PLASTICS AND SUSTAINABILITY

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This Is **Plastics**

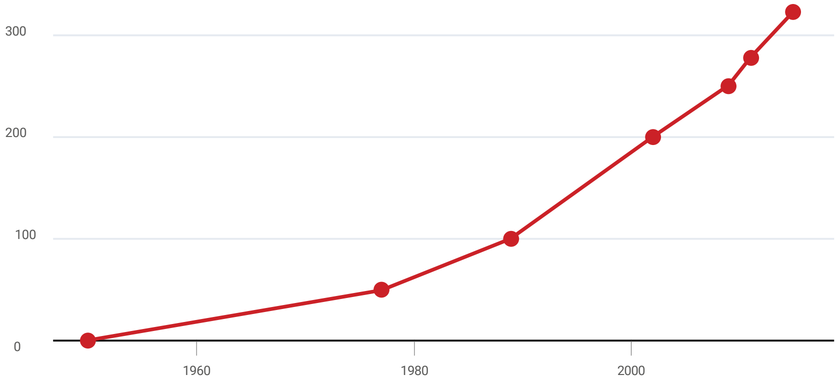
Key Findings

- Assessing the sustainability of plastics requires both holistic and historic perspective, as well as the consideration of environmental, economic, and societal impacts of alternatives to, or avoidance of, plastics as a commonplace material in human society.
- Current recycling systems are economically inefficient. However, a full reclamation of plastic monomers would bring society's use of plastic materials closer to current conceptions of environmental sustainability.
- Contrary to established wisdom, scientific life cycle assessments of plastics and alternative materials find that plastics tend to have lower carbon footprints, making them the more sustainable option among current materials in a number of applications.
- Those life cycle assessments also suggest that substituting plastics with other materials would create environmental tradeoffs that could be less environmentally sustainable.
- Plastics, a relatively novel material in the history of human goods manufacture, have become critical to sustaining prosperous and technological societies. Suggestions to discontinue using plastic would very likely be detrimental to both human and environmental well-being.

Plastics materials, novel in the geological history of the Earth and the evolutionary history of humanity, have expanded massively in production, use, and disposal since their widespread incorporation into human material economies after World War II.

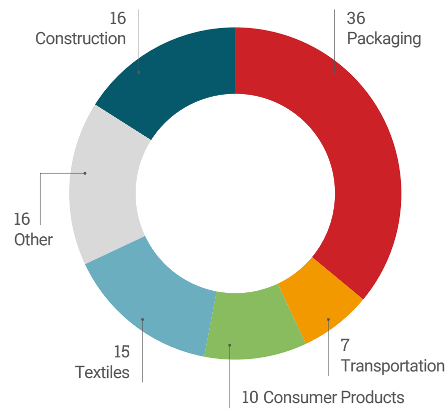
Though virtually non-existent prior to the 1900s, the materials we now know as *plastics* have become ubiquitous in most human lives, in both developed and developing societies.

More plastic has been produced this decade than in the previous century
Global plastic production, million metric tons



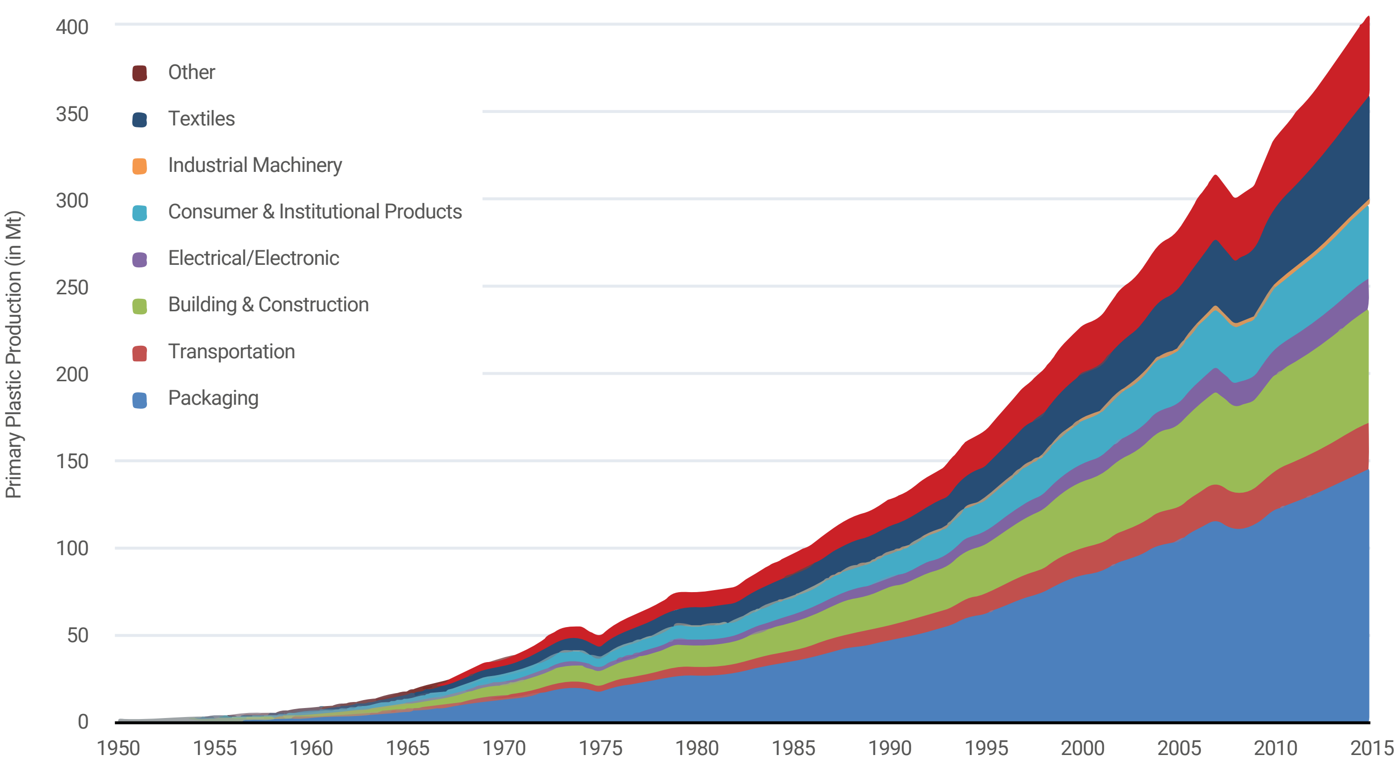
Data: Plastics Europe

Estimated consumption of plastic by end-use sector



Data: Science Advances

Global primary plastics production according to industrial use secture from 1950 to 2015 (million metric tons)



Data: Frontier Technology Quarterly, United Nations Department of Economic and Social Affairs "Frontier Technologies for Addressing Plastic Pollution"

As the nearby figures illustrate, the use of plastics and plastic-containing materials has shown nearly exponential growth in plastic production and consumption since the 1970s. Indeed, plastic materials are so omnipresent it is difficult, if not impossible, to look around oneself in an indoor environment without seeing many objects that are partially composed of plastic materials in some way, up to and including the structural materials that form the entire indoor environment itself. Today, plastics contain, preserve, protect, and allow transportation of a vast array of vital goods including foods and beverages, as well as playing a central role in the production, distribution, and use of chemicals and medicines in modern societies.

Plastics also constitute a novel form of structural material—one not provided by nature—that has critical characteristics which facilitate the production, maintenance, and use of those vital goods as well: whether that is the plastic casing on an MRI machine; the plastic panels on the ambulance that transports us to hospital; the plastic components in refrigeration systems, plumbing systems, electrical systems, transportation systems, food containers; and plastic-containing fabrics of all sorts. One common use of plastics is also expanding in ways that are less immediately visible: Plastics are used widely in the manufacturing (and implantation) of medical devices and prosthetics. Some examples of medical implants that use plastics include hip joints, cardiovascular implants, drug delivery devices, vascular grafts, bone cement for orthopedic implants, dental cement, heart valves, pacemakers, artificial materials for ear, chin, and nose reconstruction, sutures, and of course, breast implants and other cosmetic implants. Some of the more familiar plastics used in medical implants include polyethylene, polypropylene, polyvinyl chloride (PVC), polyethylene glycol, cellulose acetate, and the ubiquitous nylon.

The unique characteristics of plastics not commonly found together in natural materials—including their non-reactivity, non-conductivity, flexibility, conformability, malleability, durability, impermeability, foaming capacity, textural variability, and colorization—make them uniquely useful in a broad range of human endeavors—a utility that is reflected in consistently strong market demand for plastic bearing materials.

Ironically, the very characteristics that make plastic materials so useful and so strongly demanded in modern societies—particularly their non-reactivity and physical durability—also pose plastic's primary challenge to environmental management. Because plastics are long-lived materials that are resistant to physical, biological, biochemical, and geochemical degradation in the environment, plastic wastes, when released into the environment, can accumulate, and build up to significant concentrations that endure for long periods of time. Plastics eco-accumulation has most often been discussed in the context of aquatic environments, where discarded plastics-containing materials can pose risks to aquatic wildlife and aquatic ecosystems more broadly.

The source-materials that are used to manufacture plastics are also of concern in a context of environmental sustainability, primarily regarding the problem of climate change. Plastics are (largely) made from hydrocarbons found in fossil fuels, most particularly, petroleum and its derivatives. Petroleum production and consumption create a significant share of the human greenhouse gas emissions that contribute to climate change.

As a result of several decades of haphazard waste management of plastic materials in both the private and public sectors, some advocates of environmental sustainability argue that plastic materials are not—and cannot be made—environmentally sustainable. Some environmental groups such as Greenpeace, call for the outright elimination of the use of many plastic materials in human society. While single-use plastics are the focus of most current efforts to restrict or ban plastic use and production, in the not too distant past, arguments for greater restriction of plastics production and use have also involved medical devices, children's toys, diapers, feminine hygiene products, foam and plastic beverage and food containers, and more durable materials used for packaging humanity's ever-increasing volume of durable goods.

At present, the focus of most of the plastic-eliminationist debate is over what are colloquially called "single-use" plastics including such items as plastic grocery bags, drinking straws, sanitary wipes, clam-shell food containers, and plastic packaging and films, used in a range of consumer applications. According to the World Economic Forum, many governments have started to enact bans on single-use plastics around the world. The Footprint Foundation, tracks single-use plastic bans in the United States, which have been enacted (as of this writing) in Hawaii, Washington, New York, New Jersey, Florida, Maine, Maryland, Vermont, Connecticut, Oregon, and the District of Columbia.

But what is in a phrase: "environmental sustainability?"

While a seemingly simple phrase, the concept of environmental sustainability is surprisingly difficult to define (as is the case with several other popular environmental terms such as "renewable," and "precautionary"). The difficulty with defining "sustainability" arises because it is contingent on both an *objective* understanding of the fine and gross-scale level impacts that an action or product might have both on society and the environment, as well as the *subjective* consideration of what current human value systems view as tolerable, intolerable, or needed in terms of the net benefits of those actions or product to individuals and societies. When equity considerations are included, as they are in most formulations of environmental and developmental sustainability, an entirely new dimension of subjective judgements come into play that make defining "sustainability," ever more elusive.

Consider only a few of the questions enfolded in the concept of sustainability, itself a very novel concept in the history of either the Earth (which has gone through prolonged periods of unsustainability), or humanity, which has tempted the same.

When we ask if an action or material is "sustainable," are we asking if it is sustainable in its magnitude of impact? In the potency of its impact? In the geographic scale of its impact? Do we mean sustainable in the context of a particular location, or ecosystem, or in a temporary location, versus a permanent one? Is sustainability a matter of an object's transience or durability, mobility, or fixity? It is also reasonable to ask, when considering sustainability, the historical context of the issue at hand. Plastics are, as mentioned earlier, a novel material in the history of the Earth, and widespread concerns over environmental sustainability are more recent still. How long a period of time is suitable for the determination of sustainability in the broader context of human utilization of materials as modern societies require?

And when we ask if something is sustainable, are we considering sustainability holistically: in the context of everything else that humans produce, transform, consume, convey, and dispose of? Are we considering whether a world with objects or materials made without plastic components would be more "sustainable" than a world which employs those materials? Would whatever materials that replaced the theoretically "non-sustainable" plastic materials themselves be any more environmentally sustainable? And in the larger picture, regarding plastic materials, would a world without the activities enabled by plastics, and the human needs plastics now satisfy, be more sustainable from the perspective of human beings as well as the environment?

Three prominent definitions of sustainability give a window into its official use-definition of the day, from three of the world's leading authorities on environmental protection initiatives, the United Nations (UN), the United States Environmental Protection Agency (EPA), and the world's largest organization for the setting of standards, the International Organization for Standardization (ISO).

The landmark Brundtland Report of the United Nations elaborates: "Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities."

Note that the emphasis in the Brundtland report is anthropocentric. It is about meeting the needs of humanity, present and future. It does not elevate one particular aspect of the combined Earth-human ecosystem as being above this fundamental value of securing humanity's fundamental needs for survival and prosperity.

According to the United States Environmental Protection Agency, "Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations." The EPA observes that "The National Environmental Policy Act of 1969 committed the United States to sustainability, declaring it a national policy *"to create and maintain conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations."*

As with Brundtland, the EPA's definition of sustainability is centered on human well-being, and harmony with nature, not describing exactly which of the many activities defining the nature of humanity are to be kept or discarded, are "sustainable, or unsustainable."

The International Organization for Standardization enfolds three sub-components in its definition of sustainability:

Sustainability – the state of the global system, which includes environmental, social and economic subsystems, in which the needs of the present are met without compromising the ability of future generations to meet their own needs;

Sustainable development – development that meets the needs of the present without compromising the ability of future generations to meet their own needs; and,

Social Responsibility – the responsibility of an organization for the impacts of its decisions and activities on society and the environment, through transparent and ethical behavior that contributes to sustainable development, including the health and the welfare of society; takes into account the expectations of stakeholders; is in compliance with applicable law and consistent with international norms of behavior, and is integrated throughout the organization and practiced in its relationships.

The definitions of ISO are, if anything, significantly more centered around the satisfaction of human needs than are either the United Nations, or the United States Environmental Protection Agency.

At the end of the day, "environmental sustainability" is a relatively novel concept in human history. It is a mixture of objective (or at least semi-objective) empirical determinations such as *"the ability of the biosphere to absorb the effects of human activities"* and entirely subjective human value judgements involving the definitions of present and future "needs" in an ever-changing framework of equity, both present-day and future generations. This essay on the nature of plastics and sustainability will focus primarily on the issue of environmental sustainability, leaving the treatment of sustainability related to non-environmental values such as societal development, equity, for later, but no less important, consideration.

And what is the sustainability of alternatives?

Everyone is familiar now with the symbols of the current paradigm of plastics management, which involves a three-phase cycle that aims to ***reduce*** the use of plastic materials where possible, ***reuse*** those materials as much as possible during their life cycle, and then ***recycle*** those products into new products once they are no longer useful in their manufactured forms.

In colloquial use, the entire 3R cycle is simply referred to as "recycling." But this is not helpful for understanding which elements of the cycle are working well, working poorly, or were never particularly useful to begin with. For clarity, therefore, I will use the term "3R" for the entire cycle and reserve the term "recycling" for the part of the cycle in which depleted plastic materials and products are recrafted (by whatever technology) into new raw materials or finished products.

The 3R management scheme calls for maintaining a closed cycle in which plastic materials pass through their different product life cycles contained away from harming the environment, ostensibly without growing in absolute levels of creation and use over time. If one has an iterative reduction component of a closed cycle, the presumption is that the overall cycle will contract over time as the cycle repeats. This concept is often promoted in the context of a broader "circular economy" that applies to essentially all human use of both natural and synthetic materials.

Recycling programs are common in most developed countries (and many less-developed countries) for most of the physical materials that developed human society consumes. Wood, paper, glass, metals, plastics—are widely managed through the basic 3R materials management paradigm. The symbol of the recycling paradigm has become so ubiquitous that along with certain icons for colas, hamburgers, and an infamous fruit, future generations of anthropologists might well come to believe it had religious significance to humans in the 20th and 21st centuries!

Recently, however, the 3R model of plastics management is seen as deficient by sustainability proponents, because, in part, two of the three parts of the cycle have largely or entirely failed to put plastics use on a trajectory toward current conceptions of environmental sustainability.

The limitations of "reduce"

The limitations of the "reduce" component of the 3R framework is rendered explicit in the charts depicting plastics production, consumption, and disposal at the start of this article: plastic production, consumption and disposal have all grown in recent decades. The consuming public, globally, has essentially rejected the idea of "reduction," or "using less stuff" as a desirable element of the total 3R management model.

The limitations of reuse, replace, or displace

Though it is understood that consumers do routinely engage in the "reuse" of plastic materials such as grocery bags, delivery-food containers, and so on, the "reuse" component of the 3R management cycle is limited in its potential to reduce the life cycle negative climate impacts of plastic use. Since climate change is a process that plays out over several hundred years through the actions of greenhouse gases released into the atmosphere, whether a person uses their plastic grocery bag three times, or six times in the one year they may keep it before disposing of it does not matter much at the end of the day when the carbon emissions released in its manufacture will remain in the air for many decades. Consequently, the focus of environmental sustainability advocates with regard to things like plastic bags and plastic drinking cups has been more about ***"replacing"*** them with non-plastic alternatives: cloth bags, and ceramic or metal cups, for example. As will be discussed further, the substitution of plastics with other materials carries its own environmental tradeoffs which have been shown, in several prominent cases, to be less, rather than more environmentally sustainable.

The limitations of recycling

The "recycle" leg of the 3R triad is increasingly challenged around the world, primarily for economic reasons. From an economic perspective, conventional recycling programs have been seen to largely fail the market test of profitability. With a few exceptions, recycled products have lower market value than newly manufactured products, and thus the economics of recycling are disfavored compared to the economics of new production. As a result of this value down-scaling, conventional recycling requires government subsidization in direct and indirect ways, which both increases its economic inefficiency and is also a cause of political objections by to the entire public finance model of recycling.

Unpacking the limitations of reuse / replacement

While there is great nostalgia involving cloth, mesh, and paper grocery bags, which earlier generations remember fondly as precursor materials for textbook covers, lunch bags, and school projects, analysis suggests that the simple idea of returning to previous methods of carrying our groceries carries consequences of its own that are not immediately apparent. In-depth examination of the environmental consequences of plastic replacement or substitution suggests, rather, that one might actually increase environmental harms rather than mitigating them.

Making those determinations is complex and is achieved—when it is performed, which has been only rarely done—by comparing the life cycle environmental impacts of plastic goods to the life cycle environmental impacts of whatever goods would replace them. Comparative life cycle assessment is a growing field of study which offers a rigorous method of computing the tradeoffs involved in replacing one material with another.

All life cycle analyses, however, are not created equal. A critical issue involving life cycle analysis is the question of where one draws the boundary of the life cycle to be analyzed. That is, what one includes and excludes, from the framework of analysis in life cycles in both time and space, in human and non-human ecosystems, and in economic and intergenerational perspectives. Without proper caution, these boundaries can sometimes be drawn too narrowly, or too broadly, too inclusively, or not inclusively enough, leading to inappropriate comparisons—the dreaded apples-to-oranges situation.

Life cycle analysis in a sustainability context

Life cycle analysis, as the name implies, is an attempt to estimate the impacts of a material over the full life cycle of its existence, and like sustainability, the concept seems simple enough on first consideration. But a deeper look at what the life cycle of an object (or an activity, for that matter) entails over the course of its production, use, and disposal reveals that the issue of sustainability is far more complex than it would appear.

Taking just one thought-exercise, let's consider the life cycle of a humble plastic cup, only in terms of one of the inputs into its life cycle of creation, distribution, use, disposal, and re-distribution to a recycling or landfill site, in terms of energy consumed over the course of the cup's life cycle. A superficial life cycle view would include the energy used to extract the raw material that will be transformed into plastic, the energy used to form that material into a product, package it, transport it, employ it/maintain it over time, and then dispose of it safely (we hope).

While that might seem like a reasonably comprehensive energy accounting on first glance, appearances can be deceiving. What is left out of that analysis? A few omissions would include the energy used to make the machines that produced the raw materials that would be turned into plastics, for example. Another omission from that simple life cycle analysis would be the energy used to dispose of the intermediate-stage life cycle components of packaging used to protect it during shipping at all levels of production, from packaging the raw materials, to packaging used to protect the intermediate component parts of a final product, to the packaging that might be used to palletize the products for shipment by ocean tanker, train, and truck, to the packaging the consumer will eventually place the products to be disposed of. And lest we forget, even a more fulsome life cycle analysis of plastic waste will likely not include the plastic wastes generated by the degradation of the rubber-and-plastic tires that are used to transport the materials over the many thousands of miles they will travel over their life cycle. Seen accurately, the idea of a life cycle is almost infinitely recursive: that is, you can always extend the analysis deeper into the past, further into the future, more broadly in the present, more narrowly in the present, and so on.

The basic stages of life cycle analysis are (After "Environmental Management," Elsevier (2017)):

- Scoping the issue: this is the process of defining where to draw the conceptual circle encompassing a product's "life cycle" in such a way as to accurately capture the essence of its lifetime environmental impacts;
- Defining and measuring the flows of energy and materials in all of the processes, and subprocesses, as well as inputs and outputs that might flow into or out of the system boundary; and
- Determining the environmental impacts that result from the overall production/consumption/disposal cycle of a product in terms of measured quantities of air emissions, greenhouse gas pollutions, plastic materials released into the environment, and arguably, the costs of abating those impacts as well once they are discovered.

Generally, there are three routinely used scoping boundaries in life cycle analysis that readers will commonly encounter:

Cradle-to-Grave

Cradle-to-grave will be the most familiar cycle boundary to most readers, as this framework of analysis has a long precedent in public policy analysis, and is routinely used to discuss individual social programs (healthcare), and the nature of entire forms of government as well (i.e. the cradle-to-grave welfare state). A cradle-to-grave life cycle assessment includes all aspects of a product's creation from its first manufacture (in the cradle) through the use phase of the product, to the disposal phase of the product, when it finds its way to its final resting place (its grave). All inputs and outputs are considered for all the phases of the life cycle. Note that cradle-to-grave analysis does not include activities that precede production of a given product. For example, a life cycle analysis of plastic cups might include all of the energy used in extracting the raw materials that would make up the plastic cups, transporting all of those elements to the facility that would form the cups, as well as all of the energy used to package the cups for shipment, to transport them to market, and then transport them again for disposal. But a cradle-to-grave assessment would not include, for example, the manufacturing impacts of building the forklifts, warehouses, trucks, trains, or other machinery needed to transport the plastic cups throughout their life cycle. Nor would a cradle-to-grave analysis of our pallet of cups include any of the energy and natural resources that were used to produce the various vehicles and vessels that will move them on their way through their life cycle by land, sea, or air. All of those environmental impacts are, perhaps, assessed elsewhere in analyses of sectoral life cycle analysis of transportation systems, but they are not allocated over to our plastic cups.

Cradle-to-Gate

Cradle-to-gate will also be a familiar term to many people as it is associated with widely used products such as agricultural products (which are assessed only until they exit the *farm gate*, or petroleum products, when their impacts are assessed only within the context of production, but not consumption or disposal at *the refinery gate*. Cradle-to-gate analysis is often used in order to compartmentalize the emissions of different elements of a product's life cycle into discrete stages for the purposes of tax responsibility.

Usage and disposal elements of a product's life cycle are generally omitted from cradle-to-gate life cycle analyses for a variety of reasons. The goal of understanding the more limited life cycle might be necessary for understanding the differential environmental impacts of the various life cycle stages in order to determine which stage has the most environmental impacts, the most manageable ones, or to ascribe those environmental impacts to discrete sectors involved in the life cycle of the product for regulatory or responsibility purposes. Bringing livestock from the farm to its gate might involve a very different set of environmental impacts than would later stages of moving from gate to factory, from factory to warehouse, and so on.

Cradle-to-Cradle

Cradle-to-cradle analysis is arguably the most comprehensive, as it goes beyond the conventional endpoints for end-of-life products (typically the landfill, incinerator, or environment) and extends to the reclamation of the materials and energy inherent in the product to feed into the production cycle of new or derivative/related products. Examples of this would include aluminum beverage cans manufactured from reclaimed aluminum recovered from post-consumer use cans, or the production of glass wool insulation from recycled glass bottles.

Environmental life cycle analyses can focus on a large range of different environmental endpoints, affecting different environmental systems via different types of physical impacts. Those endpoints most relevant to the management of plastics include impacts to wildlife and ecosystems, greenhouse gas production, and, in some analyses, energy consumption is considered a negative environmental endpoint by itself, within a framework that presumes imminent resource depletion of energy-containing materials on earth, such as fossil fuels.

As with sustainability (above), there are several accepted definitions of what constitutes a proper life cycle analysis in the context of environmental impacts promulgated by credible authorities.

The International Organization for Standardization is a group consisting of standard-setting entities of the world's governments. ISO membership is strictly controlled to minimize the interests of individuals or companies that might have a financial incentive to bias its standards. As the ISO FAQ states:

> *"Individuals or businesses can't join ISO. Membership of ISO is only open to national standards institutes or similar organizations that represent standardization in their country (one member in each country). It's important to realize that companies that apply or certify ISO standards are not ISO members."*

ISO publishes a set of standards for environmental management systems, called ISO14001, which defines life cycle analysis as it is generally accepted by world governments:

> *"The definition of life cycle is 'Consecutive and interlinked stages of a product (or service) system, from raw material acquisition or generation from natural resources to final disposal. Life cycle stages include acquisition of raw materials, design, production, transportation/ delivery, use, end-of-life treatment and final disposal.'"*

To be compliant with ISO14001 standard of performance: "Within the defined scope of the environmental management system, the organization shall determine the environmental aspects of its activities, products and services that it can control and those that it can influence, and their associated environmental impacts, considering a life cycle perspective."

Selected Case Studies

As discussed, while it can be complex and quantitative in execution and presentation, environmental life cycle analysis is still fundamentally a subjective framework of analysis, requiring numerous judgmental assessments of what is included in the analysis, the timeframe, scope, scale, and even the definition of environmental harms. However, life cycle analysis is the best tool we have to rationally assess and compare materials in any logical way for any particular sort of impact it may have.

Several high-resolution comparative life cycle assessment (LCA) studies have been performed in recent years, and the findings to date suggest that replacing plastics with other materials can have perverse consequences that themselves cut against the concept of environmental sustainability. These are a few examples of such comparative LCA studies.

Beverage container alternatives

As anyone who frequents coffee houses would know, one faces (or used to face) a choice when placing one's order: to accept the beverage in a wax-coated paper cup (or often two), or a foamed-plastic cup, or to grab a can of a cold version of your beverage of choice, or to snag one of the pre-filled sterile drink boxes of your favorite libation, or perhaps even to bring your own ceramic or metal cup. But what are the environmental impacts of that choice?

A study conducted by researchers *Voulvoulis* et. al, published by the Imperial College London reviewed the findings of 73 publications on life cycle analysis which compared different types of beverage packaging. Likely contrary to many people's expectations, *Voulvoulis'* findings indicate that in the applications where it is used, most of the time, plastic beverage packaging actually performs better than its alternatives, mainly due to its very lightweight properties.

The life cycle analyses *Voulvoulis* used to explore the question of which type of bottles used as beverage containers would be more "sustainable," looked at plastic bottles, glass bottles, steel bottles, aluminum cans (actually aluminum/plastic hybrids), and "liquid fiberboard packaging," which is a laminated material used to contain a variety of sterilized, shelf-stable liquids. Think of your children's lunchtime juice box, or the carton of chicken broth or almond milk that you might have in the pantry.

Voulvoulis examined sustainability of the different products through the lens of **life cycle carbon emissions**, which is the pre-eminent concern involving plastics use at the global level. The figure below displays the central findings of the Voulvoulis study, revealing again, perhaps contrary to prevailing wisdom, when seen in a full life cycle analytic framework, production of plastic bottles and composite bottles with plastic components, results in considerably lower life cycle carbon emissions than other types of container.

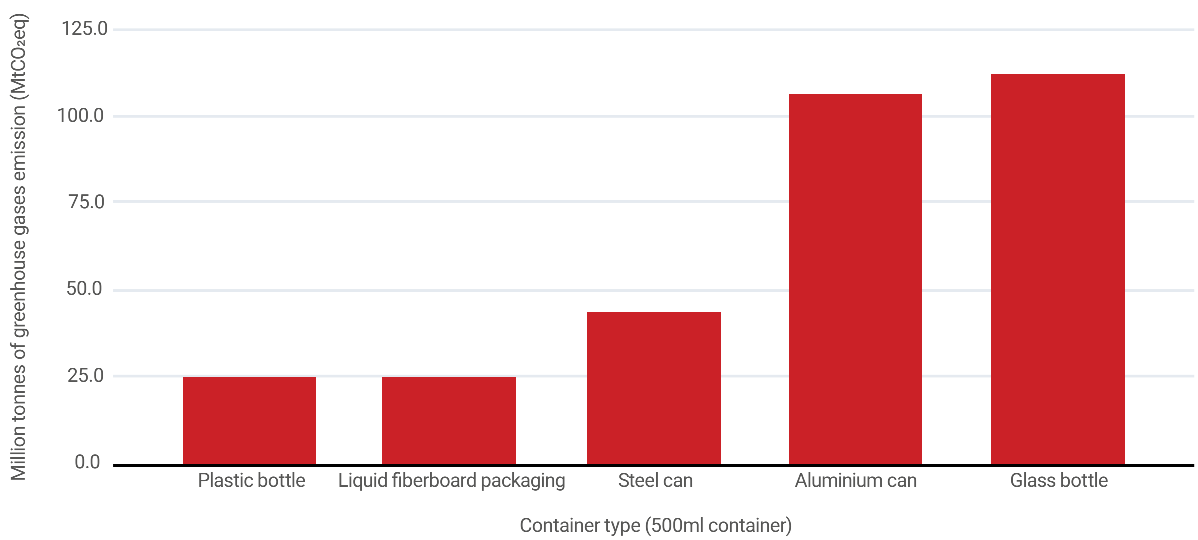


Figure 2 - Greenhouse gases emissions for producing all 500ml containers in 2016 from alternative materials

Source: Voulvoulis

Glass bottles are seen as particularly intensive producers of greenhouse gases over production, likely due to their weight. The transportation of mass is a highly greenhouse gas intensive activity. Aluminum cans, the production of which entails large amounts of energy, also produce higher levels of greenhouse gases during production than do either plastic or steel containers. As can be seen in the two bars on the left of the chart, the two plastic, and plastic-composite materials turn out to have the lightest climate change footprint of the available choices.

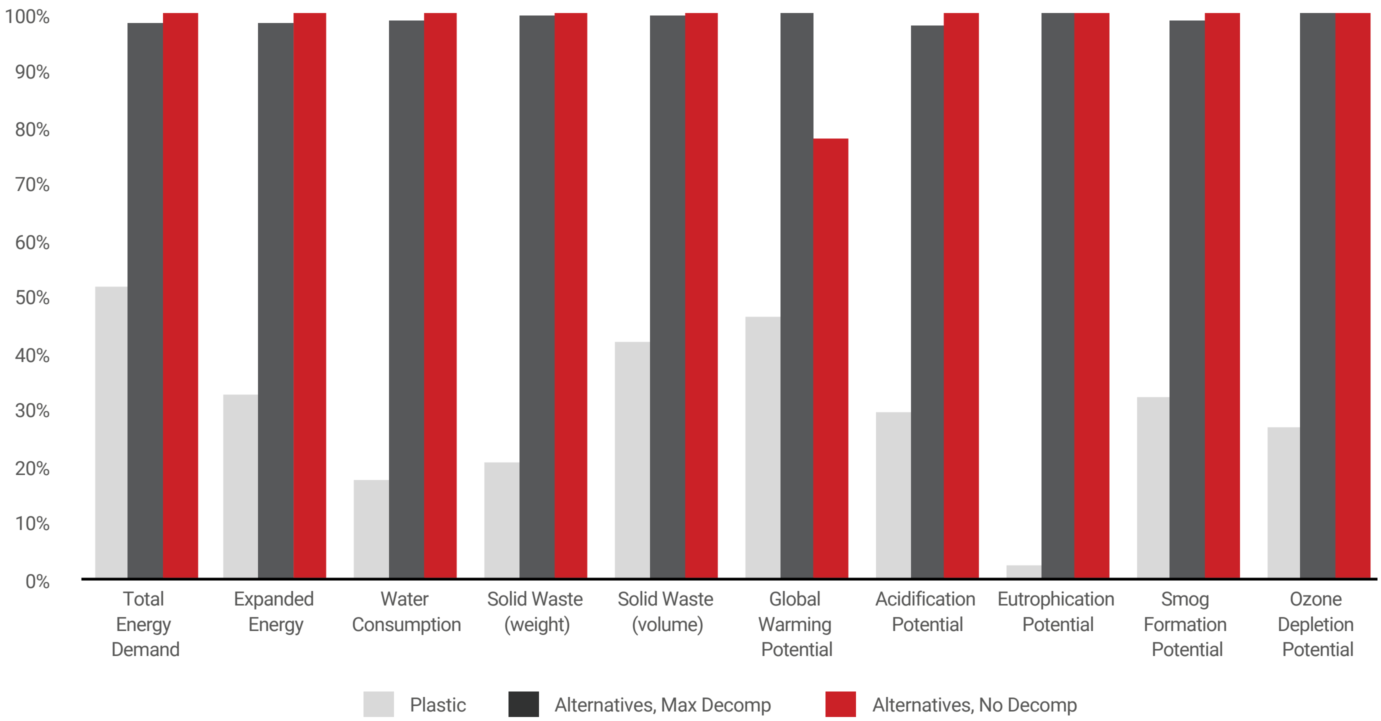
Plastic packaging alternatives

Another comparative life cycle analysis conducted by Franklin Associates for the American Chemistry Council, asked the question, "If plastic packaging were replaced with alternative types of packaging, how would environmental impacts be affected?"

The environmental impacts studied in *Franklin* included a broad range of environmental metrics including:

- energy demand;
- water consumption;
- solid waste;
- global warming potential;
- acidification potential (of water bodies);
- eutrophication potential (of water bodies);
- smog formation potential; and,
- ozone depletion potential.

The figure below illustrates the findings of the Franklin study at a glance:



Source: Franklin

Again, the counter-intuitive findings of the *Franklin* study are stark: On the 10 metrics of environmental degradation that *Franklin* studied, plastics were the least detrimental, followed by alternative materials that had been maximally decomposed (Max Decomp), which were very slightly better than alternative materials (except in the case of global warming potential) disposed of with "No Decomp," i.e., landfilled.

The tables below break out the findings of the *Franklin* study for the United States and Canada in more detail. As a point of reference, the population of Canada is approximately one-tenth that of the United States. As of this writing, there were approximately 330 million people living in the United States, and about 38 million Canadians living in, well, Canada.

Table ES–4. Summary of Savings for Plastic Packaging Compared to Substitutes

		US Savings		Canadian Savings	
Results Category	Units	Compared to Substitutes with Max Decomp	Compared to Substitutes with No Decomp	Compared to Substitutes with Max Decomp	Compared to Substitutes with No Decomp
Total Energy Demand	billion MJ	1,196	1,235	121	123
Expended Energy	billion MJ	1,396	1,435	143	145
Water Consumption	billion liters	1,106	1,121	130	133
Solid Waste by Weight	thousand metric tons	52,887	53,162	4,044	4,050
Solid Waste by Volume	million cubic meters	55.1	55.4	3.73	3.74
Global Warming Potential	million metric tonnes CO_2 eq	67.1	39.5	8.66	3.65
Acidification Potential	thousand metric tonnes SO_2 eq	526	541	52.3	52.7
Eutrophication Potential	thousand metric tonnes N eq	340	341	37.4	37.4
Smog Formation Potential	thousand metric tonnes O_3 eq	6,549	6,682	666	670
Ozone Depletion Potential	metric tonnes CFC-11 eq	1.15	1.15	0.13	0.13

Source: Franklin

A second table from *Franklin* puts the findings in a more intuitively understandable perspective, comparing the environmental impact “savings” of plastic materials use in more colloquially familiar terms such as miles driven by vehicles, or the number or Olympic swimming pool volumes of water consumed.

Table ES–5. Savings Equivalents for Plastic Packaging Compared to Substitutes

		US Savings		Canadian Savings	
Results Category	**Equivalence Factor**	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp
Total Energy	Million passenger vehicles per year	18	18	1.8	1.8
	Thousand tanker trucks of gasoline	1,073	1,108	108	110
Global Warming Potential	Million passenger vehicles per year	14	8.5	1.9	0.8
	Thousand tanker trucks of gasoline	889	523	115	48
Water Consumption	Thousand Olympic swimming pools	461	467	54	55
Solid Waste by Weight	Thousand 747 airplanes	290	291	22	22
Solid Waste by Volume	U.S. Capitol Rotundas	1,496	1,505	101	102
Acidification	Thousand railcars of coal	292	301	29	29

Source: Franklin

As with *Voulvoulis*, the findings of *Franklin* confound the popular narrative, finding that plastic materials, again seen in full life cycle perspective, outperform alternative materials on ten major metrics of environmental sustainability.

Plastic grocery bag alternatives

Research group Boustead Consulting conducted a life cycle analysis examining the comparative sustainability impacts of three types of grocery bags:

- Traditional plastic grocery bags (polyethylene);
- A type of grocery bag made from compostable plastics (a blend of 65% EcoFlex, 10% polylactic acid, and 25% calcium carbonate; and,
- A paper grocery bag made using at least 30% recycled fibers.

The Boustead analysis normalizes the different types of bag for their carrying capacity, to ensure a like-to-like comparison. The results, which looked at five separate metrics of sustainability/environmental impact are below.

	Impact Summary of Various Bag Types (Carrying Capacity Equivalent to 1000 Paper Bags)		
	Paper (30% Recycled Fiber)	**Compostable Plastic**	**Polyethylene**
Total Enegy Usage (MJ)	2,622	2,070	763
Fossil Fuel Use (kg)	23.2	41.5	14.9
Municipal Solid Waste (kg)	33.9	19.2	7.0
Greenhouse Gas Emissions (CO2 Equiv. Tons)	0.08	0.18	0.04
Fresh Water Usage (Gal)	1,004	1,017	58

Source: Boustead

In all five metrics of sustainability, the simple disposable polyethylene bags had lower impacts on the environment than either compostable plastics or paper bags—even paper bags that already contained 30% recycled paper fiber.

But the Boustead analysis is not the only analysis done to compare the environmental impacts of plastic bags nor by any means the first. A study released in February, 2011, by the Environmental Agency of England, entitled Evidence: Life Cycle Assessment of Supermarket Carrier Bags, conducted a "cradle-to-grave" review of seven different types of grocery store bags: conventional lightweight bags made of high-density polyethylene (HDPE); an HDPE bag doped with a chemical to speed its degradation; a lightweight bag made from a biodegradable starch-polyester blend; a regular paper bag; a heavy-duty "bag for life" made from low-density polyethylene (LDPE); a heavier duty polypropylene bag; and a cotton bag. Environmental endpoints assessed included global warming potential; abiotic depletion; acidification; eutrophication; human toxicity; freshwater aquatic ecotoxicity; marine aquatic ecotoxicity, and petrochemical oxidation.

Their key findings were:

- The conventional HDPE bag had the lowest environmental impacts of the lightweight bags in eight out of nine impact categories;
- The biodegradable HDPE bag had larger environmental impacts than the regular kind;
- The starch-poly bag (similar to HDPE bags, but made of a mixture of starch and polyethylene) was worse yet, with the highest environmental impact rankings on seven of the nine categories examined;
- The heavy-duty LDPE bag must be used five times in order to get its global warming potential below that of a conventional HDPE bag;
- The non-woven polypropylene "bag for life" had to be used 14 times to get its global warming potential down to that of HDPE;
- Paper bags performed poorly on the environmental impact tests, and must be used four or more times to match the global warming potential of the HDPE bags; and, finally,
- Cotton bags were found to have greater environmental impacts that the conventional HDPE bag in seven of nine categories, even when used 173 times, which is needed for their global warming potential to drop down to that of HDPE.

The table below shows how many times non-HDPE bags needed to be reused in order to bring their global warming potential down to that of an HDPE bag under a range of assumed reuse rates. The first column, for example, shows that one has to reuse a paper bag three times to reduce its global warming potential to that of the HDPE bag, while one would have to use an LDPE bag four times, a non-woven polypropylene bag 11 times, and a cotton bag 131 times to achieve the same end.

Type of carrier	HDPE bag (No secondary reuse)	HDPE bag (40.3% reused as bin liners)	HDPE bag (100% reused as bin liners)	HDPE bag (Used 3 times)
Paper bag	3	4	7	9
LDPE bag	4	5	9	12
Non-woven bag	11	14	26	33
Cotton bag	131	173	327	393

Source: Environmental Agency of England

Bio-Plastic Straws and Paper Straws

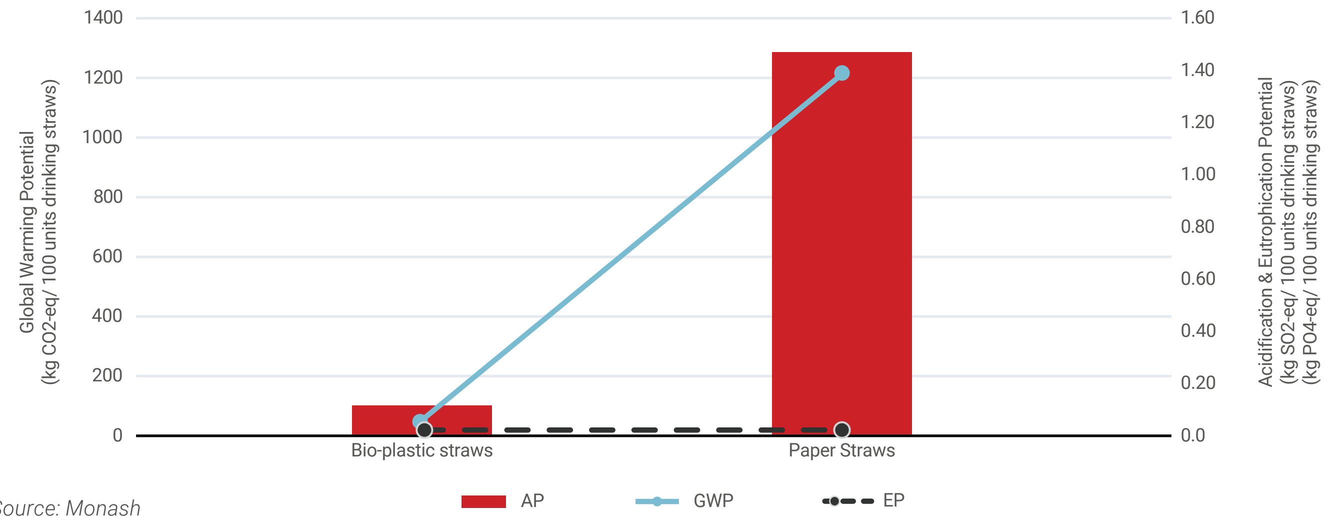
Finally, although the detailed research on the subject is scant, one recent study illuminates the tip-of-the-spear in the modern debate over disposable plastics, the battle to ban disposable plastic drinking straws.

Monash

In the Malaysian open-access journal "processes," a research team based out of Monash University in Malaysia, published a study comparing the life cycle impacts of two types of drinking straws: bio-plastic polymers and paper drinking straws.

Plastic waste is a matter of serious concern in Malaysia, which "…has been listed as the eighth-worst country worldwide for the mismanagement of plastic waste. It was estimated that there were almost one million tons of mismanaged plastic waste in Malaysia, of which 0.14 to 0.37 million tons may have been washed into the oceans in 2010."

The Monash researchers focused on three metrics of sustainability, Global Warming Potential, Eutrophication Potential, and Acidification Potential. Global warming potential was assessed as emissions of carbon dioxide equivalents; Eutrophication Potential was assessed in terms of phosphate emissions; and Acidification was assessed in emissions of sulfur dioxide.



Source: Monash

As the figure shows, the Monash researchers found that bio-plastic straws outperformed paper straws on the environmental metrics of global warming potential, air pollution, and eutrophication potential. They are also superior at drinking milkshakes, a finding not discussed in the Monash report.

Unpacking the limitations of recycling

If one conducts a Google search on "Is recycling broken," one gets back (as of my search) 120 million responses offering answers ranging from a blunt assessment that "The Recycling Industry in America Is Broken—EcoWatch," to more optimistic assessments, "Why the Recycling System is Not Broken—Waste 360," and pretty much every variant in between. In the UK, the BBC World Service offers "The Inquiry, Is Recycling Broken?" CNBC asks, "Is recycling a waste?" The Financial Times explains, "Why the world's recycling system stopped working." The Ocean Conservancy asks, "Is Recycling Broken?" and answers with a solid "Yes." And, not mincing words, the Sierra Club declares that the "US recycling system is garbage." Each of these articles points fingers in a variety of directions, assigning blame, and proposing various ways to "repair" the recycling system as it now exists, but the different authors and analysts are rarely in agreement over either aspect of the problem.

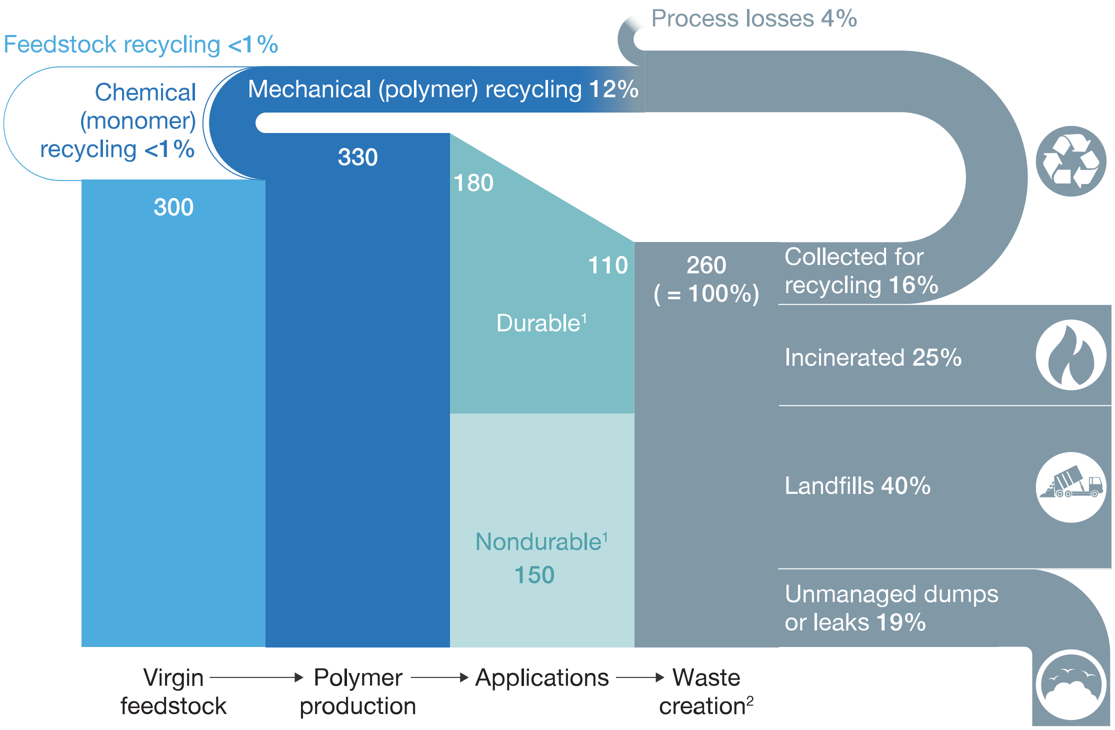
Yet the lowest common denominator in most of these articles comes down to a simple, unpleasant reality: recycling plastics, as it is now done (and as it has been done in past decades), is economically inefficient. What we get out of the recycling process at succeeding stages is generally of lower value than newly synthesized and manufactured plastic products.

This diminishing value dynamic makes every other step along the process to recycling also less economically efficient, whether that's the gathering of plastic waste, shipping it, sorting it, washing it, transporting it to a recycler, or recycling it. Because of this unavoidable "downscaling" of value that accompanies the recycling process, economic losses at all levels of the recycling process cannot be avoided, and indeed, accumulate the farther one progresses along the recycling process toward final disposal. As a result, the economics of conventional recycling programs have been shored up in different ways with outside infusions of capital via subsidies from governments, municipalities, household waste-collection fees, or taxpayers.

A 2018 study by McKinsey & Company explores the potential for more complete reclamation of the value components of plastics currently treated as wastes, most of which, as shown in the accompanying graphic, end up buried in landfills or incinerated. Nineteen percent, unfortunately, ends up being released to the environment in "unmanaged dumps or leaks."

The majority of plastics waste currently goes to landfills and incineration.

Global polymer flows, millions of metric tons per annum, 2016[1]



[1]Durable applications with an average lifetime >1 year will end up as waste only in later years; nondurable applications go straight to waste.
[2]150 million metric tons of mixed plastic waste from nondurable applications that end up as waste in same year, plus 110 million metric tons of mixed plastic waste from production in previous years.

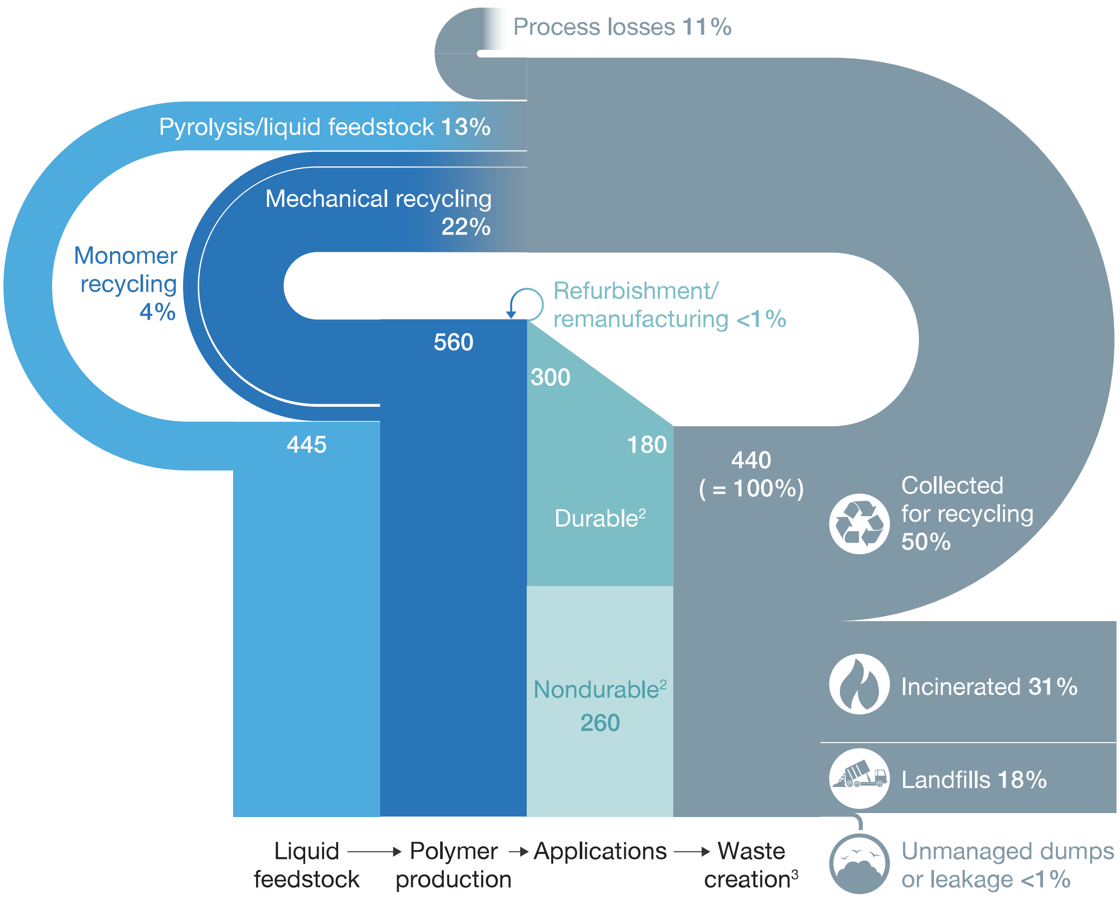
McKinsey&Company

Source: McKinsey & Company

The McKinsey study offers only one possible scenario of the future potential of reclamation of the monomer and energy components of 50 percent of the mass of plastics collected for recycling on a global basis. And in the case of the United States, the use of oil in plastics production may be overstated. Even so, the *McKinsey* study suggests that the change of conventional recycling endpoints could significantly change the balance of profitability that currently flows through the recycling process (emphasis by author).

Achieving a 50 percent reuse and recycling rate in 2030 would entail reshaping plastics-waste flows.

Global waste polymer flows 2030, millions of metric tons per annum[1]



[1]Scenario based on a multi-stakeholder push to boost recycling, regulatory measures to encourage recycling, consistent progress on technologies, and $75-per-barrel oil price.
[2]Durable applications with an average lifetime >1 year will end up as waste only in later years, while nondurable applications go straight to waste.
[3]260 million metric tons mixed plastic waste from nondurable applications that end up as waste in same year plus 180 million metric tons of mixed plastic waste from production in previous years.

McKinsey&Company

Source: McKinsey & Company

"Projecting to 2050 suggests that nearly 60 percent of plastics demand could be covered by production based on previously used plastics. This will substantially reduce the amount of oil required to cover global plastics demand, with projections suggesting oil demand running 30 percent lower than a business-as-usual scenario. This outcome would require revisions of recently published forecasts that show petrochemicals making the largest contribution to oil demand growth over the next two decades. Under the high-adoption scenario, the cost position of plastics-waste-based feedstocks—via mechanical recycling, monomer recycling, or reuse through pyrolysis or other feedstock supply—could potentially be so attractive that they could account for two-thirds of the profit-pool growth of the petrochemicals and plastics industry by 2030."

Another recent review article in *Nature Reviews*, evaluates the potential for the reclamation of plastics constituents—the transformation of plastic polymers back into purified chemical monomers for use in the creation of new materials, a process the authors call CRM: Chemical Recycling to Monomer.

Geoffrey Coates and Yutan Getzler, authors of the review article observe that there is massive monetary value lost in the current framework of plastics recycling:

> *The annual loss in value of single-use packaging waste—equating to 47 percent of polymer waste —is estimated at US$80–120 billion (corresponding to 95 percent of the embedded value), a figure that does not include externalized environmental costs. Recovered plastics are either valorized through primary (closed- loop) and secondary (cascade) recycling or, more commonly, combusted for energy production. However, most plastics are relegated to landfill or are leaked into the environment.*

Coates and Getzler review the status of several plastics monomer reclamation technologies suggesting they can help close the value-chain of recycling, providing useful materials of sufficient value at the end of the recycling process to close, or largely close the economic unprofitability of the overall recycling process.

This figure, from their *Nature Review* article, portrays the potential of full reclamation of plastic monomers to bring society's use of plastic materials closer to our current conceptions of environmental sustainability.

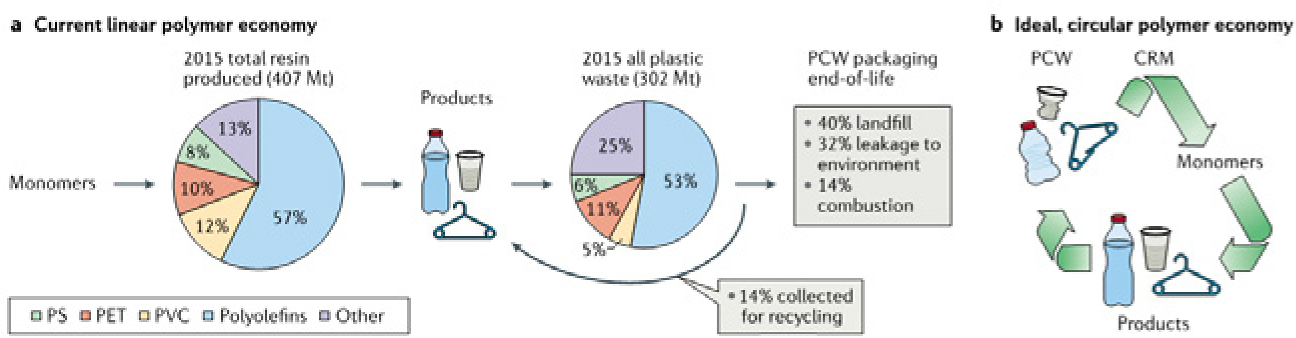


Fig. 1 | **Present and ideal polymer economies. a** | In 2015, the mass of plastic waste was 74% of the mass of resin produced[7]. The graphs show the contribution of different polymers to total plastic resin production (values averaged over 2002–2014) and waste (2015 values). A small percentage of plastic waste is collected for recycling, with the remainder going to landfill, leaking to the environment or being combusted (the values shown are for plastic packaging only)[8]. **b** | Cycle showing the idealized polymer economy, in which post-consumer waste (PCW) plastics undergo chemical recycling to monomer (CRM). Mt, megatonnes; PET, poly(ethylene terephthalate); PS, polystyrene; PVC, poly(vinyl chloride).

Source: Coates and Getzler

Concluding Thoughts

After a remarkably brief 100 years of existence as a significant human use material, the totality of plastics integration into an environmental impact framework that can meet today's (only 50-year-old and evolving) definition of sustainability has yet to take place. The same can be said of the energy use, materials use, and transformation of virtually all materials that humans use in their distinctive evolutionary niche as "materials transformation specialists." None of this should be surprising, in context: the industrial revolution only occurred around 1850, and the realization that human activities were capable of causing significant environmental degradation took many decades to become self-evident.

But as with other vital materials humans use: wood, metal, water, minerals, fossil fuels, wind, sunlight, plant-derivatives, and animal-derivatives, plastics use can be made sustainable, and indeed it must be. The value proposition of plastics use as with the other critical materials used in the sustenance of prosperous, technological societies is simply too high to surrender without sending humanity plunging backwards in developmental well-being.

The two challenges remaining to square the circle of bringing humanity's creation and use of plastic materials with our current visions of environmental sustainability are to:

1. **Rescue the lost value:** extracting the profitable energy and monomeric components and use that profit to feedback and rationalize the economics of the recycling process; which will involve procedures such as hydrolysis, pyrolysis, and more advanced technologies currently being tested; and

2 **Cutting the red tape** of governmental regulations and subsidies, standards and product specifications, micro-definitions that currently embody world government's preferred plan to manage plastic creation, use, and flows through human societies around the world so that holistic repair of the economic flows through recycling from cradle-to-cradle can function efficiently, a process which has barely begun.

Plastics are no more or less unsustainable than anything else that humans use or do, because plastics' creation and incorporation into the human ecosystem is still in its earliest stages of evolution. However, the answer is not to demand the end of material progress and history, it is to finish working the problem of plastics sustainability as we work the problems of sustainability in general.

References

Boustead Consulting and Associates (n.d.). Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper. Available at https://www.plasticpackagingfacts.org/wp-content/uploads/2016/11/Bousted-LCA-Report-Bags.pdf

Chun Hun Moy et al. (2021). Comparative Study of a Life Cycle Assessment for Bio-Plastic Straws and Paper Straws: Malaysia's Perspective. *Processes* (an open-access journal). Available at https://www.mdpi.com/2227-9717/9/6/1007

Coates, Geoffrey W., and Yutan D.Y.L. Getzler (2020). Chemical recycling to monomer for an ideal, circular polymer economy. *Nature Reviews|Materials*. Volume 5, July 2020. Available at https://www.nature.com/articles/s41578-020-0190-4.epdf?no_publisher_access=1&r3_referer=nature

Environment Agency (UK) (2011). "Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291023/scho0711buan-e-e.pdf

Footprint Foundation (2021). U.S. Bans at a glance. Available at https://footprintusfoundation.org/single-use-plastic-legislation/

Franklin Associates (2018) Life cycle impacts of plastic packaging compared to substitutes in the United States and Canada: theoretical substitution analysis. Available at https://www.plasticpackagingfacts.org/wp-content/uploads/2018/11/Life cycle-Impacts-of-Plastic-Packaging-Compared-to-Substitutes-in-the-United-States-and-Canada.pdf

Greenpeace Canada (2020). Ban on single-use plastics: let's make more noise than lobbies. Available at https://www.greenpeace.org/canada/en/story/36834/ban-on-single-use-plastics-lets-make-more-noise-than-lobbies/

Iyyanki V. Muralikrishna and Valli Manickam (2017). Environmental Management: Science and Engineering for Industry. Available at https://www.sciencedirect.com/book/9780128119891/environmental-management

International Organization for Standardization (ISO) (2012). Sustainability, sustainable development, and social responsibility. ISO definitions and terminology. Available at https://iso26000.info/wp-content/uploads/2016/03/ISO_Sustainability_brochure.pdf

International Organization for Standardization (ISO) (n.d.). Available at https://www.iso.org/frequently-asked-questions-faqs.html

International Organization for Standardization (ISO) (n.d.) Life cycle perspective: what ISO14001 includes. Available at https://committee.iso.org/sites/tc207sc1/home/projects/published/iso-14001---environmental-manage/life cycle.html

Laurence Knight (2014). A brief history of plastics, natural and synthetic. *BBC*. Available at https://www.bbc.com/news/magazine-27442625

McKinsey & Company (2018). How plastics waste recycling could transform the chemical industry. Available at https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry

Soumya Nag and Rajarshi Banerjee (2012). Fundamentals of medical implant materials. *ASM Handbook*, Vol. 23, Materials for Medical Devices. Available at https://www.asminternational.org/documents/10192/1849770/05285G_Sample.pdf

United Nations (1987). Report of the World Commission on Environment and Development: Our Common Future. Available at http://www.un-documents.net/our-common-future.pdf

United States Environmental Protection Agency (2021). Learn About Sustainability. Available at https://www.epa.gov/sustainability/learn-about-sustainability#what

Voulvoulis et al. (n.d.) "Examining material evidence: the carbon footprint." Published by Imperial College, London. Available at https://www.imperial.ac.uk/media/imperial-college/faculty-of-natural-sciences/centre-for-environmental-policy/public/veolia-plastic-whitepaper.pdf

World Economic Forum (2020). As Canada bans bags and more, this is what's happening with single-use plastics around the world. Available at https://www.weforum.org/agenda/2020/10/canada-bans-single-use-plastics/

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