MATTRESS RECYCLING

Scoping study

MAY 2021

Source: John Robson

PREPARED BY

QUT Centre for a Waste-Free World

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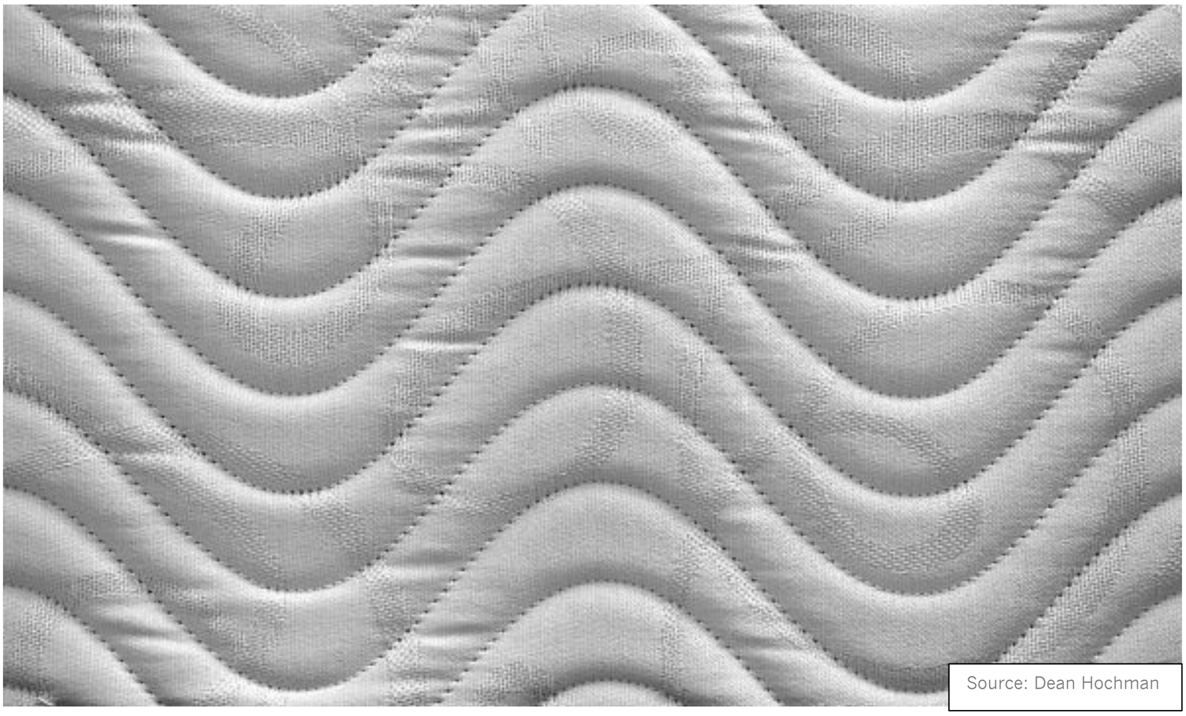
Disclaimer
This research was commissioned by Wanless Waste Management. The purpose of this report is to assist their work in diverting mattress waste from landfill. Any views and recommendations expressed in this report do not necessarily reflect the views of Wanless Waste Management or indicate a commitment to a particular course of action. Wanless Waste Management makes no representation or warranty as to the accuracy, reliability, completeness or currency of the information contained in this report.

TABLE OF CONTENTS

About waste management practices


Source: Dean Hochman

INTRODUCTION

An average of 1.6 to 1.8 million mattresses are disposed of annually in Australia (Planet Ark Recycling, 2020). Only a small percentage are recycled. The majority of mattresses post-consumer use wind up in landfill. Each one amounts to .75m^3 space (soft landing, n.d.), and the leeching of flammable chemicals may precipitate fires on site. Collectively, this practice has contributed to a waste crisis that requires better solutions. This report looks at mattress components, disposal practices post-consumer use, and waste recycling methods. Manual to technological recycling processes have been evaluated to show opportunities through research and development for improved health, safety, reduced environmental risks, and extended life cycle of resources.

Executive summary

The objective of this study was to formulate a change management plan for end-of-life (EOL) mattresses. It would provide the foundation on which activities will be built to integrate more effective ways to eliminate mattress waste, following principles of industrial ecology.

Mattress recycling reduces greenhouse gas (GHG) emissions through diversion from landfill, and it allows repurposing rather than needing as much virgin material for manufacturing. An enhanced recycling program could also save on landfill levies to generate much greater profit and income through employment.

In this study, an overview of mattress recycling to date was set forth, identifying gaps that cater to the needs of Wanless Waste Management to determine what could be addressed to fill these gaps in current mattress recycling processes.

It was imperative to detail the contents in mattresses. Mattresses are known for having carcinogens and other hazardous components, particularly in the polyurethane foam, adhesives, and flame retardants that pose serious risks to people and biodiversity. Hence, recycling procedures must be enacted according to legislative regulations to protect the health and safety of workers as well as to mitigate risks to the public. Breaking down mattress components with new processes is an opportunity to not only overcome these issues, but it can yield benefits since mattresses are composed of multiple valuable materials that can be separated to become the feedstock as input for remanufacturing.

What is apparent from conducting this study is there is enormous potential to scale value from the recovery of resources from unwanted mattresses, especially due to high turnover rates that come from commercial and industrial facilities such as hotels and aged care facilities.

Various recycling techniques were examined prior to making suggestions for introducing future pathways. Wanless aims to annually divert 250,000 mattresses from landfill by 2024, to repurpose approximately 250 tonnes of cotton/polyester fibre, 500 tonnes of foam, 500 to 700 tonnes of biomass, and 3,000 tonnes of metal.

Options were presented to shift to novel and cleaner technologies and engage in employment of locals to capture higher social, economic, and environmental outcomes using a staged approach. First, it was recommended to transition to better mattress sorting technology that can be enhanced through implementing efficiencies in robotics and better shredding devices. Next, a series of research projects were planned to utilise chemical and thermochemical processes to break down the separated waste from cotton and polyester. Fibre is very difficult to process, but it holds promising gain through conversion that can result in end products or intermediary byproducts for manufacturing.

Then investing in other types of product development from residual waste materials were explained to show how products or composites can be generated for added market value. When operational, the system can be a template for replication across Australia to position Wanless as a leader in mattress disassembly and technological innovation for industrial ecology.

As the project unfolds, milestones to carry out the proposed activities can chart progress over time.

KEY PERFORMANCE INDICATORS CAN MEASURE THE ECONOMIC, SOCIAL AND ENVIRONMENTAL IMPACTS FROM INTRODUCING INNOVATIVE SYSTEMS

Methodology

The data gathering for this project was approached through the following steps to prioritise the actions for effective waste management and resource recovery.

1. Initially meetings were conducted via telephone and Zoom with the Wanless Waste Management CEO and the Director at their Sydney recycling plant to understand the client's mattress recycling goals and operating constraints.
2. A literature review was carried out to document the myriad of internal and external mattress offerings by bedding manufacturers, and to look at studies of mattress parts and health effects thereof. Applicable governmental regulations and processes for recycling mattresses in Australia and abroad were also taken into account to become informed of how mattress recycling needs to conform with OHS and other legislative standards at recycling facilities. This review entailed searching peer-reviewed articles and grey literature on the Internet, scanning company websites, and linking to YouTube videos to assess existing labour and equipment for mattress recycling.
3. Conversations by email and phone were held with national and overseas recycling companies, Circom and Applied Machinery, that use reengineered equipment to disassemble mattresses. Follow up communication was exchanged to assess the feasibility and costs of procuring or licensing equipment. These conversations were extremely insightful about how to engage in better practices to sort and shred mattress parts.
4. Similar communication was exchanged with several consultants from Nextek that have experience in recycling polymers to investigate about processes for market development once mattress components have been 'cleanly' removed.
5. Downstream supply chain processors were considered to see how Wanless can leverage greater relationships with their existing partners. Opportunities to tap into relationships with new partners in resource recovery and reuse were also explored.
6. This report was written and presented to Wanless Waste Management to highlight the findings and strategic actions to realise greater mattress alternatives post-consumer use. These efforts would help to mitigate waste with the implementations of cost-effective and sustainable methods to prolong the life cycle of mattress components. Then solutions were proposed by members of the CWFW to develop novel technologies and IP for market commercialisation from pilot to industrial scale by harnessing the skills and experience of QUT researchers along with advisors or consultants as required.

Mattress materials & risks

Mattresses are constructed of a range of materials which are associated with known risks. Since the 1960s, the majority of mattresses have been made with polyurethane foam. This petroleum-based product emits volatile organic compounds (VOCs) which may cause skin irritation and respiratory illness (Ott, Diller & Jolly, 2003). While ingredients vary in these traditional or newer types of memory or latex foams, all of them may have dangerous chemicals. In natural foams, diphenyl diisocyanate, phenol-melamine resins, and waxes styrene-butadiene copolymer may be substituted. Diphenyl diisocyanate produces natural latex. Phenol-melamine resins gives natural latex foam its flexible property, and waxes add resistance and durability to these foams. It acts as a thickening agent due to its gelling properties, but mattresses often blend polyurethane with latex in foam.

To bond these inner layers in mattresses and to adhere the cover to the mattress core, manufacturers will apply glue which can be either rolled on between layers or sprayed over surfaces with a water-based adhesive. When the water evaporates, only the glue that tends to emit VOCs remain. Formaldehyde is one common adhesive which has been correlated with asthma, allergies and cancer. Manufacturers may add perfumes or deodorizers in polyurethane memory foams to try to cover up the strong effect of odours (Hiller, King & Henneuse, 2009). Certain chemicals in air fresheners may be carcinogenic or toxic to reproductive and development health.

In response to individual and cumulative threats, natural mattresses and glues have become increasingly popular. Further, legal restrictions were imposed to prohibit the sale and manufacture of mattresses with pentaBDE (PBDE), a member of the polybrominated diphenyl ether family of flame retardants after it was found to be bioaccumulative and a known poison to the thyroid, liver and the central nervous system (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2009).

Without this protection though foam can spark a catastrophic reaction that can lead to a ‘flashover’ effect where everything nearby that is combustible can simultaneously ignite. For this reason, the U.S. Consumer Product Safety Commission (16 CRF Part 1633) mandated that no mattress is permitted to generate a peak heat release above 220 kilowatts when subjected to gas burners that mimic burning bedding. This performance standard focusses on the heat release rate to slow the pace of a fire spreading (Betts, 2008). Hence, manufacturers no longer insert PBDE, but they add barriers, and they are not required to divulge what chemical formulas are inserted due to supposed protection of trade proprietary secrets. Instead, statements are issued by manufacturers to claim that they meet all safety standards.

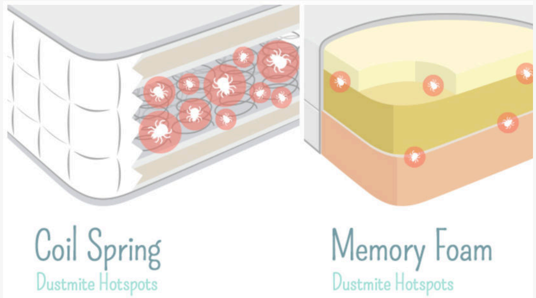
For safety reasons, many of these companies also now use a variety of fabrics treated with relatively benign chemicals such as cotton combined with boric acid, or rayon combined with silica. However, other manufacturers include fire-resistant materials, either by applying modacrylic fibre which contains antimony oxide and causes cancer, or they insert melamine as a resin which is composed of the toxic substance, formaldehyde. Further, textiles in fabrics may have been treated with pesticides which can cause nervous-system disorders and cancer (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2009). Despite the outer treatments that are employed, chemicals break down over time, and can escape.

Mattress materials & risks

Aside from spongy fills and soft fibres, mattresses often contain different types of coil springs to provide stability and sturdiness in body support. An inner spring system has cavities where dust mites can thrive and trigger asthma or allergies. Mould and mildew are other allergens that can breed in spaces that are warm and damp due to transferring one's body heat to a mattress. Latex made from natural sap is a good source of prevention. Avoiding wool batting can also keep mattresses cooler to minimize VOC emissions (Hillier, King & Henneuse, 2009), and to block nesting areas for dust mites, places where they can thrive under humid conditions.

People sometimes resort to buying waterproof plastics covers or spraying waterproof chemicals onto surfaces as a barrier, but vinyl covers which derive from polyvinyl chloride (PVC) can cause off-gassing that thereby releases the carcinogen, vinyl chloride. These forms of waterproofing are therefore ill-advised for use (U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, 2006).

To counteract possible deleterious effects, many companies now offer fabric covers and wadding that is made from GOTS certified 100 percent organic cotton or bamboo to show they are free of pesticides, fungicides and the harshest known chemicals. However, it is important to note that mattress recyclers and landfill operators receive all types of mattresses. When mattresses or components are stockpiled, fires can erupt as they derive from highly flammable petroleum-based materials and additives, e.g., flame retardants, that can leach during degradation..



Source: Time4sleep


Source: Tambako

Life cycle analysis

THE CAPACITY OF THE WASTE MANAGEMENT COMPANY TO COLLECT & RECOVER FOR REUSE

The main methods of mattress disposal and collection involves kerbside pickup, landfill drop-off or illegal dumping. Mattresses are big and bulky which renders them hard to handle though for collection and transport, resulting in a lot of illegal dumping. Their low density also means they are undesirable material for landfill, and box springs can damage transfer station and landfill equipment (ISPA, 2021). Recycling is problematic due to this poor technical feasibility coupled with low economic recovery rates of resources. Businesses that conduct recycling use manual to mechanised processes. Both methods have a different capacity for separation. Currently, Wanless operates a number of waste management facilities to fulfil commercial contracts in New South Wales, Victoria and Queensland. It has a recycling plant for mattresses in New South Wales and is looking to expand in other regions. There is another national-based company that specifically deals with mattress recycling, the social enterprise, soft landing. Not-for-profits generally fill the void by operating in the volatile marketplace of mattress recycling. However, this organisation cannot keep up with the volume of mattresses that they collect. Therefore, Wanless is responsible for handling their excessive load. It contributes an additional burden to its waste stream.

However, studies show environmental benefits of recycling. Natural fibre spring mattresses emit marginally less GHG than foam spring mattresses. Yet, when EOL scenarios are measured, results demonstrate ample reductions in GHG for natural fibre than foam mattresses. Refurbishing and repurposing the natural fibre, springs and residual waste can lessen emissions by 90 percent compared to sending mattresses to landfill. Research on high-end pocket spring mattresses from a U.K. manufacturer alone estimated that implementing recycling can annually save between 210 and 2092 thousand tCO_2-eq (Glew et al., 2012). Another U.S. study estimated that by annually recycling all 35 million EOL mattresses there, it could save 1 to 1.5 million MT of GHGs (Geyer, Kuczenski & Trujillo, 2015). Alternatively, by converting the textile waste to ethanol reduces GHG emissions except to a lesser extent than refurbishment and recycling. And incineration in heat and power plants of stitched panels and mostly felt and polyurethane layers is reserved for energy-from-waste (Griffiths et al., 2013). Each mattress emits 48 kilos of CO_2. As a consequence, the Department of Environmental Protection in the state of Massachusetts proposed a ban on disposal, incineration or transfer of mattresses and textiles for disposal at a solid waste facility (Massachusetts Municipal Association, 2020), The Netherlands also wants to impose restrictions on incineration to surmount the enormous quantity of emissions that resulted from burning mattresses (RetourMatras, 2021).

Post-consumer waste options

EVIDENCE FROM RESEARCH & DEVELOPMENT

Mechanical recycling of polyurethane foam can transform cutoffs into rebonded foam for remanufacturing purposes. However, the market lacks the capacity to absorb the large volume of foam that could be derived from all used mattresses, and there are limited applications. Foam also cannot be melted into pellets like other plastics at its EOL. Therefore, other technologies are needed to arrive at solutions for this waste stream. Multiple projects across Europe in particular are tackling commercialisation of regenerated polyurethane technology (European Association of Flexible Polyurethane Foam Blocks Manufacturers (EUROPUR), 2021). Through chemical reprocessing with glycolysis, repolyol has been achieved by researchers at the quality and consistency of virgin polyol and for both rigid and flexible foam (Gama et al., 2020). The intent of companies like BASF SE and Dow Polyurethanes is to use repolyol in industrial scale remanufacturing. They are collaborating with H&S Anlagentechnik on a RENUVA™ Mattress Recycling Program that aims to turn discarded foam back into new mattresses, a truly circular endeavour.

Another team is working to develop a new type of polyurethane, covalent adaptable polyurethane (CAPU), that ideally would possess the properties of other plastics and facilitate easier recycling (EUROPUR, 2021). Taking polyester back to polyol even without further separation from foam is a further area of research and development that is underway. Researchers Vanbergen et al. (2020) investigated how to obtain higher efficiencies of flexible polyurethane foam through additives and alcoholyzing agents. They found “split-phase alcoholysis of flexible polyurethane (PU) foam yields an apolar phase containing the recycled polyether polyol, and a lower, polar phase of the alcoholyzing agent and aromatic compounds. However, multiple purification steps are required to render the polyether polyol suitable for synthesis of new flexible PU foams; the unfavorable mass balance limits industrial applications. In this work, 2-pyrrolidone was identified as a performant additive for accelerating the dissolution and depolymerization process. By applying a lactam to PU foam in a weight ratio of 0.1:1, the glycol to PU foam weight ratio can be decreased from 1.5:1 to only 0.5:1, without loss of purity or yield of the recycled polyether polyol. Diglycerol was discovered as a novel, promising alcoholyzing agent; it allows the recycling of the polyether polyol in high purity (97%) and excellent yields (98%), and after a single washing with diglycerol, a sufficiently low hydroxyl value (61 $mg_{KOH}\ g^{\square 1}$) is reached.

The recycled polyether polyol can replace the virgin polyether polyol (48 $mg_{KOH}\ g^{-1}$) for up to 50 % in the synthesis of new flexible PU foams with effects on the foam quality that stay within the limits of generally accepted specifications. A first step towards the valorization of the lower phase was also taken by applying hydrolysis of the newly formed carbamates to toluenediamines, which are readily reintegrated in new PU foams (Vanbergen et al., 2020, 3835).”

There are also experiments in transit to make composites of mattress parts. A team from the Czech Republic (H´ysek et al., 2019) designed thermal insulation panels by bonding polyurethane foam with wheat husks. Utilising natural fillers over synthetics is growing in industry applications such as making automotive components and construction materials due to inherent advantages. Husk takes less energy to process; it is non-abrasive; it has a lower density as a finished product; it has good acoustic and thermal properties; and it can be fabricated into panels for buildings. Although using natural fibre or a composite that includes filler for strength can absorb moisture which might interfere with the mechanical properties, by mixing husks with polyurethane, any downside with synthetics can be avoided, resulting in high-quality thermal conductivity of the boards at 0.0418-0.0574 W/(m.K).

Biological degradation is another area, testing how to degrade post-consumer and post-production polyurethane waste, and trying to desensitise those materials that are sensitive to degradation. Bioremediation of water and soil that is contaminated with polyurethane is additionally being explored by researchers (Kemona & Piotrowska, 2020). All this work reflects the critical importance of finding more sustainable pathways to eliminate polyurethane waste and discover new applications for all mattress materials.

Evaluation of equipment

MANUAL TO AUTOMATED PROCESSES TO REACH OPTIMAL RECYCLING & REUSE

Upcycling components

Approximately 85 percent of mattress materials are currently capable of being salvaged and resold (European Commission, n.d.) Common purposes for upcycling are:

12.5kg of steel in springs –> scrap metal
2kg of timber in frames –> mulch, chipboard, kindling, animal bedding & biofuel
1.5kg of foam and latex –> carpet underlay, gym mats, boxing bags, acoustic insulation panels & packaging
Wheat husk –> weed matting & mulch
Felt padding & fabric –> acoustic insultation panels & oil filters

Source: Alan Stanton

Wanless accepts up to 1,000 mattresses per day and processes them with a European manufactured slow-speed shredder. The recycling centre is located in a 5,000 square metre building that has a 12-metre internal clearance, a dust extraction unit and runs on a 600amp electrical supply to remove a portion of metal with an overbelt magnet. This machine has the ability to process 15 to 30 tonnes of mattress materials per hour using intertwining shafts for shredding. Remaining materials (wood, fabric, PU foam and natural fibres) are compressed, but they are difficult to separate from each other and wind up commingled in landfill. Yet, there are markets for the majority of materials in the marketplace.

If Wanless can upgrade this process to separate more materials, and clean the metal to remove fibre, then the company could exploit such opportunities. Wanless is also interested is discovering better ways to divert the textiles that are challenging to find reuses but are considered quite valuable relative to other mattress elements.

The waste management company also wants to resolve problems with fires that trigger in the residual solid waste mix. Refinement of their processes in conjunction with safer storage and disposal of the mattresses at their recycling centre is deemed of utmost importance.

Equipment options for greater impact

ECONOMIC
BENEFITS

SOCIAL
BENEFITS

ENVIRONMENTAL
BENEFITS

Alternative mattress recycling processes, predominantly mechanical, have been developed, both overseas and in Australia to improve the efficiency and raise the value of recycled materials; hence, to reduce the amounts of materials send to landfill. These mattress recycling processes involve:

- Manual or automated cutting of the outer cover to enable stripping of top/ bottom/ sides from metal spring core
- High-pressure air or water jetting with an overbelt magnetic separator
- Automated shredding / ripping rollers to remove the outer polyester / cotton and polyurethane foam from metal
- Metal compaction or cutting and baling to increase built-up density for resale
- Facilities to separate and store residual materials for downstream remanufacturing

There are pros and cons with each method. Manual recycling is highly labour intensive, but workers can be hired to perform certain tasks. It offers income and social opportunities. This method has historically been a successful business model, particularly by employing people who experience disadvantage.

Workers can cut apart the sides to pull off the cloth and extract the foam which may have springs that need to be detached. The foam can be chopped and baled for reuse. However, box springs are challenging to separate because they might be affixed to wooden slats or a board with fasteners or staples.

A patent was issued for automated box spring separation (U.S. Patent No. 9,321,138 B2, 2016). This device basically relies on placing a mattress in a block support frame. Then a cylinder operates to push out the box springs while forks simultaneously hold onto the springs in place to prevent them from buckling under the pressure. The cover can be cleaned and sanitised, and the filler and foam can be chopped for reuse. A U.K. recycler, TFR Group, invented a machine that exclusively deals with pocket spring mattress recycling as well. Since Wanless recycles only a small portion of these types of mattresses, it has limited value for them. They are seeking equipment which Is multi-functional.

Regulatory considerations

PRODUCT STEWARDSHIP TO CONSUMER PROTECTION

Source: Alan Stanton

Although the decision to support and follow a Product Stewardship Scheme is voluntary in Australia, the mattress recycling site must comply with regulatory measures to manage health and safety of workers, contractors and the general public. These measures avoid chemical contamination among other forms of protection. It is likely for policy to become more stringent due to recent passage of National Waste Policy Action Plan 2019 (Australian Government, 2019), phasing out exporting of specific material groups e.g., unsorted mixed plastics, unprocessed single polymer or resin plastics. Nevertheless, states and territories are working towards developing their own laws for mandatory EOL product management, so it is foreseeable that the scope of materials will enlarge to encompass mattresses because this waste stream is a major contributor to the overall waste crisis.

Only the countries, France and Belgium, have extended producer responsibility (EPR) schemes. This is a broader product stewardship standard that holds producers, importers, and occasionally sellers responsible with environmental legislation. Other nations may follow suit. The UK is emerging with a strong preference for a mandate led by Scotland. The U.S. has three EPR schemes at state level. Connecticut, Rhode Island, and California enacted a producer responsibility ordinance (PRO),

RELEVANT EPA GUIDELINES AT THE SYDNEY RECYLING CENTRE PREVENTS THE USE OF HEAT TO PROCESS MATERIALS, BUT SEPARATING, CRUSHING, AND GRINDING ARE PERMITTED.

and they set up a Mattress Recycling Council to oversee the fees, Infrastructure, and reporting practices through running a collective program. Connecticut became the first U.S. state to pass a consumer protection law to enforce sanitisation of used mattresses since bed bugs lurking in mattresses can cause infestation, especially when transported elsewhere. Consumers actually find mattresses a nuisance to dispose of and landfill operators incur fees due to the higher volume of space that they occupy. However, individual states and local agencies seem to bear the brunt of waste management costs. Levies are administered to try to offset these expenses. Two U.S. systems, however, have been established to target producer responsibility and pass on fees that usually extend to consumers—cost internalisation and advanced recycling fees. Europe and Japan opted instead to enact systems for joint responsibility. Producers are held accountable for their part in the process where they can exert an influence, that is, during transport and recycling; and municipalities or retailers must pay for collection costs (Product Stewardship Institute, Inc., 2011). The remaining responsibility falls on recyclers.

Recommendations

BEST PRACTICES

Five main technical operations have been identified in a best performing EOL mattress treatment facility (European Commission, n.d.):

- feeding and storage: reception (unloading) and dry storage to avoid contamination, sorting by type
- sanitising: applying chemical or heat treatments for sterilisation
- filleting: cutting the mattress' outer fabric cover and the binding flanges
- disassembling and sorting: separating and sorting the different materials by type
- handling materials: baling processes, product storage as bales, loose material (sorting residues) or in containers (metals), before delivery to downstream processers (e.g., recycling of metals)

Despite waste management and resource recovery of mattresses varying across state, national and international levels, there is still monumental global demand to come up with better solutions. Adopting change is not only prudent, but it can become a competitive advantage. Organisations that recognise this significance are leaders, expending efforts in higher throughput from mattress separation and repurposing of embedded material streams. To make inroads through change cannot realistically happen overnight.

A phased approached is therefore suggested to attain improved waste management and resource recovery practices by Wanless. First and foremost, equipment should be upgraded or replaced as soon as possible to improve mattress processing, allowing room for future growth, especially to replicate the model at a forthcoming recycling park in Queensland and steer further expansion.

While this is happening, the easiest materials to separate by hand should be carried out to complement the current shredding process at the Sydney recycling centre. It will raise the resale value of components well above the present $30 per mattress rate of extracting and selling only a portion of metal for scrap with the current inadequate shredder.

During this period to sign an agreement to purchase, license a new system or obtain accessory pieces that can be linked to the currently used shredder, more interstate buyers should be contacted to sell the larger supply of mattress parts. If buyers are nearby, then the logistics will not make the recycling exercise cost prohibitive.

Profit earned from selling additional material can help to offset hiring workers who need to hand strip and remove fibre or wood components prior to shredding and dislodging any metal. These staff can be retrained when better automated equipment is integrated into business operations.

Viable equipment should entail a shredder, conveyor belts, separation chamber, and a dusting system (see appendix). The shredder fitted with overbelt magnets for metal extraction should not macerate and intermingle all valuable components. Then the conveyor belts can partition metal from non-metal objects that comprise low-grade textiles and foams. Air jets can help to disperse the fibre from foam. Machinery speeds may also be adjusted to obtain less metal contamination and preferred fibre lengths for reprocessing. Another equipment option is a self-contained hydrologic engineered unit. Jets of water pressure blast the mattresses, effectively forcing foam and fabric to fall off the metal, but the water leaves any further separation challenging.

Recommendations

Innovative research and development

For this reason, a single or modified dual shredder device with a conveyor system is suggested to keep components in a drier state. As seen in the project flow diagram overleaf QUT researchers can lend their expertise to enhance this technology through sensors and analysis that will bring more efficient sorting of different mattresses, e.g., coil springs Next, robotics and other appropriate technology can facilitate further physical breakdown of mattresses into material streams.

Then researchers can contribute their knowledge of biochemical conversions and thermochemical processes to develop new applications for the separated materials. One team has already trialled breakthrough processes for fibre through a patented process to separate polyester cotton fabrics into cotton powder and polyester pellets that is ready for production.

While there has been success in recycling the other components for specific applications, there is little to no way to recycle the fabric covers taken from all products (Australian Bedding Stewardship Council, n.d.). Fabrics is a logical choice to pursue with R&D based on the under-research in this area, and its higher potential to source economic value. Several innovations to be explored involve processes to degrade or partially degrade cotton and/or polyester for multiple potential constructive uses.

Techniques that would be suitable are to:

- Separate cotton from polyester in the outer fabric layer
- Process cotton for new commercial opportunities, e.g., an oil
- Investigate fabric as a feedstock to develop unique carbon materials if it is sustainable.

QUT researchers can also foster broader uses for residual components in creating standalone products, e.g., foam insulation. Otherwise, the materials can be used to make composite products for downstream markets.

Some feasible composite product ideas include:

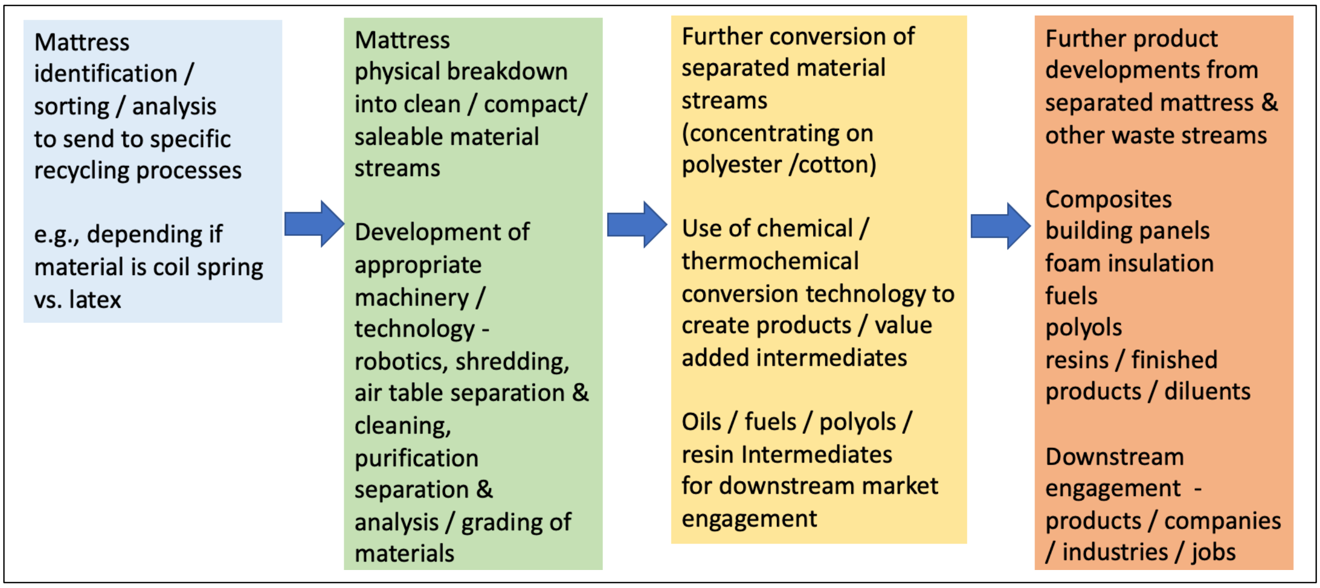
- Pressed and moulded building panels
- Asphalt and road furniture
- Resin/filler additives
- Lignocellulosic biomass with other waste streams for infrastructure or carbon-neutral energy

Lastly, Wanless could also effect change within its industry through engaging in another strategic initiative. In light of the lack of clear regulatory guidance about mattress recycling that results in illegal and inconsistent activity plus the limited incentives to stimulate secondary markets for waste, Wanless should associate with governmental bodies over the long-term to help regulators introduce a standard code of conduct for mattress recycling.

This effort could lead to uniform and ethical business practices, and it will pave the way for higher returns for resources if an EPR scheme is introduced. Furthermore, if systems are brought in to share the costs among producers, retailers, recyclers and consumers, then a level playing field could ensue whereby everyone is taking responsibility to remediate mattress waste.

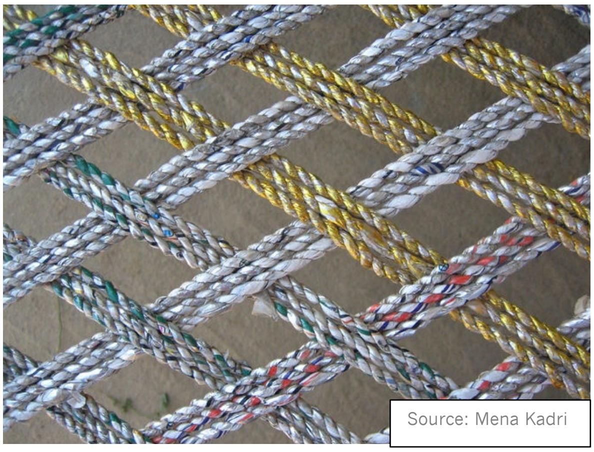
Recommendations

Project flow diagram



Partnerships for a circular economy

Resellers and remanufacturers can become associates to extend the life cycle of separated components



Source: Mena Kadri

There are many examples of how disaggregated materials can become part of a circular economy. From large corporations down to smaller start-ups, numerous businesses can become alliances to spur a marketplace for exchanging materials. Wanless already has partnerships in place for C&D (construction and demolition) and C&I (commercial and industrial) reprocessing. As stated, their recycling centre forwards metal to a downstream processor, Action Metals, and it has a relationship with a tree service company, Treeserve, that can turn excess wood into mulch or general solid waste is sent to Benedict Recycling for chipping into landfill cover or industry reuse. These relationships can be leveraged for further value to achieve its goal of 85 percent resource recovery and reuse. New partnerships can also be forged nationally and internationally when supplies enlarge. Bluescope Steel is a major purchaser of used metal. Dunlop Foams buys processed foam, and many companies accept timber that is not chemically treated or painted for upcycling, altogether saving up to 5000+ tonnes per annum in sending metal, foam and timber from landfill. This significantly helps to conserve precious timber resources. Mattress bags are desirable as sustainable cotton fabrics, and with R&D, polymers could become pelletised to remanufacture plastic that can be woven into making a bed base. In the Mandvi bazaar of India, the rope as shown above is made from spinning discarded plastic waste. A collaboration between UNSW researchers and a property developer produced 'green ceramics' from mixing composites with glass and textile waste of mattresses for a spec apartment.

PUBLIC AND PRIVATE COMPANIES CAN BE ENLISTED AS PARTNERS IN THE SUPPLY CHAIN

This pilot demonstration site revealed potential applications in wall tiles, flooring, kitchen and lighting, furniture and artwork. It revealed a glimpse of pioneering waste technology for commercial use. While recycling opened a window for waste treatment, more efforts are required to scale up methods for profit. Wanless can take advantage of modern manufacturing initiatives through more research and product development. In return, the company can give back to the community through direct employment at its site with plant operators and maintenance personnel, and indirect employment to construct new recycling plants. These efforts will preserve finite resources, and the company can support wildlife organisations that replace cut down forests by replanting trees to curtail emissions.

Summary of proposed project activities for added value

To create cleaner mattress component feedstocks for remanufacturing, and to develop new products from these recycled EOL feedstocks

PHASES	ACTIVITIES
1	BUILD INNOVATIVE, EFFICIENT & EFFECTIVE MATTRESS DISASSEMBLY PROCESS
2	CREATE & ENTER INTO NEW SUPPLY CHAINS FOR EOL MATTRESS COMPONENTS & PENETRATE FURTHER INTO EXISTING MARKETS
3	R&D TO CREATE NEW VALUE-ADDED PRODUCTS FROM WASTE STREAMS WITH LITTLE OR NO CURRENT MARKET VALUE WITH A FOCUS ON TEXTILES & FOAM
4	MARKET DEVELOPMENT FOR THE NEW COMMODITIES THAT WERE CREATED TO BE EXPLOITED

Members of the project team

PROFILES

LEONIE BARNER
RESEARCH DIRECTOR

ROBERT SPEIGHT
RESEARCHER

MIKE O'SHEA
RESEARCHER

ZHANYING ZHANG
RESEARCHER

DEEPAK DUBAL
RESEARCHER

LALEHVASH MOGHADDAM
RESEARCHER

AJAY PANDEY
RESEARCHER

JUDITH HERBST
PROJECT ADVISOR

As Director of the Centre for a Waste-Free World, Leonie Barner follows a holistic research approach that spans all disciplines of the Centre to support and connect academics in their pursuit of a waste-free world, applying principles of a circular economy and working towards the UN Sustainable Development Goals. Her research expertise lies in the field of macromolecular and materials chemistry.

Robert Speight has extensive experience in research for industrial applications. He maintains close industry collaborations and has built a portfolio of projects in the areas of industrial biotechnology, biochemistry and cell biology, and microbiology.

Mike O'Shea has more than 30 years of experience working as a chemist, chemical engineer, polymer scientist, innovator and developer of technologies/platforms and industry consultant. At QUT, he served as Chief Investigator of industrial and synthetic biology projects. Presently, he acts as the Research Leader of the Biorefining Research Facility for QUT.

Zhanying Zhang has many years of research experience in development of bioprocessing and biorefinery technologies for value-adding to byproducts and wastes generated from agricultural, forestry, food and wastewater treatment industries. His research aims to develop industrially applicable and sustainable technologies to solve real-word problems.

Deepak Dubal designs advanced nanomaterials, for purposes such as emerging clean energy storage technologies. He is involved in research around the recycling and repurposing of lithium-ion batteries, creating potassium and aluminium-ion batteries from textile waste and giving agricultural waste value.

Lalehvash Moghaddam is an analytical chemist with 10 years' experience researching the production of sustainable fuels, chemicals and plastics from industry byproducts. In collaboration with industry, she works to value-add agricultural byproducts to develop biofuels, bioplastics, and biocomposites.

Ajay Pandey's research interests include an interdisciplinary mix of photonics, chemical physics, molecular electronics, computer science and robotics that are aimed at creating new technological solutions to interdisciplinary research problems. He leads a number of major research projects, including development and implementation of advanced sensing technology for applications in neuroscience, intelligent bionics, medical robotics, energy up-conversion and robotic vision. He is a program leader within QUT's Centre for a Waste-Free World.

Judith Herbst has an industry background in marketing, and taught units on sustainability and innovation in management. Her research investigates enterprises that are undertaking industrial ecology initiatives. They are working to transform waste from commercial and industrial sectors into valuable resources, and thereby demonstrate how to adopt innovative processes for sustainable development.

QUT scientific researchers' skills and experience for project feasibility

No	Technology/Skill	Staff	Experience	Credibility
1	Robotics / Mechanical Engineering/ Sorting	Ajay Pandey	Intelligent Bionics, Medical and Soft Robotics	Intelligent Robotic Imaging System
2	Sensors / Analysis	Leonie Barner, Ajay Pandey	Macromolecular and Materials / analytical chemistry Fluorescent polymer nanoparticles as optimal imaging agents Intelligent sensors	Nanoparticle driven templating of microspheres as chromato-graphic materials
3	Thermochemical Conversion	Robert Speight, Zhanying Zhang	Thermochemical processes to control degradation / scission/ conversion of cotton/ cellulose	BlockTexx
4	Biochemical Conversion /Processing (including Reactive Processing / Extrusion)	Lalehvash Moghaddam Mike O'Shea	Catalytic fuel treatment Controlled breakdown of polyesters via REX / extrusion processing/ conversion of biomass (also upgrading/ foaming)	Publications/ Patents / Licenses/ Scale up
5	Separation Technology	Lalehvash Moghaddam	Distillation, solvent extraction	Phase separation, fractionation, recycling, lignocellulosic biomass
6	Downstream Product Development	Lalehvash Moghaddam Mike O'Shea	Wood adhesives from bioOil PU foams from PET PU foams from bioOil (lignocellulose) Recycled plastics/ polymers to value added products (upgrading, foams, coatings) Products from biomass	Ciba Irgamod RA20, VISY recycled PET / dual ovenable trays, nylex milk bottles, Pepsi BioPET, Coke can coatings

QUT's research centres have extensive expertise in the development of new recycling technologies and processes, especially in the area of biomaterials and plastics. These centres include QUT's state-of-the-art Central Analytical Research Facility (CARF) which is central for the characterisation of recycled materials and new value-added products.

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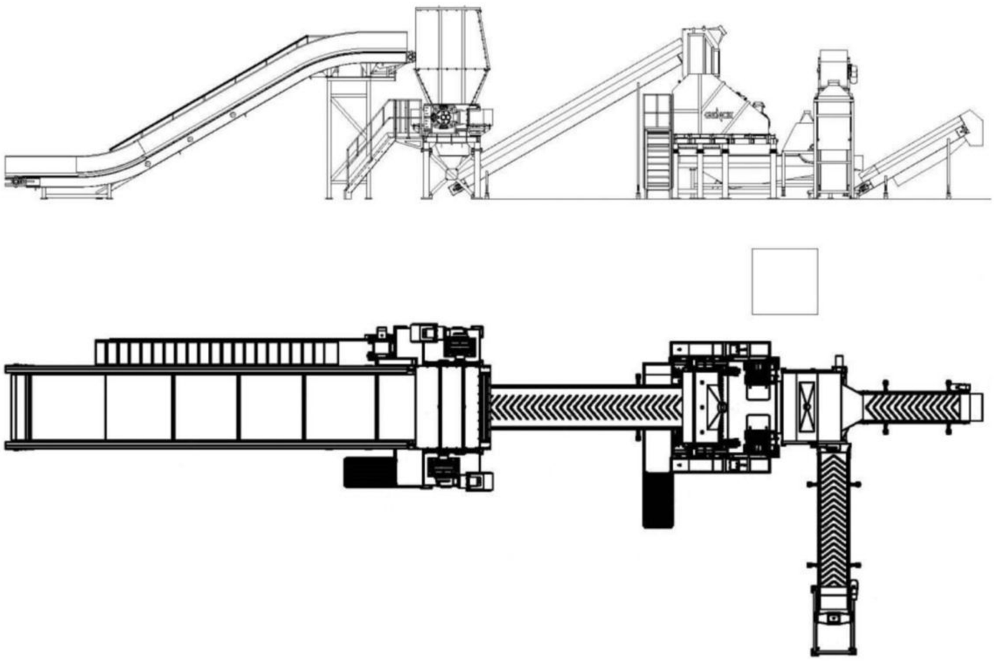
Appendix

MATTRESS RECYCLING SYSTEM

Conveyor belts, shredder, separation chamber and dusting system

Layout

Application Information
For Recycling used mattress into separated material Output Separated ferrous material and non-ferrous material.