Closing the loop

Upcycling plastic waste for carbon capture

Two of the most important environmental concerns of our times are CO_2 emissions and plastic pollution. Dr Xiangzhou Yuan, Research Professor at the Department of Chemical and Biological Engineering at Korea University (Seoul), and Dr Shuai Deng, Associate Professor of Mechanical Engineering at the School of Tianjin University (China), propose an approach that uses one problem to solve the other. They upcycled waste plastic bottles to a material able to attract CO_2 and reduce CO_2 emissions from large point sources into the atmosphere. Their approach was shown to be carbon negative, removing more CO_2 than required for the production and operation of the proposed system.

Plastic pollution has become a household term in the past few years. From the need to recycle plastic items, to microplastics, to the islands of plastic waste in the Pacific Ocean and elsewhere, we have all become aware of this threatening environmental concern. Another familiar concern is the rise of greenhouse gas emissions, especially carbon dioxide, CO_2, which are causing what's known as 'global warming' or 'climate change'. These problems have attracted the attention of the research community, and the focus on the observation and solution of issues arising both from plastic pollution and excessive CO_2, has resulted in proposals for sustainable waste management. Despite the overall progress towards this goal, however, there have been a few setbacks, with the most recent one being the COVID-19 pandemic. Although one could claim that home working, isolating, and obeying lockdown rules, might have reduced the release of CO_2 into the atmosphere, this is not the case with plastic pollution: quite the opposite. The production of plastic waste has dramatically increased, with gloves, masks, facial coverings, single-use plastic used to minimise contamination, being only a few examples of the newly added categories on the long list of items contributing to plastic pollution. Furthermore, it is not only production and transportation that contribute to CO_2 levels. All activities have a carbon footprint – they release a certain amount of CO_2 at every stage in their cycle. This also applies to the production of plastics, making plastic waste a problem both for CO_2 emissions and pollution: a 'double problem' if you will.

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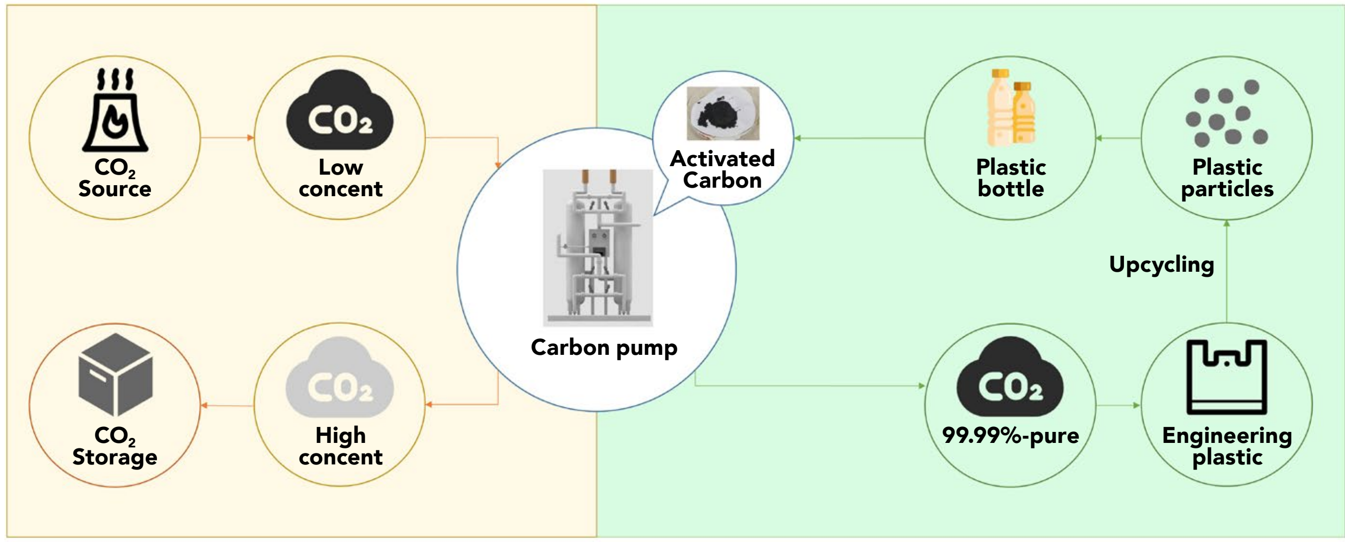
SUSTAINABLE WASTE MANAGEMENT

Out of the several categories of plastic responsible for plastic pollution, a dominating one is PET: polyethylene terephthalate. PET is the type of plastic that water bottles, storage jars, and protective packaging materials are made of, and it's creating a global pollution problem. According to metrics for water bottles alone, about 90% of the water bottles purchased around the world are being discarded to landfill or the ocean. There have been global efforts and much research devoted to reducing the annual amount of discarded plastic, to accelerating PET degradation (which currently takes around 450 years), and into producing types of plastic from more sustainable sources. All these efforts have shown some potential, but unfortunately not enough to give hope for fully sustainable management of plastic waste. Similarly, there is a great amount of research devoted to CO_2 capture and storage, and the reduction of CO_2 emissions during the product life cycle. Efforts in this field are also promising, but we are not quite there yet.

Dr Xiangzhou Yuan, Research Professor at the Department of Chemical and Biological Engineering at Korea University (Seoul), and Dr Shuai Deng, Associate Professor of Mechanical Engineering at the School of Tianjin University, China, have proposed a new sustainable waste-management approach that shows great potential for addressing both those problems, by creating a closed carbon and plastic loop. Whereas research efforts so far have mostly focused on the problems of pollution and CO_2 emissions separately, this approach uses one problem as a solution for the other, using plastic pollution to enhance CO_2 storage by engineering plastic bottles to capture CO_2.



One problem as a solution for another: PET plastic pollution to enhance CO_2 storage by engineering plastic bottles.

The new sustainable waste management approach shows great potential for creating a closed carbon and plastic loop.

CLOSED CARBON AND PLASTIC LOOP

Yuan and Deng have explored in detail the use of waste PET for the production of activated carbon that can be used to capture CO_2. The main idea behind this innovative approach is to turn plastic waste, specifically water bottles, into a 'sponge' that would adsorb and mitigate CO_2 emitted from industries including power plants and cement plants and help transfer it in safe storage. If a bottle-sponge could manage to capture an equal or higher amount of CO_2 than the amount released during its production, then this would result in a closed carbon and plastic loop.

Creating activated carbon – or a CO_2-adsorbing 'sponge' – out of a PET bottle might sound far-fetched; not only is it possible, however, but it also enables better disposal of the plastic bottle afterwards because the activated carbon derived from the plastic bottles is in a state closer to raw materials. In addition, it could be further used as a 'sponge' to enable cultivation on contaminated soils. The final used activated carbon can be used for soil remediation with or without biochar. This suggests that carbon in activated carbon is finally fixed in the soil. It is therefore important for carbon sequestration and soil health, and there is no solid waste generation from the life cycle perspective.

Yuan and Deng have shown in previous published works that creating this carbon-rich, porous (spongy) structure out of PET bottles, starts by subjecting the bottles to very high temperatures. The resulting material is a type of activated carbon, which means it has adsorbing property due to the voids that are created on the original structure after other elements have burned off. What this means in practice is that this type of material can suck in gases whose molecules are smaller than the available pores, or voids, in the plastic; CO_2 is one such molecule. Yuan and Deng have further enhanced the ability of this PET-derived activated carbon to attract and retain CO_2 by introducing micropores and functional groups that can act like a glue to 'stick' the CO_2 in place – this is its adsorbing ability. To understand adsorbing a little better, imagine a carnivorous plant attracting an insect with its pollen; once the insect is within the

The final activated carbon can be used for soil remediation.

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Working towards a closed carbon and plastic loop supports the achievement of several of the UN's Sustainable Development Goals.

plant, the plant closes around it. In our case, the plastic 'sponge' is the plant, the introduced micropores and functional groups are the pollens, and the insect is a CO_2 molecule; once the CO_2 is close enough to the micropores and functional groups (adsorbed within the pores of the sponge), it is attracted to it through van der Waals interaction and remains trapped (adsorbed). The materials used through this process depend on whether these steps would happen one after the other or simultaneously, the introduced properties of the entity chosen to make CO_2 stick, and the temperature used to dry off the final product. The researchers tested all these materials to identify the best method for creating the plastic 'sponge'.

MOVING TO LOW-CARBON TECHNOLOGY

As well as working at the experimental level, Yuan and Deng also did a full life-cycle assessment of the proposed process, capturing information from every step from production to waste: or from production, through checking potential for carbon capture, to waste. The authors compared their findings with information on other similar cycles and procedures, either obtained from their own research or from other groups worldwide, so they could refine their methods for optimal energy and water use, and potential to mitigate global warming. Pivotal to this stage was Dr Deng's previous work on renewable energy resources and how they can be integrated to assist the energy requirements of CO_2 capture. Using several sensitivity analyses models, the researchers demonstrated that their proposed technique for converting plastic waste to CO_2-adsorbent is carbon negative. This means that more CO_2 was adsorbed by the engineered plastic than was released collectively from every step of the life cycle of the production, upcycling, and alternative use of the water bottles.

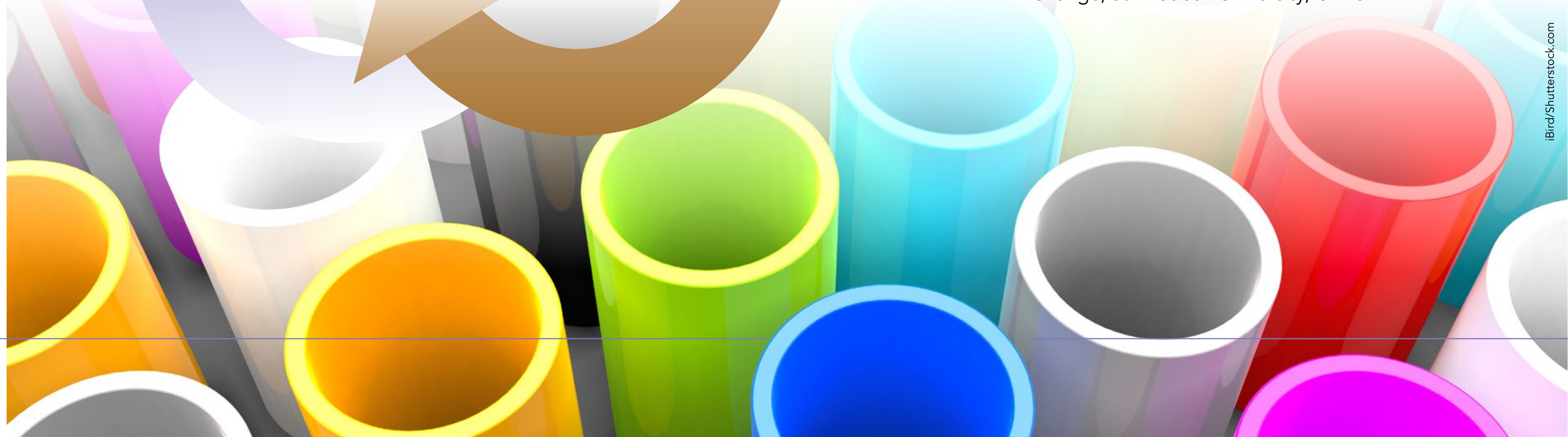
THE FUTURE OF PLASTIC POLLUTION MANAGEMENT

The next step for this innovative approach would be to use the captured CO_2 from the upscaled plastic waste. In a recently published article, Dr Yuan mentioned the synergy between the upcycling of plastic waste and the production of biodegradable plastics, in an effort to support low-carbon technology and plastic pollution mitigation. Working towards a closed carbon and plastic loop is far from just an academic exercise. It supports the achievement of UN Sustainable Development Goals such as Goal 11: Sustainable Cities and Communities; Goal 12: Responsible Production and Consumption; Goal 13: Climate change; Goal 14: Life Below Water; and Goal 15: Life on Land.

The proposed technique for upcycling plastic waste to CO_2-adsorbent was carbon negative.

Developing a sustainable system that mitigates plastic pollution to develop an upscaled vehicle for carbon capture, simultaneously relieving two major environmental concerns, is definitely a step in the right direction.

A closed carbon and plastic loop will address two major environmental concerns together.



Behind the Research

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Research Objectives

A new approach to clean energy technology, through sustainable waste management and carbon capture and storage.

Detail

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Dr Xiangzhou Yuan is Research Professor in the Department of Chemical and Biological Engineering at Korea University (Seoul) and R&D director of Sun Brand Industrial Inc. (South Korea). He mainly specialises in greenhouse gases sorption and separation, sustainable waste management, and clean energy technology.

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Funding
The authors are grateful for the support provided by the National Key Research and Development Program of China under Grant No. 2017YFE0125100, and the General Program of National Natural Science Foundation of China under Grant No. 51876134.

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Personal Response

Could this approach be applied as successfully to plastic waste other than PET?

" To date, one of the most promising routes to mitigate ubiquitous plastic pollution is to upcycle plastic waste into value-added products including combustible syngas, liquid fuels, and solid carbons, using thermo-chemical conversions. As it could synergistically and efficiently solve the complicated challenges from environment protection and sustainable development, the methodology we propose could be applied successfully in a larger range. At the current stage, based on the major research findings, in addition to PET plastic, mixed plastic waste could be considered as potential candidates to synthesise activated carbons for capturing CO_2. "