Losing the bottle: methodology

The calculations presented in this infographic are predominantly based on peer reviewed papers on plastic water bottles and other containers and calculations involving specific examples of three increasingly common containers for water made from aluminium, glass and paper carton. The three specimens used for our calculations were all purchased from Victoria train station in London, within eyesight of a water fountain and in a location where there are at least seven business outlets that are registered as refill stations with the app Refill: Pret (two outlets), Costa (two outlets), Wetherspoons, and Starbucks (two outlets).

To compare the impacts of different containers for water, we first devised a scoring system to evaluate the relative impacts of different material options at three different stages of their lifecycle: wastes from production; greenhouse gas emissions associated with production and transport; and end of life options. A full lifecycle assessment for each container was not considered appropriate for this research as the infographic is highlighting that different materials have different sorts of impacts, making direct overall comparisons less valuable and potentially impossible. There are also well documented shortcomings to do with lifecycle assessments, not least that they do not currently account for marine plastic pollution, which is one of the main public and environmental concerns with plastic use. We therefore determined that consideration of specific impacts was more appropriate for this exercise.

It is worth noting, also, that while two of the specimens – the aluminium can and the carton – are explicitly marketing themselves as alternatives to plastic water bottles, all of the containers still contain considerable amounts of plastic. The aluminium can, for instance, included a complex plastic closure weighing around 4g (nearly half the weight of a single use plastic bottle); the glass container included a relatively heavy plastic lid – 14g (meaning it weighs more than a lightweight plastic water bottle); and the multilayer carton included nearly 10g of plastic (roughly the weight of a plastic water bottle), with 6.4g derived from sugar cane, and a 3.5g layer of conventional plastic film.

Production impact evaluation

Material	Material input per tonne of final material	Toxicity of production waste and by-products	Material requirements per 500ml of water delivered
Plastic (PET)	1.6t[1]	High – including toxic emissions to air from petrochemical additives[2]	10g
Aluminium	13t[3]	High – including 2.373t of highly alkaline bauxite residue, known as 'red mud'[4]	16g (plus 4g of plastic)
Glass	1.2t, although the process to produce soda ash, one of the raw materials, will result in further waste[5]	Medium – including from the Solvay process used to make soda ash, which produces calcium chloride, which is hazardous to human health[6]	360g (plus 14g of plastic)
Carton	1.8t[7]	High – including petrochemical additives to conventional plastic and the toxic red mud that would result from the thin layer of aluminium	23g

Carbon emissions impact evaluation

For our comparison across material types, we took estimates for 0.5l water in each of aluminium, PET, glass and a multi-layer carton and assumed 100 per cent of demand was supplied by this type of packaging. We compared the production emissions for aluminium, PET, glass and a multi-layer carton to understand the carbon impact of a complete shift to any of the types of container using peer reviewed estimates.[8] Our estimate for the carbon emissions from tap water are based on a review of 24 LCA studies which were harmonised to produce an average figure of 0.09 kgCO_2e/100l.[9]

Comparing the environmental impact of a reusable water bottle with a single use container is not easy. This is partly a function of the fact that single use containers vary in terms of materials and weights, and there is a considerably greater variety of possibilities for sizes and weights of reusable containers. Our literature review did not uncover peer-reviewed academic assessments that address this area, but some industry assessments – from both reusable and single use bottle manufacturers – exist. Our figure of 15 uses for a reusable bottle to be better than multiple single-use plastic bottles is based on a report by Nestlé in North America analysing aluminium, plastic and steel reusable bottles which found 'the break-even point for use of a reusable bottle is between 10 and 20 uses, with some variation depending on the type of bottle'.[10] This analysis was based on a comparison per 500 ml serving size, meaning smaller single use water bottles would perform even worse against reusable containers.

The Nestlé analysis roughly corresponded with other industry evaluations. The reusable bottle manufacturer 24Bottles, for instance, suggests that a single use bottle emits .08kg CO_2e during its lifecycle, compared to .543 for 24Bottles' lightweight stainless steel bottle or 1.137kg CO_2e for a heavier 'Clima' bottle. That means a consumer would have to reuse it between 6 and 14 times to have the same CO_2e impact as single-use bottles.[11]

Our market research also identified a number of instances where a reusable bottle will weigh roughly ten times as much as a single use bottle made of the same or similar material. From a materials use perspective then, the impact of the heavier reusable in terms of production wastes and greenhouse gas emissions would be expected to be roughly ten times greater than the single use alternatives, although there will, of course, be differences in terms of sources of materials, production processes and transport. Based on all these factors, we believe it is reasonable to assume a typical reusable bottle would need to be reused 15 times to have a lower impact than a single use alternative, and we believe it will be fewer times in some instances.

End of life impact evaluation

Material	Closed loop recycling possible	Closed loop recycling likely in UK[12]	Likelihood it is found in litter[13]	Damage to marine life if littered
Plastic (PET)	Yes	Infrequently	High	High
Aluminium	Yes	Sometimes	High	Low
Glass	Yes	Frequently	Medium	Low
Carton	No	No	Low	High

A direct comparison of reusable bottles with single use alternatives in this category is also difficult to achieve as reusable bottles are made from a variety of materials, some of which are recyclable while others are not. We awarded the reusable bottle with a score of 'low' for end of life impact on the grounds of waste avoidance. If reusable bottles were to replace 50 per cent of the current market for bottled water (thus bringing us in line with the bottled water consumption rate of 15 years ago), it would mean we would avoid the need for 3.85 billion single use water bottles each year.[14] If these were made of lightweight plastic (10g/500ml bottle), that would mean avoiding at least 38,500t of waste, a figure that would rise considerably if it were heavier plastic, aluminium, cartons or glass being displaced. This must, however, be weighed up against the waste that will eventually be created by refillable bottles. Assuming every UK citizen aged 16 or older (53,240,571 people, according to 2016 ONS statistics) disposes of a water bottle that weighs ten times more than a single use bottle once a year (which should not be necessary), that would create 5,324t of waste. The net result in that instance would therefore be 33,176 tonnes of waste avoided.

Drawing out of each material's detrimental impact

Following on from our overarching comparison on three environmental fronts, we drew out a negative consequence for each material to illustrate the potential impact of a large scale shift away from plastic water bottles to alternative single use containers, which are almost always unnecessary. For each container, we estimated what the impact would be if it fulfilled 50 per cent of the current market demand for bottled water.

Bauxite tailings production from aluminium cans

We estimated the volume of bauxite tailings ('red mud', a highly alkaline and therefore very hazardous material) produced by aluminium cans by weighing a representative can for water and using the estimate of 2.373kg of red mud production per kg of aluminium.[15] At a 50 per cent market penetration rate, the aluminium requited for the cans would result in annual bauxite tailing production of 162,010t. We converted this to volume using the estimate of density of 2.98g/cm^3 and took the volume of the Royal Albert Hall to be 86,650m^3.[16]

Although aluminium is a highly recyclable material and aluminium drink cans are high in recycled content, we considered it fair to calculate the impact of mining new aluminium for cans of water. This is because the market for aluminium drink cans is growing in the UK and we do not yet have a system that captures all containers for recycling. Although all aluminium drink cans are theoretically recyclable, the latest figures suggest a recycling rate of 75 per cent. [17] What's more, a large proportion of this (roughly a quarter) is material recovered after incineration, meaning it is not currently suitable for recycling back into cans.[18] Opening a new and unnecessary market for aluminium cans means that there will be less recycled content to go around in other applications and additional material will have to be mined.

CO_2 Emissions from a glass bottle of water shipped to the UK

We estimated production and transport emissions of 500ml water in a glass bottle with a PET lid based on the following assumptions: PET has production of emissions of 1,280 kgCO_2e/tonne and the cap weight for our specimen was 14g.[19] Glass has average production emissions of 600 kgCO_2e/tonne and our specific bottle had a weight of 360g.[20] We estimated shipping emissions based on the distance from a popular brand's bottling facility to London (1,425 km by road, 184 km by ferry), as well as EU estimates of road (75.33 gCO_2) and ferry (14.02 gCO_2) transport emissions per tonne-km and the weight of the bottle, cap and water.[21]

Amount of waste from cartons

We estimated the amount of waste from cartons by assuming a weight of 23g per carton (weighed from a representative water brand) and a payload of a typical refuse collection vehicle of 1,100 kg. At 50 per cent market penetration, the cartons would add up to 98,141,000kg, which would be enough to fill 8,922 bin lorries.

We consider it reasonable to call this low quality waste because cartons are complex, multi-layer materials that are notoriously difficult to recycle and that cannot be recycled back into cartons. Cartons are not reported as a separate packaging category in recycling information, so it is impossible to say what the current recycling rate is. The UK only has one open loop recycling facility for cartons, though, with a capacity of 25,000 tonnes per annum. This compares to a market size of at least 60,000 tonnes per annum, meaning that it is already impossible to domestically recycle all the cartons put on the market in the UK.[22] At a time when the country's waste strategy has highlighted the need for the nation to "stop offshoring its waste", it is inadvisable to place on the market material that cannot be closed loop recycled and, based on limited capacity, is also unlikely to be open loop recycled in this country.[23]

Endnotes

[1] PlasticsEurope, 2017, *Eco-profiles*
[2] CIEL, 2019, *Plastic and health: the hidden costs of a plastic planet*
[3] UN, 2012, 'Mining waste generated from aluminium production'
[4] World Aluminium, June 2017, *Life cycle inventory data and environmental metrics for the primary aluminium industry*
[5] WRAP, 2008, *Realising the value of recovered glass: an update*
[6] European Soda Ash Producers Association, 2004, *IPPC BAT reference document: Large volume solid inorganic chemicals family: process BREF for soda ash*
[7] The carton we analysed was more than 50per cent fibre, with considerable amounts of both conventional and sugarcane based plastics and less than five per cent aluminium. We arrived at this raw material figure by multiplying the fraction of each material by the amount of waste required to create the component parts. So, for the paper, we used the figure of 100kg of waste per tonne (as indicated in Monte, MC et al, 2009, 'Waste management from pulp and paper production in the European Union' in Waste management); for aluminium, we used the 13t/t figure used above; for plastic, the1.6t/t figure used above; and for sugarcane, an estimate of nearly two tonnes of material required to produce every one tonne of fermentable sugar content produced (See Bos, HL et al, 2012, 'Accounting for the constrained availability of land: a comparison of bio-based ethanol, polyethylene, and PLA with regard to non-renewable energy use and land use' in Biofuels, bioproducts and biorefining).We then multiplied this figure by 1.04 to account for a four per cent waste rate in carton production itself, which is commensurate with that reported by carton producer Tetra Pak in its 2017 'Performance data'
[8] Simon B et al, 2016 'Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles' in *Journal of cleaner production*
[9] Fantin V et al, 2014, 'A method for improving reliability and relevance of LCA reviews: the case of life-cycle greenhouse gas emissions of tap and bottled water' in *Science of the total environment*
[10] Nestlé Waters America, 2010, *Environmental life cycle assessment of drinking water alternatives and consumer beverage consumption in North America*
[11] 24 Bottles' website
[12] These evaluations are derived from the Environment Agency's National Packaging Waste Database 'Monthly packaging waste exported and accepted for reprocessing' 2018 figures. According to the figures, in 2018, 63 per cent of plastic packaging collected was exported from the UK, compared to 56 per cent of glass packaging collected being closed loop recycled in the UK (known as 'remelt', a separate category for glass) and 46 per cent of aluminium being reprocessed in the UK. There is no separate category for cartons, but the UK only has one recycling facility for cartons with a capacity of 25,000 tonnes per annum (compared to a market size of 60,000 tonnes per annum), and in any case cartons are multi-layer materials that are not suitable for closed loop recycling.
[13] CPRE, 2018, 'Green Clean 2018: the results'. In September 2018, a CPRE initiative collected 11,212 containers through 35 litter picks. Aluminium made up 50 per cent of the total number of containers found to be littered, plastic made up 35 per cent, and glass 14 per cent. Cartons only made up one per cent of containers littered, but if their share of the market increased, it is reasonable to assume the number littered might also increase. In any case, as cartons received a rating of 'red' for end of life, this would not affect its overall rating in this category.
[14] EAC, 2017, *Plastic bottles: turning back the plastic tide*
[15] World Aluminium, 2017, op cit
[16] Wang P and Liu DY, 2012, 'Physical and chemical properties of sintering red mud and Bayer red mud and the implications for beneficial utilization', in *Materials (Basel)*
[17] Letsrecycle.com, 19 June 2019, 'Aluminium can recycling rate reaches 75% in 2018'
[18] Green Alliance, 2019, *Closing the loop: four steps towards nearly 100 per cent aluminium packaging recycling*
[19] Dormer A et al, 2013, 'Carbon footprint analysis in plastics manufacturing' in *Journal of cleaner production*
[20] Schmitz, A et al, 2011. 'Energy consumption and CO2 emissions of the European glass industry' in *Energy policy* (adjusted for recycled content)
[21] European Environment Agency, 2015, 'Specific CO_2 emissions per tonne-km and per mode of transport in Europe, 1995-2011'
[22] MRW, 25 October 2017, 'Frugalpac develops recyclable carton'
[23] HM Government, 2018, *Our waste, our resources: a strategy for England*