

# Mining Plastic: Harvesting Stored Energy in a Re-use Revolution

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**To spur action, the perception of discarded plastics must change from burdensome waste to a physical store of non-renewable resources. Major investment in developing catalysts, processes, and infrastructure for energetically efficient chemical recycling is critical. It is time for governments to commit to “mining” plastics.**

The global crisis of environmental contamination by plastic refuse—both intact products and evolved micro-plastics—has made it to the top of the agenda at international discussions. The crisis is acute, as illustrated by near daily reports of crippling levels of plastic pollution. A recent *New York Times* report about a dead whale found with 88 pounds of plastic in its stomach captured global attention and condemnation.<sup>1</sup>

Provoked by these emblematic anecdotes, myriad private and government initiatives reflecting a consumer desire to reduce plastic-waste streams, from Pepsi moving to canned water to localities banning single-use products, are now commonplace. Despite these well-intentioned efforts, the continued use and disposal of plastic products remains highly likely. Plastics are cheaply sourced, chemically robust, structurally customizable, and efficiently transported, making them a class of *de facto* miracle materials that have dramatically affected our way of life. Moreover, with the continued, unchecked growth of the global middle and upper classes, the rate of plastic consumption will only exponentially increase with time.

Projections show that 25 billion tons of plastic waste will be produced by the year 2050, and the majority will be discarded to landfills and the environment.<sup>2</sup> Because societal reliance on plastics is most likely here to stay, we must strive for ambitious multinational and industrial initiatives to create an economically favorable and energetically viable top-down infrastructure for managing past and future plastic-waste streams rather than

solely focus on small-scale, consumer-driven, point-of-use initiatives.

Recognizing this crisis, the final communiqué from this summer’s G20 summit, an assembly of 19 leading nations and the EU, included the Osaka Blue Ocean Vision, which sets a dramatic, and needed, objective to “... reduce additional pollution by marine plastic litter to zero by 2050 through a comprehensive life-cycle approach that includes reducing the discharge of mismanaged plastic litter by improved waste management and innovative solutions while recognizing the important role of plastics for society.”<sup>3</sup> Although this vision takes the necessary first step of recognizing the issue while also recognizing the inevitability of continued plastic use, it does not include proposals for policies, systems, or core technologies for achieving improved waste management. The economic and energetic nuance of any such proposals is critical. Current efforts to integrate carbon-capture systems at fossil-fuel-fired power plants to offset CO<sub>2</sub> emissions illustrate that any approach to tackling plastic waste must meet stringent energy-efficiency requisites that directly affect economic variables. These economic considerations in turn influence the chances of adoption by both private industry and government institutions.

## Mechanical Recycling Is Not the Solution

So, what can we do? Given what we have been told by decades of public service announcements, our first instinct would most likely be to improve existing mechanical recycling through public initiatives to increase collection while

simultaneously improving sorting and submission. Additionally, we can consider reducing the environmental impact of plastic manufacturing by taking advantage of low renewable energy costs and degradable plastics made from renewable feedstocks.<sup>4</sup> A greatly expanded effort regarding this step toward sustainable materials should be on the global agenda for research, development, and deployment.

Even with greener production, the reality, which was made brutally clear when the Chinese government recently ceased the acceptance of foreign rubbish, is that our mechanical recycling infrastructure is ineffective and insufficient.<sup>5</sup> Currently, only about 14% of plastics are collected for recycling, and 10% are re-introduced into the market as post-consumer plastic.<sup>6</sup> Yet, the vast majority of that 10% is “cascaded” recycling, through which less valuable products are being made. This downcycling is necessitated by random mechanical scission of the plastics’ underlying polymers during the physical recycling process. Additionally, many plastic products, such as single-use bags and films, cannot be submitted for mechanical recycling without specialized infrastructure.

These factors, combined with the energy consumption associated with collecting, sorting, and processing, often make mechanical recycling a poor alternative to virgin plastic production from crude oil. As a result, only 2% of plastics are “closed-loop” recycled into similar products from which they came.<sup>6</sup> Even if the economic and energetic consequences that stifle mechanical-recycling

infrastructure could be overcome, it appears that we cannot obviate that mechanical recycling downcycles plastics into less valuable materials. This is simply not acceptable.

### Changing the Plastic-Waste Narrative

Given the poor returns from mechanical recycling and the continued inability to rely on environmental consciousness as a motivator for the public, it comes as no surprise that we find ourselves with our current plastic-waste problem. Indeed, post-consumer plastics are generally perceived as valueless, useless trash pre-destined to be thrown away and forgotten. Given the consequences of this point of view, what if we can change the perception of plastic refuse from waste to resource? Important to remember is that the vast majority of plastics, around 70%, are composed of petrochemically sourced polyolefins, namely polyethylene and polypropylene. As such, post-consumer plastics are effectively “trapped” hydrocarbon fossil fuels that have been drilled, purified, processed, and then subsequently used all too briefly and unceremoniously disposed of. This energetically and chemically rich hydrocarbon resource is now stagnating and remaining intact for hundreds of years in a landfill.

Therefore, we should aim to change the narrative to one in which polyolefin-based post-consumer plastics can be harvested, or “mined,” for their valuable chemical and energetic resources. We briefly discuss existing, developing, and future technologies for harnessing post-consumer plastic waste as an energy- and chemical-rich resource, namely (1) plastic to energy through incineration, (2) plastic to fuel through pyrolysis, and (3) chemical recycling to constituent building blocks.

Alongside landfilling and mechanical recycling, the most prolific fate for collected plastic waste is incineration, through which the inherent energy stored in the hydrocarbon polymers is released through direct combustion to produce electricity and heat for the local grid. Although relatively rare in North America, waste incineration is commonplace in Europe, where about 500 incineration plants burn nearly 42% of collected plastic waste.<sup>7</sup> Although this approach has

proven valuable as an energy source and means of reducing the physical volume of waste needing landfilling, environmental and health concerns are rampant. Most obviously, similar to coal-, oil-, and gas-fired power plants, the incineration of polyolefin plastic produces large quantities of carbon dioxide, contrary to the general desire to reduce greenhouse gas emissions.

This primary consideration is compounded by concerns regarding environmental and biological contamination with byproducts of burning intact plastics, namely fine and microfine particulates, heavy metals, and carcinogenic organic byproducts. Manufactured plastics are more compositionally complex than pure hydrocarbon fuels; thus, their direct combustion results in undesirable additional byproducts. Although the conversion of plastic to energy through incineration allows for the harvesting of resources stored in waste, whereby some countries go so far as to import waste, the byproducts of this process make it environmentally unsustainable as a global solution to plastic-waste management.

In a vein similar to recovering and harvesting the stored energy in polyolefin plastics, a recent boom in efforts to commercialize the thermal cracking of plastic waste into liquid hydrocarbons concomitant with gasoline or diesel has arisen. Whereas the plastic-to-energy approach via incineration converts polyolefins to heat on site, this plastic-to-fuel approach aims to produce a refined hydrocarbon fuel, through controlled pyrolysis at lower temperatures and under low-oxygen conditions, that can be packaged and sold for later use. Plastic-to-fuel technologies have been recently commercialized; for example, startup companies such as Renewology and Agilyx are aiming to demonstrate the technological viability and economic profitability of this approach. The plastic-to-fuel approach offers advantages that make it preferable to incineration, such as lower operating temperatures ( $\sim 500^{\circ}\text{C}$  versus  $1,000^{\circ}\text{C}$ ) and lessened environmental contamination. Yet, although the existence of these companies offers glimmers of hope, this general approach is still relying on energetically consumptive high-temperature conditions to produce hydrocarbon fuels that are to be eventu-

ally burned, producing carbon dioxide emissions.

### Mining Resources from Plastic Waste

In each of the previous approaches, petrochemical resources are eventually removed from the economy through combustion to produce energy. Despite providing a second use for these waste streams, they permanently destroy a rich commodity. A philosophical alternative to this terminal use of finite resources is a so-called “circular economy,” which fully accounts for waste streams by keeping commodities in the economy across many uses and applications. Notions of the circular economy are making their way on to the political radar. For example, the recycling of batteries or solar panels is becoming the focus of new research and development and regulations, where valuable finite resources, such as gold and lithium, are being recovered, or “re-mined,” from post-consumer waste. The potential exists to analogously “mine” the original petrochemical feedstocks stored in discarded post-consumer plastic refuse for re-use through intelligent chemical processes.

This concept of “chemical recycling” most ideally seeks to selectively return polyolefin polymers found in plastics to their initial monomer constituents through catalyzed reactions at temperatures near the melting point of plastics, much lower than those found in incineration and pyrolysis. The collected monomers could be re-introduced into the economy as effectively virgin feedstock for polymers and other commodity chemicals, representing a true circular process. Importantly, this could preclude the drilling of additional crude oil to supply these feedstock chains. Indeed, this concept of a circular-plastics economy through chemical recycling to monomers is an ideal process, so why is this not done? A fundamental scientific answer is that polyolefin plastics have been specifically designed by chemists and engineers to be superbly robust to chemicals, heat, and light. Therefore, any action taken to degrade these materials requires immense amounts of energy to break strong carbon-carbon bonds in the polymer backbone. Moreover, to specifically return constituent monomers, a level of control over this high-energy process is

required. Therefore, given that chemistry birthed these materials, chemists, materials scientists, and chemical engineers must take up the challenge of developing chemical tools and systems to make such a process energetically and economically viable.

We believe that a dramatic uptick in research investment is warranted for the study and development of scalable and environmentally amenable catalytic systems that can selectively degrade polyolefinic polymers into constituent building blocks at low temperatures.

Only through the development of high-performing catalytic systems, with design based on a strong foundational understanding of the polymer degradation process, will we be able to achieve energy economy in chemical recycling. In order for such work to occur, government and private funding groups must recognize the importance of this work, from fundamental studies to catalyst design to large-scale systems optimization. Only with strong, consistent, top-down investment resulting from agreeable environmental policy will we see the necessary

cross-disciplinary research efforts to make meeting this challenge a reality. In what can be perceived as perhaps the first commercial exploration of a plastics circular economy, just this summer, the Dow Chemical Company announced a partnership with a Dutch pyrolysis company, Fuenix Ecology Group, to use oil produced from plastic waste to synthesize virgin polymers.<sup>8</sup>

Other instruments, such as an XPRIZE, could be used to motivate this type of research focus. Wider policies could also help move the needle—e.g., make plastics a focal point of international trade negotiations. The COP25 summit is a natural place for nations to voice their commitments to plastic reduction and ocean health. Indeed, academia, government, and industry must bring further attention to this grand challenge for chemistry, wherein chemistry can enable the mining of non-renewable natural resources from refuse, pushing toward a circular economy in which we can energetically offset the seemingly inevitable continued use of non-degradable plastics.

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