-05	3.32E-05	5.60E-06	6.15E-06	6.08E-06
Cesium	1.50E-05	3.85E-07	-9.54E-08	8.83E-08	3.92E-08	3.98E-05	3.75E-05	5.99E-05	4.78E-05	2.10E-06	5.48E-06	8.75E-06
Chromium VI	6.33E-04	3.64E-06	8.50E-05	8.50E-05	6.22E-05	6.09E-05	-8.85E-05	9.34E-04	4.21E-04	8.86E-05	8.55E-05	7.71E-05
Iron	9.27E-04	1.88E-03	-3.30E-02	-3.29E-02	-2.33E-02	4.96E-02	3.24E-02	8.14E-04	2.99E-04	1.30E-04	7.46E-05	5.48E-05
Lead	1.03E-03	2.79E-02	1.95E-03	1.96E-03	9.22E-03	2.85E-04	-9.98E-03	1.71E-03	8.67E-04	1.45E-04	1.56E-04	1.59E-04
Manganese	1.75E-02	5.19E-02	4.54E-02	4.54E-02	4.72E-02	2.74E-03	-5.11E-02	2.57E-02	1.21E-02	2.45E-03	2.36E-03	2.21E-03
Molybdenum	7.50E-04	3.29E-04	7.98E-04	7.98E-04	6.67E-04	7.83E-05	-7.44E-04	1.15E-03	5.22E-04	1.05E-04	1.06E-04	9.57E-05
Nickel, ion	3.26E-03	5.59E-04	4.70E-04	4.72E-04	4.95E-04	2.36E-04	-7.60E-04	4.72E-03	2.05E-03	4.57E-04	4.32E-04	3.75E-04
Selenium	1.79E-04	3.46E-07	-7.45E-06	-7.40E-06	-5.27E-06	2.52E-05	7.95E-06	2.81E-04	1.31E-04	2.50E-05	2.58E-05	2.40E-05
Silver, ion	1.28E-05	3.09E-07	-8.91E-08	8.06E-08	2.25E-08	3.18E-05	2.99E-05	4.89E-05	3.86E-05	1.79E-06	4.48E-06	7.08E-06
Strontium	1.02E-01	2.33E-03	-1.05E-03	5.26E-05	-1.07E-04	2.40E-01	2.26E-01	3.78E-01	2.95E-01	1.43E-02	3.46E-02	5.41E-02
Thallium	3.31E-05	5.80E-08	-3.95E-07	-3.93E-07	-2.68E-07	3.05E-06	-8.05E-07	4.75E-05	2.15E-05	4.63E-06	4.35E-06	3.93E-06
Tin, ion	1.59E-04	6.29E-07	-1.04E-05	-1.04E-05	-7.35E-06	1.84E-05	4.71E-06	2.57E-04	1.16E-04	2.22E-05	2.36E-05	2.13E-05
Titanium, ion	3.04E-02	2.40E-05	-4.63E-04	-4.60E-04	-3.27E-04	2.96E-03	-5.72E-04	4.50E-02	2.03E-02	4.26E-03	4.12E-03	3.73E-03
Tungsten	2.42E-04	9.14E-08	-7.48E-06	-7.46E-06	-5.36E-06	2.51E-05	4.20E-07	3.63E-04	1.65E-04	3.39E-05	3.32E-05	3.03E-05
Vanadium, ion	3.13E-03	2.94E-06	-5.21E-05	-5.17E-05	-3.67E-05	3.15E-04	-4.37E-05	4.64E-03	2.11E-03	4.38E-04	4.25E-04	3.86E-04
Zinc, ion	4.36E-03	1.48E-02	1.73E-04	2.74E-04	4.28E-03	3.32E-03	-2.00E-03	9.31E-03	5.74E-03	6.11E-04	8.53E-04	1.05E-03
Inorganic Emissions												
Acidity, unspecified	1.56E-05	1.01E-07	-3.66E-07	-3.14E-07	-2.35E-07	1.05E-05	8.48E-06	3.14E-05	1.88E-05	2.18E-06	2.87E-06	3.45E-06
Aluminum	6.88E-01	7.11E-03	-1.96E-02	-1.95E-02	-1.21E-02	7.31E-02	-2.61E-03	1.06E+00	4.84E-01	9.63E-02	9.75E-02	8.86E-02
Ammonium, ion	1.77E-01	4.05E-01	-8.85E-05	-7.38E-05	1.13E-01	3.31E-03	-1.48E-01	2.41E-01	9.69E-02	2.47E-02	2.20E-02	1.77E-02
Barium	2.09E-02	3.53E-04	-6.70E-04	-5.08E-04	-3.84E-04	3.54E-02	3.28E-02	6.46E-02	4.71E-02	2.92E-03	5.92E-03	8.62E-03
Beryllium	8.62E-05	9.16E-08	-4.32E-06	-4.30E-06	-3.08E-06	9.62E-06	1.89E-06	1.35E-04	6.18E-05	1.21E-05	1.24E-05	1.13E-05
Boron	9.99E-03	2.11E-03	9.11E-04	9.15E-04	1.25E-03	1.48E-03	-1.19E-03	1.71E-02	7.94E-03	1.40E-03	1.56E-03	1.45E-03
Bromate	5.81E-05	2.70E-07	4.86E-05	4.86E-05	3.51E-05	1.46E-05	-3.11E-05	9.33E-05	4.69E-05	8.13E-06	8.54E-06	8.59E-06
Bromine	1.11E-02	2.72E-04	-8.05E-05	4.81E-05	1.83E-05	2.79E-02	2.63E-02	4.28E-02	3.38E-02	1.56E-03	3.92E-03	6.20E-03
Calcium, ion	1.79E+00	1.45E-01	2.16E-02	2.77E-02	5.61E-02	1.39E+00	1.08E+00	4.11E+00	2.50E+00	2.51E-01	3.77E-01	4.59E-01
Carbonate	7.74E-04	1.36E-06	-2.25E-05	-2.21E-05	-1.58E-05	1.40E-04	6.06E-05	1.21E-03	5.86E-04	1.08E-04	1.11E-04	1.07E-04
Chlorate	4.78E-04	2.17E-06	3.69E-04	3.70E-04	2.67E-04	1.23E-04	-2.28E-04	7.74E-04	3.91E-04	6.69E-05	7.09E-05	7.16E-05
Chloride	1.61E+01	5.26E-01	2.15E-01	3.07E-01	3.02E-01	2.07E+01	1.82E+01	4.20E+01	2.93E+01	2.25E+00	3.84E+00	5.37E+00
Chlorinated solvents, unspecified	2.66E-07	8.11E-10	1.06E-07	1.06E-07	7.65E-08	5.51E-08	-6.56E-08	4.17E-07	2.01E-07	3.73E-08	3.82E-08	3.68E-08
Cyanide	1.36E-04	7.33E-07	-2.01E-07	1.68E-07	6.08E-08	7.58E-05	5.51E-05	2.55E-04	1.46E-04	1.90E-05	2.34E-05	2.68E-05
Fluoride	5.28E-03	2.10E-02	2.03E-02	2.03E-02	2.05E-02	2.83E-03	-2.02E-02	9.97E-03	5.77E-03	7.39E-04	9.13E-04	1.06E-03
Hydrogen sulfide	9.27E-04	9.08E-03	-6.59E-06	-6.56E-06	2.54E-03	6.97E-05	-2.84E-03	1.27E-03	5.62E-04	1.30E-04	1.16E-04	1.03E-04
Hydroxide	1.84E-09	2.78E-12	4.30E-10	4.31E-10	3.10E-10	4.02E-10	-1.63E-10	2.91E-09	1.45E-09	2.57E-10	2.67E-10	2.65E-10
Hypochlorite	7.64E-04	3.27E-07	-3.34E-05	-3.33E-05	-2.40E-05	8.75E-05	1.75E-05	1.18E-03	5.43E-04	1.07E-04	1.08E-04	9.95E-05
Iodide	1.55E-03	3.85E-05	-1.10E-05	7.38E-06	2.88E-06	3.98E-03	3.75E-03	6.06E-03	4.81E-03	2.17E-04	5.55E-04	8.81E-04
Magnesium	3.34E-01	2.00E-01	1.64E-01	1.65E-01	1.74E-01	2.41E-01	6.07E-03	7.36E-01	4.44E-01	4.68E-02	6.74E-02	8.14E-02
Metallic ions, unspecified	7.80E-03						-1.19E-03	9.27E-03	3.59E-03	1.09E-03	8.49E-04	6.58E-04
Nitrate	1.27E-01	1.06E-01	4.62E-02	4.62E-02	6.30E-02	7.79E-03	-7.93E-02	1.72E-01	7.32E-02	1.78E-02	1.57E-02	1.34E-02
Nitrite	1.73E-04	2.15E-02	-3.88E-05	-3.87E-05	5.99E-03	2.82E-05	-6.58E-03	3.70E-04	1.75E-04	2.42E-05	3.39E-05	3.20E-05
Nitrogen	7.35E-02	5.08E-04	-3.37E-04	-3.29E-04	-1.00E-04	2.89E-03	-8.00E-03	1.02E-01	4.21E-02	1.03E-02	9.32E-03	7.72E-03
Nitrogen, organic bound	3.94E-03	6.33E-01	-2.83E-05	-1.59E-05	1.77E-01	2.66E-03	-1.93E-01	7.97E-03	4.78E-03	5.51E-04	7.30E-04	8.75E-04
Phosphate	1.21E-02	2.38E-03	1.26E-02	1.26E-02	9.76E-03	1.37E-03	-1.08E-02	1.85E-02	8.43E-03	1.69E-03	1.69E-03	1.54E-03
Potassium, ion	2.92E-01	6.71E-02	5.98E-02	6.06E-02	6.19E-02	1.85E-01	7.92E-02	5.80E-01	3.47E-01	4.09E-02	5.31E-02	6.35E-02
Rubidium	1.54E-04	3.86E-06	-1.06E-06	7.73E-07	3.14E-07	3.98E-04	3.75E-04	6.04E-04	4.80E-04	2.15E-05	5.53E-05	8.80E-05
Scandium	4.59E-04	7.28E-08	-6.44E-06	-6.42E-06	-4.62E-06	4.17E-05	-1.07E-05	6.57E-04	2.97E-04	6.43E-05	6.02E-05	5.44E-05
Sodium, ion	4.80E+00	1.31E-01	-1.59E-02	3.99E-02	2.53E-02	1.21E+01	1.14E+01	1.85E+01	1.47E+01	6.73E-01	1.70E+00	2.69E+00
Sulfate	2.82E+00	3.55E-01	1.96E-01	1.97E-01	2.40E-01	4.31E-01	-2.05E-01	4.64E+00	2.17E+00	3.95E-01	4.25E-01	3.97E-01
Sulfide	1.27E-04	4.55E-07	-2.83E-06	-2.61E-06	-1.91E-06	5.12E-05	3.58E-05	2.21E-04	1.20E-04	1.78E-05	2.03E-05	2.20E-05
Sulfite	3.11E-03	8.83E-07	-6.87E-04	-6.87E-04	-4.95E-04	4.90E-04	6.73E-04	6.58E-03	3.11E-03	4.35E-04	6.02E-04	5.69E-04
Sulfur	2.91E-03	6.13E-05	-3.79E-05	-1.64E-05	-1.01E-05	6.39E-03	5.99E-03	1.03E-02	7.97E-03	4.08E-04	9.46E-04	1.46E-03

Organic Emissions												
Acenaphthene	9.32E-08	2.40E-09	-5.93E-10	5.49E-10	2.44E-10	2.48E-07	2.34E-07	3.72E-07	2.97E-07	1.31E-08	3.41E-08	5.44E-08
Acenaphthylene	5.83E-09	1.50E-10	-3.71E-11	3.43E-11	1.52E-11	1.55E-08	1.46E-08	2.33E-08	1.86E-08	8.17E-10	2.13E-09	3.40E-09
Acetic acid	4.82E-06	8.87E-08	-2.60E-07	-2.15E-07	-1.63E-07	9.25E-06	8.75E-06	1.64E-05	1.22E-05	6.75E-07	1.51E-06	2.23E-06
Benzene	1.08E-03	2.71E-05	-1.05E-05	2.06E-06	1.04E-08	2.80E-03	2.64E-03	4.26E-03	3.38E-03	1.52E-04	3.90E-04	6.19E-04
Benzene, ethyl-	3.60E-04	9.25E-06	-2.29E-06	2.12E-06	9.41E-07	9.55E-04	9.01E-04	1.44E-03	1.15E-03	5.04E-05	1.32E-04	2.10E-04
Butene	4.48E-06	5.79E-12	4.22E-09	4.22E-09	3.04E-09	9.30E-10	-6.88E-07	6.03E-06	2.38E-06	6.27E-07	5.52E-07	4.36E-07
Chlorinated solvents, unspecified	2.66E-07	8.11E-10	1.06E-07	1.06E-07	7.65E-08	5.51E-08	-6.56E-08	4.17E-07	2.01E-07	3.73E-08	3.82E-08	3.68E-08
Cumene	6.08E-05	1.01E-06	-2.95E-06	-2.43E-06	-1.84E-06	1.06E-04	9.91E-05	1.95E-04	1.42E-04	8.51E-06	1.79E-05	2.60E-05
Ethene	2.40E-05	4.25E-07	-1.25E-06	-1.03E-06	-7.81E-07	4.43E-05	4.18E-05	7.99E-05	5.88E-05	3.36E-06	7.32E-06	1.08E-05
Ethylene diamine	7.97E-10	1.04E-13	-6.94E-12	-6.92E-12	-4.97E-12	7.07E-11	-2.31E-11	1.13E-09	5.08E-10	1.12E-10	1.03E-10	9.31E-11
Ethylene oxide	4.31E-09	3.67E-12	-1.06E-10	-1.06E-10	-7.56E-11	4.13E-10	-5.09E-11	6.35E-09	2.87E-09	6.03E-10	5.81E-10	5.26E-10
Formaldehyde	4.34E-02	5.36E-08	-6.37E-07	-6.10E-07	-4.44E-07	7.54E-05	-6.57E-03	5.86E-02	2.31E-02	6.08E-03	5.36E-03	4.23E-03
Glutaraldehyde	1.99E-09	2.47E-12	4.77E-10	4.78E-10	3.44E-10	3.82E-10	-2.38E-10	3.11E-09	1.52E-09	2.79E-10	2.85E-10	2.78E-10
Hydrocarbons, unspecified	2.01E-04	9.33E-07	-5.08E-06	-4.65E-06	-3.40E-06	1.00E-04	7.67E-05	3.78E-04	2.14E-04	2.82E-05	3.46E-05	3.91E-05
Methanol	1.39E-02	4.39E-08	-3.00E-04	-3.00E-04	-2.16E-04	1.15E-04	-1.76E-03	1.98E-02	7.93E-03	1.95E-03	1.81E-03	1.45E-03
Oils, unspecified	1.23E+00	2.62E-02	-1.49E-02	-5.41E-03	-3.41E-03	2.73E+00	2.56E+00	4.38E+00	3.39E+00	1.72E-01	4.01E-01	6.21E-01
PAH, polycyclic aromatic hydrocarbons	1.05E-04	2.25E-06	-6.98E-07	3.27E-07	1.27E-07	2.32E-04	2.17E-04	3.71E-04	2.87E-04	1.47E-05	3.40E-05	5.26E-05
Phenol	5.81E-03	3.69E-05	-1.13E-05	5.60E-06	2.18E-06	3.81E-03	2.93E-03	1.16E-02	6.90E-03	8.14E-04	1.07E-03	1.26E-03
Propene	2.96E-05	3.98E-07	-1.10E-06	-8.95E-07	-6.79E-07	4.15E-05	3.80E-05	8.43E-05	5.88E-05	4.15E-06	7.72E-06	1.08E-05
Propylene oxide	1.35E-06	3.08E-08	-6.22E-09	7.34E-09	4.14E-09	3.18E-06	2.98E-06	4.96E-06	3.89E-06	1.89E-07	4.54E-07	7.12E-07
Sodium formate	3.29E-08	1.45E-11	1.15E-09	1.16E-09	8.34E-10	2.42E-09	-2.98E-09	4.57E-08	2.00E-08	4.61E-09	4.19E-09	3.66E-09
Toluene	2.01E-03	4.89E-05	-1.27E-05	1.03E-05	4.53E-06	5.05E-03	4.75E-03	7.72E-03	6.11E-03	2.82E-04	7.07E-04	1.12E-03
Triethylene glycol	7.58E-04	2.26E-08	-2.43E-04	-2.43E-04	-1.75E-04	9.13E-05	1.86E-04	1.83E-03	8.32E-04	1.06E-04	1.67E-04	1.52E-04
VOC, volatile organic compounds, unspecified origin	5.50E-03	1.35E-04	-4.05E-05	2.38E-05	8.65E-06	1.40E-02	1.31E-02	2.13E-02	1.69E-02	7.70E-04	1.95E-03	3.09E-03
Xylene	1.54E-03	3.95E-05	-1.08E-05	7.67E-06	3.28E-06	4.08E-03	3.85E-03	6.14E-03	4.90E-03	2.16E-04	5.63E-04	8.97E-04
Analytical measures												
AOX, Adsorbable Organic Halogen as Cl	4.62E-04	3.06E-07	-4.24E-07	-3.06E-07	-2.19E-07	3.26E-05	-3.75E-05	6.55E-04	2.78E-04	6.47E-05	5.99E-05	5.09E-05
BOD5, Biological Oxygen Demand	3.89E+00	2.63E+01	3.21E+00	3.24E+00	9.68E+00	8.64E+00	-2.53E+00	1.39E+01	1.07E+01	5.45E-01	1.27E+00	1.97E+00
COD, Chemical Oxygen Demand	4.11E+00	1.11E+02	9.89E+00	9.92E+00	3.83E+01	8.70E+00	-3.39E+01	1.43E+01	1.09E+01	5.76E-01	1.31E+00	2.00E+00
Solids, inorganic	3.34E-01	5.66E-04	-4.26E-02	-4.24E-02	-3.05E-02	5.29E-02	4.04E-02	6.27E-01	2.91E-01	4.68E-02	5.74E-02	5.33E-02
Solved solids	1.28E-01	2.14E-05	-1.12E-03	-1.12E-03	-8.02E-04	1.19E-02	-3.10E-03	1.81E-01	8.19E-02	1.79E-02	1.65E-02	1.50E-02
Suspended solids, unspecified	4.93E-02	4.14E-04	-7.76E-04	-5.86E-04	-4.43E-04	4.34E-02	3.71E-02	1.11E-01	7.07E-02	6.91E-03	1.01E-02	1.29E-02
TOC, Total Organic Carbon	1.31E+00	1.01E+02	3.92E+00	3.93E+00	3.11E+01	2.62E+00	-3.18E+01	4.38E+00	3.32E+00	1.83E-01	4.01E-01	6.09E-01

Table 34 Material emissions, discharged as solid, kg/tonne MDF waste utilised

Substance	Production of 1 tonne of waste from MDF production	Disposal Options						Displacement of 1 tonne of virgin fibre with recycled to produce:		Production of 1 tonne of:		
		Landfill	Energy from waste, onsite	Energy from waste, offsite	Current disposal practice	Microrelease (without avoided)	Microrelease (with avoided)	rMDF 10%	rMDF 20%	vMDF	10% rMDF	20% rMDF
Heavy Metals												
Antimony	1.51E-11	1.45E-14	-4.05E-13	-4.03E-13	-2.88E-13	1.62E-12	6.66E-14	2.25E-11	1.03E-11	2.11E-12	2.06E-12	1.89E-12
Arsenic	7.34E-07	5.64E-11	-3.42E-09	-3.41E-09	-2.45E-09	7.00E-08	-1.61E-08	1.03E-06	4.69E-07	1.03E-07	9.40E-08	8.59E-08
Cadmium	2.65E-06	1.30E-07	-9.87E-10	1.08E-07	3.57E-08	2.78E-07	-1.17E-07	3.70E-06	1.67E-06	3.71E-07	3.39E-07	3.06E-07
Chromium	3.52E-05	1.17E-06	-3.98E-08	9.37E-07	3.00E-07	3.24E-06	-1.79E-06	4.85E-05	2.17E-05	4.93E-06	4.44E-06	3.97E-06
Cobalt	1.97E-06	1.52E-10	-9.23E-09	-9.19E-09	-6.60E-09	1.88E-07	-4.32E-08	4.89E-08	2.42E-08	4.32E-09	4.47E-09	4.44E-09
Copper	2.62E-05	1.95E-06	2.97E-08	1.66E-06	5.68E-07	4.18E-06	1.27E-07	3.86E-05	1.83E-05	3.67E-06	3.53E-06	3.35E-06
Iron	1.02E-01	1.68E-05	5.81E-06	5.18E-05	8.88E-06	3.13E-03	-1.20E-02	1.40E-01	5.78E-02	1.44E-02	1.29E-02	1.06E-02
Lead	1.13E-05	6.51E-07	4.47E-09	5.47E-07	1.85E-07	1.35E-06	-3.46E-07	1.60E-05	7.31E-06	1.58E-06	1.46E-06	1.34E-06
Manganese	2.19E-03	1.72E-07	-1.10E-05	-1.09E-05	-7.85E-06	2.09E-04	-4.69E-05	3.06E-03	1.40E-03	3.06E-04	2.80E-04	2.56E-04
Mercury	6.86E-08	2.01E-12	5.78E-11	5.84E-11	4.22E-11	1.21E-09	-8.95E-09	8.60E-08	3.46E-08	9.61E-09	7.88E-09	6.34E-09
Molybdenum	4.06E-07	3.38E-11	-1.64E-09	-1.63E-09	-1.17E-09	3.89E-08	-8.94E-09	5.68E-07	2.60E-07	5.69E-08	5.20E-08	4.76E-08
Nickel	1.02E-05	1.04E-06	2.61E-08	8.94E-07	3.10E-07	1.61E-06	-9.26E-08	1.50E-05	7.09E-06	1.43E-06	1.38E-06	1.30E-06
Silver	9.70E-11	2.04E-13	2.15E-11	2.16E-11	1.56E-11	2.69E-11	-2.14E-12	1.59E-10	8.19E-11	1.36E-11	1.46E-11	1.50E-11
Strontium	5.23E-07	1.72E-08	-9.82E-11	9.30E-09	4.76E-09	1.78E-06	1.70E-06	2.48E-06	2.06E-06	7.32E-08	2.27E-07	3.77E-07
Tin	5.83E-09	1.62E-11	1.67E-09	1.68E-09	1.21E-09	1.67E-09	-3.96E-10	9.50E-09	4.89E-09	8.17E-10	8.70E-10	8.96E-10
Titanium	1.51E-04	1.12E-08	-7.59E-07	-7.57E-07	-5.44E-07	1.44E-05	-3.30E-06	2.11E-04	9.64E-05	2.11E-05	1.93E-05	1.77E-05
Vanadium	4.32E-06	3.20E-10	-2.17E-08	-2.17E-08	-1.56E-08	4.11E-07	-9.45E-08	6.04E-06	2.76E-06	6.05E-07	5.53E-07	5.05E-07
Zinc	7.30E-04	1.04E-04	4.54E-06	9.17E-05	3.25E-05	1.22E-04	-1.97E-05	1.07E-03	5.01E-04	1.02E-04	9.83E-05	9.18E-05
Inorganic Emissions												
Aluminum	2.28E-03	2.58E-07	-9.95E-06	-9.87E-06	-7.09E-06	2.26E-04	-4.26E-05	3.20E-03	1.47E-03	3.20E-04	2.93E-04	2.69E-04
Barium	6.83E-07	5.40E-09	1.29E-07	1.32E-07	9.42E-08	5.92E-07	4.02E-07	1.52E-06	9.75E-07	9.57E-08	1.39E-07	1.79E-07
Chloride	3.71E-04	5.92E-08	3.23E-06	3.25E-06	2.34E-06	3.81E-05	-9.45E-06	5.24E-04	2.40E-04	5.20E-05	4.80E-05	4.40E-05
Fluoride	7.52E-08	1.02E-10	1.78E-08	1.79E-08	1.29E-08	1.53E-08	-8.04E-09	1.18E-07	5.80E-08	1.05E-08	1.08E-08	1.06E-08
Phosphorus	1.07E-03	7.95E-08	-5.38E-06	-5.36E-06	-3.85E-06	1.02E-04	-2.34E-05	1.50E-03	6.85E-04	1.50E-04	1.37E-04	1.25E-04
Sulfur	1.01E-03	8.80E-08	-3.60E-06	-3.58E-06	-2.57E-06	9.72E-05	-2.24E-05	1.42E-03	6.47E-04	1.42E-04	1.30E-04	1.18E-04
Organic Emission												
Carbon	1.41E-03	1.57E-06	8.55E-06	9.33E-06	6.59E-06	2.77E-04	9.79E-05	2.12E-03	1.04E-03	1.97E-04	1.94E-04	1.91E-04
Metaldehyde	2.79E-07	2.08E-13	-1.20E-11	-1.19E-11	-8.58E-12	1.59E-10	-4.25E-08	3.42E-07	1.33E-07	3.91E-08	3.13E-08	2.44E-08
Oils, unspecified	1.07E+00	2.78E-02	-6.42E-03	3.23E-03	3.15E-03	2.87E+00	2.71E+00	4.30E+00	3.44E+00	1.50E-01	3.94E-01	6.30E-01

Waste & Resources
Action Programme

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

www.wrap.org.uk/recyclingindustry