DON'T WASTE IT!

SOLVING THE DARK SIDE OF TODAY'S PLASTIC

TNO innovation for life

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SUMMARY

Plastics (bulk, coatings, and glues), like many other commodities, including metal, wood, glass, and ceramics, are of essential importance to the wellbeing of today's society. This will not be any different in the decades to come. We expect plastics to remain important due to their unique properties and the possibilities for mass production enabling plastics to be used as a commodity in existing and new applications, but also to replace other materials, e.g. metals in existing applications. Moreover, due to a lack of real alternatives, we will continue to depend on plastics.

This increasing demand for plastics will accelerate due to the growth in world population and wealth combined with a growing demand for use in, for instance, packaging, buildings and the automotive industry.

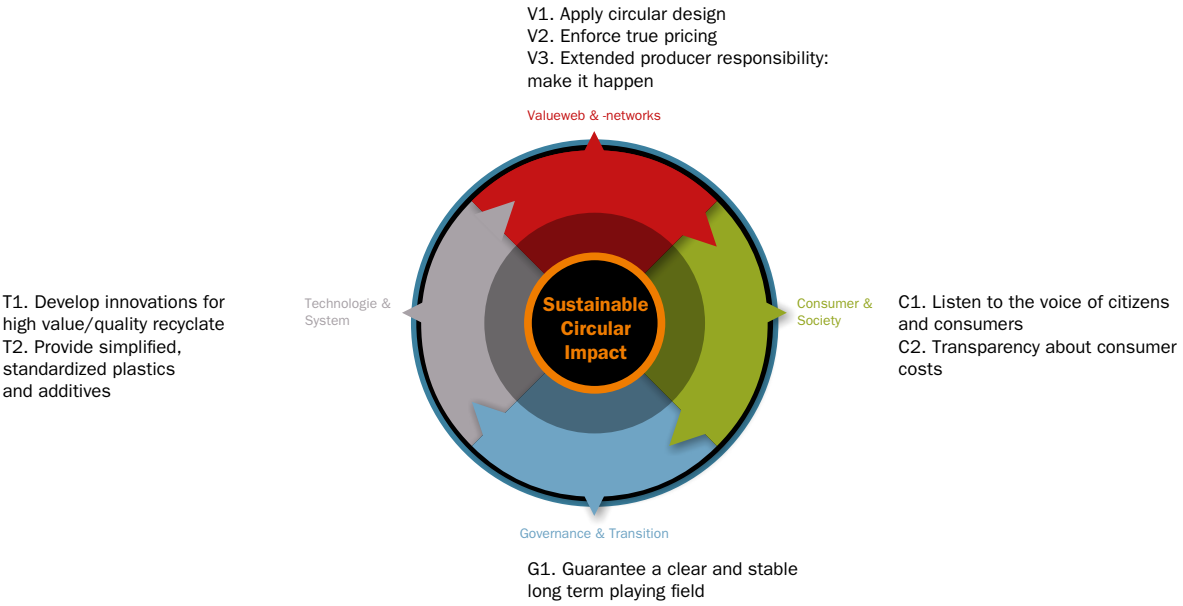
However, the use of plastics is not sustainable and the associated negative impact of greenhouse gas emissions, plastic waste, and micro- and nano-plastics on the environment and health are unacceptable. And the hidden costs of plastics in a make-take-dispose society are equally unacceptable.

Due to government regulations and/or consumer pressure, the plastics industry is in danger of losing its licence to operate if it does not remedy the dark side of plastics: plastic waste, litter, GHG emissions and hidden costs. In recently years, the topic has attracted much attention and it is clear that it will not be easy to solve. Simply replacing the feedstock base, e.g. biomass instead of fossil, will only (partially) solve the GHG emissions, whilst litter and hidden costs remain unsolved, because, after all, the product is still made of plastic. Hence, biobased plastics will not alleviate the dark side of today's plastics.

An even more drastic solution could be to eliminate plastics and to revert to other materials. Denkstatt[1] analysed a scenario for a world without plastics and concluded that this would result in doubling of the energy consumption and greenhouse gas emissions, due to the replacement of plastics by existing, new or no materials. In addition, this approach cannot be used in the majority of applications without severe damage to the economy. Because alternatives do have these drastic negative effects and given the essential and unique functionality of plastics we should instead accelerate the sustainable circular use of plastics. The only viable way out is the switch to a circular plastics economy that strives to reduce its consumption footprint. We need to do this fast or reduce welfare and wellbeing.

Our analysis of the plastics ecosystem with our PRISM model shows that an accelerated transition from a linear to a circular plastics economy is not only necessary, but also technologically feasible. The new business models for the ecosystem will strengthen the economy. The future affordability for consumers could be acceptable if the situation stabilises at a point where, firstly, true costs are accounted for and where, secondly, compensation is provided for the present hidden costs, through lower costs for healthcare and waste.

Through this integral approach, the Netherlands could be a world leader in this area. If we continue at today's pace then our plastics will not be fully circular by 2050 and the downsides of plastics will outweigh the benefits. A strong acceleration is needed, and fundamental choices need to be made fast. The plastic ecosystem is complex, a transition is needed to meet the requirements of circularity and CO_2 mitigation. We envision solutions that we trust to strongly accelerate the transition; integrated solutions that, besides innovations in technology, also bring about socioeconomic and transitional changes. This systematic approach aims for solutions from four important perspectives: value web & networks, technology & system, consumer & society and government & transition. Based on these perspectives we developed eight must-have solutions that are essential to the realisation of the aspired situation for 2050, namely fully circular plastics.



TNO'S EIGHT MUST HAVE SOLUTIONS, APPLIED TO THE NWA CIRCULAR ECONOMY CONTEXT

Firstly, the plastics ecosystem needs to transform, from linear value chains into value networks, from make-take-dispose into design for reuse and recycling, whilst fully adopting Lansink's principles (V1). This requires collaboration between waste management companies, recyclers, chemical converters, plastics producers, end-users and brand-owners. To enforce this, a clear and stable long-term playing field must be guaranteed (G1).

Secondly, innovations for new recycling technologies must be implemented quickly, for sorting, washing, mechanical recycling (including dissolution), as well as for chemical recycling (e.g. pyrolysis), in order to deliver recyclate of a higher quality (T1). Standardisation of plastics and additives would very much simplify the plastics value cycle (T2) in closing the loop.

Thirdly, an accelerated transition to these value networks requires implementation of true pricing of plastics products (V2). Today, hidden costs originating from the environmental burden or toxicity are paid through waste taxes or the costs for medical expenses insurances. Paying the true prices promotes the use of sustainable plastics and leads to improved quality of life and reduced hidden costs, such that the total costs remain the same. Transparency about consumer costs is key to realising this (C2).

Finally, producer responsibility (V3) for sustainable solutions, and the willingness of consumers to embrace the same, should be promoted through intelligent legislation and incentives (e.g. tax discounts for sustainability). In this respect, the involvement of citizens, by including their voice in this complex transition, is of key importance (C1).

All stakeholders, namely the industry, government and consumers, have an important role to play in quick-starting and implementing these eight must-have solutions.

As an independent RTO, we aim to contribute optimally to all of the eight must-have solutions. In TNO's mission we promise to create impact by contributing to the societal transitions, including the material transition, through the alignment of Dutch & European public and private interests at the level of system integration. In addition, we contribute to the earning power of the Dutch economy and strengthen the competitive advantage of companies based in the Netherlands. The transition to a circular plastics economy is at the heart of our mission.

We fully support the transition to circular plastics in our 2018-2021 multiannual strategic plan in which we aim for the creation of a circular and cleaner world for the benefit of the industry and citizens. We are proud of what we have achieved to date, but we also realise that we need to cooperate with many more, perhaps yet unknown, partners to create more impact. If you feel motivated by our paper then please seize the momentum and contact us to discuss how we can tackle your linear economy challenge and turn it into a circular opportunity.

STORYLINE

THE BRIGHT SIDE OF PLASTIC

We live in the plastic age

Today's world is full of plastics. Just walk into your house, and you are surrounded by plastics. The window frames of your house, the kitchen chairs or the bed, all made out of plastics. When you get dressed, you are likely to wear plastics for the rest of the day. Open your fridge and it is filled with plastic bags and containers to keep your food fresh. Or when you travel, the public transport card is made of plastic, and the same can be said of large parts of the car, tram or plane you travel on. Without plastics our daily lives would be lacking much of what we take for granted today. This mass use of plastics started around World War II following the development of families of polymers with unique properties[2]. These materials are still widely used in professional and consumer applications. One could say that we are now in the plastic age, because plastics enable and interact with virtually every aspect of 21st century life due to their unique properties for which no acceptable alternatives are available in the next 10-20 years[3]. This lack of alternatives is caused by inferior performance or an even more negative environmental footprint. Abandoning plastics without alternatives would yield a substantial reduction of welfare and wellbeing[4].

In 2018, the global annual production of plastics arrives at about 360 Mton of which 17% in Europe. In Europe, this industry (Figure 1) realises a turnover of about 360 BEUR (2018) with 60,000 companies and 1.6 million employees. In 2019 the main end-use in Europe is packaging (PE/PP, PET, 40%), building & construction (PVC, 20%) and automotive (various, 10%)[5,6].

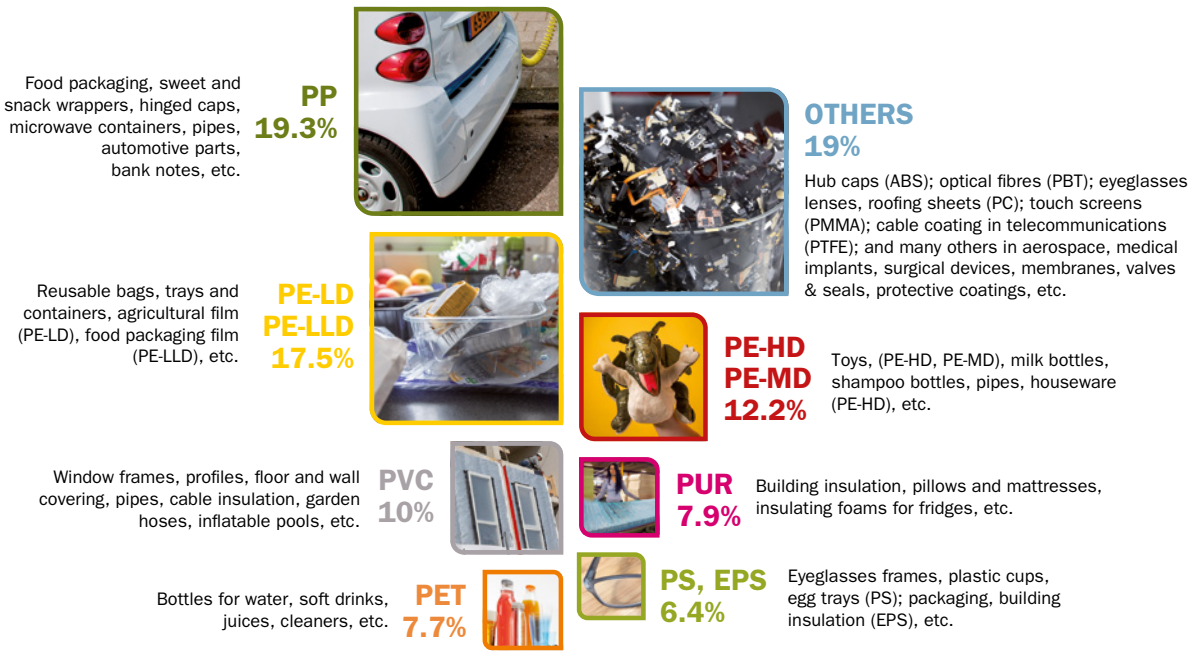


FIGURE 1: EUROPEAN PLASTIC CONVERTER DEMAND BY POLYMER TYPES IN 2018. SOURCE: PLASTICS EUROPE MARKET RESEARCH GROUP AND CONVERSIO MARKET & STRATEGY GMBH

Extrapolation of production data for plastics to reflect the 2050 numbers could result in a fourfold increase in volume of plastics. This increase is equivalent to about 20% of the total oil consumption and 15% of the global annual carbon budget by 2050, based on the 2° C increase in global warming[7]. The data draw particular attention to the resulting steep increase in uncontrolled loss of plastics into the environment, resulting in significant economic and environmental costs. In this scenario, plastic packaging would remain the largest field of application but building and construction (20%) and automotive (10%) are and will also be strong markets of application (Figure 1).

The validity of this fourfold growth scenario of the use of plastics is, of course, uncertain and susceptible to global crises (e.g. Covid-19), consumer actions (refuse), global measures (e.g. European Plastic Pact[8]) and price developments (e.g. the recent price drop of virgin oil[9]).

WHAT ARE PLASTICS?

The common noun plastic is derived from the Greek πλαστικός (plastikos) meaning "capable of being shaped or moulded"[10]. Most plastics consist of organic polymers. These polymers typically consist of repeated chains of carbon atoms, 'pure' or with the addition of oxygen, nitrogen or other hetero atoms and a variety of side chains. The molecular structure of the repeating unit and the side chains can be fine-tuned to influence processing, functional and structural properties of the polymer. Additives are often added for stability or to give plastics specific properties such as flame retardants.

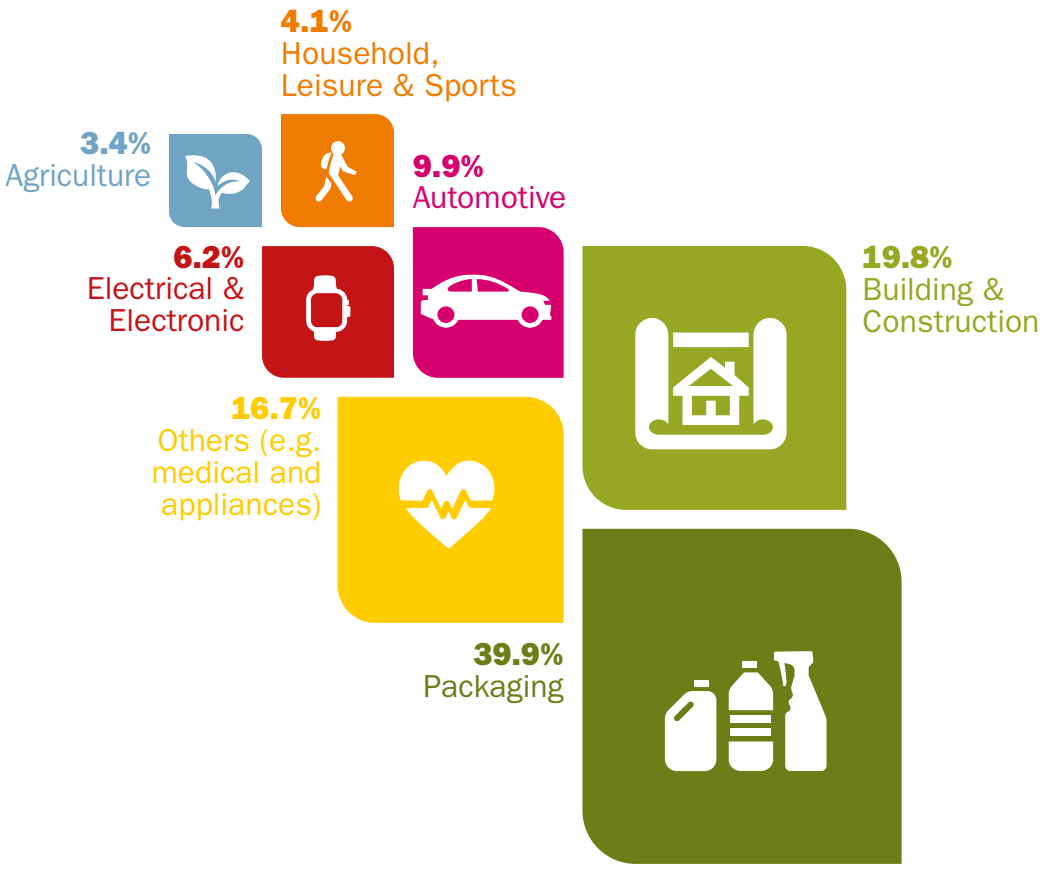


FIGURE 2: EUROPEAN PLASTICS CONVERTERS DEMAND 2018, BASED ON END USE. TOTAL DEMAND REACHED 51.2MT. SOURCE: PLASTICS EUROPE MARKET RESEARCH GROUP AND CONVERSIO MARKET & STRATEGY GMBH

THE DARK SIDE OF PLASTIC

The make-take-dispose economy of the plastic age must end

The role of end-users, especially consumers through the voice of NGOs and individual initiators, has become a major factor in the push for a more sustainable use of plastics[11,12] or complete abandonment of single-use plastics. The dark side of plastics can be attributed to 1) plastic waste (including micro- and nano-plastics), resulting in human and ecological risks, and 2) greenhouse gas emissions by using fossil raw materials, resulting in an increase of the global temperature. These effects cause hidden costs that are basically the result of our make-take-dispose society and must be solved in order to avoid plastics from becoming the showpiece of the linear economy.

CONCERN 1: PLASTIC WASTE

Images of plastic waste and pollution are etched on our memories and generate civic pressure on brand owners and the entire plastic manufacturing chain. Big companies like IKEA and Unilever are starting to experience the need to act or will risk losing their licence to operate[13,14]. Plastic waste is responsible for the generation of micro- and nanoparticles in the oceans, rivers and soil through physical and chemical degradation, which can have an ecological impact and can also enter the human body through liquids and food[15],[16] or through inhalation[17].
In response, as a measure to reduce marine litter, the European Union aims to ban Single-Use Plastics, including plastic cotton buds, cutlery, and drink stirrers, by July 2021[18]. In this respect, the empowerment of citizens in a highly connected digital world, especially the younger generations, plays a very important role[19]. The role of end-users, especially consumers through the voice of NGOs and individual initiators, has become a major factor in the push for a ban on or a more sustainable use of plastics[20,21] and a reduction of waste. However, they do impact the branding of plastic producers and brand owners and, in the end, also the licence to operate of companies. Circular plastics can play a vital role in reducing plastic waste levels when other solutions have insufficient effect (e.g. a ban) or have unacceptable drawbacks (e.g. increased GHG emissions). The aim of moving towards increased use of circular plastics is a tall order.

Our data compiled for the life cycle of plastic waste in the Netherlands are shown in Figure 3. Of the total of 990 kton of plastics produced and discarded in the Netherlands (excl. industry) in 2018 856 kton were fossil based, 124 kton were sourced from so-called high-quality recyclate, and 10 kton were biobased[22]. We conclude that 100% circularity is still a dream, because about 85% of the plastics used still originate from fossil sources.

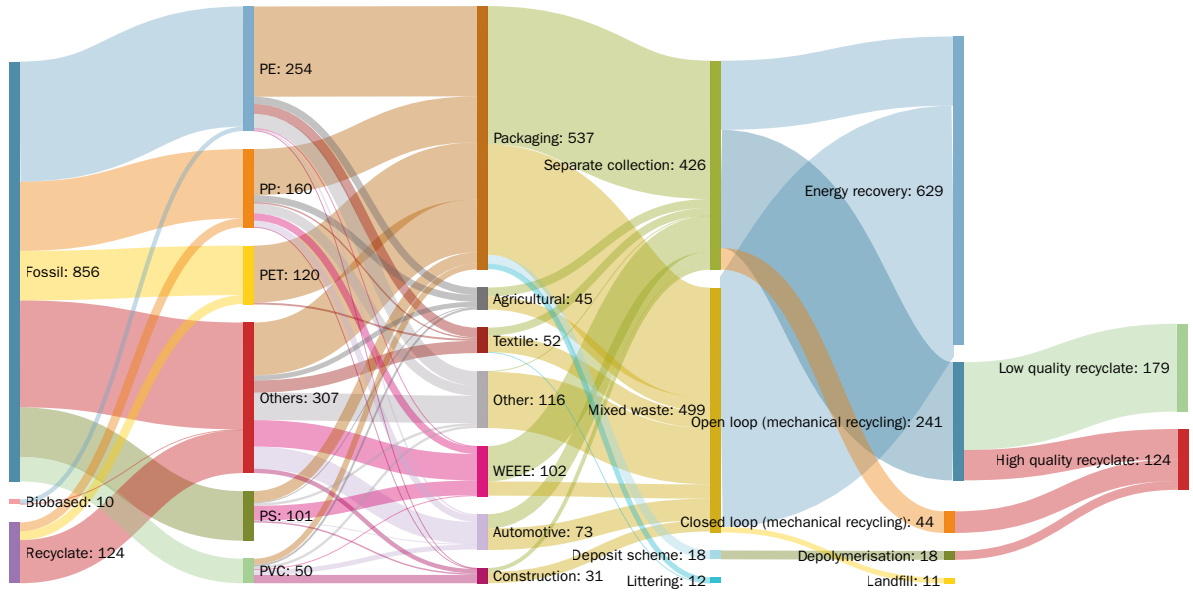


FIGURE 3: LIFE CYCLE OF PLASTIC WASTE IN THE NETHERLANDS 2018 (SANKEY DIAGRAM) COMPILED BY TNO USING OUR PRISM MODEL. THE FIRST COLUMN (LEFT) DEPICTS DIFFERENT FEEDSTOCKS (FOSSIL FUEL, BIOMASS & RECYCLATE) AS USED BY THE CHEMICAL INDUSTRY TO PRODUCE DIFFERENT POLYMERS (SECOND COLUMN). THE THIRD COLUMN DEPICTS PLASTIC MARKETS (PACKAGING, TEXTILE, AUTOMOTIVE, ETC.). THE FOURTH AND FIFTH COLUMN INDICATE HOW PLASTIC WASTE IS COLLECTED (SEPARATE OR MIXED) AND TREATED (ENERGY RECOVERY, MECHANICAL RECYCLING, DEPOLYMERISATION, LANDFILL). THE SIXTH COLUMN SHOWS THE CIRCULARITY OF THE CURRENT SYSTEM: A TOTAL OF 13% OF PLASTIC WASTE CAN BE TURNED INTO RECYCLATE WITH SUFFICIENT QUALITY FOR CIRCULATION IN THE PLASTIC LOOP. THE REMAINING 87% ARE CURRENTLY SENT TO ENERGY RECOVERY AND LANDFILL

Most Dutch plastic waste is burnt for energy recovery (629 kton), mechanical recycling is picking up pace (285 kton), but chemical recycling required for complex plastics (depolymerisation) or highly disperse feedstocks (pyrolysis) is in its infancy (18 kton). Also, the amounts of litter and landfill in the Netherlands are fairly small. In brief, the data show that the potential for drastic improvement towards more sustainable plastics is considerable, i.e. improvement of the quality of recyclate and a transition from energy recovery to material recovery by mechanical/chemical recycling.

Global reports from 2016 show that only 16% of end-of-life plastics worldwide are available for recycling, 65% are incinerated or landfilled, 19% are unmanaged dumps and leak into the environment[23]. In the Netherlands landfill of waste that can be reused or burnt for energy recovery has been forbidden since 2019[24], because it was considered to be the least desirable way of waste management according to the so-called "Ladder of Lansink" or waste hierarchy[25].

MICRO- AND NANO-PLASTICS

The abrasion and degradation of plastic can give rise to an insidious secondary type of plastic pollution known as 'microplastics', which contaminates marine, terrestrial and atmospheric environments. Whilst their environmental impacts have been the focus of much scientific research, international policy and public debate for several years, little consideration has been allocated to their potential to impact public health. Accordingly, the growing discoveries of microplastics pollution in seafood, drinking water and the air has prompted concern for public health risk (Figure 4). However, a lack of evidence on exposure concentrations and toxicity has hindered risk assessment.

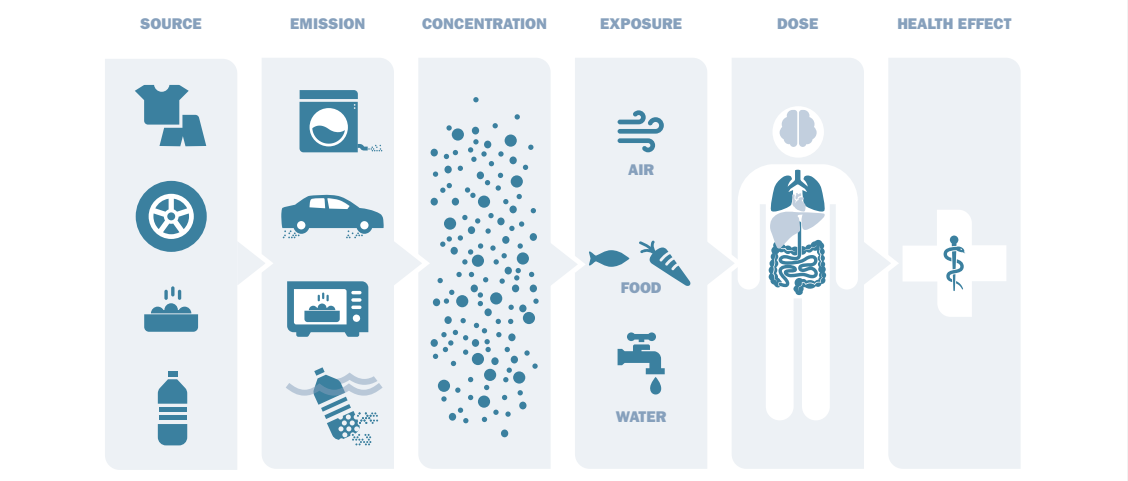


FIGURE 4: ARE HUMANS AT RISK DUE TO MICROPLASTICS POLLUTION ORIGINATING FROM DIFFERENT SOURCES?

There is an increasing public awareness of the potential health impact of microplastics. Governmental bodies were forced to respond, despite there being a dearth of evidence on this. Microplastics (with a size of less than 5 mm) and nanoplastics (with a size from 1 to 1000 nm) have been measured in food, household dust, drinking water and in air, and now even in human stools, but, crucially, the influence of the possible absorption, distribution, and excretion behaviour on microplastics in humans is unknown. Due to their small size range, especially the nanosized plastic particles, are assumed to have health relevance, however, there has been no in depth mechanistic toxicity screen of microplastics. Without this knowledge, risk assessment is hindered. Additionally, apart from the various types of microplastics (e.g. PET, polypropylene, nylon) in various sizes and forms, the presence of chemical contaminants (metals, PCBs, flame retardants) and/or of microbial contamination may also influence the health impact. This overall knowledge gap makes it difficult for policy makers and regulatory bodies to make choices in terms of risk mitigation actions to be taken to lower human health risks.

TNO supports policymakers in the development of legislation and regulations. Together with industrial and academic partners we conduct research into the biological uptake and effects. What are the main sources and what are the effects of exposure to microplastics on human health, for example in the lungs and intestines? How can we measure and detect micro- and nano-plastics? What measures can we take to reduce exposure to microplastics? Can we develop new 'safe by design' plastic materials, e.g. for packaging?

Legislation also identifies specific waste streams that should be recycled as mono-streams, and not be burnt, including mattresses, carpets, nappies and artificial grass, which provided the impetus for the development of recycling technologies for these high-volume largely plastic products.

CONCERN 2: GREENHOUSE GAS EMISSIONS

The production of plastics from dwindling fossil raw materials results in significant emissions of greenhouse gases: about 4 kg of CO_2 per kg of plastic for production and incineration with energy recovery of LDPE[26]. If we multiply this by all plastics currently combusted (623 kton), this results in an estimated life cycle of CO_2 emission of approximately 3 Mton of CO_2 annually. Because the Netherlands has been producing 4 times as many plastics as its own consumption, the production represents an annual savings potential of (at least) 12 Mton of CO_2 emissions[27] which is a significant number in the total amount of GHG emissions in the Netherlands. Moreover, these emissions are often accompanied by emission of particulate matter, NO_x and SO_2, with negative effects on air quality, acidification and eutrophication.

These emissions result in a call for change in the plastics industry in view of the Paris Climate Agreements. A 2050 roadmap by the industry association for the Dutch chemical industry VNCI[28] clarifies the considerable (economic) challenges ahead and possible solutions to eliminate fossil fuel, notably including recycling as an important option. Emissions prevented by recycling are so-called scope-3 emissions. Unfortunately, these are not allowed to be accounted for formally, although prevention of these emissions is considered to contribute significantly to the CO_2 reduction targets. This means that, formally, the CO_2 emission footprint will increase, while in practice the said CO_2 footprint will decrease significantly.

Plastic incineration for energy recovery purposes leads to undesired greenhouse gas emissions

Moreover, the incineration of plastic waste has the positive side effect of generating about 10 PJ, or 2.4% of the electricity production in the Netherlands, but it also has a downside. It leads to undesired emissions of greenhouse gases (up to 3 kg of CO_2 per kg of plastic) and residual waste streams[29]. To TNO incineration is not the preferred route from a resource efficiency point of view[30] because the burnt material is lost as energy. Only for a small part of the plastic waste streams, such as medical waste, there is no option other than incineration available. Resolving this is a challenge that is strongly connected to the energy transition, as waste incineration is a source for sustainable district heating. Because of all the current interests of waste incinerators and investors, including governmental organisations, who invested significant amounts of money, this situation results in strong resistance when it comes to change.
At present, a lock-in is created. Loorbach concluded that this lock-in prevents the waste system from becoming more circular and that this situation is difficult to overcome[31].

HIDDEN COSTS

Plastic waste and CO_2 emissions present some of the hidden costs of plastics to society: external costs imposed on parties who are not involved in the transaction, and who consequently have no direct control over whether it occurs or not. Hidden costs include, for example: 1) costs to society (taxpayers) to clean up oceans and land, to burn or dump waste, 2) health costs related to poor air quality (dust) or microplastics (air, water, food), 3) production losses in other sectors such as agriculture, and 4) damage due to loss of biodiversity not only directly attributable to plastics and its ingredients but also attributable to the GHG emissions related to climate change[32].

REWARD THE DEVELOPMENT OF PRODUCTS WITH MINIMAL HIDDEN COSTS

The ban on single-use plastics does, in our opinion, not provide a positive mechanism because a ban on single-use paper or metal could be imposed based on much of the same arguments. We believe it is much better to depart from minimisation of environmental and resource footprints as the guiding principle.

A straightforward, but challenging, example: promote the development of single-use plastics that degrade into nutrients for marine life or shoes that wear into nutrients for food, much in keeping with the principles of Braungart (Cradle-to-Cradle)[33]. One way to stimulate reduction of footprints would be to make hidden costs visible in the economy and to pay the true costs. This way, products compete based on their true price, consumers can make purchase decisions on the basis of the actual value of alternatives, and producers generate actual market analyses and reach actual investment decisions, collectively resulting in the development of actual solutions.

If the government does not take action to eliminate these undesired negative effects, citizens (i.e. taxpayers or victims of environmental and health damage) will increasingly put pressure on the government, brand owners and plastic producers to do so and they will question policies or the licence to operate of companies. Hidden costs can be broken down into two categories: 1) costs that can directly be attributed to manufacturing and use of a specific material and product, and 2) costs that could be avoided by choosing alternative solutions, eg. a different material.

In 2014 UNEP estimated that the total hidden costs for the plastics industry arrive at about 75 B$ per year[34] of which 30% due to greenhouse gas emissions. This number is probably an underestimate because of new awareness of the damage of plastic waste in oceans and soil and the severity of the effects of greenhouse gas emissions on climate change. This amounts to about 14% of the annual turnover in plastics of 523 B$. In 2020, Carbon Tracker estimated that the total hidden costs for plastics arrive at 350 BEUR per year[35].

Modern-day society decided to defer payment of some of the hidden costs of today's plastics to tomorrow. On 22 August 2020 "Earth Overshoot Day" took place: The day when we, as humanity, collectively consumed more of nature than the Earth can renew in one year. Simply put, this means that from that day up to 31 December of this year, we are in the red on our planet. These hidden costs of today's plastics, that need to be paid in the future, have not been included in the purchase price of today's products yet or are still in use in the value chain without the commitment of the producer or government to handle and pay for them.

HIDDEN COSTS OF PLASTIC BAGS

Hidden costs go both ways. For simple products like a bag, they can be estimated as part of a Life Cycle Analysis (LCA) and compared to other material solutions showing the relative advantage of plastics[36]

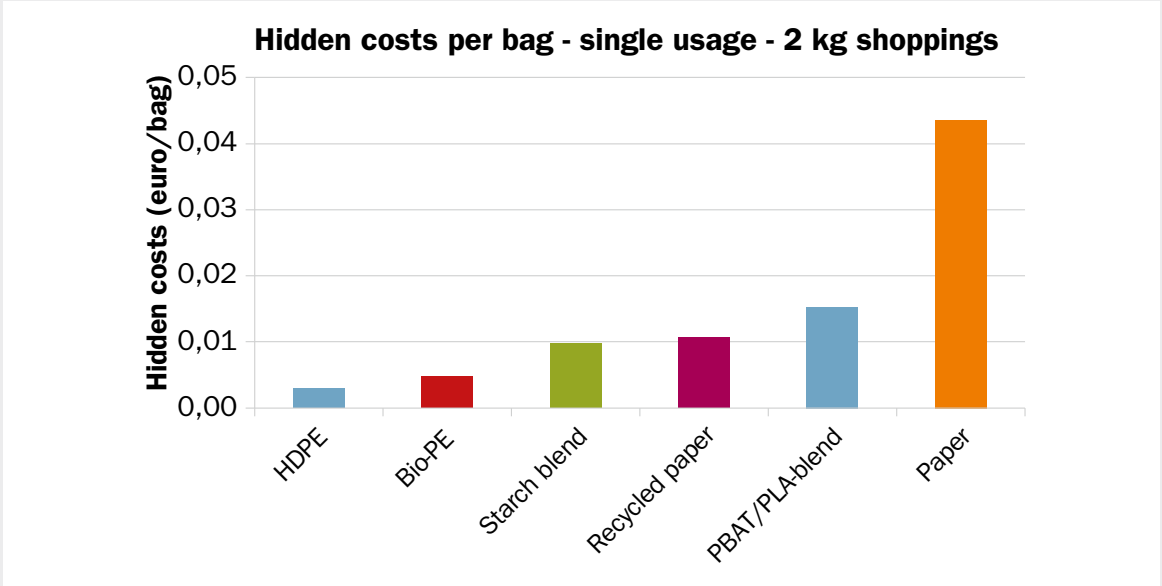


FIGURE 5: THE HIDDEN COSTS OF PLASTIC BAGS AND ALTERNATIVES

With rising CO_2 tax up to 150 euro/ton, the hidden costs of a HDPE bag are of the same order of magnitude as the HDPE production costs: 1000 euro/ton hidden costs, which is similar to the material costs. Here it should be noted that costs for litter are not included in this analysis. Also, resource depletion costs are not taken into account. Hence, we can assume that a plastic bag results in environmental damage to society in line with its value on the market. So it seems a logical step that plastic bags were largely and successfully banned in the Netherlands in 2016[37] to counter littering and greenhouse gas emissions.

However, it is also clear from Figure 5 that bags from other materials are equally or (much) more damaging to society. So a ban of plastic bags and replacement by, for instance, paper bags come at a price for the environment and, consequently, also at a price for society. In our opinion, it is always dangerous when a solution is prescribed. The best solution for society would be to make hidden costs visible in the economy, pay the true costs and let markets decide on the development of solutions.

THE ONLY VIABLE OPTION IS THE SWITCH TO CIRCULAR PLASTICS

Transition to circular plastics is challenging but has a strong potential

The plastics industry is in danger of losing its licence to operate due to government regulations and/or consumer pressure if they do not remedy the dark side of plastics: plastic waste, litter, GHG emissions, and hidden costs. The topic has attracted much attention in recent years and evidently will not be easy to solve. Simply replacing the feedstock base, e.g. biomass instead of fossil, will only (partially) solve the GHG emissions, whilst litter and hidden costs remain unsolved, because, after all, the product is still a plastic. Hence, biobased plastics are not mitigating the dark side of plastics.

Elimination of plastics leads to doubling of the energy consumption and GHG emissions

An even more drastic solution could be to eliminate plastics and to revert to other materials. Denkstatt[38] analysed a scenario for a world without plastics and concluded that this would result in doubling of the energy consumption and greenhouse gas emissions, due to the replacement of plastics by existing, new or no materials. Moreover, this approach cannot be used in the majority of applications without severely damaging the economy.

The switch to circular plastics is the only viable option[39]. But we need to do this fast to avoid a decline in welfare and wellbeing, we need to start tossing the coin. We follow the path of a circular economy that aims for a reduction of its consumption footprint[40]. In the Netherlands this translates to adding value to waste, not eliminating waste at the lowest cost[41], departing from two important approaches: 1) maximising resource efficiency, and 2) minimising the ecological footprint. We change the paradigm from waste management to (value) management of raw materials from which industry, consumers and government will benefit as it reduces the hidden costs. In fact, we would prefer a third approach, namely a change to rewarding maximisation of the positive footprint of products.

The target is a 100% circular economy by 2050, which is a daunting task as it involves a complete system transition[42]. This transition runs in parallel and reinforces the transition to a drastic reduction of greenhouse gas emissions.

Is this feasible?

We analysed a 2050 scenario with TNO's in-house PRISM model[43], which could be described as a reverse forecasting methodology. The basis for the 2050 scenario is a combination of meeting targets set by the Dutch government and our prediction of the future waste composition. The latter is an estimate based on knowledge of the market growth in the different relevant sectors (packaging, construction, mobility, WEEE, etc.) and of the magnitude of application of refuse, reduction, reuse and recycling principles in the relevant sectors. Moreover, the PRISM model defines the preferred technologies, in terms of lowest life-cycle CO_2 emissions and the highest material efficiency (quantity and quality), for the different (mixtures) of polymer types, assuming that collection and sorting will be adapted accordingly. Here our methodology differs from most alternative forecasting methods. We depart from sorting for recycling technologies that leads to high-quality feedstock or recyclates that will actually lead to increased market re-introduction. The 2050 scenario is shown in the box text (together with the main assumptions).

The only viable option is the switch to circular plastics

FUTURE SCENARIO 87% CIRCULAR ECONOMY BY 2050, ANALYSED WITH TNO'S PRISM MODEL

The 2050 scenario is illustrated by the Sankey diagram below. The first column (on the left) depicts the different feedstocks used by the chemical industry to produce different polymers (second column). The third column depicts market segments of those polymers while the fourth and fifth column indicate with which methodology these plastic products are collected and recycled, remanufactured or recovered. The last column (on the right) shows the circularity of the system: a total of 87% of plastic waste can be recirculated into new products (as input on the left), the remaining 12% will be sent toward energy recovery, 1% disappears from the system as litter including microplastics.

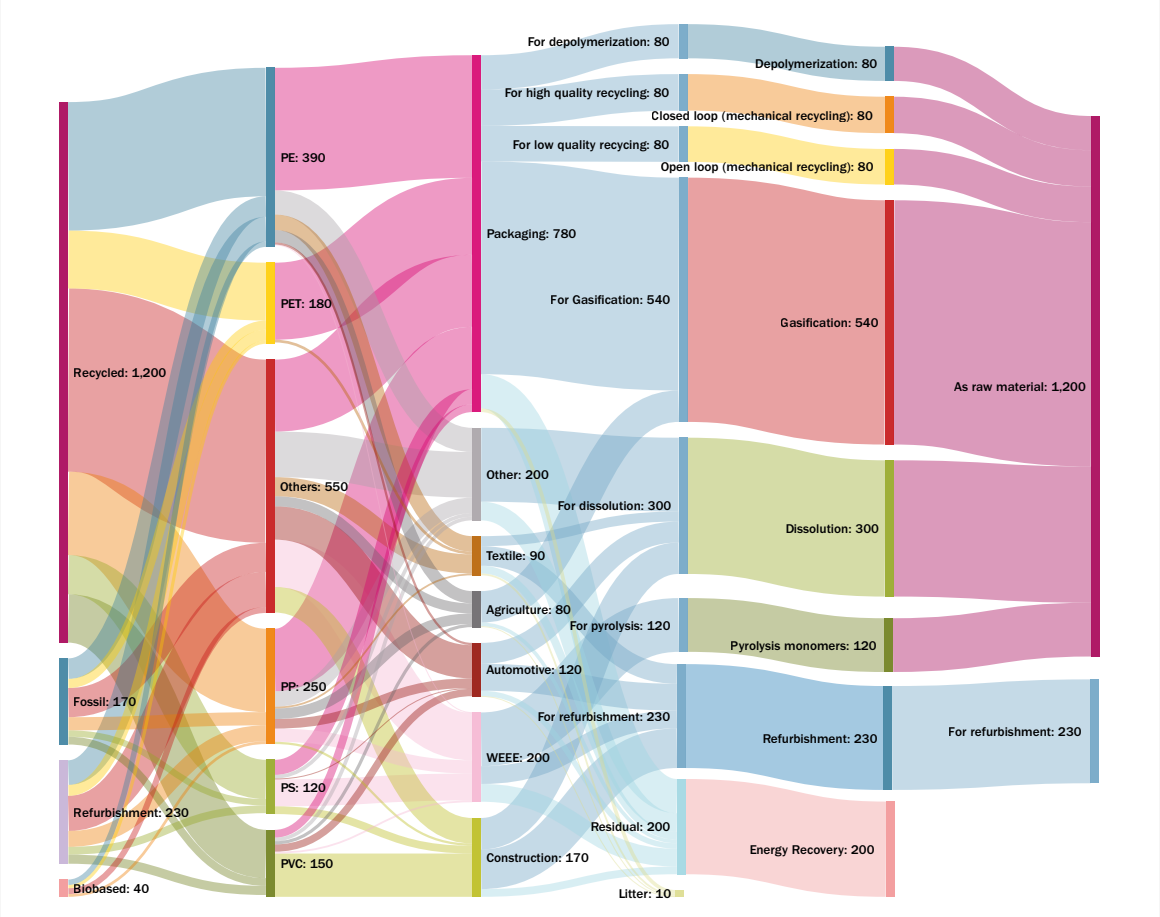


FIGURE 6: PLASTIC WASTE LIFE CYCLE IN THE NETHERLANDS 2050 (SANKEY DIAGRAM) COMPILED BY TNO

The most important assumptions used as input for the PRISM model are:

- Use of plastics waste in the Netherlands grows by 50% up to 2050
- Plastics products are reused or remanufactured as much as possible
- Sorting will be optimal for all recycling technologies; recycling will have 50% less material losses
- Littering will be reduced to 50% of current rates
- Biomass will partly have replaced fossil resources
- Landfill is completely absent
- Incineration is used for energy recovery for specific plastic waste streams only
- Overall 13% of plastics are lost in the waste stream, corresponding to 6 full quality material cycles

Our analysis of the plastics ecosystem based on our PRISM model shows that an accelerated transition from a linear to a circular plastics economy is technologically feasible (up to 87%). Besides the obvious focus on technological developments in sorting and recycling, steady policy, consumer acceptance, and producer responsibility, value networks are also required to accomplish the daunting task ahead.

WHAT IS THE BUSINESS CASE FOR THE INDUSTRY?

Several sources do state a benefit for the economy if circular principles are applied. "Adopting circular economy principles could not only benefit Europe environmentally and socially but could also generate a net economic benefit of €1.8 trillion by 2030", Mc Kinsey stated for the sectors mobility, food, and the built environment[44]. In total, the old linear way of producing and using products and resources costs Europe €7.2 trillion every year for the three sectors analysed in depth in this report (mobility, food, and the built environment). Out of this total, true resource costs arrive at €1.8 trillion; other related cash costs, which include all other household and government expenditures in the three sectors, arrive at €3.4 trillion; and externalities, such as traffic congestion, carbon, pollution, and noise, arrive at €2.0 trillion. In a 2030 circular scenario Mc Kinsey analysed the total costs, to add up to €5,4 trillion/year (resources costs €1.2 trillion, other related costs €2.7 trillion, €1.5 trillion externalities). This adds up to a reduction of 1.8 trillion benefit in 2030. In addition, the Ellen Mc Arthur foundation stated "Plastics production is expected to double over the next two decades. After a short first-use cycle, 95% of plastic packaging material value, or USD 80–120 billion annually, is lost to the economy"[45].

This all benefits the economy but will it also benefit the industry? Is there a business case? Due to increased customer pressure companies will design more and better sustainable circular products. Circularity will become a branding asset and companies that do best will survive. Brand owners are more and more focused on improving their brand sustainably. This unlocks business potential for old and new companies. Apart from the brand owners we see various examples to support this. An example is Chemelot that is currently in the transition to become the first European Circular Hub. Other examples are new companies that develop and sell new (recycling) technologies, including Ioniqa and Synova, and big material/chemical companies that are driven to change, including Sabic and DSM. We expect new companies to step in this new business. For the Netherlands this creates strong new possibilities with 1) our unique high level of design, process innovation and manufacturing capabilities that can be exported to other countries, and 2) the unique presence of complete and closed value chains for several industrial areas with significant export markets as supported by top-sectors and mission-driven innovation. In addition, the Covid-19 crisis shows the dependency on regional supply. Circular plastic networks will be strongly regionally oriented. Regional networks for plastics will, in our opinion, admittedly transcend the region and be more of the size of Northern Europe, but will still diminish our dependence on other countries outside Europe. In our view, the post-Covid-19 period will, therefore, stimulate the break-down of current linear chains and stimulate regional circular networks in the longer term.

Increased customer pressure leads to more sustainable circular products

The full business case is not so easy to analyse. It depends on the plastic (product) but it also strongly depends on the inclusion of the hidden costs and the determination of the true price, which will make circular products more favourable. If we grow into a society where true costs are included then we expect there to be room for a business case. This needs further investigation though. Often, the international level playing field is used as the argument to refrain from true costing and it is argued that this kind of business case is not possible in a globalised economy. So we continue with conventional business cases on the linear unsustainable path, like lemmings to the cliff. This is also the reason why, in the "Groene Troonrede"[46], Jonker urges to make drastic changes, including a number of drastic measures to eliminate hidden costs.

WHY WILL CONSUMERS PARTICIPATE AND IS IT AFFORDABLE?

Currently, consumers and citizens already pay the true costs through other mechanisms, indirectly by governmental taxes for e.g. waste treatment, by others elsewhere and by future generations. Consumers will only be motivated to buy plastics at the true price when the (future) situation is beneficial, as a consumer and as a citizen.

Consumers and citizens could benefit from two aspects in the future, increased health and increased value of waste, which might compensate the hidden costs. Increased health is an important benefit for citizens from two perspectives. Firstly, a reduced or absent environmental burden will reduce national healthcare costs and should thus lower the direct costs for citizens, i.e. annual insurance costs. Secondly, a healthier environment increases the quality of life through improved biodiversity, air quality, etc. Furthermore, the value of waste will increase due to its use as a value-based raw material instead of waste with costs to dispose or incinerate.

True costing strategies require knowledge and information of the true costs and mechanisms for the imposition of hidden costs. With the said knowledge and information all stakeholders can take action and accept responsibility[47]. The best strategy for true costing of circular plastics has yet to be developed based on more accurate information and knowledge, a transition for the next decades to be developed and shaped fast. Much more attention in (social) media is required to explain the issue and choices (to be) made. Early adopters will play a critical role in convincing younger and older generations, positive mechanisms should be introduced. By way of example: plastic waste has value in the circular economy. Presently, this value is not visible to consumers, they must pay taxes to have waste collected and disposed. Directly returning the value of (plastic) waste to consumers through reduced taxes or other mechanisms could trigger more awareness and positive bottom-up initiatives.

During the transition to true costing of products imbalances may occur, because our society decided to defer payment of some of the hidden costs of today's plastics to tomorrow. These hidden costs of today's plastics that need to be paid in the future have not been included in the purchase price of today's products yet or are still present in the value chain without the commitment of the producer or government to handle and pay for the future downside of plastics. A transparent transition plan on how to overcome this gap, not putting all of the burden on the consumer, is needed. To govern this well, brave leadership of the government is needed.

The total costs of the system are not expected to increase if the hidden costs are taken into account. Therefore, the future affordability for consumers could be acceptable if the situation stabilise into a situation where, on the one hand, true costs are accounted for and are not deferred to future generations and, on the other hand, compensation of present hidden costs takes place through lower costs for healthcare and waste. In that way sustainable products may be affordable for consumers and citizens in the future. If so the hidden costs for non-sustainable products should be paid through taxation (paid by citizens) or increased product prices (paid by consumers). A reward for the production of circular products is beneficial, by taxing non-circular products and providing a discount based on circularity/sustainability.

The affordability for consumers could be acceptable in the future, but only if true costing and compensation of hidden costs through lower costs for healthcare and waste are applied.

WHAT PACE AND ACCELERATION DO WE NEED?

How fast is fast enough? As always, Europe has a choice how important the ambitions of a circular plastics economy are, what priority is attributed to it, and what approach to take. Despite all intentions and initiatives for circular economy and reduction of plastic waste, the Dutch circular economy is still at its infancy. Steps were taken in a number of industries and regions/cities, but as a whole max. 10-20% of our economy can be labelled as circular at the moment[48]. In Europe this is not any better, if we continue at the present pace and intensity then the ambitious targets for 2050 will not be met. In the Netherlands, departing from the raw material agreement, five transition agendas were set up and, following on from that, national knowledge and innovation agendas, at a national and regional level. They all contain detailed plans for execution.
In Brussels, the green deal initiative fully embraces the circular economy translated into the CEAP (Circular Economy Action Plan)[49] with big ambitions. But in the recent negotiations the budget for the green deal and associated research programmes was strongly diminished. Fortunately, we do see many initiatives from industry and regions to make things happen[50]. We observe the willingness to move in this direction at the European and national level, e.g. by the Chemelot Circular Hub initiative.

But we strongly doubt that apart from these initiatives enough action is being taken. To make this happen the government plays a crucial role both for the business case for the industry and for the affordability of the consumer. The government should take leadership by creating incentives, implementing new legislation and stimulating initiatives. In addition, involvement of the full value chain should be stimulated. Frontrunners can be rewarded and stimulated to scale-up fast.

The transition is complex and needs a system perspective

We pledge to seize the opportunity and to grab the momentum in order to increase the pace and the intensity of the transition into circular plastics. We strongly believe in the economic importance of plastics and the role plastics have to play in the solution to societal challenges because of their unique properties. But we must not only focus on technological or consumer actions because the transition is complex and it also requires a system perspective with actions aligned by all stakeholders.

A SYSTEM PERSPECTIVE FOR A WORLD WITH CIRCULAR PLASTICS

The plastic ecosystem is complex, a transition is needed to meet the requirements of circularity and CO_2 mitigation. We envision solutions that we trust will strongly accelerate the transition that aims for integrated solutions that, besides innovations in technology, also need socio-economic and transitional changes. This was confirmed in several studies. The "Brede Maatschappelijke Heroverweging 11: naar een economie zonder afval" ("Broad Social Reconsideration 11: towards an economy without waste")[51] presents a number of priorities to consider for the next decade. These priorities are also found in the Innovation Action Plan for the Dutch mission CE[52]. These priorities are well in line with our first reference framework, the approach formulated by the Circular Economy and Resource Efficiency route within the framework of the Dutch National Science Agenda[53] (Figure 7). This systematic approach aims for solutions from four important perspectives:

- Value web & networks: How can we make sustainable business models that create financial, ecological and social value? **How can we eliminate hidden costs?**
- Technology & system: What technology and sustainable value cycles need to be developed? **How can we preserve quality, not low costs?**
- Consumer & society: How can we achieve recognition and acknowledgement of all stakeholders to support the circular economy through their own behaviour? **How can we give a voice to consumers in order to accomplish acceptance of the use of circular plastics and a licence to operate for industry?**
- Government & transition: How can we create a consistent policy context at every level and an agreed collective agenda? **How can we draft legislation that stimulates value creation and is not blocking the transition?**

FIGURE 7: NWA ROUTE CIRCULAR ECONOMY AND RESOURCE EFFICIENCY (NATIONALE WETENSCHAPAGENDA)

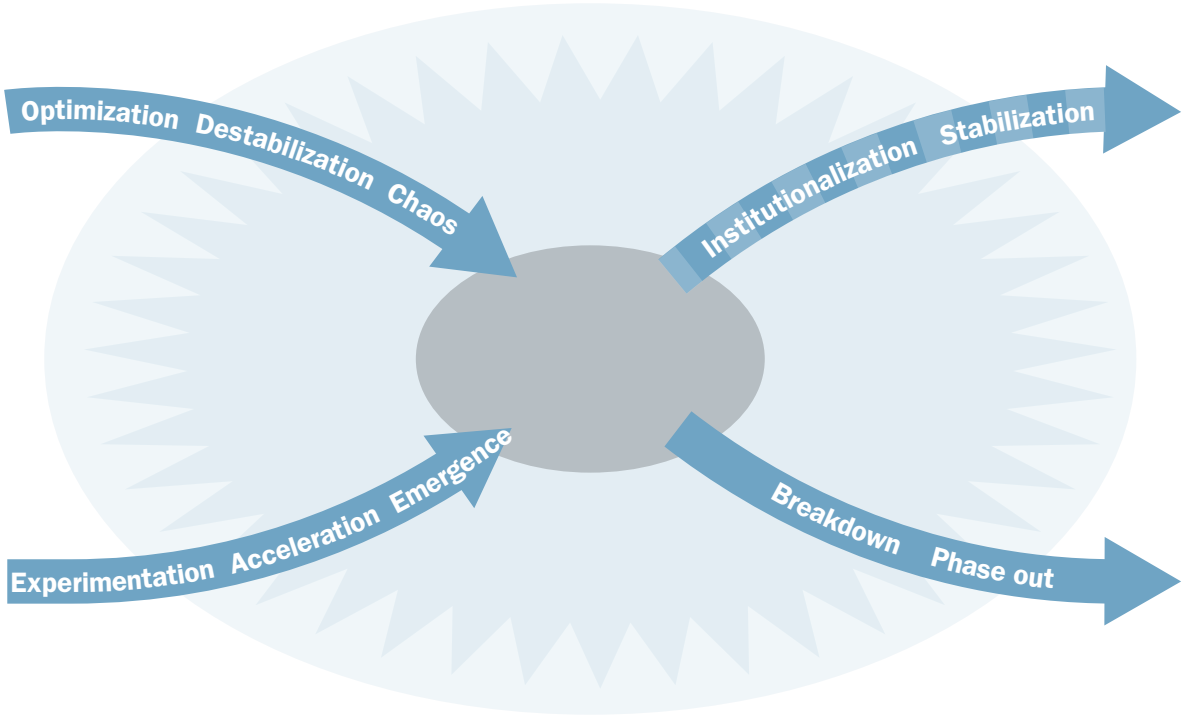


FIGURE 8: DRIFT TRANSITION MODEL (LOORBACH)

The NWA agenda above focuses on what is needed, but not on how the transition can be accelerated. The second framework we use comprises the transition framework developed by Loorbach (DRIFT, Figure 8). This framework is important as it considers both creation of new activities and breakdown of older/obsolete ones or "Where initially experimentation and acceleration were the main foci in transitions research, in recent years increasing attention has been given to processes of destabilisation, emergence, and institutional change. By building on historical cases as also by reflecting on and analysing currently evolving transitions, a theoretical basis was developed that identifies the different patterns and mechanisms of change that drive non-linear structural change in complex societal systems. The analytical model of transitions in figure 8 provides a systematic way to reflect on ongoing and past transitions as evolutionary revolutions in complex societal systems"[54].

OUR EIGHT MUST HAVE SOLUTIONS: ACCELERATION TOWARDS A WORLD WITH CIRCULAR PLASTICS

To arrive at this 2050 situation fast, we need fundamental changes. We developed eight must have solutions that are essential to achieve this 2050 situation in which plastics are fully circular. These eight must have solutions are in line with the NWA framework and the DRIFT transition model, which were introduced in the section "A system perspective for a world with circular plastics". The eight solutions are presented in Figure 9 and are described in more detail below.

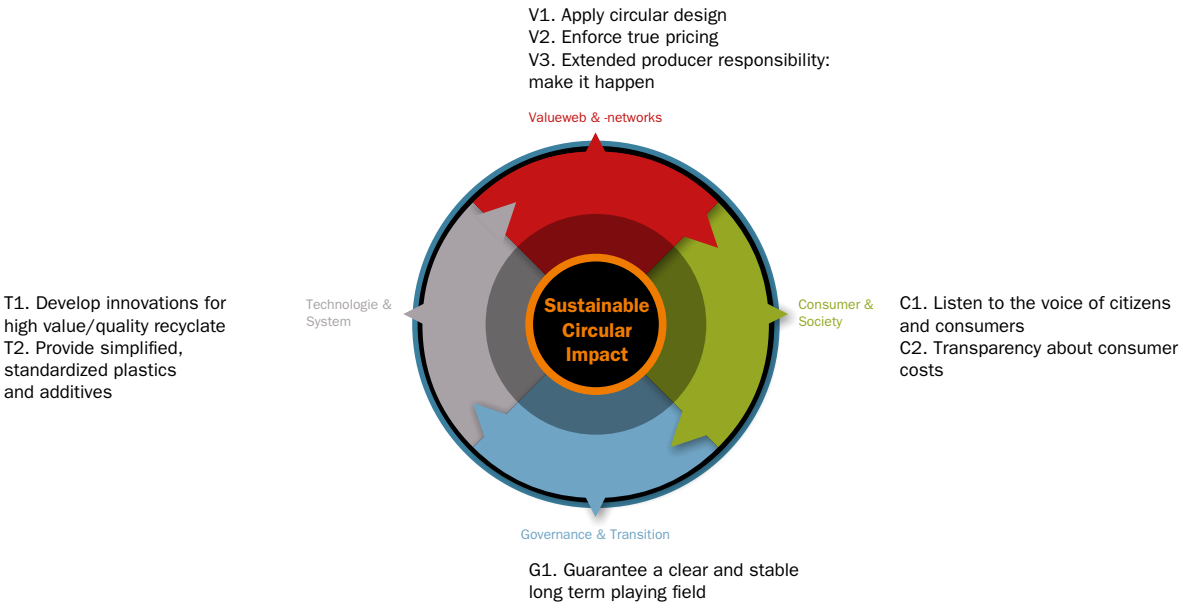


FIGURE 9: TNO'S EIGHT MUST HAVE SOLUTIONS, APPLIED TO THE NWA CIRCULAR ECONOMY CONTEXT

VALUE WEB & NETWORKS: SOLUTION V1. APPLY CIRCULAR DESIGN

A circular design of value cycles and networks assesses all stages of the waste hierarchy. It should start with refuse and the entire value chain should be reconsidered: if any, what are the best alternatives to a specific application and what end-of-life strategy is selected? Examples include refill systems to avoid packaging, specifically targeted sorting and recycling with track & trace options, market introduction strategies through cooperative ventures between companies. The need to do so is high because at the moment the majority of products are developed and put on the market without taking these considerations into account. In the past, the current installed industrial base made huge investments that cannot all be abandoned in a few years' time. Presently, these industrial companies are, however, facing two major challenges. They are already being confronted with significant competition from other parts of the world and high decarbonisation requirements. In addition, significant decisions are often reached abroad because a considerable part of the industry has its corporate headquarters outside the Netherlands or Europe. Circular value chains/cycles need to be created whilst combining activities and infrastructure of various (industrial) stakeholders. Knowledge present in different sectors needs to be combined and knowledge development needs to transcend sector boundaries. Quality and preservation of quality should be the guiding principle for these new value cycles, not low costs. Secondly, value cycles cannot be closed at present because current recycling technologies have their limitations. A circular design of products and materials (e.g. restricting certain chemicals, not mixing different plastics, enabling dismantling) will result in winners and losers in the value chain and a considerable part of its effect involves hidden costs after the lifetime of a product when it has been discarded. To make this happen we need to find a way to share benefits and costs as well as time lag / legacy of the loss of hidden costs to stimulate the transition to circular plastics.

VALUE WEB & NETWORKS: SOLUTION V2. ENFORCE TRUE PRICING

Current plastics are a perfect match for the make-take-dispose business model because of the low price of fossil oil. This will probably continue for the next decades with oil prices not decreasing due to climate change policies. The hidden costs are not included, we are not paying the true price, because the costs to deal with the negative environmental and health effects are passed on to society, i.e. taxpayers. The inclusion of hidden costs in the price of products will make products more expensive, but will also trigger deliberate choices of users and will increase the pressure to change to circular plastics. In the end, the net effect for consumers may be limited because it should result in reduced taxes as well as a longer and healthier life as explained above in more detail. The government can and should stimulate payment of the true price. For plastics this should at least be agreed on at the European level, but preferably at the global level. Because this is a considerable system change and the effects should be considered thoroughly and a transition plan should be prepared to prevent chaos and unmeant effects. A precondition for this solution is that (European) government formally includes scope 3 emissions (indirect emissions) of greenhouse gases in its formal calculation rules to comply with the Paris agreements. After all, when plastics are reused or recycled, emissions due to incineration are prevented. This way the costs of CO_2 emissions that are prevented (e.g. CO_2 tax) should be reduced as well.

VALUE WEB & NETWORKS: SOLUTION V3. ENFORCE EXTENDED PRODUCER RESPONSIBILITY

Extended producer responsibility (EPR) can be defined according to the OECD as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle." The development of EPR in Europe has contributed to improvements in waste prevention, reuse and recycling (OECD, 2016). EPR is typically understood to involve a shift in responsibility (administratively, financially, or physically) from governments or municipalities to producers as well as an encouragement of producers to take environmental considerations into account during the design and manufacturing phases of product development. EPR seeks to achieve a reduction in the environmental impact of products, throughout their lifespan, from production through end-of-life. The circular economy action plan will include a 'sustainable products' policy to support the circular design of all products based on a common methodology and principles. It will prioritise reducing and reusing materials before recycling them. It will foster new business models and set minimum requirements to prevent environmentally harmful products from being placed on the EU market. We view EPR as a critical policy tool with a track record in holding manufacturers accountable for the end-of-life impacts of their plastic products and packaging, as well as encouraging holistic eco-design in the business sector. This should be promoted by smart legislation and incentives (e.g. tax discounts for sustainability). We are glad that the EU circular action plan did include the implementation of the new EPR schemes. But we are aware that this needs further guidance and determination for it to be implemented. All countries currently have different schemes for plastics. The lack of a common approach leads to different implementation and performances across the EU[55]. Good European alignment is essential to make this a reality.

Align plastics EPR schemes at European level

TECHNOLOGY & SYSTEM: SOLUTION T1. DEVELOP INNOVATIONS FOR HIGH VALUE/QUALITY RECYCLATE

The recycling industry will produce high-quality recyclate that allows for recycling (instead of the current downcycling). This requires a step-change innovation compared to the state-of-the-art, not only in terms of mechanical and chemical recycling technologies, but also in terms of collection, sorting, and corresponding logistics. A recent review[56] clearly reveals the existing knowledge and technology gaps for large parts of the plastic waste stream. Existing mechanical recycling and pyrolysis options are subject to strict specifications of the input streams (homogeneity, chemical composition etc.) and have a limited range of output specifications (e.g. polymer chain length). This is why we should consider sorting for the specific recycling technologies on the one hand and on the other hand why we need more and new options that are designed to fill these gaps and that are optimised to deal with new plastics designed for (and from) recycling. Currently at TNO we aim at three generations of recycling technologies:

1. Thermal cracking of plastics (in Brightsite[57]) as a versatile and more efficient feedstock alternative to the pyrolysis cracking train currently being scaled-up by industry. Next steps: scale-up, determination of best logistical fit (at waste management facility – vicinity of feedstock or at chemical site – vicinity of downstream operations)
2. Physical recycling (dissolution of polymer and separation from additives) targeting multi-material engineering plastics and multi-layer packaging materials aiming at high-value re-use of polymer backbone (instead of going back to monomers). Next steps: obtain proof-of-concept, including efficient solvent reuse, develop strategy for valorisation of residue (pigments, flame retardants, etc.)
3. Exploration of novel technologies to tackle hurdles of feedstock specificity (mono vs. mixture) and effectivity (product over feedstock). Catalytic depolymerisation of polyolefins to decrease energy intensity (process at lower temperature) and improve effectivity (less loss of plastic waste) as well as plasma cracking as end-of-pipe solution for rejects of other recycling technologies, resulting in syngas as basic building block for the chemical industry, are promising options.

Furthermore, TNO is involved in the Brightlands Material Centre[58], which aims to contribute to the development of new circular packaging materials.

TECHNOLOGY & SYSTEM: SOLUTION T2. PROVIDE SIMPLIFIED AND STANDARDISED REQUIREMENTS FOR PLASTICS AND ADDITIVES

As shown in the circular plastic scenario for 2050, a mixture of technologies that still need to be developed will contribute interactively to the desired circular plastics network. However, true costs alone will not guide us to the desired solutions since market barriers and knowledge gaps have hindered a fruitful cooperation and technology development in the value chain. In our view, the optimisation of end-of-life strategies as well as circular value chains can very much benefit from new simplified, perhaps even standardised, requirements for plastics and additives. The big challenge here is to preserve functionality and to gain recyclability. Many attempts and proposals (e.g. SUEZ, Ceflex, Borealis, and many others) to structure Product Design for Recycling or better, for Circularity, were made public. Nevertheless, we believe that Design for Circularity, apart from the considerable challenge not to lose on functionality, can only work in a newly designed Circular System: A system that leads to actual market re-introduction of products, feedstock or molecules. Such a system should be designed circularly at all stages, starting from collection and sorting, 'ending' at market re-introduction. The result of this kind of system is shown in Figure 6. The way the world will collect and sort in the future will be decisive to know what Product Design for Circularity will look like. For example, if MPO (Mixed Polyolefines) will be a dedicated sorted stream for Chemical Recycling and not a leftover of today's sorting – Design for Recycling requirements would allow for multilayer systems containing, for instance, HDPE, LDPE, PP. Furthermore, the contamination with additives would be dependent on the system as well and minimisation of the variety in additives will certainly help. The current legacy of a wide variety of toxic flame retardants shows the bitter fruits of total freedom. If we forbid, for instance, certain highly toxic substances (plasticisers, flame retardants, pigments, and inks etc.) and undesirable combinations of resins and other materials (if we know that recycling is hampered severely by this), the development and implementation of effective and profitable recycling technologies could benefit greatly from this.

CONSUMER & SOCIETY: SOLUTION C1. LISTEN TO THE VOICE OF CITIZENS AND CONSUMERS

The voice of citizens and consumers will become of increased importance. Today, ever more citizens doubt the need for plastics and doubt the sincerity of the industry to arrive at sustainable solutions. Emotion is frequently used to focus on just the negative impact of plastics and to forget the benefits it can have. The licence to operate of the industry is at stake. On the one hand their voice is needed to put pressure on the system. A louder voice will stir up the process to have industry and government initiate action. Both industry and government should take this voice more seriously and learn how to deal with this to come to acceptable solutions. On the other hand, consumers do have an essential role to stimulate and welcome circular plastics and are subject to their consumer responsibility. The voice of citizens is needed to understand where they see barriers in order to arrive at their willingness to accept the use of circular plastics. Both industry and government should take this voice more seriously and learn how to deal with it to come to acceptable solutions. However, consumers should also accept responsibility themselves and make more sustainable choices.

We are not convinced that we can change the non-circular behaviour of the consumer easily, we believe that such change must be an important part of a transition to a system that provides new circular products and does not dispose used products. Therefore this sustainable behaviour should be promoted by smart legislation and incentives (e.g. tax discounts for sustainability).

A louder voice of citizens will stir up the process to have industry and government initiate action

The responsibility is primarily borne by the industry and the government. Citizen science and active involvement of citizens in e.g. innovation programmes must be used effectively to create a voice of citizens and consumers in addition to that of NGOs. In addition there is, in our view, question of a need for methods that are accessible to the broad public that puts the plastics problem and the alternatives into perspective. Social media and influencers could play an important role in achieving this, by sharing objective analyses of circular solutions. Moreover, nowadays many innovations and developments do include the industry, governments & official authorities, and knowledge providers in a triple helix cooperation. In the future we will see these cooperative ventures extend to quadruple helixes by including consumers and citizens in these developments. This way consumers and citizens can further influence these developments and their voice can consequently better be heard in order to achieve acceptable solutions. In addition, nowadays many non-binding voluntary agreements (e.g. Plastic Pact) are used. They have the advantage of involving many stakeholders, but the effectiveness of these agreements is not clear to citizens and consumers and the progress is too slow. This requires that a wider audience is heard and that results are pursued more persistently.

CONSUMER & SOCIETY: SOLUTION C2. TRANSPARENCY ABOUT CONSUMER COSTS

As discussed above in the section "The only viable option is the switch to circular plastics" it is not clear how the costs for consumers will develop exactly. The affordability for consumers could be acceptable, but only if true costing is applied and hidden costs are included in non-sustainable solutions of today's plastics. It is essential that developments around this topic are communicated to consumers transparently. This way consumers can make the right decisions to buy certain products and to ban others. Secondly, consumers will consequently become aware that prices may increase if all costs (including the hidden costs) are included if a true price is asked, but that, on the other hand, these costs might be compensated by an increased quality of life and by decreased costs for healthcare and waste. Hence, also governments and official authorities can issue the right financial and non-financial measures to stimulate circular plastics and to tax non-circular plastics. A strong continued analysis and transparency of developments is needed, also to create the right commitment for the change to circular plastics and well-informed decisions for the citizens and consumers.

Stimulate circular plastics and tax non-circular plastics

GOVERNANCE & TRANSITION: SOLUTION G1. CREATE A CLEAR AND STABLE LONG-TERM PLAYING FIELD

A long-term playing field and governmental support is needed because the time and costs to complete the transition to circular plastics are considerable. Legislation is blocking the transition as it is driven by waste removal and not by value creation. Value is formed by both quantity and quality. In today's perspective of waste prevention quantity prevails, whereas quality (or recyclate) – in our view – is essential to the success of the envisioned transition. The system transition needed, in a world that changes ever faster, is so complex, that solutions cannot be known and prescribed. Instead, the government should create the conditions for the development and upscaling of sustainable solutions through research and industry. Existing littering policies are effective because the quality of the recycled materials creates value (e.g. PET bottles) or items are banned. However, the ban on single-use plastics created awareness, but if we only use the approach of banning then value is rather lost. These two – totally different – approaches serve a common goal. However, it is crystal-clear that we need a policy approach that will intrinsically maintain the value of produced materials in the system upon market re-introduction. We therefore fully support the Policy Mix variant 2 in the Brede Maatschappelijke Heroverweging 11[59], including an active approach for destabilisation and phase-out of non-circular activities. Actions taken by the government could include stimulation and active support of circular frontrunners for scale-up, regulation and pricing to initiate new coalitions and to break down existing linear chains. Clear communication to and between all stakeholders should be a high priority and should be stimulated in a concerted campaign, positive incentives should be introduced to support and illustrate this campaign.

Our 8 must have solutions can be connected to the DRIFT transition model and will result in new initiatives and will also break down old structures, leading to both new stable structures and the phase out of existing ones. Transition paths must be developed to shape and guide these changes for the next decades. To stimulate and support this long-term transition, solutions should not be prescribed but clear conditions and requirements for a sustainable and circular system should be set, which enable all stakeholders to play their part in the transition. Overall, the circular plastics economy will replace the existing linear plastics economy: phase out the old view and implement the new view. The stakeholders involved all have to play an individual and collective role: industry, government and consumers. Who should act first ?

Industry should take the lead in working together to create circular value cycles in which the guiding principle is quality and preservation of quality (V1). With better cooperation between stakeholders, knowledge can be shared beyond current borders. Industry should also take the lead in the development of innovations for high-value quality recyclate and more standardised plastics and additives, which are part of their core production processes and products. (T1, T2). In addition, industry should accept its responsibility to adopt and include EPR (Extended Product Responsibility) in their products and ensure that it is implemented (V3). Norms and standards for EPR should be developed in close cooperation with governments.

Governments and official authorities should take the lead to guarantee a clear and stable long-term playing field in order to govern and stimulate the transition from the existing linear plastics economy to a circular economy, phasing out the old view and implementing the new view (G1). In addition, the government plays a crucial role in creating the boundary conditions to enforce true pricing and to create transparency about consumer costs (C2).

Moreover, consumers and citizens play an important role by sharing their voice (C1). On the one hand to put pressure on the system to commit to sustainable solutions and to have industry and government initiate action. On the other hand to understand where they see barriers in order to accomplish their willingness to accept the use of circular plastics. They need to be invited to participate by industry and government, but they should also accept responsibility for choosing sustainable solutions and starting many bottom-up initiatives.

All stakeholders, industry, government and consumers have an important role to play

TNOS CONTRIBUTION TO CIRCULAR PLASTICS

To conclude this paper we urge all stakeholders to follow a path towards circular plastics in order to flip the coin and to work on plastics without environmental and health burdens for citizens and that also create new economic possibilities for the industry.

We would like to put the Material Transition (Circular Economy) on an equal level with the Energy Transition (GHG reduction) in view of the thereto-pertaining ambitions and solutions. The circular community in the Netherlands needs better organisation and narrative to achieve this, we must jointly be manning the (circular) barricades.

Put the material transition at an equal level as the energy transition

As an independent RTO, we aim to contribute to all of the eight must have solutions to the full. In TNO's mission we commit to the creation of impact by contributing to the societal transitions, including the material transition, through the harmonisation of Dutch and European public and private interests at the level of system integration. Furthermore, we contribute to the earning power of the Dutch economy and strengthen the competitive advantage of companies based in the Netherlands. The transition to a circular plastics economy is at the heart of our mission.

To contribute to these eight must have solutions we conduct multidisciplinary R&D in public-private citizen partnerships with (inter-)national partners from the entire knowledge chain, from developing alternatives to demonstrating solutions on full scale. The circular economy works in small communities like Werkhoven but also at national and European level. These levels of organisation must be connected for collective learning and cooperation.

We fully support the transition to circular plastics in our 2018-2021 multiannual strategic plan, aiming to create a circular and cleaner world for the benefit of the industry and citizens. We are proud of what we have achieved to date, but we also realise that we need to cooperate with many more, perhaps yet unknown, partners to create more impact. If our paper has motivated you then seize the moment and contact us to discuss how we can tackle your specific challenge in the area of the linear economy and transform it into a circular opportunity.

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