



Mattresses must be disassembled by hand before their component materials can be recycled.

RECYCLING

Mattress recycling wakes up

New laws and evolving technologies for breaking down polyurethanes aim to create a more circular economy for mattresses

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When David Traub visited a landfill for the first time to dump a truckload of wood and drywall from a home improvement project, he expected to find a big pit full of junk and trash. He did not expect it to contain so many mattresses.

Old mattresses, Traub soon learned, are challenging for landfills to deal with because they're large and hard to compact. Landfills need to be able to fit as much trash as they can into as small a space as possible, so "anything that's preventing them from doing that is an annoyance," he explains.

Traub decided to do something to address that annoyance. In 2022, he started a mattress-recycling business, Deco Solutions, in a warehouse just north of Baltimore.

Maryland isn't the only place where people are trying to do something useful with discarded mattresses. Motivated in large part by rapidly diminishing landfill space, California and Connecticut

established statewide mattress-recycling schemes in 2015. Rhode Island followed in 2016. And, as of Jan. 1, Oregon became the fourth US state to implement a mattress-recycling program.

As recyclers work to improve the efficiency with which they disassemble old mattresses and pass the components along to secondary markets, researchers are working to develop new and improved technologies for turning polyurethane mattress foam into new products using chemistry.

"We're at the very nascent stages of what we can do with mattresses," says Michelle Williams, president of Mat Recyclers in Rancho Cucamonga, California.

Bed, trash, and beyond

According to the Mattress Recycling Council (MRC), the nonprofit organization that facilitates the four statewide recycling programs, about 75% of the materials in the average innerspring mattress can be recovered and resold to secondary markets. But fewer than 10% of the mattresses discarded in the US are currently recycled.

Traub says the mattresses his facility handles come mainly from hotels and hospitals in Maryland and the surrounding states. Most people are unaware that such facilities exist—or indeed, that their options for disposing of an old mattress could extend beyond calling a junk removal service or setting it on the curb on their city's bulk-trash pickup day.

Mike O'Donnell, MRC's chief operating officer, says the MRC program structure was inspired by paint recycling programs in the US as well as Ecomaison, an industry-funded organization formed to

comply with furniture-recycling regulations in France.

The state programs are designed to make mattress recycling easier for mattress owners, retailers, and local waste facilities, O'Donnell says. The programs are funded by fees added to the purchase of every mattress sold in participating states. Retailers are encouraged—or required, in California—to offer take-back options for old mattresses when people buy new ones. They then send the mattresses to collection sites throughout the state, where the program picks them up and transports them to recycling facilities. Individuals can also drop off old mattresses at the collection sites or take them directly to recycling facilities.

About 80% of discarded mattresses in California are now recycled through the program, Williams says.

Mattress recycling in the US isn't restricted to the four states that MRC operates in. Independent recyclers—including Deco—are scattered throughout the country. Massachusetts implemented a law in 2022 that prohibits disposing of mattresses in landfills, though there's no statewide recycling program in place. Other states are considering mattress-recycling legislation, including Maryland, New York, and Virginia.

Traub says he's advocated for the Maryland bill. It's moving more slowly than he'd like, but he hopes it will pass in the next few years. In the meantime, more people are learning that mattresses are recyclable, which he still considers a win.

In addition to administering recycling programs, MRC funds research projects aimed at making mattress recycling more efficient and developing new markets for mattress materials.

Bulkiness aside, mattresses aren't terribly difficult to recycle compared with other durable goods, says MRC research director Mike Gallagher. They're all approximately the same shape and made of the same few materials—fabric, foam, and metal, plus wood, if a box spring is in the mix. "It's fairly simple to separate the components," he says.

The separation process is, for the most part, manual. Inside Deco's warehouse, stacks of mattresses and box springs at one end of the shop floor give way to piles of metal and wood and bales of foam and fabric at the other end. In the middle, a worker uses a knife to slice the fabric topper off a mattress like he's gutting a fish. A second worker bales fabric by compressing it in a hydraulic press.

The metal springs are the most

recyclable of the lot, Gallagher says; the steel is sold as scrap metal and melted to make construction materials. The wood is typically turned into mulch. Textile layers can be used as insulation or padding. And the polyurethane foam is usually shredded and turned into carpet padding.

But as fewer people carpet their homes and all-foam mattresses rise in popularity, recyclers are looking for new things to do with postconsumer mattress foam. And that's where the chemistry comes into play, says Gallagher, a chemist by training who started working with MRC after retiring from the polyurethane maker Covestro.

All roads lead to foam

"Polyurethanes are the most complex polymeric materials I can think of," says Timothy Long, a polymer scientist and director of the Biodesign Center for Sustainable Macromolecular Materials and Manufacturing at Arizona State University.

By the numbers

4

Number of US states with mattress-recycling programs

61

Number of mattress-recycling facilities in the US and Canada

Under 10%

Proportion of discarded mattresses in the US that are currently recycled

75%

Proportion of material in a mattress that can be recycled

Source: Mattress Recycling Council.

The challenging thing about polyurethanes, Long explains, is that they're thermosets. Thermosets are highly cross-linked polymers that can't be melted and remolded like polyethylene or the other thermoplastics that people are used to tossing in their recycling bins. To do almost anything other than chop it up and glue the bits together into padding, recyclers must alter polyurethane foam on a chemical level.

There are two main schools of thought on the best way to use chemistry to elevate polyurethane's end-of-life fate. One is to break the polymer down completely to recover its component polyol and isocyanate monomers. The other is to modify it some other way to get value out of the material without fully depolymerizing it. Many of the full-breakdown efforts are concentrated in Europe, Gallagher says, because the European Union has more-aggressive waste-management policies that require a bigger push for recycling innovations.

Dow has been working on mattress-recycling technology since 2017. The company has been recycling up to 200,000 mattresses' worth of polyurethane per year at its plant in Semoy, France, since 2021. In an email, Andrea Benvenuti, a technical service & development fellow, says Dow's is the first industrial-scale process for chemical recycling of mattress foam. He adds that the company chose to pilot this technology in France because of the country's established collection scheme for mattresses.

Dow's process uses acids and alcohols to break down polyurethanes into polyol and amine compounds. The amines are not recovered, but the recycled polyol can be mixed with fresh polyols and isocyanates to make new polyurethanes for furniture and bedding. Ultimately, those new polyurethanes will contain about 10% recycled content.

BASF and Covestro have rolled out similar initiatives in Europe for depolymerizing mattress foam. BASF's approach also recycles just the polyol. Covestro recovers both polyol and an isocyanate precursor.

Separating the recovered monomers from one another and ensuring they're pure enough to be reused is the most challenging part of this kind of chemical recycling, says organic chemist Troels Skrydstrup of Aarhus University. Skrydstrup is part of a team of academics collaborating with industry partners in Denmark, including the mattress company Tempur, to devise better ways to chemically recycle polyurethane.

It's hard enough to efficiently recover the polyol and isocyanate components from a single polyurethane. But there are

many types of polyurethanes. Even within a single product category, such as mattresses, the foams' chemical makeup can vary quite a bit, Skrydstrup says. Additives such as surfactants and flame retardants further complicate separation.

"You can't just go to a dumpster and take all the mattresses and think you can recycle them" in the same waste stream into pure monomers, he says.

Skrydstrup and his colleagues devised a method for disassembling polyurethanes into polyols and amines using an inexpensive alcohol solvent and potassium hydroxide (*ACS Sustainable Chem. Eng.* 2023, DOI: 10.1021/acssuschemeng.3c01469). After the products are separated, the polyols can be used directly to make new polymers. The amines can become the precursors to new isocyanates.

Skrydstrup says it's almost "embarrassingly simple." The key is heating the polymer above its ceiling temperature—the point at which polymerization and depolymerization happen at the same rate. For polyurethane foam, that point is usually around 200 °C.

It's not flashy chemistry, Skrydstrup says, but it works. And most importantly, it works on samples of postconsumer polyurethane foam, though currently the project is focused on recycling waste from factories. Skrydstrup and his coworkers have patented the process and are now applying a similar approach to recycling textiles.

Jumping on new chemistry

Meanwhile, other chemists are investigating how to break just enough of the bonds in polyurethane so that it's recyclable using the existing infrastructure that's used to reprocess thermoplastics. That tactic might save money and energy compared with full depolymerization, so it's one of the strategies MRC is most interested in, Gallagher says.

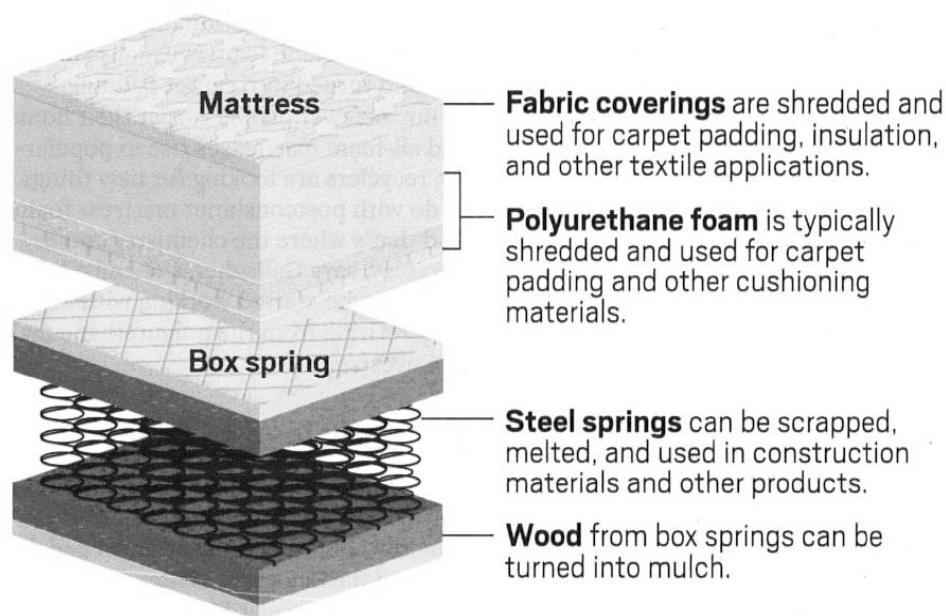
William Dichtel's laboratory at Northwestern University has been collaborating with BASF researchers for about 5 years to give polyurethane a dynamic covalent makeover. Dichtel's team found that embedding a catalyst into polyurethane makes the carbamate bonds in the cross-linked network exchangeable with one another. Exchangeable bonds make what was

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Mattress recycling breakdown

Most materials in a discarded mattress can be separated and used for a secondary application.



Source: Mattress Recycling Council.

once a thermoset remoldable, with a little bit of heat (*Adv. Mater.* 2024, DOI: 10.1002/adma.202305387).

"It's very possible that most of the polyurethane used today could be reprocessed," Dichtel says. He thinks mattresses are an interesting arena for this type of recycling because there are dedicated collection schemes for them that could provide a steady supply of foam.

Dichtel's process can turn scrap foam into hard plastic or new foam. No solvent or separation is necessary. The flip side is that the reprocessed material will carry with it all of the additives of its predecessor, so it's not infinitely circular. Dichtel says the team is now making the process more efficient and affordable for scaling up.

MRC gave funding to a company called Edge Global Innovation to develop a similar dynamic covalent recycling solution. Known as VitriCycle, the technology converts polyurethane mattress foam to plastic pellets that can be incorporated into shoe soles, phone cases, and similar products.

Polyurethanes may be challenging to break down, but foams have a lot of surface area, which presents interesting opportunities for doing chemistry on

them, Arizona State's Long says. He and his team have investigated a myriad of strategies for polyurethane recycling, including partially de-cross-linking the polymers to make adhesives and producing easier-to-deconstruct polyurethanes using bis(2-hydroxyethyl) terephthalate from recycled polyethylene terephthalate plastic. They have even begun looking into engineering enzymes to break down the polymers. "We're casting a fairly broad net," Long says.

Long recently wrapped up a yearlong collaboration with MRC to chemically modify used foam to make absorbent materials for cleaning oil spills. Working with MRC "really transformed how we think about our chemistry and recycling," he says. In particular, the collaboration taught him how important local recyclers are and how crucial it is to design recycling technologies that serve their needs.

It's exciting to approach recycling challenges with high-concept, novel chemistry, Long says. But the world needs solutions now that are simple, affordable, safe, and compatible with existing infrastructure.

As a local recycler, Traub is extremely interested in new technologies. He's read about VitriCycle on the MRC website and looks forward to a future where he can turn the piles of foam in his warehouse into new products that are totally unrelated to carpeting. "As much as I'm excited about the fact that this stuff is not going to [the] landfill, I'm more excited to turn it into something useful," he says. ■