Cold sintering may rescue plastic, ceramics, battery components from landfills

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Yi-Chen Lan, doctoral student in chemical engineering at Penn State and first author of a paper published in ChemSusChem, holds a battery coin cell that contains composite electrolytes reprocessed through cold sintering. Credit: Poornima Tomy/Penn State

Recycling does not necessarily prevent an item from eventually ending up in a landfill, according to Enrique Gomez, interim associate dean for equity and inclusion and professor of chemical engineering in the Penn State College of Engineering. Instead, recycling simply delays its end of life. Plastic bottles that are recycled and then turned into carpet, for example, eventually end up in the landfill when the carpet gets worn out and is thrown away.

However, cold sintering—the process of combining powder-based materials into dense forms at low temperatures through applied pressure using solvents—allows for materials to be recycled again and again.

"That's the idea with cold sintering: you can take two or more materials that were destined for the landfill, combine them and create a composite, and recycle the composite again and again, without a loss in performance," Gomez said.

In three recent papers, Gomez and his team outline three new uses for cold sintering that advance recycling in materials science.

In a paper published in *Materials Horizons*, researchers used cold sintering to combine polypropylene—a common waste plastic that is hard to recycle due to issues with processing and sorting—with a ceramic material. The result was a composite that could be used to make structural building materials like drywall or outdoor decks.

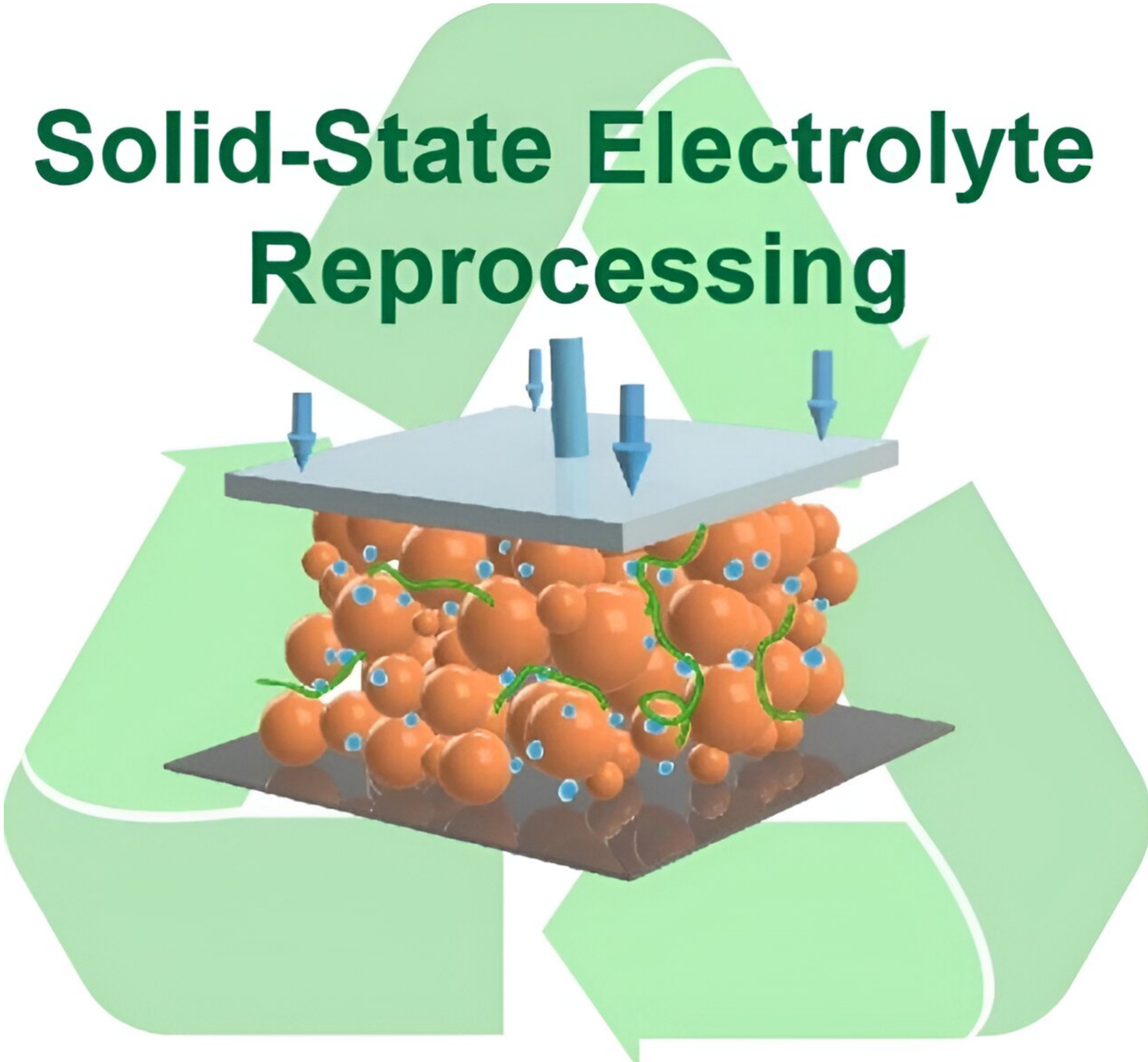
"Cold sintering plastic with ceramic materials produces strong, tough composites perfect for use in construction," said Po-Hao Lai, a doctoral student in chemical engineering and first author on the paper. "These composites can undergo multiple recycling cycles with only the addition of water, offering lower energy and water demands compared to conventional construction materials."

Additionally, traditional recycling often leads to downcycling, where the quality of the material decreases with each recycling cycle, resulting in the loss of valuable properties, according to researchers. By combining plastic waste with ceramics into composites, the method not only addresses the limitations of mechanical recycling but also overcomes the drawbacks of ceramics, such as brittleness.

When the building materials have reached their end of life, they can be ground up again in the cold sintering process and reused. The researchers demonstrated proficiency in regrinding and cold sintering the composite up to 10 times.

"If you redo your deck using these materials, and then decide you want to change its design, you can simply recover it, grind and cold sinter it, and remake it into something else, like a porch or a bench," said Bryan Vogt, professor of chemical engineering and co-corresponding author on the Materials Horizons paper.

In a study published in *ChemSusChem*, researchers applied cold sintering to the solid and liquid electrolyte components of solid-state batteries. Solid-state lithium batteries are energy-dense, safe, nonflammable and can be used in electric vehicles, wearable devices or laptop batteries.



Graphical abstract. Credit: *ChemSusChem* (2024). DOI: 10.1002/cssc.202301920

"Defects in batteries, such as voids and cracks caused by mechanical stress on the solid-state electrolytes in batteries, may block lithium-ion transport pathways and lead the battery to short circuit," said Yi-Chen Lan, doctoral student in chemical engineering and first author on the paper.

"To recycle electrolytes that have undergone mechanical degradation, we use cold sintering to re-densify the microstructures and reprocess composite electrolytes by mixing ceramics with polymers and lithium salts."

The idea for cold sintering the liquid electrolytes needed in solid-state batteries came about in 2018, when a postdoctoral scholar in the Gomez Group accidently broke a sample of liquid electrolyte during an experiment.

"He decided to reprocess the electrolyte sample through cold sintering, and we found out it worked just as well after being reprocessed," Gomez said. "We didn't realize at the time that this was a concept we could exploit, and that was the birth of this paper."

Reprocessing and reusing the electrolytes used in these batteries leads to lower energy consumption and a lesser environmental impact over time, which in turn promotes the viability and sustainability of all solid-state battery types, according to Lan.

In a paper published in *MRS Communications*, researchers cold sintered a composite that goes into capacitors, which are important components of electric vehicles. In the experiments, they combined the ceramic barium titanate with Teflon, or polytetrafluoroethylene.

"Our work in *MRS Communications* demonstrates the potential for recycling materials that will be crucial for the electrification of transportation, and therefore the reduction of greenhouse gases," said Hongtao Sun, assistant professor of industrial and manufacturing engineering and co-corresponding author on the paper.

Cold sintering was developed in 2016 by a team of researchers led by Clive Randall, director of Penn State's Materials Research Institute and distinguished professor of materials science and engineering.

"We are now seeing many other research groups adopt the cold sintering process all over the world in universities, national labs and even within industry," Randall said.

"I have been amazed by the diversity of applications that are emerging, but the research in the Gomez Group establishes a path for a circular economy, an extremely important strategy that is required for a sustainable future."

More information: Po-Hao Lai et al, Upcycling plastic waste into fully recyclable composites through cold sintering, *Materials Horizons* (2024). DOI: 10.1039/D3MH01976D

Yi-Chen Lan et al, Cold Sintering Enables the Reprocessing of LLZO-Based Composites, *ChemSusChem* (2024). DOI: 10.1002/cssc.202301920

Juchen Zhang et al, Nano-sized polymer-assisted cold sintering and recycling of ceramic composites, *MRS Communications* (2024). DOI: 10.1557/s43579-024-00524-9

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