Life Cycle Analysis of Mattress Recycling in California

Critically Reviewed Final Report

SCOPE 3
CONSULTING

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Executive Summary

Introduction

The Mattress Recycling Council California, LLC (MRC) sponsored a life cycle analysis (LCA) of mattress recycling in California. The baseline study was conducted for the calendar year 2021. MRC is a non-profit organization which administers California’s mattress recycling program. Since 2016, MRC has collected, transported, and recycled over 10 million mattresses and box springs (together called ‘mattresses’ or ‘units’) in California. Scope 3 Consulting LLC conducted the LCA. The modeling is designed to describe and measure the environmental implications of this mandated statewide recycling program. This report does not measure the economic feasibility of the modeled recycling systems.

The study establishes baseline environmental performance parameters for the mattress recycling system in California. In an effort to improve the mattress industry’s environmental performance, members of the mattress supply chain are investing in research and pilot facilities to enhance product and materials designs, develop lower carbon footprint materials, and explore alternative recycling technologies. MRC expects to use the results of this study as a benchmark for evaluating future technologies.

Key Findings

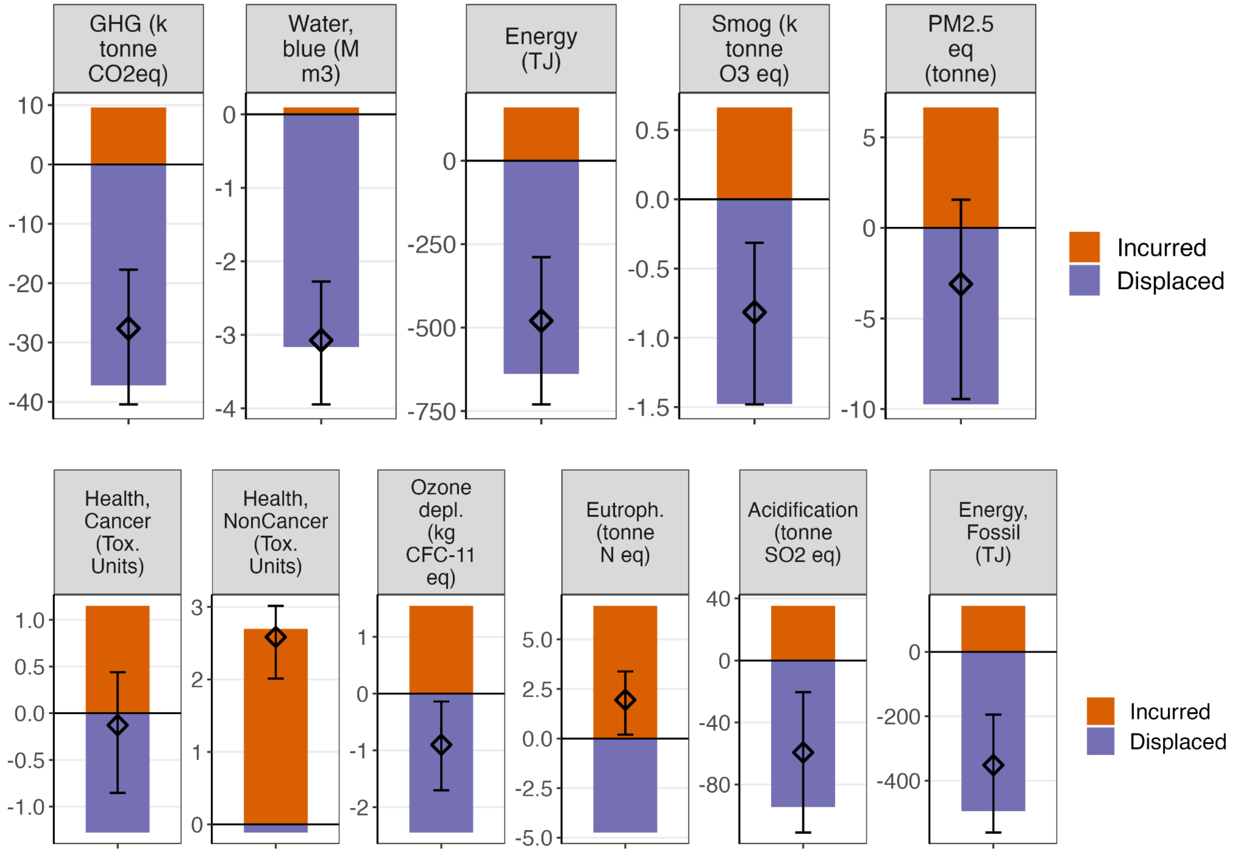
Baseline Performance

In 2021, the California program recycled 1.6 million mattresses. Of the 40.7 thousand metric tons (90 million lbs.) of materials recovered, 31.4 thousand tons (77%) were recycled, and 9.3 thousand tons (23%) were landfilled. The assessment of the 2021 recycling system found that it provides the following net environmental benefits:

- Greenhouse gas reduction: 28,000 metric tons (61 million lbs.) CO_2 equivalents
- Energy demand reduction: 480 terajoules (133 million kWh)
- Blue water demand reduction: 3.1 million m^3 (819 million gallons)
- Particulate matter reduction: 3.1 metric tons PM2.5 equivalent (6.8 thousand lbs.)
- Smog reduction: 820 metric tons O_3 equivalents (1810 thousand lbs.)

According to the LCA model, the mattress recycling system provided environmental benefits in all 5 of the headline study indicators. For supplemental indicators, the overall impact was mixed. Three of the indicators showed consistently better performance (ozone depletion; acidification; fossil energy), two had consistently worse performance (non-cancer health; eutrophication), and one was marginal (cancer). The body of this report defines these indicators, explains the modeling methods, and discusses findings in greater detail. Incurred impacts, avoided impacts (displacement), and net results are illustrated in Figure ES.1

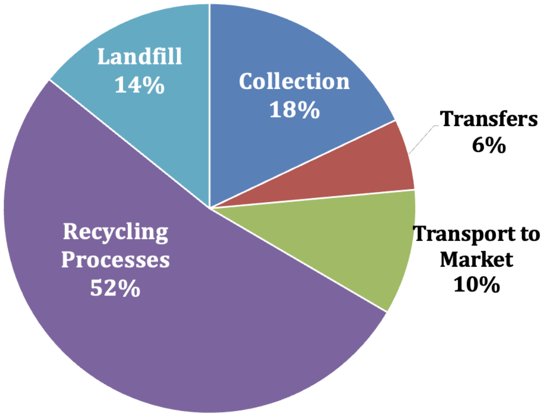
Figure ES.1. Total system impacts for managing 41 thousand tonnes (kt) of used mattresses. Each pane shows the incurred, displaced, and net total impacts of mattress recycling in CA (yr2021). The Diamonds represent the Net total. Top five panes show the headline indicators; bottom panes show the six supplemental indicators. The Error bars show net total results for a range of assumed displacement rates (see §Displacement rates for explanation, and §Displaced production for ranges). Tabular data in §Appendix.



<u>Incurred Impacts</u>

The *incurred* environmental impacts are from processes related to used mattress collection, transportation, deconstruction, reclamation, transport of extracted mattress materials to final disposition, and remanufacturing. Figure ES.2 illustrates the major drivers for incurred greenhouse gas emissions resulting from the mattress recycling system. Within the Recycling Processes category, the activity of California recyclers and rebond foam pad production are major drivers. The production of methylene diphenyl diisocyanate (MDI) used in rebond foam pad production is also a significant contributor to the Recycling Processes impacts.

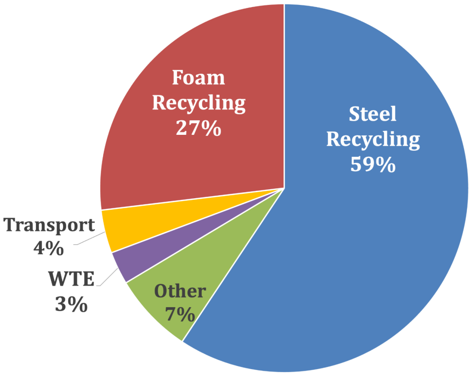
Figure ES.2. Incurred greenhouse gas impacts by process. Estimate of total incurred was 9.6 KT CO_2eq / yr.



Material, Product and Energy Displacement

In addition, the study reports potentially avoided impacts (*displaced*), which would be realized if the supply of recycled materials from mattresses displaces primary (virgin) materials. This relationship between the supply of mattress-derived materials and the displaced production of primary materials is an important uncertainty in this study. For this reason, we model a range of displacement values (depending on the material), and always show incurred impacts (from the mattress recycling system) and potentially avoided impacts (from displaced production), not just a net total. Figure ES.3 illustrates that the major drivers for avoided greenhouse gas impacts were steel recycling and avoided polyurethane foam production.

Figure ES.3. Greenhouse gas displacement drivers by material. Estimate of total displaced climate impact was 37 KT CO_2eq per year.



Net Impacts

For climate impact, water use, smog, and energy use, the magnitude of the potentially displaced impacts is consistently larger than the incurred impacts of the recycling system. For the particulate matter indicator, the baseline estimate indicates a net benefit, but a pessimistic assumption about displacement would result in a net burden.

Alternative Process Assessments

As mentioned previously, global industry research and investments are in progress to develop new pathways for recycling end-of-life materials. This LCA study made a preliminary assessment of several of these technologies.

Initial findings indicate that all established recycling processes, including mechanical recycling, chemical recycling, incineration, and pyrolysis, are more preferable options than landfilling. Chemical recycling may have more favorable environmental impacts than current mechanical recycling processes and market channels. However, it is important to note that the model relies on publicly available proxy data for the chemical recycling facility. Evaluation of an actual commercial scale chemical recycling facility is necessary to make that firm conclusion.

Improvement Opportunities

The study identified potential short- and long-term opportunities for improving the environmental impacts of mattress recycling.

Transportation of mattresses from collection nodes to recyclers and recovered materials to secondary markets represented approximately 34% of incurred climate impacts. The number, size and location of collection nodes, and primary and secondary recycling facilities, is an important consideration as the mattress recycling industry expands.

Automation to improve recyclers' ability to efficiently separate materials has the potential to increase throughput for recyclers. However, the impact on recovery rates and landfill rates will affect the overall environmental performance..

Development of new end markets for recovered materials remains a key driver for growing and diversifying demand. To maintain and improve current baseline performance, recycling rates for all materials recovered should exceed 75% and must be robust through economic cycles.

Conclusion

The LCA found that the current industry-led product stewardship program offers environmental benefits in all 5 of the headline indicators. Even under the most pessimistic assumptions, the recycling system provides environmental benefits in 4 of the 5 headline indicators. According to the best estimates of the study, approximately 28,000 metric tons (61 million pounds) of greenhouse gases were avoided when compared with the production of products from virgin raw materials – the same amount as burning 10.4 million gallons of diesel. The program also saved an estimated 812 million gallons of water and mitigated the production of 480 terajoules of primary energy.

This LCA report follows ISO 14040 and 14044 guidelines. It has been critically reviewed by an independent panel of LCA and subject experts, and was found to be in conformance with the ISO standard.

1 Goal and Scope

Mattresses and box springs (mattresses) are bulky, and thus can be challenging to properly manage at their end-of-life (EOL). At the same time, they contain materials that have value, and materials that have a relatively high energy content in energy recovery applications.

As a consequence of these factors, mattresses are increasingly the target of extended producer responsibility (EPR) programs, where mattress manufacturers are responsible for developing EOL management solutions. In 2013, EPR laws in Connecticut, Rhode Island, and California were passed that require the industry to develop statewide recycling programs for discarded mattresses. The Connecticut program launched first in 2015, followed by California and Rhode Island in 2016.

The Mattress Recycling Council California, LLC (MRC) is a non-profit organization that operates mattress recycling programs in states with mattress recycling requirements; it was formed by the mattress industry in 2014. MRC's California subsidiary coordinates the activities of over 200 collection sites and 10 independently operated recyclers to handle the state's flow of EOL mattresses.

In 2020, MRC commissioned a life cycle assessment (LCA) study to better understand the environmental footprint of its current recycling practices. The study methodology and reporting follow ISO 10404 and 14044 guidelines. MRC selected Scope 3 Consulting LLC, a California-based consulting firm, to conduct the study.

1.1 Goal of the Study

Purpose of the Study

The end-of-life (EOL) management of mattresses and box springs (mattresses) is a multi-functional activity that generates recycled materials and products, and that disposes of waste. The primary goals of this life cycle assessment (LCA) study are to understand the major contributors to environmental impacts arising from EOL management of mattresses, and to estimate the possible environmental benefits associated with recycling. The study evaluates the environmental performance of several proposed or emerging recycling pathways, as well as the current baseline.

Another important goal is to develop a modeling framework that could support the development of an assessment tool for stakeholders. The results of this study are specific to the situation in California. However, the framework can be applied to other systems, using region-specific data on logistics, recovery-rates of different materials, waste makeup, disposal types, etc. For example, all-foam mattresses are more common in Europe than in the USA. In addition, collection logistics between the two are different, owing to differences in the population densities. And disposal in the USA usually includes landfill, while incineration is more common in Europe. Using a common framework can foster international collaboration and knowledge sharing with similar programs abroad. This framework can also be used to estimate future environmental impacts, as alternative materials, new recycling technologies, and novel end uses are introduced to the market.

The results generated during the mattress LCA are numerical indicators of potential environmental burdens. The LCA uses primary data, existing inventory databases, as well as published research and documentation to estimate a suite of environmental impacts. Data privacy and anonymity are primary concerns throughout and after the study.

Intended Application

The study is conducted by first establishing a baseline model that describes the material flow of EOL mattresses generated in California in recent years. The model then estimates the environmental impacts directly attributed to the actions of individuals and firms within the recycling system. These impacts are compared to the impacts of new products in the marketplace that compete with mattress-derived products.

Models representing existing and novel treatment routes have been constructed, and different recycling pathways are evaluated to understand the advantages and disadvantages of each. These models are used to perform consequential analyses and are intended to also serve as the basis for knowledge sharing with outside partners.

Intended Audience

This report is intended primarily for internal use by the Mattress Recycling Council California, LLC (MRC). The results will be used to direct future efforts, pursue collaborations, and for reporting to regulators. Some of the results presented represent comparative assertions, where the performance of different recycling pathways are compared. In such cases, critical review is required to satisfy ISO requirements (ISO 14044, 2006). This report has been critically reviewed by 3rd party experts, in compliance with ISO requirements and guidelines.

1.2 Scope of the Study

There are several types of sleep products to be recycled (Table 1.1). In this study, the term “mattress” is used generically to denote any of the sleep product types considered.

1.2.1 Function of the System

There are many functions of End-of-Life (EOL) mattress management. The functions we consider in this study include:

1. Collection of EOL mattresses to satisfy regulatory requirements
2. Production of mattress-derived products (which includes raw material feedstocks, finished products, and fuels made from recycled mattress components)
3. Responsible disposal of the mattress-derived materials that do not provide a marketable material or service

The product system under study includes the processes and facilities engaged in EOL management of mattresses and box springs (collectively, "mattresses") in California. These actors work together to pursue the goal of responsible product stewardship established by California's Used Mattress Recovery and Recycling Act, SB 254, as amended. Their collective activities are the subject of the analysis. The five types of sleep products included in the study are shown in Table 1.1.

Table 1.1. The five sleep product types considered in this study.

Mattress (sleep product) type	Examples of Recovered Materials
pocket coil innerspring mattress	steel; polyurethane foam; latex/rubber foam; quilt panels & toppers; fabric; felt/shoddy; fibers; plastics
tied-spring innerspring mattress	steel; polyurethane foam; latex/rubber foam; quilt panels & toppers; fabric; felt/shoddy; fibers; plastics
foam mattress	polyurethane foam; latex/rubber foam; quilt panels & toppers; fabric; plastics
box spring support (containing metal and wood support)	wood; steel; polyurethane foam; cardboard; fabric
all-wood box spring support (no metal support)	wood; polyurethane foam; cardboard; fabric

1.2.2 Functional Units

The functional unit of the study is one tonne of used mattresses destined for recycling. Because the function of the recycling system is to manage end-of-life mattresses within a geographic area, over a specified period of time, we show results for two reference quantities:

- Impacts per tonne of mattress
- Impacts of the mattresses recycling system in California during the calendar year 2021

Mattresses are commonly quantified in terms of number of units, so life cycle results could be presented per unit collected for recycling. This "average unit" could represent a mix of all sizes and types, or it could be specified separately for each of the five mattress types. Results per unit are not presented in this report, but the per-tonne impacts could be converted to per-unit, using the mass and area of each mattress type and mattress size. This primary data (collected during a project separate from this LCA study) is described in §Mattress Characterizations.

1.2.3 System Boundary

Used mattresses enter the Recycling system when they are received by a registered used mattress collector. The system boundary is illustrated in Figure 1.1. The study includes activities relating to collecting scrap mattresses and transporting them to recyclers, processing the mattresses to recover materials, and disposal of wastes. Post-deconstruction manufacturing processes that convert mattress-derived materials into products are also included. In addition, the potentially displaced products are included within the system boundary as well (see §Mattress-derived products). Thus, the study boundary includes two distinct systems: the Recycling system (logistics, deconstruction, disposal, and manufacturing of mattress-derived products), and the Displacement (Expanded) system.

An EOL mattress enters the recycling system boundary when it is transferred into the physical possession of a network participant. We assume that mattresses arrive at takeback/collection points with zero environmental burdens. This means that none of the impacts of mattress manufacturing, mattress use or interim transportation activities (including the consumer's transport to a drop-off location) are "carried over" to the recycling system.

The transport of mattresses from collection sites to recycling facilities is included, along with transfers between facilities. In addition, transport from recycling facilities to disposition locations is included. However, transportation of mattresses by consumers (bringing to collections sites or recyclers) and by informal haulers (bringing to recyclers) is excluded. Thus, the headline and supporting impacts do not include impacts due to consumer and informal hauler transport. This exclusion is reasonable, since the recycling program operator does not have influence over transport by consumers, and this activity could reasonably be considered the final act in the life of a mattress. Nonetheless, stakeholders are interested in the scale of these impacts. For this reason, the impact of this transport is modeled, based on simple assumptions about transport by consumers and informal collectors. The impacts of this assumed transport are presented separately, as a standalone comparison (§Collection Scenarios). The estimates of private transport are based on simple assumptions and are for illustrative purposes only.

All upstream inputs to mattress recycling (trucks, road infrastructure, recycling equipment, electricity, supplies, etc.) are modeled "cradle to grave", meaning from the raw material acquisition through to the delivery of the product or service for its use in mattress recycling. This is true for mattress recycling, manufacturing processes, and potentially displaced products.

In general, the recycling system boundary ends when the mattress-derived material becomes a substitute for another product/material. For some recovered materials, like steel, the material will leave the recycling system boundary when it arrives at a scrap metal facility. For other materials, the LCA system boundary will include the post-deconstruction manufacturing processes required to produce a mattress-derived product. An example of this "re-manufacturing" step would be when recovered foam is used in the manufacture of rebond foam padding (a process which includes electricity use, heat, binder, and equipment).

When mattress-derived material is used as a fuel, the energy itself is the mattress-derived product, and thus the combustion or other means of energy supply is included in the system boundary.

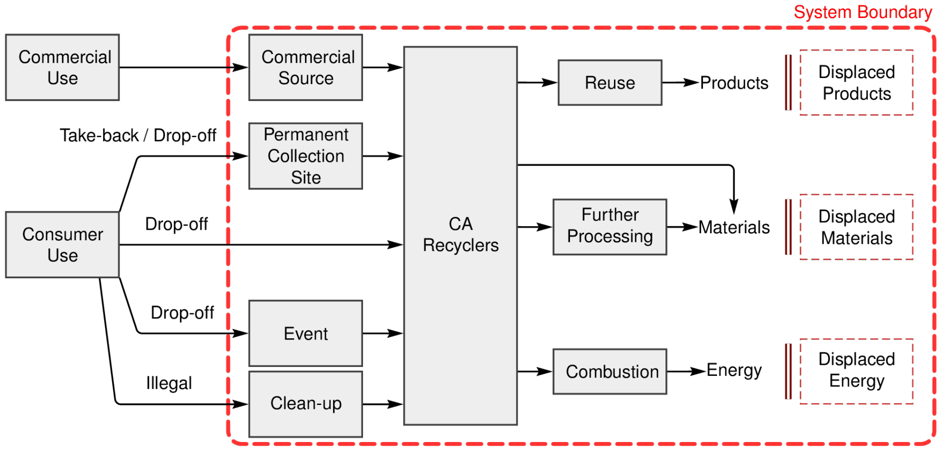


Figure 1.1. Basic system boundary diagram. The LCA system boundary includes activities related to scrap mattress management, in addition to activities displaced by the products of scrap mattress management. The "Further Processing" box to the right of "CA Processors" represents additional processing (downstream of the recyclers) required to produce some of the mattress-derived products. Mattress-derived products are described in §Mattress-derived products; the processing steps are described in §Other processing and manufacturing activities.

1.2.4 Allocation Procedures and System Expansion

We apply the "cut-off" system modeling methodology throughout our inventory model. With the cut-off approach, a mattress is "reborn" when it goes from being an "in-use" mattress to a "used, to be recycled" mattress. When the used mattress enters our system (e.g. when it arrives at a collection site, or is delivered by an independent collector to a recycler), it has zero burdens - the products' prior life cycles are "cut off" when the product is made available for recycling.

Mattress recycling generates environmental impacts, just as any other industrial activity. In an LCA of a recycling system, the impacts of recycling can be compared to the potential benefits of the recycled material. Thus, the activity of mattress recycling has two functions: management of the end of life mattress, and production of secondary materials for later use. To avoid allocating the burdens of mattress recycling between these two functions, we accounted for the effects of supplying mattress-derived products using *consequential system expansion*. This means that we expand the scope of the study to include the production of products judged to compete with mattress-derived products in the marketplace. We distinguish between the recycling system (collection, deconstruction, and manufacturing mattress-derived products) and the displacement systems that produce similar products as the recycling system, but with non-mattress-derived (usually virgin) materials. These displaced products are shown with the dashed boxes on the right side of Figure 1.1.

When recycled materials are made available for use, these products may or may not reduce the production of virgin material – the effect on the market is often unknown. However, it is conventional to consider that the use of recycled products can offset demand for similar products from other sources. We calculate "avoided burdens" that result from the displacement of those competing production activities. Avoided burdens (or credits) usually have negative impact scores and are always reported separately from incurred burdens.

By modeling the activities that give rise to displaced products, we can perform a direct comparison of the impacts of different mattress recycling routes. This allows us to build “what if” scenarios to describe alternate management strategies, and to estimate the possible effects of changes in the supply of mattress-derived recycled products. These scenarios could be further validated by an economic analysis of the markets where mattress-derived materials are sold (to estimate demand elasticities), but that is beyond the scope of this study.

1.2.5 Mattress-derived products and Potentially displaced products

For each mattress-derived product or service, a Displaced Product is defined (Table 1.2). We assume that for each recycling route shown in Table 1.2, the mattress-derived product and the displaced product provide the same function, and therefore compete with each other in the marketplace. To account for the effects of supplying mattress-derived products, we use a *consequential system expansion* framework (Earles & Halog, 2011; Ekvall & Weidema, 2004; Guinee, 2002). The scope of the study includes not just the recycling system, but it also includes the products judged to compete (in the marketplace) with mattress-derived products. We calculate the potentially avoided burdens that result from the displacement of those competing production activities. Avoided burdens (or credits) have negative impact scores and are always reported separately from incurred burdens of the recycling system.

The actual recovery rates for the Mattress-derived materials in Table 1.2 will vary with each mattress recycled, and with region and time. The routes included in Table 1.2 represent the scope of the LCA model used to estimate environmental impacts and potential avoided impacts (benefits). Furthermore, all the routes shown in Table 1.2 have a default displacement rate of < 100%. This means, for example, that when 1 kg of foam pad is produced from recycled foam, this displaces only 0.3 kg of virgin polyurethane foam (see next section).

Materials that are heavily soiled are not usually recyclable. In particular, quilt is often the most contaminated component of an end of life mattress. For any fabric, quilt, foam, or whole unit to be reused (as opposed to recycled), the material’s condition must be close-to-new. For these reuses, a cleaning/disinfection post-process is assumed to be performed (see §Cleaning for process details).

Table 1.2. The recycling routes and displacement relations considered in the study. Left column shows mattress-derived materials, as they exit the primary recycling chain (collection, handling, and deconstruction). The columns “Mattress-derived feedstock/product” and “Displaced products” represent products that perform the same functions. The column “Post-processing required?” indicates whether the mattress-derived material must undergo further processing and/or manufacturing to produce the mattress-derived feedstock/products. Waste-to-energy and Waste to Landfill are mixes of all the other Mattress-derived materials. The amount of mattress-

derived material (if any) flowing through each of these routes depends on the time and place. See §Material processing routes for the actual amounts in California during the study period. See also appendix §Descriptions of recycling routes.

Primary Mattress-derived material	Mattress-derived feedstock/product	Post-processing required?	Displaced product
Steel	Steel, recycled content	no	Steel, displaced
Steel (reused)	Steel spring (reused)	no	Steel spring, displaced
Foam	Rebond Foam Pad	yes	Virgin Polyurethane Foam Pad, displaced
	Scrap foam	no	Post industrial scrap foam, displaced
	Polyol (via acidolysis)	yes	Polyol, displaced
	Polyol (via glycolysis)	yes	Polyol, displaced
	Pyrolysis oil & Char	yes	Crude oil & Black carbon, displaced
Foam (reused)	Foam (reused)	yes	Virgin Polyurethane Foam Pad, displaced
Quilt	Rebond Foam Pad	yes	Virgin Polyurethane Foam Pad, displaced
	Scrap quilt	no	Post industrial scrap foam, displaced
Quilt (reused)	Quilt	yes	Quilt, displaced
Wood	Mulch	yes	Wood chips, displaced
	Bioenergy (heat from wood fuel)	yes	Heat, natural gas, displaced
Wood (reused)	Wood boards	yes	Wood boards, displaced
Whole unit (reused)	Whole mattress	yes	New whole unit, displaced
Cotton	Cotton fiber	no	Cotton thread, displaced
Cotton (reused)	Cotton fabric	yes	Cotton fabric, displaced
Shoddy	Mixed fibers	no	Fibers (mix), displaced
Shoddy (reused)	Shoddy	yes	Shoddy pad, displaced
Other fiber	Mixed fibers	no	Fibers (mix), displaced
Other fiber (reused)	Polyester fabric	yes	Polyester fabric, displaced
Cardboard	Cardboard, recovered	no	Wood pulp, displaced
Plastic	Plastic, recovered	no	Polypropylene granulate, displaced

Waste-to-Energy	Heat from incineration	yes	Heat, natural gas, displaced
Waste to Landfill	NA	no	NA

1.2.6 Displacement rates

Although mattress-derived materials are considered to provide the same function as displaced products, it is not necessarily true that the production of secondary materials from mattress recycling leads to the *avoidance* of primary production. In other words, producing one tonne of mattress-derived product does not necessarily displace an equivalent amount of the competing product. The *displacement rate* is the amount of primary (virgin) product that is expected to be displaced through the generation of secondary (recycled) material. A rate of 100% indicates that recycled products displace primary products on a one-to-one basis. In reality, the actual displacement rate is likely less than 100%, meaning that some recycled materials will be used to create products that would not otherwise have been created, if the recycling had not occurred. In conducting an LCA of a recycling system, the best practice is to evaluate the sensitivity of the results to the displacement rate (Zink et al., 2018).

Displacement of primary production can occur when the recycled material is used in the same type of product from which it came (“closed-loop” recycling), but it can also occur if the recycled material is used to make a different type of product (“open-loop” recycling). For example, the steel recovered from a mattress can displace primary steel production, even if it is used in a product other than a mattress.

Displacement rates can depend on many factors, including ones that are well outside the control of a consumer, a recycling company, or a recycling program operator. Displacement is more likely when demand for a particular product is inelastic, and recycled content does not already dominate a market. In this case, increasing the supply of a commodity will not necessarily lead to increased consumption, and could displace primary production. In these cases, a consumer who purchases a product made from recycled mattresses is likely to do so *instead* of purchasing a non-mattress-derived product, thus leading to displacement of primary production. On the other hand, if a recycled material already dominates a market, increasing the supply is not likely to cause large displacement, regardless of demand elasticity.

Displacement associated with rebond foam pad made from recycled foam requires some explanation. In this case, the mattress-derived product that enters the market is “rebond foam pad”. There is no virgin foam used in rebond pads. Scrap foam (post-industrial and post-consumer) is mixed with a binder and a pad is manufactured - but this product is distinct from the scrap foam it is made of. We assume this rebond product competes with prime foam pads, made of virgin foam. These prime pads are not rebonded - they are a continuous piece of foam. We acknowledge that rebond foam dominates the market for carpet pad. However, if the supply of scrap foam were significantly reduced, we expect that the amount of prime foam used in carpet pad would increase. Of course, not enough to completely replace the reduction in rebond pad due to lowered scrap availability. Nonetheless, there would be shifts in consumption, and this is one reason why we think that the displacement rate of virgin foam (not rebond) by rebond foam pad is greater than zero. Furthermore, carpet pads are not the only use for rebond foam - it could be used in cushions for upholstery and equipment. Thus, we consider the scrap foam rebond pad product to compete in a general 'foam pad' market, not only the carpet pad market. For this reason, we think it is appropriate to assign a relatively low, but non-zero displacement rate of 30%. However, we also show results for a scenario where recycled foam only displaces freight of post-industrial foam (§System Management Scenarios).

We assign a displacement rate for each displacement relationship (each row in Table 2.1). The overall displacement rate is calculated as the product of two factors, each of which has a value between 0% and 100%:

- a functional equivalency value (**τ**)
- an economic factor (***ε***) .

The functional equivalency represents the degree to which the mattress-derived product provides that same amount of service (utility) as the "virgin" product. With a value of 50% for **τ**, 2 kg of mattress-derived product would be required to provide the same function as 1 kg of a virgin product. The economic displacement factor represents the likelihood that the mattress-derived product will lead to a reduction in other manufacturing activity. A value of 100% for ***ε*** means that 1 tonne of mattress-derived products avoids the production of 1 tonne of virgin-derived products. A value of 50% means that 1 tonne of mattress-derived products avoid the production of 0.5 tonne of virgin-derived products. The overall displacement rate = **τ** * ***ε***.

For most of the mattress-derived materials, the technical equivalency (**τ**) value is 100%, with two exceptions. One exception is the combustion of mattress-derived waste for energy recovery. The technical displacement is assumed to be 75% because the efficiency of wood and waste combustion is less efficient than the competing option (combustion of natural gas). The second exception is reuse of whole mattresses - we assume that a mattress that is in good enough condition for reuse (like-new) will supply 75% of the service of a brand new unit.

Because of fundamental uncertainty in the displacement relationship, we apply sensitivity cases to the economic displacement (ε) rate, depending on the type of product being displaced (Figure 1.2). For fuels and commodities, we assume there is a high likelihood of displacement, so we consider the range of 80-100% economic displacement, with 90% as the median (reported) case. On the other hand, rebond pad, as discussed above, is a particularly interesting case. In the carpet pad market, rebond made from scrap foam is a "market leader" - it is dominant in the market. This type of product is less likely to cause displacement of alternative products. However, rebond pads can be used as cushions and pads as well, which may compete in a broader foam pad market, where displacement of prime foam is more likely. Due to these variables, we assign a wide range for the economic displacement rate: 10-60%, with 30% as the median.

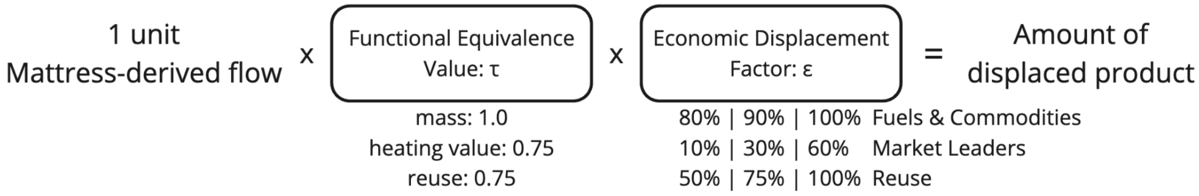


Figure 1.2. Framework for modeling displacement relationships between mattress-derived products and the competing products in the marketplace.

1.2.7 Scenarios and Scales

Several recycling scenarios are modeled. Scenarios may be distinguished by the system being modeled (e.g. alternative collection methods, different processing routes, and/or different mattress types) and by the scale (whether results are presented per tonne of mattress or recovered material, or at the statewide-scale).

The Baseline system is representative of the management of used mattresses collected in California during the year 2021. The collection statistics and material outputs generated are based on data provided by MRC. In addition to the Baseline system, three other recycling pathways are modeled. The four pathways are described in Table 1.3, and a product system diagram for each pathway is illustrated in Figure 1.3.

Within each of the pathways shown in Figure 1.3, several alternative scenarios are considered. First, a scenario is developed for each type of sleep product (listed in Table 1.1), in addition to the "mix of units" considered in the baseline. Scenarios also represent different uses for the same recovered material (e.g. multiple routes for wood recycling and foam recycling, and pyrolysis and incineration for non-ferrous materials). In addition, a compaction truck scenario is included to quantify the effect of increasing load size for improving collection system efficiency.

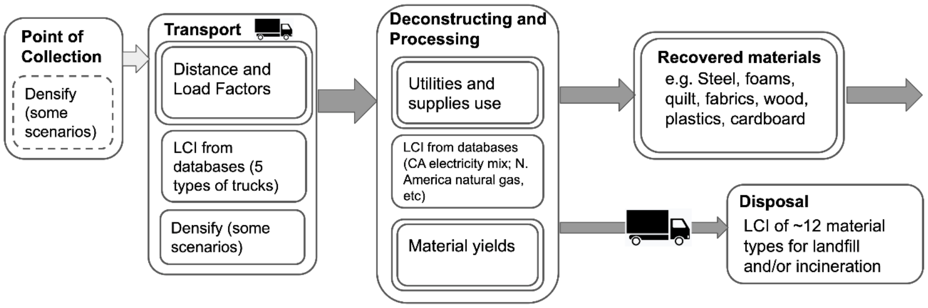
For the Baseline system, results are shown both at the statewide scale, and at the per-tonne scale. For all other scenarios, results are only shown at the "per tonne" scale.

Table 1.3. Description of the four mattress recycling pathways modeled in the study.

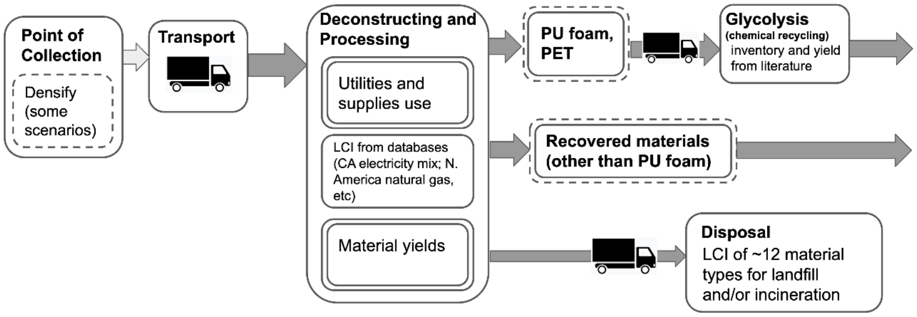
Pathway name	Description
Baseline	Based on common practice in California (2021). Mostly hand-deconstruction and recycling for commodity materials and fuels for energy recovery (includes mechanized separation of some materials, e.g. separating pocket coils into steel and fabric)
Baseline + Chemical Recycling	As in Baseline, except some material is used as feedstock for depolymerization via chemical recycling (e.g. glycolysis of polyurethane foam)

Shred, Steel, and Fuel	Mass-shred; separate and recycle ferrous; non-ferrous used as fuel for electricity generation
Shred, Steel, and Pyrolysis	Mass-shred; separate and recycle ferrous; non-ferrous materials used for pyrolysis to produce crude oil and char

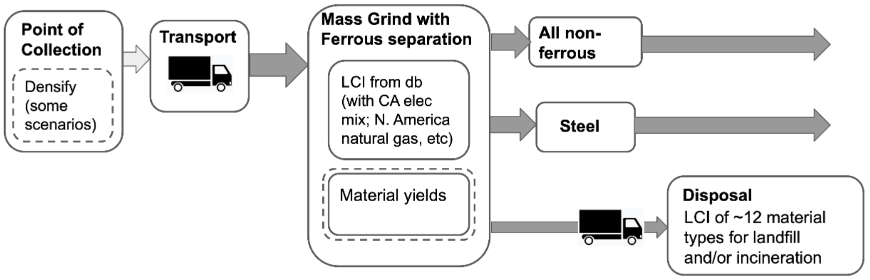
Fig 1.A) Baseline



1.B) Baseline + Chemical recycling



1.C) Mass Shred, Steel and Fuel



1.D) Mass Shred, Steel and Pyrolysis

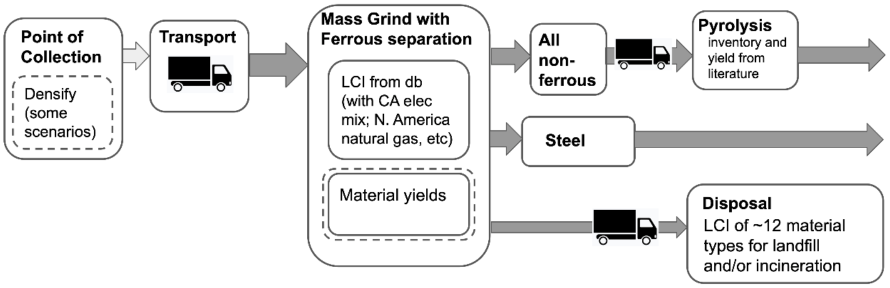


Figure 1.3. Illustrations of the four mattress recycling pathways. Pathways are defined by the types of deconstruction and remanufacturing/recovery processes they employ. Each type of mattress (**Table 1.1**) may produce distinct mixes of recovered materials from each pathway. Boxes represent material flow and transformations. Pathways are modeled with and without densification at collection, so this process is shown with a dashed border. Materials are baled for transport after deconstruction/separation (not shown). The double-bordered boxes show processes for which primary data was collected. Panel 1.A represents the practice of hand-deconstruction with material recovery, and some material sent to disposal. The recovered materials are used as a mix of raw materials and fuel. Panel 1.B represents hand-deconstruction as in (A), but with some material further processed via chemical recycling (e.g. glycolysis). Other materials are recovered as in (A). The pathway in 1.C represents a mass-shred with steel separation recycling system, where non-ferrous materials are likely used as mattress-derived fuel. The coproduct yield may be informed by data that has been collected by MRC, so this is shown with a dashed double-border. Panel 1.D is similar to (C), but non-ferrous materials are further processed via thermochemical recycling (e.g. pyrolysis) before being marketed. In all figures, final arrows represent marketed material leaving the *recycling system* to its next use. Non-mattress processing inputs (e.g. electricity, natural gas, supplies) are excluded from the figure for clarity, but they are included in process inventories. LCI = Life Cycle Inventory; PU = polyurethane.

1.2.8 Types and Sources of Data

The data required for modeling the recycling systems includes primary and secondary data. Primary data include:

- Transport distance, truck type, and load factors (# of mattresses per load)
- Mattress counts by type and size
- Material makeup of mattress units by type and size
- Usage of electricity and other utilities, machinery, and supplies during handling, deconstruction and processing
- Amount (and kind) of mattress-derived materials and products that are delivered to a market
- Amount and kind of mattress-derived material used as fuel
- Amount and kind of mattress-derived material sent to disposal.

Primary data about freight statistics and the fate of mattress-derived materials (whether used as raw materials, fuels, or sent to disposal) is sourced from MRC. Data about the material makeup of mattresses was collected by MRC.

Data to develop an inventory of current deconstruction operations (primary recyclers) were collected via surveys, discussions with recyclers, and site visits, carried out by Scope 3 Consulting. With the data collected, a synthesis model of mattress recycling was developed. Survey data contributed by facilities is aggregated into the synthesis model. No data from individual recyclers/processors has been (nor will be) released by Scope 3 Consulting to MRC nor any other party.

No significant direct emissions to the environment from activities modeled in the study foreground are expected, other than fuel combustion and equipment operation, which are assumed to be well characterized in background databases. No study-specific measurement of combustion emissions or equipment operation was performed.

The primary background database for the model was ecoinvent version 3.8, using the cut-off system model (2021). Ecoinvent is the premier scientific life cycle assessment database worldwide. It includes 17,910 activity models and incorporates data from a wide range of industrial, scientific, and public resources.

For stationary equipment operation powered by diesel, gasoline, and propane, these processes were modeled using the fuel production and combustion processes in the US Life Cycle Inventory database (USLCI), part of the Federal LCA commons. The USLCI database was developed based on US air quality regulations, operator surveys, and refinery data.

The treatment of steel scrap was modeled using the World Steel Association's most recent reference data (World Steel Association, 2021). Their methodology includes a survey-derived model of global steel production, allocated amongst different uses. They also publish a "value of scrap" activity which is a reverse allocation (an induced burden) on the steelmaking process based on their measurement of global scrap consumption. Generating scrap input to this process produces an avoided burden (WorldSteel 2017), which we use to represent the environmental benefit of scrap steel.

1.2.9 LCIA Methodology and Types of Impacts

In an LCA study, results are reported in terms of different categories of environmental effects, such as climate change or water depletion. Each category is represented by a numerical indicator that has a representative reference quantity. Numerical impact scores are computed for each activity in the product life cycle, for each indicator under consideration. This part of the study is called the "Life Cycle Impact Assessment" (LCIA).

We use the TRACI (version 2.1) life cycle impact assessment methodology to characterize the environmental impacts of the life cycle inventories (Bare, 2012). TRACI was developed by the US EPA and is more proximate to United States conditions than alternative LCIA methodologies, which tend to focus on European conditions.

Eleven impact categories are included, grouped into "Headline" and "Supporting" indicators (Table 1.4). Descriptions of the impact categories are included in the Appendix. Please refer to (Bare, 2012) for more information. Each indicator's characterized flows were carefully reviewed for consistency with the emission inventories in ecoinvent (2021), WorldSteel (2021), and US LCI (2021). Impact characterization factors were compared with ReCiPe 2016 to ensure consistency and completeness.

The TRACI fossil depletion methodology is incomplete, so this indicator was not included. Instead, characterization factors were defined to estimate fossil energy use and cumulative energy demand. To estimate cumulative energy demand, we use the ‘harvested energy’ approach, which characterizes the energy that actually enters an engineered system. This method can be applied to combustible fuels, nuclear, and renewable energy sources (Frischknecht et al., 2015). The heating values of fossil fuels are taken from (Frischknecht et al., 2015 [Table 3]); shale and bitumen are from (IPCC, 2006 [Vol.2, Chap. 1, Table 1.2]); wood and biomass are from (USEPA, 2022); peat is from (FAO, 1988). Flows of water were characterized according to the blue water footprint, to calculate the water use impact (see appendix §Headline Indicators for details).

Table 1.4. Impact categories included in the LCA study. A description of each indicator is included in the Appendix.

Impact Category	Unit	Headline or Supporting?	Area of Protection
Climate Change (GHG emissions)	kg CO_2 eq	Headline	Human & Environmental Health
Respiratory Impacts (Particulate Matter emissions)	kg PM 2.5 eq	Headline	Human Health
Water Use (blue water footprint)	m^3 blue water	Headline	Environmental Health & Natural Resources
Smog Formation	kg O_3 eq	Headline	Human & Environmental Health
Total primary energy demand	MJ	Headline	Natural Resources
Toxicity to Humans (Cancer)	Toxicity Units	Supporting	Human Health
Toxicity to Humans (Non-Cancer)	Toxicity Units	Supporting	Human Health
Ozone Depletion	kg CFC-11 eq	Supporting	Human & Environmental Health
Acidification	kg SO_2 eq	Supporting	Environmental Health
Eutrophication (terrestrial and aquatic)	kg N eq	Supporting	Environmental Health
Fossil Fuel Use	MJ	Supporting	Natural Resources

Biogenic Material Content

The materials in mattresses may contain a mix of bio-based materials and fossil-based materials. Wood and cotton are two obvious bio-based materials in some mattresses. For polyurethane (PU) foam, polyol monomers can be sourced from bio-based materials. In addition to PU foam, mattresses may contain bio-based latex rubber and/or fossil-based synthetic rubber.

For the purposes of climate impact accounting, biogenic carbon is “ignored” in the life cycle inventory. This means that a material production process does not receive a credit for its bio-C content; it also means that the portion of CO_2 released during combustion that is biogenic does not contribute to the GHG emissions impact. However, we have reported biogenic CO_2 emissions separately in §Biogenic CO2 Emissions, where they are presented alongside the total incurred climate impacts.

1.2.10 Data Quality, Assumptions, and Limitations

The data used in this study comprise primary data, secondary (literature or proxy) data, and background life cycle inventory (LCI) datasets. To meet the goal of the study, primary data must be drawn directly from the system under study, while secondary and background data must be suitably representative.

Primary Data

Primary data include data on the material flows of mattresses under management in the recycling system (collection, processing, and transfers of mattresses), utility usage and other inventory data from mattress processing facilities, and measured data about the physical characteristics of mattresses. These data make up the core of the study. Material flow and facility inventory data were collected directly from facilities included in the system boundary, over the entire study period, and are quintessentially representative of the temporal, geographic, and technological aspects of the system under study. Mattress counts (by size and type) and mattress characterization data (weight by component material) were collected from recycling facilities in California, independent of the current LCA work (see §Mattress Characterizations). All known flows were included in the facility inventories. Overall, the primary data used in the study were judged to be complete, consistent, and highly representative of the system.

Secondary Data

Secondary data are used to enrich or further develop process inventory models used in the study foreground. These data were drawn from technical reports, product marketing specifications, as well as the scientific literature. In applying proxy data, expert judgment was used to select the most highly representative data values available for modeling. Secondary data were used to model, for example, the foam rebond process, the cleaning process (for reuse), and the chemical recycling pathways.

Background LCI Data

The use of standard background databases to represent industrial processes includes an implicit assumption that the operation of these processes is approximately consistent around the world and does not vary widely from year-to-year. Many of the most important contributors to environmental impacts, including fuel production and combustion, electricity generation, and transportation, are well-understood and well-represented in reference databases.

In our selection of the ecoinvent (2021) database as our primary database, we acknowledge its limitations in scope and completeness apply to our own study results. In applying ecoinvent, our data quality assessment is limited to the selection of suitable datasets and generally does not extend to evaluating the quality of the datasets themselves. In cases where ecoinvent data were judged to be inadequate to the scope, alternative data sources were selected (See §Types and Sources of Data). Generally, ecoinvent has poor coverage for North American datasets, so our results rely strongly on ecoinvent's "rest-of-world" geographic category (typically excluding Europe). This is consistent with LCA best practices. Future studies could be improved in this respect only with the availability of higher-quality US-specific datasets.

An exception to ecoinvent's lack of US-specific data is in electrical grid mixes and production emissions. Here, ecoinvent's modeling is exemplary. This is notable because electricity grid emissions often account for a large portion of overall emissions. Where possible, activities known to occur in specific regions were modeled with electricity supplied from regionally-appropriate grid mixes drawn from ecoinvent.

Data Consistency and Validity

The principle of mass balance is the key method for ensuring consistency for material flow-based LCA.

Cut-off criteria

We do not employ an arbitrary cut-off criterion. All known flows are included in the construction of inventories, implementation of processes, and the calculation of impact scores. Known flows whose magnitudes are unknown were estimated according to engineering principles, including mass balance and technical feasibility. Flows for which background LCI data were unavailable were represented with proxy datasets.

1.2.11 Reporting and Interpretation

Life cycle impact assessment scores are computed for each scenario under consideration, for each indicator reported in §LCIA Methodology. The indicator scores are interpreted through contribution analysis, in which different activities in the product life cycle are aggregated into stages, whose individual scores add up to the total score. By ranking the contributions of each life cycle stage, we can identify the largest sources of impacts. The following stages are used in the presentation of results:

- Freight for collection (from collection site to recycler)
- Deconstruction (not including shredding of pocket coils)
- Pocket coil shredding
- Foam chopping
- Rebond foam pad manufacture (including material and energy inputs)
- Freight for transport to disposition
- Displaced manufacturing of products
- Displaced freight
- Chemolysis (including material and energy inputs)
- Pyrolysis (including energy inputs)
- Landfill and Incineration

We assess the variability of the results through scenario analysis. As discussed in §Scenarios and Scales, we define a baseline model (CA 2021) that describes the mattress recycling system in 2021. By running the model under alternative scenarios, we can evaluate the effects of the scenario on the indicator scores of various life cycle stages.

One of the most significant parameters in the life cycle performance of most recycling systems is the assumed displacement rate, as discussed in §Displacement rates. We indicate the sensitivity of the result to the displacement rate assumptions with error bars or “whiskers” on results indicating potentially displaced production.

1.2.12 Critical Review

This study underwent critical panel review in accordance with ISO 14040, 14044 and ISO 14071. The panel was chaired by Jeff Zeman, a principal at TrueNorth Collective - Sustainability Consulting, and an expert in life cycle assessment. The panel also included two subject matter experts, Tracey Pryor, a Business Development Manager with the Australian Bedding Stewardship Organization, and Bob Clark, the Executive Director of the Carpet Cushion Council.

The original version of the report was delivered to the review panel in the Spring of 2023, and the report was critically reviewed by the three panelists. The present report (v1.0) is the outcome of two rounds of comments and revision. The Verification of Conformance with ISO standards was signed in November 2023. Detailed review comments and practitioner responses are available from MRC.

2 Flow of mattress-derived materials

The life cycle impacts of mattress recycling depend on the types and amounts of materials flowing through the recyclers. In this subsection, the collection of mattresses, their processing, and transport from recyclers to the next users are described. The raw data used to generate the information in this section was supplied from MRC. Scope 3 reviewed and processed data describing mattress collection and recycling in California for the year 2021. Figure 2.1 shows a high-level overview of the material flow.

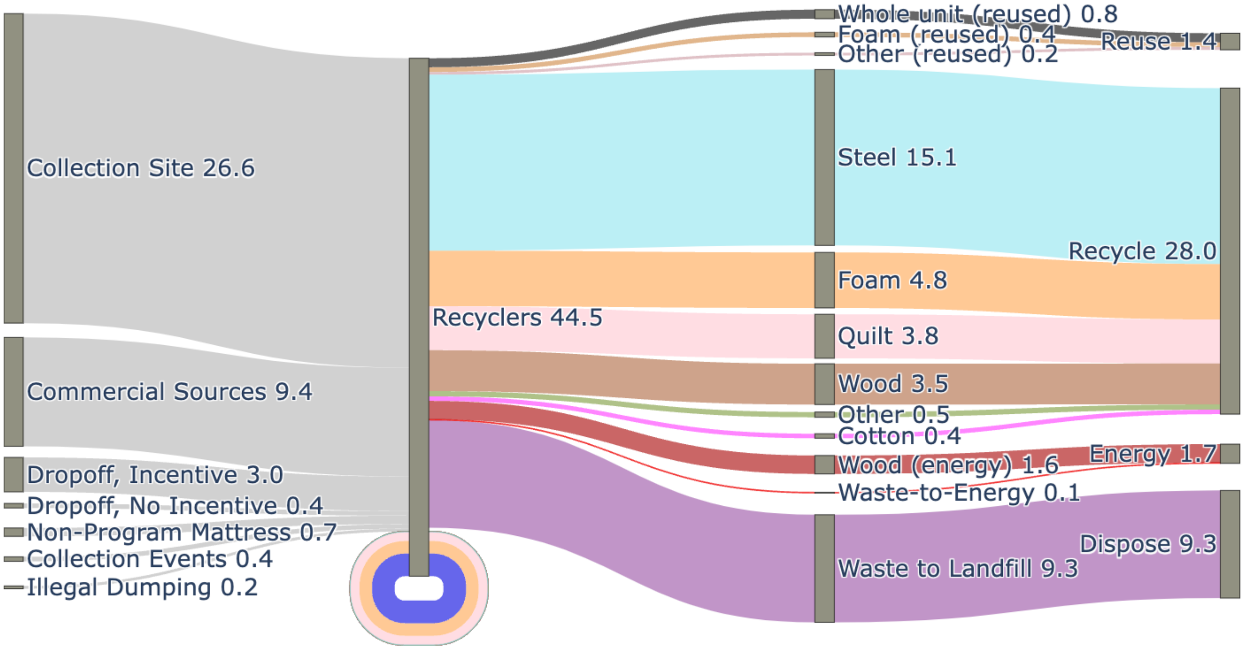


Figure 2.1. Sankey diagram indicating the flow of mattresses through the recycling system. Nodes on the left represent different collection types. Material moves through recyclers, where different types of materials are produced as output. The nodes on the right represent different fates (recycled, reused, energy conversion, disposal). The thickness of the lines represents the mass of material (thousand metric tonnes, kt). The "loop" on the Recyclers node indicates mattresses and material transferred between facilities. Data table in Appendix A4.

2.1 Highlights

I. According to the data provided to Scope 3, a total of 40,694 tonnes of mattresses (1.63 million units) were received by recyclers
    A. 65.4% from Permanent Collection Sites, 23.0% from other commercial and institutional sites, 7.3% from drop-off with incentive, 1.0% from drop-off without incentive, 1.0% from events, 0.6% from illegal dumping, and 1.8% non-program units
II. Freight for collection is estimated at 3.79 million tonne*kilometers (2.6 M short ton*miles)
    A. 9% of mattresses received by recyclers have an unknown origin location (not including drop-offs); average distance for freight with known collection location was used for these locations.
III. Transfer between recyclers adds 1.20 million tonne*kilometers (0.82 M short ton*miles) of freight
IV. According to the data provided to Scope 3, a total of 40,375 tonnes (44,506 short tons) of materials were output from recycling facilities
    A. 69% to recycling, 23% to disposal, 4% to energy recovery, and 4% to reuse/refurbish
    B. The mass difference between inputs and outputs is about 1%. We assume that stock changes at recyclers accounts for this difference.

V. Freight from recyclers to disposition vendors is estimated to be 9.7 Mtkm (6.7 million short ton miles)
    A. 59% of recycling output mass has an unknown disposition location (excl. transfers); average distance for materials with known disposition was applied to trips with unknown disposition location.

VI. See §Freight for details about the data and the life cycle model

2.2 Material processing routes

The materials generated by recyclers are shown in Figure 2.2. This illustrates all the material processing routes considered in the study. The scenarios generally include a subset of these routes. In many cases, post-deconstruction processing and remanufacturing is required to produce the mix of products included in the model. For example, multiple routes are included for the fate of foam recovered from mattresses. But for the baseline period, all the recycled foam (not reused) was used to make rebond foam pad. Table 2.1 shows the amounts of the mattress-derived materials that are produced in each of the four scenarios considered. The “Baseline” scenario in Table 2.1 shows the actual amounts in California, during the study period, as reported by recyclers to MRC. The values for the other 3 scenarios in Table 2.1 are modeled estimates.

Reuse of materials is possible when a mattress or material is in very good condition. During the study period, reuse made up a small fraction of the mass of all recovered material (less than 5%). Whole unit reuse made up about half of the reuse mass; foam made up about one quarter of all reused material; wood and steel made up the remainder. Reused foam may be used to make seating pads and other cushion products, and not strictly used for mattresses. Reuse of other components is included in the framework, but these routes did not occur during the Baseline California scenario.

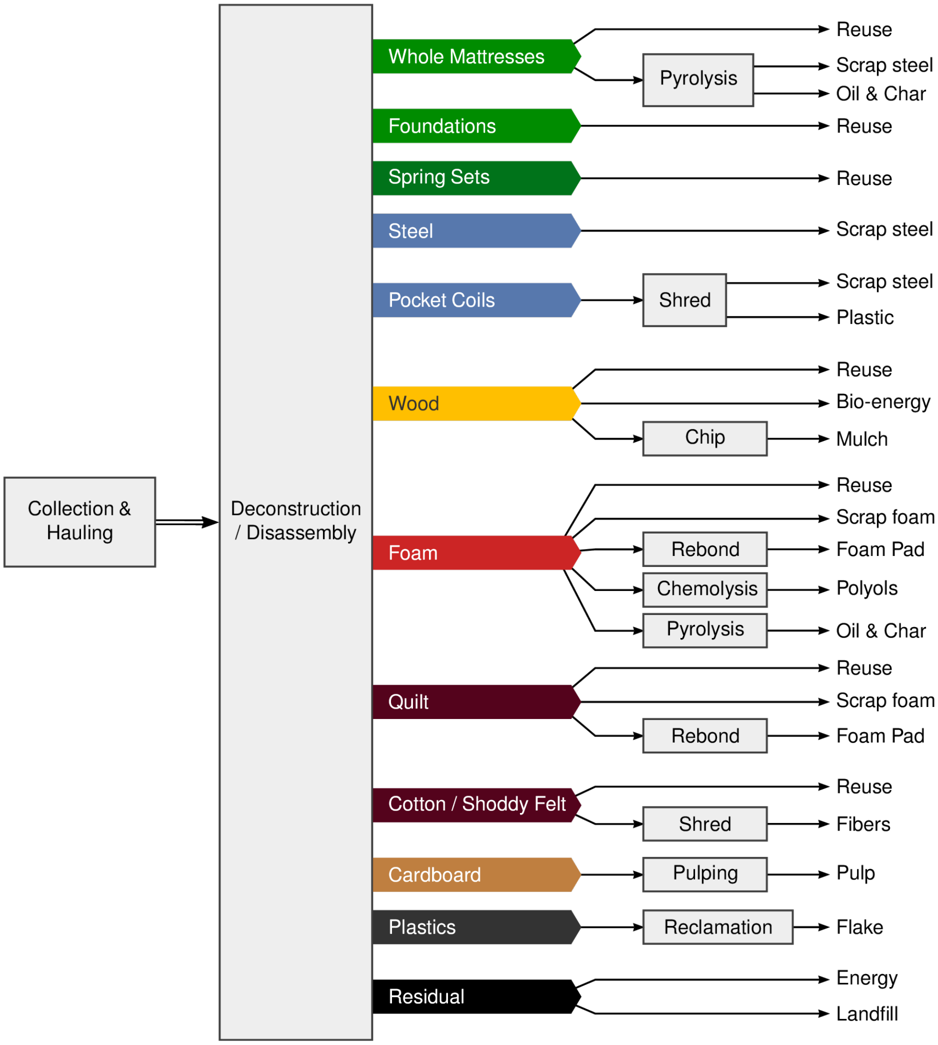


Figure 2.2. System diagram showing reuse and recycling routes. The boxes to the right of Deconstruction/Disassembly represent further processing before the material is sold as a product. For simplicity, not all the processes included in the model are shown. For example, transport from Deconstruction facility to subsequent facilities is not shown, and foam chopping is not shown for the Foam Rebond and Glycolysis pathways, although these are included (see §Other processing).

Table 2.1. The annual mass (k tonne) of mattress-derived material (MDM) that is used in each possible recycling route, for the Baseline Scenario, as well as alternative scenarios. A row represents one possible use of a mattress-derived material. 'Primary MDM' indicates the form of a material directly after it is recovered from a mattress. 'Marketed MDM' represents the form of the material that is used in a particular product.

		k tonne / yr			
Primary MDM	Marketed MDM	**Baseline**	**Foam to Chemical Recycling**	**Whole units to Pyrolysis**	**Shred and burn**

Steel	Steel to mill	15.13	15.13	15.13	15.17
	Reuse	0.04	0	0	0
Foam	Rebond pad	4.77	0	0	0
	Scrap	0.00	0	0	0
	Reuse	0.40	0	0	0
	Polyol	0.00	5.18	0	0
Quilt	Rebond pad	0.95	0.95	0	0
	Scrap	2.84	2.84	0	0
	Reuse	0.00	0	0	0
Wood	Mulch	3.51	3.51	0	0
	Reuse	0.20	0.20	0	0
	Energy	1.59	1.59	0	0
Whole mattress	Reuse	0.78	0.78	0	0
	Pyrolysis Oil & Char	0.00	0.00	25.20	0
Cotton	Thread to mill	0.39	0.39	0	0
	Reuse	0.00	0.00	0	0
Shoddy	Plastic to mill	0.22	0.22	0	0
	Scrap	0.00	0.00	0	0
	Reuse	0.00	0.00	0	0
Other fiber & fabric	Thread to mill	0.17	0.17	0	0
	Reuse	0.00	0.00	0	0
Cardboard	Pulp to mill	0.05	0.05	0	0
	Reuse	0.00	0.00	0	0
Plastic	Plastic granulate	0.01	0.01	0	0
Residuals	Landfill	9.26	9.26	0	0
	Energy	0.06	0.06	0	25.20

Total Processed Material	40.38	40.38	40.38	40.38

2.3 Mattress Characterizations

In order to build recycling scenarios for different types of mattresses, it is necessary to estimate the mass of different component materials, for each type of mattress (e.g. no steel will be recovered from an all-foam mattress). To characterize mattress units, we used data from two studies that were undertaken by MRC, independently of this LCA study: the Mattress Composition study, and the Mattress Size and Type Count study.

In the Mattress Composition study, four units of each type and size were manually deconstructed, and the mass of each component was weighed separately. A total of 72 units were deconstructed: The mattress-type units each have 4 sizes; the foundation-type units each have 3 sizes. The average compositions of each mattress type and size are shown in Figure 2.3. In addition to each specific type-size combination, the average composition was calculated for mixes of mattresses: All sizes for a given type; And an aggregate average of all sizes and types. The “all sizes and type” average gives the mass composition of an aggregate mattress, composed of all the different types in the system.

To calculate the characteristics of an aggregated average mattress, the results of the Mattress Size and Type Count study counted and characterized more than 1,000 units by type and size, as defined in Table 1.1; sizes are twin, double, queen, and king.

The average size of a mattress–type unit (pocket coil, tied spring, all foam) and the average size of a foundation-type unit (all wood foundation, other foundation) are necessary to construct scenarios based on a mix of mattress types. Table 2.2 shows the raw area and mass of each mattress type. To create scenarios where one type of mattress is replaced with another (e.g. replace some fraction of pocket coil units with all foam units), we want that comparison to be equal-area. The data in Table 2.2 would allow such apples-to-apples scenarios to be constructed.

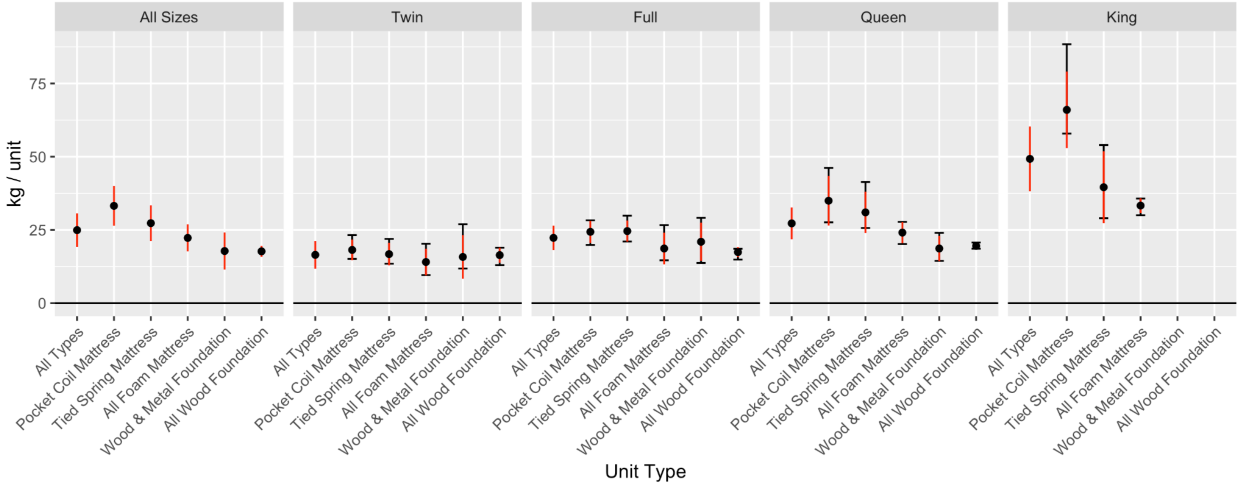


Figure 2.3. The average mass (kg) of mattresses. Mass data is from the Mattress Composition study. Averages are calculated using frequency of types and sizes from the Mattress Count study. The aggregated, average unit (average across All Types and All Sizes) is 25 kg (55 lbs), shown at the far left of the figure. Foundations do not exist in King size (far right). Black whiskers show max and min values; red lines show standard deviation.

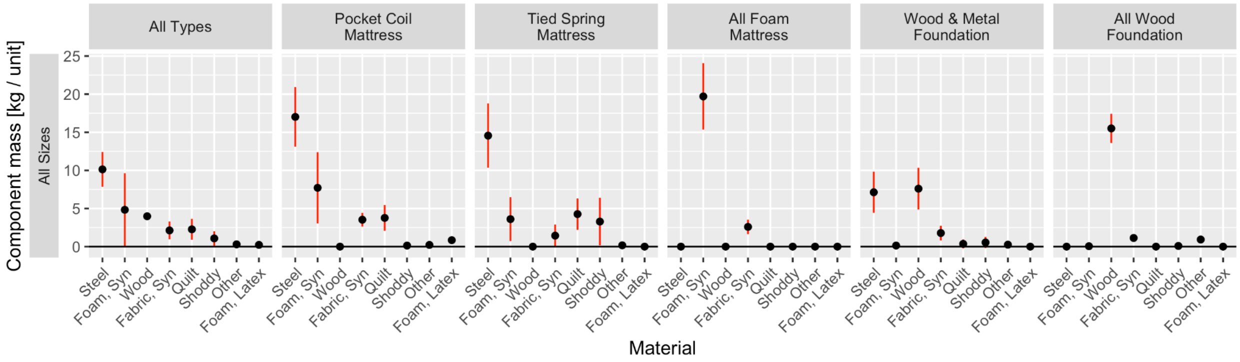


Figure 2.4. Average composition for the five different mattress types, plus the aggregated average unit (left panel).

Table 2.2. Multiplicative factors to convert unit masses to a standard size unit mass.

Type	Size	Area (sq m.)	Mass (kg)	Mass per Area
All Types	All Sizes	2.63	24.95	9.48
Pocket Coil Mattress	All Sizes	2.75	33.23	12.09
Tied Spring Mattress	All Sizes	2.78	27.33	9.84
All Foam Mattress	All Sizes	2.81	22.29	7.94
Wood & Metal Foundation	All Sizes	2.41	17.81	7.4
All Wood Foundation	All Sizes	2.38	17.71	7.45

2.4 Recovery rates for Scenarios

In the Baseline scenario, the mix of outputs from recyclers is known from data. However, to estimate the recovery rate for the non-baseline scenarios, we need estimates of the recovery rate for each component within the mattresses. This information comes from the MRC's Waste Characterization Study (independent of this LCA study), which estimated the recovery rates shown in Table 2.3.

Table 2.3. Recovery rates for mattress component materials. These values represent the fraction of a material or component within a mattress that is recovered during deconstruction, and made available as a raw material for a next use.

Material	Recovery Rate
Steel	99.8%
Wood	97.9%
Foam	79.2%
Cardboard	80.7%
Quilt & Toppers	70.2%
Cotton	38.9%
Other Fiber	6.5%
Felt/Shoddy	9.7%
Plastics	1.6%
Other Non-Recoverable	0%

3 Life Cycle Inventory

This section presents data sources and assumptions used to model the environmental implications of mattress recycling. *Processes* are used as building blocks to construct models of mattress recycling systems. *Inventories* describe the inputs and outputs for processes. These *process inventories* may be “off the shelf” from an LCI data provider, or they may be custom built, based on direct observations and data collection. In both cases, the items (input and output flows) that make up a process inventory are linked to background life cycle data, and environmental impact scores can be calculated. Where possible, we use process inventories from ecoinvent, using the “cutoff” system model (ecoinvent, 2021). The custom process inventories defined include an aggregated CA Recycling Facility (§3.2), electricity mixes (§3.3), pocket coil shredding, rebond foam pad manufacture, pyrolysis, and chemolysis (§3.4).

The Baseline Scenario models the mattress recycling system in California, calendar year 2021. Additional Scenarios are developed to assess alternative recycling processes and product mixes. Mattress-derived material flows for each Scenario are shown in §Material Processing Routes.

3.1 Freight

Freight includes Collection Transport (truck transport from a collection site to a recycler), Transfers (truck transport between recyclers), and Disposition Transport (from a recycler to a disposition location).

3.1.1 Collection Freight

Mattresses are generated throughout the state and must be marshaled from the point of generation (where it was last used) to a facility for processing. Mattresses may be brought to a collection site, event, or recycling facility by unaffiliated parties (e.g. a consumer or small independent collector), and/or they may be collected by an entity that works with MRC to manage collection and freight to recyclers.

The collection model is based on data at the level of trailer trip. For most trips, the distance is known based on the origin and destination. When the distance is unknown, the average distance of known trips is applied.

A mix of truck-trailer combinations are included in the model. The trailer mix is based on a sample of data, with average load and distance shown in Table 3.1, along with the relative share of freight for each trailer type. This truck-trailer mix is assumed to apply to all collection freight.

In the Baseline scenario, mattress transport by consumers and independent collectors is excluded. The impacts of this unaffiliated transport are explored in a standalone collection comparison (see §Collection Scenarios), where consumer transport is assumed to be 15 km per mattress, and independent collector transport is assumed to be 40 km per vehicle round-trip.

The independent collector vehicle is modeled as a pickup truck with a capacity of 10 units per full load.

Table 3.1. Trailer types involved in the mattress collection network, along with total known freight (tkm = tonne * kilometers), average load in tonnes, and the total mass shipped for each trailer type. The data here are for truck loads with known distance and trailer type (a subset of all freight).

Trailer type	Freight (tkm)	tonne / load (avg)	Mass, all loads (tonne)	Fraction of all mass	Fraction of all freight	Distance / load (avg)
53'/48'	1,125,522	2.81	10,273	93%	92%	109.6
28'	41,785	1.74	371	3%	3%	112.6
40' Sea	4,754	1.05	36	0%	0%	132.9
20' Sea	650	1.06	10	0%	0%	67.8
Other	8,388	1.68	159	1%	1%	52.7
Roll-Off	38,827	1.01	248	2%	3%	156.9
All Trailer Types	1,219,925	2.71	11,096	100%	100%	109.9

NOTE: tkm is a measure of the amount of freight transport. If a truck with 10 tonne of baled foam drives 100 km, the amount of freight equals the mass of the load (10 tonne) multiplied by the distance traveled (100 km), for a total freighting of 1000 tkm.

3.1.2 Disposition Freight

Materials leaving the mattress deconstruction facilities are transported to their next use (disposition) by truck. Distances to some dispositions are unknown, as indicated in Table 3.2. The average distance to the known locations is about 240 km. Truck trips with unknown destinations are assumed to travel the average distance of known trips.

Table 3.2. Freight from recycling facilities to disposition location. To estimate the freight associated with unknown destinations, the average distance of known trips is used.

Trip distance known?	tonne	average distance of known trips (km)	Freight, calculated (Mtkm)
known	16,474	241	3.96
unknown	23,901	NA	5.75

3.1.3 Load factors & LCI model linkages

Mattresses are relatively bulky freight. With an average 53’ trailer load of 110 mattresses, the payload weight is only 2.75 tonnes, compared to a weight capacity of over 30 tonnes for a typical 53’ trailer. This section describes the ecoinvent freight processes used to represent truck transport, and how these were corrected to account for the bulky nature of used mattress freight.

There are seven types of trailers used in the used mattress collection network. The fuel consumption for each trailer type is shown in Table 3.3. The last column also shows the truck class from ecoinvent that is used to model the particular trailer type.

We assume that a truck (with trailer, where applicable) at its maximum rated Gross Vehicle Weight consumes 29% more fuel (per mile) than with an empty load (based on fuel efficiency of 7 MPG for max payload, and 9 MPG for an empty load). In order to calculate the load-specific fuel consumption (shown in Table 3.3), the fuel consumption from the ecoinvent models is adjusted. Table 3.4 shows the default load factors and fuel consumption for each of the ecoinvent truck types.

For material transferred between facilities, we assume that a 53’ trailer is used, with the same capacity utilization as in the collection mix, 2.75 tonnes per load.

Table 3.3. Diesel consumption and load factors for the truck freight models. Calculated by adjusting the fuel consumption in the ecoinvent activities (Table 3.4), based on load factor and the difference between fuel consumption at full payload and empty payload (discussed in the text). The ‘ecoinvent truck class’ column indicates which ecoinvent truck model is applied for each trailer size (ecoinvent processes “transport, freight, lorry [truck class] metric ton, EURO6_RoW_2021_Allocation, cut-off”).

Trailer size	Diesel consumption [kg / tkm]	Load factor [t / t]	Diesel consumption [kg / km]	ecoinvent truck class
53'	0.0978	0.092	0.269	>32
28'	0.1100	0.087	0.192	16-32
48'	0.0858	0.105	0.270	>32
Roll-Off	0.1946	0.065	0.191	16-32
40' Sea	0.1539	0.062	0.191	16-32
20' Sea	0.1192	0.081	0.145	7.5-16
Other	0.1459	0.088	0.192	16-32

Table 3.4. Details of the ecoinvent freight activities (ecoinvent, 2021), including fuel consumption per km and per tkm. These parameters are used to calculate the fuel consumption of mattress hauling.

ecoinvent truck class [t]	Diesel consumption [kg / km]	Load Factor [t / t]	Payload max [t]	Fuel consumption [kg / tkm]

3.5-7.5	0.108	0.26	3.7	0.110
7.5-16	0.155	0.34	9.8	0.047
16-32	0.212	0.45	12.8	0.037
>32	0.306	0.59	27.2	0.019

3.1.4 Mattress compaction for collection

To assess the impact of increasing the load factor of mattress collection freight, we include a scenario where mattresses are compacted at the collection locations. For mattress compaction, we model a compression trailer, which will double the capacity of a typical trailer. This type of equipment could reduce the risks of shipping compressed bales of mattresses (since the trailer itself would provide the protective cage). And it would reduce the impacts associated with freight by reducing the number of truck trips required.

The compression of springs can be a dangerous proposition. However, shipping compressed springs is routinely practiced in the mattress manufacturing supply chain, with specialized equipment to protect people from injury.

We assume that the compression and decompression of mattresses would require 25 kW of power for a total of 10 minutes (4.2 kWh shaft energy). This is supplied by diesel fuel burned at 35 percent efficiency in the truck, amounting to 1.1 liters of diesel per compaction cycle, and is represented by the same combustion model as used for the transport process. Fuel use per compaction cycle should be measured from actual equipment in the future.

3.2 Primary Mattress Recycling

The primary recycling facilities were surveyed to construct an aggregated facility inventory model. These primary recycling facilities perform the primary deconstruction to recover materials from used mattresses. Survey data was received from facilities that process over 70% of the mattresses in CA. Table 3.5 shows the aggregated inventory of the CA primary recycling facilities. This synthetic inventory excludes the shredding of pocket coils (pocket coil shredding is included in §Other processing).

Table 3.5. Aggregated inventory of CA mattress recycling facilities. Amounts represent the amount of an input (item) used per tonne (1000 kg) of scrap mattresses processed.

Item	unit	amount	notes
Scrap mattress (avg. unit)	t	1	mix of sizes and types
Electricity, at user, CA	kwh	36.5	
Natural gas, at user, combusted	m3	0.0	combusted in industrial furnace/boiler
Water, Industrial, at user	kg	555.7	
Propane, combusted	l	2.4	combusted in equipment
Diesel, combusted	l	1.6	combusted in equipment
Gasoline, combusted	l	0.2	combusted in equipment
Knives and Blades	item	0.408	
Wire, baling	kg	1.183	
Lubricating oil	l	0.036	
Grease	kg	0.005	
Shredder blades	item	0.141	
Gloves (PPE)	item	0.474	
Masks (PPE)	item	6.695	
Goggles (PPE)	item	0.466	
Hard Hats (PPE)	item	0.007	
Vests (PPE)	item	0.005	
Boots (PPE)	item	0.003	
Baler (vertical)	item	4.11E-05	5 year lifetime
Baler (horizontal)	item	8.22E-05	5 year lifetime
Shredder	item	0.00E+00	5 year lifetime
Fork lift	item	1.82E-04	5 year lifetime
Separator	item	4.11E-05	5 year lifetime
Cuber	item	3.43E-05	5 year lifetime
Hopper/Dumpster	item	1.77E-04	5 year lifetime

3.2.1 LCI data linkages

To model the environmental impact of the primary recycling, each item in the facility inventory (Table 3.5) is represented by appropriate ecoinvent processes. These assignments are shown in Table 3.6. Some items require a combination of multiple ecoinvent processes (e.g. baling wire is modeled as steel production plus wire drawing).

Table 3.6. The ecoinvent (2021) activities that represent the supplies and equipment used during recycling. Ecoinvent v3.8 model is used ("Allocation, cut-off by classification"), with either the GLO (global) or RoW (rest of world) region. Electricity generation mixes and linkages to ecoinvent processes are shown in §Electricity.

Item	amount	unit	process name
Propane, combusted in equipment	1	l	Liquefied petroleum gas, combusted in industrial boiler [US LCI]
Diesel, combusted in equipment	1	l	Diesel, combusted in industrial equipment [US LCI]
Gasoline, combusted in equipment	1	l	Gasoline, combusted in equipment [US LCI]
Natural gas, combusted in boiler	1	MJ	heat production, natural gas, at boiler condensing modulating >100kW
Water, Industrial, at user	1	kg	tap water production, conventional treatment
Knives and Blades	1	kg	steel, low-alloyed, hot rolled
	1	kg	metal working, average for metal product manufacturing
Wire, baling	1	kg	wire drawing, steel
	1	kg	steel, low-alloyed
Lubricating oil	1	kg	lubricating oil production
Hydraulic oil	1	kg	lubricating oil production
Grease	1	kg	lubricating oil production
Hopper	0.1	unit	building machine
Baler (vertical)	0.5	unit	building machine
Baler (horizontal)	0.5	unit	building machine
Fork lift	0.33	unit	skidder production
Shredder	1	unit	building machine
Separator	0.25	unit	building machine

Cuber	0.5	unit	building machine
Goggles (PPE)	0.5	g	polycarbonate production
	0.5	g	polyethylene production, high density, granulate
	1	g	thermoforming of plastic sheets
Masks (PPE)	6	g	textile production, nonwoven polyester, needle-punched
Hard Hats (PPE)	1	kg	polyethylene production, high density, granulate
	1	kg	injection moulding
Vests (PPE)	400	g	polyester fibre production, finished
	400	g	textile production, cotton, air jet loom weaving
Boots (PPE)	1	kg	polyester fibre production, finished
	1	kg	textile production, cotton, air jet loom weaving
	0.75	kg	synthetic rubber production
Gloves (PPE)	50	g	polyester fibre production, finished
	50	g	textile production, cotton, air jet loom weaving

3.3 Electricity: Generation mix and LCI linkages

The electricity mix for the state of CA, and for different CA utilities, is shown in Table 3.7. We assume that system transmission and distribution losses are 10% of generation, so 1 kWh of delivered electricity requires 1.11 kWh generated. The ecoinvent process models that are used to represent each generation type are shown in Table 3.8.

Table 3.7. Electricity generation mixes for the California state mix (CA), as well as SCE (Southern California Edison), PG&E (Pacific Gas & Electric), and LADWP (Los Angeles Department of Water and Power) utility mixes. The “Unspecified” mix is based on guidance from the California Energy Commission to treat Unspecified power as generated with Natural Gas.

Electricity Source	Unit	CA	SCE	PGE	LADWP	Unspecified
Electricity, Biomass	kWh	2.5%	0.1%	2.6%	0.1%	
Electricity, Geothermal	kWh	4.9%	5.5%	2.6%	9.6%	
Electricity, Hydro (small)	kWh	1.4%	0.8%	1.2%	1.7%	
Electricity, Solar	kWh	13.2%	15.1%	15.9%	14.5%	

Electricity, Wind	kWh	11.1%	9.4%	8.3%	10.8%	
Electricity, Coal	kWh	2.7%	0.0%	0.0%	16.0%	
Electricity, Oil	kWh	0.2%	0.0%	0.0%	0.0%	
Electricity, Hydro (large)	kWh	12.2%	3.3%	10.1%	5.4%	
Electricity, NatGas Combined Cycle	kWh	33.4%	13.7%	14.8%	25.1%	90.0%
Electricity, NatGas Simple Cycle	kWh	3.7%	1.5%	1.6%	2.8%	balance
Electricity, Nuclear	kWh	9.3%	8.4%	42.8%	14.0%	
Electricity, Unspecified	kWh	5.4%	42.3%	0.0%	0.1%	

Table 3.8. ecoinvent (ecoinvent, 2021) processes used to model electricity generation.

Electricity Generation Type	ei Model Name	ei Region
Electricity, Biomass	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Geothermal	ecoinvent, v3.8, Allocation, cut-off by classification†	US-WECC
Electricity, Hydro (small)	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Solar	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Wind	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Coal	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Oil	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Hydro (large)	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, NatGas Combined Cycle	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, NatGas Simple Cycle	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
Electricity, Nuclear	ecoinvent, v3.8, Allocation, cut-off by classification	US-WECC
† - All impacts are allocated to electricity (i.e. heat cogeneration is ignored)		

3.4 Other processing and manufacturing activities

In this section, inventories are presented that represent activities occurring (or that may occur) outside the MRC-contracted recycling facilities. This includes landfilling and incineration. In addition, the following mattress-derived products may require processing and manufacturing after material leaves a primary recycler:

- Steel from pocketed coils
- Wood chips

- Rebond foam pad
- Pyrolysis oil and char
- Polyol from chemical recycling (glycolysis and acidolysis of PU foam)

This section also presents the inventories of resources required to produce each of these products.

3.4.1 Waste: Landfill and Incineration

Wastes from mattress recycling include a mix of materials. The assumed mix is from the MRC Waste Characterization Study.

Table 3.9. Landfill and incineration processes applied to materials that make up waste flows. For materials without a direct match in the ecoinvent database, proxy processes are defined.

Material name	ei Landfill Process	ei Combustion Process	Biogenic C fraction
Cardboard	treatment of waste paperboard, sanitary landfill	treatment of waste paperboard, municipal incineration	1
Cotton	treatment of waste graphical paper, sanitary landfill	treatment of waste graphical paper, municipal incineration	1
Fabric, synthetic	treatment of waste polyethylene terephthalate, sanitary landfill	treatment of waste polyethylene terephthalate, municipal incineration	0
Fabric, plant fibers	treatment of waste graphical paper, sanitary landfill	treatment of waste graphical paper, municipal incineration	1
Mixed Non-Woven Fibers	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Fibers, synthetic	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Foam, latex	treatment of waste wood, untreated, sanitary landfill	treatment of waste wood, untreated, municipal incineration	1
Polyurethane Foam	treatment of waste polyurethane, sanitary landfill	treatment of waste polyurethane, municipal incineration	0
Other Material	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Plastic parts	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Quilt Panels	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Shoddy Felt Pad	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Steel springs	treatment of inert waste, sanitary landfill	treatment of scrap steel, municipal incineration	0

Wood	treatment of waste wood, untreated, sanitary landfill	treatment of waste wood, untreated, municipal incineration	1
Fabric, synthetic, woven	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Foam, synthetic	treatment of waste polyurethane, sanitary landfill	treatment of waste polyurethane, municipal incineration	0
Other material	treatment of waste plastic, mixture, sanitary landfill	treatment of waste plastic, mixture, municipal incineration	0
Fabric, PP, nonwoven	treatment of waste polypropylene, sanitary landfill	treatment of waste polypropylene, municipal incineration	0
Fabric, PET, nonwoven	treatment of waste polyethylene terephthalate, sanitary landfill	treatment of waste polyethylene terephthalate, municipal incineration	0
Fiber, PP	treatment of waste polypropylene, sanitary landfill	treatment of waste polypropylene, municipal incineration	0
Fiber, PET	treatment of waste polyethylene terephthalate, sanitary landfill	treatment of waste polyethylene terephthalate, municipal incineration	0

3.4.2 Pocketed coil shredding

Table 3.10. Inventory for shredding 1 tonne of pocketed coils. Some data are withheld to protect confidentiality.

Item	in/out	value	unit	notes
Pocketed Coils	in	1	t	
Electricity, at user, CA	in	50	kWh	based on XR2000 specs, and the ecoinvent process "treatment of used glider, passenger car, shredding"
Water, Industrial, at user	in	***	l	
Propane, combusted	in	***	l	
Diesel, combusted	in	***	l	
Gasoline, combusted	in	***	l	
Lubricating oil	in	***	l	
Grease	in	***	l	
Gloves (PPE)	in	***	item	
Masks (PPE)	in	***	item	
Goggles (PPE)	in	***	item	

Hard Hats (PPE)	in	***	item	
Vests (PPE)	in	***	item	
Boots (PPE)	in	***	item	
Shredder	in	***	item	10 tonne machine
Fork lift	in	***	item	
Hopper/Dumpster	in	***	item	
Steel, recycled as scrap	out	0.90		cubed, clean steel
Waste (from pocket coils)	out	0.10		PP fabric scraps

3.4.3 Wood chipping

The recycled wood leaving recyclers is assumed to be subsequently chipped and used as mulch. The wood chipping model is based on the ecoinvent process “wood chips production, softwood, at sawmill” (ecoinvent, 2021), but customized to exclude the raw material input (“slab and siding, softwood, wet, measured as dry mass”) and to utilize a western US power grid.

3.4.4 Rebond Foam pad manufacturing

Table 3.11. Inventory of the rebond foam pad manufacturing process.

Item	in/out	value	unit	Comment
Foam (recycled), Chopped	in	1	kg	Post-consumer polyurethane foam; pre-chopped
Isocyanate (binder)	in	0.070	kg	Based on 16 liters binder per 272 kg (600 lb) foam
Electricity, at user, CA	in	0.040	kWh	assuming 33 kW for 20 minutes to make a 272 kg (600 lb) batch of rebond foam
Heat, natural gas, at user	in	0.387	MJ	assuming 80% steam system efficiency
Water, Industrial, at user	in	0.119	kg	assuming 2x volume of binder (binder density = 1.18 g/cm3)
Rebond capital equipment	in	1.20E-07	items	Model uses 10000 hr equipment lifetime to amortize cost of a 20t piece of equipment
Landfill, PU	out	0.054	kg	Assuming 95% yield
Rebond foam pad	out	1.017	kg	

3.4.5 Cleaning for reuse

We were not able to obtain process inventories for specific mattress and recovered material cleaning. So, to represent cleaning for reuse, we applied the “washing, drying and finishing laundry” process from ecoinvent (ecoinvent, 2021). The cleaning process was implemented with the following customizations:

- For wood reuse we assume a dry disinfection process, with no water consumption. So the process was implemented with zero water consumption.
- For cleaning all other materials, we assume 2 kg of water consumed per kg of clean material (lower than the default value for laundry washing)

Cleaning is assumed for all reuses, except for steel component reuse.

3.4.6 Pyrolysis

Pyrolysis is a thermochemical process that has been studied for many years. It can be used to break down many types of materials, usually into a liquid portion (raw pyrolysis oil), a solid portion (char), and a gaseous fraction. The process inventories below for whole mattresses (Table 3.12) and PU foam (Table 3.13) are adapted from a number of studies of pyrolysis using foam and plastic as feedstocks.

Table 3.12. Inventory for the whole-mattress pyrolysis process. Sources include (Altayeb, 2015; Czajczyńska et al., 2017; Iribarren et al., 2012; Kemona & Piotrowska, 2020; Khoo, 2019; TNO, 2022).

Item	in/out	value	unit	notes
Scrap mattress (avg. unit)	in	1	kg	includes steel
Pyrolysis Facility	in	3.30E-11	unit	Use "petroleum refinery" as proxy; per mass of input
Heat, natural gas, at user	in	3.0	MJ	assumption
Electricity, at user, CA	in	0.04	kwh	Average of Iribarren (2012), Altayeb (2015), and Khoo (2019)
Water, Industrial, at user	in	2	kg	(Iribarren, 2012)
Water to treatment	out	1.5	kg	Assumption that 75% of water input ends up in the drain
Landfill, pyrolysis sludge	out	0.03	kg	mass balance
Pyrolysis gas, burned onsite	out	6	MJ	adapted from (TNO, 2022)
Pyrolysis char	out	0.08	kg	adapted from (TNO, 2022)
Pyrolysis oil	out	0.24	kg	adapted from (TNO, 2022)
Steel, recycled as scrap	out	0.398	kg	From deconstruction/count studies

Table 3.13. Inventory for the foam-only pyrolysis process. Sources include (Altayeb, 2015; Czajczyńska et al., 2017; Iribarren et al., 2012; Kemona & Piotrowska, 2020; Khoo, 2019).

Item	in/out	value	unit	notes
Foam, recovered	in	1	kg	
Pyrolysis Facility	in	3.30E-11	unit	Use "petroleum refinery" as proxy; per mass of input
Heat, natural gas, at user	in	3.0	MJ	assumption
Electricity, at user, CA	in	0.04	kwh	Average of Iribarren (2012), Altayeb (2015), and Khoo (2019)
Water, Industrial, at user	in	2.0	kg	(Iribarren, 2012)
Water to treatment	out	1.5	kg	Assumption that 75% of water input goes to wastewater
Landfill, pyrolysis sludge	out	0.06	kg	mass balance
Pyrolysis gas, burned onsite	out	6.0	MJ	adapted from (TNO, 2022)
Pyrolysis char	out	0.03	kg	adapted from (TNO, 2022)
Pyrolysis oil	out	0.80	kg	adapted from (TNO, 2022)

3.4.7 Glycolysis of PU foam

Table 3.14. Inventory for the chemical recycling of post-consumer recovered PU foam via glycolysis. The use of diethylene glycol (DEG) as a glycolysis agent is common in the literature, at a DEG:PU ratio of 1.5 by mass (Herrero, 2017; Marson et al., 2021; Simón et al., 2014; Wu et al., 2003). Electricity use is based on (Marson et al., 2021, p. 1722). The rate of evolution of CO_2 from the reaction is from (Borda et al., 2000, Fig.4). Since this process inventory is based on laboratory studies, we include an uncertainty range of +/- 25% for the non-foam inputs and CO_2 emission.

Item Name	in/out	amount	unit	notes
Foam (recycled), Chopped	in	1.0	kg	foam recovered from mattresses; pre-chopped
Diethylene glycol	in	1.5	kg	various sources
Diethanolamine	in	0.01	kg	catalyst
Electricity, at user, CA	in	0.08	kwh	(Marson et al., 2021, p1722) [10.1021/acsomega.0c05844]
CO2 emission	out	0.02	kg	(Borda et al., 2000) [10.1016/S0141-3910(00)00030-6]
Polyol, recovered	out	2	kg	

3.4.8 Acidolysis of PU foam

Table 3.15. Inventory for chemical recycling, via acidolysis, of post-consumer recovered PU foam. The ratios of foam, virgin polyol, acids, and catalyst are from the technical documentation brochure of a commercial PU foam recycling process (H&S Anlagentechnik, 2022). Succinic and adipic acid are the acids assumed to be used, based on literature (Gama et al., 2020; Grdadolnik et al., 2022). The fact that two dicarboxylic acids are used in the process was indicated in the brochure (H&S Anlagentechnik, 2022); we assume they are used in equal proportion.

Item Name	in/out	amount	unit	notes
Foam (recycled), Chopped	in	1.00	kg	
Polyol	in	1.05	kg	H&S Anlagentechnik brochure
Succinic acid	in	0.14	kg	H&S Anlagentechnik brochure; assuming equal parts succinic and adipic acids
Adipic acid	in	0.14	kg	H&S Anlagentechnik brochure; assuming equal parts succinic and adipic acids
Diethanolamine	in	0.05	kg	catalyst
Electricity, at user, CA	in	0.07	kwh	(Marson et al., 2021, p1722) [10.1021/acsomega.0c05844]
CO2 emission	out	0.02	kg	(Borda et al., 2000) [10.1016/S0141-3910(00)00030-6]
Water to treatment	out	0.12	kg	
Polyol, recovered	out	2.24	kg	assuming 95% product yield

3.4.9 LCI model linkages (other processing)

Table 3.16. Linkages to the ecoinvent database. The items in the *Activity* column correspond to *Items* in the inventories in the previous sections. The *process name* column provides the ecoinvent process (ecoinvent, 2021) used to model the inventory items.

Activity	amount	amount unit	process name
common			
Water, Industrial, at user	1	kg	tap water production, conventional treatment
Water to treatment	1	kg	treatment of wastewater, average, capacity 1E9l/year
Heat, natural gas, at user	1	MJ	heat production, natural gas, at boiler condensing modulating >100kW
pocket coil shredding			

Shredder (equipment)	1	item	building machine
rebond foam pad			
Isocyanate (binder)	1	kg	market for methylene diphenyl diisocyanate
Rebond equipment	2	item	building machine
pyrolysis			
Pyrolysis Facility	1	item	Petroleum refinery construction
Pyrolysis gas to self-use	1	kg	Refinery gas, burned in furnace (proxy)
chemolysis			
polyol	1	kg	polyol production
adipic acid	1	kg	market for adipic acid
succinic acid	1	kg	market for succinic acid
Diethylene glycol	1	kg	market for diethylene glycol
Diethanolamine	1	kg	market for diethanolamine

3.5 Displaced production and Logistics

Table 3.17 shows the overall displacement rates for each route considered in the model. The degree to which a product with recycled material will displace production of virgin material is quantified with the overall displacement rate parameter, which depends on many factors. The values in Table 3.17 are based on the method and assumptions described in §Displacement rates.

Freight transport of mattress-derived products was estimated based on actual product deliveries information, as reported by MRC (Table 3.18). Representative distances were estimated for potentially displaced products, based on the following assumptions: A mix of intercontinental and regional transport is assumed for displaced scrap foam; local or regional transport is assumed for virgin foam pad, wood chips and boards, and new mattresses; all other displaced products are assumed to be transported at a continental scale (Table 3.18).

Table 3.17. Displacement rates for each displacement relationship. The column 'Primary MD material?' indicates whether the Mattress-Derived (MD) product is produced directly by CA mattress recyclers ('Yes'), or whether the material requires other processing before being marketed ('No').

Mattress-derived Product	Primary MD material?	Displaced product	Displacement rate (low | rate | hi)
Steel, recycled as scrap	Yes	Steel, displaced	80% | 90% | 100%
Rebond foam pad	No	Foam pad, displaced	10% | 30% | 60%
Foam, recovered	Yes	Post industrial scrap foam, displaced	80% | 90% | 100%
Quilt, recovered	Yes	Post industrial scrap foam, displaced	80% | 90% | 100%
Wood mulch, recovered	No	Wood chips, displaced	80% | 90% | 100%
Cotton, recovered	Yes	Cotton fiber, displaced	50% | 75% | 100%
Shoddy, recovered	Yes	Fibers (mix), displaced	50% | 75% | 100%
Other fiber, recovered	Yes	Fibers (mix), displaced	50% | 75% | 100%
Cardboard, recovered	Yes	Wood pulp, displaced	80% | 90% | 100%
Plastic, recovered	Yes	Plastic, displaced	50% | 75% | 100%
Whole unit, cleaned (reuse)	No	New whole unit, displaced	38% | 56% | 75%
Foam, cleaned (reuse)	No	Foam pad, displaced	50% | 75% | 100%
Wood, cleaned (reuse)	No	Wood, displaced (board)	50% | 75% | 100%
Steel component (reuse)	Yes	Steel spring, displaced	50% | 75% | 100%
Quilt, cleaned (reuse)	No	Quilt, displaced	50% | 75% | 100%
Cotton fabric, cleaned (reuse)	No	Cotton fabric, displaced	50% | 75% | 100%
Other fabric, cleaned (reuse)	No	Polyester fabric, displaced	50% | 75% | 100%
Other, cleaned (reuse)	No	Unknown (reuse)	50% | 75% | 100%
Shoddy, cleaned (reuse)	No	Shoddy pad, displaced	50% | 75% | 100%
Wood fuel	Yes	Heat, natural gas, displaced	60% | 68% | 75%
Electricity from incineration	No	Electricity, Unspecified	80% | 90% | 100%
Heat, from wood chips	No	Heat, natural gas, displaced	60% | 68% | 75%
Polyol, recovered	No	Polyol, displaced	80% | 90% | 100%
Pyrolysis oil	No	Petroleum, displaced	80% | 90% | 100%
Pyrolysis char	No	Carbon black, displaced	80% | 90% | 100%
Synthetic cement	No	Cement (Portland), displaced	75% | 113% | 150%

Table 3.18. Transport distances of mattress-derived (MD), and distances for displaced products. See text for assumptions behind the displaced transport.

Mattress-derived Product	Displaced product	Transport of MD product (km, truck)	Displaced transport (km, truck)	Displaced transport (km, ocean)
Steel, recycled as scrap	Steel, displaced	416	300	1,000
Rebond foam pad	Foam pad, displaced	594	500	0
Foam, recovered	Post industrial scrap foam, displaced	0	800	5,250
Quilt, recovered	Post industrial scrap foam, displaced	0	800	5,250
Wood mulch, recovered	Wood chips, displaced	16	1,000	0
Cotton, recovered	Cotton fiber, displaced	313	300	1,000
Shoddy, recovered	Fibers (mix), displaced	45	500	5,000
Other fiber, recovered	Fibers (mix), displaced	67	500	5,000
Cardboard, recovered	Wood pulp, displaced	3	500	5,000
Plastic, recovered	Plastic, displaced	1	500	5,000
Whole unit, cleaned (reuse)	New whole unit, displaced	79	500	0
Foam, cleaned (reuse)	Foam pad, displaced	248	500	5,000
Wood, cleaned (reuse)	Wood, displaced (board)	79	1,000	
Steel component (reuse)	Steel spring, displaced	23	500	5,000
Quilt, cleaned (reuse)	Quilt, displaced	248	500	5,000
Cotton fabric, cleaned (reuse)	Cotton fabric, displaced	48	500	5,000
Other fabric, cleaned (reuse)	Polyester fabric, displaced	48	500	5,000
Other, cleaned (reuse)	Unknown (reuse)	100	500	5,000
Shoddy, cleaned (reuse)	Shoddy pad, displaced	48	500	5,000
Wood fuel	Heat, natural gas, displaced	37	0	0
Heat, from wood chips	Heat, natural gas, displaced	66		0
Polyol, recovered	Polyol, displaced	37	0	5,000
Pyrolysis oil	Petroleum, displaced	100	500	0
Pyrolysis char	Carbon black, displaced	200	500	5,000

3.5.1 LCI model linkages and customizations

Each displaced product is modeled using a combination of ecoinvent process inventories, as outlined in Table 3.19.

Table 3.19. Model specification to estimate the impacts of the potentially displaced activities (ecoinvent, 2021). For the “New whole unit” displaced product, the mattress is modeled as a combination of the material composition for an average mattress in CA (see §Mattress Unit Characterizations)

Potentially Displaced Product	ecoinvent Process Model
Steel, displaced	steel production, converter, unalloyed
Steel spring, displaced	wire drawing, steel
	steel, low-alloyed
Quilt, displaced	polyurethane production, flexible foam, TDI-based, high density
	textile production, air jet loom weaving
	polyester fibre production, finished
Foam pad, displaced	polyurethane production, flexible foam, TDI-based, high density
Wood chips, displaced	market for wood chips, wet, measured as dry mass
Wood, displaced (board)	lath, softwood, raw, kiln drying to u=10%
Cotton fabric, displaced	textile production, cotton, air jet loom weaving
Fibers (mix), displaced	market for fibre, cotton
	market for waste polyethylene terephthalate, for recycling, sorted
	market for polyethylene terephthalate, granulate, amorphous
New spring mattress, displaced	mattress production, pocket spring
New foam mattress, displaced	mattress production, polyurethane foam
New whole unit, displaced	(various processes)
Polyol, displaced	polyol production
Petroleum, displaced	market for petroleum
Carbon black, displaced	carbon black production
Scrap foam and quilt, displaced	(displaces truck and ocean freight associated with imported scrap)

Table 3.20. Activities based on customized ecoinvent inventories.

Custom Activity	ei Process	Customization Applied
Textile weaving (process only)	textile production, cotton, air jet loom weaving	Exclude “yarn, cotton”
Needle punching	textile production, nonwoven polyester, needle-punched	Exclude “fibre, polyester”
Fibre, PP	polyester fibre production, finished	Replace “polyethylene terephthalate, granulate, amorphous” with “polypropylene, granulate”

4 Life Cycle Impact Assessment

In this section we present quantitative results of the life cycle impact assessment. There are 11 impact categories included in the model (descriptions of each in §Appendix).

The results presented have two types of contributions: incurred impacts (positive-valued contributions) and potentially displaced impacts (negative-valued contributions).

- Incurred environmental impacts result from the actions taken within the mattress recycling system. These include emissions from transportation of mattresses from collection centers to processors, direct emissions from facility operations, upstream emissions from materials and equipment used by processors, and emissions from electricity generation. Impacts are also modeled for the transport of the mattress-derived products to their next use in the market (disposition).

- Potentially displaced impacts represent emissions associated with the production of products that compete with mattress-derived products in the marketplace, and so are potentially avoided by mattress recycling. There is considerable uncertainty about displacement rates (see §Study Scope).

The sum of these positive and negative impact scores indicates the potential net environmental impacts that could occur if mattress-derived products are displacing primary products as assumed. In the figures below, when the net totals are shown, uncertainty ranges are also shown, based on the displacement rates in §Displaced Production.

4.1 California state-wide scenario, 2021

The results in this section represent the Mattress recycling system in California, circa 2021, including the potentially displaced products. During 2021 MRC operations in California, 1.63 million mattress units were delivered to primary recyclers. Assuming an average of 25 kg / mattress (55 lb), this amounts to 40.7 thousand tonnes (kt) of mattresses. The outputs from the recyclers were 40.4 kt.

Figure 4.1 shows the impacts of mattress recycling activities, including the impacts that could potentially be avoided if the recycled materials displace virgin material production. Figure (A) shows the Headline indicators; Figure (B) shows the Supporting indicators. In each figure, the bars on the far right show the Net total impacts: the sum of the incurred impacts from the recycling system and the potentially avoided (negative) impacts associated with the displaced products. In the figures, activities are grouped into stages (x-axis). Detailed results for the baseline scenario, where the stage groups are dis-aggregated, are shown in §Baseline Incurred Impacts.

Figure 4.1(A) shows that the potentially avoided impacts from displaced production exceed the incurred impacts in all headline indicators, although the particulates indicator (PM2.5eq) exceeds break-even for the most pessimistic displacement rates. Benefits for Climate impact

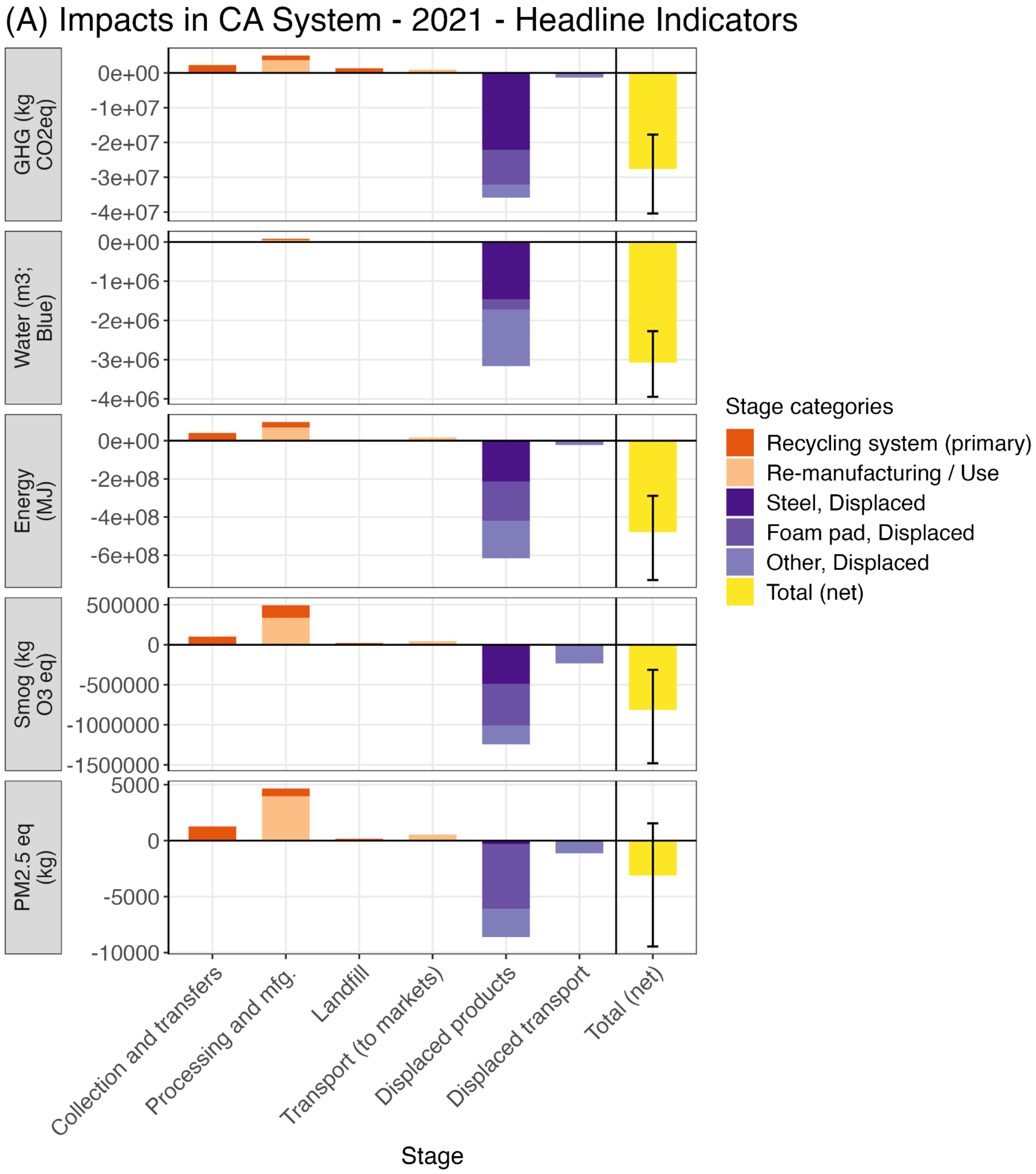
(GHG), Water use, Primary energy demand, and Smog appear to be robust to the uncertainties modeled. The “processing and manufacturing” stage is dominated by the foam rebond activity (see §Baseline Incurred Impacts). Nonetheless, the potentially avoided impacts due to displaced production of primary (virgin) polyurethane foam are larger in magnitude, and so rebond foam appears to be a beneficial use of recovered foam. The generation of steel scrap also provides benefits. For the Water use indicator, displaced textile production is significant (included in the “Other, Displaced” category), in addition to the displaced steel. Impacts from collection and transport are generally smaller than impacts from production activities.

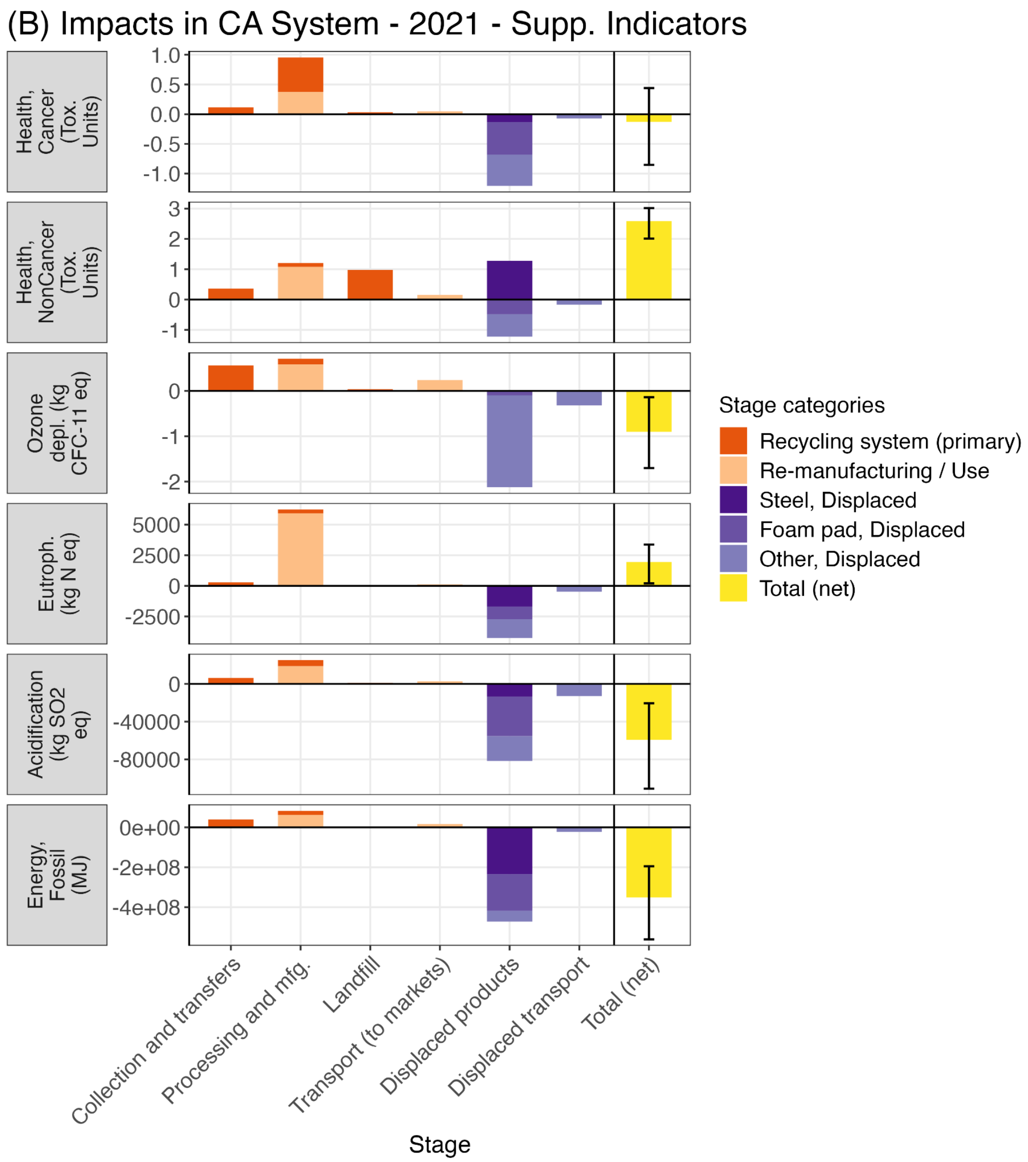
In Figure 4.1(B), the results show that the avoided impacts from displaced production are greater in magnitude than incurred impacts in four out of six supporting indicators, although one of those (health-cancer) is marginal.

In the other two categories (health-noncancer, eutrophication), the incurred impacts of recycling exceed the magnitude of the avoided impacts of the potentially displaced products. The production of methylene diphenyl diisocyanate (MDI, required for the rebond process) is a major contributor in every impact category (not shown). In the health-noncancer case, steel recycling actually generates an incurred impact, driven by emissions of mercury and zinc that are modeled to increase under steel recycling (ecoinvent, 2021; World Steel Association, 2021). In cases like this, recycled material has a higher impact than its primary (virgin) alternative for these indicators. Landfill impacts are also significant for the health-noncancer indicator.

In the Eutrophication impact category, the rebond process is dominant (due to MDI production). In Ozone depletion, impacts are due to MDI production, as well as heavy truck transport and electricity production. In Health-cancer, production of heavy equipment for recycling is the largest contributor, followed by MDI production, due to emissions of mercury, nitrobenzene, and formaldehyde (not shown).

Figure 4.1. Impacts of mattress recycling activities, and of the potentially displaced products. These results represent the recycling and management of 1.6 million used mattresses in California during calendar year 2021 Each panel shows results for one type of indicator (Greenhouse gas impact at the top); each panel has a distinct y-axis. Different stages in the system are shown along the horizontal axis. The error bars show the Total (net) impact for the higher and lower displacement rates. Data table in Appendix.




(B) Impacts in CA System - 2021 - Supp. Indicators

4.2 Impacts per tonne of mattresses

The results in this section show impacts per tonne of mattresses recycled. Results for multiple scenarios are included (see §Scenarios and Scales for an explanation of each scenario). Scenarios are defined by the mix of mattress types, the recycling activities included, and the products that are assumed to be displaced.

4.2.1 System Management Scenarios

Results for six different recycling scenarios are shown in Figure 4.2. These scenarios all use the Baseline mix of collected mattress unit types and sizes.

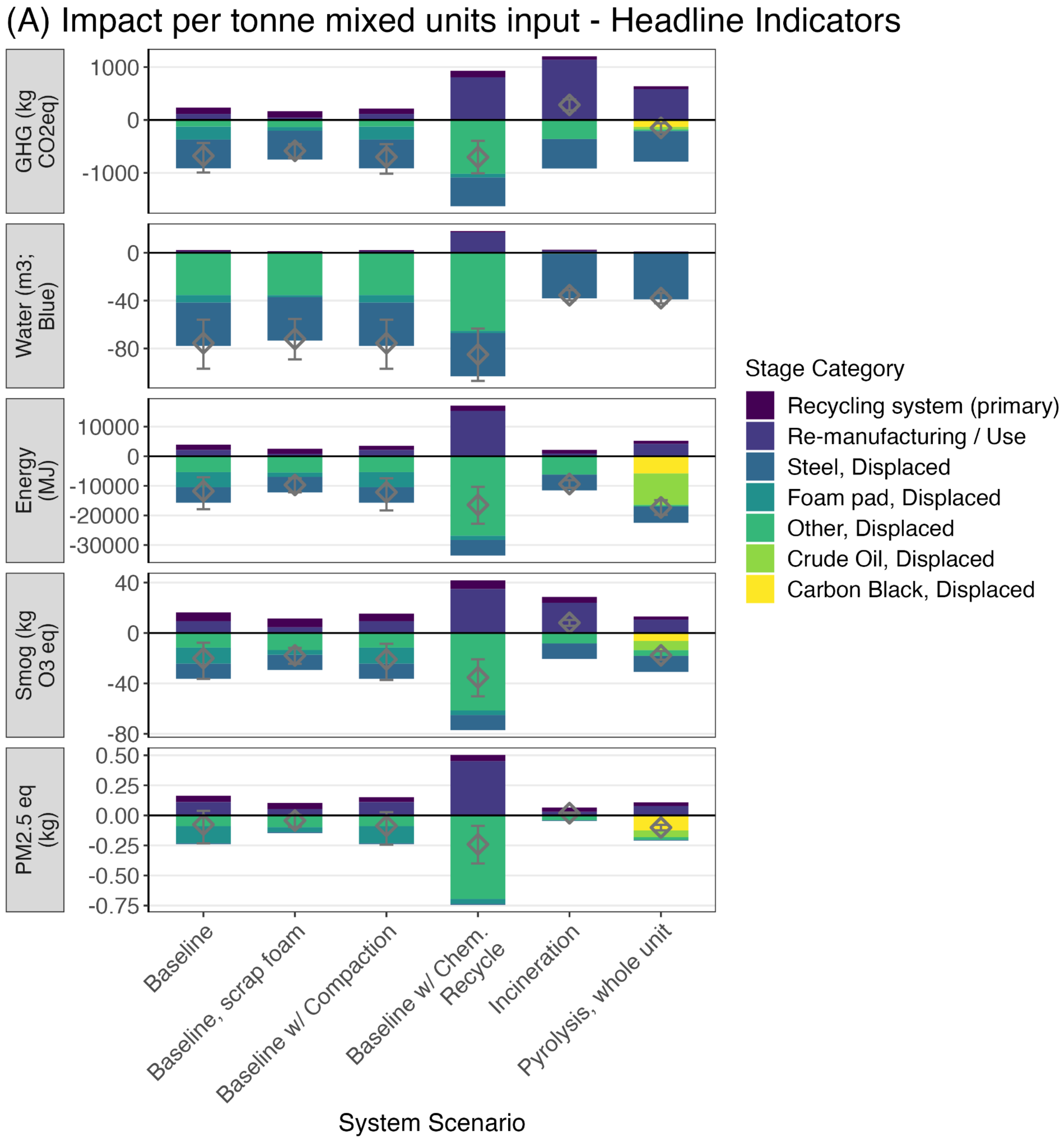
The results for the Headline indicators are shown in Figure 4.2(A). In the “Baseline, Scrap foam” scenario, mattress-derived foam is assumed to displace the transport of post-industrial scrap foam. In this scenario, there is no rebond manufacturing process, and there is no displaced virgin foam. Results are similar to the Baseline scenario (where the displacement rate for virgin foam is small, 30%), since the incurred impacts are lower for the scrap foam scenario without the rebond process, but there are also no avoided impacts from virgin foam displacement.

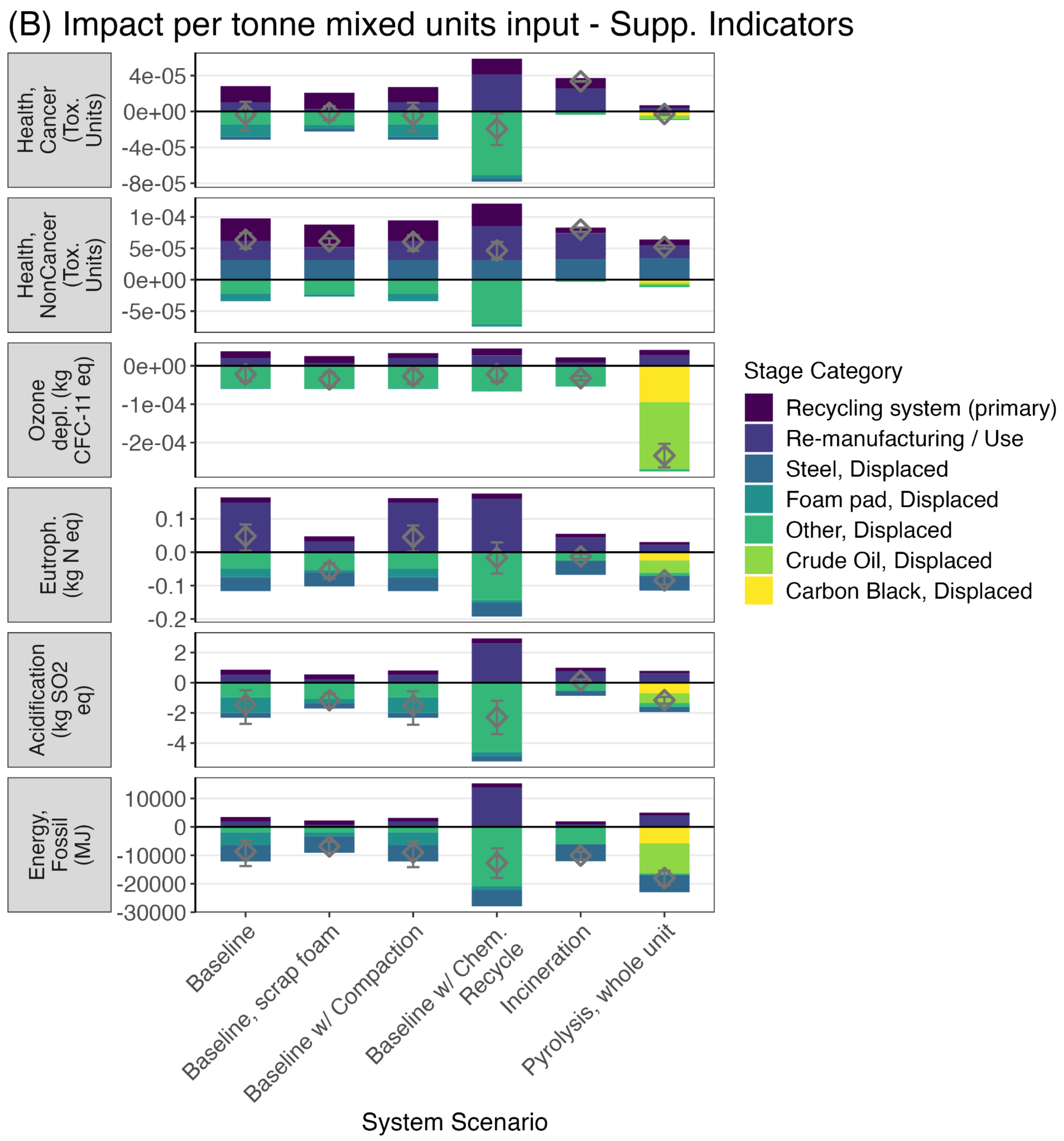
In the compaction scenario, impacts from mattress collection are reduced, but that has a small effect on the overall system. In the case where all foam is chemically recycled rather than used for rebond, both incurred and avoided impacts increase substantially (driven by upstream chemicals production), although the net effect is one of slight improvement. The incineration case shows an increase in climate change, particulate, and smog impacts in exchange for energy (and potentially cost) savings. The results suggest that pyrolysis with steel recovery is a possible materials management strategy to avoid impacts.

The results in figure 4.2(B) show supporting indicators for the management scenarios. These results largely mirror the CA 2021 scenario. In particular, the incurred impacts from MDI production in the rebond process dominate the health categories, along with steel recycling in the health-noncancer category. In eutrophication and ozone depletion, the chemical recycling route approaches break-even, but only pyrolysis shows likely benefits. Acidification mirrors the other categories driven by air emissions (climate change, particulates, and smog). All routes show reductions in fossil energy demand.

No management routes show potential improvement in the health-noncancer category. The incurred impacts in this indicator are driven by multiple stages. The largest contributor is the steel recycling impact, which indicates an increase in zinc and mercury emissions resulting from the processing of steel scrap. Other contributors are the landfill process, the wood combustion process, and the production of methylene diphenyl diisocyanate (MDI) for rebond foam.

Figure 4.2. Impacts of six used mattress management system scenarios. The scenario on the far left represents the Baseline (representative of the situation in CA 2021). Data table in Appendix.

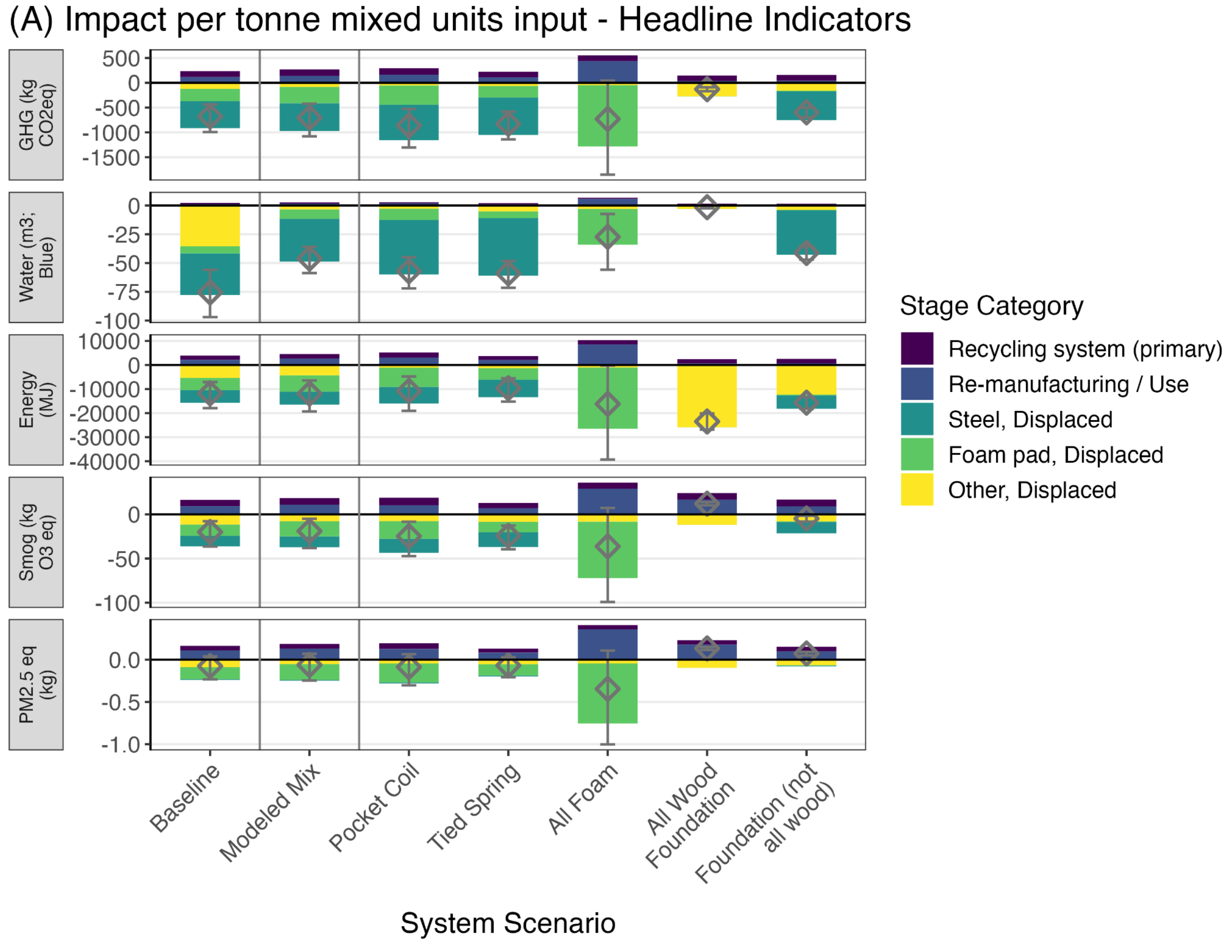

(A) Impact per tonne mixed units input - Headline Indicators

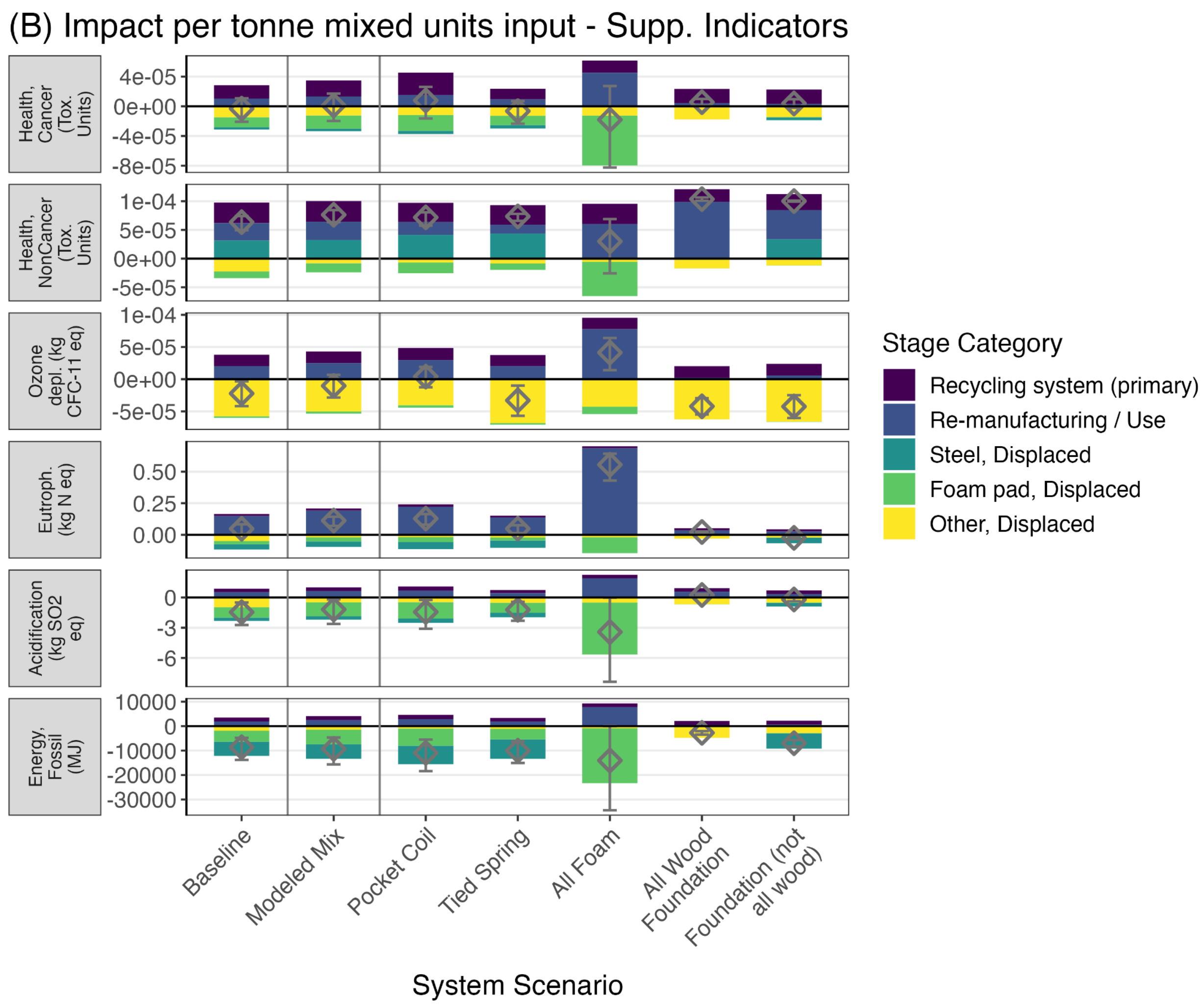


4.2.2 Results by Mattress Type

The impacts and potential benefits of recycling different mattress types are shown in Figure 4.3. Both innerspring mattress types are similar, with pocket coils performing slightly better for more favorable displacement rates (owing to their higher foam content). Foam mattresses show larger potential benefits but also proportionately larger uncertainty (due to the large range for the displacement rate for rebond foam pad). Recycling of wood foundations is mixed, showing large reductions in primary energy demand (due to avoided forestry activity), but increased or marginally increased smog and particulate emissions.

Figure 4.3. Impacts of recycling six different types of used mattress types. The Baseline scenario (far left) is included for comparison. For all other scenarios, the uses (dispositions) of recovered materials are as in the Baseline, but the relative amounts of the materials are determined by the makeup of each type of mattress (see §Mattress Unit Characterizations). The "Modeled Mix" scenario is similar to the "Baseline" scenario, but the mix of material outputs is based on the makeup of the mix of mattresses (not on the material outputs reported annually by MRC). Data table in Appendix.



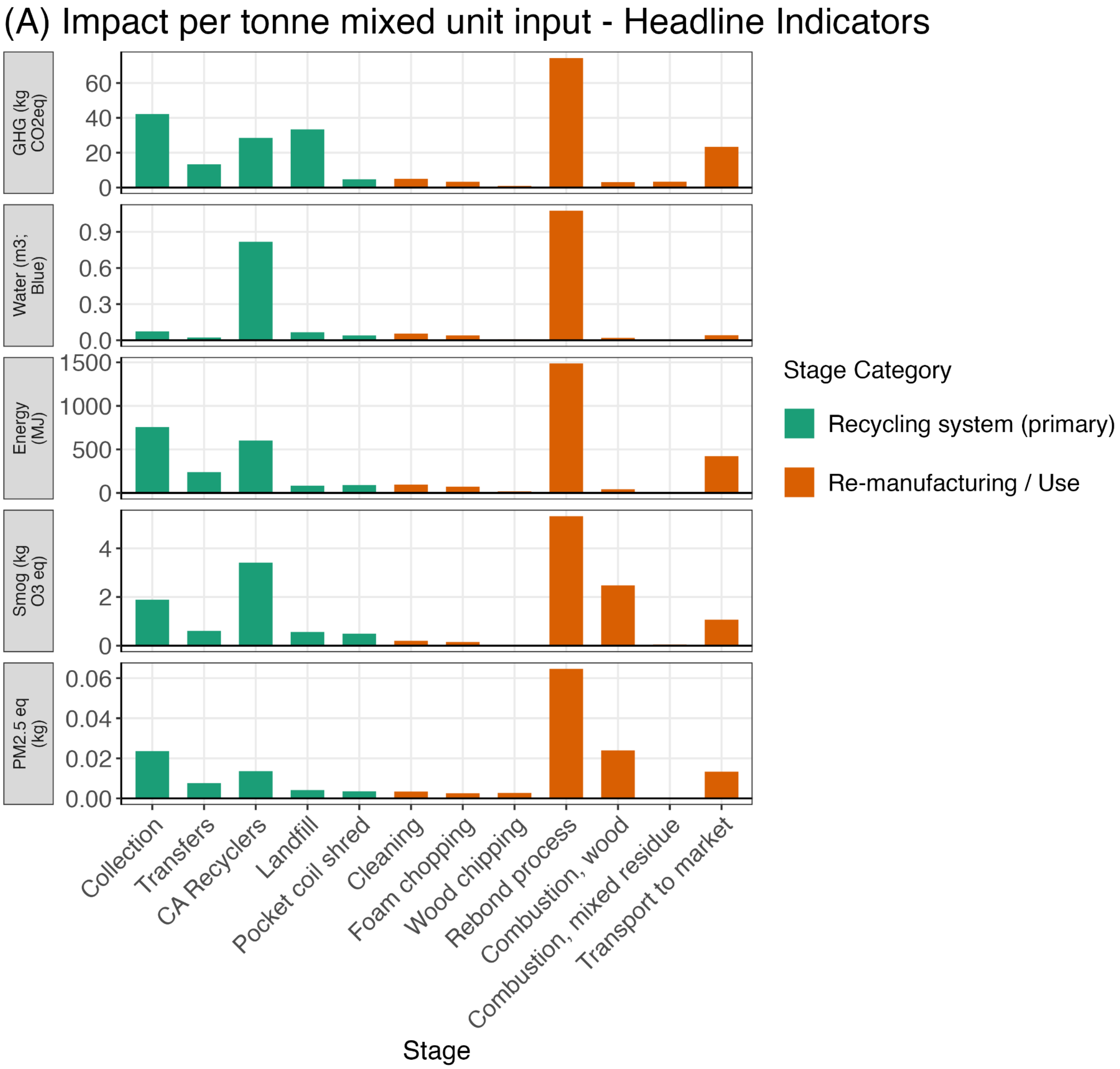


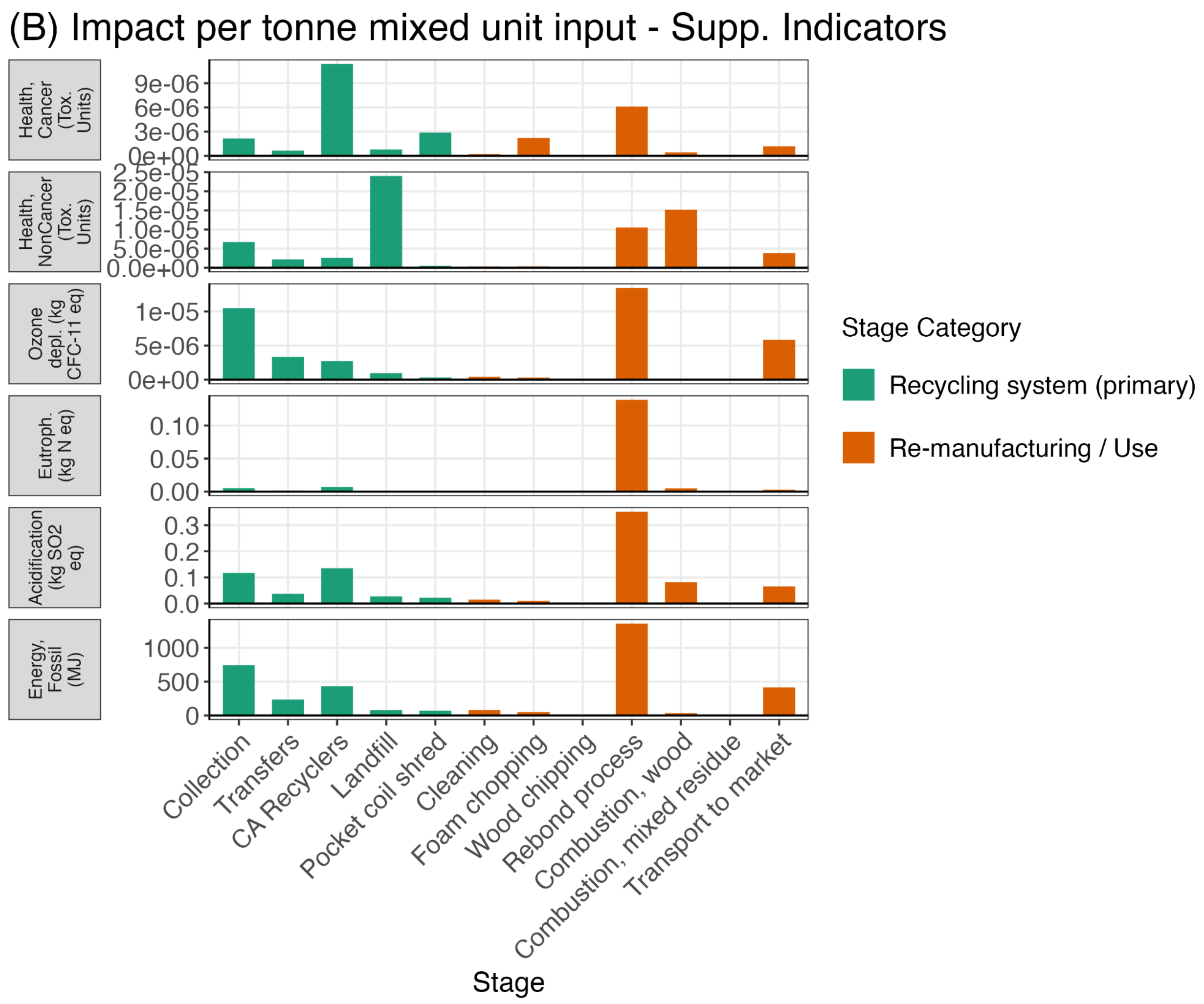
4.2.3 Baseline Incurred Impacts

The charts in this subsection show only the activities in the mattress recycling system that lead to incurred impacts. Impacts are grouped into Primary recycling activities (including collection, transfers, deconstruction, and landfill) and Re-manufacturing / Use (downstream manufacturing and transport of recycled products to markets).

The results show that the rebond process is the dominant source of impacts for every headline indicator, and for 4 out of 6 supporting indicators. As discussed above, this impact is primarily driven by the production of MDI used in the rebond process. The collection and deconstruction (CA Recyclers) stages are also important in several of the impact categories.

Figure 4.4. Incurred impacts in the recycling system. These results exclude the potentially avoided impacts associated with displaced products.

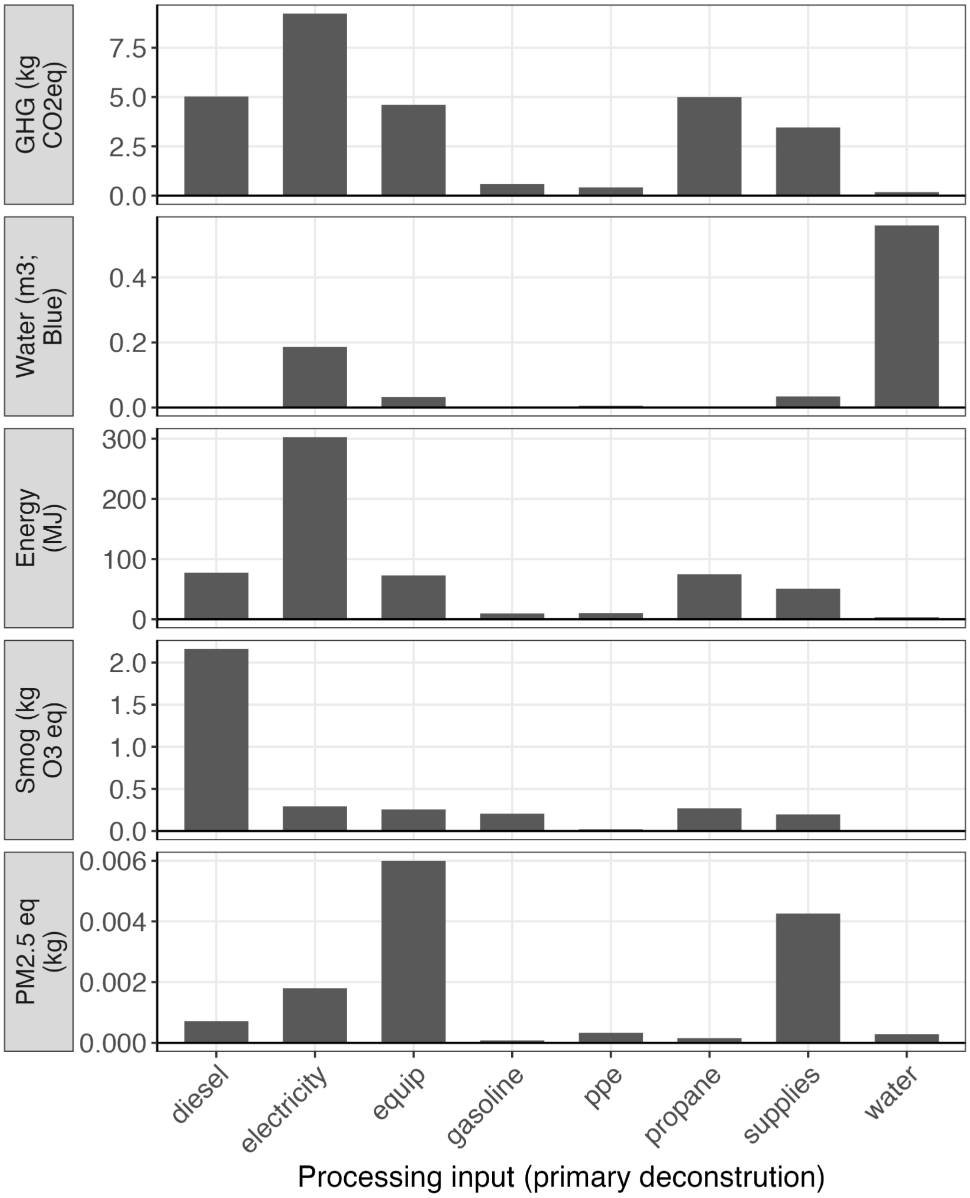


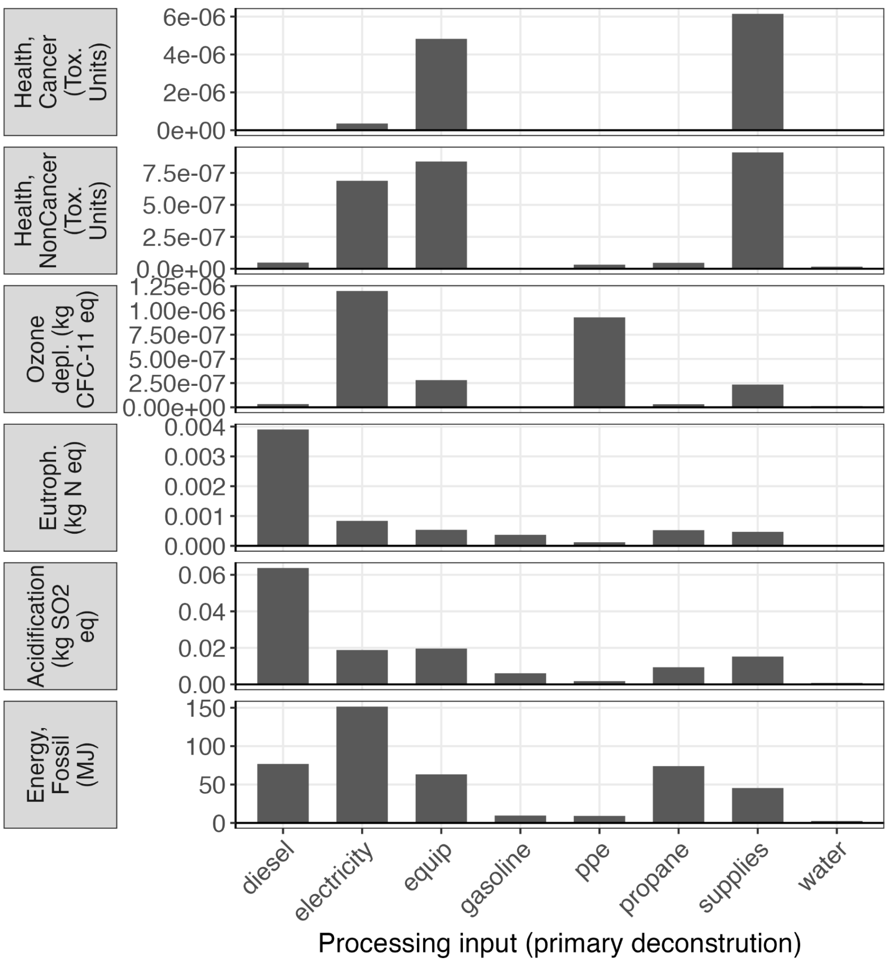


4.2.4 CA Processors (deconstruction)

Figure 4.5 shows a stage contribution analysis of the California mattress recycling facilities for all eleven indicators. The charts show that different activities are significant for different indicators. Electricity use is perhaps the most important stage, along with diesel use and equipment manufacturing. Both electricity use and diesel use can be addressed through management interventions such as installing or purchasing clean energy, using cleaner-burning equipment, and electrifying heavy equipment.

Figure 4.5. Impacts of activities during primary mattress deconstruction. These impacts do not include pocket coil chopping or foam shredding (see previous section). The charts show the impact of processing one tonne of mixed mattress units. Data table in Appendix.





4.3 Material Disposition Routes

The results in this section show comparative impacts for different uses of a given material. The results do not include the impacts of collection or deconstruction. Thus, they should be used to compare among the options, but should not be understood as complete life cycle impacts.

4.3.1 Foam Routes

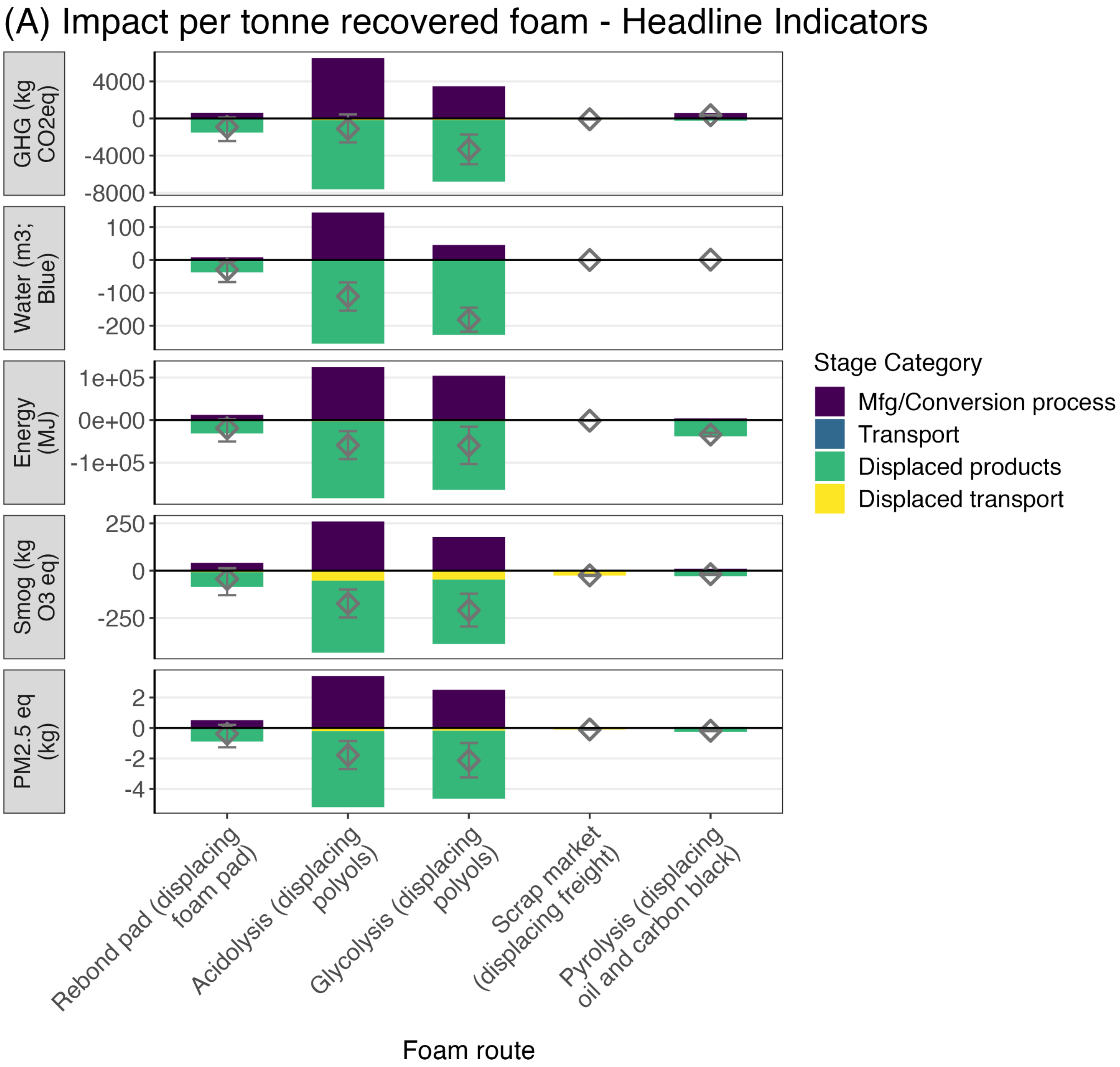
The foam recycling system includes five possible disposition fates. In the baseline case, the default assumption is that recycled foam is chopped and used to create pads in a rebond process. Rebond foam is assumed to displace new polyurethane foam (at a rate of 30%).

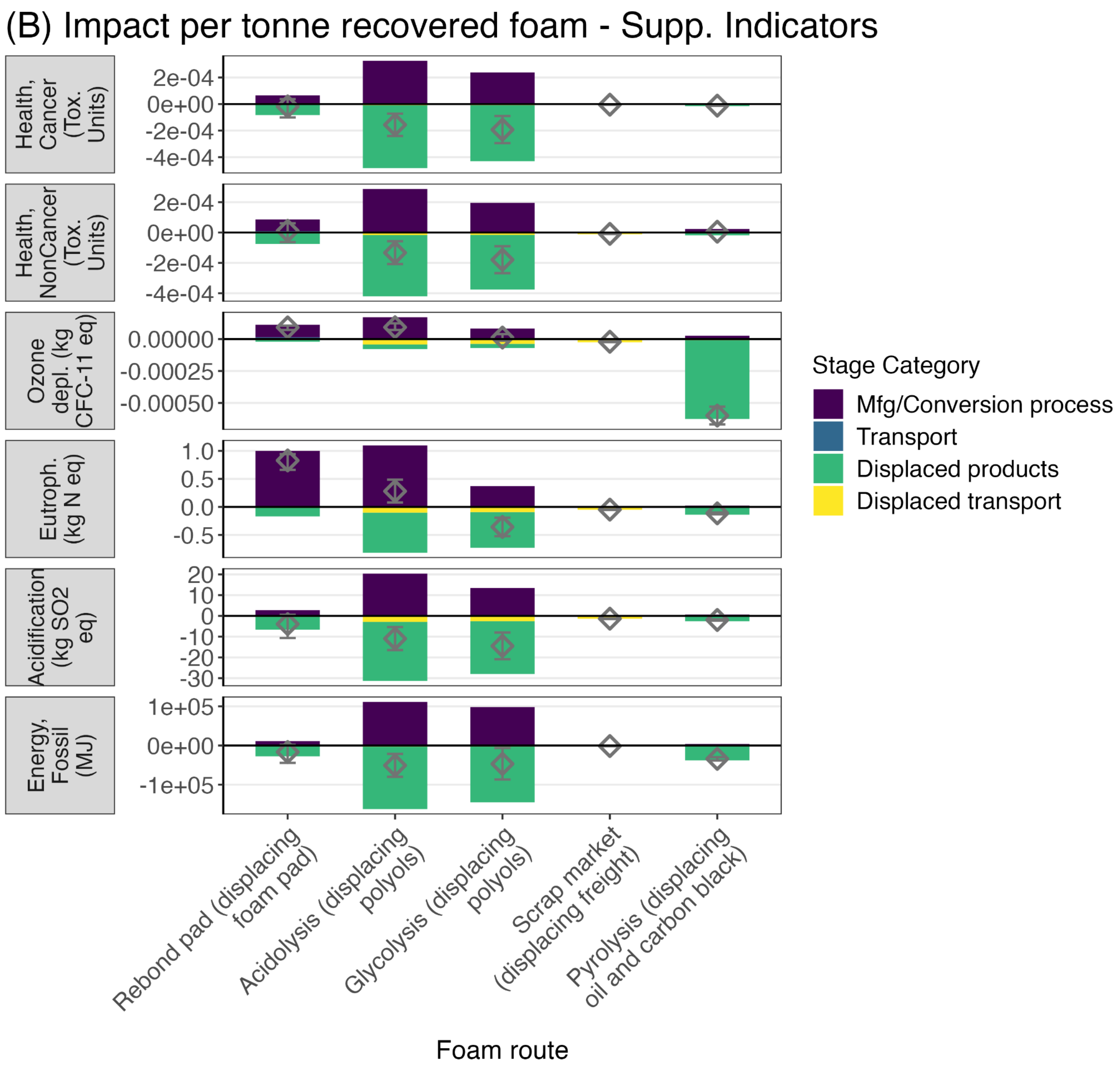
Two chemical recycling processes (acidolysis and glycolysis) were modeled, with the acidolysis process based on actual commercial scale facilities (§Acidolysis), and the glycolysis process based on literature reports of lab experiments (§Glycolysis). In both chemical recycling routes, the output of the process is reclaimed polyols. The Scrap market scenario represents foam that is sold as scrap and does not displace any primary production, only transport of other industrial foam scrap. Foam used as a pyrolysis feedstock would generate pyrolysis oil and char, which could displace crude oil and carbon black.

The results (Figure 4.6) show that rebond, along with both chemical recycling routes, are the best performers in most categories. Rebond shows improvement in all five headline indicators and three out of six supporting indicators. Inferior performance in health-noncancer, ozone depletion, and eutrophication can be attributed to MDI production as discussed above.

Chemical recycling via the acidolysis route shows an improvement in 4 out of 5 headline indicators (marginal on global warming) and 4 of 6 supporting indicators (impacts increase in ozone depletion and eutrophication). Adverse scores are again due to upstream chemical production of adipic acid and succinic acid. The glycolysis route performs better in some indicators, showing improvement in all 5 headline indicators, and 5 of 6 supporting indicators. However, this scenario is based on lab-scale studies, while the acidolysis scenario is based on commercial-scale installations.

Figure 4.6. Impacts of the different foam disposition routes. These results do not include impacts from Collection or Primary deconstruction. They represent the use of one tonne of recovered foam. Data table in Appendix.



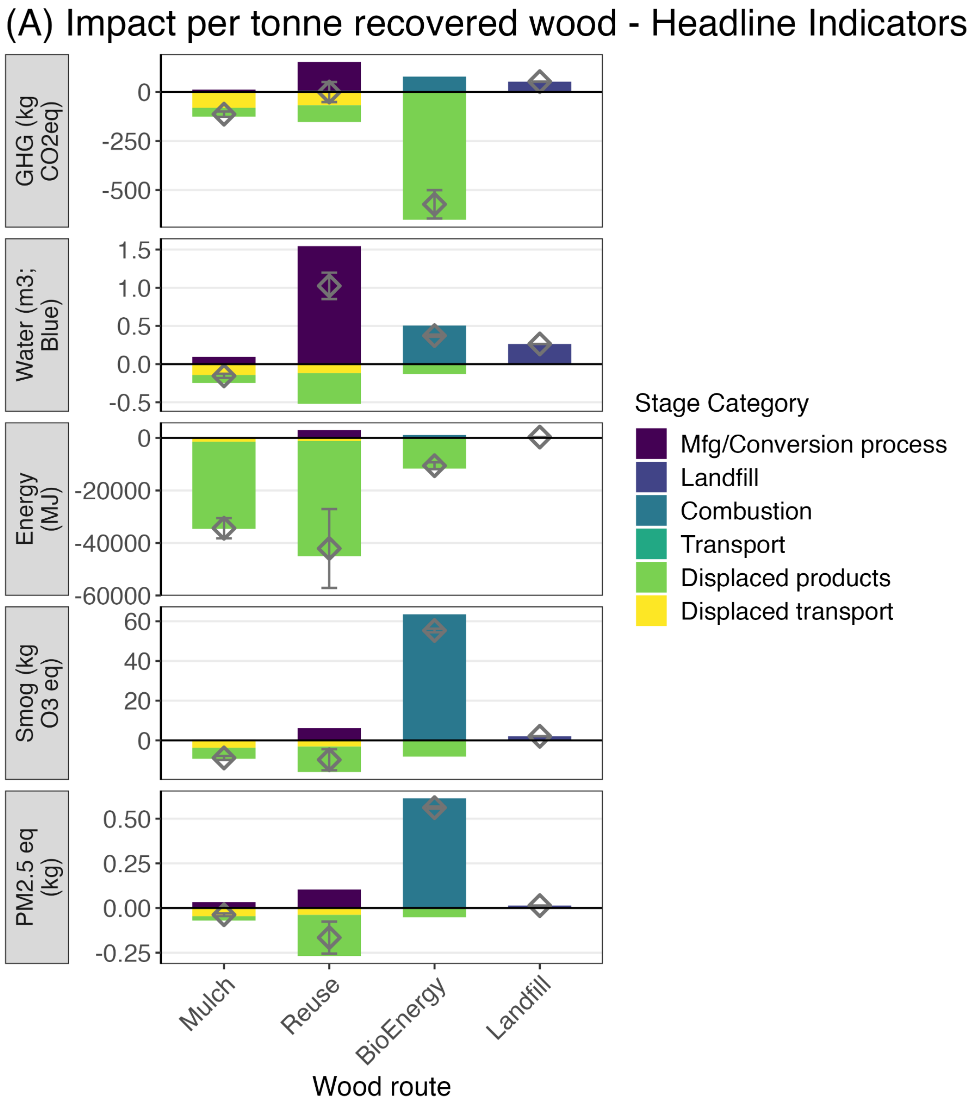


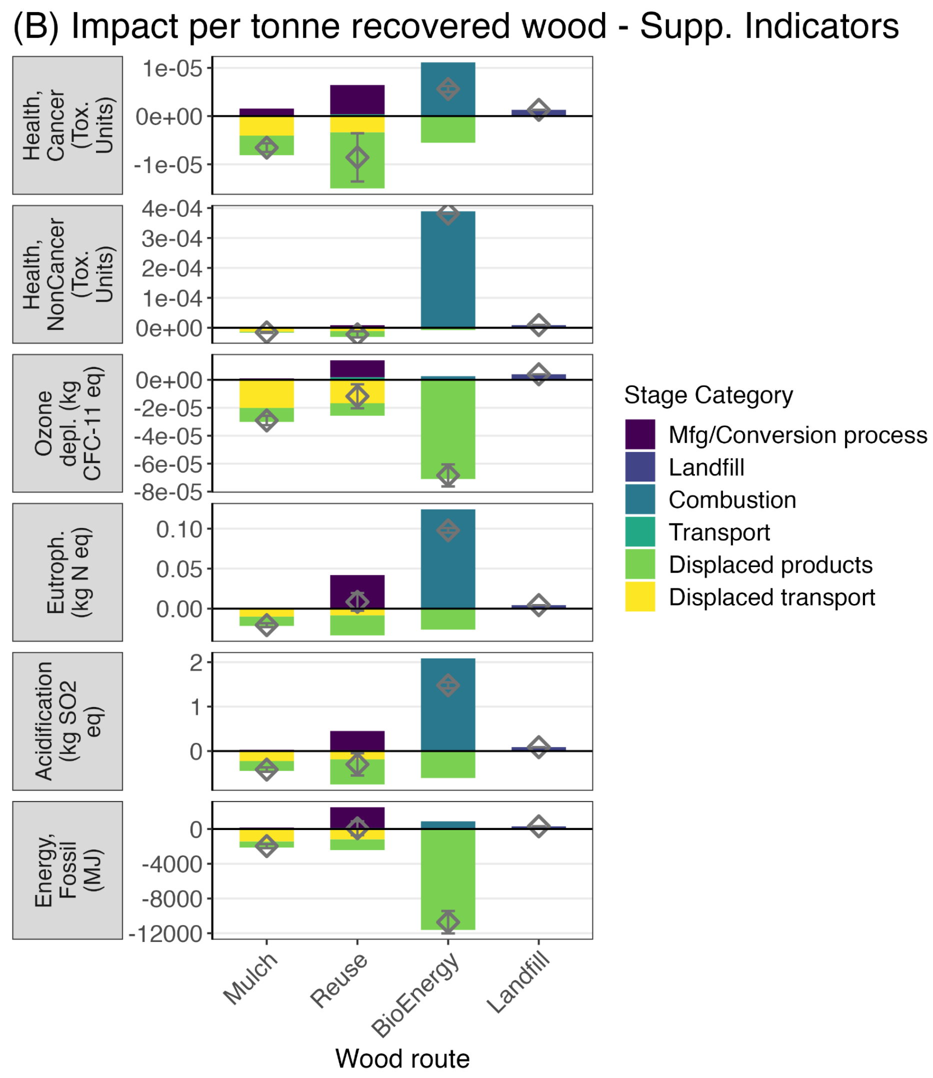
4.3.2 Wood Routes

Wood recovered from mattress recycling originates in foundations, which are between 25 and 60 percent wood according to the deconstruction study. We modeled four different end-of-life fates for wood: recycling as mulch, direct reuse as whole boards, combustion for bio-energy to displace natural gas, and disposal in landfill.

The results show that the recycling and reuse routes both show the potential for benefits in every indicator (five baseline plus six supporting). In contrast, combustion for bio-energy shows a mix of potential benefits and incurred emissions. The substantial reduction in GHG emissions is a result of the methodological assumption that bio-based fuels are carbon neutral. Other than climate change, air-pollution-related indicators show an increase in impacts over the displaced natural gas process. Wood in landfill is considered to be fairly inert, with less than 2 percent of the wood breaking down over a 100 year time-scale, resulting in comparatively low incurred impacts. The BioEnergy route shows net increases in seven out of 11 indicators, mainly driven by direct emissions from wood combustion.

Figure 4.7. Impacts of different wood disposition routes. These results do not include impacts from Collection or Primary deconstruction. They represent the use of one tonne of recovered wood. Data table in Appendix.





4.4 Collection Scenarios

This section discusses the comparative impacts of different mattress collection methods. In the Baseline case, collection burdens arise from the transport of mattresses in bulk from collection points to processors using a mix of trailer trucks, representative of MRC's material flow data. In the Baseline case, delivery of mattresses to collection points by the consumer are outside the scope of the study.

Figure 4.8 compares the impacts of the baseline collection freight to other freight scenarios, including independent transport by consumers and scavengers. The scenarios are as follows:

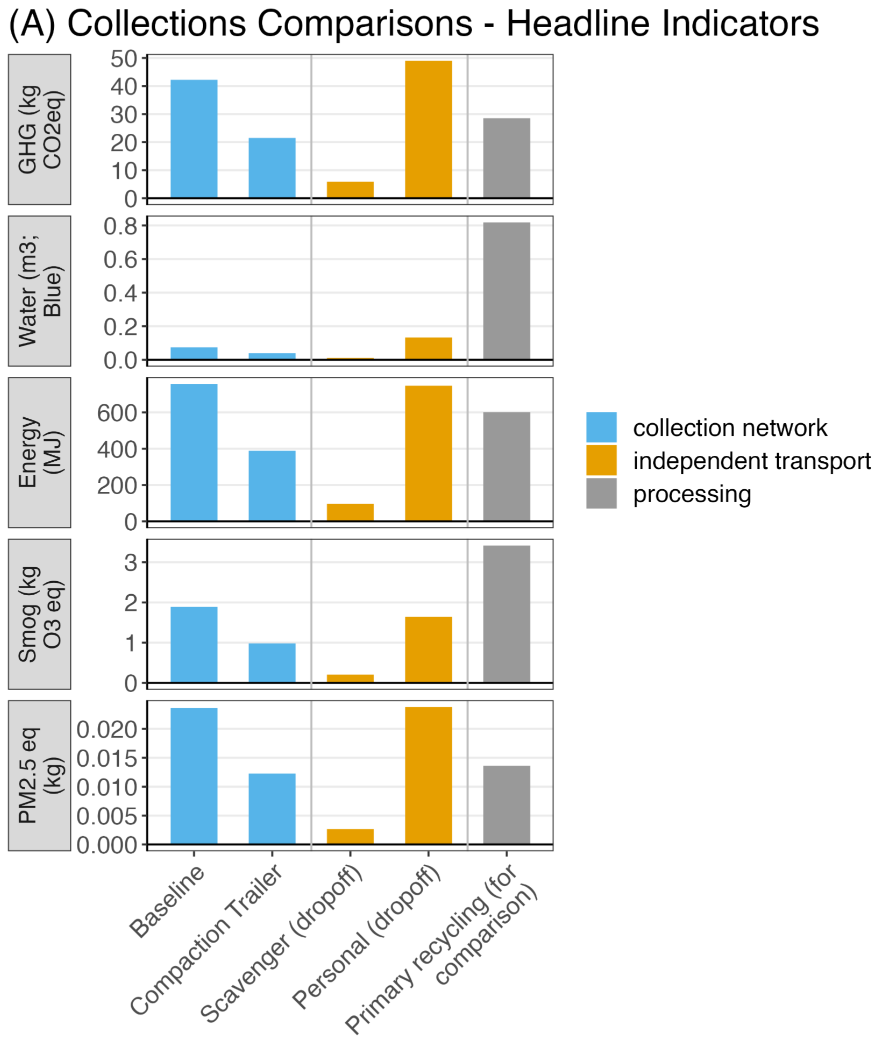
- The compaction case is the same as the Baseline, except that compaction trailers can carry twice the number of mattresses and are assumed to be used at every collection point.
- In the scavenger case, mattresses are collected by private pickup trucks, traveling 4 km per mattress on a round-trip journey delivering truckloads of mattresses to processors.

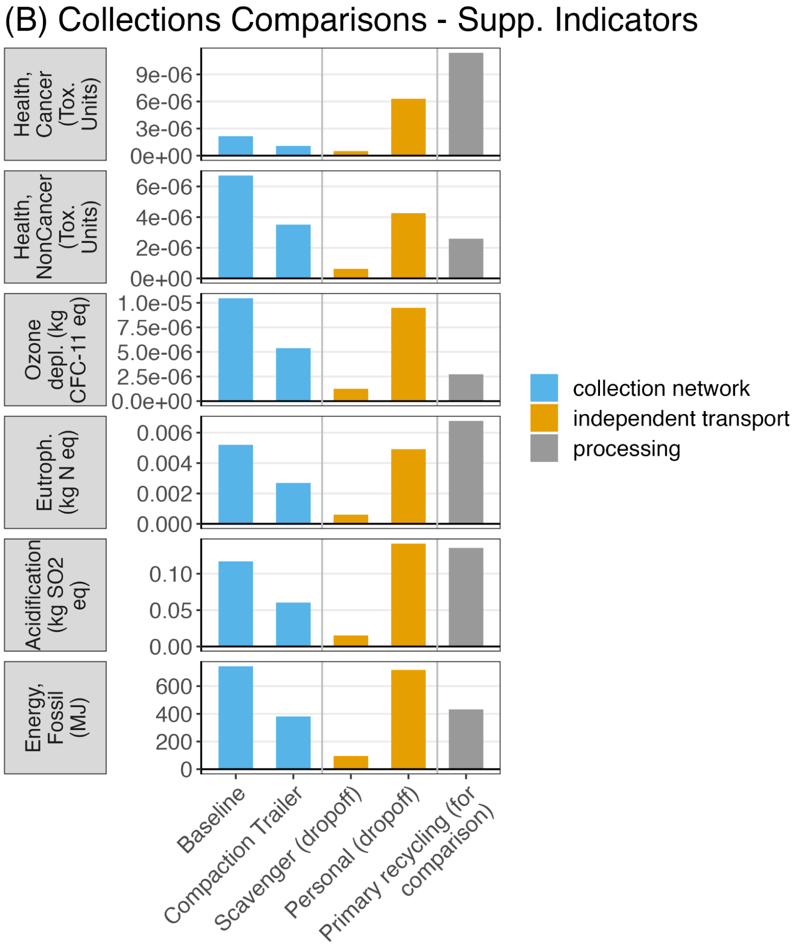
The impacts shown in Figure 4.8 represent the impacts of scavenger collection for about 7% of all the recycled units (according to the data from MRC)

- In the personal dropoff case, private vehicles are used to transport single mattresses, traveling a round trip of 15 km. The impacts in Figure 4.8 assume that 20% of all units are transported via consumer transport, before they enter the formal recycling system (30% of the units at Collection Sites, Collection Events, and Dropoffs to recyclers without incentive).

Figure 4.8 shows that private transport can be a significant source of impacts, compared to the impacts associated with primary recycling. This suggests that a robust network has an important role to play in avoiding private vehicle use.

Figure 4.8. Impacts associated with different collection scenarios. Blue bars (left two) represent the baseline collection freight impacts and an alternative “compaction trailer” scenario. Orange bars represent independent scavenger and consumer transport scenarios (described in main text). The gray bar shows the impacts of the primary recycling process, for comparison.




(B) Collections Comparisons - Supp. Indicators

5 Life Cycle Interpretation

This study was designed and carried out to provide a structured life cycle framework to estimate the potential environmental implications of mattress recycling in California. The main objectives of the study are twofold:

- To estimate the environmental impacts of the current (baseline) conditions for mattress recycling in California
- To understand the advantages and disadvantages of alternative management scenarios

The study scope is defined to allow comparison of the incurred impacts of mattress recycling on the one hand (impacts of the Recycling system), with potentially avoided impacts on the other hand (associated with the Displacement system).

5.1 Results

Baseline

The results indicate that mattress recycling is beneficial according to all five headline indicators (global warming potential, particulates, water depletion, smog, and primary energy demand) and three out of six supporting indicators (fossil energy demand, ozone depletion, and acidification). In these indicators, the finding is robust even under the most pessimistic assumptions regarding product displacement. In one of six supporting indicators (human health - cancer), mattress recycling is marginal (net results near zero within the bounds of uncertainty about displacement). In two supporting indicators (human health - non-cancer and eutrophication), the model indicates that mattress recycling results in increased impacts in comparison to the displaced products.

The major drivers of the incurred impacts included rebond foam pad production, reverse logistics, and the activity of California recyclers. Within the rebond activity, production of methylene diphenyl diisocyanate (MDI) was the major driver. The major drivers for avoided impacts were steel recycling and avoided polyurethane foam production.

Scenarios

The scenarios modeled in the study revealed several important findings about mattress end of life management.

- Impacts from collection and reverse logistics impacts make up a somewhat large share of incurred impacts. This is in contrast to many other recycling systems, and can largely be explained by the low density of mattresses during collection. We estimated that a 53’ trailer containing a full load of 110 average units is utilizing only 9% of its hauling capacity (by weight).
- Any bulk collection process is far superior (lower in impacts) to the return of mattresses to drop-off locations by consumers in private vehicles.

- Of the scenarios considered, incineration of mattresses with energy recovery has the worst performance in all but two impact categories (Ozone depletion and Eutrophication).
- The environmental performance of foam chemical recycling depends strongly on the technology and the assumed application. Chemolysis generally performs well in comparison to virgin polyol production. Impacts of chemical recycling pathways were largely driven by upstream chemical production, and not from direct emissions or energy use.
- Combustion of wood for bio-energy led to significant avoided impacts in the global warming indicator, driven by the assumption that wood fuel is carbon-neutral in comparison to displaced fuels. In other indicators, bio-energy was more mixed, and reuse and recycling were preferable.

Biogenic CO_2 emissions

In the results presented, the impacts of biogenic CO_2 are not included (see §LCIA Methodology and Types of Impacts). However, for completeness, we have included tables with biogenic CO_2 emissions in Appendix A3 (§Biogenic CO_2). In the baseline scenario (based on management in California during the year 2021), including biogenic CO_2 would add about 35% to the incurred GHG emissions. The overall benefit of the recycling system (after accounting for displaced production) would be reduced by about 14%. Most of the biogenic CO_2 in the baseline mattress recycling system results from wood combustion for energy recovery.

Private Transport

Impacts associated with consumers driving their EOL mattresses to collection sites (or recyclers) could be as large as the impacts from the existing collection network. Although these emissions from private transport are variable, depending on the distance traveled, and the type of vehicle, the comparison shows the importance of optimizing collection to avoid private transport, where possible.

5.2 Identification of significant issues

The following items should be kept in mind when reviewing the results:

- The mattress recycling system has the capability to reduce environmental impacts through the displacement of primary production. The extent of the environmental benefit depends on how much primary production is actually avoided.
- Downstream manufacturing and disposal operations, particularly rebond manufacturing, were the largest contributors to incurred impacts.
- The largest sources of potential benefits came from displaced primary foam production and reduced life-cycle impacts associated with scrap steel recovery.
- Isocyanates (chemicals used in foam and many other materials) contribute significantly to the results (MDI in the process for foam rebond pad manufacturing, and TDI in

displaced new flexible foam), but the models are not transparent and are likely inconsistent.
- The energy and water use during rebond foam pad production are based on proxy models and first principles.
- The inventories for the incurred recycling processes (collection, deconstruction, and re-manufacturing/use) do not include sensitivity ranges.
- The inventories for pyrolysis are adapted from laboratory studies. Specific studies on whole-mattress units and on foam derived from mattresses should be conducted to refine these process inventories.
- The direct emissions from mattress deconstruction facilities only include emissions from combustion (e.g. propane in forklifts, diesel in equipment). They do not include other sources of air emissions, for example, dust.

5.3 Evaluation - Completeness and Consistency

The study included all relevant flows, subject to the exclusions and limitations discussed in §Goal and Scope. In particular, gate-to-gate inventory requirements during used mattress collection, processing, and mattress-derived product manufacturing, were modeled using all available information. The impacts of production activities were modeled based on primary data provided by mattress deconstruction facilities in the scope of the study.

The consequential system expansion method that is used is intended to show the potential implication of a policy or decision. In this case, the decision is about how to recycle mattresses, and what policies (if any) to use. As a consequence, the models in the Displacement system are “cradle-to-marketplace”, representing the activities that would likely be different if the mattresses were not recycled.

To ensure flow completeness, we reconciled the lists of flowables (substances by name, CAS number, or other identifier, that could be emitted into many environmental compartments) described in each inventory source with the impact assessment methodology. The inventory sources included ecoinvent 3.8, US LCI, and WorldSteel.

One area of inconsistency is the recovery rate assumed for the mattress constituent materials. There are two methods by which these recovery rates can be calculated:
- Using data collected about the type of material in the waste streams from a sample of deconstruction facilities
- Using data collected about the mass of constituent materials in a sample of mattresses received at a deconstruction facility

In the study, we used the recovery rates calculated using waste flow characterizations (the former), since the rates calculated based on mattress compositions (the latter) resulted in a value over 100% (Table 5.1).

Table 5.1. Recovery rates for materials recovered from used mattresses, calculated using two different methods.

Material (within mattress)	Recovery Rate (Based on Waste Materials)	Recovery Rate (Based on Mattress Composition)
Metal	99.8%	94.4%
Foam	79.2%	66.9%
Quilt	79.2%	109.7%
Wood	97.9%	84.8%
Shoddy/Felt	9.7%	12.8%
Other Fabric/Fiber	6.5%	13.7%
Other	21.0%	17.4%

5.4 Evaluation - Validity check

The principle of mass balance is the key method for ensuring consistency for material flow-based LCA. We performed an intensive review of primary data received during the study to ensure its consistency and to correct errors and omissions. Mass flows through facilities included in the system boundary were taken from directly reported data. Because data collection occurred over a fixed time period, it is expected that inflows and outflows to any given facility over that time period would not match exactly. Discrepancies between inflows and outflows can be attributed to changes in material stocks within the facility. Stock changes of less than one percent of annual material flows were judged to be insignificant.

5.5 Evaluation - Sensitivity

Sensitivity of the study results was analyzed with respect to three different perspectives.

- The displacement relationship was varied for every displacement route, to account for uncertainty in the economic relationship between mattress-derived products and potentially displaced products.
- Sensitivity of collection impacts to inclusion/exclusion of consumer transport was explored
- Impacts were modeled according to a wide range of possible displacement relationships, including multiple potentially displaced products per mattress-derived product (e.g. rebond pad or base chemical for foam, wood chips or boards for wood).

The results of the sensitivity analysis are as follows:

- The results of the study were robust to sensitivity analysis, showing that even with pessimistic assumptions regarding displacement and processing impacts, a net reduction in environmental impact scores was still likely in many cases.
- Impacts from consumer transport are potentially the same magnitude as other collection impacts.
- Some displacement relationships appear to have better environmental performance than others: For the foam scenarios, rebond foam pad manufacture, as well as the two chemical recycling pathways all had strong performance, compared to pyrolysis and synthetic cement. For the wood scenarios, mulch and reuse both had good performance, compared to bioenergy and landfill.

5.6 Limitations

We identified the following limitations to the study results:

- The study did not include an economic analysis of the potential market demand for mattress-derived products. Products made from recycled materials can only provide environmental benefits (e.g. negative emissions of greenhouse gases) if they are fulfilling a market demand in a manner that replaces primary production. Although we tested the sensitivity of our results to lower displacement rates, only market research can reveal whether specific mattress-derived products can displace competing products made from primary materials.
- Constituents of the mattresses are based on deconstruction of actual units at recycling facilities, circa 2021. These data may become outdated.
- Study does not include projections about the mix of mattresses entering the recycling system in the future.
- For emissions from the primary recycling facilities, we did not measure air quality. The only emissions from these facilities that are included in the models are emissions related to fuel combustion (which are included in the databases used). Other sources of emissions are not considered.
- Results for rebond foam pad do not include an explicit uncertainty treatment for the amount of (isocyanate) binder required.
- No data for cleaning and sterilization of mattress-derived materials for reuse was available. We adapted an industrial laundering process model for use as a proxy.
- Toxicity impact assessment, for both human and ecological indicators, is highly inexact and is inherently subject to high uncertainty. The study used the TRACI 2.1 implementation of USEtox, which includes a subset of USEtox flows. The TRACI 2.1 toxicity implementation includes both recommended and “interim” factors, the interim factors being associated with heavy metals whose characterization factors are very high due to the (infinite) persistence of metal ions in the environment. Consequently, the toxicity impact scores tend to be dominated by metals emissions.

5.7 Overall Data Quality Evaluation

The overall quality of data used in the study foreground is judged to be very high, due to the fact that data describing logistics, mattress composition, the mix of mattress types, and the activities of California processors all came from primary sources. Foreground models for production activities, including rebond foam pad, chemical recycling of polyurethane foam, and pyrolysis were developed specifically for the study and are judged to be medium-high quality.

Many models used to describe background activities are proxy models, and some data quality issues affect the quality of the results.

- In the scrap steel process, which was prepared by the WorldSteel Association, the utilization of scrap steel leads to an increase in certain heavy metal emissions, leading to a large positive score in the human health - non-cancer indicator. This finding cannot be validated without access to the details of the WorldSteel model. However, it is consistent with the assumption of increased electricity production to power electric arc furnaces, if that electricity is supplied using coal and other polluting fuels. It is important to note that the “Value of Scrap” process being used represents a globally-averaged activity. Because a considerable share of scrap steel collected in the US is utilized domestically, it is possible that a US-specific model of scrap recycling would show different results.
- Several activities describing polymer production in ecoinvent are adapted from the eco-profiles database published by PlasticsEurope. This database includes several processes that have been aggregated for confidentiality, including the processes for production of virgin polyols and toluene diisocyanate (TDI). These aggregated processes appear to include a less comprehensive set of emissions than the dis-aggregated process models such as MDI, which make use of ecoinvent’s internal models. As a result, direct comparisons between these activities may be inconsistent or misleading. We believe this discrepancy is responsible for the apparent poor performance of rebond foam in comparison to primary foam in §Foam Routes.
- Water depletion is unevenly represented in life cycle inventory databases. The current study includes inventory data from USLCI and WorldSteel, as well as ecoinvent. Because of differences in the methodology accounting for water depletion in these databases, the quality of the water depletion indicator is lower than that of the other indicators. The large avoided water depletion score resulting from scrap steel recycling may be overstated, and the water depletion associated with the production of fuels burned in mattress recycling facilities may be understated.
- Constituents of the mattresses are based on deconstruction of actual units at recycling facilities, circa 2021. These data may become outdated.
- Capital equipment used at recycling facilities made a somewhat large contribution to the impacts of these facilities. This equipment was modeled using a set of simple proxy processes in ecoinvent and further investigation may be appropriate.
- The study used generic combustion models for diesel and propane burned in mobile equipment in processing facilities. Due to the significance of emissions from combustion equipment in these facilities for employee health, it would be appropriate to investigate the degree to which the models are representative of conditions at recyclers.

Glossary

Acidolysis: A chemical recycling process that uses acids, catalyst, and heat to perform depolymerization. In this report, acidolysis is a pilot-stage technique for performing chemical recycling of polyurethane foam.

Avoided Burden: The life cycle impacts associated with producing a primary product that competes with a recycled product in the market, represented by a negative-valued impact indicator score. When recycled materials are consumed in the market instead of primary materials, the avoided burdens of primary production can be compared to the incurred burdens of recycling.

Biogenic Carbon, Biogenic CO2: Substances or compounds, such as carbon dioxide, which contain carbon originated from a biological source such as agriculture or forestry. Biogenic carbon was recently extracted from the atmosphere via photosynthesis, so its release back into the environment is not considered to contribute to global warming in the same manner as fossil carbon.

Critical review: A process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment (ISO 14040).

Displacement: A market relationship in which materials made available from recycling are expected to cause a reduction in the amount of primary materials consumed. When displacement occurs, the impacts of displaced production are known as avoided burdens.

ecoinvent: A world-renowned life cycle inventory database, originally created as a research partnership in Switzerland in the 1990s. The ecoinvent database contains over 18,000 data sets describing the production and distribution of thousands of products in the global economy.

End of Life (EOL): The life cycle stage that occurs after a product or material has reached the end of its useful life. The scope of this study includes the collection of scrap mattresses, transportation to recyclers, processing the mattresses to recover materials, and disposal of wastes.

Extended Producer Responsibility (EPR): A product stewardship framework in which the firms responsible for producing and selling a product also bear responsibility for managing the product's end of life. Rather than being operated by government or public agencies, EPR programs are generally operated by private companies and non-profit organizations.

Foam mattress: A mattress whose inner, resilient layer is made up of a foam material, such as latex or polyurethane, instead of a steel innerspring.

Foundation: A ticking or fabric-covered structure used to support a mattress or sleep surface and may be composed of a frame, foam, springs or other structure, or other materials, used alone or in combination, regardless of whether the product is stationary or adjustable (MRC 2021 Annual Report).

Functional Unit: The quantified performance of a product system for use as a reference unit (ISO 14040). The functional unit gives a precise statement of what product or activity is modeled in a life cycle assessment study.

Glycolysis: A chemical reaction in which a glycol solution is used to depolymerize a polyurethane material via transesterification. In this report, glycolysis is a pilot-stage technique for performing chemical recycling of polyurethane foam.

Incurred Burden: The life cycle impacts that are the result of an activity or process being performed. Incurred burdens are environmental impacts that have positive-valued indicator scores. Incurred burdens from recycling activities can be compared to avoided burdens of potentially displaced production.

Innerspring: An interior support structure inside a mattress, typically constructed of coiled steel springs. Innerspring mattresses include both tied-spring designs, in which all springs are tied together into a single unit, and pocket-coil designs, in which springs are individually contained within fabric pockets.

Life cycle assessment (LCA): A scientific methodology for compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040). LCA is governed by a family of international standards (ISO 14040, 14044, 14071, and others) and includes a worldwide community of practice.

Life cycle inventory (LCI): The collected set of resource requirements and emissions that result from a product or service throughout its life cycle, including both direct and indirect (supply chain) activities. Compilation of a life cycle inventory, also known as life cycle inventory analysis, is one of the main steps in completing a life cycle assessment study.

Life cycle impact assessment (LCIA): The phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. Life cycle impact assessment is one of the main steps in completing a life cycle assessment study.

Life cycle impact indicator: Also known as an impact category indicator or category indicator, the numerical score that describes the environmental burdens or impacts associated with a product or service in life cycle assessment. The outcome of life cycle impact assessment (LCIA) is a set of life cycle impact indicator scores. These scores are the quantitative results of a life cycle assessment study.

Mattress: Any sleep surface covered with ticking or fabric that contains resilient material such as steel innersprings, foam, fiber or other filling or upholstery materials, used alone or in combination, regardless of size or shape (MRC 2021 Annual Report).

Mattress Recycling Council California, LLC (MRC): The California subsidiary of the Mattress Recycling Council, a non-profit corporation created by the International Sleep Products Association to develop, implement, and administer recycling programs for mattresses and foundations to comply with state Extended Producer Responsibility programs.

Mtkm: One million tonne-kilometers (measure of freight).

Non-Program Mattress: A mattress that is not included in the scope of the extended producer responsibility program operated by MRC. Non-program units include mattresses obtained from franchise haulers and waste facilities that do not participate in the program; mattresses manufactured by the Prison Industry Authority, which are exempt from the recycling charge; and units collected from sources outside of California. MRC compensates its recyclers for processing program units only (MRC 2021 Annual Report).

PPE: Personal Protective Equipment. Masks, gloves, goggles, and other items worn to protect a worker from potential hazards.

Pocket Coil (Pocketed coil): A design for a mattress innerspring, in which springs are individually encased inside a fabric layer. Pocket-coil mattresses must undergo an additional processing step during recycling to separate the spring material from the fabric.

Pyrolysis: A chemical reaction to bring about the decomposition of a polymeric material through the exposure to high heat in the absence of oxygen. Pyrolysis products include a liquid material, comparable to some crude oil products, and a solid material analogous to carbon black. Pyrolysis can be used to recover resources from a wide range of materials, including polyurethane foam and whole mattresses.

Quilt: The mattress sleep surface. Quilt is typically a composite material that includes a decorative outer fabric (also called ticking), one or more layers of fiber batting, non-woven fabric or foam (polyurethane and/or latex) and a thin backing fabric (usually a non-woven fabric) (MRC 2021 Annual Report).

Shoddy: Shoddy is a non-woven material comprised of mixed shredded recycled post-industrial fabric and apparel, usually is placed between the metal springs and foam layers to insulate the foam from sharp points on the springs and to keep the foam from working its way into the springs during the life of the mattress (MRC 2021 Annual Report).

System Boundary: The set of criteria specifying which unit processes are part of a product system (ISO 14040). The system boundary describes what activities are included within the scope of a life cycle assessment study.

Tied Spring: A type of innerspring mattress, in which steel coils are tied together to form larger spring assemblies within the mattress.

Tonne-kilometer (tkm): A measure of the functional utility of a freight service. A tonne-kilometer represents the transfer of one tonne (metric ton; 1,000 km) of goods over the distance of one kilometer. A large truck carrying 20 tonnes of freight over a distance of 50 km provides 1,000 tkm of freight service. A related unit, the ton-mile, represents the transfer of a short ton (2,000 lb) over the distance of one mile, and is equal to about 1.45 tkm.

TRACI: Tool for the Reduction and Assessment of Chemical Impacts. A life cycle impact assessment (LCIA) methodology, created by the US Environmental Protection Agency, intended for use in life cycle assessment to quantify the environmental burdens of products and services in the North American context.

USLCI: The United States Life Cycle Inventory database. A freely available, contributed collection of data sets describing the resource requirements and environmental emissions resulting from production activities in the US. The USLCI database is part of the Federal LCA commons.

References

Altayeb, R. K. (2015). *Liquid fuel production from pyrolysis of waste tires: Process simulation, exergetic analysis, and life cycle assessment* [Masters]. American University of Sharjah.

Bare, J. (2012). *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1* (EPA/600/R-12/554). US Environmental Protection Agency. https://nepis.epa.gov/Adobe/PDF/P100HN53.pdf

Borda, J., Pásztor, G., & Zsuga, M. (2000). Glycolysis of polyurethane foams and elastomers. *Polymer Degradation and Stability*, *68*(3), 419–422. https://doi.org/10.1016/S0141-3910(00)00030-6

Czajczyńska, D., Anguilano, L., Ghazal, H., Krzyżyńska, R., Reynolds, A. J., Spencer, N., & Jouhara, H. (2017). Potential of pyrolysis processes in the waste management sector. *Thermal Science and Engineering Progress*, *3*, 171–197. https://doi.org/10.1016/j.tsep.2017.06.003

Earles, J. M., & Halog, A. (2011). Consequential life cycle assessment: A review. *The International Journal of Life Cycle Assessment*, *16*(5), 445–453. https://doi.org/10.1007/s11367-011-0275-9

ecoinvent. (2021). *Ecoinvent, v3.8, Allocation, cut-off by classification* [Computer software].

Ekvall, T., & Weidema, B. P. (2004). System boundaries and input data in consequential life cycle inventory analysis. *The International Journal of Life Cycle Assessment*, *9*(3), 161–171. https://doi.org/10.1007/BF02994190

FAO. (1988). *Nature and Management of Tropical Peat Soils*. https://www.fao.org/3/x5872e/x5872e0b.htm#:~:text=The%20calorific%20value%20of%2

0oven,only%20about%2010%20MJ%2Fkg.

Frischknecht, R., Wyss, F., Büsser Knöpfel, S., Lützkendorf, T., & Balouktsi, M. (2015). Cumulative energy demand in LCA: The energy harvested approach. *The International Journal of Life Cycle Assessment*, *20*(7), 957–969. https://doi.org/10.1007/s11367-015-0897-4

Gama, N., Godinho, B., Marques, G., Silva, R., Barros-Timmons, A., & Ferreira, A. (2020). Recycling of polyurethane scraps via acidolysis. *Chemical Engineering Journal*, *395*, 125102. https://doi.org/10.1016/j.cej.2020.125102

Grdadolnik, M., Drinčić, A., Oreški, A., Onder, O. C., Utroša, P., Pahovnik, D., & Žagar, E. (2022). Insight into Chemical Recycling of Flexible Polyurethane Foams by Acidolysis. *ACS Sustainable Chemistry & Engineering*, *10*(3), 1323–1332. https://doi.org/10.1021/acssuschemeng.1c07911

Guinee, J. B. (2002). Handbook on life cycle assessment operational guide to the ISO standards. *The International Journal of Life Cycle Assessment*, *7*(5), 311, BF02978897. https://doi.org/10.1007/BF02978897

Haugen, H. H., Furuvik, N. C. I., & Moldestad, B. M. E. (2016). *Characterization of biomass wood*. 257–269. https://doi.org/10.2495/EQ160241

Herrero, D. S. (2017). *Glycolysis process for polyurethane waste recycling* [Doctoral]. Universidad de Castilla–La Mancha.

H&S Anlagentechnik. (2022). *Your specialist for PUR: recycling, blending, storing*. https://www.hs-anlagentechnik.de/files/pdf/broschuere.pdf

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Iribarren, D., Dufour, J., & Serrano, D. P. (2012). Preliminary assessment of plastic waste valorization via sequential pyrolysis and catalytic reforming. *Journal of Material Cycles and Waste Management*, *14*(4), 301–307. https://doi.org/10.1007/s10163-012-0069-6

ISO 14044. (2006). *14044: Environmental Management—Life Cycle Assessment—Requirements and guidelines*.

Kemona, A., & Piotrowska, M. (2020). Polyurethane Recycling and Disposal: Methods and Prospects. *Polymers*, *12*(8), 1752. https://doi.org/10.3390/polym12081752

Khoo, H. H. (2019). LCA of plastic waste recovery into recycled materials, energy and fuels in Singapore. *Resources, Conservation and Recycling*, *145*, 67–77. https://doi.org/10.1016/j.resconrec.2019.02.010

Marson, A., Masiero, M., Modesti, M., Scipioni, A., & Manzardo, A. (2021). Life Cycle Assessment of Polyurethane Foams from Polyols Obtained through Chemical Recycling. *ACS Omega*, *6*(2), 1718–1724. https://doi.org/10.1021/acsomega.0c05844

Simón, D., Borreguero, A. M., de Lucas, A., & Rodríguez, J. F. (2014). Glycolysis of flexible polyurethane wastes containing polymeric polyols. *Polymer Degradation and Stability*, *109*, 115–121. https://doi.org/10.1016/j.polymdegradstab.2014.07.009

TNO. (2022). *Feasibility mattress recycling – TNO measurement campaign*. https://www.cbm.nl/wp-content/uploads/2022/03/220310-Feasibility-mattress-recycling-TNO-measurement-campaign-final.pdf

US LCI. (2021). *U.S. Life Cycle Inventory Database (Q1)*. National Renewable Energy

Laboratory. www.lcacommons.gov/nrel/search

USEPA. (2014). *Emission Factors for Greenhouse Gas Inventories*. US Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

USEPA. (2022). *Emission Factors for Greenhouse Gas Inventories*. https://www.epa.gov/system/files/documents/2022-04/ghg_emission_factors_hub.pdf

World Steel Association. (2021). *Life cycle inventory methodology report for steel products (2017); with 2021 reference data*. https://www.worldsteel.org/en/dam/jcr:6eefabf4-f562-4868-b919-f232280fd8b9/LCI+methodology+report_2017_vfinal.pdf

Wu, C.-H., Chang, C.-Y., Cheng, C.-M., & Huang, H.-C. (2003). Glycolysis of waste flexible polyurethane foam. *Polymer Degradation and Stability*, *80*(1), 103–111. https://doi.org/10.1016/S0141-3910(02)00390-7

Zink, T., Geyer, R., & Startz, R. (2018). Toward Estimating Displaced Primary Production from Recycling: A Case Study of U.S. Aluminum. *Journal of Industrial Ecology*, *22*(2), 314–326. https://doi.org/10.1111/jiec.12557

Appendix

A1 Descriptions of Impact Categories

A1.1 Headline Indicators

Global Climate Change (kg CO_2 equivalent)
Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, attributable to the release of carbon dioxide and other substances from industrial processes, including combustion of fuels. TRACI 2.1 utilizes global warming potentials (GWPs) for the calculation of the potency of greenhouse gases consistent with the guidance of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC -The United Nations Framework Convention on Climate Change 2003). The indicator uses GWPs with 100-year time horizons.

Particulate Matter formation (kg PM2.5 equivalent)
Particulate matter is a collection of small particles in ambient air which can cause negative human health effects including respiratory illness and death. Particulate matter may be emitted as particulates, or may be the product of chemical reactions in the air (secondary particulates). The most common precursors to secondary particulates are sulfur dioxide (SO2) and nitrogen oxides (NOx). The method for calculation of human health impacts includes the modeling of the fate and exposure into intake fractions (i.e., that portion of the emitted substance, which is expected to be inhaled by a human being).

Water use (cubic meters of water)
To assess water use by the product system, we will follow the methodology of the Global Water Footprint Standard (Hoekstra et al., 2011). We will estimate "blue water footprint," which reports consumptive use of surface and ground water throughout the product supply chain, including actions that result in the transfer of water between reservoirs. The blue water footprint is reported in units of physical volume of water consumed, and does not reflect water scarcity or any other spatial or geographic factors of water use. Blue water also excludes natural rainwater for irrigation ("green water") and ignores the emission of pollutants or contaminants into water ("gray water").

Photochemical Smog Formation (kg O_3 equivalent)
Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Smog creation potential is modeled using the Maximum Incremental Reactivity (MIR) method.

Primary Energy Demand (MJ net calorific value)
This indicator reports the total amount of energy extracted from the natural environment in any form that was required to bring about the modeled activities. While the environmental impacts of energy production are accounted for by using the other methods, the primary energy demand can be used to express the relative energy efficiency of different scenarios regardless of the source of energy used. Primary energy obtained from renewable sources was counted on a one-to-one basis. Energy content assigned to different fuels is reported in Table A1.1 below.

Table A1.1. Heating values used to quantify fossil fuel use. The heating values of fossil fuels are taken from (Frischknecht et al., 2015 [Table 3]); shale and bitumen are from (IPCC, 2006 [Vol.2, Chap. 1, Table 1.2]); wood and biomass are from (USEPA, 2022); peat is from (FAO, 1988). Corroborated with (Haugen et al., 2016; USEPA, 2014).

Fuel Type	**Heating Value (MJ/kg)**	
	Higher	**Lower**
Lignite	9.9	9.6
Hard Coal	19.1	18.5
Crude Oil	45.8	42.8
Natural Gas	47.9	43.5
Methane	55.0	50.0
Bitumen	40.0	38.1
Shale	9.4	9.0
Peat	10.0	9.5
Biomass (byproducts)	12.1	10.1
Biomass (wood)	18.0	15.0
	Heating Value (MJ/m3)	
Wood, standing (MJ/m3)	8000-12000	

A1.2 Supporting Indicators

Human Health, Cancer and Non-cancer (Comparative toxicity units)
Under the Life Cycle Initiative of the United Nations Environment Program (UNEP) / Society of Environmental Toxicology and Chemistry (SETAC), various international multimedia toxicity model developers created a global consensus model known as USEtox (Rosenbaum et al,

2008). The USEtox model adopted many of the best features of earlier models and was used to develop human health cancer and noncancer toxicity potentials for over 3000 substances including organic and inorganic substances. In the current report, human health cancer and non-cancer (including physical damage, cardiovascular diseases, reproductive harm, and other adverse effects) impact scores are included. These indicators are best interpreted in relative terms and used as a basis for comparison among alternatives.

Acidification (kg SO_2 equivalent)
Acidification is the increasing concentration of hydrogen ion (H+) within a local environment, as the result of the release of acids such as sulfur dioxide. Acidifying emissions are often emitted to air as byproducts of combustion, and can travel long distances before later deposition in the form of acid rain or other precipitation. Acidification can cause damage to human property and also adversely affect the health of ecosystems. Acidification as an indicator is often correlated to fossil fuel consumption, particularly coal, so it often closely tracks other indicators such as global warming potential and primary energy demand.

Stratospheric Ozone Depletion (kg CFC-11 equivalent)
High concentrations of ozone in the upper atmosphere provide an absorptive layer that protects the Earth from solar radiation. The presence of certain human-created compounds known as chlorofluorocarbons (or CFCs) can cause stratospheric ozone to be depleted into oxygen, which lacks this protective characteristic. Because CFCs persist for long periods in the upper atmosphere, small amounts of emission can have compounding effects. The problem of ozone depletion was largely addressed by the Montreal Protocol of 1987, under which these compounds were phased out in favor of less-harmful alternatives.

Eutrophication (kg N equivalent)
Many processes result in the deposition of nitrogen or phosphorus into soil or water, which can lead to an overabundance of algae and other microorganisms that deplete aqueous oxygen and have other unintended effects. Eutrophication can occur from combustion emissions or from runoff of excessive fertilizers applied to agricultural land. Because of the low prominence of agriculture in the present LCA, eutrophication is not regarded as a prominent indicator.

Fossil Fuel Use (MJ net calorific value)
Fossil fuel use is quantified in energy units (MJ). This indicator is useful to assess the degree to which a product or process depends on the use of fossil fuels, a limited and depletable resource. Representative heating values were assumed for each of the fuel classes listed in Table A1.1 in the previous section.

A2 Descriptions of recycling routes

A2.1 Routes included in baseline scenario

Steel, recycled, to Scrap market
Steel recovered from mattresses and foundations is assumed to be shipped to brokers, from which point it is sold to steelmakers. This includes steel recovered from foundations, Bonnell springs, and pocketed coils. The benefit of scrap steel recycling is estimated using the World Steel Association's value of scrap model (World Steel Association, 2021), which reflects the reduction in environmental burdens associated with the increased use of scrap steel.

Foam, recycled
Foam to recycling is modeled as a mix of multiple pathways. In the baseline scenario, 100% of the foam is used to manufacture rebond foam pad, which displaces a new (virgin) frothed polyurethane foam pad (although not on a one-to-one basis; see §Displacement rates). In this case, the mattress-derived foam is chopped, mixed with adhesive, compressed, cooked, and sliced. This mattress-derived rebond then potentially displaces the manufacture of virgin high-density frothed foam, which would be suitable as a carpet pad.

In addition to the rebond manufacturing process, additional foam use routes include chemolysis and pyrolysis.

Quilt, recycled
Quilt, as a mix of foam and fiber, is assumed to either displace post-industrial scrap foam, or to be used as an ingredient in Rebond Foam Carpet pad (as with the Foam, recycled).

Wood, recycled
Recycled wood is chipped and used to displace softwood landscaping mulch.

Shoddy, recycled; Other fiber, recycled
Fibers recovered from shoddy and other fiber are assumed to be used as an ingredient in a similar non-woven pad. We assume these recycled fibers displace a mix of materials: 10% cotton fiber, 50% scrap fiber, and 40% PET granulate (by mass).

Cardboard, recycled
Used as an ingredient for paper manufacturing, potentially displacing paper pulp.

Plastic, recycled
Recycled plastic potentially displaces virgin polypropylene granulate.

Cotton fiber, recycled

Cotton recovered for recycling is assumed to be processed into rags. Since the product of rags from virgin material would require cotton thread, we assume the recycled cotton displaces cotton thread.

Whole Mattresses and Foundations, reused
In this route, a recovered mattress or foundation is used to displace the production of a new unit. The displaced product will include a mix of innerspring and foam mattresses (and foundations) that matches the mattress size and type mix for a given scenario. Whole units are cleaned before reuse.

Foam, reused
High-quality foam recovered from mattresses may be reused as-is (not chopped and rebonded) in bedding, furniture, or other applications. This potentially displaces the production of virgin (prime) PU foam. Foam is cleaned before reuse.

Wood, reused
Whole wood boards that are recovered from deconstruction are assumed to displace the equivalent weight in new sawn lumber.

Steel component (i.e. spring assembly), reused
A complete innerspring set extracted from a recovered mattress can be re-used inside of a new mattress, displacing the production of an equivalent amount of steel wire. No refurbishing impacts are assigned.

Quilt, reused
If quilt is reused as-is, it would displace a mix of foam production and woven synthetic fabric production. Quilt is cleaned before reuse.

Cotton, reused
If cotton is reused as-is, it would displace production of new cotton fabric. Cotton is cleaned before reuse.

Other fabric, reused
Reused fabric could displace new polyester fabric production. Fabric is cleaned before reuse.

Shoddy pad, reused
Shoddy pad is made mostly with recycled fibers. Thus, reuse of shoddy is assumed to displace the fabrication (not including raw material) of a non-woven synthetic pad. Shoddy is cleaned before reuse.

Wood, to energy
Recycled wood is burned for energy recovery, potentially displacing combustion of natural gas. Because wood contains only biogenic carbon, the CO2 emissions from wood combustion are excluded from GWP.

Waste, to energy
Waste (residuals) from recycling is burned for energy recovery, potentially displacing natural gas. The mix of material in the waste stream determines the biogenic C fraction of the fuel.

A2.2 Routes in Additional Scenarios

Foam glycolysis
In this scenario, recycled foam undergoes chemical recycling to produce polyols, which displace virgin polyol production.

Foam Acidolysis
In this scenario, recycled foam undergoes chemical recycling to produce polyols, which displace virgin polyol production.

Pyrolysis
Pyrolysis is included for Foam and for Whole units. The pyrolysis gas is used in the process, and pyrolysis oil and char are the mattress-derived products, which may displace crude oil and black carbon, respectively.

Foam and Quilt Scrap
The Scrap route represents the displacement of a 50/50 mix of intercontinental transport and regional transport of scrap foam. Post-industrial scrap does not carry any impacts from manufacture. However, since scrap material markets are global, we assume that a locally generated and used material that enters a scrap market would displace some transport of scrap material. Intercontinental freight assumes 600 km of truck transport plus 10,500 km in a large ocean freighter. Regional freight assumes 1000 km of truck freight.

A3 Data: Biogenic CO2

Table A3.1. Estimated emissions associated with the mattress recycling system in California, during the year 2021. The leftmost numerical column, "GHG" , includes all greenhouse gases, except biogenic CO_2. The "bio CO2" column is only biogenic CO_2. The rightmost column, "all GHG" is the sum of the two. Units are thousands of tonnes per year.

Scenario	Incurred/ Displaced	GHG (excl. bio CO2) [ktonne CO2eq]	bio CO2 [ktonne CO2]	all GHG [ktonne CO2eq]
Baseline (CA 2021)	Incurred	9.6	3.7	13.3
Baseline (CA 2021)	Displaced	-37.2	-0.1	-37.3
Baseline (CA 2021)	Net	-27.6	3.7	-23.9

Table A3.2. Estimated emissions associated with different mattress recycling scenarios. The estimates represent the management of one tonne of mixed EOL mattresses. The mix of mattresses in the Incineration scenario is the same as Baseline. The Baseline scenario is based on the situation in California, 2021; other scenarios represent alternative management systems, including emerging practices and technologies. See §Scenarios and Scales for details on the scenarios. Units are kg of CO_2 equivalent.

Scenario	Incurred/ Displaced	GHG (excl. bio CO2) [kg CO2eq]	bio CO2 [kg CO2]	all GHG [kg CO2eq]
Baseline	Incurred	235.6	91.6	327.2
Baseline	Displaced	-914.5	-1.8	-916.3
Baseline	Net	-678.9	89.8	-589.1
Baseline, scrap foam	Incurred	166	90.1	256.1
Baseline, scrap foam	Displaced	-748.6	1.9	-746.7
Baseline, scrap foam	Net	-582.6	92	-490.6
Baseline w/ Compaction	Incurred	214.9	91.5	306.4
Baseline w/ Compaction	Displaced	-914.5	-1.8	-916.3
Baseline w/ Compaction	Net	-699.6	89.7	-609.9
Baseline w/ Chem. Recycle	Incurred	928	109	1037
Baseline w/ Chem. Recycle	Displaced	-1631	-19.6	-1650.6
Baseline w/ Chem. Recycle	Net	-703	89.4	-613.6
Incineration	Incurred	1203.2	270.9	1474.1
Incineration	Displaced	-918.2	6.9	-911.3
Incineration	Net	285	277.8	562.8
Modeled Mix	Incurred	267.1	81.3	348.4

Modeled Mix	Displaced	-970.4	-4.8	-975.2
Modeled Mix	Net	-703.3	76.5	-626.8
Pocket Coil	Incurred	294.7	12.8	307.5
Pocket Coil	Displaced	-1156	0	-1156
Pocket Coil	Net	-861.3	12.8	-848.5
Tied Spring	Incurred	222.9	11.1	234
Tied Spring	Displaced	-1051.1	3.6	-1047.5
Tied Spring	Net	-828.2	14.7	-813.5
All Foam	Incurred	553.8	19.1	572.9
All Foam	Displaced	-1283.6	-27.2	-1310.8
All Foam	Net	-729.8	-8.1	-737.9
All Wood Foundation	Incurred	146.2	520.1	666.3
All Wood Foundation	Displaced	-276.3	-51.5	-327.8
All Wood Foundation	Net	-130.1	468.6	338.5
Foundation (not all wood)	Incurred	156.6	257.1	413.7
Foundation (not all wood)	Displaced	-751.9	3.6	-748.3
Foundation (not all wood)	Net	-595.3	260.7	-334.6
Pyrolysis, whole unit	Incurred	637.9	3.5	641.4
Pyrolysis, whole unit	Displaced	-787.5	5.8	-781.7
Pyrolysis, whole unit	Net	-149.5	9.3	-140.2

A4 Tabular Data: Incurred, Displaced, and Net total

Data for Figure ES.1. and Figure 4.1: Overall results of the LCA study. Impacts of recycling and managing 1.6 million mattress recycling in CA (yr2021).

Scenario	Impact Type	Incurred, Displaced	result	result_lo	result_hi
Baseline (CA 2021)	GHG (kt CO2eq)	Incurred	9.6	9.6	9.6
Baseline (CA 2021)	GHG (kt CO2eq)	Displaced	-37.2	-50.0	-27.3
Baseline (CA 2021)	GHG (kt CO2eq)	Net	-27.6	-40.4	-17.7
Baseline (CA 2021)	Water (k m3; Blue)	Incurred	92.2	92.2	92.2
Baseline (CA 2021)	Water (k m3; Blue)	Displaced	-3,167.1	-4,038.7	-2,367.3
Baseline (CA 2021)	Water (k m3; Blue)	Net	-3,074.8	-3,946.4	-2,275.1
Baseline (CA 2021)	Energy (TJ)	Incurred	159.3	159.3	159.3
Baseline (CA 2021)	Energy (TJ)	Displaced	-638.7	-889.3	-448.0
Baseline (CA 2021)	Energy (TJ)	Net	-479.4	-730.0	-288.7
Baseline (CA 2021)	Smog (t O3 eq)	Incurred	662.1	662.1	662.1
Baseline (CA 2021)	Smog (t O3 eq)	Displaced	-1,477.6	-2,142.6	-975.5
Baseline (CA 2021)	Smog (t O3 eq)	Net	-815.5	-1,480.5	-313.4
Baseline (CA 2021)	PM2.5eq (t)	Incurred	6.6	6.6	6.6
Baseline (CA 2021)	PM2.5eq (t)	Displaced	-9.7	-16.1	-5.1
Baseline (CA 2021)	PM2.5eq (t)	Net	-3.1	-9.5	1.6
Baseline (CA 2021)	Health, Cancer (Tox. Units)	Incurred	1.1	1.1	1.1
Baseline (CA 2021)	Health, Cancer (Tox. Units)	Displaced	-1.3	-2.0	-0.7
Baseline (CA 2021)	Health, Cancer (Tox. Units)	Net	-0.1	-0.9	0.4
Baseline (CA 2021)	Health, NonCancer (Tox. Units)	Incurred	2.7	2.7	2.7
Baseline (CA 2021)	Health, NonCancer (Tox. Units)	Displaced	-0.1	-0.7	0.3
Baseline (CA 2021)	Health, NonCancer (Tox. Units)	Net	2.6	2.0	3.0
Baseline (CA 2021)	Ozone depl. (kg CFC-11 eq)	Incurred	1.5	1.5	1.5
Baseline (CA 2021)	Ozone depl. (kg CFC-11 eq)	Displaced	-2.4	-3.2	-1.7
Baseline (CA 2021)	Ozone depl. (kg CFC-11 eq)	Net	-0.9	-1.7	-0.1
Baseline (CA 2021)	Eutroph. (t N eq)	Incurred	6.7	6.7	6.7
Baseline (CA 2021)	Eutroph. (t N eq)	Displaced	-4.7	-6.5	-3.3

Baseline (CA 2021)	Eutroph. (t N eq)	Net	2.0	0.2	3.4
Baseline (CA 2021)	Acidification (t SO2 eq)	Incurred	35.3	35.3	35.3
Baseline (CA 2021)	Acidification (t SO2 eq)	Displaced	-94.6	-146.3	-55.7
Baseline (CA 2021)	Acidification (t SO2 eq)	Net	-59.4	-111.0	-20.5
Baseline (CA 2021)	Energy, Fossil (TJ)	Incurred	142.9	142.9	142.9
Baseline (CA 2021)	Energy, Fossil (TJ)	Displaced	-494.5	-703.9	-337.8
Baseline (CA 2021)	Energy, Fossil (TJ)	Net	-351.6	-561.0	-194.9

Data for Figure 2.1: Sankey chart overview of material through the primary recycling system

mfaType	flowType	type	ktonne
collections	mixed units	Collection Site	26.61
collections	mixed units	Commercial Sources	9.36
collections	mixed units	Dropoff, Incentive	2.97
collections	mixed units	Non-program Unit Recycling	0.72
collections	mixed units	Collection Events	0.4
collections	mixed units	Dropoff, No incentive	0.39
collections	mixed units	Illegal Dumping	0.24
outputs	Steel	recycle	15.13
outputs	Waste to Landfill	dispose	9.26
outputs	Foam	recycle	4.77
outputs	Quilt	recycle	3.79
outputs	Wood	recycle	3.51
outputs	Wood	energy	1.59
outputs	Whole unit (reused)	reuse	0.78
outputs	Foam (reused)	reuse	0.4
outputs	Cotton	recycle	0.39
outputs	Shoddy	recycle	0.22
outputs	Wood (reused)	reuse	0.2
outputs	Other fiber	recycle	0.17
outputs	Waste-to-Energy	energy	0.06
outputs	Cardboard	recycle	0.05

outputs	Steel (reused)	reuse	0.04
outputs	Plastic	recycle	0.01
outputs	Other fiber (reused)	reuse	0
outputs	Shoddy (reused)	reuse	0
outputs	Quilt (reused)	reuse	0
outputs	Cotton (reused)	reuse	0
transfer	pocket coil	NA	1.94
transfer	foam	NA	1.08
transfer	quilt	NA	0.78
transfer	other	NA	0.05

Data for Figure 4.5: Impacts of primary recycling facilities (one tonne of mattress processed)

Impact Type	diesel	electricity	equip	gasoline	ppe	propane	supplies	water	total
GHG (kg CO2eq)	5.0	9.2	4.6	0.6	0.4	5.0	3.5	0.2	28.5
PM2.5 eq (kg)	7.1E-04	1.8E-03	6.0E-03	8.0E-05	3.3E-04	1.5E-04	4.3E-03	2.8E-04	1.4E-02
Water (m3; Blue)	0.00	0.19	0.03	0.00	0.01	0.00	0.03	0.56	0.82
Energy (MJ)	77.6	302.5	72.8	9.7	10.1	74.8	51.0	3.2	601.7
Smog (kg O3 eq)	2.16	0.29	0.26	0.21	0.02	0.27	0.20	0.01	3.41
Health, Cancer (Tox. Units)	4.5E-10	3.5E-07	4.8E-06	5.7E-11	3.6E-08	3.9E-10	6.1E-06	2.5E-08	1.1E-05
Health, NonCancer (Tox. Units)	4.8E-08	6.9E-07	8.4E-07	6.0E-09	3.2E-08	4.7E-08	9.1E-07	1.6E-08	2.6E-06
Acidification (kg SO2 eq)	0.06	0.02	0.02	0.01	0.00	0.01	0.02	0.00	0.14
Ozone depl. (kg CFC-11 eq)	3.3E-08	1.2E-06	2.8E-07	4.1E-09	9.3E-07	3.2E-08	2.3E-07	1.3E-08	2.7E-06
Eutroph. (kg N eq)	3.9E-03	8.4E-04	5.4E-04	3.7E-04	1.2E-04	5.3E-04	4.7E-04	1.9E-05	6.8E-03

Energy, Fossil (MJ)	76.8	151.5	63.2	9.6	9.1	74.0	45.5	2.5	432.3

Data for Figure 4.2: Impacts of recycling one tonne of mattresses; six system scenarios

Scenario	**Impact Type**	**Incurred, Displaced**	**result**	**result_lo**	**result_hi**
Baseline	GHG (t CO2eq)	Incurred	0.236	0.236	0.236
Baseline	GHG (t CO2eq)	Displaced	-0.915	-1.229	-0.672
Baseline	GHG (t CO2eq)	Net	-0.679	-0.993	-0.436
Baseline	Water (m3; Blue)	Incurred	2.266	2.266	2.266
Baseline	Water (m3; Blue)	Displaced	-77.820	-99.237	-58.168
Baseline	Water (m3; Blue)	Net	-75.554	-96.971	-55.902
Baseline	Energy (GJ)	Incurred	3.914	3.914	3.914
Baseline	Energy (GJ)	Displaced	-15.695	-21.851	-11.009
Baseline	Energy (GJ)	Net	-11.781	-17.937	-7.095
Baseline	Smog (kg O3 eq)	Incurred	16.270	16.270	16.270
Baseline	Smog (kg O3 eq)	Displaced	-36.307	-52.648	-23.970
Baseline	Smog (kg O3 eq)	Net	-20.037	-36.378	-7.700
Baseline	PM2.5 eq (kg)	Incurred	0.163	0.163	0.163
Baseline	PM2.5 eq (kg)	Displaced	-0.239	-0.395	-0.125
Baseline	PM2.5 eq (kg)	Net	-0.076	-0.232	0.038
Baseline	Health, Cancer (Tox. Units)	Incurred	2.83E-05	2.83E-05	2.83E-05
Baseline	Health, Cancer (Tox. Units)	Displaced	-3.14E-05	-4.92E-05	-1.75E-05
Baseline	Health, Cancer (Tox. Units)	Net	-3.14E-06	-2.10E-05	1.08E-05
Baseline	Health, NonCancer (Tox. Units)	Incurred	6.63E-05	6.63E-05	6.63E-05
Baseline	Health, NonCancer (Tox. Units)	Displaced	-2.78E-06	-1.69E-05	7.80E-06
Baseline	Health, NonCancer (Tox. Units)	Net	6.35E-05	4.94E-05	7.41E-05
Baseline	Ozone depl. (g CFC-11 eq)	Incurred	0.038	0.038	0.038

Baseline	Ozone depl. (g CFC-11 eq)	Displaced	-0.060	-0.080	-0.041
Baseline	Ozone depl. (g CFC-11 eq)	Net	-0.022	-0.042	-0.003
Baseline	Eutroph. (kg N eq)	Incurred	0.164	0.164	0.164
Baseline	Eutroph. (kg N eq)	Displaced	-0.116	-0.160	-0.081
Baseline	Eutroph. (kg N eq)	Net	0.048	0.005	0.083
Baseline	Acidification (kg SO2 eq)	Incurred	0.867	0.867	0.867
Baseline	Acidification (kg SO2 eq)	Displaced	-2.325	-3.595	-1.369
Baseline	Acidification (kg SO2 eq)	Net	-1.459	-2.729	-0.503
Baseline	Energy, Fossil (GJ)	Incurred	3.512	3.512	3.512
Baseline	Energy, Fossil (GJ)	Displaced	-12.150	-17.297	-8.300
Baseline	Energy, Fossil (GJ)	Net	-8.639	-13.785	-4.789
Baseline, scrap foam	GHG (t CO2eq)	Incurred	0.166	0.166	0.166
Baseline, scrap foam	GHG (t CO2eq)	Displaced	-0.749	-0.886	-0.623
Baseline, scrap foam	GHG (t CO2eq)	Net	-0.583	-0.720	-0.457
Baseline, scrap foam	Water (m3; Blue)	Incurred	1.321	1.321	1.321
Baseline, scrap foam	Water (m3; Blue)	Displaced	-73.418	-90.417	-56.710
Baseline, scrap foam	Water (m3; Blue)	Net	-72.096	-89.096	-55.389
Baseline, scrap foam	Energy (GJ)	Incurred	2.525	2.525	2.525
Baseline, scrap foam	Energy (GJ)	Displaced	-12.224	-14.724	-9.967
Baseline, scrap foam	Energy (GJ)	Net	-9.699	-12.199	-7.442
Baseline, scrap foam	Smog (kg O3 eq)	Incurred	11.484	11.484	11.484
Baseline, scrap foam	Smog (kg O3 eq)	Displaced	-29.283	-35.935	-23.293
Baseline, scrap foam	Smog (kg O3 eq)	Net	-17.799	-24.451	-11.809
Baseline, scrap foam	PM2.5 eq (kg)	Incurred	0.104	0.104	0.104
Baseline, scrap foam	PM2.5 eq (kg)	Displaced	-0.147	-0.200	-0.101
Baseline, scrap foam	PM2.5 eq (kg)	Net	-0.043	-0.096	0.003
Baseline, scrap foam	Health, Cancer (Tox. Units)	Incurred	2.07E-05	2.07E-05	2.07E-05
Baseline, scrap foam	Health, Cancer (Tox. Units)	Displaced	-2.23E-05	-3.05E-05	-1.48E-05
Baseline, scrap foam	Health, Cancer (Tox. Units)	Net	-1.62E-06	-9.77E-06	5.90E-06

Baseline, scrap foam	Health, NonCancer (Tox. Units)	Incurred	5.65E-05	5.65E-05	5.65E-05
Baseline, scrap foam	Health, NonCancer (Tox. Units)	Displaced	4.64E-06	-8.17E-07	9.52E-06
Baseline, scrap foam	Health, NonCancer (Tox. Units)	Net	6.11E-05	5.57E-05	6.60E-05
Baseline, scrap foam	Ozone depl. (g CFC-11 eq)	Incurred	0.025	0.025	0.025
Baseline, scrap foam	Ozone depl. (g CFC-11 eq)	Displaced	-0.061	-0.078	-0.043
Baseline, scrap foam	Ozone depl. (g CFC-11 eq)	Net	-0.035	-0.053	-0.018
Baseline, scrap foam	Eutroph. (kg N eq)	Incurred	0.048	0.048	0.048
Baseline, scrap foam	Eutroph. (kg N eq)	Displaced	-0.103	-0.127	-0.080
Baseline, scrap foam	Eutroph. (kg N eq)	Net	-0.055	-0.079	-0.032
Baseline, scrap foam	Acidification (kg SO2 eq)	Incurred	0.551	0.551	0.551
Baseline, scrap foam	Acidification (kg SO2 eq)	Displaced	-1.704	-2.207	-1.254
Baseline, scrap foam	Acidification (kg SO2 eq)	Net	-1.153	-1.656	-0.703
Baseline, scrap foam	Energy, Fossil (GJ)	Incurred	2.255	2.255	2.255
Baseline, scrap foam	Energy, Fossil (GJ)	Displaced	-9.109	-11.032	-7.400
Baseline, scrap foam	Energy, Fossil (GJ)	Net	-6.854	-8.777	-5.145
Baseline w/ Compaction	GHG (t CO2eq)	Incurred	0.215	0.215	0.215
Baseline w/ Compaction	GHG (t CO2eq)	Displaced	-0.915	-1.229	-0.672
Baseline w/ Compaction	GHG (t CO2eq)	Net	-0.700	-1.014	-0.457
Baseline w/ Compaction	Water (m3; Blue)	Incurred	2.231	2.231	2.231
Baseline w/ Compaction	Water (m3; Blue)	Displaced	-77.820	-99.237	-58.168
Baseline w/ Compaction	Water (m3; Blue)	Net	-75.590	-97.007	-55.938
Baseline w/ Compaction	Energy (GJ)	Incurred	3.546	3.546	3.546
Baseline w/ Compaction	Energy (GJ)	Displaced	-15.695	-21.851	-11.009
Baseline w/ Compaction	Energy (GJ)	Net	-12.149	-18.305	-7.463
Baseline w/ Compaction	Smog (kg O3 eq)	Incurred	15.363	15.363	15.363
Baseline w/ Compaction	Smog (kg O3 eq)	Displaced	-36.307	-52.648	-23.970
Baseline w/ Compaction	Smog (kg O3 eq)	Net	-20.944	-37.285	-8.606
Baseline w/ Compaction	PM2.5 eq (kg)	Incurred	0.152	0.152	0.152

Baseline w/ Compaction	PM2.5 eq (kg)	Displaced	-0.239	-0.395	-0.125
Baseline w/ Compaction	PM2.5 eq (kg)	Net	-0.088	-0.244	0.027
Baseline w/ Compaction	Health, Cancer (Tox. Units)	Incurred	2.72E-05	2.72E-05	2.72E-05
Baseline w/ Compaction	Health, Cancer (Tox. Units)	Displaced	-3.14E-05	-4.92E-05	-1.75E-05
Baseline w/ Compaction	Health, Cancer (Tox. Units)	Net	-4.22E-06	-2.20E-05	9.71E-06
Baseline w/ Compaction	Health, NonCancer (Tox. Units)	Incurred	6.31E-05	6.31E-05	6.31E-05
Baseline w/ Compaction	Health, NonCancer (Tox. Units)	Displaced	-2.78E-06	-1.69E-05	7.80E-06
Baseline w/ Compaction	Health, NonCancer (Tox. Units)	Net	6.03E-05	4.62E-05	7.09E-05
Baseline w/ Compaction	Ozone depl. (g CFC-11 eq)	Incurred	0.033	0.033	0.033
Baseline w/ Compaction	Ozone depl. (g CFC-11 eq)	Displaced	-0.060	-0.080	-0.041
Baseline w/ Compaction	Ozone depl. (g CFC-11 eq)	Net	-0.027	-0.047	-0.009
Baseline w/ Compaction	Eutroph. (kg N eq)	Incurred	0.162	0.162	0.162
Baseline w/ Compaction	Eutroph. (kg N eq)	Displaced	-0.116	-0.160	-0.081
Baseline w/ Compaction	Eutroph. (kg N eq)	Net	0.045	0.002	0.081
Baseline w/ Compaction	Acidification (kg SO2 eq)	Incurred	0.810	0.810	0.810
Baseline w/ Compaction	Acidification (kg SO2 eq)	Displaced	-2.325	-3.595	-1.369
Baseline w/ Compaction	Acidification (kg SO2 eq)	Net	-1.515	-2.785	-0.559
Baseline w/ Compaction	Energy, Fossil (GJ)	Incurred	3.151	3.151	3.151
Baseline w/ Compaction	Energy, Fossil (GJ)	Displaced	-12.150	-17.297	-8.300
Baseline w/ Compaction	Energy, Fossil (GJ)	Net	-9.000	-14.147	-5.150
Baseline w/ Chem. Recycle	GHG (t CO2eq)	Incurred	0.928	0.857	1.012
Baseline w/ Chem. Recycle	GHG (t CO2eq)	Displaced	-1.631	-1.866	-1.408
Baseline w/ Chem. Recycle	GHG (t CO2eq)	Net	-0.703	-1.010	-0.395
Baseline w/ Chem. Recycle	Water (m3; Blue)	Incurred	18.227	16.473	19.859
Baseline w/ Chem. Recycle	Water (m3; Blue)	Displaced	-103.293	-123.612	-83.266
Baseline w/ Chem. Recycle	Water (m3; Blue)	Net	-85.066	-107.139	-63.407
Baseline w/ Chem. Recycle	Energy (GJ)	Incurred	17.117	15.657	18.598

Baseline w/ Chem. Recycle	Energy (GJ)	Displaced	-33.559	-38.430	-28.932
Baseline w/ Chem. Recycle	Energy (GJ)	Net	-16.442	-22.773	-10.334
Baseline w/ Chem. Recycle	Smog (kg O3 eq)	Incurred	41.845	38.820	44.943
Baseline w/ Chem. Recycle	Smog (kg O3 eq)	Displaced	-77.096	-89.061	-65.793
Baseline w/ Chem. Recycle	Smog (kg O3 eq)	Net	-35.251	-50.242	-20.851
Baseline w/ Chem. Recycle	PM2.5 eq (kg)	Incurred	0.503	0.464	0.544
Baseline w/ Chem. Recycle	PM2.5 eq (kg)	Displaced	-0.744	-0.863	-0.632
Baseline w/ Chem. Recycle	PM2.5 eq (kg)	Net	-0.241	-0.400	-0.088
Baseline w/ Chem. Recycle	Health, Cancer (Tox. Units)	Incurred	5.88E-05	5.52E-05	6.24E-05
Baseline w/ Chem. Recycle	Health, Cancer (Tox. Units)	Displaced	-7.82E-05	-9.26E-05	-6.45E-05
Baseline w/ Chem. Recycle	Health, Cancer (Tox. Units)	Net	-1.94E-05	-3.74E-05	-2.05E-06
Baseline w/ Chem. Recycle	Health, NonCancer (Tox. Units)	Incurred	8.98E-05	8.65E-05	9.32E-05
Baseline w/ Chem. Recycle	Health, NonCancer (Tox. Units)	Displaced	-4.32E-05	-5.40E-05	-3.30E-05
Baseline w/ Chem. Recycle	Health, NonCancer (Tox. Units)	Net	4.65E-05	3.25E-05	6.02E-05
Baseline w/ Chem. Recycle	Ozone depl. (g CFC-11 eq)	Incurred	0.045	0.043	0.047
Baseline w/ Chem. Recycle	Ozone depl. (g CFC-11 eq)	Displaced	-0.067	-0.085	-0.049
Baseline w/ Chem. Recycle	Ozone depl. (g CFC-11 eq)	Net	-0.022	-0.042	-0.001
Baseline w/ Chem. Recycle	Eutroph. (kg N eq)	Incurred	0.176	0.163	0.190
Baseline w/ Chem. Recycle	Eutroph. (kg N eq)	Displaced	-0.192	-0.226	-0.160
Baseline w/ Chem. Recycle	Eutroph. (kg N eq)	Net	-0.016	-0.063	0.030
Baseline w/ Chem. Recycle	Acidification (kg SO2 eq)	Incurred	2.934	2.699	3.181
Baseline w/ Chem. Recycle	Acidification (kg SO2 eq)	Displaced	-5.214	-6.107	-4.374
Baseline w/ Chem. Recycle	Acidification (kg SO2 eq)	Net	-2.280	-3.408	-1.193
Baseline w/ Chem. Recycle	Energy, Fossil (GJ)	Incurred	15.293	13.987	16.621
Baseline w/ Chem. Recycle	Energy, Fossil (GJ)	Displaced	-27.947	-31.964	-24.146
Baseline w/ Chem. Recycle	Energy, Fossil (GJ)	Net	-12.654	-17.977	-7.525
Incineration	GHG (t CO2eq)	Incurred	1.203	1.203	1.203

Incineration	GHG (t CO2eq)	Displaced	-0.918	-1.020	-0.816
Incineration	GHG (t CO2eq)	Net	0.285	0.183	0.387
Incineration	Water (m3; Blue)	Incurred	2.581	2.581	2.581
Incineration	Water (m3; Blue)	Displaced	-38.075	-42.306	-33.845
Incineration	Water (m3; Blue)	Net	-35.494	-39.725	-31.264
Incineration	Energy (GJ)	Incurred	2.157	2.157	2.157
Incineration	Energy (GJ)	Displaced	-11.547	-12.829	-10.264
Incineration	Energy (GJ)	Net	-9.390	-10.673	-8.107
Incineration	Smog (kg O3 eq)	Incurred	28.605	28.605	28.605
Incineration	Smog (kg O3 eq)	Displaced	-20.543	-22.826	-18.261
Incineration	Smog (kg O3 eq)	Net	8.062	5.779	10.344
Incineration	PM2.5 eq (kg)	Incurred	0.065	0.065	0.065
Incineration	PM2.5 eq (kg)	Displaced	-0.047	-0.052	-0.042
Incineration	PM2.5 eq (kg)	Net	0.018	0.013	0.023
Incineration	Health, Cancer (Tox. Units)	Incurred	3.71E-05	3.71E-05	3.71E-05
Incineration	Health, Cancer (Tox. Units)	Displaced	-3.61E-06	-4.01E-06	-3.21E-06
Incineration	Health, Cancer (Tox. Units)	Net	3.35E-05	3.31E-05	3.39E-05
Incineration	Health, NonCancer (Tox. Units)	Incurred	5.03E-05	5.03E-05	5.03E-05
Incineration	Health, NonCancer (Tox. Units)	Displaced	2.95E-05	3.28E-05	2.62E-05
Incineration	Health, NonCancer (Tox. Units)	Net	7.98E-05	8.30E-05	7.65E-05
Incineration	Ozone depl. (g CFC-11 eq)	Incurred	0.022	0.022	0.022
Incineration	Ozone depl. (g CFC-11 eq)	Displaced	-0.054	-0.060	-0.048
Incineration	Ozone depl. (g CFC-11 eq)	Net	-0.032	-0.038	-0.026
Incineration	Eutroph. (kg N eq)	Incurred	0.055	0.055	0.055
Incineration	Eutroph. (kg N eq)	Displaced	-0.068	-0.075	-0.060
Incineration	Eutroph. (kg N eq)	Net	-0.012	-0.020	-0.005
Incineration	Acidification (kg SO2 eq)	Incurred	0.994	0.994	0.994

Incineration	Acidification (kg SO2 eq)	Displaced	-0.866	-0.963	-0.770
Incineration	Acidification (kg SO2 eq)	Net	0.127	0.031	0.223
Incineration	Energy, Fossil (GJ)	Incurred	1.977	1.977	1.977
Incineration	Energy, Fossil (GJ)	Displaced	-12.072	-13.413	-10.730
Incineration	Energy, Fossil (GJ)	Net	-10.094	-11.436	-8.753
Pyrolysis, whole unit	GHG (t CO2eq)	Incurred	0.638	0.638	0.638
Pyrolysis, whole unit	GHG (t CO2eq)	Displaced	-0.787	-0.875	-0.700
Pyrolysis, whole unit	GHG (t CO2eq)	Net	-0.150	-0.237	-0.062
Pyrolysis, whole unit	Water (m3; Blue)	Incurred	1.061	1.061	1.061
Pyrolysis, whole unit	Water (m3; Blue)	Displaced	-38.959	-43.287	-34.630
Pyrolysis, whole unit	Water (m3; Blue)	Net	-37.898	-42.226	-33.569
Pyrolysis, whole unit	Energy (GJ)	Incurred	5.193	5.193	5.193
Pyrolysis, whole unit	Energy (GJ)	Displaced	-22.506	-25.006	-20.005
Pyrolysis, whole unit	Energy (GJ)	Net	-17.312	-19.813	-14.812
Pyrolysis, whole unit	Smog (kg O3 eq)	Incurred	13.107	13.107	13.107
Pyrolysis, whole unit	Smog (kg O3 eq)	Displaced	-30.851	-34.279	-27.423
Pyrolysis, whole unit	Smog (kg O3 eq)	Net	-17.744	-21.172	-14.316
Pyrolysis, whole unit	PM2.5 eq (kg)	Incurred	0.109	0.109	0.109
Pyrolysis, whole unit	PM2.5 eq (kg)	Displaced	-0.210	-0.233	-0.187
Pyrolysis, whole unit	PM2.5 eq (kg)	Net	-0.101	-0.124	-0.078
Pyrolysis, whole unit	Health, Cancer (Tox. Units)	Incurred	0.000	0.000	0.000
Pyrolysis, whole unit	Health, Cancer (Tox. Units)	Displaced	0.000	0.000	0.000
Pyrolysis, whole unit	Health, Cancer (Tox. Units)	Net	0.000	0.000	0.000
Pyrolysis, whole unit	Health, NonCancer (Tox. Units)	Incurred	0.000	0.000	0.000
Pyrolysis, whole unit	Health, NonCancer (Tox. Units)	Displaced	0.000	0.000	0.000
Pyrolysis, whole unit	Health, NonCancer (Tox. Units)	Net	0.000	0.000	0.000
Pyrolysis, whole unit	Ozone depl. (g CFC-11 eq)	Incurred	0.041	0.041	0.041

Pyrolysis, whole unit	Ozone depl. (g CFC-11 eq)	Displaced	-0.275	-0.306	-0.245
Pyrolysis, whole unit	Ozone depl. (g CFC-11 eq)	Net	-0.234	-0.264	-0.203
Pyrolysis, whole unit	Eutroph. (kg N eq)	Incurred	0.031	0.031	0.031
Pyrolysis, whole unit	Eutroph. (kg N eq)	Displaced	-0.115	-0.128	-0.102
Pyrolysis, whole unit	Eutroph. (kg N eq)	Net	-0.084	-0.097	-0.071
Pyrolysis, whole unit	Acidification (kg SO2 eq)	Incurred	0.786	0.786	0.786
Pyrolysis, whole unit	Acidification (kg SO2 eq)	Displaced	-1.945	-2.161	-1.729
Pyrolysis, whole unit	Acidification (kg SO2 eq)	Net	-1.159	-1.375	-0.943
Pyrolysis, whole unit	Energy, Fossil (GJ)	Incurred	4.983	4.983	4.983
Pyrolysis, whole unit	Energy, Fossil (GJ)	Displaced	-22.990	-25.545	-20.436
Pyrolysis, whole unit	Energy, Fossil (GJ)	Net	-18.008	-20.562	-15.453

Data for Figure 4.3: Impacts of recycling one tonne of mattresses; five types of mattresses, and one mix of types

Scenario	Impact Type	Incurred, Displaced	result	result_lo	result_hi
Modeled Mix	GHG (t CO2eq)	Incurred	0.27	0.27	0.27
Modeled Mix	GHG (t CO2eq)	Displaced	-0.97	-1.35	-0.69
Modeled Mix	GHG (t CO2eq)	Net	-0.70	-1.08	-0.42
Modeled Mix	Water (m3; Blue)	Incurred	2.67	2.67	2.67
Modeled Mix	Water (m3; Blue)	Displaced	-48.80	-61.39	-38.51
Modeled Mix	Water (m3; Blue)	Net	-46.13	-58.72	-35.85
Modeled Mix	Energy (GJ)	Incurred	4.55	4.55	4.55
Modeled Mix	Energy (GJ)	Displaced	-16.46	-23.84	-11.00
Modeled Mix	Energy (GJ)	Net	-11.90	-19.28	-6.44
Modeled Mix	Smog (kg O3 eq)	Incurred	18.34	18.34	18.34
Modeled Mix	Smog (kg O3 eq)	Displaced	-37.25	-56.44	-23.31
Modeled Mix	Smog (kg O3 eq)	Net	-18.91	-38.09	-4.96
Modeled Mix	PM2.5 eq (kg)	Incurred	0.19	0.19	0.19
Modeled Mix	PM2.5 eq (kg)	Displaced	-0.25	-0.43	-0.12

Modeled Mix	PM2.5 eq (kg)	Net	-0.06	-0.25	0.07
Modeled Mix	Health, Cancer (Tox. Units)	Incurred	3.5E-05	3.5E-05	3.5E-05
Modeled Mix	Health, Cancer (Tox. Units)	Displaced	-3.4E-05	-5.5E-05	-1.8E-05
Modeled Mix	Health, Cancer (Tox. Units)	Net	1.2E-06	-2.0E-05	1.7E-05
Modeled Mix	Health, NonCancer (Tox. Units)	Incurred	6.8E-05	6.8E-05	6.8E-05
Modeled Mix	Health, NonCancer (Tox. Units)	Displaced	8.5E-06	-4.3E-06	1.7E-05
Modeled Mix	Health, NonCancer (Tox. Units)	Net	7.6E-05	6.4E-05	8.5E-05
Modeled Mix	Ozone depl. (g CFC-11 eq)	Incurred	0.04	0.04	0.04
Modeled Mix	Ozone depl. (g CFC-11 eq)	Displaced	-0.05	-0.07	-0.04
Modeled Mix	Ozone depl. (g CFC-11 eq)	Net	-0.01	-0.03	0.01
Modeled Mix	Eutroph. (kg N eq)	Incurred	0.21	0.21	0.21
Modeled Mix	Eutroph. (kg N eq)	Displaced	-0.10	-0.14	-0.07
Modeled Mix	Eutroph. (kg N eq)	Net	0.11	0.07	0.14
Modeled Mix	Acidification (kg SO2 eq)	Incurred	1.00	1.00	1.00
Modeled Mix	Acidification (kg SO2 eq)	Displaced	-2.19	-3.62	-1.18
Modeled Mix	Acidification (kg SO2 eq)	Net	-1.19	-2.61	-0.18
Modeled Mix	Energy, Fossil (GJ)	Incurred	4.07	4.07	4.07
Modeled Mix	Energy, Fossil (GJ)	Displaced	-13.36	-19.70	-8.72
Modeled Mix	Energy, Fossil (GJ)	Net	-9.29	-15.63	-4.64
Pocket Coil	GHG (t CO2eq)	Incurred	0.29	0.29	0.29
Pocket Coil	GHG (t CO2eq)	Displaced	-1.16	-1.60	-0.82
Pocket Coil	GHG (t CO2eq)	Net	-0.86	-1.31	-0.53
Pocket Coil	Water (m3; Blue)	Incurred	2.87	2.87	2.87
Pocket Coil	Water (m3; Blue)	Displaced	-59.97	-74.89	-47.79
Pocket Coil	Water (m3; Blue)	Net	-57.10	-72.01	-44.92
Pocket Coil	Energy (GJ)	Incurred	5.19	5.19	5.19
Pocket Coil	Energy (GJ)	Displaced	-15.96	-24.24	-9.97
Pocket Coil	Energy (GJ)	Net	-10.77	-19.05	-4.78
Pocket Coil	Smog (kg O3 eq)	Incurred	18.84	18.84	18.84
Pocket Coil	Smog (kg O3 eq)	Displaced	-43.57	-66.14	-27.22

Pocket Coil	Smog (kg O3 eq)	Net	-24.74	-47.30	-8.38
Pocket Coil	PM2.5 eq (kg)	Incurred	0.19	0.19	0.19
Pocket Coil	PM2.5 eq (kg)	Displaced	-0.28	-0.50	-0.13
Pocket Coil	PM2.5 eq (kg)	Net	-0.09	-0.30	0.07
Pocket Coil	Health, Cancer (Tox. Units)	Incurred	4.5E-05	4.5E-05	4.5E-05
Pocket Coil	Health, Cancer (Tox. Units)	Displaced	-3.7E-05	-6.2E-05	-1.9E-05
Pocket Coil	Health, Cancer (Tox. Units)	Net	7.9E-06	-1.6E-05	2.6E-05
Pocket Coil	Health, NonCancer (Tox. Units)	Incurred	5.6E-05	5.6E-05	5.6E-05
Pocket Coil	Health, NonCancer (Tox. Units)	Displaced	1.6E-05	1.6E-06	2.5E-05
Pocket Coil	Health, NonCancer (Tox. Units)	Net	7.2E-05	5.8E-05	8.1E-05
Pocket Coil	Ozone depl. (g CFC-11 eq)	Incurred	0.05	0.05	0.05
Pocket Coil	Ozone depl. (g CFC-11 eq)	Displaced	-0.04	-0.06	-0.03
Pocket Coil	Ozone depl. (g CFC-11 eq)	Net	0.00	-0.01	0.02
Pocket Coil	Eutroph. (kg N eq)	Incurred	0.24	0.24	0.24
Pocket Coil	Eutroph. (kg N eq)	Displaced	-0.11	-0.16	-0.08
Pocket Coil	Eutroph. (kg N eq)	Net	0.13	0.08	0.16
Pocket Coil	Acidification (kg SO2 eq)	Incurred	1.09	1.09	1.09
Pocket Coil	Acidification (kg SO2 eq)	Displaced	-2.52	-4.19	-1.34
Pocket Coil	Acidification (kg SO2 eq)	Net	-1.44	-3.11	-0.25
Pocket Coil	Energy, Fossil (GJ)	Incurred	4.64	4.64	4.64
Pocket Coil	Energy, Fossil (GJ)	Displaced	-15.59	-23.04	-10.14
Pocket Coil	Energy, Fossil (GJ)	Net	-10.95	-18.41	-5.50
Tied Spring	GHG (t CO2eq)	Incurred	0.22	0.22	0.22
Tied Spring	GHG (t CO2eq)	Displaced	-1.05	-1.36	-0.81
Tied Spring	GHG (t CO2eq)	Net	-0.83	-1.14	-0.58
Tied Spring	Water (m3; Blue)	Incurred	2.07	2.07	2.07
Tied Spring	Water (m3; Blue)	Displaced	-61.03	-73.59	-50.16
Tied Spring	Water (m3; Blue)	Net	-58.97	-71.52	-48.09
Tied Spring	Energy (GJ)	Incurred	3.69	3.69	3.69
Tied Spring	Energy (GJ)	Displaced	-13.37	-18.91	-9.22

Tied Spring	Energy (GJ)	Net	-9.68	-15.22	-5.53
Tied Spring	Smog (kg O3 eq)	Incurred	12.85	12.85	12.85
Tied Spring	Smog (kg O3 eq)	Displaced	-37.08	-52.29	-25.67
Tied Spring	Smog (kg O3 eq)	Net	-24.23	-39.45	-12.82
Tied Spring	PM2.5 eq (kg)	Incurred	0.13	0.13	0.13
Tied Spring	PM2.5 eq (kg)	Displaced	-0.20	-0.34	-0.10
Tied Spring	PM2.5 eq (kg)	Net	-0.07	-0.21	0.03
Tied Spring	Health, Cancer (Tox. Units)	Incurred	2.3E-05	2.3E-05	2.3E-05
Tied Spring	Health, Cancer (Tox. Units)	Displaced	-3.0E-05	-4.7E-05	-1.7E-05
Tied Spring	Health, Cancer (Tox. Units)	Net	-6.4E-06	-2.4E-05	7.0E-06
Tied Spring	Health, NonCancer (Tox. Units)	Incurred	5.0E-05	5.0E-05	5.0E-05
Tied Spring	Health, NonCancer (Tox. Units)	Displaced	2.4E-05	1.6E-05	2.8E-05
Tied Spring	Health, NonCancer (Tox. Units)	Net	7.4E-05	6.6E-05	7.8E-05
Tied Spring	Ozone depl. (g CFC-11 eq)	Incurred	0.04	0.04	0.04
Tied Spring	Ozone depl. (g CFC-11 eq)	Displaced	-0.07	-0.09	-0.05
Tied Spring	Ozone depl. (g CFC-11 eq)	Net	-0.03	-0.06	-0.01
Tied Spring	Eutroph. (kg N eq)	Incurred	0.15	0.15	0.15
Tied Spring	Eutroph. (kg N eq)	Displaced	-0.10	-0.14	-0.08
Tied Spring	Eutroph. (kg N eq)	Net	0.05	0.01	0.08
Tied Spring	Acidification (kg SO2 eq)	Incurred	0.74	0.74	0.74
Tied Spring	Acidification (kg SO2 eq)	Displaced	-1.96	-3.05	-1.17
Tied Spring	Acidification (kg SO2 eq)	Net	-1.22	-2.31	-0.43
Tied Spring	Energy, Fossil (GJ)	Incurred	3.35	3.35	3.35
Tied Spring	Energy, Fossil (GJ)	Displaced	-13.39	-18.44	-9.56
Tied Spring	Energy, Fossil (GJ)	Net	-10.04	-15.09	-6.21
All Foam	GHG (t CO2eq)	Incurred	0.55	0.55	0.55
All Foam	GHG (t CO2eq)	Displaced	-1.28	-2.40	-0.51
All Foam	GHG (t CO2eq)	Net	-0.73	-1.85	0.04
All Foam	Water (m3; Blue)	Incurred	6.74	6.74	6.74
All Foam	Water (m3; Blue)	Displaced	-34.05	-62.55	-14.12

All Foam	Water (m3; Blue)	Net	-27.31	-55.82	-7.39
All Foam	Energy (GJ)	Incurred	10.31	10.31	10.31
All Foam	Energy (GJ)	Displaced	-26.49	-49.60	-10.52
All Foam	Energy (GJ)	Net	-16.18	-39.28	-0.21
All Foam	Smog (kg O3 eq)	Incurred	35.87	35.87	35.87
All Foam	Smog (kg O3 eq)	Displaced	-72.13	-135.07	-28.65
All Foam	Smog (kg O3 eq)	Net	-36.27	-99.20	7.22
All Foam	PM2.5 eq (kg)	Incurred	0.41	0.41	0.41
All Foam	PM2.5 eq (kg)	Displaced	-0.76	-1.41	-0.30
All Foam	PM2.5 eq (kg)	Net	-0.35	-1.00	0.11
All Foam	Health, Cancer (Tox. Units)	Incurred	6.1E-05	6.1E-05	6.1E-05
All Foam	Health, Cancer (Tox. Units)	Displaced	-8.0E-05	-1.4E-04	-3.4E-05
All Foam	Health, Cancer (Tox. Units)	Net	-1.8E-05	-8.2E-05	2.7E-05
All Foam	Health, NonCancer (Tox. Units)	Incurred	9.5E-05	9.5E-05	9.5E-05
All Foam	Health, NonCancer (Tox. Units)	Displaced	-6.5E-05	-1.2E-04	-2.7E-05
All Foam	Health, NonCancer (Tox. Units)	Net	3.0E-05	-2.6E-05	6.9E-05
All Foam	Ozone depl. (g CFC-11 eq)	Incurred	0.10	0.10	0.10
All Foam	Ozone depl. (g CFC-11 eq)	Displaced	-0.05	-0.08	-0.03
All Foam	Ozone depl. (g CFC-11 eq)	Net	0.04	0.01	0.06
All Foam	Eutroph. (kg N eq)	Incurred	0.70	0.70	0.70
All Foam	Eutroph. (kg N eq)	Displaced	-0.15	-0.27	-0.06
All Foam	Eutroph. (kg N eq)	Net	0.56	0.43	0.64
All Foam	Acidification (kg SO2 eq)	Incurred	2.24	2.24	2.24
All Foam	Acidification (kg SO2 eq)	Displaced	-5.66	-10.60	-2.25
All Foam	Acidification (kg SO2 eq)	Net	-3.42	-8.36	-0.01
All Foam	Energy, Fossil (GJ)	Incurred	9.29	9.29	9.29
All Foam	Energy, Fossil (GJ)	Displaced	-23.33	-43.70	-9.26
All Foam	Energy, Fossil (GJ)	Net	-14.04	-34.42	0.03
All Wood Foundation	GHG (t CO2eq)	Incurred	0.15	0.15	0.15
All Wood Foundation	GHG (t CO2eq)	Displaced	-0.28	-0.32	-0.24

All Wood Foundation	GHG (t CO2eq)	Net	-0.13	-0.17	-0.09
All Wood Foundation	Water (m3; Blue)	Incurred	1.55	1.55	1.55
All Wood Foundation	Water (m3; Blue)	Displaced	-3.06	-3.93	-2.21
All Wood Foundation	Water (m3; Blue)	Net	-1.51	-2.38	-0.66
All Wood Foundation	Energy (GJ)	Incurred	2.46	2.46	2.46
All Wood Foundation	Energy (GJ)	Displaced	-25.94	-29.30	-22.60
All Wood Foundation	Energy (GJ)	Net	-23.48	-26.84	-20.14
All Wood Foundation	Smog (kg O3 eq)	Incurred	24.15	24.15	24.15
All Wood Foundation	Smog (kg O3 eq)	Displaced	-12.05	-13.93	-10.21
All Wood Foundation	Smog (kg O3 eq)	Net	12.10	10.21	13.93
All Wood Foundation	PM2.5 eq (kg)	Incurred	0.23	0.23	0.23
All Wood Foundation	PM2.5 eq (kg)	Displaced	-0.10	-0.12	-0.08
All Wood Foundation	PM2.5 eq (kg)	Net	0.13	0.12	0.15
All Wood Foundation	Health, Cancer (Tox. Units)	Incurred	2.3E-05	2.3E-05	2.3E-05
All Wood Foundation	Health, Cancer (Tox. Units)	Displaced	-1.8E-05	-2.2E-05	-1.3E-05
All Wood Foundation	Health, Cancer (Tox. Units)	Net	5.6E-06	1.1E-06	1.0E-05
All Wood Foundation	Health, NonCancer (Tox. Units)	Incurred	1.2E-04	1.2E-04	1.2E-04
All Wood Foundation	Health, NonCancer (Tox. Units)	Displaced	-1.7E-05	-2.0E-05	-1.4E-05
All Wood Foundation	Health, NonCancer (Tox. Units)	Net	1.0E-04	1.0E-04	1.1E-04
All Wood Foundation	Ozone depl. (g CFC-11 eq)	Incurred	0.02	0.02	0.02
All Wood Foundation	Ozone depl. (g CFC-11 eq)	Displaced	-0.06	-0.07	-0.05
All Wood Foundation	Ozone depl. (g CFC-11 eq)	Net	-0.04	-0.05	-0.03
All Wood Foundation	Eutroph. (kg N eq)	Incurred	0.05	0.05	0.05
All Wood Foundation	Eutroph. (kg N eq)	Displaced	-0.03	-0.04	-0.03
All Wood Foundation	Eutroph. (kg N eq)	Net	0.02	0.02	0.03
All Wood Foundation	Acidification (kg SO2 eq)	Incurred	0.93	0.93	0.93
All Wood Foundation	Acidification (kg SO2 eq)	Displaced	-0.68	-0.80	-0.57
All Wood Foundation	Acidification (kg SO2 eq)	Net	0.24	0.13	0.36
All Wood Foundation	Energy, Fossil (GJ)	Incurred	2.09	2.09	2.09
All Wood Foundation	Energy, Fossil (GJ)	Displaced	-4.82	-5.50	-4.15

All Wood Foundation	Energy, Fossil (GJ)	Net	-2.73	-3.42	-2.06
Foundation (not all wood)	GHG (t CO2eq)	Incurred	0.16	0.16	0.16
Foundation (not all wood)	GHG (t CO2eq)	Displaced	-0.75	-0.85	-0.65
Foundation (not all wood)	GHG (t CO2eq)	Net	-0.60	-0.70	-0.50
Foundation (not all wood)	Water (m3; Blue)	Incurred	1.52	1.52	1.52
Foundation (not all wood)	Water (m3; Blue)	Displaced	-42.74	-48.57	-37.01
Foundation (not all wood)	Water (m3; Blue)	Net	-41.23	-47.06	-35.49
Foundation (not all wood)	Energy (GJ)	Incurred	2.55	2.55	2.55
Foundation (not all wood)	Energy (GJ)	Displaced	-18.19	-20.72	-15.73
Foundation (not all wood)	Energy (GJ)	Net	-15.64	-18.17	-13.18
Foundation (not all wood)	Smog (kg O3 eq)	Incurred	16.72	16.72	16.72
Foundation (not all wood)	Smog (kg O3 eq)	Displaced	-21.51	-24.96	-18.27
Foundation (not all wood)	Smog (kg O3 eq)	Net	-4.79	-8.25	-1.55
Foundation (not all wood)	PM2.5 eq (kg)	Incurred	0.15	0.15	0.15
Foundation (not all wood)	PM2.5 eq (kg)	Displaced	-0.08	-0.10	-0.06
Foundation (not all wood)	PM2.5 eq (kg)	Net	0.07	0.05	0.09
Foundation (not all wood)	Health, Cancer (Tox. Units)	Incurred	2.3E-05	2.3E-05	2.3E-05
Foundation (not all wood)	Health, Cancer (Tox. Units)	Displaced	-1.9E-05	-2.5E-05	-1.3E-05
Foundation (not all wood)	Health, Cancer (Tox. Units)	Net	3.8E-06	-2.0E-06	9.5E-06
Foundation (not all wood)	Health, NonCancer (Tox. Units)	Incurred	7.9E-05	7.9E-05	7.9E-05
Foundation (not all wood)	Health, NonCancer (Tox. Units)	Displaced	2.1E-05	2.2E-05	2.0E-05

Foundation (not all wood)	Health, NonCancer (Tox. Units)	Net	1.0E-04	1.0E-04	9.9E-05
Foundation (not all wood)	Ozone depl. (g CFC-11 eq)	Incurred	0.02	0.02	0.02
Foundation (not all wood)	Ozone depl. (g CFC-11 eq)	Displaced	-0.07	-0.08	-0.05
Foundation (not all wood)	Ozone depl. (g CFC-11 eq)	Net	-0.04	-0.06	-0.02
Foundation (not all wood)	Eutroph. (kg N eq)	Incurred	0.04	0.04	0.04
Foundation (not all wood)	Eutroph. (kg N eq)	Displaced	-0.07	-0.08	-0.06
Foundation (not all wood)	Eutroph. (kg N eq)	Net	-0.02	-0.03	-0.01
Foundation (not all wood)	Acidification (kg SO2 eq)	Incurred	0.70	0.70	0.70
Foundation (not all wood)	Acidification (kg SO2 eq)	Displaced	-0.90	-1.08	-0.73
Foundation (not all wood)	Acidification (kg SO2 eq)	Net	-0.20	-0.38	-0.03
Foundation (not all wood)	Energy, Fossil (GJ)	Incurred	2.22	2.22	2.22
Foundation (not all wood)	Energy, Fossil (GJ)	Displaced	-9.19	-10.53	-7.92
Foundation (not all wood)	Energy, Fossil (GJ)	Net	-6.97	-8.31	-5.70

Data for Figure 4.6: Foam routes, processing one tonne of recovered foam (not including collection or primary recycling)

Scenario	**Impact Type**	**Incurred/Displaced**	**result**	**result_lo**	**result_hi**
Rebond pad (displacing foam pad)	GHG (kg CO2eq)	Incurred	611.22	611.22	611.22
Rebond pad (displacing foam pad)	GHG (kg CO2eq)	Displaced	-1,522.94	-3,045.88	-507.65
Rebond pad (displacing foam pad)	GHG (kg CO2eq)	Net	-911.72	-2,434.66	103.57
Rebond pad (displacing foam pad)	Water (m3; Blue)	Incurred	8.09	8.09	8.09

Rebond pad (displacing foam pad)	Water (m3; Blue)	Displaced	-37.67	-75.35	-12.56
Rebond pad (displacing foam pad)	Water (m3; Blue)	Net	-29.59	-67.26	-4.47
Rebond pad (displacing foam pad)	Energy (MJ)	Incurred	12,164.89	12,164.89	12,164.89
Rebond pad (displacing foam pad)	Energy (MJ)	Displaced	-31,365.89	-62,731.79	-10,455.30
Rebond pad (displacing foam pad)	Energy (MJ)	Net	-19,201.00	-50,566.90	1,709.59
Rebond pad (displacing foam pad)	Smog (kg O3 eq)	Incurred	41.62	41.62	41.62
Rebond pad (displacing foam pad)	Smog (kg O3 eq)	Displaced	-85.43	-170.86	-28.48
Rebond pad (displacing foam pad)	Smog (kg O3 eq)	Net	-43.81	-129.24	13.14
Rebond pad (displacing foam pad)	PM2.5 eq (kg)	Incurred	0.51	0.51	0.51
Rebond pad (displacing foam pad)	PM2.5 eq (kg)	Displaced	-0.89	-1.78	-0.30
Rebond pad (displacing foam pad)	PM2.5 eq (kg)	Net	-0.38	-1.27	0.22
Rebond pad (displacing foam pad)	Health, Cancer (Tox. Units)	Incurred	6.51E-05	6.51E-05	6.51E-05
Rebond pad (displacing foam pad)	Health, Cancer (Tox. Units)	Displaced	-8.30E-05	-1.66E-04	-2.77E-05
Rebond pad (displacing foam pad)	Health, Cancer (Tox. Units)	Net	-1.79E-05	-1.01E-04	3.74E-05
Rebond pad (displacing foam pad)	Health, NonCancer (Tox. Units)	Incurred	8.66E-05	8.66E-05	8.66E-05
Rebond pad (displacing foam pad)	Health, NonCancer (Tox. Units)	Displaced	-7.48E-05	-1.50E-04	-2.49E-05
Rebond pad (displacing foam pad)	Health, NonCancer (Tox. Units)	Net	1.17E-05	-6.31E-05	6.16E-05
Rebond pad (displacing foam pad)	Ozone depl. (kg CFC-11 eq)	Incurred	1.12E-04	1.12E-04	1.12E-04
Rebond pad (displacing foam pad)	Ozone depl. (kg CFC-11 eq)	Displaced	-2.04E-05	-4.08E-05	-6.80E-06
Rebond pad (displacing foam pad)	Ozone depl. (kg CFC-11 eq)	Net	9.14E-05	7.10E-05	1.05E-04

Rebond pad (displacing foam pad)	Eutroph. (kg N eq)	Incurred	1.00	1.00	1.00
Rebond pad (displacing foam pad)	Eutroph. (kg N eq)	Displaced	-0.17	-0.34	-0.06
Rebond pad (displacing foam pad)	Eutroph. (kg N eq)	Net	0.83	0.66	0.94
Rebond pad (displacing foam pad)	Acidification (kg SO2 eq)	Incurred	2.74	2.74	2.74
Rebond pad (displacing foam pad)	Acidification (kg SO2 eq)	Displaced	-6.70	-13.40	-2.23
Rebond pad (displacing foam pad)	Acidification (kg SO2 eq)	Net	-3.96	-10.66	0.51
Rebond pad (displacing foam pad)	Energy, Fossil (MJ)	Incurred	11,030.06	11,030.06	11,030.06
Rebond pad (displacing foam pad)	Energy, Fossil (MJ)	Displaced	-27,675.99	-55,351.97	-9,225.33
Rebond pad (displacing foam pad)	Energy, Fossil (MJ)	Net	-16,645.92	-44,321.91	1,804.73
Acidolysis (displacing polyols)	GHG (kg CO2eq)	Incurred	6,513.60	5,904.57	7,231.18
Acidolysis (displacing polyols)	GHG (kg CO2eq)	Displaced	-7,630.65	-8,478.50	-6,782.80
Acidolysis (displacing polyols)	GHG (kg CO2eq)	Net	-1,117.05	-2,573.93	448.38
Acidolysis (displacing polyols)	Water (m3; Blue)	Incurred	144.16	129.21	158.07
Acidolysis (displacing polyols)	Water (m3; Blue)	Displaced	-254.84	-283.15	-226.52
Acidolysis (displacing polyols)	Water (m3; Blue)	Net	-110.68	-153.94	-68.45
Acidolysis (displacing polyols)	Energy (MJ)	Incurred	124,723.89	112,274.52	137,349.11
Acidolysis (displacing polyols)	Energy (MJ)	Displaced	-183,661.22	-204,068.02	-163,254.42
Acidolysis (displacing polyols)	Energy (MJ)	Net	-58,937.33	-91,793.51	-25,905.31
Acidolysis (displacing polyols)	Smog (kg O3 eq)	Incurred	259.65	233.85	286.05
Acidolysis (displacing polyols)	Smog (kg O3 eq)	Displaced	-433.16	-481.29	-385.03
Acidolysis (displacing polyols)	Smog (kg O3 eq)	Net	-173.51	-247.44	-98.98
Acidolysis (displacing polyols)	PM2.5 eq (kg)	Incurred	3.41	3.07	3.76
Acidolysis (displacing polyols)	PM2.5 eq (kg)	Displaced	-5.19	-5.77	-4.62
Acidolysis (displacing polyols)	PM2.5 eq (kg)	Net	-1.78	-2.70	-0.86
Acidolysis (displacing polyols)	Health, Cancer (Tox. Units)	Incurred	3.26E-04	2.95E-04	3.57E-04

Acidolysis (displacing polyols)	Health, Cancer (Tox. Units)	Displaced	-4.82E-04	-5.36E-04	-4.29E-04
Acidolysis (displacing polyols)	Health, Cancer (Tox. Units)	Net	-1.56E-04	-2.41E-04	-7.21E-05
Acidolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Incurred	2.87E-04	2.59E-04	3.16E-04
Acidolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Displaced	-4.20E-04	-4.67E-04	-3.73E-04
Acidolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Net	-1.33E-04	-2.07E-04	-5.72E-05
Acidolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Incurred	1.71E-04	1.58E-04	1.93E-04
Acidolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Displaced	-7.86E-05	-8.74E-05	-6.99E-05
Acidolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Net	9.24E-05	7.09E-05	1.23E-04
Acidolysis (displacing polyols)	Eutroph. (kg N eq)	Incurred	1.10	0.99	1.21
Acidolysis (displacing polyols)	Eutroph. (kg N eq)	Displaced	-0.82	-0.91	-0.73
Acidolysis (displacing polyols)	Eutroph. (kg N eq)	Net	0.28	0.08	0.49
Acidolysis (displacing polyols)	Acidification (kg SO2 eq)	Incurred	20.36	18.36	22.47
Acidolysis (displacing polyols)	Acidification (kg SO2 eq)	Displaced	-31.33	-34.81	-27.85
Acidolysis (displacing polyols)	Acidification (kg SO2 eq)	Net	-10.96	-16.45	-5.38
Acidolysis (displacing polyols)	Energy, Fossil (MJ)	Incurred	111,464.29	100,328.29	122,787.24
Acidolysis (displacing polyols)	Energy, Fossil (MJ)	Displaced	-162,347.05	-180,385.61	-144,308.49
Acidolysis (displacing polyols)	Energy, Fossil (MJ)	Net	-50,882.76	-80,057.32	-21,521.25
Glycolysis (displacing polyols)	GHG (kg CO2eq)	Incurred	3,472.69	2,634.78	4,333.10
Glycolysis (displacing polyols)	GHG (kg CO2eq)	Displaced	-6,813.08	-7,570.09	-6,056.07
Glycolysis (displacing polyols)	GHG (kg CO2eq)	Net	-3,340.39	-4,935.31	-1,722.97
Glycolysis (displacing polyols)	Water (m3; Blue)	Incurred	45.61	34.56	56.96
Glycolysis (displacing polyols)	Water (m3; Blue)	Displaced	-227.53	-252.81	-202.25
Glycolysis (displacing polyols)	Water (m3; Blue)	Net	-181.92	-218.25	-145.29
Glycolysis (displacing polyols)	Energy (MJ)	Incurred	104,314.32	79,009.06	130,299.01
Glycolysis (displacing polyols)	Energy (MJ)	Displaced	-163,983.23	-182,203.59	-145,762.87

Glycolysis (displacing polyols)	Energy (MJ)	Net	-59,668.92	-103,194.53	-15,463.86
Glycolysis (displacing polyols)	Smog (kg O3 eq)	Incurred	177.88	134.84	222.08
Glycolysis (displacing polyols)	Smog (kg O3 eq)	Displaced	-386.75	-429.72	-343.78
Glycolysis (displacing polyols)	Smog (kg O3 eq)	Net	-208.87	-294.88	-121.70
Glycolysis (displacing polyols)	PM2.5 eq (kg)	Incurred	2.51	1.90	3.14
Glycolysis (displacing polyols)	PM2.5 eq (kg)	Displaced	-4.64	-5.15	-4.12
Glycolysis (displacing polyols)	PM2.5 eq (kg)	Net	-2.12	-3.25	-0.98
Glycolysis (displacing polyols)	Health, Cancer (Tox. Units)	Incurred	2.38E-04	1.84E-04	2.92E-04
Glycolysis (displacing polyols)	Health, Cancer (Tox. Units)	Displaced	-4.31E-04	-4.78E-04	-3.83E-04
Glycolysis (displacing polyols)	Health, Cancer (Tox. Units)	Net	-1.93E-04	-2.94E-04	-9.04E-05
Glycolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Incurred	1.96E-04	1.49E-04	2.43E-04
Glycolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Displaced	-3.75E-04	-4.17E-04	-3.33E-04
Glycolysis (displacing polyols)	Health, NonCancer (Tox. Units)	Net	-1.79E-04	-2.67E-04	-8.99E-05
Glycolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Incurred	8.22E-05	6.39E-05	1.01E-04
Glycolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Displaced	-7.02E-05	-7.80E-05	-6.24E-05
Glycolysis (displacing polyols)	Ozone depl. (kg CFC-11 eq)	Net	1.20E-05	-1.41E-05	3.86E-05
Glycolysis (displacing polyols)	Eutroph. (kg N eq)	Incurred	0.37	0.29	0.46
Glycolysis (displacing polyols)	Eutroph. (kg N eq)	Displaced	-0.73	-0.81	-0.65
Glycolysis (displacing polyols)	Eutroph. (kg N eq)	Net	-0.36	-0.52	-0.19
Glycolysis (displacing polyols)	Acidification (kg SO2 eq)	Incurred	13.47	10.21	16.82
Glycolysis (displacing polyols)	Acidification (kg SO2 eq)	Displaced	-27.97	-31.08	-24.86
Glycolysis (displacing polyols)	Acidification (kg SO2 eq)	Net	-14.50	-20.87	-8.04
Glycolysis (displacing polyols)	Energy, Fossil (MJ)	Incurred	98,030.08	74,214.21	122,487.38
Glycolysis (displacing polyols)	Energy, Fossil (MJ)	Displaced	-144,952.73	-161,058.58	-128,846.87

Glycolysis (displacing polyols)	Energy, Fossil (MJ)	Net	-46,922.64	-86,844.37	-6,359.48
Scrap market (displacing freight)	GHG (kg CO2eq)	Incurred	17.80	17.80	17.80
Scrap market (displacing freight)	GHG (kg CO2eq)	Displaced	-108.23	-120.26	-96.21
Scrap market (displacing freight)	GHG (kg CO2eq)	Net	-90.44	-102.46	-78.41
Scrap market (displacing freight)	Water (m3; Blue)	Incurred	0.03	0.03	0.03
Scrap market (displacing freight)	Water (m3; Blue)	Displaced	-0.14	-0.16	-0.12
Scrap market (displacing freight)	Water (m3; Blue)	Net	-0.11	-0.12	-0.09
Scrap market (displacing freight)	Energy (MJ)	Incurred	321.71	321.71	321.71
Scrap market (displacing freight)	Energy (MJ)	Displaced	-1,773.09	-1,970.10	-1,576.08
Scrap market (displacing freight)	Energy (MJ)	Net	-1,451.38	-1,648.39	-1,254.37
Scrap market (displacing freight)	Smog (kg O3 eq)	Incurred	0.81	0.81	0.81
Scrap market (displacing freight)	Smog (kg O3 eq)	Displaced	-25.54	-28.38	-22.70
Scrap market (displacing freight)	Smog (kg O3 eq)	Net	-24.73	-27.57	-21.89
Scrap market (displacing freight)	PM2.5 eq (kg)	Incurred	0.01	0.01	0.01
Scrap market (displacing freight)	PM2.5 eq (kg)	Displaced	-0.10	-0.12	-0.09
Scrap market (displacing freight)	PM2.5 eq (kg)	Net	-0.09	-0.11	-0.08
Scrap market (displacing freight)	Health, Cancer (Tox. Units)	Incurred	8.96E-07	8.96E-07	8.96E-07
Scrap market (displacing freight)	Health, Cancer (Tox. Units)	Displaced	-5.81E-06	-6.45E-06	-5.16E-06
Scrap market (displacing freight)	Health, Cancer (Tox. Units)	Net	-4.91E-06	-5.56E-06	-4.27E-06
Scrap market (displacing freight)	Health, NonCancer (Tox. Units)	Incurred	2.90E-06	2.90E-06	2.90E-06
Scrap market (displacing freight)	Health, NonCancer (Tox. Units)	Displaced	-1.16E-05	-1.29E-05	-1.03E-05

Scrap market (displacing freight)	Health, NonCancer (Tox. Units)	Net	-8.70E-06	-9.99E-06	-7.41E-06
Scrap market (displacing freight)	Ozone depl. (kg CFC-11 eq)	Incurred	4.46E-06	4.46E-06	4.46E-06
Scrap market (displacing freight)	Ozone depl. (kg CFC-11 eq)	Displaced	-2.53E-05	-2.82E-05	-2.25E-05
Scrap market (displacing freight)	Ozone depl. (kg CFC-11 eq)	Net	-2.09E-05	-2.37E-05	-1.81E-05
Scrap market (displacing freight)	Eutroph. (kg N eq)	Incurred	0.00	0.00	0.00
Scrap market (displacing freight)	Eutroph. (kg N eq)	Displaced	-0.05	-0.06	-0.05
Scrap market (displacing freight)	Eutroph. (kg N eq)	Net	-0.05	-0.05	-0.04
Scrap market (displacing freight)	Acidification (kg SO2 eq)	Incurred	0.05	0.05	0.05
Scrap market (displacing freight)	Acidification (kg SO2 eq)	Displaced	-1.41	-1.56	-1.25
Scrap market (displacing freight)	Acidification (kg SO2 eq)	Net	-1.36	-1.51	-1.20
Scrap market (displacing freight)	Energy, Fossil (MJ)	Incurred	315.69	315.69	315.69
Scrap market (displacing freight)	Energy, Fossil (MJ)	Displaced	-1,744.68	-1,938.54	-1,550.83
Scrap market (displacing freight)	Energy, Fossil (MJ)	Net	-1,429.00	-1,622.85	-1,235.14
Pyrolysis (displacing oil and carbon black)	GHG (kg CO2eq)	Incurred	596.22	596.22	596.22
Pyrolysis (displacing oil and carbon black)	GHG (kg CO2eq)	Displaced	-244.86	-272.06	-217.65
Pyrolysis (displacing oil and carbon black)	GHG (kg CO2eq)	Net	351.37	324.16	378.57
Pyrolysis (displacing oil and carbon black)	Water (m3; Blue)	Incurred	0.96	0.96	0.96
Pyrolysis (displacing oil and carbon black)	Water (m3; Blue)	Displaced	-0.23	-0.26	-0.20
Pyrolysis (displacing oil and carbon black)	Water (m3; Blue)	Net	0.73	0.71	0.76
Pyrolysis (displacing oil and carbon black)	Energy (MJ)	Incurred	4,104.38	4,104.38	4,104.38

Pyrolysis (displacing oil and carbon black)	Energy (MJ)	Displaced	-38,150.52	-42,389.47	-33,911.58
Pyrolysis (displacing oil and carbon black)	Energy (MJ)	Net	-34,046.14	-38,285.09	-29,807.19
Pyrolysis (displacing oil and carbon black)	Smog (kg O3 eq)	Incurred	10.43	10.43	10.43
Pyrolysis (displacing oil and carbon black)	Smog (kg O3 eq)	Displaced	-29.10	-32.34	-25.87
Pyrolysis (displacing oil and carbon black)	Smog (kg O3 eq)	Net	-18.67	-21.91	-15.44
Pyrolysis (displacing oil and carbon black)	PM2.5 eq (kg)	Incurred	0.08	0.08	0.08
Pyrolysis (displacing oil and carbon black)	PM2.5 eq (kg)	Displaced	-0.25	-0.28	-0.23
Pyrolysis (displacing oil and carbon black)	PM2.5 eq (kg)	Net	-0.18	-0.21	-0.15
Pyrolysis (displacing oil and carbon black)	Health, Cancer (Tox. Units)	Incurred	3.75E-06	3.75E-06	3.75E-06
Pyrolysis (displacing oil and carbon black)	Health, Cancer (Tox. Units)	Displaced	-1.59E-05	-1.77E-05	-1.42E-05
Pyrolysis (displacing oil and carbon black)	Health, Cancer (Tox. Units)	Net	-1.22E-05	-1.39E-05	-1.04E-05
Pyrolysis (displacing oil and carbon black)	Health, NonCancer (Tox. Units)	Incurred	2.37E-05	2.37E-05	2.37E-05
Pyrolysis (displacing oil and carbon black)	Health, NonCancer (Tox. Units)	Displaced	-1.83E-05	-2.03E-05	-1.62E-05
Pyrolysis (displacing oil and carbon black)	Health, NonCancer (Tox. Units)	Net	5.43E-06	3.40E-06	7.46E-06
Pyrolysis (displacing oil and carbon black)	Ozone depl. (kg CFC-11 eq)	Incurred	2.64E-05	2.64E-05	2.64E-05
Pyrolysis (displacing oil and carbon black)	Ozone depl. (kg CFC-11 eq)	Displaced	-6.25E-04	-6.95E-04	-5.56E-04
Pyrolysis (displacing oil and carbon black)	Ozone depl. (kg CFC-11 eq)	Net	-5.99E-04	-6.68E-04	-5.29E-04
Pyrolysis (displacing oil and carbon black)	Eutroph. (kg N eq)	Incurred	0.02	0.02	0.02
Pyrolysis (displacing oil and carbon black)	Eutroph. (kg N eq)	Displaced	-0.14	-0.15	-0.12
Pyrolysis (displacing oil and carbon black)	Eutroph. (kg N eq)	Net	-0.12	-0.13	-0.10

Pyrolysis (displacing oil and carbon black)	Acidification (kg SO2 eq)	Incurred	0.62	0.62	0.62
Pyrolysis (displacing oil and carbon black)	Acidification (kg SO2 eq)	Displaced	-2.59	-2.88	-2.31
Pyrolysis (displacing oil and carbon black)	Acidification (kg SO2 eq)	Net	-1.97	-2.26	-1.69
Pyrolysis (displacing oil and carbon black)	Energy, Fossil (MJ)	Incurred	3,913.73	3,913.73	3,913.73
Pyrolysis (displacing oil and carbon black)	Energy, Fossil (MJ)	Displaced	-38,005.16	-42,227.95	-33,782.36
Pyrolysis (displacing oil and carbon black)	Energy, Fossil (MJ)	Net	-34,091.43	-38,314.22	-29,868.63
Syn. cement (displacing Portland cement)	GHG (kg CO2eq)	Incurred	9,760.28	8,922.38	10,620.69
Syn. cement (displacing Portland cement)	GHG (kg CO2eq)	Displaced	-6,706.82	-8,942.42	-4,471.21
Syn. cement (displacing Portland cement)	GHG (kg CO2eq)	Net	3,053.46	-20.05	6,149.48
Syn. cement (displacing Portland cement)	Water (m3; Blue)	Incurred	110.22	99.17	121.56
Syn. cement (displacing Portland cement)	Water (m3; Blue)	Displaced	-11.44	-15.25	-7.63
Syn. cement (displacing Portland cement)	Water (m3; Blue)	Net	98.78	83.91	113.94
Syn. cement (displacing Portland cement)	Energy (MJ)	Incurred	209,519.44	184,214.18	235,504.13
Syn. cement (displacing Portland cement)	Energy (MJ)	Displaced	-32,938.43	-43,917.90	-21,958.95
Syn. cement (displacing Portland cement)	Energy (MJ)	Net	176,581.01	140,296.28	213,545.18
Syn. cement (displacing Portland cement)	Smog (kg O3 eq)	Incurred	422.82	379.79	467.02
Syn. cement (displacing Portland cement)	Smog (kg O3 eq)	Displaced	-257.98	-343.97	-171.99
Syn. cement (displacing Portland cement)	Smog (kg O3 eq)	Net	164.84	35.81	295.04
Syn. cement (displacing Portland cement)	PM2.5 eq (kg)	Incurred	4.30	3.69	4.93
Syn. cement (displacing Portland cement)	PM2.5 eq (kg)	Displaced	-1.83	-2.44	-1.22

Syn. cement (displacing Portland cement)	PM2.5 eq (kg)	Net	2.47	1.26	3.71
Syn. cement (displacing Portland cement)	Health, Cancer (Tox. Units)	Incurred	3.68E-04	3.14E-04	4.22E-04
Syn. cement (displacing Portland cement)	Health, Cancer (Tox. Units)	Displaced	-1.44E-04	-1.93E-04	-9.63E-05
Syn. cement (displacing Portland cement)	Health, Cancer (Tox. Units)	Net	2.23E-04	1.22E-04	3.26E-04
Syn. cement (displacing Portland cement)	Health, NonCancer (Tox. Units)	Incurred	2.94E-04	2.48E-04	3.42E-04
Syn. cement (displacing Portland cement)	Health, NonCancer (Tox. Units)	Displaced	-3.49E-04	-4.66E-04	-2.33E-04
Syn. cement (displacing Portland cement)	Health, NonCancer (Tox. Units)	Net	-5.50E-05	-2.18E-04	1.09E-04
Syn. cement (displacing Portland cement)	Ozone depl. (kg CFC-11 eq)	Incurred	3.21E-04	3.02E-04	3.40E-04
Syn. cement (displacing Portland cement)	Ozone depl. (kg CFC-11 eq)	Displaced	-2.54E-04	-3.39E-04	-1.69E-04
Syn. cement (displacing Portland cement)	Ozone depl. (kg CFC-11 eq)	Net	6.66E-05	-3.65E-05	1.70E-04
Syn. cement (displacing Portland cement)	Eutroph. (kg N eq)	Incurred	0.88	0.80	0.97
Syn. cement (displacing Portland cement)	Eutroph. (kg N eq)	Displaced	-0.54	-0.72	-0.36
Syn. cement (displacing Portland cement)	Eutroph. (kg N eq)	Net	0.34	0.08	0.61
Syn. cement (displacing Portland cement)	Acidification (kg SO2 eq)	Incurred	35.44	32.18	38.79
Syn. cement (displacing Portland cement)	Acidification (kg SO2 eq)	Displaced	-12.99	-17.32	-8.66
Syn. cement (displacing Portland cement)	Acidification (kg SO2 eq)	Net	22.46	14.87	30.14
Syn. cement (displacing Portland cement)	Energy, Fossil (MJ)	Incurred	195,715.44	171,899.57	220,172.74
Syn. cement (displacing Portland cement)	Energy, Fossil (MJ)	Displaced	-29,714.89	-39,619.85	-19,809.92
Syn. cement (displacing Portland cement)	Energy, Fossil (MJ)	Net	166,000.55	132,279.72	200,362.81

Data for Figure 4.7: Wood routes, processing one tonne of recovered wood (not including collection or primary recycling)

Scenario	Impact Type	Incurred/ Displaced	result	result_lo	result_hi
Mulch	GHG (kg CO2eq)	Incurred	12.62	12.62	12.62
Mulch	GHG (kg CO2eq)	Displaced	-125.61	-139.57	-111.66
Mulch	GHG (kg CO2eq)	Net	-112.99	-126.95	-99.03
Mulch	Water (m3; Blue)	Incurred	0.09	0.09	0.09
Mulch	Water (m3; Blue)	Displaced	-0.25	-0.28	-0.22
Mulch	Water (m3; Blue)	Net	-0.15	-0.18	-0.13
Mulch	Energy (MJ)	Incurred	237.47	237.47	237.47
Mulch	Energy (MJ)	Displaced	-34,640.00	-38,488.89	-30,791.11
Mulch	Energy (MJ)	Net	-34,402.53	-38,251.42	-30,553.64
Mulch	Smog (kg O3 eq)	Incurred	0.44	0.44	0.44
Mulch	Smog (kg O3 eq)	Displaced	-9.29	-10.32	-8.26
Mulch	Smog (kg O3 eq)	Net	-8.85	-9.88	-7.82
Mulch	PM2.5 eq (kg)	Incurred	0.03	0.03	0.03
Mulch	PM2.5 eq (kg)	Displaced	-0.07	-0.08	-0.06
Mulch	PM2.5 eq (kg)	Net	-0.04	-0.05	-0.03
Mulch	Health, Cancer (Tox. Units)	Incurred	1.56E-06	1.56E-06	1.56E-06
Mulch	Health, Cancer (Tox. Units)	Displaced	-8.10E-06	-9.00E-06	-7.20E-06
Mulch	Health, Cancer (Tox. Units)	Net	-6.54E-06	-7.44E-06	-5.64E-06
Mulch	Health, NonCancer (Tox. Units)	Incurred	8.10E-07	8.10E-07	8.10E-07
Mulch	Health, NonCancer (Tox. Units)	Displaced	-1.63E-05	-1.81E-05	-1.45E-05
Mulch	Health, NonCancer (Tox. Units)	Net	-1.55E-05	-1.73E-05	-1.37E-05
Mulch	Ozone depl. (kg CFC-11 eq)	Incurred	1.01E-06	1.01E-06	1.01E-06
Mulch	Ozone depl. (kg CFC-11 eq)	Displaced	-3.01E-05	-3.34E-05	-2.67E-05
Mulch	Ozone depl. (kg CFC-11 eq)	Net	-2.91E-05	-3.24E-05	-2.57E-05
Mulch	Eutroph. (kg N eq)	Incurred	0.00	0.00	0.00
Mulch	Eutroph. (kg N eq)	Displaced	-0.02	-0.02	-0.02
Mulch	Eutroph. (kg N eq)	Net	-0.02	-0.02	-0.02
Mulch	Acidification (kg SO2 eq)	Incurred	0.03	0.03	0.03

Mulch	Acidification (kg SO2 eq)	Displaced	-0.45	-0.50	-0.40
Mulch	Acidification (kg SO2 eq)	Net	-0.42	-0.47	-0.37
Mulch	Energy, Fossil (MJ)	Incurred	173.87	173.87	173.87
Mulch	Energy, Fossil (MJ)	Displaced	-2,141.44	-2,379.38	-1,903.50
Mulch	Energy, Fossil (MJ)	Net	-1,967.57	-2,205.51	-1,729.63
Reuse	GHG (kg CO2eq)	Incurred	153.35	153.35	153.35
Reuse	GHG (kg CO2eq)	Displaced	-153.30	-204.40	-102.20
Reuse	GHG (kg CO2eq)	Net	0.05	-51.05	51.15
Reuse	Water (m3; Blue)	Incurred	1.55	1.55	1.55
Reuse	Water (m3; Blue)	Displaced	-0.52	-0.69	-0.35
Reuse	Water (m3; Blue)	Net	1.02	0.85	1.20
Reuse	Energy (MJ)	Incurred	2,941.89	2,941.89	2,941.89
Reuse	Energy (MJ)	Displaced	-45,036.91	-60,049.21	-30,024.61
Reuse	Energy (MJ)	Net	-42,095.02	-57,107.32	-27,082.71
Reuse	Smog (kg O3 eq)	Incurred	6.16	6.16	6.16
Reuse	Smog (kg O3 eq)	Displaced	-15.91	-21.22	-10.61
Reuse	Smog (kg O3 eq)	Net	-9.75	-15.06	-4.45
Reuse	PM2.5 eq (kg)	Incurred	0.10	0.10	0.10
Reuse	PM2.5 eq (kg)	Displaced	-0.27	-0.36	-0.18
Reuse	PM2.5 eq (kg)	Net	-0.17	-0.26	-0.08
Reuse	Health, Cancer (Tox. Units)	Incurred	6.44E-06	6.44E-06	6.44E-06
Reuse	Health, Cancer (Tox. Units)	Displaced	-1.50E-05	-2.00E-05	-1.00E-05
Reuse	Health, Cancer (Tox. Units)	Net	-8.56E-06	-1.36E-05	-3.56E-06
Reuse	Health, NonCancer (Tox. Units)	Incurred	8.74E-06	8.74E-06	8.74E-06
Reuse	Health, NonCancer (Tox. Units)	Displaced	-3.08E-05	-4.11E-05	-2.05E-05
Reuse	Health, NonCancer (Tox. Units)	Net	-2.21E-05	-3.23E-05	-1.18E-05
Reuse	Ozone depl. (kg CFC-11 eq)	Incurred	1.39E-05	1.39E-05	1.39E-05
Reuse	Ozone depl. (kg CFC-11 eq)	Displaced	-2.57E-05	-3.43E-05	-1.71E-05
Reuse	Ozone depl. (kg CFC-11 eq)	Net	-1.18E-05	-2.04E-05	-3.22E-06
Reuse	Eutroph. (kg N eq)	Incurred	4.20E-02	4.20E-02	4.20E-02
Reuse	Eutroph. (kg N eq)	Displaced	-0.03	-0.04	-0.02

Reuse	Eutroph. (kg N eq)	Net	0.01	0.00	0.02
Reuse	Acidification (kg SO2 eq)	Incurred	0.45	0.45	0.45
Reuse	Acidification (kg SO2 eq)	Displaced	-0.75	-1.00	-0.50
Reuse	Acidification (kg SO2 eq)	Net	-0.30	-0.55	-0.05
Reuse	Energy, Fossil (MJ)	Incurred	2,500.32	2,500.32	2,500.32
Reuse	Energy, Fossil (MJ)	Displaced	-2,414.91	-3,219.88	-1,609.94
Reuse	Energy, Fossil (MJ)	Net	85.41	-719.56	890.38
BioEnergy	GHG (kg CO2eq)	Incurred	78.85	78.85	78.85
BioEnergy	GHG (kg CO2eq)	Displaced	-651.84	-724.26	-579.41
BioEnergy	GHG (kg CO2eq)	Net	-572.99	-645.42	-500.56
BioEnergy	Water (m3; Blue)	Incurred	0.51	0.51	0.51
BioEnergy	Water (m3; Blue)	Displaced	-0.13	-0.15	-0.12
BioEnergy	Water (m3; Blue)	Net	0.37	0.36	0.39
BioEnergy	Energy (MJ)	Incurred	1,084.07	1,084.07	1,084.07
BioEnergy	Energy (MJ)	Displaced	-11,659.80	-12,955.34	-10,364.27
BioEnergy	Energy (MJ)	Net	-10,575.74	-11,871.27	-9,280.20
BioEnergy	Smog (kg O3 eq)	Incurred	63.51	63.51	63.51
BioEnergy	Smog (kg O3 eq)	Displaced	-8.17	-9.07	-7.26
BioEnergy	Smog (kg O3 eq)	Net	55.35	54.44	56.25
BioEnergy	PM2.5 eq (kg)	Incurred	0.61	0.61	0.61
BioEnergy	PM2.5 eq (kg)	Displaced	-0.05	-0.06	-0.05
BioEnergy	PM2.5 eq (kg)	Net	0.56	0.56	0.57
BioEnergy	Health, Cancer (Tox. Units)	Incurred	1.11E-05	1.11E-05	1.11E-05
BioEnergy	Health, Cancer (Tox. Units)	Displaced	-5.53E-06	-6.14E-06	-4.91E-06
BioEnergy	Health, Cancer (Tox. Units)	Net	5.61E-06	5.00E-06	6.23E-06
BioEnergy	Health, NonCancer (Tox. Units)	Incurred	3.89E-04	3.89E-04	3.89E-04
BioEnergy	Health, NonCancer (Tox. Units)	Displaced	-7.61E-06	-8.46E-06	-6.77E-06
BioEnergy	Health, NonCancer (Tox. Units)	Net	3.81E-04	3.80E-04	3.82E-04
BioEnergy	Ozone depl. (kg CFC-11 eq)	Incurred	2.57E-06	2.57E-06	2.57E-06
BioEnergy	Ozone depl. (kg CFC-11 eq)	Displaced	-7.09E-05	-7.88E-05	-6.31E-05
BioEnergy	Ozone depl. (kg CFC-11 eq)	Net	-6.84E-05	-7.63E-05	-6.05E-05

BioEnergy	Eutroph. (kg N eq)	Incurred	0.12	0.12	0.12
BioEnergy	Eutroph. (kg N eq)	Displaced	-0.03	-0.03	-0.02
BioEnergy	Eutroph. (kg N eq)	Net	0.10	0.09	0.10
BioEnergy	Acidification (kg SO2 eq)	Incurred	2.09	2.09	2.09
BioEnergy	Acidification (kg SO2 eq)	Displaced	-0.61	-0.67	-0.54
BioEnergy	Acidification (kg SO2 eq)	Net	1.48	1.41	1.55
BioEnergy	Energy, Fossil (MJ)	Incurred	882.88	882.88	882.88
BioEnergy	Energy, Fossil (MJ)	Displaced	-11,611.90	-12,902.11	-10,321.69
BioEnergy	Energy, Fossil (MJ)	Net	-10,729.02	-12,019.23	-9,438.81
Landfill	GHG (kg CO2eq)	Incurred	53.23	53.23	53.23
Landfill	GHG (kg CO2eq)	Net	53.23	53.23	53.23
Landfill	Water (m3; Blue)	Incurred	0.26	0.26	0.26
Landfill	Water (m3; Blue)	Net	0.26	0.26	0.26
Landfill	Energy (MJ)	Incurred	318.58	318.58	318.58
Landfill	Energy (MJ)	Net	318.58	318.58	318.58
Landfill	Smog (kg O3 eq)	Incurred	2.07	2.07	2.07
Landfill	Smog (kg O3 eq)	Net	2.07	2.07	2.07
Landfill	PM2.5 eq (kg)	Incurred	0.01	0.01	0.01
Landfill	PM2.5 eq (kg)	Net	0.01	0.01	0.01
Landfill	Health, Cancer (Tox. Units)	Incurred	1.29E-06	1.29E-06	1.29E-06
Landfill	Health, Cancer (Tox. Units)	Net	1.29E-06	1.29E-06	1.29E-06
Landfill	Health, NonCancer (Tox. Units)	Incurred	9.00E-06	9.00E-06	9.00E-06
Landfill	Health, NonCancer (Tox. Units)	Net	9.00E-06	9.00E-06	9.00E-06
Landfill	Ozone depl. (kg CFC-11 eq)	Incurred	3.94E-06	3.94E-06	3.94E-06
Landfill	Ozone depl. (kg CFC-11 eq)	Net	3.94E-06	3.94E-06	3.94E-06
Landfill	Eutroph. (kg N eq)	Incurred	0.004	0.004	0.004
Landfill	Eutroph. (kg N eq)	Net	0.004	0.004	0.004
Landfill	Acidification (kg SO2 eq)	Incurred	0.09	0.09	0.09
Landfill	Acidification (kg SO2 eq)	Net	0.09	0.09	0.09
Landfill	Energy, Fossil (MJ)	Incurred	308.95	308.95	308.95
Landfill	Energy, Fossil (MJ)	Net	308.95	308.95	308.95

Critical Review Verification Statements

November 15, 2023

Critical Review Statement

Report Title:	Life Cycle Analysis of Mattress Recycling in California
Commissioner:	Mattress Recycling Council California, LLC
Report Version/Date:	v1.0 / November, 2023
Report authors:	Kyle Meisterling, Brandon Kuczenski Scope 3 Consulting, LLC
Reviewers:	Panel Leader: Jeff Zeman, Principal at TrueNorth Collective - Sustainability Consulting Panel Experts: Tracey Pryor, Director of Innovation with the Australian Bedding Stewardship Council Bob Clark, Executive Director of the Carpet Cushion Council
Reviewed for consistency with:	ISO 14040:2006, ISO 14044:2006

Review background

A panel of experts was commissioned to review the LCA report ‘Life Cycle Analysis of Mattress Recycling in California’. The panel of experts was:

- Jeff Zeman, Principal at TrueNorth Collective - Sustainability Consulting
- Tracey Pryor, Director of Innovation with the Australian Bedding Stewardship Council
- Bob Clark, Executive Director of the Carpet Cushion Council

The goal of the review process was to ensure that the report and the review process conform to the following LCA standards:

- ISO 14040:2006. Life cycle assessment — Principles and framework
- ISO 14044:2006. Life cycle assessment — Requirements and guidelines
- ISO/TS 14071. Life cycle assessment — Critical review processes and reviewer competencies

The LCA report is intended for use internally at MRC, but also for knowledge sharing with similar programs in other countries and regions, and for communication with the public and regulators. Since the study is intended to be used for comparative assertions shared with third parties (including the public), the critical review panel was convened. The panel was asked to assess whether:

- The report is understandable and results are presented clearly
- The methods used to build the LCA model are consistent with ISO 14040 and 14044, and are technically valid
- The information and data used to build the models are appropriate and scientifically defensible
- The interpretation of results is reasonable, and consistent with the limitations identified

The review did not include a separate assessment of the Life Cycle model. However, the review did include review of the process inventories developed for this study. It also included an assessment of the general approach used to complete the study, including consideration of the individual datasets applied, and specific assumptions regarding displacement relationships.

Critical review Process

The critical review process began with a meeting between the study practitioner and all members of the review panel. An overview of the study was presented by the practitioner, including the goals of the study, and the methodologies used. The review panel then met separately, to begin the review process. Each panelist reviewed the report and provided independent comments. The review panel met again separately to review the comments and allow the panel chair to produce the consolidated feedback form, which was shared with the LCA practitioners.

The practitioners then provided responses to each comment and described the updates to the models and report. Changes were made to address every comment. The practitioners provided the panel chair with the updated report, data tables, and the replies to each comment. The replies identified the changes made, and the section of the report containing the edits.

Result of the critical review

The following topics, from the reviewers' comments, are important when understanding the scope of the study and nuances and assumptions reflected in the results:

- One of the goals of the study is to develop a framework that can enable international collaboration. At the same time, a reader should understand that any particular set of results are relevant for a particular context. In this study, the baseline scenario is California, circa year 2021. Results will depend on the geography, markets, and practices of the particular time and place for any scenario.
- The degree of substitution between rebond foam pad (made with recycled foam) and a new foam pad is uncertain. Because the product made from recycled material (rebond foam pad) is usually economically preferred, we assume a relatively low value for the replacement value (1 unit of recycled foam pad replaces 0.3 units of new foam pad). We present a range of values on all displacement values to account for this uncertainty. And

we present an alternative scenario where mattress-derived, post-consumer foam does not displace any new foam. The market dynamics governing these relationships will change with time and place.

- The baseline scenario represents the situation in California in 2021. As the types of mattresses in the end-of-life stream changes, and as the compositions of those mattresses changes, the model should be updated to reflect the evolving end-of-life mattress mix.

The practitioners thank the reviewers for their keen and constructive comments.

Opinion of the reviewers

Based on the independent verification objectives, the Life Cycle Analysis of Mattress Recycling in California- Final Report, v1.0, November 2023 was determined to be in conformance with the applicable ISO standards. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

Critical review sign-off

As the Chair of the external independent third-party review panel, I confirm that the members of the panel have sufficient scientific knowledge and experience to evaluate the referenced products and the applicable ISO standards to carry out this verification.

Jeffrey J. Zeman
Principal
TrueNorth Collective LLC

TrueNorth Collective

November 15, 2023

Kyle Meisterling
Scope 3 Consulting LLC

Verification Report: Life Cycle Analysis of Mattress Recycling in California- Final Report

The Life Cycle Assessment (LCA) practitioner, Scope 3 Consulting, commissioned a panel of experts to perform an external independent verification of an LCA study on mattress recycling and material reuse activities in California on behalf of the commissioning organization, the Mattress Recycling Council, California.

The review of the study was performed to demonstrate conformance with the following standards:

- International Organization for Standardization. (2020). *Environmental management - Life cycle assessment - Principles and framework* (ISO 14040:2006/Amd 1:2020).
- International Organization for Standardization. (2020). *Environmental management - Life cycle assessment - Requirements and guidelines* (ISO 14044:2006/Amd 1:2017/Amd 2 2020).
- International Organization for Standardization. (2014). *Environmental management -- Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006.* (ISO/TS 14071:2014).

The independent third-party verification was conducted by the following panel of experts per ISO 14044:2006 Section 6.2: Critical Review:

Jeffrey Zeman
Principal
TrueNorth Collective

Robert Clark
Executive Director
Carpet Cushion Council

Tracey Pryor
Director of Innovation
Australian Bedding Stewardship Council

Review Scope

The intent of this review was to provide an independent third-party external verification of an LCA study report in conformance with the referenced ISO standards. This review did not include an assessment of the Life Cycle Inventory (LCI) model; however, it did include a detailed analysis of the individual datasets used to complete the study.

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Review Process

The review process involved verification of all requirements set forth by the applicable ISO standards cataloged in a comprehensive review table along with editorial comments. There were several rounds of comments by the reviewers submitted to the LCA practitioner. Responses by the LCA practitioner to each issue raised were resolved and acknowledged by the review panel to have been satisfactorily addressed.

Verification Statement

Based on the independent verification objectives, the **Life Cycle Analysis of Mattress Recycling in California- Final Report, v1.0, November 2023** was determined to be **in conformance** with the applicable ISO standards. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

As the Chair of the external independent third-party review panel, I confirm that the members of the panel have sufficient scientific knowledge and experience to evaluate the referenced products and the applicable ISO standards to carry out this verification.

Sincerely,

Jeffrey J. Zeman
Principal
TrueNorth Collective LLC