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BEHAVING BADLY**
Radical new reactions
shaking up chemistry

DON'T LOOK UP
Hundreds of near-Earth
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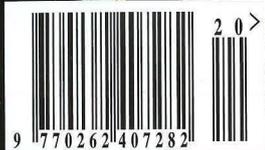
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Why the problem got so big – and what to do about it

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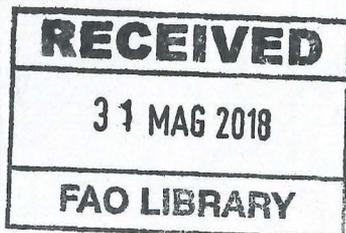
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HOW TO SOLVE A PROBLEM LIKE PLASTICS

Everybody is talking about plastic waste. But we should guard against quick - and potentially flawed - fixes, warns Aisling Irwin



STEPHEN WILKES/GALLERY STOCK

BYNOW, it is just a question of which heart-rending image you choose. There is the hawksbill turtle struggling to free itself from a plastic bag. The sea of polystyrene trash floating over a Caribbean nature reserve. Or the sperm whale washed ashore in Spain, its stomach filled with plastic waste.

Since the introduction of mass-produced plastics in the early 20th century, humanity has produced an estimated 8300 million tonnes of the stuff. Around three-quarters has been thrown away, and 80 per cent of that has drifted into the environment or gone into landfill. Eight million tonnes a year end up in the ocean – 5 trillion pieces and counting.

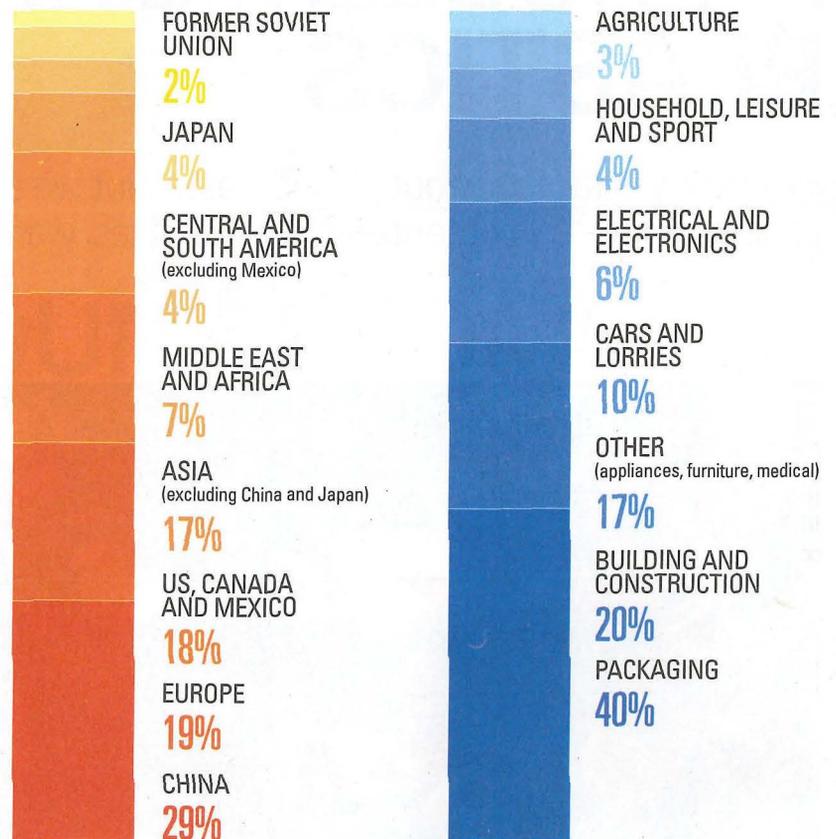
It is an environmental catastrophe and a human one, too, as some people in parts of the developing world live ankle-deep in filthy, non-biodegrading plastic trash. The long-term health implications for all of us remain uncertain, as ingested plastic works its way up the food chain.

Everyone agrees something must be done. From banning plastic straws to rebooting recycling systems to harnessing plastic-munching bacteria, there is no shortage of touted solutions. It is less clear what would work best. But fixing the plastic waste crisis is going to take some seriously joined-up thinking. If we make the wrong decisions now, we risk making the problem worse.

If plastics didn't exist, we would have to invent them. Generally made of oil-derived polymers, they can be hung with different chemical groups and spiced up with additives to give them wildly differing properties such as hardness, strength, density and heat-resistance. This makes them just the thing for

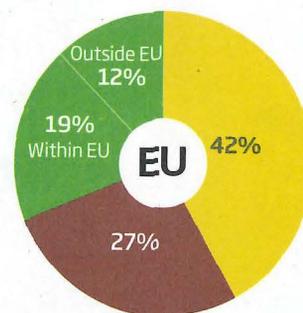
WHO MAKES PLASTIC AND WHAT FOR?

Total world plastic production in 2016 was 280 million tonnes. China was the biggest producer, with packaging the most common use

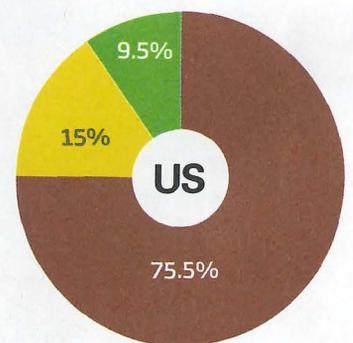


WHERE DOES IT END UP?

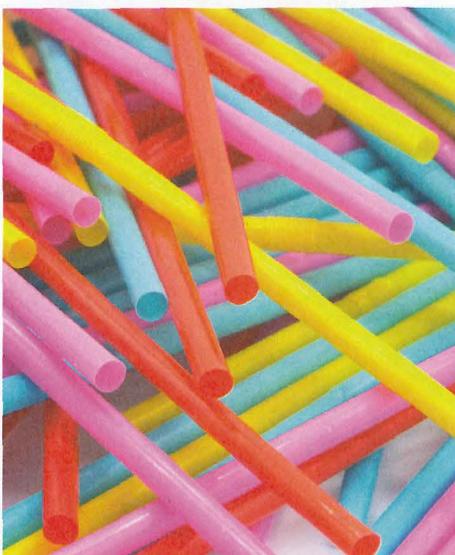
● Landfill ● Incinerated ● Recycled



27 million
tonnes of plastic waste were produced in the EU in 2016



33.3 million
tonnes of plastic waste were produced in the US in 2016



TIMOTHY SMITH / ALAMY STOCK PHOTO

everything from colourful, durable kids' toys to throwaway wrappings and foils.

You can argue the rights and wrongs of deriving materials from fossil fuels, but it is this throwing away that has excited the recent attention. The persistence of plastics in the environment if they aren't properly disposed of makes them incredibly bad news.

The nature of the problem varies according to where in the world you live. Five countries in Asia – China, Indonesia, the Philippines, Thailand and Vietnam – are responsible for 55 to 60 per cent of all the plastics that leak from land to ocean, according to a 2015 report by Ocean Conservancy and the consultants McKinsey. Another study in 2017 found that around 90 per cent of river-borne plastic was coming from just 10 rivers, eight of them in Asia.

The 2015 report calculated that three-quarters of plastic leakage from the five Asian countries comes from uncollected waste. The rest is waste that was gathered but ended up illegally dumped or put into sites too close to coasts or rivers. It is a stark reminder of global inequalities, says Chris Cheeseman, a waste specialist at Imperial College London. "There are 2 billion people in this world who don't have proper waste collection systems."

A big part of any effective solution lies in helping these countries improve their waste management. But that doesn't let richer countries off the hook.

In richer nations, says Cheeseman, the plastic problem starts with many people simply not caring. A parliamentary report in 2017 concluded that 700,000 plastic bottles in the UK end up as litter every day, for example.

But it is what happens to the rest that is more telling. Transparent plastic drinks bottles are principally made of polyethylene terephthalate, or PET. Globally, some 50 per cent of PET is collected for recycling, but only about 7 per cent is turned into new bottles, according to a report co-authored by the Ellen MacArthur Foundation. And PET is the poster child of plastics: it melts at a low temperature and can be reformed without much damage to its polymer chains. Of all plastics, just 14 per cent is collected for recycling around the world, with still less actually reprocessed. The rest is destined for incineration or landfill, where it will persist for centuries.

Why? Because once discarded, plastic is essentially worthless. It is cheaper to start afresh.

This is the dark secret of the recycling bin. For many, the solution is to give waste plastic a value. That is the philosophy behind ➤

WHEN WASTE EATS ITSELF

Biodegradable plastic has great promise – and great problems



Can we simply magic plastics away?

That's the promise of biodegradable plastics – and they are at least part of the plastic waste solution, says Kevin O'Connor of University College Dublin, Ireland.

Perhaps the best-known biodegradable plastic is polylactic acid, or PLA. Made from maize starch or sugar cane, it has uses ranging from medical implants to packaging. O'Connor is working on fermenting sugars or plant oils, or even breaking down waste PET, to make polyhydroxyalkanoates (PHAs), a family of plastics that can be used to make bottles, films and glues. The most popular biodegradable plastic on the market is probably Mater-Bi, a thermoplastic starch made by the Italian company Novamont from sugar, plant oils and even thistles. The hope is that wood chips and other biomass waste could eventually be used as feedstocks for biodegradable plastics.

Existing biodegradables generally need industrial conditions to break down, for example up to 12 weeks at 57°C for compostable plastics that decompose with food waste. Recycling firms don't like them, complaining that they further contaminate waste streams, while industrial food composters fear that people will get confused and put conventional plastic in food waste collection bins as well, rendering the resulting fertiliser worthless.

Biodegradable plastics that can rot unaided in a ditch or in landfill are harder to make. Possible sources include plant sugars and starches, and also seaweed, which

Almost all the world's plastic waste persists in the environment

doesn't need fresh water and fertiliser to grow. These plastics would probably decay to carbon dioxide (or, in landfill, more likely to methane), water and biomass after just one outing, to the distaste of circular-economy enthusiasts. The argument is that greenhouse gases emitted are "short cycle", already taken out of the atmosphere when the plant ingredients were grown. Making a tonne of plastic from some types of biomass absorbs the equivalent of 2.2 tonnes of CO₂, while making a tonne of fossil fuel-based plastic releases 1.8 tonnes.

Not all bioplastics – those derived from today's biomass, rather than yesterday's fossil fuels – are biodegradable. Coca-Cola's PlantBottle, for example, is around 30 per cent ethylene glycol that comes from plants, helping wean us off oil. But as it is chemically identical to conventional PET, it will stick around in the ocean for just as long if not disposed of properly.

No biodegradable plastic yet invented has the gas-barrier properties of PET, so any fizzy drink held in a container made from one would soon go flat. Despite these problems, however, O'Connor calls the lack of take-up of biodegradables regressive: "It's a bit ironic that somebody in the recycling business says: 'Oh, they'll contaminate our recycling system, which is grossly inefficient and is not capturing even half of the plastic waste that is generated'. I say the system needs to change."

CAN WE CLEAN UP THE MESS?

Efforts to remove plastic already in the ocean are fraught

The robotic filter feeder's mouth gapes, like that of the whale shark that inspired its design. Helpless, a bobbing Coca-Cola bottle drifts into its mouth - and WasteShark glides off down the Dutch canal, leaving a patch of pristine water behind.

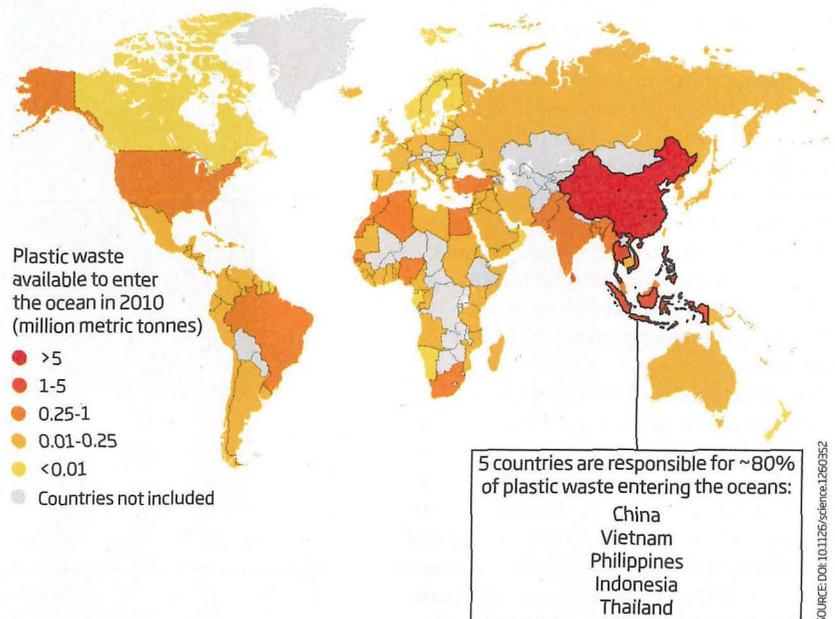
WasteShark was born from the irritation of one man, Richard Hardiman of RanMarine Technology in the Netherlands, at ineffective attempts to remove waste plastic from water. It is not the only such project. In Baltimore, Maryland, Mr Trash Wheel has scooped more than 640,000 plastic bottles from the Fall Jones river since mid-2014. Floating "sea bins" suck in the plastic drifting in UK, Finnish and Spanish ports. Dutch entrepreneur Boyan Slat's 1-kilometre-long booms are due to start work in the Great Pacific Garbage Patch between Hawaii and California later this year as part of the Ocean Cleanup project. He has claimed that half the patch could be cleared within five years by funnelling rubbish towards a central tank for collection by passing ships.

Others are less convinced. "People have knee-jerk responses: 'Trash in the ocean? Well go get it,'" says Marcus Eriksen, co-founder of the 5 Gyres Institute, a US non-profit organisation. "The truth is that it's so spread out, it's so fragmented, it doesn't make sense economically to do that." Even the most well-known ocean clean-up projects are between them removing just 0.5 per cent of marine plastic trash.

Another possibility is to somehow harness bacteria that seem to be evolving enzymes to gobble plastic. Could these be sprayed onto islands of ocean garbage to make them melt away? It is possible they could break the plastics down sufficiently for microalgae to do the rest - but that could create massive algal blooms, as well as release toxic chemicals into the ocean. *With the plastics we have already poured into the ocean, it seems we may not like it, but we will have to lump it.*

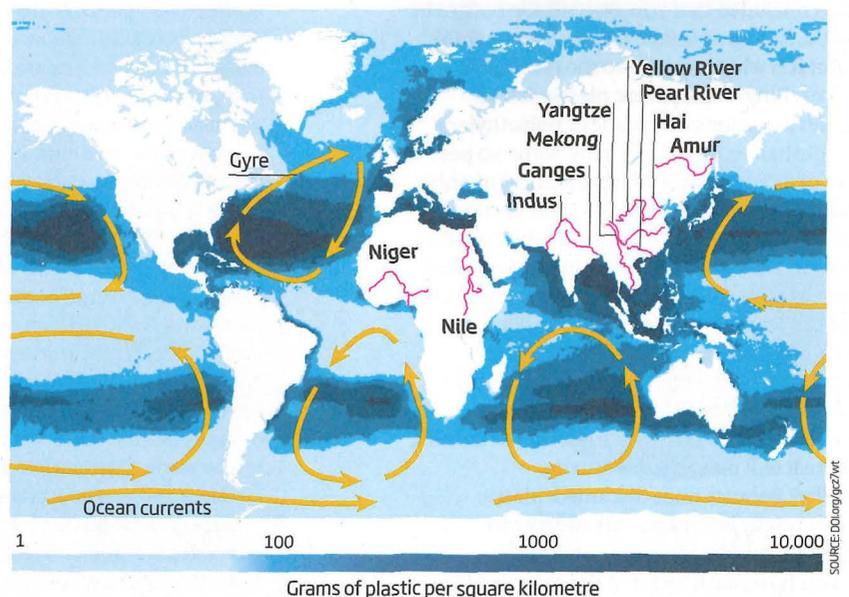
WHERE OCEAN WASTE COMES FROM...

Population density near coastlines and the efficiency of waste management determine how much plastic waste leaks into the ocean - with South-East Asian countries scoring badly on both fronts



... AND WHERE IT ENDS UP

Just 10 rivers transport 90 per cent of river-borne waste entering the oceans, making up more than a quarter of the total plastic in the ocean. Once there, much of it is swept into mid-ocean "gyres"



deposit schemes, for example, in which consumers pay a small refundable fee for plastic bottles. These have transformed disposable bottles into collectibles in several US states and European countries. The UK looks set to follow suit, while most of Australia should be operating deposit schemes by 2019.

The bigger vision is to create a "circular economy" for plastics. Out goes "take-make-dispose", a one-way journey from oil to landfill or incineration. In comes a system where producers are incentivised to make reusable, recyclable or compostable products, while the recycling industry learns to scoop up all the detritus so no piece of litter is left behind.

A PET bottle, for example, might be brought into an endless "closed loop" in which it quenches your thirst, surfs through the recycling plant and emerges as pristine PET from which it is moulded into a new bottle, time and time again. That is good not just for waste, but also for the climate. Producing a tonne of recycled plastic generates between 1 and 3 tonnes less CO₂ than a tonne made fresh from oil.

The idea has been taken up with enthusiasm by some governments, charities, scientists, manufacturers and retailers. At the World Economic Forum in January, the New Plastics Economy initiative, spearheaded by the Ellen MacArthur Foundation, announced a list of companies that have sworn to make all their packaging recyclable, compostable or reusable by 2025. "We're talking about the survival of some of these big brands," says Edward Kosior of recycling consultancy Nextek, highlighting pledges such as that of Danone, the food giant behind products such as Evian water, to move to 100 per cent recycled bottles. "What the brands are saying is: 'The problem is not with the plastic we're using, it's with the way we have mismanaged the material.'"

But significant obstacles lie in the way. Oil is still cheap – currently around \$68 per barrel, down from \$140 in 2008 – while recycling is expensive and complex. Take that PET bottle again. Many are encased in a sleeve made of another plastic, confusing the infrared detectors used for sorting. "The more complex the bottle, the less recyclable it is," says Kosior. PET meat trays contaminated with other layers of plastic foil are another problem, as is the requirement that all PET for new drinks bottles be "food grade". PET that once held paint thinner and the like must be laboriously separated out. Then there are brands that prize their bottles being colourless, so won't accept recycled PET visually tainted by previous generations of coloured bottles. ➤

"It's the dark secret of the recycling bin: waste plastic is essentially worthless"



GONE IN A PUFF OF SMOKE

Sometimes simply burning plastic is the best option

Incineration is often derided as the dinosaur's approach to the plastics problem, belching pollutants into the air. But it has many attractions, particularly as a way of ridding ourselves of plastic that can never be recycled because of its chemistry or small size. In developing countries, it is perhaps the only option.

About 14 per cent of plastic packaging is currently incinerated across the world, with China in particular investing heavily in the technology. The plastics are burned in air, producing carbon dioxide and other gases, heat and ash. Incineration with energy recovery harnesses the heat to convert water to steam and drive a turbine, generating electricity. Combined heat and power plants push this one step further, using the remaining heat to warm local homes, schools and offices.

Other related technologies could beat incineration. Around 90 pyrolysis plants scattered around the world heat valueless waste plastic, often from car tyres, to several hundred degrees in the absence of air, breaking them down into a rich fuel. Gasification breaks plastic down into energy-rich gases such as hydrogen, methane and carbon monoxide, which can generate power or be transformed into diesel, ethanol or other chemicals.

Proponents say that modern incinerators employing "scrubbing" technologies to clean their exhaust gases release only imperceptible amounts of pollutants into the atmosphere. Using incinerators can replace the need to burn dirtier coal, and therefore reduce CO₂ emissions, while pyrolysis and gasification release no CO₂ at all.

Critics are less convinced, and not just on the CO₂ front. Scrubbed-out pollutants are still there in the scrubber or the ash that goes to landfill, they say. And all three techniques lose all the labour and much of the energy that went into crafting the plastic and its product – while making the economics of reusing and recycling plastics even trickier (see main story).

Nextek has developed one solution: invisible fluorescent markers, including one for food-grade PET, that manufacturers could incorporate into their product labels and that could be detected by kit retrofitted in recycling plants. Then there are emerging technologies that aim to break plastics down chemically into the monomer units they are built from. Ioniqa Technologies, a spin-out company from Eindhoven University of Technology in the Netherlands, has developed a system that heats PET mixed with a magnetic smart liquid. A magnetic field then scrapes contaminants off, creating pristine PET free from colourants, adhesive and the patina of age.

Short-sighted solutions

All good stuff, but these high-tech solutions are just about PET, and are ill-suited to developing economies with limited recycling set-ups. Another concern, says Tom Domen of Ecover, which makes less environmentally damaging cleaning products in plastic packaging, is that the fixes focus on improving an existing situation – perhaps at the expense of more radical, longer-term solutions, such as developing better biodegradable plastics (see “When waste eats itself”, page 27).

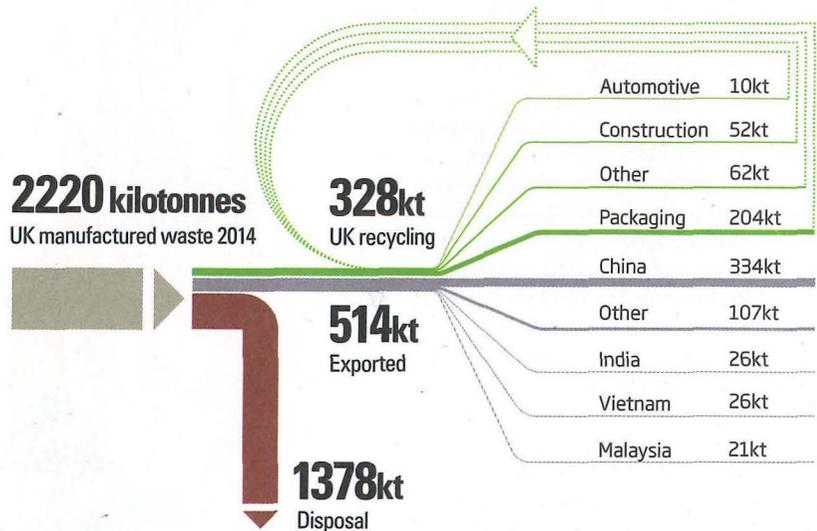
“You have the camp of the technical cycle that sees recycling as the ultimate answer and then you have the camp of the biological cycle, which sees biodegradability as the final answer,” says Domen. “Unfortunately, those two are often head to head when they should not be because both solutions are there for different purposes.” The fear is that short-sighted investments in infrastructure could make better, future options too expensive to adopt. Similar claims and counterclaims swirl around the case for incinerating plastic to recover energy from it (see “Gone in a puff of smoke”, page 29).

Roland Geyer, an industrial ecologist at the University of California, Santa Barbara, and leading cruncher of plastic statistics, adds another objection. In a paper about to be published, he and his colleague Trevor Zink of Loyola Marymount University in Los Angeles argue that an obsession with recycling encourages single-use products rather than the best option: reducing consumption. If you know your bottle is going to be recycled via a bottle-deposit scheme, why bother taking your reusable one with you?

The truth is that recycling is beneficial only if it reduces the production of virgin plastic from oil, says Geyer. “A lot of people just take it for granted that every tonne of material

BROKEN CYCLE

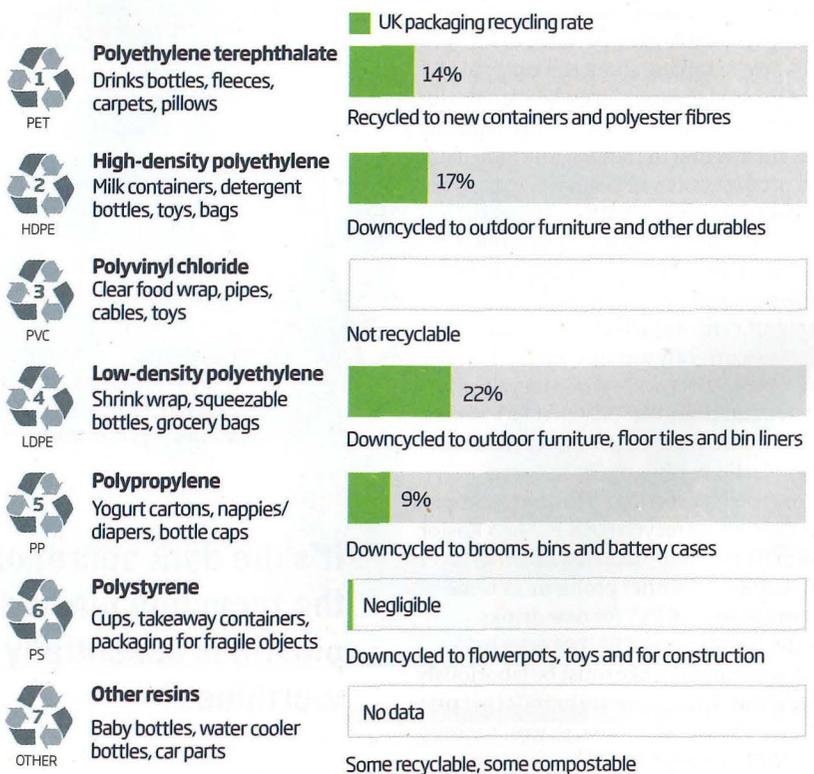
The UK is typical of developed countries in recycling very little plastic waste. Before this year, when China banned waste plastic imports, the UK exported more waste than it recycled at home



SOURCE: WRAP estimates

LOW RECYCLING RATES

Seven different types of plastic packaging have been given codes to aid domestic recycling, but in the UK, as elsewhere, very little is actually recycled



SOURCE: WRAP/RECOUP



recycled reduces primary production, but this is a market-mediated thing," he says. "There's no law of physics that says it will."

In fact, standard economic theory suggests that flooding markets with recycled material boosts supply, driving the price down and increasing demand for virgin plastic, too. It is nearly impossible to prove such causality, says Geyer, but this assertion seems to be backed by the data. Even as we get better at turning used bottles into new ones, more and more are being made – from new and old plastic. Global plastic bottle production is predicted to rise by 20 per cent between 2016 and 2021.

"The big challenge with plastics is not technology, it's human behaviour"

Tony Breton of bioplastics firm Novamont agrees that recycling alone won't stem the tide of plastic waste. "One of the big things that's lost within a lot of the circular economy discussions is the role minimisation and reuse can play," he says. "There's not a lot of money to be made in reducing consumption, and measures to reduce consumption are generally not politically well-received."

Efforts are generally piecemeal: France has passed a law to ban the sale of disposable plates and cutlery; Italy insists that all plastic bags sold are either thick, reusable ones or compostable; Germany has a deposit scheme for reusable coffee cups; the UK, having

Few drinks bottles are made from recycled plastic, as in this Canadian plant

introduced a plastic bag tax, is proposing banning plastic straws and cotton buds.

The ultimate solution to the plastic waste crisis will have many strands. It will require coordination between government, retailers, manufacturers and recycling firms for better packaging design, advanced recycling technologies and new plastics – as well as aid for developing countries to improve their waste systems and water supplies. It must also take care to avoid excluding new ideas that might be just around the corner.

One such leap could be the eye-catching promise of bacterial enzymes that have evolved to break down plastic waste. These work at low temperatures, around 30°C, although their efficiency is currently poor. It is even possible that, once split apart, this waste plastic could be turned into other chemicals.

In the end, says Kevin O'Connor of University College Dublin, Ireland, there is no one solution. And while we should keep the pressure up on industry and government to implement sensible, joined-up solutions, the onus must be on us to mend our own ways, too. "The big challenge is human behaviour, it's not actually technology," says O'Connor. "I think the technology will eventually come to maturity. But the big challenge is us." ■

Aisling Irwin is a freelance writer based in Oxfordshire, UK

WHAT YOU CAN DO

In our personal drive to reduce plastic waste, we should beware easy, but false, solutions

CUTTING OUT SINGLE-USE PLASTIC – water bottles, straws, disposable plates and so forth – is a good place to start reducing waste. But make sure you aren't inadvertently increasing your carbon footprint. A cotton tote bag must be used 131 times before its environmental cost falls below that of a disposable plastic bag, mostly because of the impact of growing cotton. Similarly, you must use a steel water bottle 500 times for its carbon footprint to shrink to less than that of a disposable PET bottle. One undergraduate study found a permanent plastic bottle to result in less carbon emissions than a stainless steel one.

REDUCING THE PACKAGING YOU USE by buying large containers and, for example, avoiding single-serve yogurt pots, also helps. And switch to bar soap. It is a complicated life-cycle analysis, but it tends to have a much lighter footprint than liquid soap from a dispenser.

BUYING CONCENTRATED FORMS OF PRODUCTS such as detergents is also a case of more bang for less packaging. Life-cycle comparisons show they reduce other environmental impacts, too.

BOYCOTTING MIXED PACKAGING, which often can't be recycled, may also help: for instance, crisp bags and stand-alone pouches that are all the rage for baby food. Avoid black plastic food trays, whose colouring confuses the infrared detectors used to distinguish plastics in most recycling plants. Go for brands that have made meaningful packaging changes, such as the few drinks companies using 100 per cent recycled PET.

TAKING ANY RECYCLABLE WASTE HOME with you helps if, as in the UK, kerbside recycling is much easier and cheaper for local authorities. If you tip it into a public bin, it's unlikely that anyone will take the time to separate it out for recycling.