Epilogue

Bales of crushed PET bottles and other plastics in Oloumouc, Czech Republic, 2012.

12. 'A Toxic Love Story'

The history of plastic after the Second World War reads like a succession of superlatives. No other material has succeeded in conquering the world in such a short period of time. Following a series of inventions in the pre-war era – starting with Bakelite in 1907 and continuing with three vital basic plastics: PVC in 1912, polyethylene in 1933 and nylon in 1935 – the production of plastics in the 1960s surpassed that of wood, glass, zinc and copper. These conventional materials had taken centuries to become commonplace product ingredients. Plastic, on the other hand, took just a few decades to complete the same journey. Ever since the 1930s right up to the present day, the rise in the production and consumption of plastics has been virtually unceasing – and indeed spectacular. The volume of plastics produced in the first decade of the 21st century was the same as in the entire preceding century.[1]

The pros...

The general impression conveyed by the story to date is that there is no other material that is as adaptable as plastic: no other material is capable of assuming so many different shapes, of possessing so many different properties and of serving so many different purposes – and is at the same time so comparatively cheap. No material has made life for the masses so easy, comfortable, safe and pleasant as plastic has. Plastic is everywhere and forms part of every human life. Plastic follows us from the cradle to the grave. Plastic has penetrated just about every single human culture in the world, every single economic system and each and every political regime. It is no exaggeration to describe the era in which we are now living as 'the plastic age'.

...and cons

At the same time (and perhaps precisely because of its success), the history of plastic is also riddled with negative superlatives, even up to the present day. Plastic is quite simply a controversial material. The response to the large scale on which it is produced, coupled with its high degree of penetration into human society, has been ambivalent. The question is: what is the impact of these materials on our health and how do they interact with natural ecosystems? Frustratingly, the answer is clouded in uncertainty.

Not only are large tracts of the sea bed at risk of being covered in a layer of plastic, but big pieces of plastic can be found floating on the surface. What sort of impact is this having? Minuscule particles of plastic find their way into the atmosphere, the soil, rivers, the polar ice cap and also end up – in high concentrations – in swirling confluences of ocean currents called gyres. But do they damage the environment in this way? These plastic particles absorb dioxin and other substances that are toxic once they reach certain

Cover illustration of Ik lust geen plastic in mijn soep! *('I don't like plastic in my soup'), 2015. This Dutch book by Monique Bruining (text) and Miranda Vries (illustrations) raises children's awareness of the problem of plastic waste in a playful manner.*

concentrations. Given that they end up in the food chain, the question is: how and at what point do they pose a risk? And to which species of animal? How and at what point do they pose a risk to human health? The modern human body contains tiny but measurable quantities of plastic. Each one of us is 'just a little plastic', as the *Washington Post* wrote back in 1972.[2] But what does this imply for human health and behaviour?

A number of the adverse consequences have been indisputable. We tend to get worked up about the plastic bags, plastic bottles and the countless other forms of plastic litter we come across on beaches, in forests and on the streets. And yet the aesthetic problem is negligible compared with the direct damage caused by such litter. Large numbers of albatrosses and other marine animals in Hawaii are dying as a result of all the plastic products with which their stomachs are filled. The same phenomenon is also seen closer to home – along the Dutch coastline, where birds, seals and other animals are dying as a result of eating plastic waste.

The issue of finite natural resources and the problems surrounding CO_2 emissions are two more chapters of the same story. The raw material used in the production of plastic these days is either natural gas or petroleum (as opposed to coal, which was used in the old days). While it is true that the supply of fossil raw materials (coal in particular) could in theory last for centuries, their use would continue to exacerbate global warming – albeit not as the prime contributor.

A love-hate relationship

It was these two sides of the same coin, the two extreme faces presented by plastic, that prompted Susan Freinkel to entitle her brilliant book on plastics *Plastic. A Toxic Love Story*.[3] Our attachment to plastic is clearly a sort of love-hate relationship. We are aware of the downside, but can't live without the stuff. So how are we going to get out of this addictive love affair?

There are various possible ways of dealing with this relationship. Take the current debate on bisphenol A, a mass-produced synthetic compound that is employed to make a variety of plastics such as polycarbonate (a hard, transparent plastic) or which is used in synthetic resins that are used as protective coating.[4] Bisphenol A is found in medical devices, food packaging and a wide range of consumer products such as CDs and sunglasses. All these products are capable of emitting bisphenol A residues, which may then find their way into the human body as food, by means of dermal absorption (i.e. through the skin) or in the form of environmental pollution. The Dutch Health Council has stated that 'the use of this substance has been the cause of a great deal of unrest in recent years, as it is suspected of posing a risk to human reproduction and development, metabolism and the immune system…'.[5] The European Union has imposed an upper limit on the daily intake of bisphenol A and used this figure as the basis for setting standards for food packaging, for example. A Dutch medical journal concluded that 'there is a growing body of evidence to suggest that bisphenol A, plasticisers and other substances that disrupt the hormonal balance pose a threat to human health. Given that these substances are used in medical devices such as drips, there is every reason for doctors to help get rid of them…'[6]

Groundless fears

Some commentators have claimed that the stories published about bisphenol A have been tendentious. According to journalist and essayist Jaffe Vink, for example, publications such as that by the Dutch Health Council have led directly to newspaper headlines such as 'Sunglasses and CDs may pose health risk to unborn babies'.[7] By citing all sorts of applications of bisphenol A in its report, the Health Council is simply '…causing needless alarm among pregnant women … Should a pregnant woman now worry about bisphenol A leaking from her sunglasses? Should she be afraid that this might affect the nervous system of the child she is carrying? … Should it not be the Council's duty to dispel groundless fears?'

In his book entitled *Wie is er bang voor de vooruitgang* ('Who's afraid of progress?'), Vink claimed that critics of modern technology often create groundless feelings of anxiety about issues such as the use of bisphenol A. They misuse the findings of poor scientific research, twist conclusions drawn by competent researchers, or present uncertain adverse effects as undisputed facts. In doing so, they create a climate of unease, anxiety and panic around scientific and social progress: 'We are afraid. We distrust our food. We stand in fear of the climate. We are concerned about the untrammelled growth of the world population and we're worried about the state of the natural environment…'[8] At the same time, we are no longer able to acknowledge the unique quality of the age in which we live: the prosperity that has put an end to poverty and hard labour. We should count our blessings, Vink says.

The precautionary principle

The precautionary principle takes a completely different angle.[9] A common definition of this principle states that new technologies should not be used without taking certain precautions, where there is a risk of their causing serious or irreversible damage, even if there is a lack of scientific certainty about the risks. Although the precautionary principle is regularly encountered in relation to plastics, a strict interpretation rarely leads to sensible conclusions. For example, according to a 2011 report on plastic waste in the oceans, the application of the principle could mean '…blocking the launch of plastic products that could pollute the sea with plastic waste, fragments and particles, and their toxic, persistent additives.'[10] While this could form an incentive for action on the part of the plastics industry, it is unlikely to happen because a strict application of the principle would result in the bulk of plastics production being halted.[11]

However, this is not the only problem with the precautionary principle. Not only is there never any scientific certainty, the degree of uncertainty is particularly great in the case of plastics. While there can be no doubt that massive quantities of plastics end up in the natural environment – and in the marine environment in particular – it has yet to be shown that this is capable of causing 'major' disruption to the ecosystem or 'major' damage to public health.

A time bomb?

So are we living on a time bomb? Even this is not a serious question – or not yet, at least. Admittedly, there is now greater clarity about certain aspects of the problem, such as the harmful effects of cadmium, phthalates and other additives, where we have seen an increasing demand for alternative chemicals. However, there are many thousands of chemicals currently in use whose toxicity has scarcely been researched, indeed if at all. Any closer examination means re-engendering further doubts and going through the whole process once again, right from the start.

It was due to considerations such as these that Susan Freinkel (the author of the toxic love story) bemoaned our fate: we must navigate a world of imperfect choices. Markets are not the answer: as an instrument for warding off risks, they are unreliable. Our lives are so closely bound up with plastic that we can no longer escape the plastic world. Nor is public opinion sufficient as a means of pressurising companies into remedial action. There is not enough public support for the government to enact tough legislation. Each of us will have to negotiate the traffic of choice in plastics in his or her own way. There is no perfect choice.

Labyrinth of options

On the other hand, there are organisations that can analyse and explain decision-making processes on behalf of companies, government bodies and consumers.[12] There is a wide variety of plastics, each with its own technical, economic and sustainability profile. Every plastic product scores differently on aspects such as the raw material on which it is based, the type of catalyst used, the additives utilised in the production process, the quantity of recycled plastic that the product contains, the risks that the product poses to the environment and public health, the availability of alternative plastics or materials, the price-quality ratio, and so forth. In any quest to find a sustainable product, such analyses can form valuable guides to the labyrinth of alternative options.

The question remains, though: how can we kick our addiction? The answer seems to lie in a less stringent application of the precautionary principle. In simple terms, as public concern builds, so it would appear to make sense from a social viewpoint to take up the challenge of devising new future scenarios for plastics – despite all the uncertainties with which they are surrounded.

Bio-based economy

The chemical industry has already formulated one such scenario: bio-based materials as part of a 'bio-based economy'.[13] The objective is to produce plastics from biomass, making use of additives that do not pose a risk to either human or animal health, and aiming for degradable plastics that can easily be broken down in the natural environment after use. Although the scenario builds on the research into biopolymers that has been performed in recent years (see Box 11: 'The bio-based economy'), there is still a long way to go.[14] While bio-based plastics do exist, not all of these are biodegradable. And while

The Dutch company Haags Kunstogen Laboratorium produces prosthetic eyes made of top-quality plastics. Until 1945, artificial eyes made of glass were the only solution.

biodegradable plastics also exist, not all of these are bio-based.

The main problem is that bio-based materials are not very competitive: they cannot compete, either technically or economically, with conventional plastics, which is why there has been very little investment in research and production.[15] The need to adjust machinery and equipment is another problem: injection-moulding and other machines must be capable of processing the new bio-based plastics. Moreover, the use of bio-based plastics will create new waste flows, to which solutions will also need to be found.[16]

Fortunately, the chemical industry has already acquired a great deal of knowledge about bio-based feedstocks and additives such as vegetable oil, starch, flax and jute. There is already a lot of expertise on bio-based plastics, composites, adhesives, paints and coatings; and experience has been gained in processing bio-based plastics. Indeed, the Dutch chemical industry believes that, by 2050, the Netherlands could build a reputation for itself as the global leader of the green chemical industry. As far as plastics are concerned, although the bio-based scenario may well play a part in this, it will not be the sole success factor.

Replicating the ultimate closed loop

Another scenario involves trying to replicate the 'ultimate closed loop' as seen in nature itself. For example, in natural photosynthesis, the sun provides the necessary energy, and water (H_2O) and carbon dioxide (CO_2) are the raw materials that plants, algae and bacteria convert into carbohydrates and oxygen. Carbohydrates are the ingredients in the formation, first of monomers, then of polymers and finally of plastics. Plastics can be either reused or incinerated. In the latter case, they supply energy and revert to water and CO_2. One important aspect at the beginning of the loop is the need to make CO_2 reactive, so that it can react with water, thus creating chemical building blocks for the formation of carbohydrates.

The key question is: is it possible to design artificial processes that work in the same way as

Cleaning up plastic litter from an Amsterdam canal, 2015. The boat used was made from the plastic waste collected.

natural processes, but are more efficient? The terms used to describe the research now being performed into these areas include 'artificial photosynthesis', 'synthetic biology', 'solar fuels' and 'artificial leaves'. Most of the research currently performed in the Netherlands is as part of the BioSolar Cells research programme, in which nine research centres and industrial companies are taking part.[17] Imitating photosynthesis is proving to be a tough challenge. Key details of the process still need to be worked out.

In the case of artificial photosynthesis, CO_2 is regarded not as a waste product of combustion processes, but as a raw material for renewable plastics and fuels. Other research projects share the same principle. For example, the Dutch Institute for Fundamental Energy Research (DIFFER) is trying to use plasmas as an energy-efficient way of making CO_2 reactive. Microwave energy makes the CO_2 molecule vibrate and break down. The carbon monoxide (CO) produced as a result then reacts with hydrogen (H_2) to produce synthesis gas, which conventional process can convert into chemical building blocks that can be used to make fuels and plastics.[18] It should be pointed out that synthesis gas can in fact already be produced in a sustainable manner by thermochemical means.

Artificial photosynthesis and the plasma technology needed to convert CO_2 are still at an early stage of development. The scenarios based on this technology that should form part of the solution to the problem of our addictive love affair with plastic are not likely to prove effective in the short term. There is another scenario that offers a better hope for the future.

Life without plastic

Plastic represents contemporary culture and a modern lifestyle. A wide range of plastic garden furniture, plastic beach gear and plastic games form part of our leisure culture; plastic caters for children in the form of countless plastic toys and gadgets; plastic has acquired a place in our eating culture through its use in a variety of kitchen appliances and in food packaging; plastic clothing, bags and shoes form part of our fashion culture; and short-life, fast-changing plastic consumer goods have become the cornerstone of our consumer society with its reliance on disposable goods. One of the intrinsic aspects of our contemporary culture is the problem of plastic waste. This is a modern problem to which equally modern solutions have been found – in the form of technology (i.e. recycling), management (i.e. waste collection) and psychology (i.e. training consumers to separate their plastic waste).

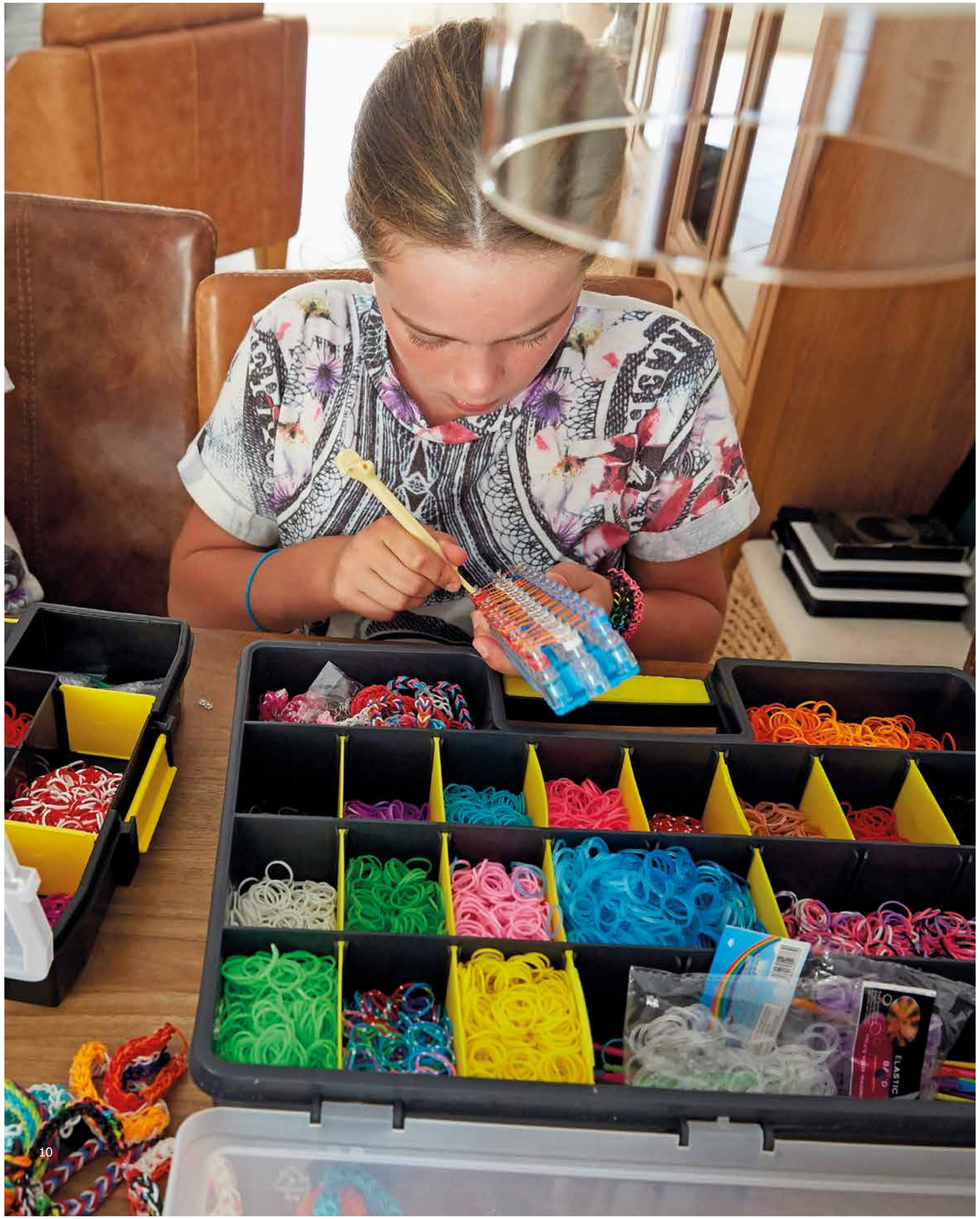
However, there is another, completely different way of tackling the problem: by living without plastic. In the US, this is a lifestyle championed by a group known as the 'Zero Waste' movement, whose main advocate in the Netherlands is Emily-Jane Lowe. One of the movement's principal targets is plastic packaging. 'There I stood, feeling a bit uncomfortable and slightly nervous as I stood in front of a market stall holding a glass jar in my hand ... Half a pound of mixed nuts, please. *Could you put them in this jar*?' is how her book entitled *Leven zonder Afval* ('Living without Waste') begins. '...This was the start of my new lifestyle. It was to be a life without unnecessary packaging and without feelings of guilt about the huge pile of rubbish my family and I used to leave out for collection each week. I had spent years agonising over climate change, plastic soup, deforestation ...'

Nuts, biscuits, coffee and tea all go into jars and tins; loaves of bread are placed in cotton bags; fruit juices are poured into glass bottles; and cheeses are wrapped in cloths coated with beeswax. Shopping expeditions now follow a completely different routine which means that all sorts of things have to be taken along to the shops. Supermarkets are no-go areas as the vast majority of the products sold there are prepacked. Health food shops are not really a good alternative. In 2015, there was just one health food shop in the whole of the Netherlands that claimed to be entirely free of packaging materials and which sold all its products loose. Markets and farm shops are the best options. The result has been a sharp decrease in the volume of plastic waste thrown out by Lowe's family.

Nor is this the only change in the family's lifestyle. The family now makes its own peanut butter, crunchy muesli and 'speculaas' biscuits – all products that are not sold in unpackaged form. Another way of reducing waste is simply by consuming less. Aggressive cleaning agents have been barred, as have care products containing plastic particles, as well as plastic toys, plastic crockery and so forth. The ultimate aim of the *Zero Waste* philosophy is the creation of a 'green household', in which recycling and composting are the end of the road for the tiny quantity of waste that is nonetheless produced.

SOURCES:

Emily-Jane Lowe, *Leven zonder afval* (Amsterdam 2015).
Quote to be found on page 9. Italics added by the authors.
M.C. Pol, 'Niks om weg te gooien. Bij het gezin van Emily-Jane Lowe in Baarn staat de kliko zelden buiten; het gezin produceert nagenoeg geen afval', *Volkskrant Magazine* 6 June 2015, 32-35
Levenzonderafval.blogspot.nl



13. The closed loop

The other scenario is based on an assumption that the plastics currently in use, originating as they do from fossil fuels, will continue to dominate for the time being. This scenario does not aim to align the technology as closely as possible with the natural ecosystem, but rather to isolate plastics from the natural ecosystem as radically as possible. Principles such as 'cradle to cradle', 'the closed loop' and 'the circular economy' all tie in nicely with this scenario.[19] These all view plastics as part of a technical cycle of materials whose relationship with nature and the environment is a difficult one. From a technical perspective, a 'closed plastic loop' implies that there is hardly any need for the input of new materials and that the 'leakage' of plastics into nature and the environment is kept to a near-zero level. Energy – preferably generated from renewable sources – is the only element that needs to be brought in from outside the loop.

The current situation in the Netherlands is that 93% of plastics are given a new use when they reach the end of their life cycle. Of this figure, around 60% is incinerated and thus acts as a source of energy, while the remaining 33% or so is reused.[20] The remainder ends up either as waste in landfills or as production leakage. This means that many thousands of tonnes of plastics still find their way into the natural environment every year. The alternative scenario does not allow for any leakage or landfill disposal.

Incineration

Incineration is a moot point here. On the one hand, the heat produced by the (clean) combustion of plastics can be used instead of heat from natural gas or coal to generate electrical power, for example. Plastics can thus be put to dual use: firstly in order to make useful plastic products (the lightness of plastics used in the production of vehicles, for example, saves far more petroleum as fuel than the amount consumed in making them) and secondly to put the calorific energy contained in them to productive use.[21] On the other hand, the incineration of plastics requires a fresh supply of fossil raw materials and the fossil fuels needed to process the fossil raw materials. There is therefore every reason for keeping incineration to an absolute minimum. Ultimately, the decision will depend in part on the amount of energy needed to separate the various types of plastic waste. Incineration remains the logical solution for domestic plastic waste, for example, which is still proving difficult to separate.

Reuse

Reuse is a different story. Even today, the reuse of plastics often boils down to no more than the recovery of inferior materials. The principle of a closed loop implies collecting and dismantling products and recovering materials in such a way

Girl absorbed in making loom bands. Using a loom and coloured rubber bands, articles such as bracelets can be made. (2014)

that new materials of identical quality can be made from the old materials. In order for this to happen, all the processes in the product life cycle must be designed with this in mind. This does indeed already work in certain cases, such as in the reuse of plastic 'waste' by plastic processing plants. The material is usually so pure as to be fit for reuse as an 'original plastic' once it has been heated and subjected to certain forms of processing.

Technically speaking, and despite the fact that a considerable amount of research still needs to be performed in order to separate and reuse the various types of plastics, a closed plastic loop could be achieved in the Netherlands within the foreseeable future – some commentators even say that it could be done by the year 2025.[22]

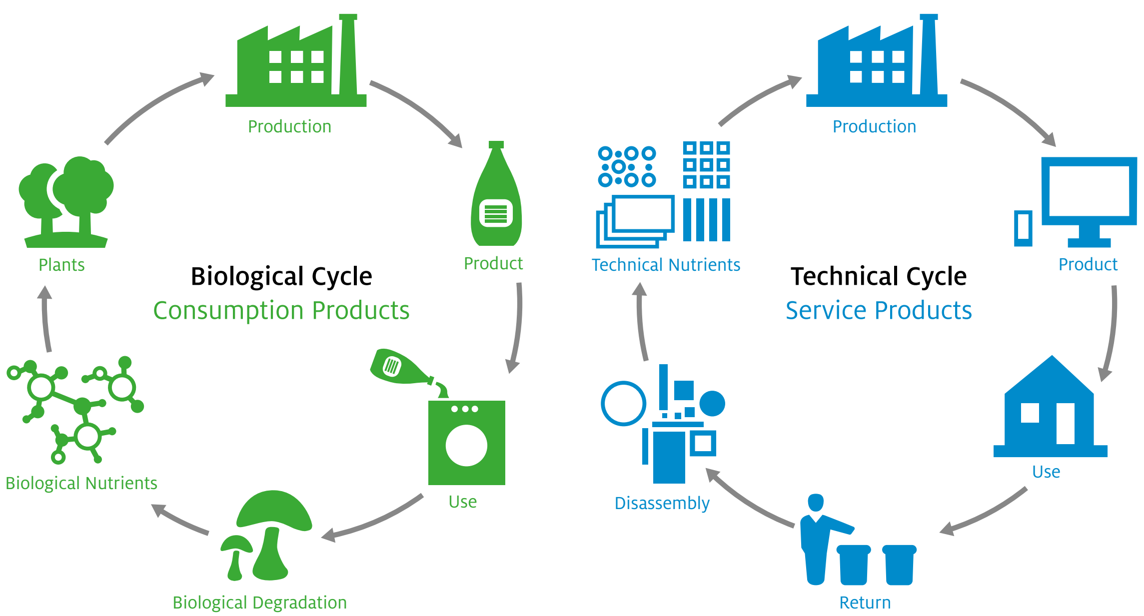
Two types of reuse

Scientists are now looking more closely at two specific types of reuse.[23] The first involves separating plastic waste and reducing it to monomers that can then be used to produce the original polymers. This is the procedure used for recycling PET bottles, for example. The second option is to break down the waste into two raw materials: carbon monoxide (CO) and hydrogen (H). These can be used as the basis for producing monomers and polymers. The main processing method in this case is the gasification or pyrolysis (i.e. heating in the absence of oxygen) of various forms of plastic waste.

As we have already seen, micro-plastics are a problem in their own right. Research into potential solutions to this critical issue has yet to get off the ground.

Design

However, creating a closed plastic loop as part of a circular economy is more than simply a technical problem. Plastic products are designed primarily with the use-phase in mind. How can manufacturers and designers be encouraged to design products for the stage after use, i.e. the reuse stage, and solve the problem of leakage? The various stages of the closed plastic loop are designed to create either economies of scale resulting from mass or bulk production or economies of scope resulting from the distribution of production and products over the widest possible area. They are not designed as part of an economic model in which sustainability considerations take centre stage. The latter means re-engineering plastic life cycles so that sustainability is no longer just one of many secondary criteria for production and use, but a vital prerequisite.



The Cradle to Cradle Principle

Returnable 1.5-litre plastic bottles await their turn to be refilled at Coca-Cola's automated filling line in Dongen (Netherlands). (1992)

Consumer behaviour

But does a closed loop not require a different type of consumer behaviour, i.e. a different way of dealing with plastics? Reuse was a normal aspect of consumer behaviour in the old days. However, the modern pattern is one of creative consumption: consumers constantly exchange one product for another, discarding one as they buy another. So is there a way of working the principle of creative consumption into a closed loop?[24] What sort of culture change is needed in order to bring this about?

Governments have a crucial role to play in this scenario. Just as they pursued policies in support of recycling in previous centuries, so they now have to break down the barriers that stand in the way of a modern, circular economy. How can they encourage manufacturers to innovate, traders to distribute products in a sustainable manner, and consumers to change their behaviour?

The scenario has the advantage of being able to mature in a favourable economic setting: the value of plastic waste is tending to rise (which means that waste is no longer just waste, but a valuable raw material). The large number of stakeholders involved in playing out the scenario is a big problem, though. They include manufacturers, processors, researchers, consumers, waste processors, government bodies, civil-society organisations and retailers, to list just the principal categories. And yet this is not a new element in the history of plastic. As we have seen, a key factor in the first plastics revolution in the Netherlands was the creation in the post-war period of an infrastructure that offered stakeholders an opportunity to work together in all sorts of different ways. The Dutch 'plastics platform' proved to be a precondition for converting a lag into a lead on the plastics

'Strandbeesten' (beach creatures) are imaginary 'walking' animals created by Dutch artist Theo Jansen. These graceful creatures are propelled by sea breeze.

market. The platform also engendered an institute that assumed the role of the self-appointed 'owner' of the plastics revolution: the TNO Plastics Institute (which later became the TNO Plastics and Rubber Institute).

The closed loop scenario also needs platforms – and owners of certain aspects of the problem. As far as research is concerned, the Dutch Polymer Institute (DPI) could well take on the ownership role (see Box 13: 'The future of the chemical industry and plastics'). The difficulty of creating a platform and designating an owner is neatly illustrated by the process of finding a solution to the problem of small PET bottles, one of the main forms of litter in the Netherlands. A partnership with the most directly concerned organisations failed to get off the ground. Even though each of the organisations claimed to pursue a policy of 'good corporate citizenship', not one of them was prepared to take the lead, afraid as they were of being tainted as the cause of the problem. The idea of collecting and storing small PET bottles also had to be dropped, due to the level of cost that this was likely to impose on supermarkets. The fact that plenty of costs were incurred at other points in the chain just goes to show how little the parties were prepared to think in terms of the product life cycle as a whole.

There is an even bigger problem with the closed loop scenario, however, and that is the international dimension. Plastic flows do not stop at national borders. Plastic raw materials and products are exported and imported. The Dutch cannot keep track of the sustainability of plastic product life cycles in other countries. Although the issue figures on the EU agenda, there are very few international fora for discussing it. This is the main reason why we are such a long way from finding a solution to one of the most urgent problems, that of marine pollution and 'plastic soup'. This is perhaps the biggest challenge facing the second plastics revolution.

The first plastics revolution created the world of plastics. Alongside a number of other countries, the Netherlands took the lead in this respect, and was one of the designers of this new world. A second revolution needs to take place in the near future so as to create a closed plastic loop as part of a circular economy. The Netherlands could uphold its tradition by being one of the leaders of this second revolution.

The future of the chemical industry and plastics

'The chemical industry has a future in the Netherlands and the rest of Europe only if it can solve the problem of its international competitiveness and come up with an answer to the increasingly urgent issue of sustainability'.

These are the words of Emmo Meijer, who chairs the Top Institute Food and Nutrition (TiFN) as well as the Agri&Food division of the Top Consortium for Knowledge and Innovation (TKI). Meijer was responsible for technology and innovation at DSM and was also the vice-chair of the Dutch Polymer Institute (DPI). He subsequently went on to head the research and development wings of both Unilever and FrieslandCampina.

Meijer's argument is simple and clear: the price of fossil fuels in Europe is two to three times higher than in the Middle East or the US. Both these regions have large stocks of cheap raw materials, and that is reflected by energy and product prices – including the prices of plastic products. At the same time, however, the chemical industry is under fire. As a bulk consumer of petroleum and gas, it is one of the biggest sinners in the Netherlands in terms of depleting stocks of fossil fuels and fossil raw materials and also as one of the causes of climate change. Not only that, but the industry is also associated with many other environmental problems, including over-fertilisation and fine particulate matter. Finally, it is also at the centre of the controversy surrounding plastic soup and micro-plastics.

'If it wishes to survive, the chemical industry in the Netherlands will need to move swiftly in the next ten years towards a circular economy...' Meijer goes on to summarise what exactly this means for the plastics industry: closing the loops for the production and use of plastics; putting an end to plastic litter; preventing micro-plastics from leaking into the natural environment; developing degradable bio-based plastics for key niche markets; making use of alternative energy sources for the energy-intensive production of plastics; supplying residual heat to houses in the vicinity of chemical production sites; transporting raw materials and products by waterway and rail; and so the list goes on. Working in partnership with nine other organisations, Meijer has drawn up a plan for putting these ideas into practice at the Chemelot industrial park in southern Limburg.

What is the role of the Dutch Polymer Institute (DPI) in this process?

DPI has a vital role to play in this process. It is unquestionably a leading technology institute that is regarded as unique by industrial companies and knowledge institutes all over the world. As an organisation, it is currently undergoing a transition since the Dutch government, which used to be its main partner, has taken a back seat in the wake of its new policy on 'top industrial sectors'. The institute is now in the process of bringing together parties in the plastics value chain: plastics producers, processors and users from all over the world.

For those organisations that join DPI, participation means gaining access to information on the entire knowledge and product chain. In this sense, entering into partnership with DPI is a critical step. The institute is a platform for business leaders, policy-makers, engineers and researchers to think about and discuss the challenges in plastics research. Provided that DPI survives into the future, and provided that its members feel a sense of responsibility for solving the sustainability problems, the institute will be able to play a vital role.

SOURCES:
Emmo Meijer, interviewed by Harry Lintsen, 24 May 2016
Visie Chemelot 2025: De meest competitieve en duurzame chemie- en materialensite van West-Europa (Chemelot 2016).

Industrial design in a circular economy

In a circular economy, products are not thrown away once they reach the end of their useful lives, i.e. they are not incinerated or consigned to a landfill. Instead, they are reused. To this end, various components or materials need to be separated so that they can lead a new life in which they serve a new purpose. However, modern products tend to be so complex as to make this fairly difficult to do. Many products consist of a number of different materials that are difficult to isolate from each other. The process is made even more challenging by the tremendous diversity of plastics which cannot be distinguished by the naked eye. That's why it's so important to start thinking about how a product can be recycled not at the time it reaches the end of its economic life, but much earlier – during the design stage.

Under EU legislation on 'ecodesign', manufacturers are obliged to start thinking during the design stage about how to restrict their products' energy consumption during use. Even though not much legislation has been enacted specifically on the post-use stage, the first EU Directive on Waste Electrical and Electronic Equipment (WEEE) did enter into force in 2003. The amended version adopted in February 2014 contains the following passage in the section on 'product design':

> *'Member States shall [...] encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials...'*

The Directive thus goes no further than simply promoting the design of products with a view to facilitating the reuse, dismantling and recovery of waste. It does not contain any mandatory regulations. The EU leaves it to the member states to decide how this directive is implemented.

Another plan for encouraging product reuse is the SPI resin identification coding system launched by the US Society of the Plastics Industry (SPI, now renamed Plastics Industry Association) in 1988. The system is intended to help identify the main types of plastics. Although no EU regulations exist at present that prescribe a similar form of product identification, manufacturers all over Europe are encouraged to use the system. Indeed, virtually all plastics products and forms of plastic packaging used or sold in Europe display the familiar logo enclosing a number (see illustration). The arrows that cycle clockwise to form a triangle show that the product in question is made of plastic. The number enclosed in the triangle, i.e. from 1 to 7, designates the type of plastic.

Design in a circular economy is about more than simply identifying materials and types of plastic, however. Designers need to develop long-life products that are also fully recyclable once they reach the end of their useful life. A book entitled *Products that last. Product design for circular business models,* published by a research team from Delft University of Technology in 2014, proposes six strategies for circular product design. The basic assumption is that the useful lives of products can be extended by designing them in such a way that they remain both attractive and functional for a longer period of time. At the same time, products also need to be designed for easy dismantling, in order to allow for the reuse of components and materials. This means, for example, that certain materials may not be glued together. Instead, screws or 'click' systems should be used.

A number of companies, including Philips, are already doing their best to apply this

philosophy as much as possible to their product design process, although there remain certain components for which it simply does not work. They are also trying to simplify the separation of materials by using just one type of plastic in each product.

While the examples of products that are fully compliant with the demands of 'design for disassembly', 'design for disposability' or the 'cradle-to-cradle' principle are few and far between, they do exist. One of them is the Ahrend 2020 office chair, which is designed for disassembly, does not contain any glue or screws and is 100% recyclable.

SOURCE:
EU Directive on Waste Electrical and Electronic Equipment: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012L0019&from=EN, retrieved 15 June 2015. The text continues as follows: '... In this context, Member States shall take appropriate measures so that the ecodesign requirements facilitating re-use and treatment of WEEE established in the framework of Directive 2009/125/EC are applied and producers do not prevent, through specific design features or manufacturing processes, WEEE from being re-used, unless such specific design features or manufacturing processes present overriding advantages, for example, with regard to the protection of the environment and/or safety requirements.'

The Ahrend 2020 office chair

These numbered symbols are used in the RIC (Resin Identification Code) system to identify the main types of plastics. They are meant to facilitate the collection, separation and recycling of plastics.

NOTES TO THE EPILOGUE

1 S. Freinkel, *Plastic. A Toxic Love Story* (Boston 2011), 10.

2 Ibid., 89.

3 Ibid.

4 'Bisfenol A', *Wikipedia*, consulted on 8 May 2015.

5 Gezondheidsraad (Health Council), *De gezondheidssrisico's van bisfenol A-analogen* (19 March 2014), Advisory Letter No. U-7831/EvV/pm/789-Y.

6 'Help hormoonverstorende stoffen de wereld uit', *Medisch Contact* 19 May 2016, no. 20.

7 'Zonnebril en cd mogelijk gevaarlijk voor ongeboren baby', *Trouw* 19 March 2014.

8 J. Vink, *Wie is er bang voor de vooruitgang* (Amsterdam 2014), 10.

9 For a recent discussion of the precautionary principle, see: A. Reichow, *Effective regulation under conditions of scientific uncertainty: How collaborative networks contribute to occupational health and safety regulation for nanomaterials* (Enschede, 2015) (PhD dissertation), 37-38.

10 H. van Weenen in collaboration with S. Haffmans, *Verkennende studie 'Plasticverontreiniging van de Oceanen'* (n.p. 2011), 4.

11 In this connection, it should be noted that, from a technical and economic perspective, biologically degradable plastics can at present hardly be considered to be an alternative. Moreover, some of these materials are produced using fossil feedstocks, which in turn gives rise to other objections.

12 Organisations in the Netherlands include 'Food and Biobased Research' at Wageningen University & Research and 'Partners for Innovation', a consultancy that presents itself as '... a leading consultancy for sustainable innovation ... [and] ... profitable solutions for a biobased and circular economy' (see their websites, consulted in June 2015). Another example to be mentioned is the DPI Value Centre's 2CE Polymers network. This network provides companies a combination of theoretical and practical guidance on the application of the principles of circular economy (CE) in practice. The network meets twice a year, preferably at the premises of one of the members of the network. (See the DPI Value Centre website, consulted in June 2015).

13 *Innovatiecontract 2012-2016. Topsector Chemie* (n.p. 2011).

14 Interview by H. Lintsen with W. Sederel, director of Biobased Delta, 2 March 2016. See also Sederel's 'Biobased Delta Business Plan 2016-2018' (n.p. 2016), which includes a discussion of five lessons that can be learned from the failure of biobased projects.

15 It is worth noting that DPI has discontinued most of its research in the field of biopolymers. With interest on the part of industry declining, the institute rarely honours applications for research subsidies in this field. A key player in the field of research into biobased polymers is Wageningen University & Research, in particular the centre for 'Food and Biobased Research'.

16 Interview by H. Linsten with L. Nelissen of Eindhoven University of Technology, 26 January 2016.

17 The experiments are still in the laboratory stage. R. Purchase, H. de Vriend, H. de Groot, *Kunstmatige fotosynthese. Voor de omzetting van zonlicht naar brandstof* (Leiden 2015).

18 See the DIFFER website, consulted in May 2015 and the article 'Differ aan de Dommel' in Cursor, the magazine of Eindhoven University of Technology, 21 May 2015, 18-21.

19 The 'cradle to cradle' principle distinguishes two types of chains: the technocycle (the chain that should be isolated from the natural eco system) and the biocycle (the chain of biodegradable substances that are compatible with the natural eco system).

20 *Plastics – The facts 2013. An analysis of European latest plastics production, demand and waste data* (n.p. 2013). This is a publication of Plastics Europe, the Association of Plastics Manufacturers.

21 See also Note 140 in Part II.

22 'Over tien jaar is afval geen probleem meer', *De Volkskrant* 2 May 2015, 33.

23 T. Können, 'Beter hergebruik. Kwaliteit van kunststoffen moet omhoog', *De Ingenieur* 128 (2016), no. 3, 14-21.

24 An example: when someone hires or leases a carpet instead of buying it, the post-use responsibility for the carpet is transferred from buyer/user to the leaser. This calls for a different business model and a different, chain-based thinking.