Brightsite Transition Outlook 2024

Brightsite
Transforming industry

Let's co-create the future of chemical industry

Transition to sustainable chemical industry is possible

We are facing an enormous challenge in the transformation toward sustainability, as it involves the Netherlands, the chemical industry and value chains. We have to switch to CO_2-free energy and raw materials have to become renewable. In our Brightsite Transition Outlook 2023, we discussed the raw material transition for the chemical industry in detail, where the availability of CO_2-free energy proved to be a crucial factor. The task for the industry is enormous because of the gigantic volumes of both renewable energy and raw materials needed to fulfill these transitions, especially since they are still scarce for the time being.

This raises a public debate as to whether we should continue with large-scale chemistry in the Netherlands. It is a huge question because it is focused on the future of one of the largest industrial sectors in the Netherlands. Tens of thousands of direct jobs are involved, an enormous infrastructure has been created, there are many suppliers and there is a great wealth of knowledge at companies, universities and institutes. It is therefore of great social and economic importance to outline how the transition of chemistry can proceed, especially in the Netherlands.

At present, contextual developments are moving fast, but actual greening is much slower despite many initiatives, and the climate cannot wait. Unfortunately, investment decisions are largely influenced by (still incomplete) sustainability frameworks deployed from different levels of government. This makes it hard for companies to make choices. The same applies to investment decisions by governments to adapt infrastructure. The scarcity and high price levels of raw materials and energy are determining factors.

In this Brightsite Transition Outlook, we discuss chemistry's importance to society and what large-scale sustainable chemistry may look like. What solution routes are there? What is the role of circularity? And what does this mean for choices yet to be made? We show that products from the chemical industry are permanently needed and explain how circularity can play an essential role in the solution. We outline solution directions for large-scale green chemistry from a technological, energy and raw materials perspective. We also discuss what is needed for it in terms of societal preconditions.

All this shows that large-scale sustainable chemistry is possible in the Netherlands. There is great potential in Europe for green energy: think of offshore wind and many renewable raw materials, such as waste streams, bio-based materials and various residual streams from landscape management, which can and should be further developed. Knowledge and skills are available, infrastructure is world class, also for import and export. Chemical supplies will have to be balanced against other applications, such as energetic (fuels) and non-energetic (cement, steel) uses. The importance of plastics in society and the importance of economy and climate will lead to a reasonable allocation of these scarce resources for chemistry.

Brightsite calls on everyone to get involved in the chemical transition and stay ahead, it can be done. Because we can also work from our own energy and carbon sources, it makes us geopolitically resilient and offers perspective for future generations. Stimulating policies are crucial to be able to carry out this major sustainability challenge for the chemistry industry. For us, Chemelot is an enduring inspiration and goal for our work. Although this publication is generic, a reflection on Chemelot's specific transition is also part of it.

Arnold Stokking
Managing Director Brightsite

Brightsite Transition Outlook 2022/2023/2024

Guidelines to a sustainable chemical industry

When you look around, you find yourself surrounded by materials and fuels based on fossil resources. For example, many parts of your bicycle are produced from rubber (tires), nylon (bicycle bag, belt, tires), polyethylene, polypropylene, acrylonitrile (carbon fiber, ABS plastic) and PVC (brake cable coating), which all originate from oil and natural gas. Practically all the products in your house, your car, public transport, etc. contain the same materials. And your daily food is kept fresh by the same materials.

At the Chemelot site, ammonia—used to make nylon, acrylonitrile, melamine and fertilizers—is produced from natural gas. Naphtha is cracked into ethylene and propylene, out of which poly-ethylene, polypropylene, PVC and acrylonitrile are produced. Chemelot stands at the beginning of an enormous value chain that stretches from crude oil to the consumer products we enjoy every day. Brightsite has explored the possibilities for transitioning the chemical industry based on fossil resources to an industry processing sustainable energy and raw materials into sustainable products.

How can we continue producing today's convenient materials without the use of fossil resources?

Brightsite Transition Outlook 2022 assessed the current fossil demand of the Chemelot cluster and delved into possible technologies and a transition path towards zero CO_2 emissions in 2050. **Brightsite Transition Outlook 2023** took a dive into replacing the fossil demand of the Chemelot cluster with sustainable carbon from either the air, biomass, waste or preferably a combination of all three.

In **Brightsite Transition Outlook 2024**, we explore the possibilities for making the actual changeover to sustainable products. How much sustainable raw material is needed? Where can we get it from? Can we continue living in comfort and what does it take from society? What are the consequences for our environment and our way of living? In this Outlook, we provide answers to these questions.

René Slaghek
Technology Manager Brightsite

Chemistry is everywhere

We might not realize it, but chemistry is all around us

We see the products of the chemical industry all around: not directly, but applied in countless consumer products.

Do you want to know, for example, what's in a bike?

Keep our daily products, eliminate fossil carbon
The majority of products we use daily are based on chemical processes and contain carbon (C), which is such a versatile element that it cannot easily be replaced. The carbon used in manufacturing typically originates from nonrenewable fossil resources. At the end of a product's life span, the carbon it contains can end up in the air as carbon dioxide (CO_2), contributing to climate change. To protect the climate, use of fossil carbon needs to be eliminated and CO_2 emissions prevented by keeping the carbon in the loop. This doesn't mean that consumer products have to disappear—but fossil carbon needs to be replaced with renewable, non-fossil carbon.

Do you know what carbon is?

Changing the carbon source
Phasing out fossil implies that the chemical industry will switch to non-fossil carbon sources. There are three possible sources of non-fossil carbon:

- **Waste-based:** from society, such as carbon as a waste product from consumer products and manufacturing
- **Bio-based:** from biomass produced on land or at sea, including waste streams
- **Air-based:** CO_2 from the air through direct air capture (DAC) technology

However, the amount required to replace the fossil carbon in chemical products is huge and this is why we talk about the future scarcity of renewable resources.

Read more about the future scarcity of renewable resources in Brightsite Transition Outlook 2023

Not only carbon
Hydrogen and ammonia are also key intermediates in the chemical industry, which although not comprising carbon, are nevertheless currently produced from fossil carbon (natural gas, coal). To avoid CO_2 emissions, it is therefore necessary to develop alternative production routes utilizing renewable resources. Brightsite Transition Outlook is illustrated with examples of carbon-containing molecules from the petrochemical industry, like ethylene and propylene. But the messages are also valid for ammonia and ammonia-derived products.

Do you know what hydrogen and ammonia are?

Take-away-message

Chemistry plays an essential role in society—we can't do without it. We don't want, nor need, to stop using products containing carbon, which have become an essential fact of daily life. Closing down the chemical industry to eliminate CO_2 emissions is not a viable solution. Instead, we must change the present situation in pursuit of a new economy based on alternative sources of energy and carbon. This will not happen spontaneously, a mindset change in broad layers of society is required.

When you see this icon, it indicates that additional information related to the topic can be found in the appendix, starting on page 18.

This image is part of an online visual scrollstory. Check here for all information, including figures and background.

On our way to a circular mindset

Changing our consumption behavior to reduce issues of scarcity

Currently, there isn't sufficient renewable carbon available as feedstock, and meeting the demand will require time. Meanwhile, global demand is expected to more than double by 2050 due to population growth, improving quality of life worldwide and socioeconomic conditions in developing countries. This will create a problem of scarcity, requiring a significant rethink about consumption, with a broad behavioral shift by both producers and consumers.

Circular consumption
First, we must *Rethink* our consumption, do we really need that product or can we share it? We can *Reduce* our product use by refusing some applications, such as single-use plastics. It's better to *Repair* a product instead of buying a new one. And don't throw away your pre-loved product, let it be *Reused* by someone else or *Refurbished* to give it a second life.

Circular production
Products can be designed with improved *Reuse* and *Repair* capability, and made fit for mechanical and chemical *Recycling*. Product waste can serve as feedstock for the chemical industry. The quality of waste is an important factor in remaking products. For particularly low-quality waste streams, where no other options are possible, it might at least be possible to *Recover* heat.

The 7R approach, also known as 'ladder strategies'
Only planned and successful implementation of these ladder strategies can enable circularity. Multiple parties, collective stakeholders in a particular future circular value chain, must purposefully and complementarily apply ladder strategies. The impact of the 7R approach should not be underestimated—depending on the application, the need for fresh feedstock could be halved or better.

ⓘ **Demonstration of the impact of 7R on feedstock demand**

Is biomass part of, and needed in, a circular economy?
The short answer is, yes. Biomass is circular in itself via absorption and transformation of carbon dioxide from the air. There will always be unavoidable losses in circularity and recycling, requiring alternative renewable carbon sources. That is where biomass comes in. Biomass can be used to produce the same materials in a sustainable manner. Moreover, a number of applications can be met in a much smarter way using biomass. New biopolymers can be developed, in low-energy transformations, preserving the molecular structure of the biomass.

Is carbon dioxide part of, and needed in, a circular economy?
CO_2 from the air, or produced in various processes, can also be captured and used as a carbon source. This can be done using direct air capture (DAC) or carbon capture and utilization (CCU). They have a relatively low level of technical readiness, requiring large installations and so much renewable electricity that large-scale implementation is likely still a long way in the future.

Take-away-message

By rethinking our consumption and production, consumer needs can be met smarter while demand for carbon resources can be reduced significantly.
Smarter, better-designed products and changed consumer behavior can reduce the need for new products and new materials, and will turn value chains into value circles.

ⓘ *When you see this icon, it indicates that additional information related to the topic can be found in the appendix, starting on page 18.*

This image is part of an online visual scrollstory. Check here for all information, including figures and background.

Changing the way we produce: different feedstock and new routes

The chemical industry: one link in the value chain of consumer products

The base chemical industry is situated between sources—like oil wells, forestryand waste, which provide feedstock, and the manufacturing industry that, using (polymer) intermediates, produce all sorts of materials, spare parts, and eventually the consumer products that we buy. The intermediates, plastic granules, films, resins, fibers, etc., no longer bear any resemblance to the feedstock.

What can the chemical industry do?

1. Green the existing processes by using green electricity for heating and by substituting fossil feedstock for feedstock with similar composition originating from renewable resources
2. Make the same intermediates from new routes, using alternative technologies that are more suitable for renewable feedstocks
3. Develop new routes, typically from biomass, to new intermediates, making new bio-polymers to replace fossil-based applications

There will be many good options and opportunities in the future to produce polymer intermediates from alternative carbon feedstocks, with green electricity. A lot of innovation is under way, aiming for electrification, process development and integration, and more.

i See examples of routes of the three different options mentioned

What volume of renewable resources is needed?
We will answer this question with a test case, illustrating what is needed to produce 1 megaton (Mt) of polymer intermediates, a typical amount produced on a large chemical site, from renewable resources.

For this test case, we chose a combination of two possible, very-large-scale routes, each producing 50% of the 1 Mt polymer intermediates:

- Electric steam cracker route, using two different renewable feedstocks: 50% derived from woody waste from forests and 50% from pyrolysis of relatively high-quality, well-sorted plastic waste
- Methanol route, with conversion of methanol to polymer intermediates via the Methanol-to-Olefin process (MtO). Additionally, methanol produced by gasification of two different renewable feedstocks: 50% woody waste from forests and fields and 50% from the carbon-containing part of mixed municipal waste

Note: The 50:50 feedstock ratio is an arbitrary choice meant for illustration purposes only and not as a prediction or recommendation.

i Data, calculations and disclaimer

We left ammonia production out of the test case but there are also several options for greening the hydrogen needed for production of ammonia and other chemicals. It can be produced from water via electrolysis, but also by gasification of renewable feedstock such as biomass waste, municipal waste, and waste streams from the chemical industry.

Is there a best or preferred route to polymer intermediates? Are the required volumes of renewable resources minimized?
This is an important question, given the current and expected future scarcity of alternative resources. The challenge is twofold: not just use renewable carbon and energy, but do so efficiently. Important criteria are carbon and energy efficiency, not so much for each individual step, but for the entire value chain—from the renewable carbon sources to the polymer intermediates. When comparing chemical pathways, comparisons must be transparent and made on an equal footing, so that the results are not overly framed or biased.

i How to assess chemical pathways. Some principles and examples that have been applied for generating the numbers shown in this BTO

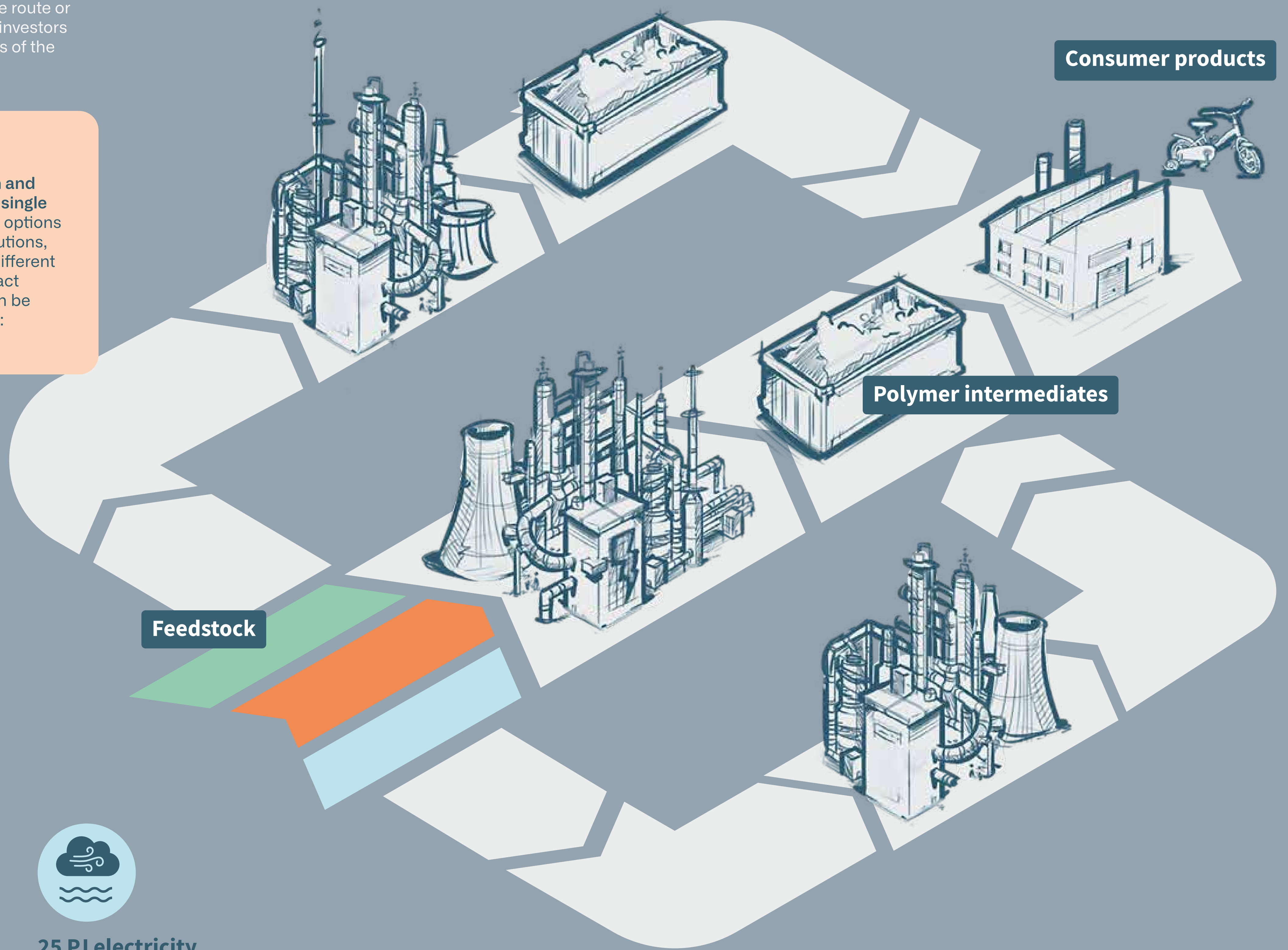
There is no one winning route
When these principles are applied to the two routes studied in the test case, regarding the required amounts of feedstock, total energy, and electricity performance, it appears that the differences between the MtO and e-Cracking routes are no longer significant. Both technologies have their merits and could well coexist—in separate parts of the Netherlands or the wider EU, or integrated on one site, benefitting from the advantages this can offer.

This analysis exemplifies two important future large-volume technologies. It certainly does not imply other routes are not relevant, such as smaller-scale depolymerization routes. Ultimately, regional factors, like flexibility, the existing technology base, and availability of resources and electricity, will favor one route or another. It is up to the innovators and investors to realize the most promising elements of the different routes.

Take-away-message

Transitioning to renewable carbon and energy is possible. But there is no single winning solution. Instead, multiple options and factors favor specific local solutions, requiring different feedstock and different routes, but all will have a large impact on society. This societal impact can be understood from another question: What does this take from society?

This image is part of an online visual scrollstory. Check here for all information, including figures and background.



1.5 Mt woody waste
for both e-Cracking (via bionaphtha) and MtO (via biomethanol)

0.6 Mt municipal waste
for MtO only
0.4 Mt plastic waste, high quality:
for the e-Cracker

25 PJ electricity
30% of the required total energy

Co-creating the future by solving the puzzle

For the test case we assumed that the required renewable resources were available. Taking a closer look, we should ask: what resources are involved for sustainable production? And what does it take, from other industries, from surrounding business chains, and from society?

National resources to be further developed and tapped. The figures relate to what is needed for the 1 Mt fictive plant in terms of several important societal resources. These alternative resources need to be developed into tappable biomass streams or "end-of-life-product" streams in the same manner as oil and gas have been developed in the past. This calls for **building a new bridge between renewable resources and future consumption.**

There is potential—but also competition
The combination of these resources shows ample potential to meet the figures for a 1 Mt chemical industry. Moreover, falling back on much larger EU resources can improve this even further. Because the current supply is insufficient, this potential should therefore be realized. Keep in mind that, today, all our carbon is imported (via natural gas and naphtha). There is an opportunity for strategic autonomy. The chemical industry, however, is not the only sector interested in alternative resources. To avoid destructive competition between societal sectors, coordinated action is required.

ⓘ Do you wonder why we are not there yet?

Other types of national resources also need to be deployed and adapted:

Infrastructure growth and adaptation
There is a requirement for transporting more electricity (e.g., 380 kV), pipelines for transporting substances like hydrogen, CO_2, transporting the renewable resources from fields, forests, society and from abroad. But satellite sites for processing these resources into feedstock for the chemical industry are also needed.

Human capital
People need to be trained and educated at all levels to make this happen. The industry provides to the country a lot of jobs, welfare, wellbeing and prosperity. The value of the industry to the overall economy is often overlooked—this needs to be made clear and put in the right perspective.

Society
Our society must be readied to embrace, build and implement circularity as a replacement for the linear consumer economy. This entails:

- Acceptance of the necessity of the transition ahead
- Educating consumers: learning why and what behavioral changes are helpful.

This will take a coordinated effort and deep breaths.

What do we need to solve the puzzle?
The transition toward a sustainable, circular industry will take **time** and considerable **investment**. The industry needs time to transform. We cannot quit fossil from one day to the next, because we cannot afford to run out of carbon; the alternative technologies, sustainable feed-stocks, infrastructure and renewable energy are just not there yet. In order to make this transition a success, a number of additional key elements are required.

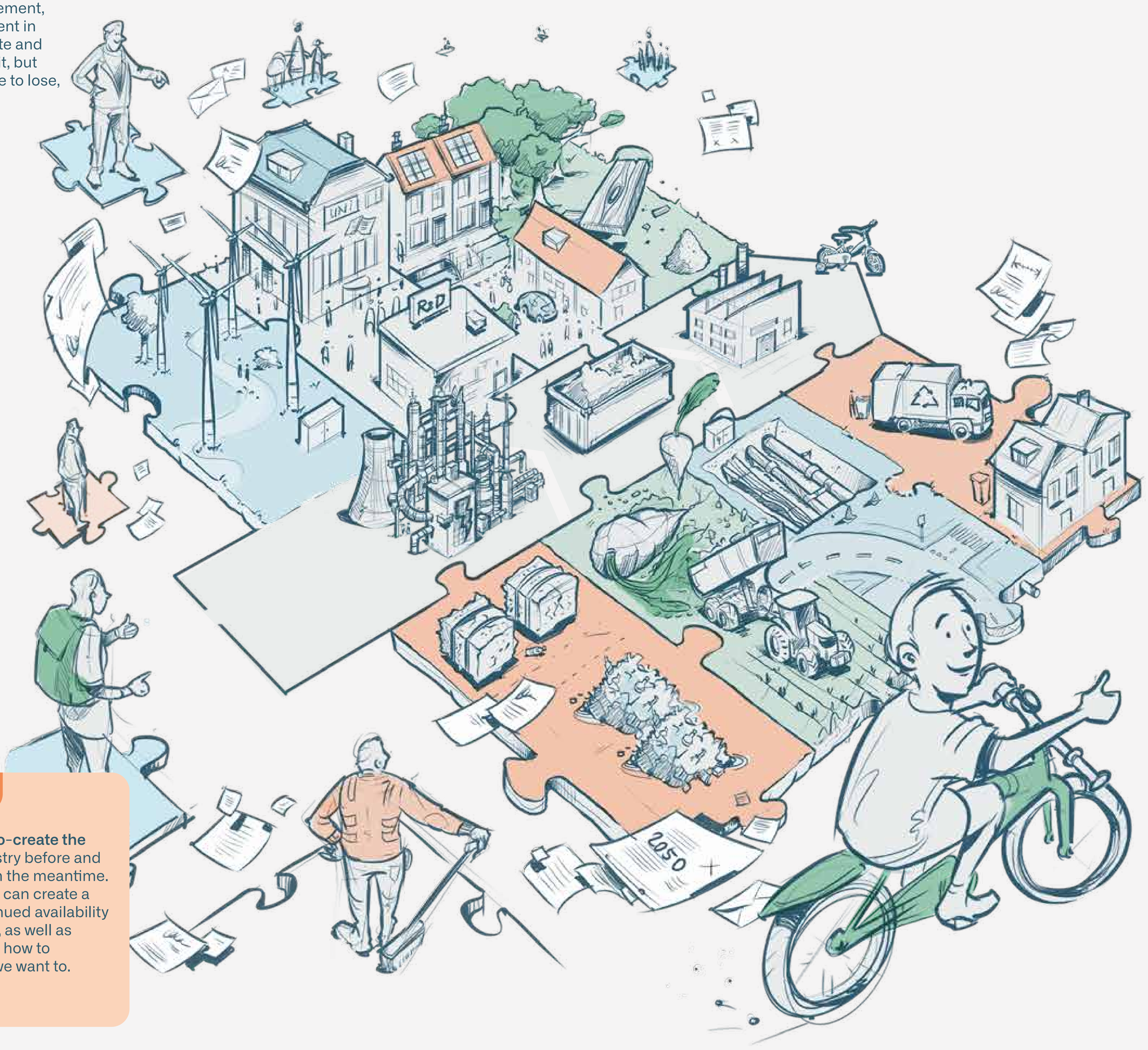
We have to do it together
To create circularity, all business partners need to collaborate, creating all necessary technical links in a value circle, including the supply of renewable feedstocks. Sufficient demand among paying consumers is needed while they have the possibility of choosing 'cheap' fossil. Without government support, efforts will likely fail. The path to success means **co-creating the future** while time continues to push us forward.

Clear and long-term policies
Choices and planning ahead are the domain of policy. Coherent long-term policies supporting circularity are urgently needed. The stimulating policies should aim at fair and gradual, but determined and controlled, replacement of fossil by alternatives, and be based on energy- and carbon-efficient consumption.

An innovative industry
Circularity implies new, well-integrated plants to process the alternative waste and biomass feedstock. This is a new, innovative industry. It will create new employment in circularity, and can even become a potential export product.

Go Go Go, co-create
There are multiple possible solutions. A vision of what kind of economy we want should be led by the future efficiency of energy and carbon use. How to arrive there implies choices and tradeoffs between quick, short-term abatement, and a solid, longer-term settlement in circularity. Meanwhile, the climate and associated problems will not wait, but rather aggravate. There is no time to lose, so: go, go, go!

This image is part of an online visual scrollstory. Check here for all information, including figures and background.



Take-away-message

No time to lose, we have to co-create the future. We transformed industry before and have learned tremendously in the meantime. Industry and society together can create a sustainable future with continued availability of plastics, economic activity, as well as strategic autonomy. We know how to accelerate developments, if we want to. So, why not do it again?

Keymessages and conclusions

We can't do without chemistry

Products of the chemical industry play an essential role in our society as the majority of products we use daily are based on chemical processes. We can't do without them. However, these products contain fossil carbon. At the end of a product's lifecycle, most of this embedded carbon turns into CO_2 in the atmosphere, contributing to climate change.

Continued and sustainable chemistry is necessary and possible provided the following happens:

a) The large amounts of fossil carbon flows (oil, natural gas) are replaced with renewable carbon (waste, biomass, CO_2 from the air) for new products, despite the fact that processing renewable carbon requires more energy than fossil carbon.

b) CO_2 emissions are avoided during the production and recycling of plastics. And, because renewable carbon and energy are scarce, we also need to:

c) Change our behavior regarding production and consumption. For example, we need to design products smarter by extending product lifetime or material lifetime through recycling.

We don't want or need to lose carbon-containing products. Plastic products often provide sustainable functionality as they are lightweight, offer high insulation and are excellent barriers for preserving food. The solution is not closing down the chemical industry that produces these products. Instead, we need to change all aspects of the current value chain: feedstock, production and consumption. To tackle the eminent scarcity of renewable carbon, we need to focus on all renewable carbon sources. Waste should be prioritized as we need to get rid of waste anyway. Biomass is underestimated and has huge potential — its development should be a priority. CO_2 from the air should follow where and when renewable energy is abundantly available.

Circularity is a key enabler for sustainability

By rethinking our consumption and production, the demand for new carbon resources can be significantly reduced. New value chains will develop. The scarcity of renewable feedstock in these new value chains will drive efficiency. Better designed, smarter products and changed consumer behavior will reduce the need for new products and new materials, and will turn value chains into value circles. This is referred to as the 7R-model, and this is how circularity will develop.

We can significantly reduce the demand for new carbon resources via circularity, recycling and extending product lifetimes. Retailers, brand owners and consumers are as important in value circles as recycling companies and chemical companies. Together, resource-efficient production and efficient societal circularity will shape the sustainable future. Renewable feedstock value circles will create additional economic activity, which also compensates for the lower production volumes for new products.

Various process technologies are possible, there is not 'one winner' in efficiency

Large-scale climate-neutral plastics production is possible following our analysis of two alternative process technologies, e-cracking and syngas methanol-to-olefins, in which we included various variants of sustainable feedstock and energy. Technology and feedstock choices in practice depend on many factors. Similar levels of carbon and energy efficiencies may be reached in different setups. There is no "winning route" from a climate or sustainability perspective.

Various solutions need to be developed parallel to each other. Technology and feedstock decisions will be made based on criteria such as required product portfolio, availability of green electricity, feedstock availability, needed investments, societal impact and site conditions. The choice between applying external green electricity or consuming part of the renewable feedstock for heating, for example, has a major impact on the overall carbon efficiency of a chosen process. A final stage using renewable electricity for all energy needs and only renewable carbon for materials may be preceded by a stage using hybrid electrical/carbon-based energy sources. Relevant pathways building on existing installations or new disruptive technologies may develop in parallel and co-exist in the future.

There are more process technologies possible for producing plastics than just e-cracking and syngas methanol to olefins. The refining of biomass may lead to bio-polyesters, for instance. These routes are also feasible and likely highly efficient, but not subject of this Outlook/current study.

The change-over to different commodities, feedstocks and technologies will have an impact on society. The question, therefore, is: "What does this take from society?" This requires assessment of the source domain: all that is required for making the renewable feedstock and energy available for the chemical industry.

The future can only be co-created; start today with what is possible and accelerate

Sustainable value circles will need resources from society. All resources mentioned are available in all regions in limited volumes: green energy, waste, biomass and eventually CO_2 from the air. Renewables include options for strategic autonomy. Scarcity of feedstock and green energy however will likely remain eminent for decades. Achieving reductions with 7R circularity measures are conditional but remain in short supply. Significant new additional capacity for both sustainable electricity and carbon needs to be developed. Non-fossil energy may need to be imported to increase the carbon efficiency of renewable materials. Infrastructure will need to be adapted to the new circumstances, including power grids, harbors, pipelines, satellite sites and more. The transition requires significant investment. A transformed industry will settle with new economic terms while also creating a sustainable world for future generations.

Future generations need affordable circularity, which implies carbon- and energy-efficient value circles and consumption. We need efficient CO_2-abating routes during transition. This may require temporary solutions such as carbon capture and storage (CCS) and the use of biocarbon for energy. The economics might not work out immediately — the "bridge over the Valley of Death" for new technologies and products needs to be crossed. It is obvious that the future can only be co-created with society, industry and government together. The government—national and European—needs to provide predictable long-term policies allowing for transition in Europe with a keen eye on the strategic availability of renewable energy and feedstock. Factors such as a level playing field between fuels and materials are essential for optimal market stimulation. The energy sector needs to maximize the generation of CO_2-free energy. The waste industry, forestry and agriculture need to prioritize and increase production for materials where possible. Various product applications will often go hand in hand: agriculture for food and materials, for energy and feedstock. Companies need to develop their own transition pathways, phasing out fossil and building up renewables. Entrepreneurs need to develop new routes and new solutions at every single point in the value circles. Financial institutions need to support and guide us toward new economic terms while embarking on a managed trajectory to phase out fossil-based processes. Innovation is to be stimulated by institutes and universities, anticipating the fossil-free future.

We need to get started under current our circumstances, shape the future together and take each other's role in a concerted campaign. A sustainable chemical industry built on value circles provides a significant contribution to a better world. The transition will happen anyway. We can build the bridge to the future, as we did before. It needs to happen first of all by us, in the Netherlands, in Europe.

This Brightsite Transition Outlook 2024 has been developed under the direction of Céline Fellay, Program Manager Transition scenarios & system integration and Paul Brandts, Intelligence Officer Brightsite.

Chemelot
Driving the future

chemelot
for today's future

Chemelot is the second largest integrated chemical site in Europe, centrally located within one of the largest chemical and material supra-clusters in the world, the so-called Antwerp Rotterdam Rhine Ruhr Area (ARRRA). Chemelot consists of an industrial park with 60 factories producing 7.5 billion kilograms of base chemicals and polymers per year and an open innovation campus with approximately 150 companies collaborating smartly together, resulting in accelerated innovation and creation of additional value.

Chemelot: A smartly integrated system for energy, feedstock and water
The 60 factories are integrated with the purpose of minimizing the amount of energy used per product volume produced. By coupling exothermic and endothermic production processes, the average energy consumption per kilogram of product is 15–25% lower than similar standalone factories. Also Chemelot has one integrated water system. Water taken in from the Juliana channel is used to generate different grades of water used in the chemical production processes. Wastewater is treated and purified in a central wastewater treatment plant before the cleaned water is emitted into the River Meuse.

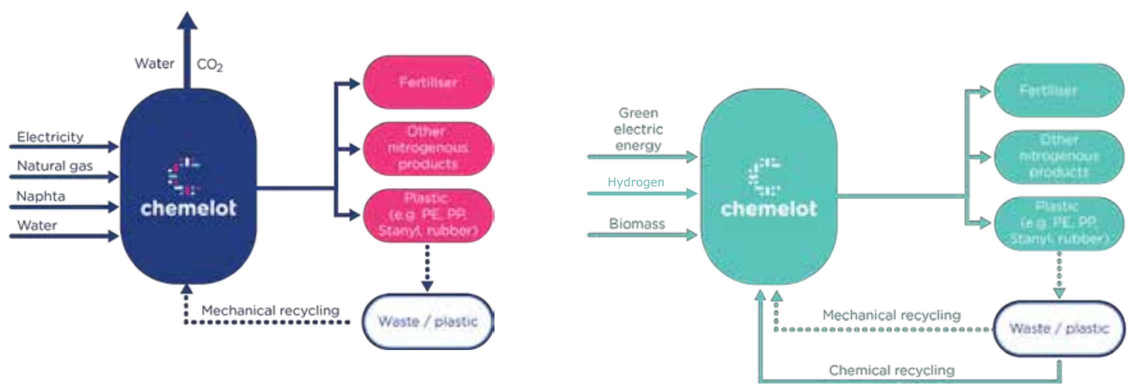
Chemelot has the ambition to become the first circular chemical site in Europe
The transition from a fossil-based site depending on natural gas and naphtha toward a circular and climate-neutral site is based on three strategic assignments:

1. Feedstock transition
2. Energy transition
3. Water transition

Feedstock transition
From a feedstock perspective, the factories can be grouped into two value chains. The first value chain starts with natural gas and leads to various nitrogen-containing products such as fertilizers, melamine and nylon. The second value chain starts with naphtha (an oil distillate) and leads to various intermediates for plastics such as polyethylene, polypropylene, EPDM-rubber, PVC and acrylonitrile.

Chemelot is embarking on both process technology routes described in the BTO to replace fossil feedstock for renewables: the cracker route and the syngas methanol-to-olefins route.

Chemelot's development towards carbon neutrality



2018　　2050

Cracker route
SABIC has developed multiple routes to renewable naphtha for its steam cracker at Chemelot. SABIC Plastic Energy Advanced Recycling is the first pyrolysis process integrated with a naphtha cracker producing circular naphtha from consumer waste plastic. SABIC and Chemelot are working on the next step, scaling up the pyrolysis oil production to several hundred kilotons per year before 2030. Parallel SABIC is feeding the naphtha cracker with bio-naphtha produced and supplied by companies outside Chemelot.

Syngas methanol-to-olefins route
Two major syngas announcements have been made at Chemelot for new installations by RWE and Uniper. In RWE's FUREC plant (operational in 2028), more than 50 kilotons of hydrogen will be produced from 800 kilotons of non-recyclable municipal solid waste and dried sewage sludge, including water, metals and inorganic materials. In 2023, Uniper announced a project focusing on the production of biogenic syngas from waste wood. The renewable syngas produced by RWE and Uniper could be used to produce renewable methanol, feedstock for the methanol-to-olefines (MTO) process.

Another example of Chemelot's feedstock transition is the production of bio-ethylene from bioethanol. The startup company Syclus, with Crop Energies (a Südzucker company) as the main shareholder, has launched plans to build a 100-kiloton bio-ethylene plant at Chemelot. The ethanol is produced based on grain grown in northern France.

Energy transition
Chemelot's current electricity demand is 250 megawatts, 24/7 during the whole year. Two-thirds of this electricity is 'green' thanks to Power Purchase Agreements (PPAs) by USG, the utilities partner at Chemelot. Together with BASF and Linde, SABIC is developing technologies enabling to heat ovens in its naphtha cracker with electricity. Tests are ongoing at the BASF Ludwigshafen site at demonstration scale. Once the ovens in the naphtha cracker are heated with electricity, the methane produced in the cracker will become available; in the current situation, the produced methane is used for heating the naphtha cracker ovens. Several projects in Chemelot's transition program are focused on the processing of that methane into hydrogen and carbon black or hydrogen and acetylene avoiding the formation of CO_2.

Water transition
The 'Circular Water for Chemelot' program is exploring various options for the Chemelot industrial park to significantly reduce water consumption and emissions to surface water, taking into account the strict regulations governing water permits and the considerable process changes that will take place on the site as a result of these developments driven by sustainability. One of our goals is to ensure that, in time, treated water will be able to be reused once it has been processed.

Chemelot and circular value chains
Via ISCC-certified mass balancing, SABIC is able to offer industrial quantities of circular and/or biogenic cracker products. There are several examples of circular products at Chemelot: Econitrile, Ecolactam, bio-attributed PVC and bio-Dyneema. The willingness to pay for these more expansive renewable base chemicals has been increasing over the last 5 years, buoyed by the A-brand companies active in the corresponding value chains.

Summarizing
The challenge is predominantly the large-scale replacement of fossil feedstock and the realization of a green electricity supply. For a successful transition, Chemelot needs:

- Integral and consistent governmental policies for the chemical industry at chemical cluster level resulting in an attractive investment climate for individual companies
- Adequate infrastructure (380-kilovolt electrical connections, pipeline connections for hydrogen, CO_2, ammonia and future renewable feedstocks such as methanol and ethanol)
- Stimulating circularity policies (e.g. mandatory use of recycled plastic)

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.

carin.romers@brightsitecenter.com
@brightsitecenter
www.brightsitecenter.com

Scan this QR-code to view the online visual scrollstory.

This publication has been created with support from ChemistryNL and the Province of Limburg.

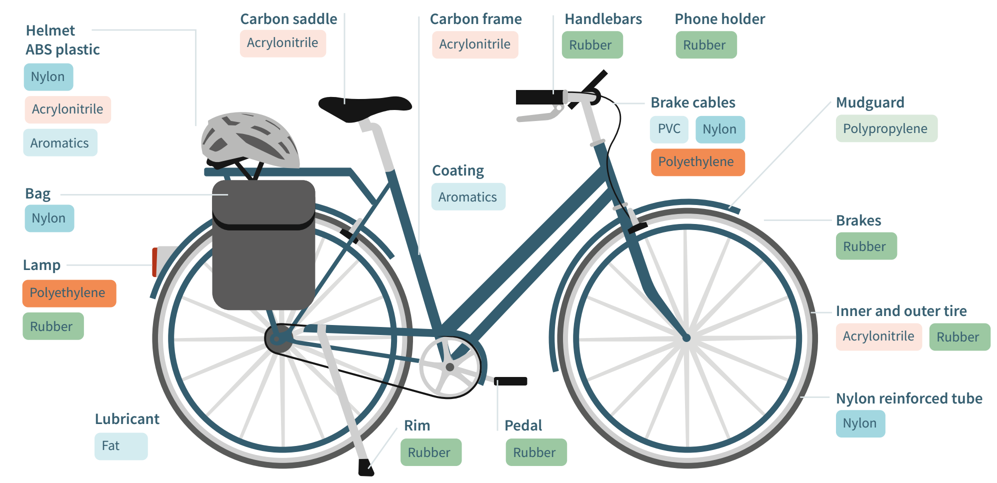
ChemistryNL

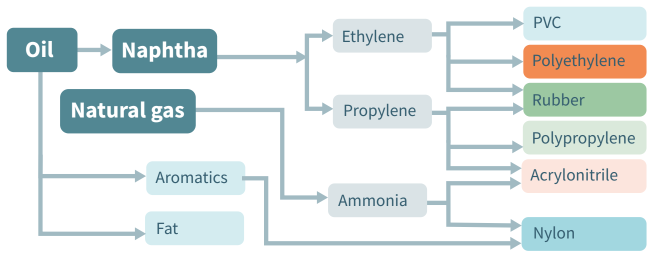
gesubsidieerd door
provincie Limburg

Appendix »

Here you will find all relevant details related to the information icon previously shown in this BTO.

Do you want to know, for example, what's in a bike?





Do you know what carbon is?

Carbon (C) is a chemical element, the fourth most abundant in the universe. It exists in many different forms, such as graphite, diamond and, combined with other elements, as countless naturally occurring compounds. It is the second most abundant element in the human body by mass (after oxygen, O). Carbon-based compounds form the basis of all known life on Earth. Carbon is part of many groups of important biological compounds: DNA, proteins, vitamins, sugars and more. Hydrocarbons also have an important role in industry as refrigerants, lubricants, solvents, chemical feedstock for the manufacturing of plastics and petrochemicals, and as fuel.

See our findings about the future scarcity of renewable resources in the Brightsite Transition Outlook 2023

In the Brightsite Transition Outlook 2023 we calculated the volume of renewable resources that would be needed to replace the fossil feedstock of the current chemical industry in the Netherlands, illustrated with the intermediates ethylene and ammonia. It became clear that the currently available resources fall short of the volumes required to replace the current fossil sources, we are facing significant scarcity.

Do you know what hydrogen and ammonia are?

Hydrogen typically refers to a molecule made of two hydrogen atoms, H2. As a feedstock for the chemical industry, hydrogen is as essential as carbon. Hydrogen is most commonly produced from natural gas, which contains carbon that is released in the form of CO_2. Hydrogen can also be produced without CO_2 emissions by using water electrolysis. This hydrogen is often referred to as 'green hydrogen'. Ammonia is an important intermediate for certain chemicals such as nylons, acrylic fibers, and ABS plastics, and for the production of fertilizers. Ammonia (NH3) is produced from nitrogen (from the air) and hydrogen. Green ammonia can be produced using green hydrogen.

Demonstration of the impact of 7R on feedstock demand

Here we illustrate the impact 7R can have, starting from the current situation (Baseline), to the impact of recycling (Scenario A), the impact of extending the life span of products (Scenario B), and a combination of scenarios A and B (Scenario C). The total "amount of consumption" is symbolized by the thickness of the horizontal product flow.

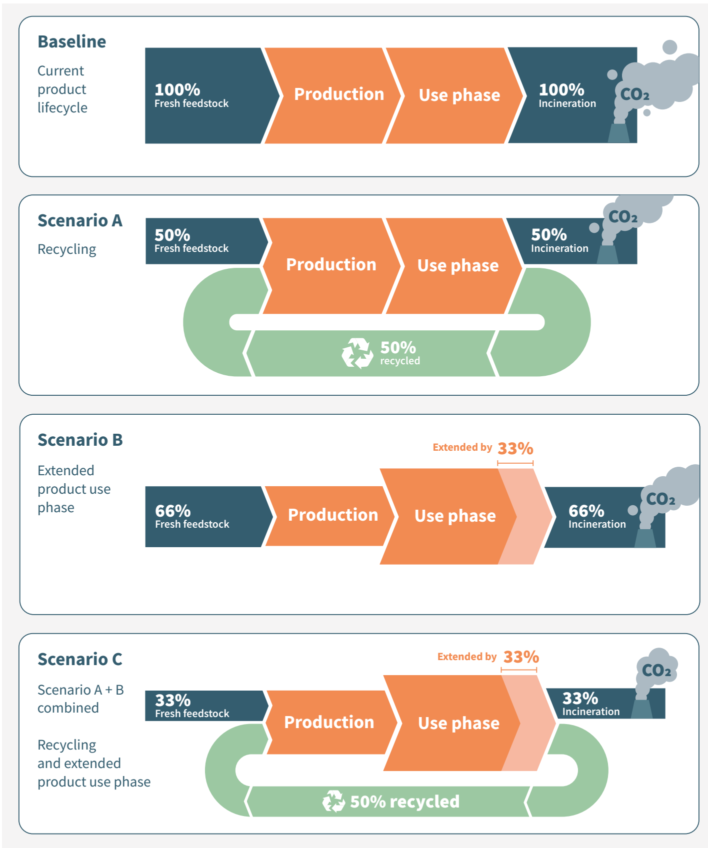
Baseline: 7R strategies are not applied. After use, products are incinerated. This system is kept running by transforming 100% fresh feedstock into products to meet consumer needs.

Scenario A: Shows the impact of recycling, both mechanical and chemical. Assuming 50% of the carbon in products is successfully recycled, 50% is still incinerated. The total emissions to maintain the same level of consumption drop by 50%; the amount of fresh feedstock to keep the system running is reduced accordingly.

Scenario B: Shows the impact of extending the life span of products. The use phase (average life span) of the products is increased by one-third. This can be achieved through a combination of product longevity, repairability, and refurbishment for reuse. As a result, the required product turnover in time can drop by one-third. In contrast, the level of consumer need does not change.

Scenario C: Combines scenarios A and B. The result shows a dramatic decrease of required fresh feedstock to only one-third of the original volume at the baseline, while the same consumer need is still met.

Impact of circularity on feedstock demand



Note: This figure isn't meant as a quantitative forecast, but it demonstrates the potentially huge positive impact of circularity and 7R on the future economic need for raw materials.

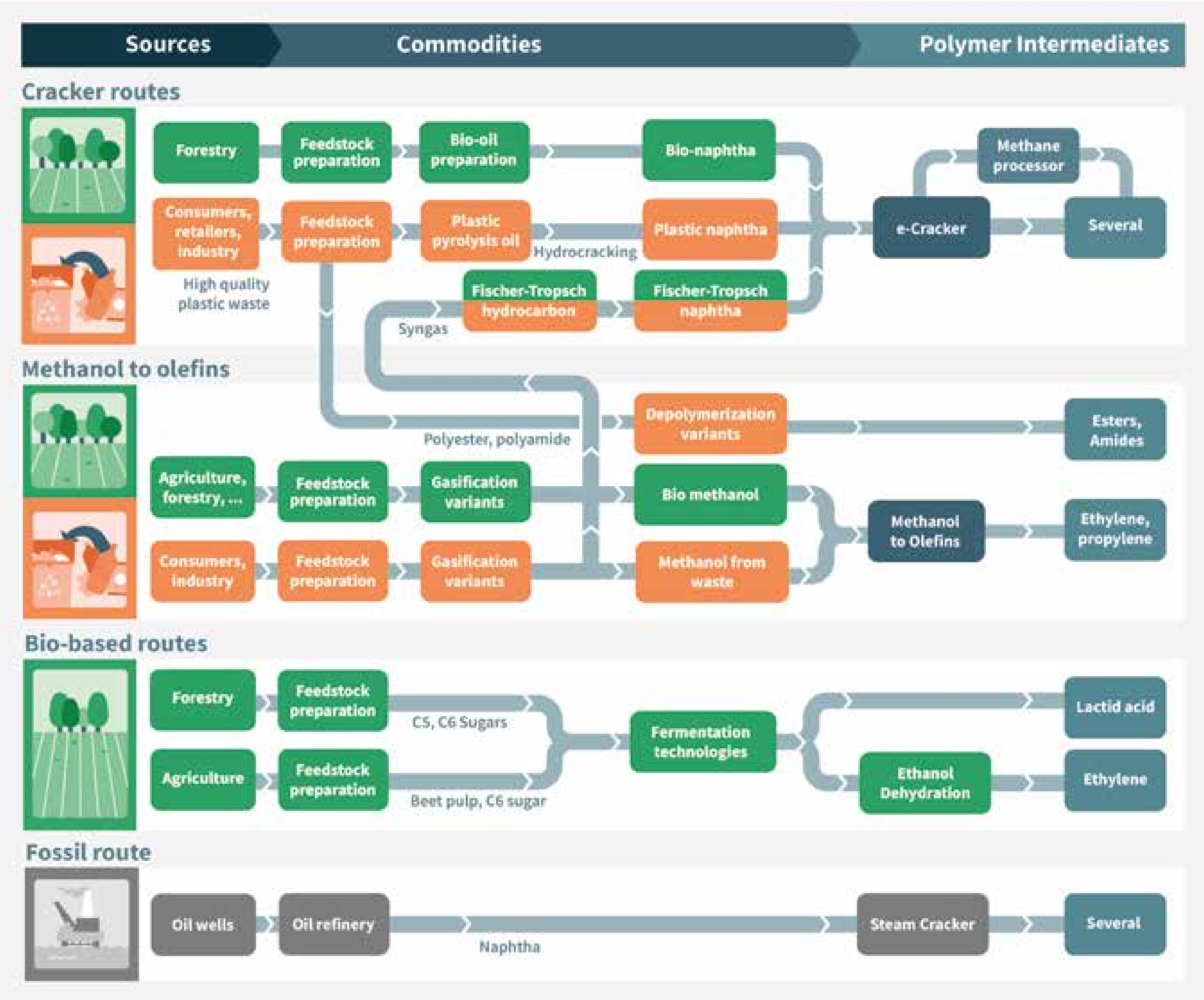
See examples of routes of the three different options mentioned.

An example of greening existing processes to existing intermediates is shown here with the cracker routes. The steam crackers still crack naphtha into polymer intermediates—such as ethylene, propylene and other high-value chemicals—but the heating is now provided by green electricity (e-Cracker) and the fossil naphtha is replaced with biobased naphtha or pyrolysis oil produced from (relatively high-quality) plastic waste. Alternatively, lower-quality mixed plastic waste (e.g., from municipal waste) can be gasified and the resulting syngas (a mixture of hydrogen, carbon monoxide and carbon dioxide) can be upgraded to naphtha via Fischer, Tropsch reaction. Methane, a byproduct of steam cracking, is no longer used as fuel for heating the cracker, but it can be further converted to useful products via different paths, gathered here under the term 'methane processor'.

Examples of new routes to existing intermediates are shown here with the methanol to olefins routes. Methanol can be prepared by gasification of waste coming from agriculture or forestry, but also from industrial processes and the consumer market. Another option is methanol from CO_2 and hydrogen from electrolysis (not shown in the figure). Methanol can be converted to ethylene and propylene in the MtO process.

An example of new routes to new intermediates is also shown with the lactic acid route. By fermentation of biomass, this new polymer intermediate can be produced to make polylactic acid, a polymer that can replace traditionally fossil-based polymers in certain applications.

Routes from sources to intermediates



Data, calculations and disclaimer

For this test case, technical data were taken from open sources and integrated. The approach, assumptions, scoping, assessment criteria, variants, input data, references, observations, interpretations and results will be available in a full technical report (Q4, 2024). It is emphasized that these figures are only meant to illustrate the impact on society in the last chapter: Co-creating the future.

How to assess chemical pathways: Some guidelines and examples

Transparency in terms of assumptions and context is very important when dealing with green propositions. On the one hand, there are obvious considerations, such as comparing entire technology chains to polymer intermediates. Even having done this, several other factors should also be taken into account. These factors are exemplified here, based on the two routes that have been chosen for illustrating this BTO: the e-Cracker route with renewable feedstock and the MtO route.

Example 1: Product slates and their applications
MtO produces ethylene and propylene, a steam cracker produces quite a lot more polymer intermediates. The olefin branch uses as a measure high-value chemicals (HVC): ethylene, propylene, acetylene, hydrogen, butadiene, benzene. But steam cracking makes even more polymer intermediates. All of this should be taken into account for a fair comparison. In fact, the residual heavy waste of the e-Cracker can be used as co-feed for gasification and via Fischer–Tropsch reaction can be fed back into the e-Cracker. This option was taken into account for the calculations of the test case shown in the BTO.

Example 2: Potential for innovation
A lot of effort is dedicated to integrated methanol synthesis in light of the potential of methanol both as an energy carrier and a renewable raw material for chemistry. Various combinations are currently being investigated, consisting of different choices of several kinds of feedstocks, auxiliary use of hydrogen or water electrolysis with heat integrations, CCS, H_2/CO ratio steering in syngas and energy integration with methanol production, side streams included. All of these target energy and/or carbon efficiency. Figures about MtO in the test case of this BTO include realistic estimations of the potential of these innovations on the amounts of feedstock and electricity needed.

Similar innovation is also going on in stream cracking, for example, electrification of steam cracking and valorization of methane no longer used as process fuel. Realistic estimation of this innovation potential is also included, because comparison would be biased if the full innovation potential of only ONE of the routes were considered.

Example 3: Carbon efficiency vs. electricity demand
When comparing future chemical routes systematically, a tradeoff often exists between carbon efficiency and electricity. It can be formulated as follows: The higher the carbon efficiency aimed for, the more additional electricity will be needed. Or, alternatively: Processes with a low electricity consumption can be technically efficient, but will intrinsically suffer from poor carbon efficiency. These tradeoffs speak to degrees of freedom in designing technical routes between the renewable sources and polymer intermediates. The availability of renewable electricity can be a determining factor here. For example, in remote rural areas, large amounts of electricity might not be available, yet there might be very good reasons (logistical or economic) to process biomass or waste there. In this case, the carbon efficiency may be low—if, for example, biomass is also used as a source of energy to drive the process.

The figures shown in the test case of this BTO are based on a medium-intensity use of electricity. This improves the carbon efficiency of the biomass route for steam cracking and of the methanol synthesis for MtO. Both routes then require approximately the same amount of electricity and show approximately the same overall carbon and energy efficiency. A question could then be whether the required volumes of renewable resources are minimized. The answer is yes, they are minimized, but with the freedom first to opt for higher or lower carbon efficiency.

Do you wonder why we are not there yet?

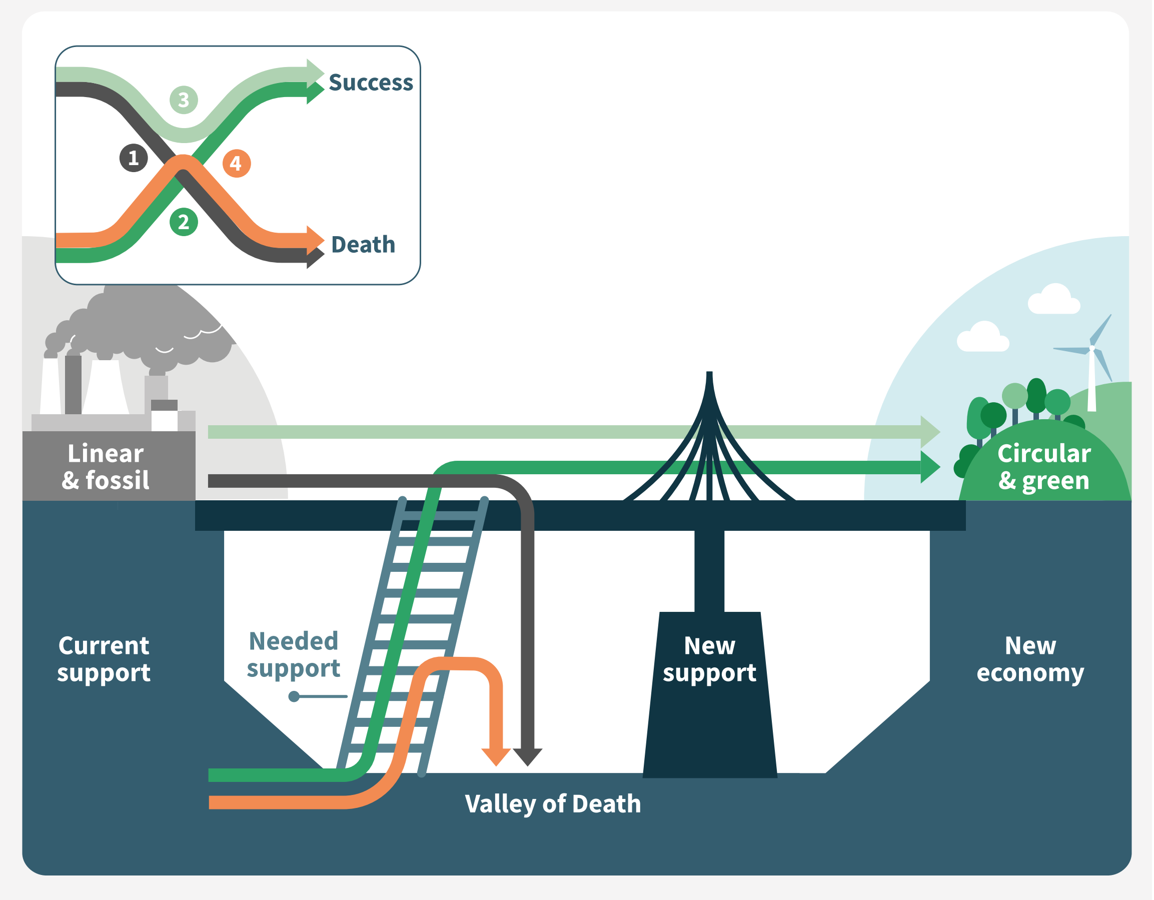
The past and current fossil-based industry converts the fossil carbon resources into our consumer products to enable our current way of living. It brought benefits to almost all societal sectors. But our use of these fossil resources is now inflicting catastrophic damage upon the climate and environment. So, the phasing out of fossil resources is more than urgent. This means we—society—must turn new but similar large-volume non-fossil resources into the future of consumption for the next generations.

There are currently no large-volume examples of new value chains between renewable resources and products/consumption, although several efforts are under way. Many have also failed, sometimes for good reasons, sometimes as regrettable loss. One might ask why. This is a good question, because learning from the 'why' of past failure is one of the best accelerators of success. There is a large amount of relevant knowledge about success and failure in open literature, for example, change theory, the so-called X-curve, and the 'Valley of Death' concept, well known to investors and entrepreneurs.

The figure shows four generic movements from present to future on the X-curve and a classic Valley of Death representation:

1. The phasing out of fossil
2. The construction of circularity and disruptive technologies
3. The adaptation of present technologies to circularity
4. Today's harsh reality: failing green technology and products

Bridging the present and the past



The second and third initiatives find themselves facing, or are beginning to cross, the Valley of Death. The unfortunate initiatives under point 4 are stranded in the Valley of Death. It should be realized that, if a successful new circular economy has materialized in 2050 or later, the current economic system will have to have built a new bridge between alternative resources and the consumers of the future society. Such a bridge will traverse the current Valley of Death. Successful drivers are the current initiators 2 and 3: the developers and users of non-fossil resources replacing fossil oil and gas and their products.

The Valley of Death is supposed to act as a healthy reality-check in the current economic system, causing a "natural selection" of new initiatives so that only the economically suitable ones survive. However, the trajectory the chemical industry (and the value chain connected to it) has to achieve to reach climate neutrality **is not an economic one in the current linear economic system**, and it is shrouded in uncertainty (long-term supply and demand, long-term policies, etc.). This is why the Valley of Death is currently also a generic graveyard for large-volume green initiatives. Some causes of failure are:

- Difficulty of organizing supplies (new value chain): suppliers already have a market
- Difficulty of sharing added value between stakeholders in new circular business models
- Heavy competition between fossil and circular products on price
- Competition for green resources between industrial branches, driven by unbalanced regulations and scarcity
- Policy often not being supportive, nor stimulating

Securing investment is extremely difficult for these reasons. Yet, we must all understand that this kind of failure is not and cannot remain an option. Without an alternative-carbon industry upstream, and a circular manufacturing industry downstream, the climate neutrality of the chemical industry and other fossil carbon users is simply unimaginable.

Brightsite

Transforming industry

Proud partners

Sitech

TNO

Maastricht University

Brightlands Chemelot Campus