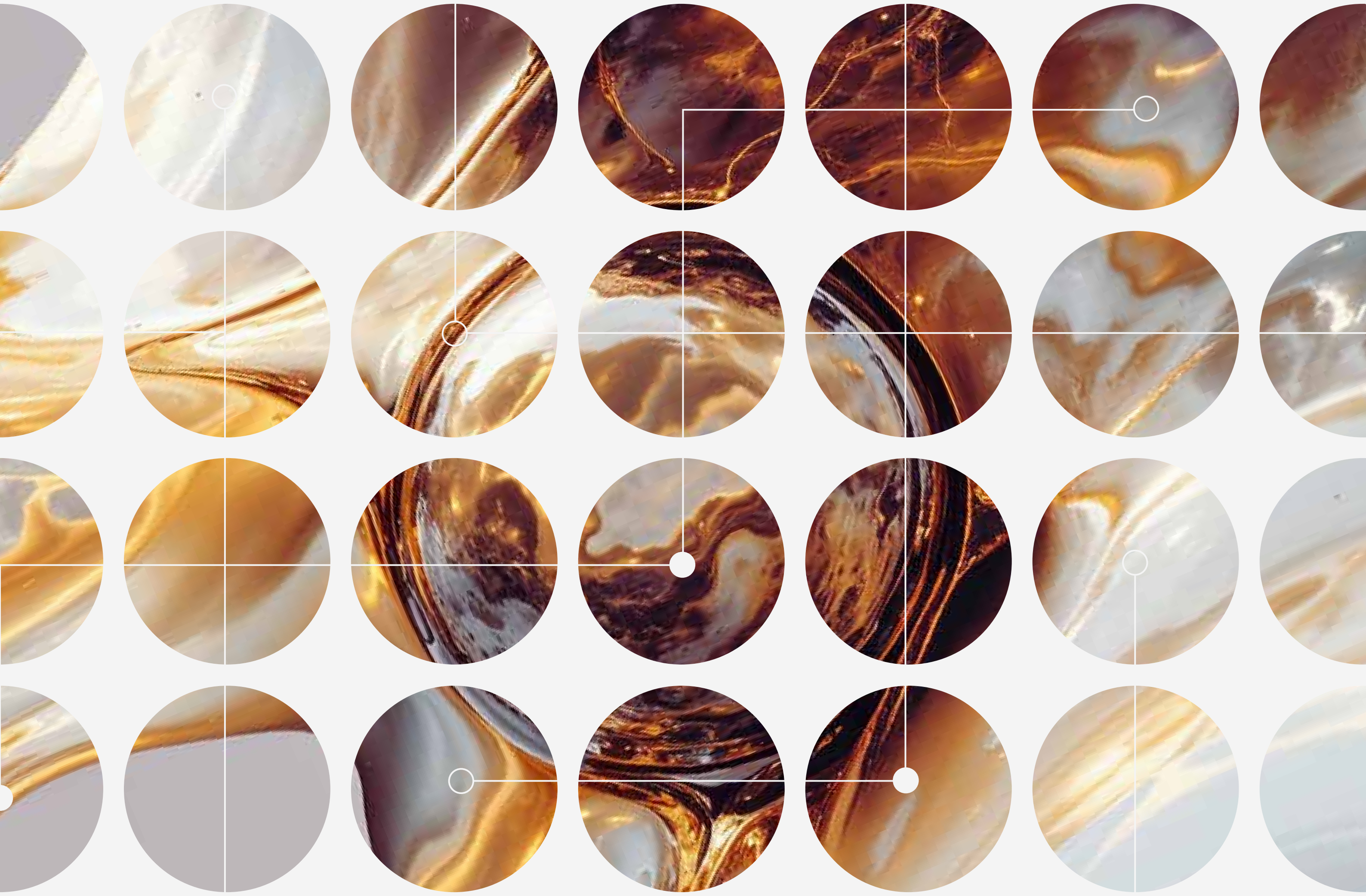
Brightsite Transition Outlook



Brightsite
Transforming industry

Edition 4
April 2026

Technology is ready. The rules – urgently needed – aren't.

Why recycling won't scale without policy

Contents

Foreword

> *"Chemistry is not only a climate issue, but also a matter of strategic autonomy and security of supply."*

The chemical industry is the quiet engine of our society. From healthcare to housing, from mobility to food systems: chemistry provides essential building blocks we often only notice when they are no longer available. At the same time, the sector stands at a crossroad. The transition to a climate-neutral and circular economy requires decisive choices, major investments, and — above all — a course that remains stable for years, not quarters.

That course has become more urgent than ever. It is driven not only by climate and environmental pressures, but also by geopolitics and economics. Europe aims to reduce dependencies on non-EU countries for critical inputs and key products, and to keep an industrial base within its own borders. Against that backdrop, the European Commission presented an action plan[1] for the chemical sector in July 2025, including the intention to establish a Critical Chemicals Alliance to address the risk of capacity closures and to strengthen the resilience of European value chains. A European delegation's visit to Chemelot in January 2026 further highlighted how tangible this challenge is: chemistry is not only a climate issue, but also a matter of strategic autonomy and security of supply.

The Netherlands has also made this more explicit. In its National Vision on Sustainable Chemistry (October 2025)[2], the government confirms that chemistry is of strategic and economic importance and plays a key role in a future-proof circular economy. Explicitly recognising this importance is a prerequisite for consistent choices and investment confidence.

It is in this context that we publish the fourth edition of the Brightsite Transition Outlook (BTO). I invite you to read this BTO for what it is: a substantive analysis and a call for targeted steering. Because if we consider the chemical industry crucial to our prosperity and strategic autonomy, it must be matched by a fair and future-proof playing field. Only then can we make the leap from ambition to delivery.

Dave Beijer
Interim Program Director, Brightsite

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[1] https://single-market-economy.ec.europa.eu/publications/european-chemicals-industry-action-plan_en

[2] https://open.overheid.nl/documenten/0f65d08e-cc22-4668-ad7b-8c29d48de98a/file

Introduction

Plastics and rubbers play a vital role in society, as integral components of our daily lives. They have largely replaced traditional materials such as metals, wood, cotton, and natural rubber due to their advantageous properties. Products made from plastics require minimal maintenance, are lightweight, and can be easily shaped and precisely machined. Their properties are consistent, highly reproducible, and can be customized to meet specific requirements.

Since the advent of Bakelite (in 1907), the first synthetic plastic, development has culminated in sophisticated materials like self-healing composites used in aerospace technology. These innovations demonstrate the remarkable progress in scientific and industrial fields. Despite their benefits, it is essential to use plastics responsibly, considering their environmental impact and the dependency on fossil resources. Plastics, and rubbers, are strongly connected to the fuel industry. The large scale provides an abundant and inexpensive source of raw materials and energy for manufacturing plastics. Plastics are produced in vast quantities at low cost, leading to a perception of disposability, especially for items like bags and food packaging. This widespread use contributes significantly to environmental pollution, with plastics ending up in oceans, landfills, or incinerators, and releasing greenhouse gases such as CO_2. Moreover, plastics degrade slowly, releasing hazardous additives into the environment and forming microplastics that pose risks to ecosystems and human health. The persistence of plastics in the environment underscores the importance of effective waste management strategies to control disposal.

Over the last decades, extensive research has been conducted on recycling technology. Progress has been made in melting, re-molding, dissolving, disassembling, and breaking down plastics into molecular feedstocks. Despite these options and the urgency to achieve a sustainable future, large-scale adoption remains limited. Barriers include economic factors, technological maturity, infrastructure gaps, and regulatory hurdles. Society needs to overcome these obstacles in order to shift towards a sustainable, circular plastics industry that will enable us to keep enjoying the benefits of plastics, without the environmental burden.
To accelerate this transition, investments in technology, policy support, and industry collaboration are essential.

Scope of this Brightsite Transition Outlook
Published at a time when the future of the chemical industry in the Netherlands and Europe is seriously at stake, demanding immediate action, this Brightsite Transition Outlook (BTO) aims to help clarifying what to do to create a sustainable future for the industry as a part of our society. It is part of the evolving logic of a BTO series since 2022, which explores the future of a sustainable chemical industry. BTO 2022 set Chemelot's ambition: greenhouse gas free production via electrification, carbon capture, and gasification, among other solutions. BTO 2023 expanded to the Dutch chemical sector, showing that by 2050 most carbon and hydrogen must come from waste and biomass rather than fossil fuels. BTO 2024 emphasized that fossil-free chemistry requires smarter production and consumption, with multiple technologies coexisting for minimized energy and carbon use. The message: 'yes, competitiveness and environmental sustainability for plastics and chemicals are very well possible', now depends more than ever on timely action in sustainable production, products, circularity, clean energy, and system integration – enabled by regulation that rewards sustainable products and processes.

The current BTO sets the required transition as a business and regulatory challenge: how to empower circularity. It investigates the research questions:

'Why is plastics circularity not emerging spontaneously in the manufacturing system under the current regulatory framework, despite the clear benefits of reduced import dependence and a smaller environmental footprint? And how should regulation facilitate circular plastics to scale effectively, overcoming systemic barriers in supply chains, economics, and market adoption, thereby contributing meaningfully to sustainable consumption?'

Reading guide
In the first part of this BTO, the functioning of the linear economy is discussed from the perspective of the various players (actors) involved in plastic based value chains. The second section highlights and explains the benefits a flourishing circular economy could bring to society. The third section analyses what is hindering the further deployment of circular solutions, again based on the perspectives of actors, both existing and new in circular value chains. The fourth section explores solutions aiming at overcoming these barriers and advancing towards closed material cycles. The final section summarizes our conclusions and offers recommendations for future actions to promote sustainable practices within the chemical industry. Throughout this BTO, the SCIARS™ model developed by Brightsite illustrates concepts and is applied quantitatively to a case study as an illustration: the polyamide 6 value chain.

SCIARS
SCIARS means Source, Commodity, Intermediate, Application, and ReSource. It assesses the carbon lifecycle in value chains, from raw material sourcing to end use, including process steps and system effects. In SCIARS, carbon flows are tracked through 'building blocks' that change flow dynamics, attributed to responsible parties (that is 'actors' who exercise technologies) and 'technologies' (chemical and non-chemical, including consumption). Change results in CO_2 emissions and energy use. Grouped into chains and cycles, SCIARS maps can represent various scenarios. The overall effects relate to consumption and associated emissions, modeled both qualitatively and quantitatively.

Different technologies, actors, and consumer choices influence transition pathways, affecting system-wide outcomes like CO_2 emissions and resource use. SCIARS offers a rational basis for decision-making in transitioning to climate neutrality by helping stakeholders understand trade-offs and systemic effects of technology and material choices, especially in energy and raw materials transitions.

Upstream generated carbon flows and recycling flows serve consumption, which is recorded per time unit on the Turnover bar. At the same time, all associated CO_2 emissions from the building blocks per time unit are summed as ACA. The ratio of ACA and TO is a measure of the total CO_2 emissions associated with specific consumption. In the case of climate neutrality, ACA = 0.

Remark
Radical innovations, involving new bio-polymers or major redesigns of products and supply chains for carbon efficiency, are beyond the scope of this BTO: it is a very important subject on its own.

Section 1

The plastic value chains in the linear economy

The current plastics industry follows a linear ‘take, make, dispose’ model, driven by efficiency and fossil fuels, ignoring resource limits. To understand why circular value chains are not taking off, it is essential to understand this economic model, how stakeholders influence this system and how shifting to circular economies is hindered.

The linear economy
Figure 1 illustrates the various actors in the linear plastic economy, such as petro-chemical companies, producers and consumers. These actors are depicted as interconnected blocks forming a supply chain, reflecting the current linear economic model. The scheme follows the SCIARS™ approach by Brightsite (see box ‘SCIARS’ on page 5) and emphasizes the linear flow from production to consumption as a one-way flow of materials and value, without detailing the entire up- and downstream process.

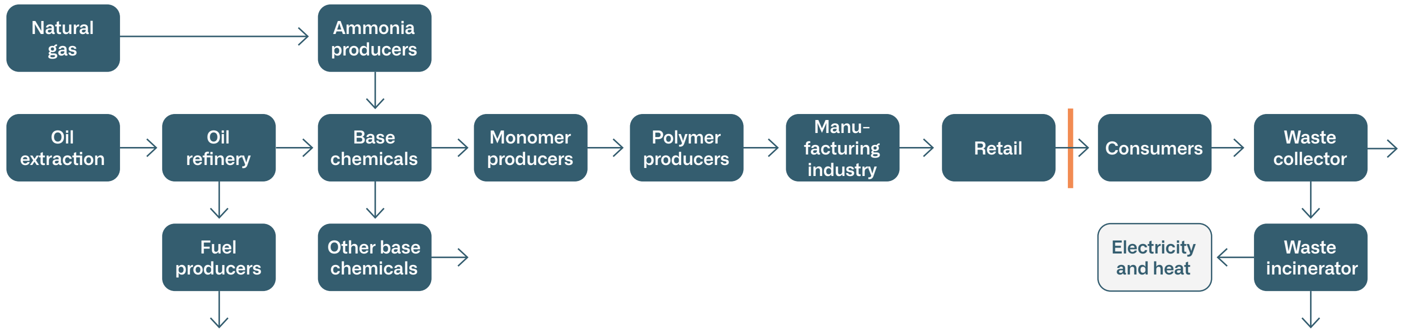

Figure 1 SCIARS representation of the plastic value chain in today’s linear economy. Explanation in the text and in Table 1.

The linear market economy in plastics involves sequential value addition from fossil resource extraction to consumers. Starting with oil and natural gas, each actor enhances the material’s functionality and market value until sale. After use, the value of products drops sharply, often incurring disposal costs. Key actors are categorized in Table 1, with their roles, profit mechanisms, and influence.

Besides direct actors, entities like governments and lobbyists influence the economy indirectly by shaping actor’s behavior. Governments set policies, while lobbyists advocate industry interests to politicians and consumers, for example through advertising.

Actor	Function	Margins	Influence
Base chemicals & monomer producers*	Production of key raw materials for plastics.	Large volumes, high capital intensity, limited differentiation; margins often cyclic, relatively low per carbon unit.	Limited direct influence over downstream market trends. Operations are capital-intensive and often tied to long-term supply contracts.
Polymer producers	Conversion of the raw materials to plastics.	Relatively low margin per unit of carbon; for specialties (engineering plastics) a bit more.	Gatekeeper between monomer producers and converters/ brand owners. Preference for multiple suppliers (competitiveness, security of supply).
Manufacturing industry	1. Compounders and converters modify polymers, resins or fibers with additives, fillers etc. Processing it into (semi-) finished goods.	Can have higher margins (customization, performance enhancements).	High technical flexibility but often constrained by specifications from customers.
	2. Brand owners and OEMs** (and some retailers) define (semi-) product requirements, sustainability targets and market positioning.	High margins, especially when plastic is a minor part of a branded product with price far exceeding the plastic material cost.	Determine standards (demand-based), are exposed to (regulatory) pressure, follow corporate sustainability goals; have upstream impact influencing material selection, certification needs, and innovation priorities and downstream influence via marketing/advertising.
Retailers and (end) consumers	Drive demand through purchasing behavior and sustainability expectations.	Some create value if brand owners give the opportunity (premium brands/private labels, cheaper imports).	Indirect influence, but consumer preferences influence brand owner’s decisions, which cascade upstream.
Waste handlers	Waste collection, transportation, and incineration for energy recovery.	Some limited margin.	No influence on market trends. They support the linear economy by dealing with waste problems and making some value out of it (energy).

Table 1 Actors in the plastic linear economy: function, margins and influence.
** Integrated for the major monomers*
*** Original Equipment Manufacturers*

Quantifying collateral damage of the linear economy

SCIARS analyzes the linear plastic value chain by tracking carbon flow and efficiency, focusing on carbon loss as CO_2 emissions. These losses cause pollution by slowly decaying plastic and global warming, damaging living environments locally and society globally, which form an important part of 'negative externalities'.[3] We use polyamide 6 (PA6; see box 'PA6') as a representative example of plastics to demonstrate how detailed, quantitative maps of carbon flows related to production, consumption and CO_2 emissions are obtained (Figure 2).

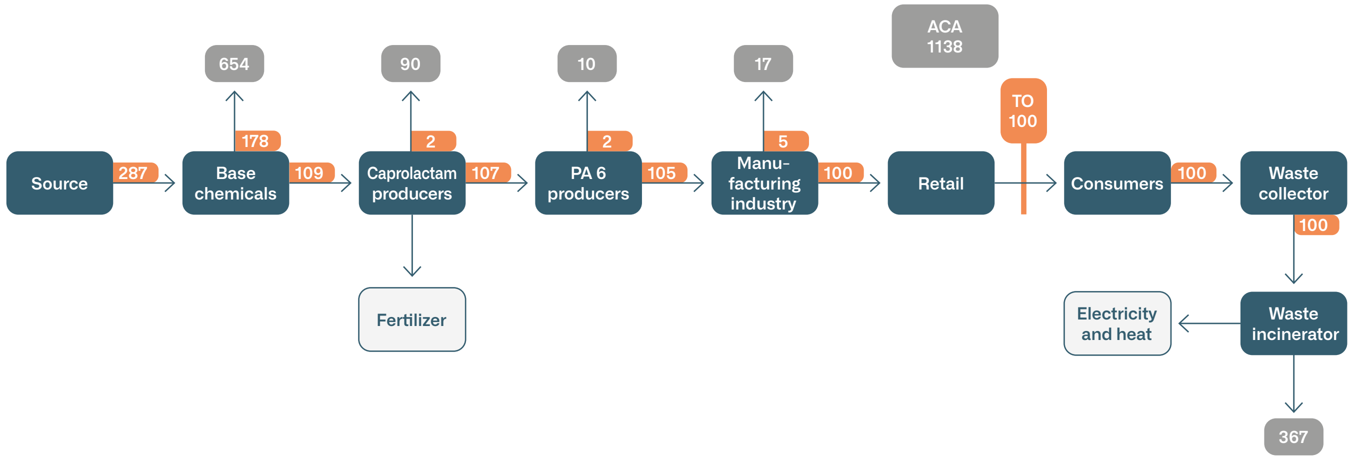

Figure 2: Quantitative SCIARS representation of the PA6 value chain in the current linear economy (without detailing the oil and gas extraction). Orange boxes: carbon units; grey boxes: CO_2 equivalents. Turnover (TO) is arbitrarily set to 100 carbon units. ACA is the overall Atmospheric Carbon dioxide Accumulation.

The assessment starts with an arbitrary number of 100 carbon units within the polyamide part of PA6-containing products. This quantity then corresponds to a turnover (TO) of 100 units per year, which enter the consumer's realm at the orange bar in Figure 2. Upstream of the consumer, the analysis tracks how many carbon units are needed to produce these 100 units, while downstream, the fate of the carbon units at the end of the products' lifecycle is tracked (using open-source data).

If a particular building block loses 1 carbon unit as CO_2, it emits 3.67 units of CO_2 (that is the mass ratio of CO_2 to carbon). Also additional CO_2 emissions, called auxiliary CO_2, can occur in a particular building block: emissions not originating from the carbon flow tracked in the material, but from other sources needed to operate the process in the building block. It can be, for example, CO_2 emissions related to electricity used by the process, or – as can be seen from the large emission of the caprolactam producer's block – from also needed hydrogen and ammonia and emissions of laughing gas during the caprolactam production process.

Upstream

Upstream from the TO-bar, some parts of the linear system achieve high efficiency due to a century of development and optimization. Producing 105 units of carbon in PA6 requires 107 units from caprolactam, which in turn needs 109 units of base chemicals with only 2 units lost (emitted) as CO_2. All these upstream emissions are included in PA6's eco-profile.[4] To produce 109 units of base chemicals, 287 units of carbon from oil and natural gas are needed of which 178 units are lost as 654 units of CO_2. The carbon loss in PA6 polymer processing is low, reflecting current practices to reuse pre-consumer waste. Energy use downstream PA6 also includes auxiliary CO_2, but is not shown.

Downstream

Downstream of the TO-bar, post-consumer waste is incinerated with energy recovery, converting 100 carbon units into 367 CO_2 units. Not shown is waste dumped into the environment, which slowly decays into CO_2.[5]

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[3] Negative externalities of a linear economy refer to all costs incurred by third parties that result from producing or using of products and for which no compensation is provided (climate, environment, health).

[4] Eco-profile of polyamide 6, Sept. 2022 (mass allocations). Details available on request. Technology has a large impact on the carbon footprint. Regulatory pressure on emissions depends on geography and does not do justice to regionally much better footprints.

[5] Emitting the same amounts of CO_2, without energy recovery, but causing pollution.

PA6

Polyamide 6 (PA6), also known as Nylon 6, is a polymer used across a wide range of industries, for example automotive industry, electronics, packaging, and textiles. The global PA6 production estimated to be approximately 6-7 million tons in 2025.[6]

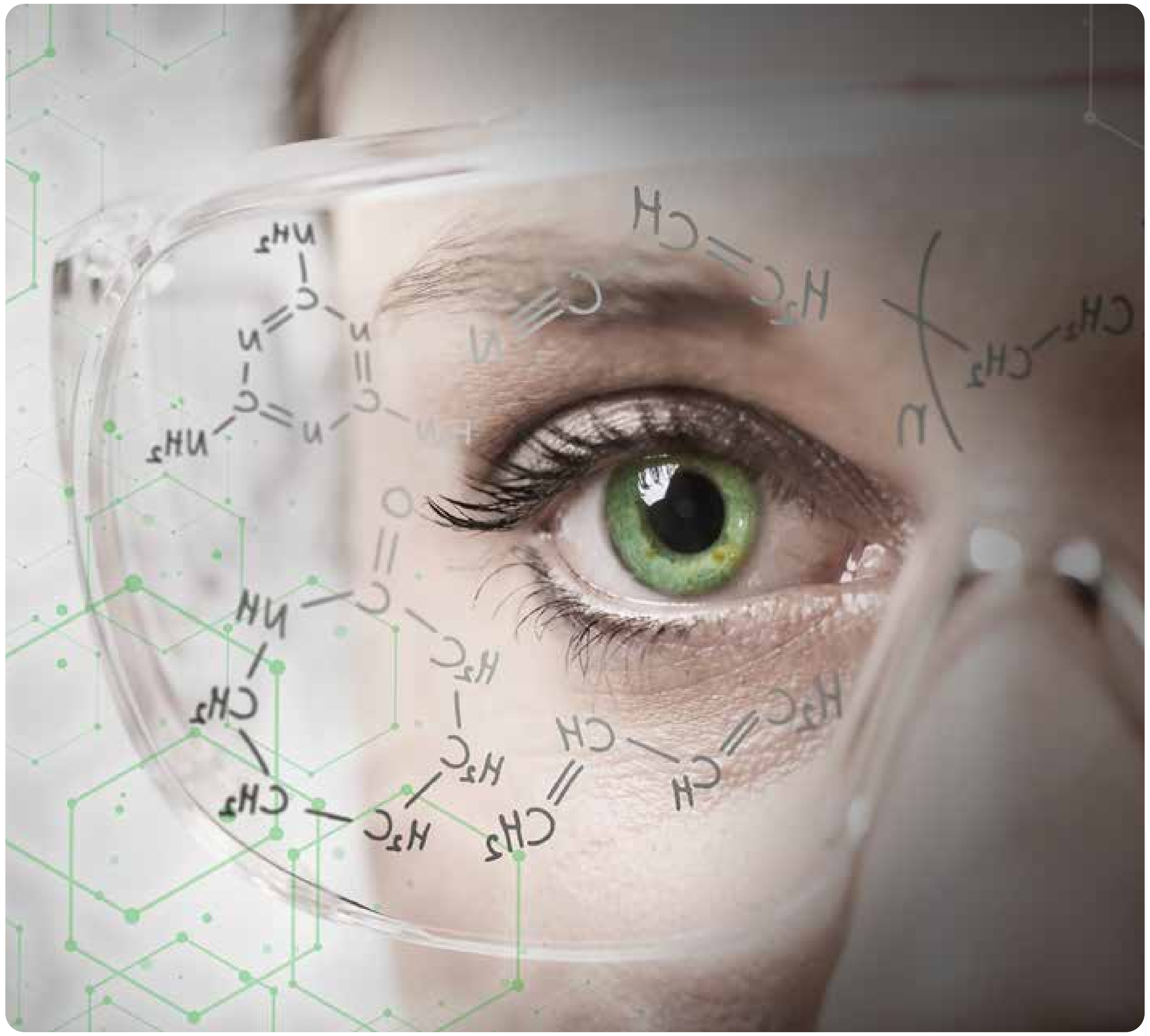
Atmospheric Carbon Accumulation

Atmospheric Carbon Accumulation (ACA) is the summed CO_2 emission of all building blocks. This 'net greenhouse gas effect' indicates the integral climate impact associated with consuming 100 carbon units in PA6 products. In this example, ACA is 1138 CO_2 units per 100 units of carbon, reflecting an open carbon loop where all extracted carbon eventually becomes atmospheric CO_2.

To summarize, the CO_2 emissions related to the consumption of PA6 in a linear economy are mainly due to:

- *Upstream emissions* from fossil feedstock extraction, processing, and chemical production, which contribute heavily due to high energy use and direct process emissions;
- *End-of-life incineration* of plastic waste, which also releases large amounts of CO_2, even if some energy is recovered.

The integral CO_2 emission is responsible for climate change. It cannot be causally attributed to one or a few actors, only to the collective, consumers included.



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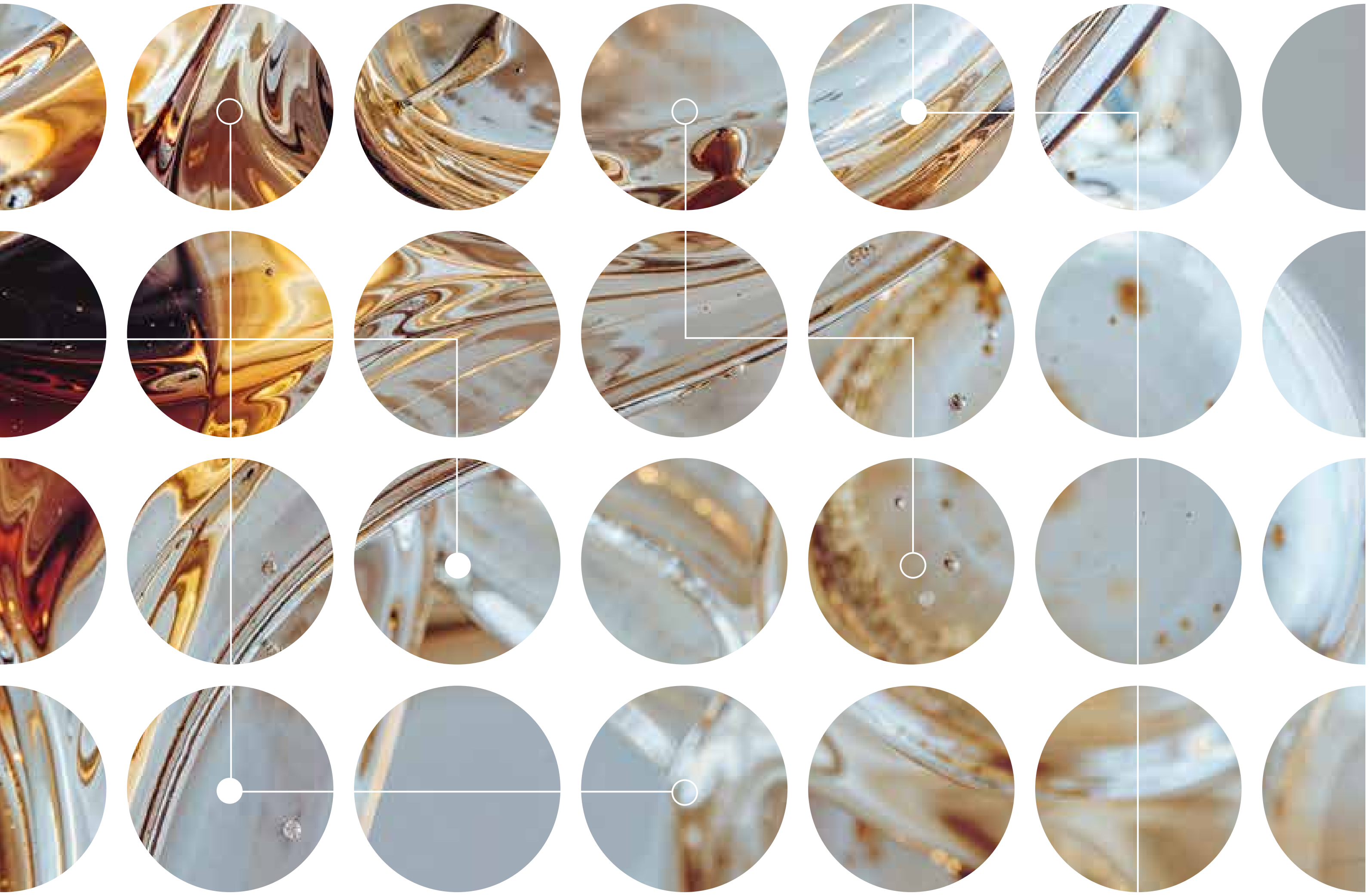
[6] Marketgrowthreports.com; Chemanalyst.com, (averaged estimate)



Section 2

Why recycling is indispensable in the future

Before analyzing the challenges faced by recycling start-ups and the reasons why recycling has not taken off yet, and discussing potential solutions, let's first consider what a fully developed circular economy could look like. It helps to understand the importance of intervention.

The circular economy
Key elements of a circular economy include circular (post-consumer) feedstock, recycling technologies, and new players. Figure 3 illustrates how the circular feedstock 'waste' can interact with the linear plastic value chain. A circular model is created where circular carbon flows exist alongside linear ones. However, many of the new processes in this figure are still undeployed, and potentially viable routes therefore remain unconfirmed at this stage.

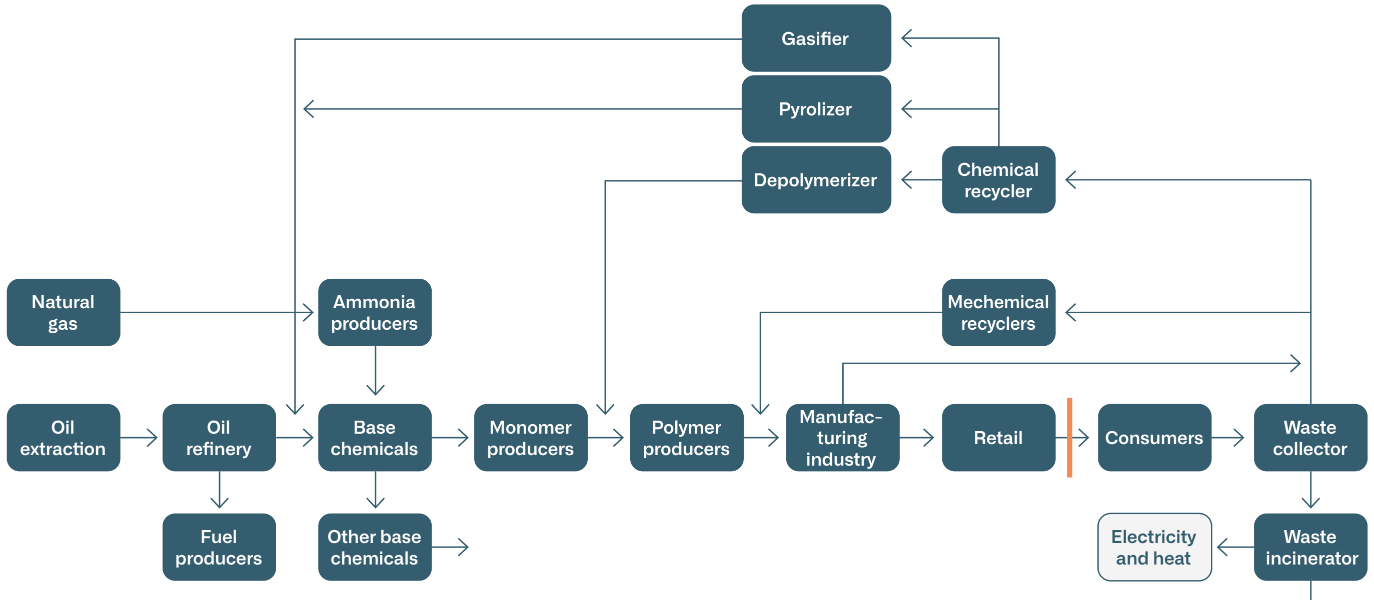


Figure 3 SCIARS representation of the plastic value chain in a hypothetical 'ideal' circular economy. Explanation in the text.

New actors and processes (see box 'SCIARS') are:

- *Mechanical recycling:* energy-efficient, preserving polymer structure, but requiring pure, mainly sorted waste. Contamination and wear reduce quality, leading to downcycling;
- *Chemical recycling:* various methods suitable for mixed, contaminated waste can produce monomers or precursors with virgin-identical quality (no downcycling). Below technologies from top to bottom are characterized with an increasing energy demand and decreasing material recovery:
    - Depolymerization: returns polymers to monomers;
    - Pyrolysis variants: convert waste into oils for processing to monomers;
    - Gasification: transforms waste into syngas for monomers synthesis.

Another key element of a circular economy is consumer behavior and 'circularity strategies' by the manufacturing industry, for example:

- Product redesign, to facilitate longer product lifetimes, repair, disassembly, reuse and recycling;
- Responsible consumption, reducing the demand for single-use items;
- Component reuse, take-back schemes, remanufacturing programs.

Quantifying the potential benefits of the circular economy
The potential benefits of a circular economy can be referred to as (partial) elimination of negative externalities (damage to climate and environment), and additional benefits: 'positive externalities', related to a new economy. In both cases it concerns value that currently is not reflected in a realistic product price. For the quantification of these positive effects on resource use and CO_2 emissions we use PA6 European production and associated value chains as an example, comparing a hypothetical circular value chain with a linear one.

As a starting point for the comparison, the 'consumer need' for PA6 products remains unchanged. However, improvements in product design (enhanced reparability, re-usability) along with shifts in consumer behavior (purchasing less frequently, opting for second-hand items) and new business models (discouraging planned obsolescence) can extend the average product lifespan. In this example, an arbitrary 50% longer product lifespan is adopted to demonstrate the combined impact of these strategies. Under these conditions consumer *needs* are still met, but *demand* is lowered by 33% (due to the 1.5 time longer lifespan of the products), reducing product turnover to 67 carbon units.

When it comes to recycling, mechanical recycling would be the first choice because of its low costs and energy consumption. However, mechanical recycling of PA6 is often difficult due to its use in composites or multilayer structures with foreign materials. It is therefore only applicable to a small fraction of the PA6 waste and can results in downcycling. PA6 can be depolymerized into caprolactam via low energy solvolysis, which also facilitates removal of additives and other polymers. PA6 is less suitable for pyrolysis than polyolefins, due to its chemical composition. PA6-containing waste can be gasified to recover carbon in the form of syngas, although this process is more energy-intensive and destroys the molecular structure. Based on these considerations and published data, quantification was performed for illustrative purposes, assuming different level of recyclability depending on the fields of application.[7]

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[7] This aligns with estimated plastic recycling potential in general: 'Plastic recycling stripped naked', J.P Lange et al. ChemSusChem, 2024. We assumed 70% of PA6 in textile (20% of all European PA6 applications) is recovered for depolymerization. We assumed that also for the other post-consumer PA6 waste 70% is collected for recycling, of which 10% is sent to mechanical recycling, 50% to depolymerization and 40% to gasification. PA6 pre-consumer waste is assumed to all be recycled by depolymerization.

Quantitative modeling results, demonstrated in Figure 4, show how the demand for virgin resources decreases significantly from 287 to 103 carbon units, due to lower TO and increased recycling. Upstream CO_2 emissions are substantially reduced from 654 to 233 units. End-of-life emissions drop from 367 to 64 units due to recycling processes and the carbon footprint ACA decreases from 1138 to 496 CO_2 units.

The new actors are crucial for the success of a circular economy. They still emit CO_2 (also auxiliary processing emissions), which could be reduced further by deploying renewable energy. In this way the ACA can reduce even further.

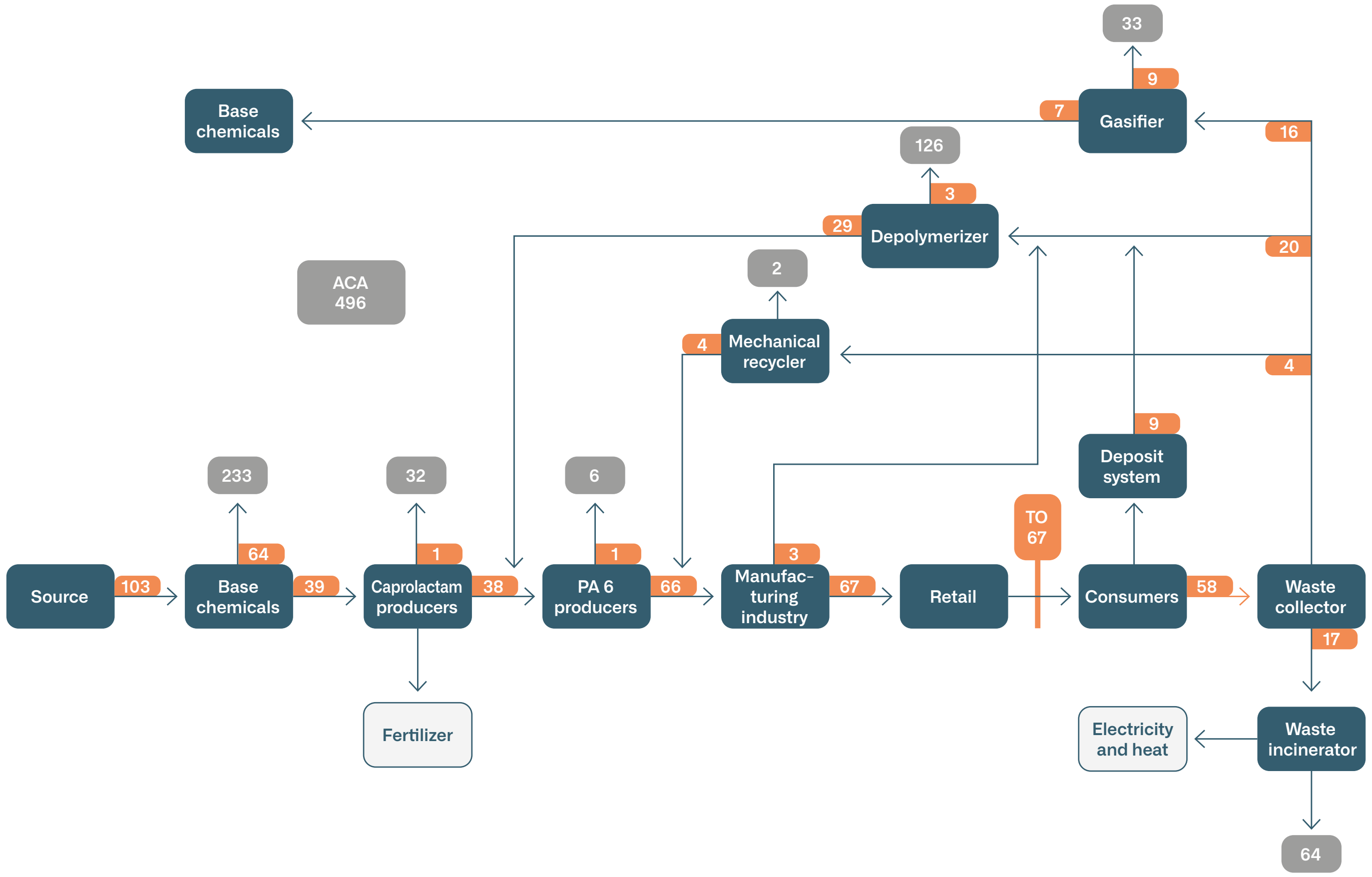

Figure 4 Quantitative SCIARS representation of the PA6 value chain in a hypothetical 'ideal' circular economy scenario (excluding extraction of oil and natural gas). Orange boxes: carbon units; grey boxes: CO_2 equivalents. The same consumer needs are met as in Figure 2. Further explanation in the text.

Table 2 compares the benefits of this 'ideal' circular economy with the linear situation, focusing on ACA, TO, virgin feedstock intake and cycle efficiency. The circular economic model achieves 64% reduction in virgin feedstock use and an overall post-consumer cycle efficiency of 45%.[8] Cycle efficiency is a collective result, determined by the efficiencies of all 'cyclic actors' together to keep carbon in the loop.

	Consumer needs*	TO	ACA	Virgin feed-stock intake	Cycle efficiency
Linear fossil-based	100% met	100	1138	100%	0%
Ideal circular	100% met	67	496**	36%	45%

Table 2 Key performance indicators linear vs "ideal" circular economy of PA6 case, as modelled in SCIARS.
** 'Need' doesn't change, the way needs are met do change*
*** Electrifications of processes can reduce ACA even further*

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[8] Cycle efficiency is a SCIARS system performance parameter, defined as the ratio of circular carbon, pre-consumer excluded (in Figure 4: 4 + 29 - 3) and the total carbon flow through the TO-bar (67).

For virtually all other plastics the significant potential benefits of an ideal circular model can be quantified in similar terms: greatly reduced demand for carbon resources, less unnecessary consumption compared to what is often possible, and greatly reduced overall CO_2 emissions (chain emissions).

Waterbed effects

The transition from a linear to a circular economy can lead to unintended consequences known as 'waterbed effects'. That means for instance that a change in one sector can spill over into others sectors. A positive effect on the one hand can generate negative effects on the other hand. A system perspective helps visualize, anticipate, and incorporate these collateral effects into decision-making. The SCIARS™ approach enables the visualization and quantification of both intended and waterbed effects on a unified map, facilitating more informed and holistic economic planning.

Example 1 concerns the significantly different energy recoveries in the linear (Figure 2) and circular (Figure 4) economies: 100 and 17 carbon units ending up in waste incineration, respectively, implying a 83% decrease in heat generation. This reduction necessitates compensating energy generation to meet societal demands. The various solutions depend on the progress of the energy transition. Because carbon is indispensable in materials but not essential for energy production (only as an energy carrier), renewable electricity is therefore preferable: it avoids CO_2 emissions and carbon loss outside the economy. See box 'The energy context of the materials transition'. Similarly, caprolactam's fertilizer co-production is reduced by 64%. If the fertilizer demand remains unchanged, additional production would be required as well, which could increase the environmental impact.

Example 2 includes the significantly reduced demand for base chemicals: from 109 carbon units in Figure 2 to 39 in Figure 4. Our case study concerns only one application (PA6), but similar demand plots for other plastics and rubbers indicate a comparable, substantial decline in demand for fossil chemical and naphtha. Refineries might need to shift production share towards more fuels and less naphtha, or reduce capacity to adapt to this decline in demand. Ongoing electrification, however, is reducing the need for fossil fuels as well, which aligns with reduced naphtha demand and with achieving climate neutrality. Careful management is required to prevent industry disruptions by transitioning away from fossil fuels and materials, especially if alternatives are not yet viable.

Consideration

It is shown in general, and quantified by the PA6 example, that reusing materials and applying other downstream circularity strategies can sharply reduce integral CO_2 emissions compared to a linear economy. Not all carbon can be recovered. Inherent inefficiencies ('unavoidable loss') in production, collection, sorting, and recycling systems necessitate replenishment with fresh fossil carbon. Climate neutrality, indicated by ACA = 0, requires replacement of all fresh fossil carbon by fresh biomass or CO_2, and renewable processing energy.

Thanks to circularity, less carbon and energy would be needed. Thus, circularity offers many more benefits than simply reducing CO_2 through product incineration. It sharply reduces the need for fresh carbon resources and energy, making us less dependent on them while creating room for new, innovative industries. However, shifting from a linear to a circular system also has side effects, such as lower energy generation, which need to be compensated for in a sustainable manner.

The energy context of the materials transition

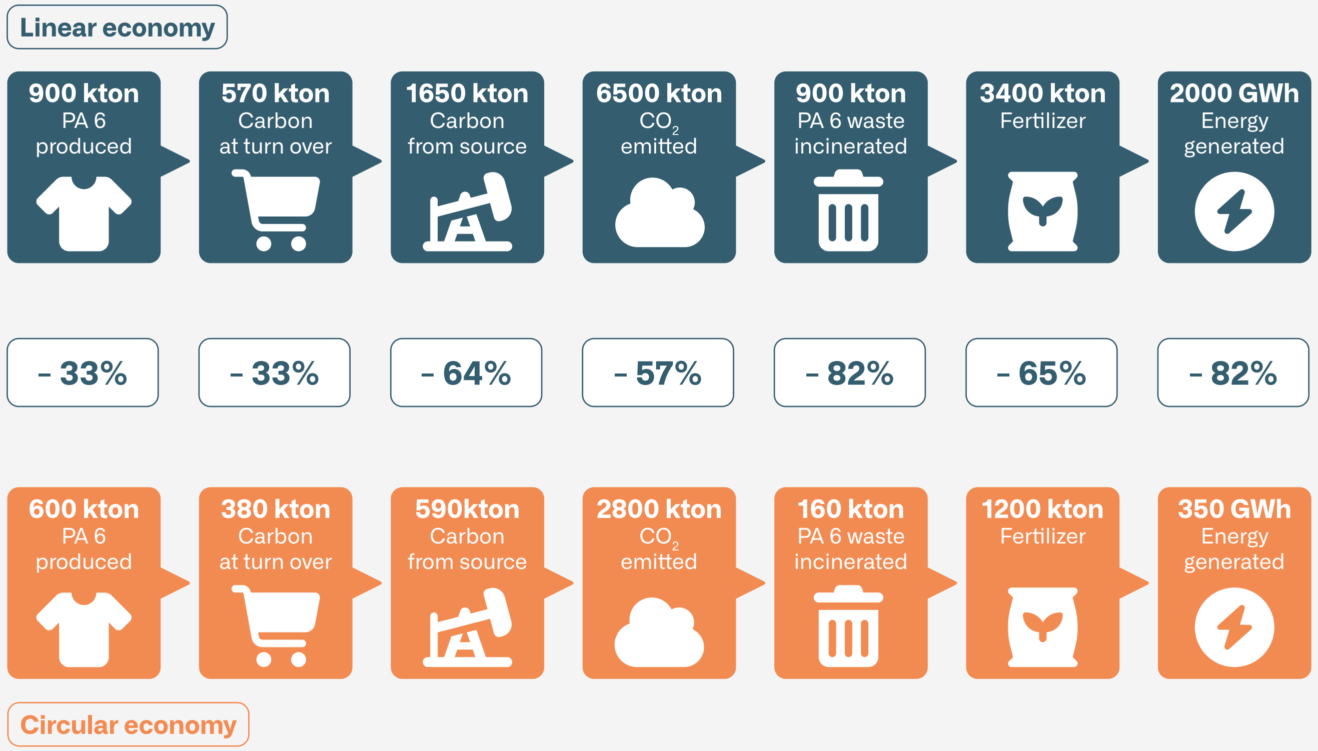
Combustion of fossil fuels is used to generate heat and electricity, releasing CO_2. The energy transition requires this combustion to stop. Renewable electricity can become the primary energy source for heating and power in grid-connected applications (domestic and industrial heating) and in near-grid applications such as transport and mobility. In off-grid applications, however, carbon-based fuels remain essential, for example in long-distance aviation. As most fuels will remain carbon-based, alternative carbon resources are needed. Using CO_2 is feasible but requires far more renewable energy than currently available. Production from biomass or waste is a much more attractive alternative.

However, the alternative raw materials for fuels or material purposes are exactly the same. Because of the limited availability, it is necessary to consider whether to convert them into fuels, or chemical building blocks. The simplicity of fuel production, the ease of blending, and existing regulatory frameworks make fuels an attractive initial outlet for waste and biomass. This can act as a drain, drawing renewable raw materials away from the chemical industry. Consequently, the transition to a circular economy and the transformation of the chemical industry and its supply can be delayed.

Both transitions – the energy and materials transition – reduce dependency on fossil resources. As the use of fossil inputs declines, so will CO_2 emissions. Carbon Capture and Storage (CCS) may still be required – particularly as temporary solution until better alternatives are in place and for hard-to-abate process emissions from sectors such as fermentation, where electrification is not technically possible or cement production.

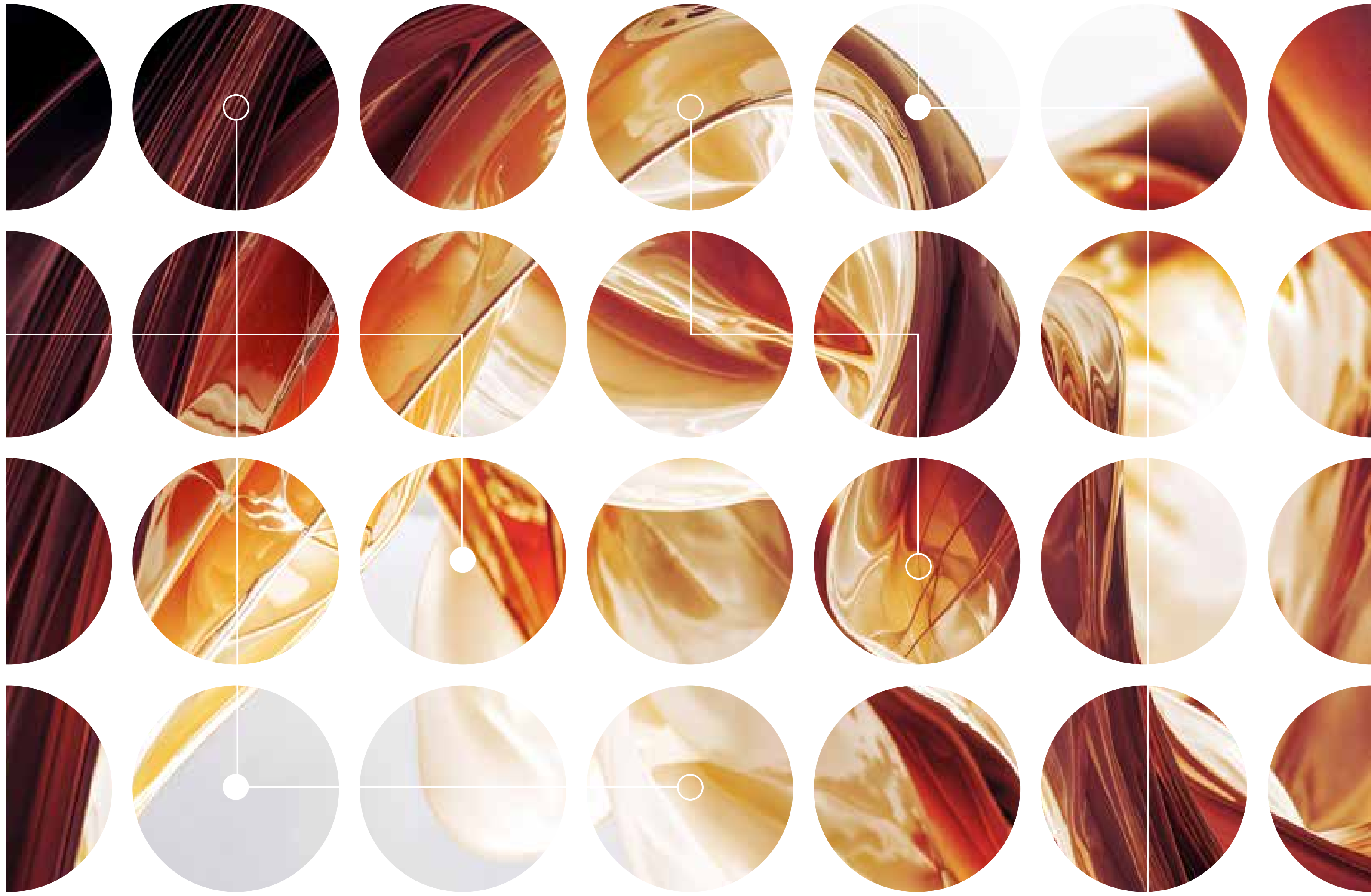
Real life data
Standardized SCIARS model data can be easily translated into real life data by calibrating turnover to reality and assigning real carbon containing products to the abstract carbon flows. We illustrate this by the transformation of linear PA6 into 'ideal circularity' depicted above, which is summarized in Figure 5. Here, the 100 carbon units passing the TO bar are calibrated as 900 kilotons (kton) of PA6 products (EU market, 2021) representing 570 kton carbon. The linear SCIARS map implies that 1,650 kton carbon is needed from pristine oil and gas. In total, 6,500 kton CO_2 is emitted during PA6's lifecycle, of which one third comes from burning waste. Waste incinerators produce 2,000 GWh of electricity and heat, and 3,400 kton of fertilizer is coproduced with PA6.

In the 'ideal' circular economy, the amount of PA6 needed to meet the same consumer needs would be reduced by 33% to 600 kton, due to the life time extension of consumer goods. The carbon amount in PA6 is reduced accordingly, but the demand for virgin carbon is further reduced (- 64%) due to the carbon kept in the loop through recycling. Overall, 440 kton of PA6 would be recycled. In total, the CO_2 emissions are reduced by 57% to 2,800 kton. The CO_2 emission reduction could be further decreased via electrification, provided green electricity is sufficiently available. However, also less energy is generated (- 82%) due to the recycling of waste and less fertilizer are co-produced (- 65%). These waterbed effects illustrate why impact analysis is so complex.



Linear economy		Circular economy
900 kton PA 6 produced	- 33%	600 kton PA 6 produced
570 kton Carbon at turn over	- 33%	380 kton Carbon at turn over
1650 kton Carbon from source	- 64%	590kton Carbon from source
6500 kton CO_2 emitted	- 57%	2800 kton CO_2 emitted
900 kton PA 6 waste incinerated	- 82%	160 kton PA 6 waste incinerated
3400 kton Fertilizer	- 65%	1200 kton Fertilizer
2000 GWh Energy generated	- 82%	350 GWh Energy generated

Figure 5: the impacts of linear and hypothetical circular PA6 in the EU market quantitatively compared, meeting the same consumer need.



Section 3

What prevents us from exploiting future benefits of recycling?

The circular economy – where are we now?
In 2022 11% (1.9 Mt) of the plastics produced in the Netherlands were circular, thus derived from recycling or bio-based sources.[9] Within the EU, an averaged 2.1% of added value is generated by the circular economy.[10] The Netherlands rank second to last with only 1%, without indications of acceleration: the economy grew faster than circularity.

Situation for PA6
The current European post-consumer recycling of PA6 involves mechanical processes, mainly from carpets and fishing nets, representing about 10% of a market that uses 2% of total polyamide production. In textiles, pre-consumer waste (such as fabric cut-offs) accounts for approximately 2% of PA6, which is 19% of total polyamide use. Incorporating these data into the SCIARS model shows minimal impact on key performance indicators, indicating limited recycling effects at this moment (Table 3).

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[9] TNO: https://www.tno.nl/nl/newsroom/2024/10/informatiebehoefte-circulaire-plastics/#:~:text=In%202022%20is%20slechts%2011,informatiebehoefte%20het%20beste%20worden%20vervuld?

[10] CLO, compendium voor de leefomgeving; https://www.clo.nl/indicatoren/nl300601-toegevoegde-waarde-circulaire-economie-2001-2022#:~:text=De%20toegevoegde%20waarde%20is%20gegenereerd,in%20Nederland%20harder%20is%20gegroeid ; PBL https://www.pbl.nl/onderwerpen/circulaire-economie/waar-staat-nederland-op-weg-naar-een-circulaire-economie

	ACA	TO	Virgin feed-stock intake	Cycle efficiency
Linear	1138	100	100%	0%
Ideal circular	496	67	36%	45%
Current	1136	100	99.8%	0.2%

Table 3 Key performance indicators of the PA6 case: the current perspective compared to previous linear and 'ideal' circular economy cases.

The circular economy - where is it stuck?

Despite the benefits and the availability of recycling technologies, recycled materials are not displacing fossil feedstock on a large scale yet. Root-cause studies identify complex systemic misalignment and actor-specific barriers throughout the current system, impeding large-scale adoption of circular practices.[11] There are several elements that consciously or unconsciously (often mixed up) bring barriers to a system transition of this size and impact. Main factors are discussed hereafter.

A circular economy will be more expensive

It is not possible to replace the highly efficient fossil fuel supply and value chains cheaply. Therefore, the new circular economy will be more expensive for all stakeholders. Meanwhile, most consumers prioritize, in some cases by necessity, price and discounts over sustainability. This seems to keep industries from adopting circular practices in their value chains; otherwise, they likely would have done so already.

> *Most actors strive for lowest costs, for example to maximize profits, improve the linear system or simply survive.*

However, reality is more nuanced. In many cases, the actual cost increase of sustainable components in most consumer products is only a few percent of the final retail price for consumers.[12] However, the sustainable products would see a disproportional price increase along the value chain and therefore never make it to the shelves.[13] The mechanism of value creation is the reason. Physically, sustainable carbon is introduced at the beginning of supply chains. The current business model leads to multiple price hikes along the links of the supply chains, as each participant highlights the value gap between traditional and sustainable products. Relatively small initial sustainability costs increase exponentially, leading to high consumers costs, while none of these actors creates additional value in the product or its externalities: **a price paradox.**

In addition, the linear fossil chain harms ecosystems, public health and climate stability with costs borne collectively by society. Consumption is encouraged through low costs and attractive, imported internet sales. Conversely, circular business models, focusing on preventing environmental damage and capturing future societal benefits, face substantial financial and operational challenges including investing in new technologies, infrastructure and overcoming regulatory and market barriers. The benefits of circular initiatives are insufficiently recognized or encouraged and individual actors are either unable or unwilling to take responsibility for negative externalities (section 1).

Recycling is structurally disadvantaged

The recycling industry faces challenges competing with established fossil fuel and waste incineration with their mature technologies, strong legal and market positions, and operational assets paid off. Conversely, recycling requires initial investments, loans, repayments: making it harder to compete cost-based. Established parties profit from optimized global supply chains through scale and intertwining with the fuels industry, whereas recycling industries' supply chains need to start from scratch: an uneven playing field for actors adopting sustainable practices. Dutch recycling is also under pressure by low priced imports of fossil raw material and products, threatening existing capacity.[14]

The current playing field is severely tilted towards retail marketing's aim to sell large quantities of inexpensive, attractive products, while also disposal methods like incineration and landfilling have little hinder.

Multiple actors and diverging interests

An analysis of the various actors and their roles and influences in the linear and circular plastic value chain is provided in the box 'Actors perspective in the linear and circular plastic value chains'. The different groups, such as start-ups in recycling and well-established companies, have different goals, roles and resources, influenced by their control mechanisms and position within either the traditional linear system or the circular model. Success depends on a solid business case and access to feedstock and capital. Perspectives on circularity differ: some operate exclusively within the circular chain, while others function in the linear or in both systems. This impacts their costs, risks, and revenues, with some heavily reliant on circular success and others exploring it.

> *The current system lacks guidance towards circularity, favoring established interest, risking resource lock-ins that hinder transformation.*

Society organizes waste collection, but waste is scattered, contaminated and heterogeneous, containing metals and biological materials. Plastic products are designed for appeal and functionality – not for recycling – and often combine different plastics requiring separate recycling methods. These issues increase operational costs for recycling companies, which must sort, clean and prevent contaminants from damaging their installations.

Unprecedented valley of death and the 'Tragedy of the Commons'

There is a sharp contrast between 'what we want' (carbon circularity) and 'what we (can) do' (the reality). It creates uncertainty and a valley of death that far exceeds what has traditionally been associated with scaling up new technologies. The uncertainty of whether investments in circularity ever pay off becomes an unsurmountable barrier and power struggles arise over who can influence decision-making. In this 'systemic uncertainty', and in the absence of a adequate national or EU visions or program to replace fossil fuels with alternatives, a **'Tragedy of the Commons'** is unfolding. A tragedy of the commons describes how individual self-interest can lead to the degradation of shared resources.[15] Our shared climate and environment are deteriorating, while all actors benefit at the expense of long-term sustainability, ultimately harming everyone. A transition to a circular economy aims to address these issues by promoting sustainable practices and benefits (see section 2). Emphasizing the need to preserve resources for future generations, failure to transition to a circular economy can be considered a societal tragedy of the commons. So far, efforts have not led to recognizing our shared climate and environment as 'assets to sustain'. Additionally, recent geopolitical events underscore the importance of a resilient, strategically independent chemical industry as a vital part of our commons.

In summary, what is happening now:

- *Market forces* are failing. The market continues to favor cheap solutions as long as this is permitted. Consequently, investments in innovation and circularity face too many uncertainties to materialize. Due to geopolitical developments and inconsistent regulations, the risk of both premature closure of industries and innovation failure increases;
- Systems change is impeded by uncertainty of permitting and lack of access to clean energy;
- *Voluntary regulations* can be bypassed, compounded by limited public support for more costly sustainable domestic products;
- *Our value system* is not configured for circularity.

The solution entails a new economic model, organizing new commons within the EU, and a roadmap taking into account that:

> *Circularity and recycling should provide society with environmental, social and strategic advantages not captured in current desired specifications or market prices of recycled products.*

Reducing the 'systemic uncertainty' mentioned above will unlock private investments: the same force that once created our current welfare state, but now with the goal to protect the climate, environment, product availability, employment, competitiveness and government financing. Only stable policies and regulations can bring us there, together with strategic considerations such as national/continental autonomy (see box 'Circular economy, an opportunity for strategic autonomy'), which is why **governmental responsibility is inescapable.** Only the government (at EU level) can organize new commons: a circular society within the EU that supports a sustainable economy while considering national interests when using national resources amid the interests of neighboring countries. The present situation is urgent and requires immediate action.

Circular economy, an opportunity for strategic autonomy

It is strategically important to keep the chemical industry in Europe to prevent too strong dependence on other countries. The transition to a circular economy greatly helps in this regard. First, the circularity of materials in itself, using locally available waste streams, can reduce dependence on imported fossil raw materials. This can be further reinforced by using renewable energy and raw materials and promoting local production of carbon for the chemical industry. To this end, an industrial base must be maintained in Europe to convert and build on it, which will generate replacing employment and tax revenues. Now is the time to provide clarity for the industry – otherwise, they will continue closing down and may never return. Clarity encompasses various aspects of both the current fossil playing field and the future playing field: the way we produce and consume in the future, and how we will get there (see section 4).

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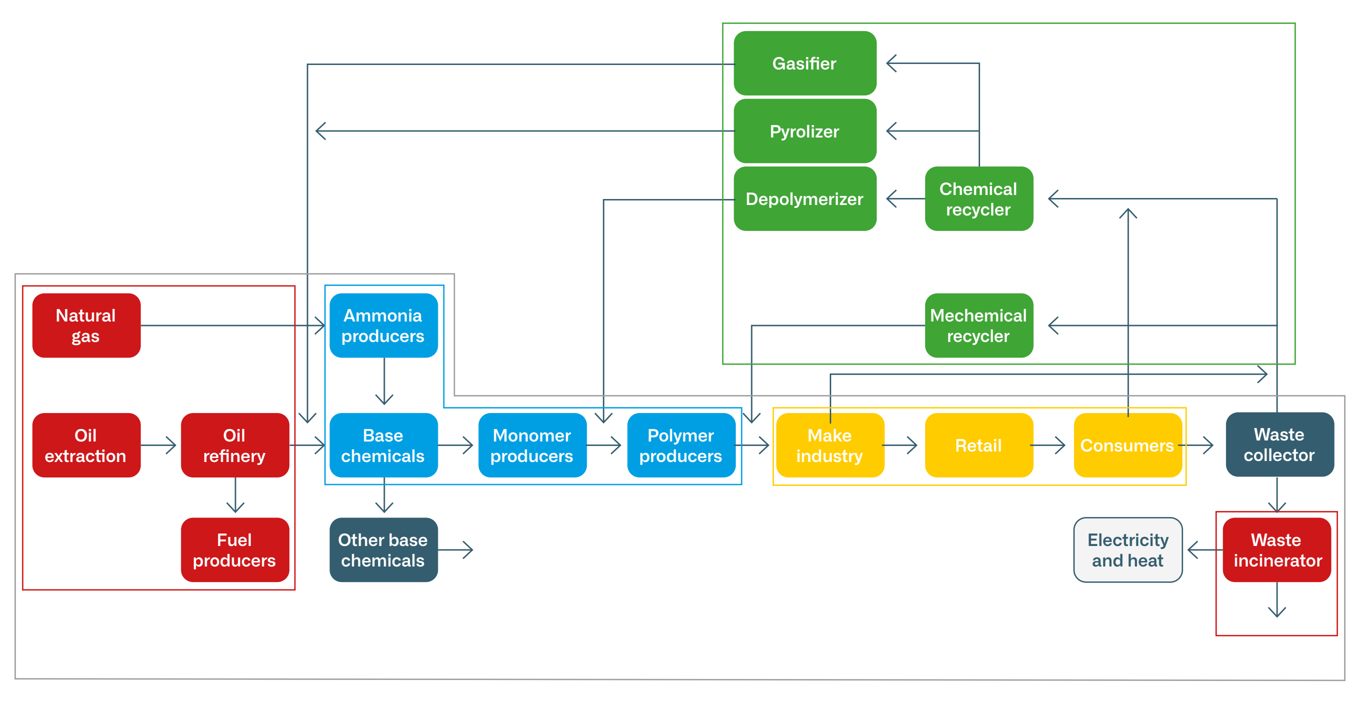
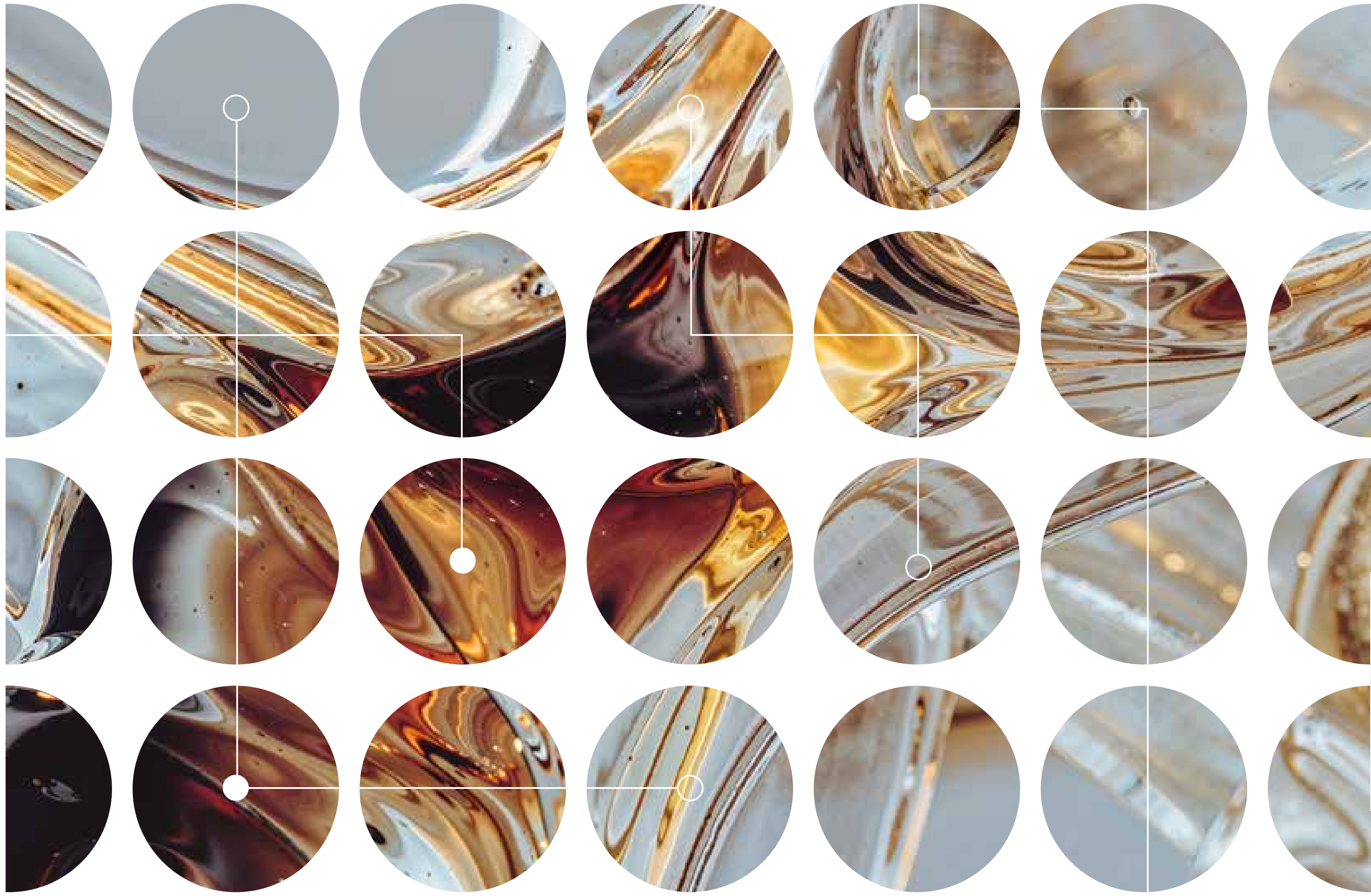
[11] See e.g. Deloitte, Utrecht University, Breaking the barriers to the Circular Economy (2016), and many more recent studies.
[12] Deloitte study, September 2025 – "Mobilizing consumer demand for sustainable investments"
[13] Karl Orrling on Linked-In: Mind the Gap: Rethinking How We Price Sustainability (and references therein Kearney.com)
[14] PBL, ICER report 2025
[15] Economic theory conceptualized by British writer William Forster Lloyd and published in the journal Science in 1968 by Garret Hardin.

Actors’ perspectives in the linear and circular plastic value chains
The Figure below shows the different actors’ perspective visualized on SCIARS circular economy map with an analysis of their role and influence related to circular economy, which is detailed in the table.



Actor	Role	Influence & dependance
Retailers and consumers (yellow box)	Selling (advertising) and purchasing, enjoying the products.	Retain the freedom to choose between fossil and renewable inputs, often opting for (demand for) the most cost-effective solution.
Manufacturing industry (yellow box)	Product redesign; acceptance and processing of recycled polymers; marketing.	Depend on downstream demand. Strong preference for maintaining flexibility in their sourcing strategies, based on cost, availability and performance criteria.
Chemical industry (blue box)	Processing new circular based feedstock.*	Limited influence due to limited interaction with end consumers.
Oil and gas (red box)	Limited prospects in a fully circular economy.	Power and influence to protect their interests.
Waste incinerators (red box)	Limited prospects in a fully circular economy.	Some influence to protect their interests.
Recycling industries (green box)	Provide the new technologies to recycle waste into new polymer or monomer.	Depend on market access for their products and on resources access (currently used by waste incinerators) as well as on legislations regarding waste transport and status. Limited/ little own influence.

** New industry (biobased feedstock and products) is an important case on its own, but out of scope here.*



Section 4
How to close the cycles?

The government organizing the new commons
Fossil industry is a key contributor to Dutch and Europe’s infrastructure, security, social cohesion and innovation. It is also key for government financing through taxes on wages, profits, energy, products and consumption, as well as taxes on waste and greenhouse gas emissions. Fossil-related operations should not cease prematurely, otherwise the Netherlands or the EU would depend on imports, making current welfare less sustainable. Viable alternatives should become available in parallel first. Planning and timing should ensure the continuous availability of current technology and knowledge: this is essential for a successful transition.

The government therefore faces complex, intertwined ambitions:

1. Achieving sustainability and independence while maintaining living standards, which means maintaining fossil assets such as income models and technologies until replacement or reconstruction. Without survival of the current fossil based industry, there will be no foundation on which future sustainable technologies can be built;
2. Ensuring that the costs of these ambitions do not spiral out of control;
3. Engaging the entire population and addressing societal needs.

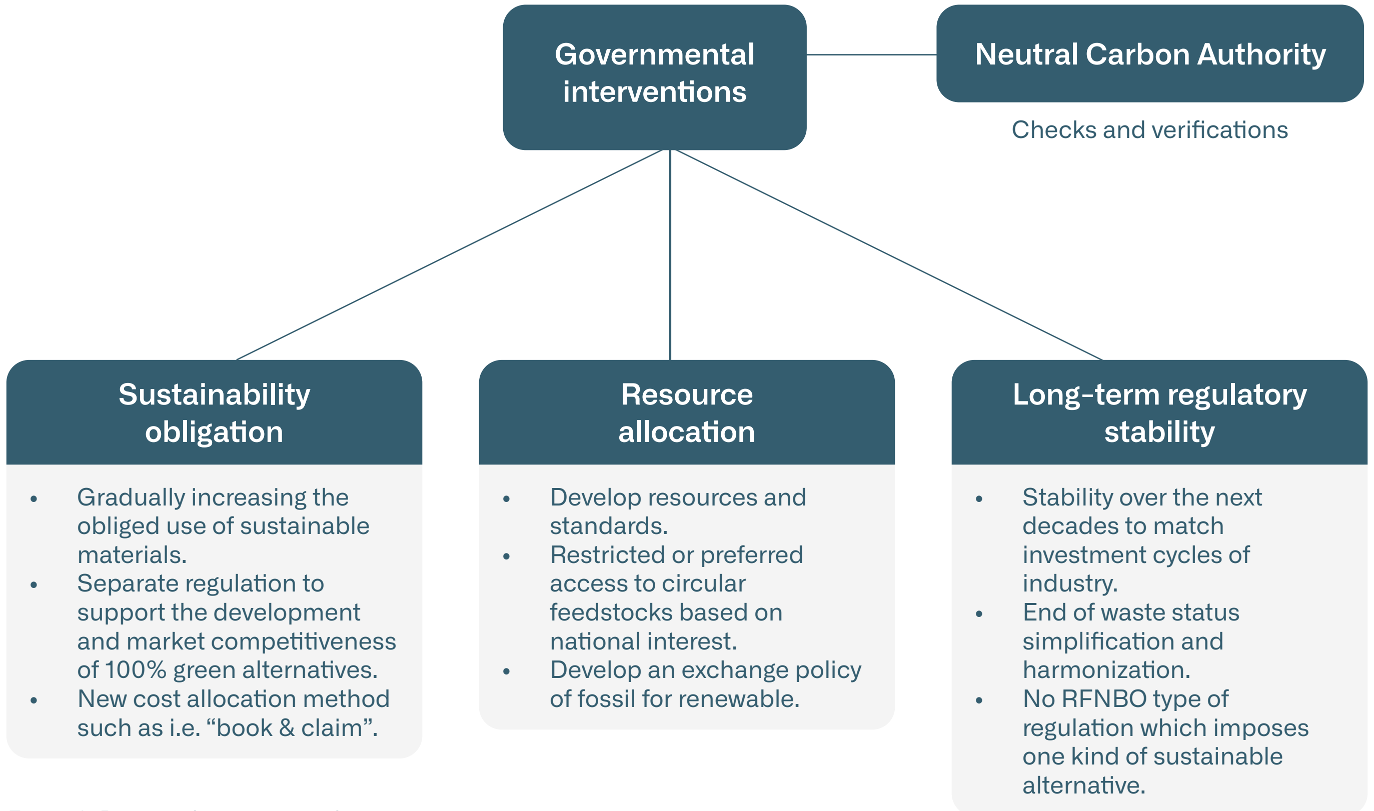
Regulation must stem from a systemic approach to the entire fossil fuel system and its evolution toward a circular, sustainable model.

> *Measures must be aimed at minimizing negative externalities associated with the linear economy and consumption, and maximizing the positive externalities associated with a circular economy and smart consumption (see section 2).*

In turn, the needs of the industry regarding stability, predictability and future profitability should be used for forward-looking policy and regulation so that market and financial interventions will enable the desired outcome.[16]

Proposed governmental interventions

We are recommending governmental interventions on three main topics, as shown in Figure 6.



Sustainability obligation

- Gradually increasing the obliged use of sustainable materials.
- Separate regulation to support the development and market competitiveness of 100% green alternatives.
- New cost allocation method such as i.e. "book & claim".

Resource allocation

- Develop resources and standards.
- Restricted or preferred access to circular feedstocks based on national interest.
- Develop an exchange policy of fossil for renewable.

Long-term regulatory stability

- Stability over the next decades to match investment cycles of industry.
- End of waste status simplification and harmonization.
- No RFNBO type of regulation which imposes one kind of sustainable alternative.

Figure 6: Proposed governmental interventions

Sustainability obligations and new cost allocation methodology

This entails a sustainability requirement for end products by gradually increasing the obliged use of sustainable materials. This obligation should be set at the stage in the supply chain where final materials are chosen, to prevent less-sustainable materials from entering afterwards. The obligation could be integrated with Extended Producer Responsibility (EPR), where brand owners expectedly will pay a tax on the product by which the collectors, sorters and recyclers are funded. Brand owners using recycled material as input receive a bonus. When combined with new cost allocation methods, unnecessary price increases for consumers (the price paradox, see section 3) can also be prevented. The virtual credit system 'Book & Claim' discussed by Shell in Deloitte's demand creation document could be an example.[12] In this case, a mandate would place the sustainability requirement down-stream, near the consumers, and each producer could offer certificates for sale on a trading platform for their sustainable products.

Products that are already 100% green from the outset could be at a disadvantage due to demand creation through mandated, gradually increasing admixture of non-fossil carbon to fossil-based product: a collateral side effect, meaning their additional externalities (less negative, and positive) continue to go unpaid for a considerable time. Additional regulation is necessary to support the development and market competitiveness of innovative, 100% green products.

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[16] Recent recommendations of the Sustainable Industry Lab point in this direction and the four bold ideas are recommendable to follow up with urgency: "Hulp bij Systeempijn", October 3, 2025.

Allocation of sustainable resources and standardization

A circular system that functions in a strategically credible manner is robust, resilient, self-sufficient and large enough to compensate for weaknesses. However, it is also more resource-constrained than the fossil system. Restricted or preferred access to circular feedstocks, renewable energy and eased access to existing markets could increasingly feed national ambitions.[17] In particular, the energy and material/plastic transition needs balancing as fuel production can easily drain resources needed for material circularity (see box 'The energy context of the materials transition', section 2). Proactive choices about which allocation best serves national interest help prevent a lack of vital resources for chemical industry.

Before intervention, industry-recognized standards must be developed at EU level for feedstock (for example, end-of-waste status and waste sorting), materials and consumer products (for example, integral chain efficiency of carbon and energy use). These standards may be adapted to reflect best-in-class options and progressing insights.[18]

Long-term regulatory stability

Before considering investing in circular solutions, industry requires a solid outlook on feasibility, which includes future earnings and the security of supply from circular supply chains that are not yet established. This requires predictability regarding when relevant regulations will take effect, as well as stability over the next decades – the time necessary for a profitable return on investments.

A few relevant examples for the chemical industry:

- The 'Waste status' of circular materials. Existing legislation often considers materials as 'waste'. Consequently, strict rules apply to storage, transport, processing and reuse. These could be redesigned without compromising the actual risks, which could make recycling used materials considerably easier;
- Complexity and bureaucracy with unclear rules regarding innovative and circular initiatives, because circularity does not fit in the traditional linear economy model;
- Renewable Fuels of Non-Biological Origin (RFNBO) type regulations which impose one sustainable alternative (for example green hydrogen), hindering the development of maybe better, more affordable, low-carbon solutions for chemical industry and making transitional change via intermediate steps, such as for example blue hydrogen, near impossible;
- Subsidies can lower costs for individual actors, temporarily boosting demand, industry growth, infrastructure development and lower prices. However, they are not a substitute for strong investment returns, which are essential for sound business decisions.

A Carbon Authority may be required to regulate and control the distribution of scarce means between the energy and materials markets using checks and balances, bookkeeping and certifications. Such an authority could manage relevant aspects:

- Waste has value. Its allocation should be managed in the national interests. Incineration only if R strategies are not possible;[19]
- Waste management. For example controlling export and import, standards for collection, sorting and the quality of waste fractions;
- Temporary aspects such as transitioning incineration facilities to gasification units and creating alternatives for the loss of electricity and heat generation.

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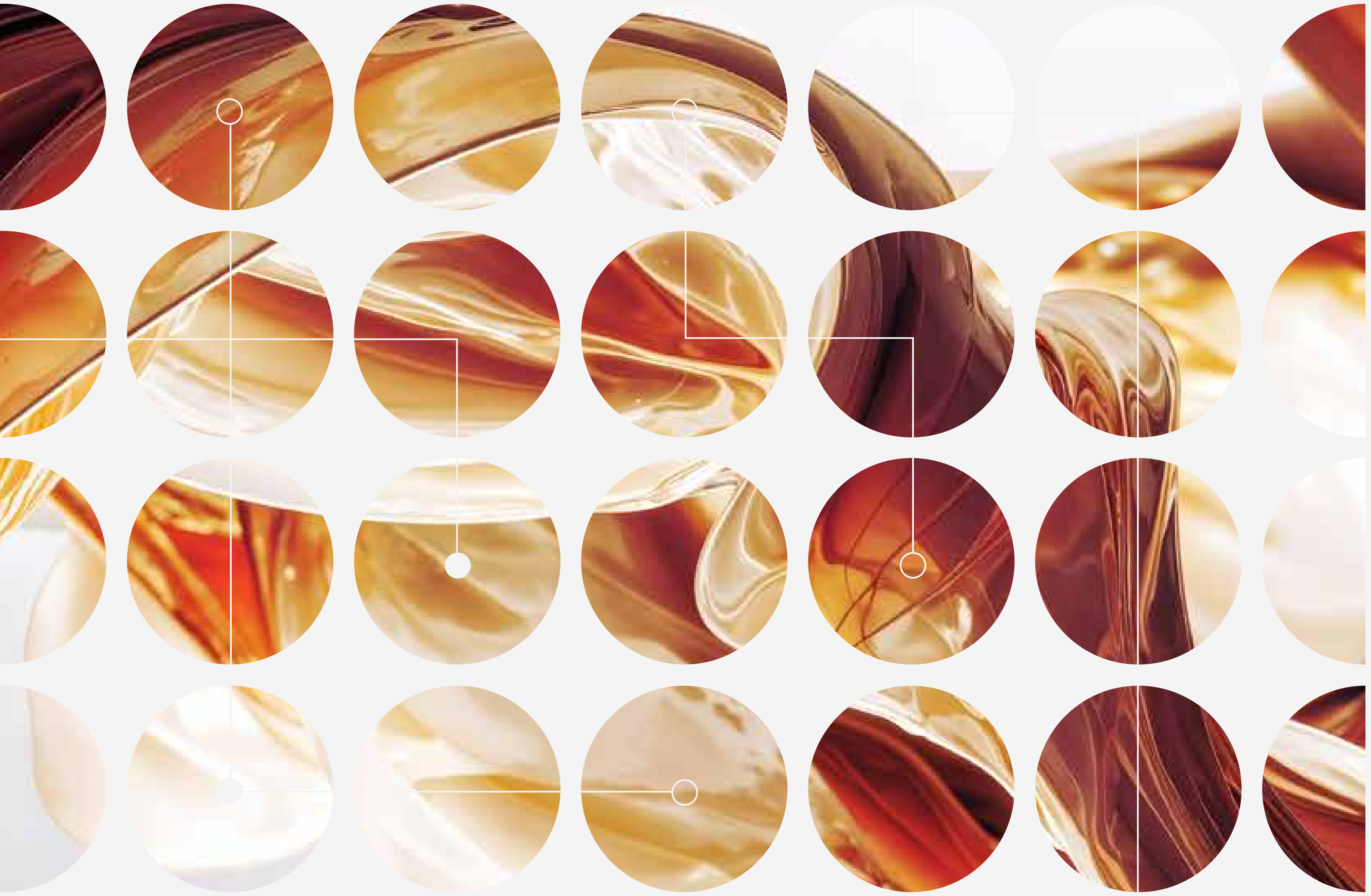
[17] OECD and European Commission on circularity, strategic autonomy, critical raw materials; industrial transition by Material Economics, Agora Industry; IPCC and others.

[18] This approach has a precedent in home appliances where the competition is on price, a performance threshold controlling market access, and labelling.

[19] The R-ladder in e.g. Monitoring Circularity Strategies, PBL, 2024.



Key messages and conclusions

The urgency to guide recycling in the transition of the chemical industry

The transformation of the plastics and chemical industry into a circular, climate-neutral system is urgent and complex. The technologies exist, and the societal benefits are clear. What is missing is an economic and regulatory framework that aligns markets with these broader goals. Achieving this transition will reduce environmental impacts and secure the industrial foundations needed for Europe's sustainable future.

Plastics are indispensable in modern life, but their responsible use requires a fundamental shift. At the end of their useful life, plastics must be reused and recycled rather than incinerated. Circularity is not merely an environmental aspiration, it is essential for a sustainable materials system.

The Brightsite Transition Outlook demonstrates that technological pathways for circular plastics are well understood and their potential benefits established. Yet large-scale deployment remains limited. Recent bankruptcies among technically ready solution providers illustrate how fragile the business environment is. When companies capable of enabling circularity cannot survive, the transition itself is at risk.

The polyamide 6 case study shows the scale of the opportunity. Shifting from today's linear consumption model to circular material use could significantly reduce virgin feedstock demand, cut fossil CO_2 emissions by more than half, and eliminate many environmental impacts of linear production and disposal.

Yet current economic and regulatory conditions favor the opposite. The combination of virgin fossil feedstocks and waste incineration still produces the lowest product prices. Because price dominates household purchasing decisions, circular products struggle to reach the mainstream market. This is a structural problem, not a technological one. Negative externalities along linear value chains are not sufficiently reflected in regulations. Policies tend to focus on CO_2 emissions and performance of individual actors, overlooking system-wide benefits of transforming entire value chains. The result is a persistent mismatch between societal value and market incentives.

Circularity should be viewed not only as an environmental necessity but also as a strategic foundation for Europe's industrial resilience, resource security, and competitiveness. The urgency is growing: several chemical plants have closed in the past year, and others face uncertainty. Without decisive action, Europe risks losing the industrial base for a circular economy, along with essential chemical products for which alternatives do not yet exist. This adds extra pressure to take action.[20]

A new economic model is needed that recognizes and rewards the full value of circular supply chains. It must integrate societal benefits into regulations while managing consumer costs. Indeed, industry must invest, but governments play a decisive role in creating prospect for a return on investment. Beyond addressing structural issues like energy-price disparities, a systemic approach is required to navigate interconnected transitions.

A central challenge lies in managing the fossil-based industry. Production systems cannot disappear overnight. Their role must gradually decline without undermining industrial stability, while radical alternatives, such as biopolymers, are enabled. Energy and materials transitions are intertwined. Scarce resources, plastic waste and biomass, must serve multiple sectors. Without strategic guidance, competing uses, particularly fuels, can divert resources from their highest-value application: maintaining carbon circularity in materials.

An enabling regulatory framework is essential, aligning societal ambitions with industrial realities. Regulatory stability and predictability are critical to mobilize capital and plan long-term investments. Innovative cost-allocation mechanisms, like virtual credit systems, can prevent unnecessary price increases while creating a level playing field for circular products. Effective governance of carbon resources is also required. A neutral Carbon Authority could manage scarcity, prioritize carbon stocks, and reward solutions that most effectively displace crude oil, maximizing climate benefits while achieving high carbon and energy efficiency.

The path to a circular, climate-neutral plastics system is no longer primarily a technological challenge. It is a challenge of economic design and governance. Aligning markets with societal goals will determine whether Europe succeeds in building a resilient circular economy, or risks losing both the environmental benefits and the industrial foundation its future prosperity depends on.

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[20] It is said that 'Only a crisis - actual or perceived - produces real change' (Milton Friedman, Nobel laureate in Economic Sciences)

Are you keen to contribute to the chemical industry's transition?

Brightsite is committed to achieving a sustainable and competitive chemical industry. To this end, we make a significant contribution to transitioning the chemical industry towards renewable energy and raw materials, with the objective being to make the sector climate-neutral without job losses.

Can you relate to Brightsite's way of working? Are you interested in finding out more about our perspective on the chemical industry's transition or are you eager to work with us?
Then we'd like to talk with you.

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This publication has been created with support from ChemistryNL and the Brightlands Chemelot Campus.

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