REPORT

# On the Road to Climate Neutrality 2050

## – the Role of Social Partners in the Decarbonisation of the Chemical, Pharmaceutical, Rubber and Plastics Industries


Authors:
Katharina Schöneberg, Birte Homann (wmp consult)
Julien Ballaire, Sarah Kessaria (Syndex)


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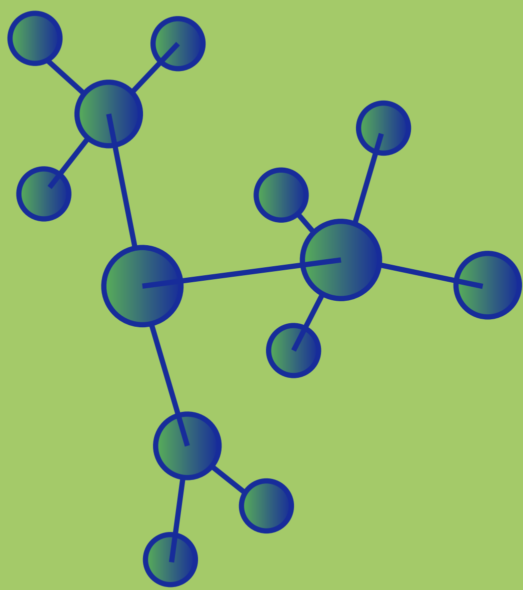
## Please note

*This is a report reflecting the state of literature collected during desk research as well as opinions of interview partners. It is a support and working document for the European Social Partner project and should not be seen as a policy statement.*



# Contents

# Executive summary

With the European Union aiming to be climate-neutral by 2050, the chemical, pharmaceutical, rubber and plastics industries being important contributors to greenhouse gas emissions, have committed to decarbonise their activities. In the framework of a quadruple transition where financial resources are needed for climate neutrality, circular economy, digitalisation and the implementation of the Chemicals Strategy for Sustainability, the ability of the sector to become climate neutral will depend on European and national policies and legislation, international competitivity and trade, development of demand and market requirements and public opinion, the availability and price of renewable energy and electricity and green hydrogen, Research and Development and innovation, investments and funding as well as cooperation among sectors.

Against this background, companies in the sector must choose between different technological pathways. Promising future-oriented technologies and production methods comprise the use of new raw materials and carbon sources, changes in own processes including the enhancement of energy efficiency in the production process, the electrification of processes, the development of new processes as well as sustainable business models and working methods. Also, alternative energy sources, the capture and storage of $CO_2$ and recycling methods play an important role. Finally, the idea of a circular economy combines several of the solutions for climate neutrality such as renewable feedstock, efficient production, recycling and carbon utilization. Companies will have to choose a technology mix that will ensure their future competitivity, also deciding on the regional focus of the undertaking, strategies and business models, and products.

Framework conditions and choices made by companies will have an impact on companies and workers calling for actions. Companies will have to engage in anticipation of change and risk management, increase cooperation and involve in strategic partnerships, promote R&D and innovation closely related to the need to secure access to financing and funding opportunities. Furthermore, they must reorganise and change their working methods, develop new organisational competences and implement an adequate strategic personnel policy while at the same time involving their employees. From a workers' perspective the impact on employment and the need to ensure job and social security, the prevention of negative effects on working conditions as well as access to relevant training and education will be important. In this context, Social Partners can play an important role in accompanying the transition and shaping it in a way that is socially and economically viable.

# 1. Introduction

## 1.1. Background and methodology

The European Union aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement to limit global warming to below 1.5 degrees Celsius. The chemical, pharmaceutical, rubber and plastics industries (henceforth: the sector) have committed to contribute to this target by massively reducing their greenhouse gas (GHG) emissions, most notably carbon dioxide ($CO_2$). As the COVID-19 pandemic is accelerating existing structural changes within the sector, strong social dialogue and collective bargaining are highly needed to find effective solutions for both workers and employers. Consequently, the European Social Partners of the sector industriAll European Trade Union and the European Chemical Employers Group (ECEG) initiated the joint project "On the Road to Climate Neutrality 2050 – the Role of Social Partners in the Decarbonisation of the Chemical, Pharmaceutical, Rubber and Plastics Industries".

The present report is based on a literature review and interviews that have been carried out by the external experts wmp consult and Syndex between April and October 2021. In total, 23 interviews with experts from European and national Social Partner organisations and company representatives from seven countries have been carried out. The report will serve as background information for scenario development in three workshops in 2022.

## 1.2. The European chemical, pharmaceutical, rubber and plastics industries and their relevance for GHG emissions

In terms of sales, Germany and France are the two largest producers in the sector in the European Union, followed by Italy and the Netherlands. When including Spain, Belgium and Austria, these countries account for more than 80% of the sales volume of chemicals. While Italy is the third largest producer of pharmaceutical products and preparations, Poland plays an important role in plastics and rubber production. The sector employs almost 3.4 million people (Eurostat 2021a). The sector is confronted with increasing competition, mainly from China but also the USA, Japan, Russia, South Korea and India.

Fuel and power consumption in the EU27 chemical industry including pharmaceuticals has decreased by 24% between 1990 and 2018, halving its energy intensity and greenhouse gas emissions while almost doubling production (cefic 2021c). Still, the chemical industry is estimated to be one of the most difficult sectors to decarbonise. Together with the iron and steel, petrochemicals, cement and lime, and aluminium industry and three key transport sectors (road freight, aviation, and shipping) it could account for 38% of energy and process emissions and for 43% of final energy use by 2050 without major policy changes (IRENA 2020). $CO_2$ emissions represented 82% of the GHG emissions of the chemical sector[1] in the EU-27, followed by nitrous oxide ($N_2O$) (11%) and hydrofluorocarbons (HFCs)[2] (3%). In addition, methane and perfluorocarbons (PFCs) accounted for 2% each. From 1990 to 2019 the European chemical industry has already reduced its GHG emissions by 66%. However, $CO_2$ emissions only have been reduced by 9% whereas methane emissions even have increased by 6% (however, continuously declining since 2014) (Eurostat, 2021b). Due to its large share in GHG emissions as well as smaller progress in reductions so far, the focus in GHG emission reductions in the sector (and in this report) is on $CO_2$.

[1] Comprising ammonia, nitric acid, adipic acid, caprolactam, glyoxal and glyoxylic acid, carbide, titanium dioxide, soda ash, petrochemical and carbon black and fluorochemical production; no comparable data available for the pharmaceutical, plastics and rubber industries
[2] HFC is a type of gas used in refrigerators and aerosols.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While the sector is a major energy user, it also helps to drive the transformation, to save energy and reduce GHG emissions. It is an “enabler” of hydrogen technologies, storage tanks, pipelines, and $CO_2$ reduction (for example through lightweight construction, building insulation or electric motors). These effects on emissions’ reduction are also called the “carbon handprint” of the sector. The transformation in Europe is inconceivable without the sector’s products and the companies’ innovations (Cefic/Ecofys 2013). Whereas the contribution of the sector to reach climate neutrality across all sectors is very important, the present report will focus on the sectors’ own GHG emissions.

# 2. Framework conditions for climate neutrality in the sector until 2050

The sector is confronted with a “double twin” or “quadruple” transition comprising the following four major challenges:
1. climate neutrality,
2. circular economy,
3. digitalisation and
4. implementation of the Chemicals Strategy for Sustainability.

As funding must be provided for all developments, a coherent and consistent sectoral approach is indispensable (VCI/Deloitte 2017; Cefic 2021b). All four aspects are closely linked and part of the EU’s zero pollution ambition, a key commitment of the European Green Deal. On the one hand, digital technologies are an enabler for climate neutrality in the chemical sector (for example through measures for automated flexibilization of industrial electricity demand depending on the grid load or increased energy efficiency through automatization and process analyses). On the other hand, increasing digitalisation itself leads to rising energy and resource consumption and thus greenhouse gas emissions (izt/Öko-Institut e.V. 2021). Interview partners estimated that digital transformation is an essential factor to meet the challenge of climate neutrality by 2050 as it will support control of costs and availability of scarce raw materials. It will also allow companies to be more competitive through integrated traffic management, e.g. by ensuring the safety of the transport of dangerous products (GeSi 2015). Within the fourfold tension field, according to literature and interviews several influence factors have an impact on the ability of the sector to become climate neutral until 2050 as shown in Figure 1.

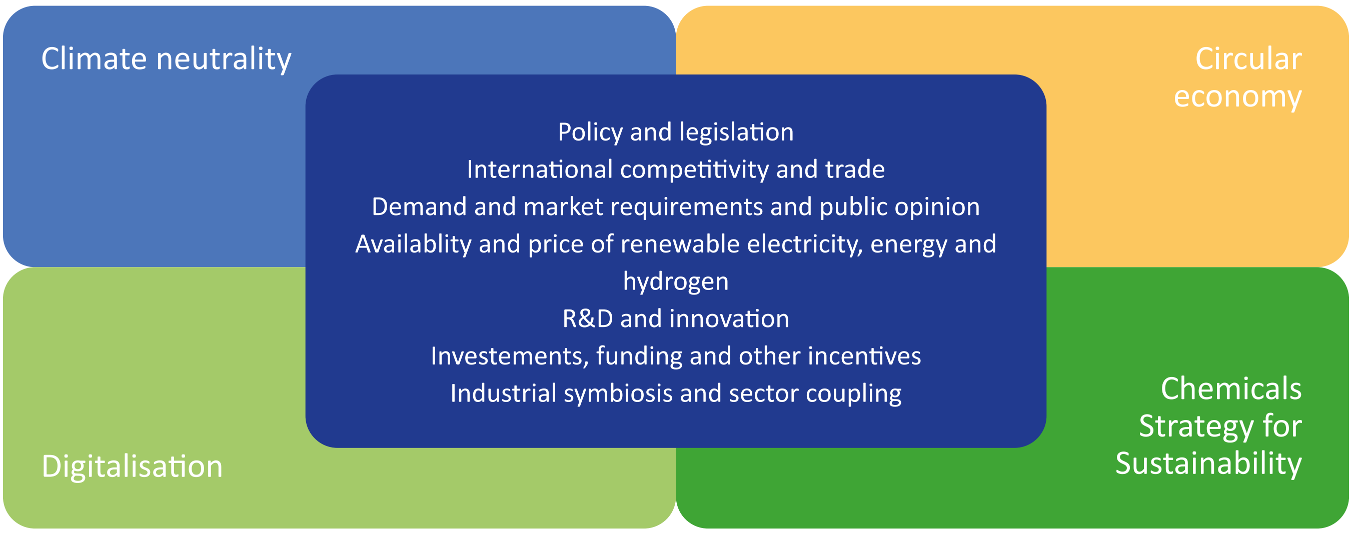


Figure 1: Influence factors for climate neutrality of the sector
Source: own illustration

Enablers and barriers to climate neutrality related to these influence factors will be described in the following paragraphs.

## • Policy and legislation

Climate strategies and targets of the European Union have been adapted several times over the years. Most recently, on June 28, 2021, member states approved a climate law setting a binding climate target for the Union to reduce net greenhouse gas emissions (emissions after deduction of removals) by at least 55% by 2030 compared to 1990 levels (European Commission n.d.). In July 2021, the European Commission adopted a package of proposals to adapt the EU Emissions Trading System, the Effort Sharing Regulation with Member States' emissions reduction targets and the land use and forestry regulation accordingly. It suggests the application of emissions trading to new sectors and a strengthening of the Union's current emissions trading scheme. Further measures are an increased use of renewable energy, improved energy efficiency, faster deployment of low-emission transport modes and related infrastructure and fuel policies, aligning fiscal policies with the objectives of the Green Deal for Europe, measures to prevent carbon leakage, and tools to preserve and expand the capacity of natural carbon sinks (European Commission 2021a). A final agreement is expected for the end of 2022 at the earliest. The following table gives an overview of European initiatives, strategies and legislation relevant for the sector on its way to climate neutrality.

Table 1: Overview of European initiatives, strategies and legislation

| Date | Initiative/Legislation | Relevant aspects for the sector |
|---|---|---|
| December 2015 | First Circular Economy Action Plan | • stimulating Europe's transition towards a circular economy<br>• identifying plastics as a key priority |
| September 2017 | A renewed EU Industrial Policy Strategy | • building on Europe's leadership in a low-carbon and circular economy as one of the key actions identified to strengthen Europe's industrial base |
| January 2018 | European Strategy for Plastics in a Circular Economy | • improving the economics and quality of plastics recycling<br>• curbing plastic waste and littering<br>• driving innovation and investment towards circular and<br>• harnessing global action |
| November 2018 | European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy | • looking at all the key sectors and exploring pathways for the transition<br>• leaving no one behind and enhancing the competitiveness of EU industry<br>• maximising the benefits of energy efficiency and the deployment of renewables and the use of electricity, reaping the full benefits of a bioeconomy and creating essential carbon sinks, and tackling remaining $CO_2$ emissions with carbon capture and storage |


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|---|---|---|
| July 2019 | Single Use Plastics Directive | • aiming at reducing plastic pollution (in particular marine litter)<br>• product design and marking requirements for plastic products, targets for separate collection of plastic bottles, EPR (Extended Producer Responsibility) obligations, and awareness-raising measures |
| December 2019 | European Green Deal | • a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas<br>• developing a "Just Transition Framework" |
| March 2020 | New industrial strategy for Europe | • highlighting the importance of industry sectors to pave the way to climate-neutrality as well as the role of digital technologies in the decarbonisation of the economy<br>• recognising chemicals as one of the priority ecosystems |
| March 2020 | An SME Strategy for a sustainable and digital Europe | • building capacity and supporting SMEs in their transition to sustainability<br>• reducing regulatory burden and improving market access<br>• improving access to financing |
| March 2020 | New circular economy action plan | • accelerating the transformational change required by the European Green Deal, while building on circular economy actions implemented since 2015 |
| July 2020 | A hydrogen strategy for a climate-neutral Europe | • exploring the potential of clean hydrogen to help the process of decarbonising the EU economy in a cost-effective way |
| October 2020 | Chemicals Strategy for Sustainability | • striving for a toxic-free environment |
| November 2020 | Pharmaceutical Strategy for Europe | • supporting industry in promoting research and technologies<br>• identifying and addressing strategic dependencies |
| January 2021 | Plastics own resource ("Plastics tax") | • national contribution by EU Member States based on the amount of non-recycled plastic packaging waste introduced as a new revenue resource to the 2021-2027 EU budget |
| May 2021 | Updating the 2020 New Industrial Strategy | • building a stronger Single Market for Europe's Recovery |

Sources: European Commission 2020a+b+c+d+e+f+g, European Union 2019, European Commission 2021c+d, European Commission 2018, European Commission 2018a, European Commission 2017, European Commission 2019c

While climate neutrality already has been a goal for companies, the process has been accelerated by the Paris Agreement and the provisions of the European Green Deal. Global, European and national policies and regulations can either inhibit development and investments or steer them in the "right" direction. Due to more restrictive environmental laws, companies will have to make further investments and incur costs (see for example Pirelli, 2021). Planning security and a clear political and regulatory framework supporting the transition are of utmost importance for the sector to remain competitive.

## • International competitivity and trade

A decisive factor for climate neutrality in the sector is the reconciliation of competitiveness and climate protection to keep production sites in Europe. Only just under 20 percent of global emissions are subject to a direct $CO_2$ pricing (World Bank Group 2020) and regional $CO_2$ prices are mostly below the European allowance price. In this context, the growing risk of production and emissions being shifted to non-European locations (carbon leakage) must be contained. To this end, as part of its Green Deal, the EU Commission in addition to the EU Emissions Trading Scheme introduces a Carbon Border Adjustment Mechanism (CBAM) on emissions from imported industrial products if they originate from regions with lower $CO_2$ price levels (European Commission 2019c; Kolev et al. 2021). However, for countries with a strongly export-oriented chemical industry, CBAM can be dangerous in terms of trade policy and not effective as carbon leakage protection and transformation support (BASF 2020). In addition to CBAM and the idea of a carbon club (a combination of climate levy on final products and dynamic allocation in the ETS), capped industry electricity prices and carbon contracts for difference (CCfDs) are discussed for carbon leakage protection (Stiftung Arbeit und Umwelt 2020). At the same time, European industry must take care not to be overtaken by non-European suppliers of climate-neutral solutions. Furthermore, the sector is largely dependent on global trade. Market opening for existing and new technologies is desirable. In the adapted EU trade strategy, however, liberalization and cooperation with partners come up short compared to unilateral steps by the EU.

## • Demand and market requirements and public opinion

Major promoters for climate neutrality on the demand side are the social pressure and rising awareness for resource efficiency and sustainability issues (see for example Trelleborg 2021). Clients of the sector (especially transnational companies such as Volkswagen) demand ecological efforts from their suppliers(see for example SNCP 2021 and Pirelli 2021). While developments such as the electric vehicles offer a chance for growth for producers of certain rubber parts, there is a great deal of uncertainty about the development of the base materials industry (Fraunhofer 2013). The competitive position of Europe has suffered in recent years due to the efforts of many emerging countries to build up their own basic industries and their more favourable raw material conditions (Cefic 2013). As consumers are not necessarily willing to pay more for sustainable goods, demand-side measures (financial support and normative measures) can help to foster competitiveness of carbon neutral products (High-Level Group on Energy-intensive Industries 2019).

## • Availability and price of renewable electricity, energy and green hydrogen

The goal of greenhouse gas neutrality of the sector is still achievable by 2050, however, under acceptance of a very strong additional increase in electricity demand as well as higher investment costs due to electrification of processes (DECHEMA/FutureCamp 2019). In view of production running 24/7 without interruption, the storage of energy (e.g., with hydrogen) is also of great importance. Cost-effective and stable supply of renewable electricity are important prerequisites. In this context, European countries' abilities to decarbonise energy generation are important. Today, the International Energy Agency (IEA) states that renewable energy is growing fast, but not fast enough (IEA 2021a). If investment patterns in renewable energies seen between 2017 and 2021 remain the same, the goal to deliver net-zero by 2050 will not be met (IEA 2021c).

Today hydrogen is mainly produced from fossil fuels ("grey hydrogen") as feedstock for fertilizer and chemicals production and to a much smaller extent as an energy carrier. But "green hydrogen" created by water electrolysis from decarbonised energy sources is the main long-term solution for decarbonising hard-to-abate sectors (DNV 2021). By 2050, hydrogen is estimated to have replaced fossil fuels in many industrial heat applications (Stiftung Arbeit und Umwelt/enervis 2021). "Blue hydrogen"- the coupling of conventional technologies (such as steam reforming) with $CO_2$ capture and storage (CCS)- today is the least expensive and the most widespread solution on a global scale (Fabrégat 2021).



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Combining green and blue hydrogen is estimated to result in the lowest costs enabling a scale-up of hydrogen use (Hydrogen Council, 2021). However, a recent study reveals that the carbon footprint of blue hydrogen is more than 20% larger than that of coal combustion for heating (Correia 2021). The pursuit of blue hydrogen creates a risk of locking in fossil fuel use in the longer term (Hock 2021). As renewable electricity-based hydrogen production generates additional costs compared to established processes, an adjustment of the levy and apportionment system and thus a falling electricity price are essential, to enable cost-effectiveness in an international comparison and not to inhibit sector coupling (IGBCE/VCI 2020). Also, storage, transport and distribution of hydrogen must be taken care of. While at European and national level a hydrogen economy is seen as one of the most important solutions for climate neutrality, critical voices warn against betting everything on it.

## • R&D and innovation

Interview partners highlighted that innovation is a main driving force for the sector. The timing of the market maturity of new technologies and processes will be the key to achieving greenhouse gas neutrality. The EU industrial strategy and the related sector-specific pathways are estimated to promote chemical innovation in Europe in accordance with the aims of the European Green Deal (Cefic 2021a). Triggering innovation is highly important for staying in business and remaining competitive. For the industry to become climate-neutral by 2050, policymakers must support research and development.

According to the International Energy Agency (IEA) most technologies necessary to decarbonise the chemicals sector remain in the pilot or pre-commercial stages and it could take a decade before wide-scale deployment becomes feasible. To drive those technologies to the scale, government support is likely to be necessary (IEA/ICIS 2020). In this context, academia and research organisations should undertake or stimulate academic and national laboratory research on large-volume and high-energy use processes (ICCA/IEA/Dechema 2013). Especially, SMEs must be empowered to innovate more. Framework conditions for cooperation between SMEs and research institutions must be improved (ArGeZ 2021). The better the policy support both in the development phase and in the market introduction, the earlier new technologies will be marketable (DECHEMA/FutureCamp, 2019). Since the alternative process routes are less economical than the conventional technologies, political instruments and international agreements must ensure competitiveness of domestic production (Neuwirth et al. 2020).

## • Investments, funding and other incentives

As 2050 is only one investment cycle away, decisions must be made now. The game-changer technologies for decarbonisation and digitalisation of industry are not only associated with high research costs, but also with enormous investment sums and implementation risks (Nelissen 2019). In many cases, the initial investment for new technologies can be a barrier even if the life-cycle costs are reduced, as requested payback periods can range between one to three years (IEA 2013). In line with the political and regulatory framework, European public funding, public procurement, and economic incentives promote innovations and market developments that have environmental benefits. Financial support already takes place within the framework of various funding programs[3]. However, it is already clear that public and private investment efforts will have to be stepped up significantly to achieve the goal of climate neutrality by 2050.

[3] Such as Horizon 2020 (2014-2020) / Horizon Europe (2021-2027) for research and innovation, the EU recovery plan (in response to the Covid-19 pandemic), the ETS Innovation Fund (for the commercial demonstration of innovative low-carbon technologies), the European Fund for Strategic Investment (EFSI), or under the EU cohesion policy. A "Circular Economy Finance Support Platform" has been set up in 2017. Funding is also provided by the European Investment Bank (EIB) often in cooperation with national development banks such as Private Finance for Energy Efficiency (PF4EE) supporting the implementation of National Energy Efficiency Action Plans or other energy efficiency programmes of EU Member States, the Joint Initiative on Circular Economy (JICE), the investment programme InvestEU, the Just Transition Fund and the Just Transition Mechanism, the Connecting Europe Facility, EU Invest and Important Projects of Common European Interest (IPCEI) promoting the diversification of international supply chains and supporting new industrial alliances and Member States' efforts to pool public resources in areas where the market alone cannot deliver breakthrough innovation.

The establishment of a transformation fund with a focus on climate-friendly technologies, production processes and products would be helpful, because it bundles government's participation in climate-friendly activities, it is subject to the secondary condition of a commitment to Environmental, Social and Governance factors to evaluate companies and countries on how far advanced they are with sustainability (EU taxonomy), and it is supervised by experts from the scientific community, trade unions and NGOs (Dullien et al. 2021). Transparent technology-oriented investment funds initiating and supporting predominantly cooperative projects and ensuring the dissemination of research results could give a decisive boost to the necessary structural change of the industry in Europe (Belitz et al. 2021). Carbon Contracts for Difference (CCfDs), a funding mechanism that offers governments the opportunity to guarantee investors a fixed price that rewards $CO_2$ emission reductions above the current price levels in the EU Emissions Trading System (ETS), could accelerate investments in decarbonised technologies (Cefic 2021).

## • Industrial symbiosis and sector coupling

Breakthrough technologies in other sectors and increased cooperation across and along value chains will be needed also because a significant part of the sector's emissions comes from upstream in the chemical value chain. A trend towards more collaboration between the power, fuels, steel and waste recycling sectors and the chemical sector can be witnessed. Still, growing nationalism and protectionism might lead to difficulties in agreeing on common global standards, consequently promoting bilateral cooperation and institutions instead (Cefic 2019b). Chemical clusters, i.e. chemical sites and processes (and sites from other sectors) that are located near each other sharing energy and raw materials to increase efficiency and reduce overall emissions will play an important role (WSP and Parsons Brinckerhoff/ DNV GL 2015). Extensive sector coupling also is seen to offer opportunities to integrate hydrogen across industries and energy sectors for optimum cost efficiency ($H_2$ cluster Finland 2021).

The following table provides an overview of the preconditions and obstacles for decarbonisation of the sector:

Table 2: Enablers and barriers for decarbonisation of the sector

| Influence factor | Enabling elements | Related barriers |
|---|---|---|
| Policy and legislation | • A stable and predictable policy framework<br>• Technology neutrality of support measures<br>• Integrated EU industry and energy policy<br>• Public procurement focusing on circular and low-carbon products and services | • Continuous adaptation of climate targets<br>• Lack of (national) industrial strategies and sector-specific roadmaps and pathways<br>• Isolated and fragmented policies reduce the potential of GHG emissions reductions by merely shifting them elsewhere |
| International competitivity and trade | • Globally harmonised $CO_2$ pricing<br>• Regulation addressing differences in carbon prices<br>• Comparable measures for climate neutrality in competing regions | • Phase out of free allocations under the EU ETS<br>• Non-harmonised and restricted compensation for increased electricity costs and costs incurred due to EU ETS<br>• Lack of liberalization and cooperation with partners |


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|---|---|---|
| Demand and market requirements/ public opinion | • Willingness of consumers to pay more for sustainable products and services | Uncertain development of certain sub-sectors due to shift of demand and production outside Europe<br>Lack of confidence in sector due to chemical spills or accidents and greenwashing<br>Local mobilisation against projects aiming to reduce the carbon footprint of the industry (e.g. windmill parks) |
| Availability and price of renewable electricity, energy and green hydrogen | • Worldwide level playing field for energy costs<br>• Internationally competitive electricity prices<br>• Development of solutions to use "surplus" electricity to produce hydrogen by means of electrolysis<br>• Development of local $H_2$-markets (decentralized generation, industrial clusters, local demand)<br>• Installation of long-distance hydrogen transport pipelines to connect large sinks with generation centres | • Increasing electricity prices hindering further electrification<br>• Alternative energy sources such as shale gas leading to a lower gas price and postponing the use of new technologies<br>• Limited storage options for surplus electricity<br>• High costs and energy need for the production of "green hydrogen"<br>• Intense competition between sectors and within sectors for access to electrolysis potential |
| R&D and innovation | • Accelerated approval procedures for new technologies<br>• Stimulation of national laboratory research on large-volume and high-energy use processes by research organisations<br>• Policy support both in the development and the market introduction phase provides for an earlier marketability | • High cost of research, development and demonstration (RD&D) of new technology<br>• Difficult commercialisation of new and unproven technology<br>• In the start-up phase, new plants cannot compete with older, depreciated plants |
| Investment, funding, and other incentives | • Financial institutions working together with the sector to better understand changes in funding requirements of a low-carbon chemical sector and funding opportunities of such a transition.<br>• Public private partnership efforts to enable fast deployment and risk sharing<br>• Special funding programmes and tax incentives tailored to small and medium-sized enterprises<br>• Creation of new funding instruments<br>• Transparent and coordinated funding mechanisms | • Energy-saving measures competing with other investment projects<br>• No or late investments due to late competitiveness of new technologies<br>• Internal competition for resources and funding, focus on economic and financial evaluation rather than on ecological aspects<br>• No or little access to capital and funding<br>• Lack of large private and public investments in both infrastructure and innovative solutions<br>• Risk of stranded assets due to investments in conventional technologies |
| Industrial symbiosis | • Creation of synergies and improved energy efficiency beyond sectorial boundaries | • Growing protectionism and competition |

Sources: Interviews and Agora Energiewende 2020, Bollen et al. 2020, CE Delft 2012, Cefic 2019b, Cefic/Ecofys 2012, DECHEMA 2017, DECHEMA/FutureCamp 2019, Fraunhofer 2013, ICCA/IEA/Dechema 2013, IGBCE/VCI 2020, Nelissen 2019, Stiftung Arbeit und Umwelt/enervis 2021, Voß 2013b, WSP and Parsons Brinckerhoff/ DNV GL 2015

# 3. Corporate practices on the way to climate neutrality

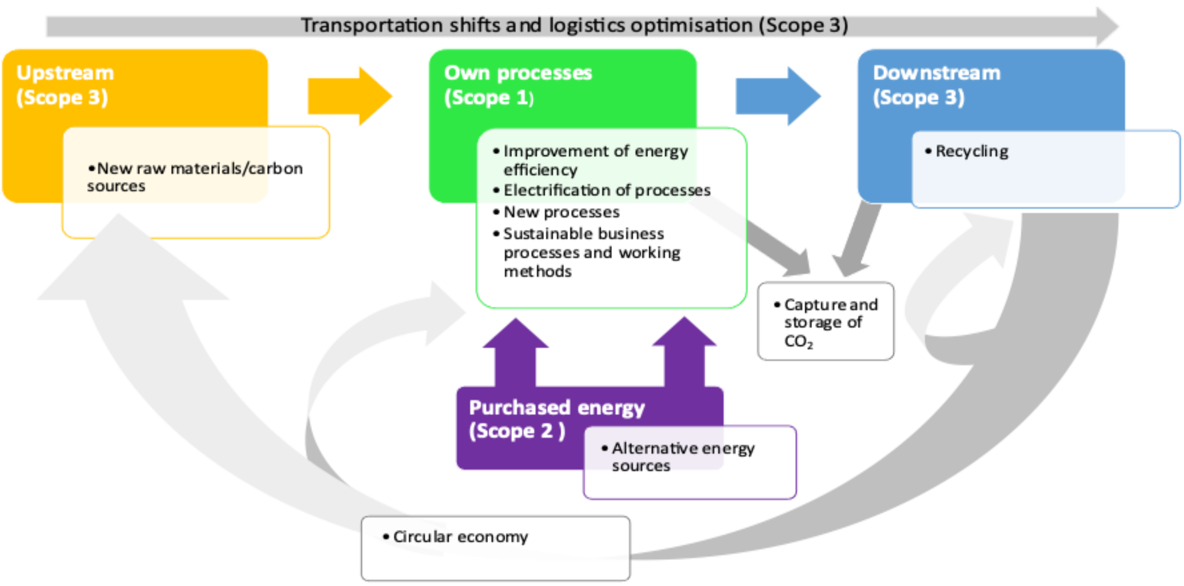
To reduce their carbon footprint, companies in the sector are confronted with a multitude of possible technologies and production methods. It will largely depend on framework conditions and the development of the influence factors named above which technological pathway they choose. The following chapter will present promising future-oriented technologies and production methods as well as possible strategic company choices.

## 3.1. Promising future-oriented technologies and production methods

While solutions differ from country to country, between sub-sectors and even from company to company as highlighted by interview partners, some widespread approaches have been discussed in literature and interviews carried out during the project. There are several starting points for companies to reduce GHG emissions including own upstream and downstream measures as well as own processes and purchased energy (see Figure 2).

Figure 2: Scopes of GHG emissions[4] and possible starting points for their reduction

Source: own, based on Cefic 2013: 7




### Upstream measures to reduce GHG emissions: New raw materials and carbon sources

Interview partners emphasised that the fossil feedstock of the sector requires a raw material conversion if the sector is to become greenhouse gas neutral by 2050. Sustainably produced biomass can already contribute to additional emission reductions before 2030, but its availability is limited. In its Mid-Century Vision, Cefic predicts that biomass consumption for production of chemicals will have doubled by 2050 with respect to 2018. To meet this forecast, both companies and EU policymakers will need to take certain measures to scale up the bioeconomy (Cefic 2021d).

[4] The GHG Protocol Corporate Standard classifies a company's GHG emissions into three 'scopes'. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions (http://www.ghgprotocol.org). Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of products and services. These three scopes are also referred to as "carbon footprint" while a fourth scope, the contributions to emission reduction from the use phase of chemical products, are also named "carbon handprint".



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On the downside, some of the interview partners feared that competition for biomass with other sectors could drive up prices. When assessing both the environmental impact and carbon footprint of plant-based products, aspects such as water consumption, the use of fertilizers and pesticides, or energy consumption and $CO_2$ emissions in the harvest and transport must also be considered. As the demand for renewable and bio-based feedstocks grows, pressures on ecosystems and competition with food production will increase.

Differing interests are likely to collide in the future, such as sourcing more renewable feedstocks to replace fossil fuels versus preserving biodiversity and ecosystem resilience (Green Chemistry & Commerce Council 2021). Consequently, opportunity costs of biomass use are high (Hock 2021). Also, the cost and availability of traditional raw materials and their alternatives will impact the choice of feedstock used. Until now, a feedstock change in the sector cannot be observed. It can be expected that the shift in the resource base will be incremental. Gradually, oil will be supplemented and substituted by renewable resources (Behrendt 2017). One interview partner assumed that the use of biomass for basic chemicals is still at an intermediate stage of development and that pilot plants are not likely to be built in this decade.

In addition, $CO_2$ may play an important role in the feedstock mix of the future. Several different chemical processes (thermochemical, photochemical, electrochemical, biochemical or catalytic) can take $CO_2$ captured at the point of emission and convert it into other valuable molecules including methanol, organic acids, aspirin, solvents, detergents and cosmetics (carbon capture and utilization - CCU). A few demonstration plants have already been built in Europe that convert $CO_2$ into high-quality plastics (Suschem 2018). A major challenge for these technologies is the cost-competitive access to $CO_2$ (Material economics 2019). Interview partners indicated that the use of $CO_2$ as a feedstock is also not expected to be implemented on a large scale in the next ten years. It remains to be clarified whether it is economically viable to produce the required hydrogen in Europe. This depends on the transportation costs for hydrogen and the available renewable energies.

### Funding of renewable methanol production within the Swedish Green Industrial Leap Programme

To reduce $CO_2$ emissions across the entire value chain, the Swedish chemical group Perstorp in cooperation with Fortum and Uniper plans to invest in a plant for renewable methanol production utilizing residual streams and capturing and using $CO_2$ from production. Together with a new electrolysis plant and biogas, the plant will produce 200,000 tonnes of sustainable methanol annually. The project is supported by the Swedish Energy Agency by around 29 million Euros (Swedish Energy Agency 2021).
*For further examples, see Annex I.*

## Changes in own processes
## Enhancing energy efficiency in the production process

To improve energy efficiency of processes, process intensification has a significant role. Changes in equipment and methods may lead to a decrease the equipment- size/production-capacity ratio, in energy and resource consumption or in waste production. Regarding process-intensifying equipment, novel reactors and furnaces with lower energy consumption, optimisation of energy used for intensive mixing in the homogenisation of mixtures or the use of static mixers utilising the energy of the flow stream for fluid mixing play an important part. As heat transfer from one fluid to another is an essential component of chemical processes either cooling down a chemical after an exothermic reaction or heating components before starting a reaction, it is important to improve energy efficiency of heat-transfer devices such as heaters, heat exchangers, water and air coolers or condensers. More energy-efficient mass transfer technology such as for absorption, evaporation, drying, precipitation, membrane filtration, and distillation used for physical separations of materials or ingredients from liquids or solids, or for filtering out undesirable elements also is crucial.

Concerning process-intensifying methods, one key solution is the integration of reaction and separation. To obtain pure products always mass separation processes in addition to carrying out the chemical reactions are required often carried out sequentially to the reaction step in a separate downstream separation apparatus. A more efficient way is the integration of a separation process directly into the reactor. Also, heat exchange between a chemical site and its vicinity for example using heat created in chemical processes for nearby district heating or for heating of other chemical sites is often carried out. Phase transition processes such as boiling, cavitation, crystallisation and precipitation play a crucial role in many transformation processes and are predestined for energy efficiency measures. For example, liquid reactants must be vaporized before feeding them into the reactor consuming a lot of cooling energy. An efficient use of power and energy can be achieved by motor system optimization and enhancement of boiler efficiency through improved or new process control methods, supply-demand optimization, reduced flue gas quantity resulting from the combustion of fossil fuels, flue gas heat recovery, and regular maintenance (Cefic/Ecofys 2013, see also SPIRE 2012; Creative Energy 2017).

### Thermal groundwater utilisation for cooling

Gummiwerk KRAIBURG GmbH & Co. KG currently employs around 400 people producing rubber and silicone compounds. The KRAIBURG rubber plant uses thermal groundwater to cool buildings and processes. Overall, the installed system can reduce electricity consumption by an average of 30,000 kWh per month. After cooling, the groundwater seeps away on the primary side via two 500 kW heat exchangers and then back into the ground via an absorption well (wdk 2019b).

Steady progress in implementing incremental improvements and deploying best practice techniques (BPT) could provide substantial energy savings and emissions reductions in the sector compared to business-as-usual practice. As around 90% of chemical processes use catalysts (also called reaction accelerators, a substance that increases the speed of a chemical reaction by reducing the activation energy not being consumed itself in the process) to start the chemical reaction, catalyst improvements will play an important role (ICCA/IEA/Dechema 2013). However, due to the already achieved decline in energy consumption and associated GHG emissions and physical and chemical limits to the reduction of energy input in many processes, for further substantial improvements new technological pathways will be necessary (Prognos 2011; ICCA/IEA/Dechema 2013; Agora Energiewende 2020).

Interview partners stated that the integration of advanced process modelling, control technologies, digitalisation and artificial intelligence allow or will allow companies in the sector to carry out energy and environmental simulations that will be able to reduce their carbon footprint. It can also be used to improve the management of available resources and raw materials. However, the question of energy is often absent from the debates around the digitalisation of the sector. The spread of digital tools will inevitably raise the question of the security of energy supply and will go hand in hand with a considerable increase in energy requirements. The latter will represent a non-negligible cost for companies in the sector. The huge servers storing data require large cooling systems consuming a lot of energy. In addition, the use of big data and connected objects as well as the development of blockchains and artificial intelligence will increase energy costs.

## Electrification of processes

The electrification of processes (also referred to as Power-to-X) in the sector comprises Power-to- Heat, Power-to-Hydrogen, Power-to-Chemicals (including Power-to-Specialties and Power-to-Commodities) and will be an important measure for decarbonisation according to interview partners. The use of electricity for the generation and upgrading of heat and steam (Power-to-Heat) is the first type of electrification that companies will implement on a large scale. The first applications will be those with more positive economics, such as waste heat upgrading and electrochemical production of fine chemicals.


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With more technical developments, higher volume products and more advanced applications of Power-to-Heat, such as technologies which not only utilise waste heat but reduce the heat demand altogether, will become feasible.

At the same time, Power-2-Hydrogen is estimated to expand from the pilot scales that are being developed today to commercially relevant scales. Green hydrogen produced through the electrolysis of water may be used as a feedstock for chemical processes, storage of energy (also named power-to gas) or as a fuel. Applying Power-to-Hydrogen for local use on-site is already being applied by some companies at small scales for specific cases. For example, a plant of Carbon Recycling International in Iceland operating since 2011 and connected to the Svartsengi geothermal power plant, produces 5 million litres of completely renewable methanol per year and recycles 5.5 thousand tons of $CO_2$ emissions per year (www.carbonrecycling.is). In addition to the direct use of electricity for electrochemical conversion in Power-to-Chemical processes, technologies such as plasma[5], microwave[6] and photocatalysis[7] are considered to lead to higher energy efficiencies and product yields than electrochemistry or conventional thermochemical processes. However, these technologies are mostly in earlier stages of development (VoltaChem 2016).

## New processes

Low-temperature processes and catalytic alternatives such as the use of cleaner biocatalytic alternatives (for example hormones or enzymes) to traditional process routes can provide additional energy savings. Using membrane technologies to replace energy intensive distillation separation steps and, for chlor-alkali production[8], a further development of the membrane process[9] using an oxygen-depolarised cathode (ODC)[10] [10]reduce the electrical power consumption considerably. The use of ODC technology will, given the existing energy mix, lead to considerable reductions in GHG emissions (Voß, 2013a).

Regarding ammonia[11] production, several new methods such as biological nitrogen fixation using bacteria, electrochemical production of ammonia directly from nitrogen and water and chemical looping processes involving chemical or electrochemical reactions producing ammonia as a by-product (The Royal Society 2020) are being developed.

### Reduction of power consumption by 30% with ODC

In 2011, a demonstration plant with an annual capacity of 20,000 metric tons of chlorine was commissioned at the Krefeld-Uerdingen Chempark. Following a successful two-year large-scale test operation, ThyssenKrupp and Bayer have been marketing the technology worldwide since 2013 and Bayer itself also gradually retooled its chlorine production. Bayer had developed this special type of electrode, while the design of the electrolytic cell comes from Thyssenkrupp Uhde / Uhdenora (chemietechnik.de 2013; chemie.de 2011).

[5] Plasma technology is based on a simple physical principle. Matter changes its state when energy is supplied to it: solids become liquid, and liquids becomes gaseous. If even more energy is supplied to a gas, it is ionized and goes into the energy-rich plasma state, the fourth state of matter.
[6] Microwave processing is defined as the use of electromagnetic waves of certain frequencies to generate heat in a material.
[7] Photocatalysis, also known as 'artificial photosynthesis', is a technology for converting photonic energy from solar radiation to chemical energy. Photocatalysts are materials that change the rate of a chemical reaction on exposure to light.
[8] The chloralkali process is an industrial process for the electrolysis of sodium chloride solutions. It is the technology used to produce chlorine and sodium.
[9] The membrane acts as a very specific filter that will let water flow through, while it catches suspended solids and other substances.
[10] In ODC technology, gas and liquid are separated in the cathode compartment by a percolator, which enables the formation of a caustic film between the membrane and the ODC enabling a homogeneous oxygen and caustic pressure distribution over the compartment, leading to an optimum flow performance.
[11] Ammonia is a compound of nitrogen and hydrogen with the formula NH3. A stable binary hydride, and the simplest pnictogen hydride, ammonia is a colourless gas with a distinct pungent smell. Ammonia is one of the most highly produced inorganic chemicals. Ammonia, either directly or indirectly, is also a building block for the synthesis of many pharmaceutical products and is used in many commercial cleaning products. It is mainly collected by downward displacement of both air and water.

Also, green e-methanol[12] may be synthesized from green hydrogen and $CO_2$. Emerging technologies such as the replacement of the steam cracking process currently run non-catalytically by a catalytic process and the methanol-to-olefin[13] (MTO) process would have to be applied in new plants (ICCA/IEA/Dechema 2013). New chemical routes to produce existing products are still at an early stage of development (WSP and Parsons Brinckerhoff/ DNV GL 2015).

## Sustainable business processes and working methods

In addition to technological solutions, sustainable business processes and working methods will play an important role in reaching climate neutrality in the sector. These may include favouring sustainable solutions supporting economic solutions in business processes (systematic green design approach for new products, implementation of a green fund and internal carbon price for all investments and business systems, changes in supply chains and transport etc.) (EFPIA 2020) or the mobility of employees. Also, low carbon transportation and the development of greener transportation routes and solutions play an important role in the reduction of GHG emissions (see for example Cefic/Smart Fright Centre 2021). In addition, the development of teleconferences and virtual meetings can be used to reduce the travelling emissions of the employees as stated by interview partners.

### Borealis Polymers: Reducing transportation routes

Borealis Polymers, a manufacturer of petrochemical products, streamlined its logistics and achieved significant emission reductions. Borealis' factories are in Kilpilahti, Porvoo. However, due to the small container field, some of the plastic granules produced by the company have had to be transported and stored at Vuosaari Harbor. The transport of containers within 30 kilometers was significantly reduced when the container field in the Kilpilahti factory area was doubled. The truck transportation route will be reduced by 10–15 per cent cutting CO2 emissions by 270 tonnes (Remes n.d.).

## Alternative energy sources

While the sector is largely dependent on the availability and price of renewable energy to be purchased, as a large consumer of electricity, the sector could make a significantly greater contribution than today to sector coupling and the electricity transition through load management measures (Stiftung Arbeit und Umwelt der IGBCE 2019b). Heat source changes such as the use of geothermal heat and an expansion of renewable energy use and a shift to low-carbon fuels are considered. Combined generation of heat and power (CHP) offers a possibility to save fuel. However, cost effectiveness of the widely applied technology is largely dependent on natural gas and electricity prices (Cefic/Ecofys 2013).

Hydrogen as an energy carrier is not estimated to be used widely for industry heating in 2030 since other decarbonisation alternatives are more mature and often less complex. But it may be part of a portfolio of decarbonisation measures in some industries in 2050 (DNV GL 2019). Availability of sufficient renewable energy or electricity as well as hydrogen at very low prices will be a big challenge (Rothermel 2020). International hydrogen and renewable energy partnerships and cooperation with other sectors will be important. However, according to interview partners, this issue is not being successfully addressed at the political level. Confronted with this insecurity, companies in the sector must act themselves. Covestro, for example, has signed a supply agreement with the Danish company Ørsted starting in 2025, which is to cover around 6% of Covestro's global electricity requirements. In Antwerp, 45% of the site's demand is to be supplied by ENGIE from onshore wind turbines. In cooperation with Henkel, BASF operates a power plant in which waste products are incinerated and energy is generated via steam turbines.

[12] Green methanol is a low-carbon fuel that can be made from either biomass gasification or renewable electricity and captured carbon dioxide (CO2).

[13] Olefin is another name for polypropylene fiber.Chemically speaking, polypropylene sounds like a complicated process, but is in fact a greener fabric than cotton, wool, silk, or rayon. Olefin, or PP, is a synthetic based polypropylene fabric that was first created in Italy in 1957.


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## Kiilto: Heating a large factory with waste heat

Kiilto will cut energy consumption by a fifth by 2025 and move to 100% renewable energy within a decade. At the Kiillo Lempäälä plant, the heat energy generated in adhesive production began to be recovered with the help of a new heat pump system. Waste heat is now used to heat factory properties. The plant has also introduced a geothermal system, which provides not only heat but also the cooling needed in production. The new heat pump system reduces the plant's energy consumption by 1,800 megawatt hours per year. $CO_2$ emissions will be reduced by about 310 tonnes per year when natural gas used for heating is replaced by renewable energy (Remes n.d.). *For further examples, see Annex I.*

BASF has also entered into a cooperation agreement with RWE to supply green electricity. Solvay has signed an agreement with Falck Renewables S.p.A for the development of a solar project in the region of Puglia, Italy. 70% of the electricity produced by the solar plant will go to four of the six Italian sites of Solvay, achieving a reduction in annual $CO_2$ emissions of over 15,000 tons.

To change the source of electricity, power purchase agreements (PPAs) to secure low-carbon electricity and joint ventures with energy companies to invest in new energy generation and storage capacity will be important for the sector.

### Capture and storage of $CO_2$

According to the International Energy Agency (IEA), the global climate goals can only be achieved if carbon capture and storage (CCS) and other negative emission technologies are researched and deployed on a large scale in a timely manner (Stiftung Arbeit und Umwelt der IGBCE 2019b). Cefic 2013 also expects these technologies to make a significant contribution to reducing emissions from the chemical industry in Europe. The EU also promotes the use of CCS technologies for example through the InvestEU investment program (Global CCS Institute 2020). Still, there is no consensus on the question whether CCS is needed to reach climate neutrality or not. There are 13 commercial CCS facilities in operation or in development in Europe (Global CCS Institute 2020), but some experts consider that the potential is limited in the near future as deployment at scale only will begin in 2040. By 2050, total carbon capture will only amount to 6% of all annual energy-related emissions (DNV 2021). Long-term technical feasibility, economic viability and actual storage capacities are difficult to determine. Fraunhofer Institute for Systems and Innovation 2019, Fraunhofer 2012 and CE Delft 2013 therefore do not include CCS technologies in their estimates. Emissions from individual plants are not of a sufficient scale to justify their own $CO_2$ pipeline and storage infrastructure. Collaboration both within the sector and externally is necessary to establish the networks, along with sources of funding to developing this shared infrastructure (WSP and Parsons Brinckerhoff/ DNV GL 2015).

### Downstream measures to reduce GHG emissions: Mechanical and chemical recycling

Currently only a small fraction of chemical product-based materials is recyclable, and an even smaller fraction are being recycled (Kemianteollisuus et al. 2020). Today mechanical recycling is the most widespread solution, but it has some limits especially regarding the quality of output. While mechanical recycling methodologies must be further developed, chemical recycling, as interview partners emphasised, becomes more important. The first pilot plants are currently being built. Large-scale implementation is expected in the late 2020s.

For example, through pyrolysis[14], the carbon can be used in crackers. This becomes even more important as refineries will prospectively cease to be a source of raw materials when cars go electric, and gasoline is no longer produced.

[14] Pyrolysis is a thermochemical treatment, which can be applied to any organic (carbon-based) product. It can be done on pure products as well as mixtures. In this treatment, material is exposed to high temperature, and in the absence of oxygen goes through chemical and physical separation into different molecules. The decomposition takes place thanks to the limited thermal stability of chemical bonds of materials, which allows them to be disintegrated by using the heat. Thermal decomposition leads to the formation of new molecules. This allows to receive products with a different, often more superior character than original residue. Thanks to this feature, pyrolysis becomes increasingly important process for today industry – as it allows to bring far greater value to common materials and waste.

The technology of pyrolysis plants needs to be further developed; the implementation is quite advanced. But if larger quantities are to be produced, larger plants are needed and there are still some issues to be solved in scaling up (e.g., regarding pollutant emissions) according to one interview partner[15].

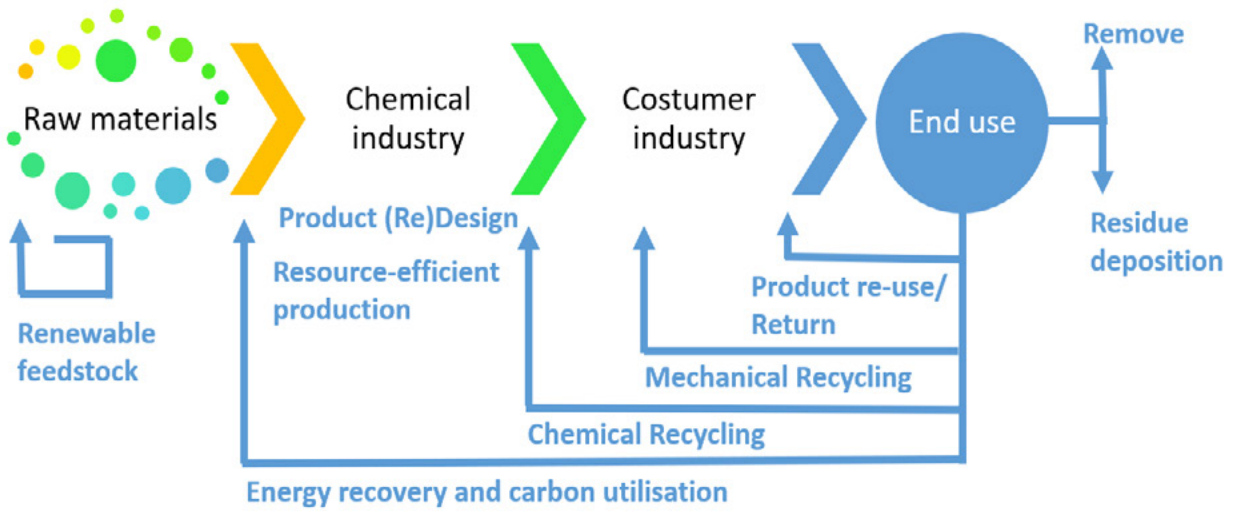
## Overarching topic: Circular economy

The idea of a circular economy combines several of the solutions for climate neutrality described above: renewable feedstock, efficient production, recycling and carbon utilization. In addition, product re-use such as the leasing model for solvents offered by SusChem and (re)design is considered (Deloitte/VCI 2017). Product design may contribute to a circular economy by making components come apart easily, using 100% recyclable material or new primary and recycled materials that meet functional requirements without unwanted additives and contaminants (Green Chemistry and Commerce Council 2021). Figure 3 shows different aspects of circularity along the chemical value chain involving raw materials, the chemical industry, the customer industry and end users.

## BASF – ChemCyclingTM project

In 2018, BASF (primary producer) launched the ChemCycling project. It focuses on chemical recycling (through pyrolysis) of plastic waste that is not recycled mechanically for technological, economic, or ecological reasons today. Value chain cooperation is key to the project. The ChemCycling™ circle is described as follows: It starts with the disposal of plastic waste, which then is collected and sorted and delivered to BASF's technology partners (at present Quantafuel, Pyrum and New Energy) that convert the waste to pyrolysis oil. The pyrolysis oil is then purified and can be used as virgin-quality-feedstock at the beginning of BASF's "Verbund" production. In the following, BASF allocates the recycled feedstock to all chemicals in the "Verbund" system via a certified mass balance approach (see Ellen MacArthur Foundation 2019). The chemicals obtained then are used by BASF's customers in their respective production processes. The project started at pilot scale through to small commercial scale projects and it is supposed to be subsequently applied on industrial scale. *For further examples, see Annex I.*

Figure 3: Circularity of the chemical value chain
Source: own, based on Accenture 2018 and Deloitte/VCI 2017




[15] For further information on recycling process technologies, see Annex II Plastics industry.



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## CEFLEX – A Circular Economy for Flexible Packaging

CEFLEX is a European initiative bringing together more than 160 partners representing the entire flexible packaging value chain from raw material producers, to ink, coating and adhesive suppliers, film producers and converters, brand owners, waste management companies, recyclers, extended producer responsibility organisations and technology suppliers. Their common goal is to make all flexible packaging in Europe circular by 2025. This is to be achieved by a 5-step roadmap, endorsed by all stakeholders, together with a set of actions (Ceflex 2021).

While conventional models of production and consumption generate waste and inefficiencies across the chemical value chain, circular economy solutions provide for material efficiency considering environmental and social sustainability. The full life cycle of products and processes should be taken into consideration. Increased cooperation among value chain partners will be sought (ICCA 2021; cefic 2019b). For circularity to be successful, downgrading and contamination must be avoided, material efficiency has to be improved and recycling rates have to be increased (Wyns et al. 2019). Digitalisation can enable and accelerate the development of circular business models and make them more efficient through data-supported product design, process simulation, modular production or robotics, analysing customer data or modern sorting technologies (Deloitte/VCI 2017).

The focus may also shift from products to services in the circular economy such as smart systems optimizing stock management, smart tyre services allowing the customer to lease industrial tyres instead of buying them (Trelleborg, 2021). In addition to this product as a service model, there are several other business models in a circular economy, such as product use extension, sharing platforms lean manufacturing[16] or take back management[17] (Kemianteollisuus et al. 2020; VUB/IES 2018).

To establish a functioning circular economy, a network of recycling facilities operating at industrial level would need a steady supply of appropriate waste streams (free of contaminants). Investments in infrastructure and assets for handling material flows are needed. Waste processing at scale will require massive investment as well as smart approaches to infrastructure transition. Market players need to establish the loops and value chains, consisting of partnerships, ventures or long-term contractual agreements. Finally, there is a need of a central authority to coordinate and ensure synergies and transition speed (Accenture 2020).

## Other GHG emissions

Generally, electrification will also reduce other GHG emissions than $CO_2$. In the sector, nitrous oxide ($N_2O$) emissions result from the production of nitric acid (fertilizer production), adipic acid (nylon polymers) and glyoxylic acid (drug precursor). Technologies exist and have been implemented for many years to cut these emissions: 95% of the $N_2O$ produced is now captured and destroyed. A rate of up to 99% thanks to a doubling of the installations or through new catalysis technologies may be reached in the next few years. Three cost-effective solutions already exist to abate $N_2O$ emissions: breaking down the gas into nitrogen and oxygen using a catalyst, installing a thermal reduction unit at the end of a plant's exhaust pipes or capturing emissions to be used for other manufacturing processes such as of flat screen displays (American Chemical Society 2021).

[16] Companies employ the strategy to increase efficiency. By receiving goods only as they need them for the production process, it reduces inventory costs and wastage, and increases productivity and profit. The downside is that it requires producers to forecast demand accurately as the benefits can be nullified by minor delays in the supply chain. It may also impact negatively on workers due to added stress and inflexible conditions. A successful operation depends on a company having regular outputs, high-quality processes, and reliable suppliers. It consists of five key principles: "Precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let customer pull value from the producer, and pursue perfection.

[17] Take-back is the idea that manufacturers "take back" the products that are at the end of their lives in order to reduce environmental impacts on the earth and also increase efficiency and lower costs for their business models. Take-back regulations have targeted a wide array of products including packaging, batteries, automobiles, and electronics and economic value can be found from recycling or re-manufacturing such products.

A phase out of HFCs is expected due to European regulation that aims at developing new refrigerants with lower Global Warming Potential (GWP)[18]. Upstream Scope 3[19] methane emissions related to sourcing of natural gas are still relevant, but inside the sector they are negligible (Conseil national de l'industrie 2021).

## Examples of technologies in the four sub-sectors

The importance of respective technological pathways differs between sub-sectors. For example, circular economy approaches are particularly important for the plastics and rubber industry. Due to the nature of the pharmaceutical industry, adoption of other circular economy business models such as product life extension, sharing platforms or product as service, present more of a challenge. The following figure shows examples of future-oriented technologies playing an important role in the four sub-sectors. For further information on sub-sector specific developments and technologies, see Annex II.

Figure 4: Examples of technologies in the four sub-sectors

Sources: Interviews, EFPIA 2016 and 2020, ETRMA 2020, Abdallas Chikri/Wetzels 2019, Bauer et al. 2018, Chan et al. 2019, Cefic 2019 b, Cefic 2021e, VoltaChem 2016, Pöyry 2020

| Chemical industry | Pharmaceutical industry | Plastics industry | Rubber industry |
|---|---|---|---|
| **New raw materials:** steel mill flue gas valorisation for chemicals; CO2 as feedstock for methanol, polymers and specialty chemicals; biomass to methanol, bioethanol and BTX; bio naphtha to olefins; cameline oil to produce paints and varnishes/use of lignin; sugar surfactants for detergents, ethylene from bio-ethanol dehydration<br><br>**Enhancing energy efficiency in the production process**: selective membrane filters in ethylene production; catalytic naphtha cracking<br><br>**New processes**: ODC technology for chlor-alkali-electrolysis; methane pyrolysis-ammonia synthesis process chain for ammonia production; synthetization of "green e-methanol", methanol to olefins, water electrolysis for green hydrogen | **Enhancing energy efficiency in the production process**: improved leak control in the chillers and coolers and a change of refrigerant solution<br><br>**New processes**: biological processes instead of chemical synthesis; reduction of the number of synthesis steps<br><br>**Circular economy**: using vapor capture technology (VCT) to reuse the gas previously lost; replacing HFa inhalers with dry powder ones | **New raw materials**: plastics from biogenic carbon; bioplastics; thermoplastic lignin production<br><br>**Recycling**: physical recycling of expanded polystyrene; high density polyethylene from advanced recycling; circular polyethylene derived from post-consumer recycled material; recycling of CFR-Composites; polymers out of plastic waste, PET and PS chemical recycling<br><br>**Circular economy**: polyurethane based on a circular feedstock sourced from a waste product of the mobility sector; circular polypropylene solutions; plastic waste pyrolysis for circular naphtha | **New raw materials**: green butadiene from plants; peptizers and processing promoters for elastomer compounds from vegetable oil, CO2 as feedstock in elastomers; thermoplastic polyurethane based on CO2 technology<br><br>**Enhancing energy efficiency in the production process**: vulcanizing agents and accelerators helping achieve vulcanization in a more efficient way at lower temperatures<br><br>**Recycling**: decomposition of old tires in high-temperature process into carbon black, oils, gas and steel; granulation of scrap tires<br><br>**Circular economy**: use of crumb rubber as infill in artificial football turf pitches; energy recovery; End-of-Life Tire management |

[18] Global warming potential is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide.
[19] For further information on different scopes of emission, see p.10.



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# 3. 2. Companies' strategic choices

Several challenges and opportunities for companies arise from the general framework conditions and the need to implement future-oriented technologies as described above as shown in the following figure:

Figure 5: Opportunities and challenges for companies on the way to climate neutrality

**Challenges**

- Local environmental regulations impacting competitivity and leading to outsourcing and delocalisation
- Regulatory reuirements such as REACH and the biocide regulation can be innovation inhibitors especially for smaller companies and drive market consolidation
- Risk-intensive projects having an impact on the solvency of companies
- Determination of the right time for marketisation
- Lower demand for carbon-intensive products
- Change in capabilities / jobs needed to accompany the transition

**Opportunities**

- Growth and new business opportunities
- Resource, energy, CO2 emissions and production cost savings
- Support to employer branding, employee engagement and retention and investor attraction through climate neutrality measures
- Enhanced value generation based on increased demand/ sales and extended product portfolios
- Value-to-society replacing shareholder value/investors increasingly orienting their investments to sustainability (sustainable finance)

Sources: Brown 2018b, DECHEMA/FutureCamp 2019, Kemianteollusuus et al. 2020, Nelissen 2019, PwC 2020, VCI/Prognos 2019, Voß, 2013a

When it comes to the impact on Small and medium-sized enterprises (SMEs), they have more problems to overcome challenges than larger companies, especially as the financial potential is more likely to be found in large companies that also have the resources for research and development. If for example BASF decides to use a certain technology, this also shapes the entire market. Small companies, on the other hand, do not decide on the technical direction themselves and often produce highly specialized products that cannot simply be replaced. SMEs will be particularly exposed to the risk of having to purchase expensive raw materials from abroad that are subject to a tariff and additionally having to pay a surcharge for renewable energies for the raw materials produced domestically. The fact that this massively impairs competitiveness and possibly means the end for small companies has not yet been considered by the EU. However, interview partners highlighted that SMEs also may profit from opportunities. Owner-managed companies have been working on climate neutrality for some time. SMEs are highly innovative and mostly future-oriented wanting to pass on the business to the next generation. Long-term and sustainable investments are in the foreground. Overall, SMEs are more flexible in the face of a different mode of production that comes with the phasing out of petrochemicals.

Due to insecurities related to the development of technological innovations (depending on which technologies will prevail), many strategic decisions must be taken by companies under uncertainty. This includes decisions on the regional focus of the undertaking, on a technology mix appropriate to the individual company, on products and production processes. Companies must respond to changes in the markets and pursue new opportunities to stay competitive (Cp. McKinsey 2018b, McKinsey 2020). The following table gives a preliminary overview of possible strategic company choices.

Table 3: Possible strategic company choices

| | |
|---|---|
| Localisation of production sites | • Outsourcing/offshoring (to other European countries or outside Europe)<br>• Retention of production in Europe |
| Company structures | • Consolidation and concentration of production at a small number of integrated sites to reduce costs to maintain competitiveness, increasing capacity per plant<br>• Decentralization and a trend towards more adaptable smaller entities using small quantities of locally available resources adapting products and services to local needs |
| Product portfolio and business model | • Opening to new business areas and diversification<br>• Specialisation and adaption to customer needs |
| R&D | • Externalisation of research<br>• Expansion of own capacities |
| Technologies | • Implementing breakthrough and disruptive technologies<br>• Applying Best-Available-Techniques<br>• Incremental improvements of energy efficiency<br>• Focus on electrification and hydrogen, circular economy, biomass and/or others |
| Investment | • Maintenance investments of existing machines<br>• Investment in new plants and machines<br>• Compensation measures (e.g., investing in forestation) |
| ... | .... |

Source: Own, non-exhaustive list



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# 4. Ensuring a successful transition

The transition to climate neutrality of the sector will only be successful if it is associated with industrial growth and good work (see for example IGBCE/VCI 2020). In this context, there are different starting points for companies to accompany the transformation as well as for assessing and shaping the impact on workers. The following paragraphs give a first non-exhaustive overview of possible starting points to ensure a successful transition collected throughout literature review and interviews.

## 4. 1. Fields of action for companies

### Anticipation of change and risk management

For the future viability of companies to anticipate and recognise technological, economic and social disruptions at an early stage and to analyse the opportunities and risks for business is essential (Deloitte/VCI 2017). However, only 15% of the respondents to PwC's Global CEO Survey from the chemical sector have assessed the potential transition risks (PwC 2020). Interview partners emphasised that if risks are not properly managed, they can result in restructuring processes, collective redundancies or even plant closures. To oversee climate related risks and to manage them, larger companies have assigned board-level committees with the management of transformation, competitiveness, integration of acquisitions and the internal control, quality, and risk management processes. Regular meetings are scheduled to reviewing and guide strategy, monitor and oversee progress against goals and targets for addressing climate related issues, to adapt business plans and to set performance objectives (see for example Michelin 2020a).

#### ERRLAB - a European network of laboratories

"ERRLAB was established by the benchmark rubber laboratories of France, Germany and Italy (LRCCP, DIK, CERISIE), with the support of the rubber industry National Associations: respectively SNCP, wdk, Assogomma and the European Tyre and Rubber Manufacturers Association ETRMA. Its objective is to share resources and expertise to provide an ever better and complete service to the rubber manufacture industry, with a special attention to small and medium enterprises, in the field of research & development, testing and certification." (ERRLAB n.d.)

### Increasing cooperation and strategic partnerships

Cooperation, and strategic partnerships between companies and along the value chain are gaining importance. Be it in the form of acquisitions, networks, (innovation) clusters or competence centres linking companies (R&D departments) with each other, or linking companies with research institutes and other stakeholders, including public-private partnerships. These alliances will exist at local, national, and global level. Risk sharing, financing, feedstock supply and the exchange of knowledge are among the advantages of such partnerships. Relocations, restructuring and organisational changes can also be part of it.Often, "bigger players" invest in start-ups undertaking promising technology developments. This can also provide an opportunity for many small companies with a limited (financial) ability to adapt to transition requirements. Strategic partnerships for innovation are also being formed for example between tyre producers and the automotive industry to bring new solutions to the market faster. The European Innovation Council (EIC), a funding program launched by the European Commission in March 2021 dedicated to disruptive technologies, promotes cooperation between chemical companies and start-ups (Cefic n.d.a). New partnerships are also required with digitalisation and tech companies creating a broader value chain to include new services and solutions (PwC 2020).

Creating synergies along the value chain as for example with the business collaboration on circular feedstock between Trinseo and BASF may lead to business expansion and an improved environmental profile of both partners (BASF 2021). In 2020, BASF acquired a stake in Pyrum, a medium-sized company that recycles oil from used tyres. BASF is already using the recycled oil in plastics production and plans to build 15 new plants over the next five years. If previously for Pyrum it was difficult to attract investors, BASF's entry has increased banks' confidence in the midmarket company and made financing easier to obtain (daserste.de 2021).

At the same time new business cooperation may change the competitive situation for companies in the sector. For example, in September 2017, a $100 million joint venture now named JoynBio between Bayer and Ginkgo Bioworks was announced aiming to engineer nitrogen-fixing microbes, which could be put into seed coatings and provide nutrients to non-legume crops. While jobs are created at the Joint Venture, for the ammonia industry, this represents potential demand destruction at a significant scale as microbes could replace ammonia in the coming decades that may lead to job destruction (Brown, 2018a).

### Dow and Shell: Joint project to develop lower $CO_2$ emission crackers

Supported by the Dutch government, Dow and Shell developed a technology programme to electrically heat steam cracker furnace also joining forces with The Netherlands Organisation for Applied Scientific Research (TNO) and the Institute for Sustainable Process Technology (ISPT). After having advanced electrification solutions for today's steam crackers while also pursuing game-changing technologies for novel designs of electrified crackers in the longer-term, the companies are now evaluating construction of a multi-megawatt pilot plant, with potential start-up in 2025. The project relies on a joint multidisciplinary team with competences in electrical design, metallurgy, hydrocarbon technology and computational fluid dynamics (Shell 2021).

## Promoting research and development and innovation

For product innovation, new raw materials, process and productivity innovation research and development activities play an important role. In most sub-sectors this leads to an enhancement of own R&D functions. Also, joint developments of new technologies become more frequent, leading to a decentralization of R&D in customer markets (VCI/ Deloitte 2017). In the pharma industry, the economic model of the industry relies more and more on the externalization of R&D, via small start-ups specialized by molecules or products. The promising technologies to reduce the carbon footprint will induce a pressure by the big pharma players on the small start-ups to incorporate those issues. Moreover, this will generate a bigger need of translational competences in the major corporations, to transform the R&D projects into low-carbon emission manufacturing processes.

### Innovation forum for scrap tyre recycling

The AZuR network is an association of companies, associations, organisations and research institutions that pursue the goal of recycling used tyres as much as possible and feeding them into a closed material cycle. The Innovation Forum was founded within the framework of the funding guideline "Innovationsforen Mittelstand" by the German Federal Ministry of Education and Research. The objective is the formation of an interdisciplinary network of business and science in the innovation field of scrap tyre recycling (azur 2021).



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## Innovation at Pirelli: Regional technology centres and an open model

Twelve technology centres are located all over the world, allowing a direct relationship with markets and end users, and with the main vehicle manufacturers whose R&D centres and factories are in the same geographical areas. Pirelli's model for research and development, implemented in accordance with the Open Innovation model, is carried out through several collaborations with partners who are external to the Group - such as suppliers, universities and the same said vehicle manufacturers - for the purposes of pre-empting technological innovations for the sector, to direct research and development activities, and to respond to and steer towards the needs of the end consumer (Pirelli 2021).

## Securing access to finance and funding opportunities

As only focusing on energy efficiency is inefficient and a diversification of technologies is required, investments will be needed in new production equipment for example when switching fuels for heat production (McKinsey 2018a) or for remodelling of existing plants. Using hydrogen instead of natural gas in ethylene crackers, however, only causes minor retrofit costs, process setup changes and shifts in safety requirements. Gradually replacing existing fuels with hydrogen enables the reuse of current infrastructure (FCH 2019). Hence, costs incurred depend on technologies chosen. Very large projects will be financed externally, and the related risk level is a key consideration for financiers considering the return on investment. Interview partners stated that investor relations and sustainability reporting will become more important. To take the step from innovation to implementation, even larger companies need external financial support. Regarding internal funds, a key barrier is the limited availability of capital for improvement projects due to the high level of competition for internal funds in multinational companies, more easily dedicated to growing markets such as Asia which present a better business case or other projects that are more closely related to the core business (WSP and Parsons Brinckerhoff/ DNV GL 2015).

## Reorganisation and changes to working methods

The need to reorganise company structures and to adapt working methods depends on the technological pathway chosen. Investing in a circular economy approach might lead to complete reorganisation of the company, as it is for example the case for Covestro. Starting in July 2021, the company aligned its corporate strategy to the circular economy. While one interviewee estimates that far fewer changes are required on the input side when switching from natural gas to electricity than is often assumed (since the subsequent value chain remains the same, as the same plant can produce the same products without natural gas), increasing energy efficiency in companies does have an impact on internal processes and structures. To exploit energy-saving potentials in companies as extensively as possible, the focus must not only be on improving plant technology, but also on organisational structures such as operational processes or staff with their qualifications and motivation. Overall, the energy transition can promote the further development of internal processes and structures as well as transparency (e.g. regarding energy data and costs) and strengthen the role of employees (Löckener et al. 2016). For example, at Worlée-Chemie GmbH, an Energy and Environment working group deals with the topics of energy, environmental and climate protection and waste management. Annual reviews are carried out as part of integrated management systems and reports on energy development are published, as well as a sustainability report for the last four years.

## Developing new organisational competences

To be successful on their way to climate neutrality, adjusting portfolios and implementing technologies, companies need new organisational competences such as market intelligence, business development and strategic marketing (Roland Berger Strategy Consultants 2017).

Strategic capabilities required for carbon neutrality can be divided into six groups that interact with each other:

1. **Leadership** (i.e., a vision of the company's role in society and sustainability as part of the strategy)
2. **Management Processes** (i.e., representation of all business units in sustainability activities, sustainability as part of reporting and emission measurement and calculation)
3. **Company culture** (i.e., sustainability as part of everyone's job description, innovative work environment)
4. **Expertise in various fields** (i.e., multidisciplinarity, permit and grant application, lobbying, data analytics, marketing, communication)
5. **Innovation** (new business models, customer-orientation, holistic management of technology development, etc.)
6. **Influencing business environment** (i.e., cooperation with external research organisations, legislation and standards, network, identification of funding opportunities) (Kemianteollisuus et al. 2020).

As mentioned under the strategic capability "Management Processes", to reduce their carbon footprint companies in the sector must assess their processes and products regarding their part in emissions. The result is highly relevant for the company's image, customers relations as well as on the capital market. A data basis for the assessment of the portfolio must be formed in the company. For example, Evonik together with seven other chemical companies, has developed a method based on the WBCSD. The PARC (Product Application, Region Combination) assesses how products perform in different applications in the regions and how this can be quantified. Next Generation Solutions will be used to further develop and grow the portfolio. This also goes along with organisational changes. For example, five years ago Evonik established a dedicated functional area for sustainability. Sustainability is to be viewed across all management processes and anchored there. Other companies such as BASF, Bayer, Covestro, Clariant and Merck also have entire staff departments with 10-30 employees that deal with the topic of climate neutrality.

## Establishing a strategic personnel policy and strategic workforce planning

Interview partners agreed that a major task for the sector will be to secure skilled workers. The challenges related to this task are diverse: Starting with the mitigation of the effects of demographic change, to the organisation of training and further education of the existing workforce, up to the recruitment of new, qualified personnel. Considering both the sometimes-negative public image of the industry and the general competition for skilled workers, it might be very challenging to recruit people. The efforts in internal and external personnel marketing must be ramped up. Offering (more) apprenticeship positions and dual studies could also be an opportunity to secure the supply of young professionals (Stiftung Arbeit und Umwelt der IG BCE 2021).

In-company education and training programs that enable innovation and the testing of new ideas are crucial for entrepreneurial innovation and transformation processes (Stiftung Arbeit und Umwelt der IGBCE 2019b). However, PwC's Global CEO Survey revealed that 33% of CEOs in the chemicals sector are extremely concerned about the availability of key skills.

### Skills development and strategic workforce planning at Michelin

Against evolving skills requirements, in 2018, Michelin established a new "Managing and Developing People and Skills" process being sustained by a strategic workforce planning process (SWP) updated in 2021. The process is managed by the Group Competency Managers, each of whom is in charge of one skills-set (competency) leading to the creation of two new positions, Development Partner and Skills Manager. The SWP consists in identifying the potential risks involving the Group's skills and workforce needs over the next five years and recommending solutions to address them covering job families for which the Group Competency Managers have identified issues requiring a response (due to a new organisation, significant changes in a job family or skill needs, etc.) (Michelin 2020b).


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Only 18% of CEOs in the chemicals sector reported significant progress in defining the skills needed to drive their future growth strategy. Leaders will need to assess and identify skills gaps and mismatches and compare workforce capabilities and needs as well as to motivate employees (PwC 2020).

### Involving employees

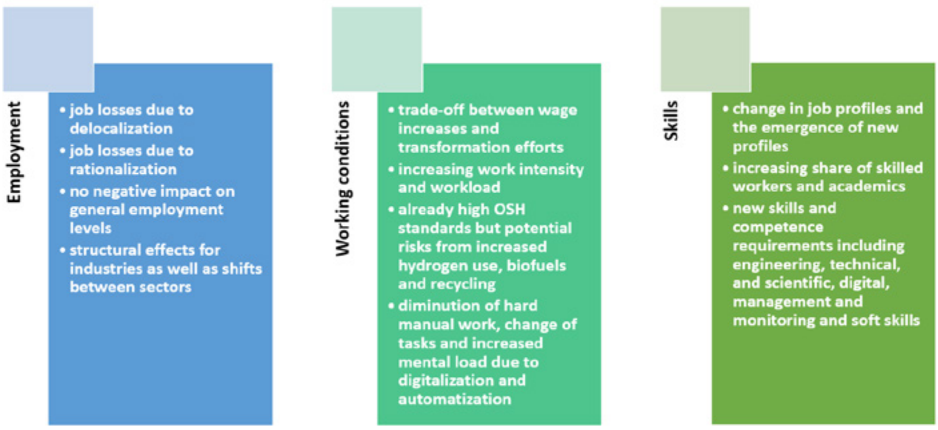
A company's workforce plays an important part in the adaption and diffusion of technical and organisational change (Toner 2011). Interviewees agreed that it is important to adapt the mindset of employees to the changes. To involve employees and raise awareness, communication to employees on climate-related issues is of utmost importance. For example, at the Finnish tyre producing company Nokian, regular training and environmental communication are implemented to increase environmental awareness among the personnel (Nokian tyres 2021).

Employees also may be involved in energy savings through idea management and made aware of the issue through competitions. Social innovations in companies, e.g. new opportunities for participation around the use of resource-saving measures can contribute to the transformation. An expansion of the in-house suggestion scheme, innovation prizes or bonuses can strengthen corporate innovation systems alongside R&D departments. To avoid cost-sharing and privatisation of benefits, as well as to increase public acceptance and to allow citizens and public authorities to share the benefits and positive effects of the climate transition, the reorientation of policies must include equitable distribution effects and the active participation and support of workers (Bollen et al. 2020). In this context works councils and trade unions need to become more involved, for example, in the issue of training. It must be clarified how the works council can support the process[20].

## 4.2. A workers' perspective

From a workers' perspective, the transition will profoundly reshape the labour market in ways that create both new risks and new opportunities for workers: new jobs but also, in some cases, destruction of jobs, replacement of some existing occupations by new ones, along with the need for new competencies and skills. The transition may also impact the quality of jobs and working conditions (OECD 2012). Figure 6 gives a non-exhaustive overview of the possible impact of climate neutrality measures on employment, working conditions and skills considered in literature and interviews so far followed by a consideration of relevant topics for Social Partners including the assessment of the impact on employment, ensuring job and social security, the prevention of negative effects on working conditions, skills forecasting and the assessment of competence needs as well as the promotion of training and education.

Figure 6: Overview of impact on employment, working conditions and skills. Source: own




[20] For further information on information and consultation, Social Dialogue at different levels and collective bargaining see chapter 5.

## Assessing the impact on employment

According to interviewees, one major concern is that moving production to countries outside Europe or the purchase of parts and services abroad due to better economic conditions will cause job losses in European countries. The quality of jobs will depend on which part of the value creation will still take place in Europe. There is also the question of the relocation of certain jobs (administration/accounting/production) to places where labour is cheaper and where the protection of workers' rights is less developed. While measures taken by the industry to increase energy efficiency can contribute to increasing the competitiveness of companies and thus to securing locations and jobs, works councils - especially from energy-intensive companies - point out that such investments can also lead to rationalisation effects reducing the volume of work, which would then also lead to job losses (Löckener et al. 2016).

However, if delocalization can be prevented, it is often assumed that measures taken to transition to a new, lower-emission economy will not have a negative impact on overall employment levels. Either they are considered to have no relevant impact (see for example Großmann et al. 2020 or OECD 2012) or to create employment due to investments in clean energy, energy efficiency in construction and electric vehicles that outweigh negative impacts in the fossil fuel industry (see for example IEA 2021b). However, studies agree that there are far-reaching structural effects for industries as well as shifts between sectors. To counteract potential employment losses, new value-added structures as well as training and further education offers must be developed in parallel.

An analysis commissioned by the Foundation for Work and the Environment of the trade union IG BCE based on three scenarios for achieving Germany's climate targets and resulting economic consequences presented in the study "Climate Paths for Germany" (BDI/Boston Consulting Group/Prognos 2018) concludes that for the German chemical industry negative effects of climate protection measures are more than offset by various positive effects. The chemical industry is estimated to benefit from the additional investments made by the economy as a whole in the climate scenarios, e.g. insulation materials, basic materials for lightweight construction and composites, other materials used, for example, in mechanical and plant engineering. While the study states that employment is increasing between 0.3 and 0.4 percent in the scenarios in which an 80 percent reduction in greenhouse gases is to be achieved, in the case of a reduction of 95 percent of GHG emissions, the number of people in employment is 1% lower, as the pressure to modernize is significantly higher here than in the other scenarios. Stronger investment activity and a higher degree of automatization are the result.

### Restructuring in the rubber and tyre industry

The technology shift in the automotive industry may lead to sales and earnings problems and cause restructuring in the rubber and tyre industry. This, for example was the case for the Freudenberg Group where 170 jobs were affected in the Oil Seals Industry, Damper & Steering and Powertrain & Driveline Divisions and the Components unit. In addition, the radial shaft seals business at the factories in Kecskemét, Hungary, and Langres, France was realigned. Production had to be adjusted in response to significantly lower demand for internal combustion engines and adapted to meet present and future market requirements. Some 250 jobs were affected (Freudenberg Group, 2021).

Confronted with decreasing demand in the automotive sector further aggravated by the pandemic, to secure growth with relevant future technologies Continental decided to bundle production, research and development tasks at the most competitive locations worldwide as well as on portfolio adjustments under the transformation 2019 to 2029 structural programme. According to a preliminary analysis up to 30,000 jobs worldwide are expected to be affected by consequent changes over the next 10 years being modified, relocated, or made redundant. In close cooperation with employee representatives, the company tries to prepare the employees affected for the technological changes with structured training measures promoting employment (Continental 2020).

As to the pharmaceutical industry employment effects are estimated to be low with reductions between 0.08% and 0.2%. In contrast, the study states that higher product prices lead to a decline in private consumption demand for rubber and plastic goods, which is noticeably below the reference level in all three climate pathways. A reduction of employees in the sector of 0.5%, 0.9% and 1.8% in the different scenarios is the result stated by the study (Stiftung Arbeit und Umwelt 2019a).

Furthermore, a study commissioned to CETA, the Centre for Economic and Market Analysis, by the Czech Social Partners in the chemical sector SCHP ČR and ECHO trade union found that severe negative impacts can be expected in employment in chemical industry in the Czech Republic decreasing by around 17 % because of the implementation of the European Green Deal. It is estimated that countries with a more important share of employment in energy-intensive industries will suffer from a more important negative impact on employment (CETA-Centrum ekonomických a tržních analýz, z. ú. 2020).

It is still difficult to predict the quantitative development of employment and this report can only give a first hint on possible developments. However, there seems to be broad agreement on certain qualitative developments linked to the structural change of employment in the sector. The crucial question is how and when an upscaling of new technologies in production will take place. The technology switch offers great opportunities for R&D jobs. However, jobs in production will depend on these not only being tried out in real laboratories, but also being scaled up.

## Employment development in the hydrogen economy

While estimated numbers differ due to different assumptions for framework conditions, experts generally estimate that the expansion of the use of “clean” hydrogen will at least secure jobs (Beesch, 2020) or even lead to job creation (see for example Hydrogen Council 2017; FCH 2019; Deutscher Wasserstoff- und Brennstoffzellen- Verband e.V. 2018). While a large part of the jobs will be created in equipment production and infrastructure as well as fuel cells, there are employment opportunities along the whole value chain (FCH 2019). Job creation potential, however, is estimated to be more important where hydrogen is used for energy creation than where it is used as feedstock as it is the case for ammonia and methanol production (Jepma et al. 2019). Also, the transport sector and vehicle maintenance have a lot larger potential for job creation than industry (CE Delft 2018). Nevertheless, clean hydrogen is estimated to be part of a just transition and good for job creation (Stelpstra 2020). This also holds true for manufacturing as it may avoid a need to restructure existing industrial processes or phase out production along with fossil fuels (Renssen 2021).

## Ensuring job and social security

The European Social Partners believe that the global transition towards a low-carbon energy production includes vital opportunities for businesses and can be achieved without compromising growth and jobs (ECEG/industriAll Europe 2015). industriAll Europe highlights the fact that the transition must be carefully monitored to ensure nobody is left behind. Consequently, it is important to avoid mass redundancies, ensure a smooth transition to another job for each worker affected, establish safety nets of social protection for workers whose job will be at risk and invest in human capital at all levels (industriAll Europe 2019b). Confronted with the uncertainty of how labour markets will evolve, policy measures must enhance their adaptability, at the same time providing adequate social protection for workers (OECD 2012) reducing the insecurity due to job displacement and making the tax and benefit systems more supportive of employment. Possible measures to tackle negative effects on job and social security named by interview partners include for example tax breaks not only for companies but also for workers, financial support measures for those losing their job, assistance to transfer to a different but similar field of work, retraining for qualifications in new occupational fields, promoting educational institutions and innovation projects and implementing a socially acceptable structural transformation program (see also Hoch et al. 2020) as well as promotion of internal mobility, job search assistance, provision of income security and identifying vulnerable regions and support re-development plans (Nelissen 2019).

## Preventing negative effects on working conditions

Companies in the coming years will need to invest massively in the transition in a context of limited access to capital. They might engage in cost-cutting programs and restructuring in different areas of the companies that might affect the current working conditions of workers in the industry. Narrowing margins and increasing investment needs may lead to lower wage increases. There is a possible trade-off between wage increases and transformation efforts. Policies that significantly reduce GHG emissions depress real wages and workers will risk bearing a disproportionate share of the costs of the transition in the absence of compensating policies (OECD 2012). Increasing work intensity and workload are observed as the energy transition has created the need for employees to constantly familiarize themselves with new regulations and topics. An accelerated digitalisation within industrial processes and services and the reduction of the workforce that it allows, contribute to complexify and intensify the work for the remaining employees.

Interviewees stated that occupational health and safety is already very much developed in the sector. Very high standards are already implemented. Consequently, they do not expect any important changes due to climate neutrality measures and new technologies. Still, some risks concerning the increased use of hydrogen, bioenergy as well as mechanical and chemical recycling are mentioned in literature. A more widespread use of bioenergy may lead to higher physical, chemical and biological risks for workers. High temperatures, and sometimes high pressures, are used in pyrolysis and gasification resulting in risks from fire and explosion. Biofuels have the potential to give rise to new biological risks (European Agency for Safety and Health at Work, 2013).

During the mechanical recycling of plastics, health hazards can arise both from hazardous chemical and biological substances. In addition to inhalable and alveolar dusts, the release of heavy metals as well as organic and inorganic gases and vapours as decomposition products of plastics is possible. So far, the quantity and composition of the process emissions are not recorded and the impact of the actual emissions on the health of the staff can often only be estimated. Health of workers will be affected by enhanced chemical recycling. In particular, the way materials are separated and reprocessed primarily creates health risks, while safety aspects play a rather minor role. Chemical recycling comprises processes, which are still far from being ready for the market and whereof risks for employees are still unclear and must be investigated as early as possible (IFA, 2020). Still, working conditions are likely to improve with each investment resulting in cleaner air and fewer carbon emissions.

Regarding digitalisation and automatization, positive impact includes a diminution of hard manual work. In addition, tasks are changing. As predictive maintenance becomes more important, workers no longer accompany the whole process but must use a specific knowledge in special occasions. Also, questions concerning work-life-balance, working conditions at home, the impact of exoskeletons and connected glasses on workers' health, sharing the workspace with robots and more autonomy and responsibility increasing the mental load must be considered. To anticipate and prevent psychosocial and physical risks assuring healthy and secure working conditions, a reinforcement of the culture of prevention in terms of OHS is necessary. Based on an assessment and analysis of risks related to digitalisation or other technological advances preventive health measures may be taken.

## Skills forecasting and assessing competence needs

As stated by the Industry 2030 high level round table, anticipating and developing skills are very important, as "our society requires knowledge concerning complex problems, like those at the nexus of technology, innovation and sustainability" (European Commission 2019b). Also, interview partners agree that a precise inventory of needs in terms of job profiles must be drawn up. Some interviewees do not consider the impact on skills and competences to be very important, since energy efficiency measures are incremental for plants operating over the long term (25-30 years) and even a modified process is still a chemical process. Others see changes in, for example, improved monitoring and control of the heating process. Training in the use of electrically heated systems may also be needed. However, systems already run largely automatically, so changes will be minimal.

A change in job profiles and the emergence of new profiles are likely. For example, retreading of tyres and the use of recyclable materials, the job profile of "material planning analyst" will require additional competences as the supply chain becomes more complex and integrated (ESCA 2016). In the pharmaceutical industry, the global trend of switching from chemical molecules to biological ones leads to the need to recruit more biologists and less chemists in the R&D teams. With electrification of processes, there will be an increased need for electrical engineers. While electrification does not change the processes themselves, other competences are needed for maintenance. Further occupations becoming more important are for example energy managers, climate change analysts, sustainability specialists, chief sustainability officers, sales engineers, transportation planners, compliance inspectors, nuclear monitoring technicians or emergency management directors (Arthur 2021). As found by the Future skills forecast initiated by German Social Partners BAVC and IGBCE, preventive maintenance, process control engineering, computer vision / image processing, virtual collaboration, additive manufacturing, Computer aided design (CAD), good, automated manufacturing practices (GAMP), continuous improvement, process simulation and machine-learning, artificial intelligence and advanced statistics become more important (BAVC/IGBCE/HR Forecast n.d.).

It is estimated that the share of unskilled and semi-skilled workers will further decrease whereas the share of skilled workers and academics is likely to increase.

New jobs and new processes require new skills (see Table 4). The general trend is towards increased demand for cross-cutting competences, such as problem solving and communications (European Commission 2018c).

Table 4: Overview of skills and competence needs on the way to climate neutrality
Sources: Arthur 2021, Roland Berger 2021, Löckener et al. 2016, Cefic 2019b, Kemianteollissus 2021, Interviews

| Engineering, technical and scientific skills | Digital skills |
|---|---|
| • applied biology, chemistry and electromechanics<br>• applied thermodynamics, mechanics, and aeronautics<br>• scientific and mathematical skills<br>• (renewable) energy technologies and design<br>• energy-saving<br>• process optimization, with an environmental focus<br>• product design ("safe and sustainable-by-design")<br>• materials science<br>• technical-scientific interface competencies<br>• research and development expertise | • industrial IoT technologies (e.g., connectivity, smart metering, predictive maintenance)<br>• robotic process automation technologies<br>• cyber & application security technologies<br>• augmented reality<br>• programming<br>• data science: artificial intelligence and big data<br>• principles of process simulation / digital twins<br>• machine learning<br>• data processing and analytics |

| Management and monitoring skills | Soft skills |
|---|---|
| • lobbying and influencing<br>• permit and grant application<br>• sales and marketing<br>• managerial agility<br>• life-cycle management and analysis, lean production and cooperation with external actors, including customers<br>• sustainable energy management (demand vs. supply) & monitoring<br>• technical standards and legal aspects<br>• environmental impact quantification and monitoring<br>• economic and financial modeling<br>• social impact analysis<br>• leadership<br>• change and transformation management<br>• stakeholder management<br>• quality management<br>• energy management<br>• sustainable & customer-oriented product and material design | • design thinking<br>• creativity<br>• adaptability, resilience and flexibility<br>• ability to work in a team<br>• ability to cooperate and communicate<br>• analytical understanding and ability to abstract<br>• responsibility<br>• critical & ethical thinking<br>• decision-making skills (based on data / assistive technologies)<br>• systems thinking / process thinking throughout the different steps of the production process<br>• creative and innovative thinking<br>• entrepreneurship<br>• willingness to learn<br>• scenario thinking<br>• flexible planning & organisation<br>• (agile) project operation<br>• coaching & training<br>• participative techniques<br>• multidisciplinary collaboration<br>• intercultural and language skills, international experience<br>• communications and media expertise<br>• self-development |



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## Changed skills and competence needs in the hydrogen economy

The future hydrogen economy will require additional well-trained specialists (Kaiser et al. 2020). Several US American research studies focused on the analysis of hydrogen economy jobs finding that the jobs created are disproportionately for highly skilled, well-paid, technical and professional workers. Still, emerging hydrogen industries do not exclusively require highly educated workers with masters or doctoral degrees but a wide variety of occupations at all skill levels.

Many of these jobs do not currently exist and require different skills and education than current jobs, and training needs must be determined. Occupation titles such as hydrogen energy technician, hydrogen energy system designer, operations engineer, program manager or safety investigator, hazardous materials management specialist or emissions reduction manager will become important in the future. Because of constantly evolving technologies, forecasting skill and training needs is quite difficult. Higher education and vocational training programs need to be assessed to understand where the opportunities lie and what additional curricula may be required (Bezdek 2019). Locally differentiated education and training strategies need to be developed, as the demand for skilled workers for project development and construction of new facilities can vary greatly at the local or regional level and can quickly lead to shortages (Krichewsky-Wegener et al. 2020).

### New job profiles at Yara: Technical expert - Ammonia Product carbon footprint and certification schemes

Yara International headquartered in Oslo, Norway is a manufacturer and supplier of chemicals and industrial gases such as fertilisers, urea, nitrates and ammonia. The Energy & Environment department presently consists of 12 persons in various locations who drive and manage Yara's decarbonisation and non-GHG environmental efforts including both project portfolio management and operational excellence initiatives globally in Yara's production system. The department is closely following up energy and climate related regulations and the development of carbon markets to assess the impact on Yara's carbon footprints. The technical expert will participate in initiatives set up for the developing of Yara's internal carbon footprint schemes, influencing the development of international standards and certifications for low carbon products (Yara International 2021).

### Training for sustainability at Evonik

Methodological competence training is offered at Evonik. There are tutorials, online training courses and digital "Evonik Learning Hours" in which up to 2,000 employees participate. The topics of sustainability and climate are also integrated into standard management training courses. New works councils are encouraged to address the issue. Actors, such as employee representatives on the supervisory board, must be qualified so that they can participate in internal and external discourse (Source: interview).

## Promoting training and education

As ECEG and industriAll European Trade Union state in a Joint declaration on the European Commission's Green Paper 'A 2030 framework for climate and energy policies'" the chemical industry can only be competitive with a highly skilled and qualified workforce. Training and education therefore also require investment to ensure a just transition and the best possible skilling for European industrial workers to handle new technologies (ECEG/industriAll Europe 2013). Confronted with a general shortage of skilled labour and many advertised positions still vacant, the need for qualified employees in the sector is increasing (IFA, 2020; see also European Commission 2019a). Workers in the sector are already highly skilled workers. Still, acquisition of new skills and training are essential. Continuing education is a necessity.

## International training network at Pirelli

As "to innovate is to keep learning", Pirelli has established an extensive training network across all countries where the company is present. Within ten Professional Academies among others the Manufacturing Academy and R&D Academy play an important role in the company's technological development. Sustainable Management elements are transversal throughout the Academies, with focus for example on environmental efficiency of the process, health and safety, sustainable management of the supply chain, risk management and diversity management (Pirelli 2020).

Regional training alliances in which large and small companies join forces would be one solution put forward by interview partners. Training structures must be created, and employees trained before they become unemployed. While large companies already provide training, smaller companies often do not have the opportunity to do so. Interaction between businesses and educational institutions must be increased. International cooperation is highly important. Policies such as increased university marketing and talent programs can help individual companies attract skilled workers (Kemianteollissus 2021).

A certain willingness to change is required from employees. This means a great deal of uncertainty, especially among more experienced employees. Here, the works council and trade union could play a role in involving employees. It must already be made clear during training that more flexibility is required.

# 5. The role of Social Partners

As stated in a recent study commissioned by the European Economic and Social Committee, regarding the future of work and a general more human-centred approach to managing change, a key component is social dialogue, including collective bargaining and tripartite cooperation (EESC 2020). Establishing a culture of social dialogue at all levels (company, sector, regional, national) will be an important element for timely anticipating change and to avoid social disputes, promoting retraining, upskilling and job-to-job transitions and necessary accompanying policies (industriAll Europe 2019a; see also industriAll global union/industriAll European Trade Union 2018; European Commission 2021b; Nelissen 2019). Social dialogue can also play a key role in managing the balanced adoption of new technology (ILO/OECD 2020).

Like companies, workers and employees in the sector, Social Partners are faced with growing challenges on the way to climate neutrality. Both, trade unions and employers' associations could be faced with an erosion of the Social Partnership and a declining importance of co-determination in the years to come. The transition might imply a shift towards a more fragmented economic system where collective agreements and trade union representation are weaker (ETUC 2018). Also, differences in countries due to relevance of the sector for the economy and the shape of industrial relations and social dialogue in the respective country as well as the impulses given by the government will have an impact on Social Partners' approaches.

Ideally, Social Partners should accompany and support their members in this transformation process and help shaping it in a way that is socially and economically viable. This encompasses measures and projects at all levels, from works council initiatives, to professional training plans, to the provision of further training measures and the monitoring of existing ones, to the negotiation of relevant company level or site agreements, to information and consultation mechanisms to better anticipate strategic, economic and technological changes and their impact on competences and skills to national measures and collective agreements (see for example ETUC 2018), and to transnational social partner cooperation including joint projects but also transnational and European framework agreements.

Relevant aspects for a successful transition such as training, health & safety and management of change may be subject to cross-border collective bargaining and transnational social dialogue (IZA 2011). Furthermore, Social Partners could engage in communication and education campaigns related to the transition as well as seeking dialogue with experts, politics, and consumers. Generally, the participation in, or setting up of concrete stakeholder initiatives or workshops can ensure that Social Partners' interests are represented on the one hand and help actively shaping the transformation on the other hand. Social Partners may exert a formative influence on the advancement of the creation of incentives to implement the transformation (including electricity prices, support for research and development). A joint discourse of the Social Partners with politics is necessary. Social Partners should promote an assessment of industrial policy consequences. A joint identification of framework conditions to keep companies in Europe or in the country will be useful. Acceptance of the entire transformation cannot be achieved through mere acceptance management and involvement, but only through co-determination and democracy.

## 5.1. Examples of social partner initiatives at company, regional, national and transnational level

### Company level

#### • Works council involvement and co-determination

At the corporate level, the issue of climate neutrality is becoming a topic for works councils and employee representatives on the supervisory board. In general, employees and co-determination bodies have a major role to play in unlocking potential energy and resource efficiencies as employee participation has a particularly positive effect on the optimization of processes and cross-cutting technologies. The works council can be involved in idea management, for example, and check whether suggestions are processed and taken into account in a timely manner. Co-determination and co-design must be raised to a new level. The competence of the employee representatives, the experts on site, must be involved at an early stage. Stakeholders in company and corporate co-determination must be just as qualified as company representatives.

With European legislation (NFRD, CSRD, REACH and taxonomy), there are many requirements for companies regarding sustainability reporting. However, works councils are usually not aware of these and their possibilities. Possibilities include regulating training on sustainability and transformation in agreements, setting up an innovation committee, extending information rights in innovation and investment decisions, and obtaining external expertise, especially on legal aspects.

The internationalization of companies is placing industrial relations on a new footing. Both Europeanisation and capacity building in Asia and the Arab countries are increasing the pressure and the need to create new forms of social dialogue and coordinate collective bargaining. Transnational company agreements have become an important tool to regulate working conditions, health protection, environmental responsibility and other aspects of corporate policy on a transnational and supranational level (Voß 2013b).

#### • Company agreements

There are attempts to include climate neutrality goals and their consequences in company agreements:

- The achievement of ecological objectives is gradually being included in some company-level social agreements, such as the accords d'intéressement in France (compensation and benefits agreements). These agreements are mainly local, site-level ones, mobilising small-size initiatives and objectives.
- At Worlée, a German producer of chemical, natural and cosmetic raw materials, a joint goal-setting agreement was concluded with the works council. A common vision was developed, from which a mission was created, and a mission statement formulated. There was a process with all employees in which values and principles of behaviour were jointly developed in townhall meetings. Energy, the environment and resource conservation play a central role here.

- A central works agreement “Safeguarding the future at Covestro stipulates that there will be no compulsory redundancies until the end of 2028 and no significant outsourcing or offshoring measures until the end of 2026. In view of the LEAP program to redesign structures, processes and support mechanisms, a key points paper was drawn up on extending the agreement on the number of trainee positions, capital expenditures, the transfer of trainees, the retention of the Group headquarters in Leverkusen and other points. Work packages are to be derived from this, including for the qualification of employees. Covestro is also committed to offering 120 - 200 company apprenticeships (including dual study programs) per year. The parties agree that modern and flexible forms of work (e.g. part-time, mobile and teleworking) and modern management structures and methods are becoming increasingly important in a digitalised working environment.
- BASF SE in Ludwigshafen has had a site agreement for many years. A new one was agreed last year also addressing the Green Deal. Two main objectives are pursued with the site agreements: firstly, to provide a reliable and resilient development perspective with investments for the Ludwigshafen site. Secondly, to establish protective mechanisms for employees. The overriding goal is to safeguard jobs; redundancies are ruled out until 2025.

Following the example of other sectors, a transition agreement providing a framework for discussion on the effects on human resources of new business structures between trade unions and company management[21] or an innovation agreement covering new business areas spun-off[22] may be additional measures.

## Regional level

As industrial cluster areas are most affected by climate neutrality goals, regional policy and measures are important. In this context, according to Unite the Union representatives, “regional hubs for decarbonisation with skills anticipation strategies and meeting the challenges of providing skilled jobs in these communities will be vital.” (Unite the Union 2021). In Belgium, for example, Social Partners are involved in the Social and Economic Council of Flanders (SERV), the main advisory body to the Flemish government on Flemish socio-economic policy. To accelerate the transition to a circular economy, the Flemish Social Partners in the social economic council of Flanders (SERV) have drawn up a policy agenda with 40 concrete recommendations. In preparation of the document “The transition to a circular economy: policy agenda and recommendations”, the SERV organised four round tables with different sectors including chemical industry.

## National sectoral level

### • Trade union or industrial association/employer organisation initiatives

Trade unions and industrial associations or employer organisations have begun to develop own projects aiming at getting a better picture of the industrial transformation ahead. For example, the German trade union IGBCE started a Transformation Camp this year to take place every year from now on and has launched a process called “Perspectives 2030+” in 2019. Based on four different scenarios members are discussing possible solutions for the upcoming challenges linked to the industry’s transformation. The aim is to develop a strategy for a future-oriented industrial policy by the end of 2021 (IG BCE 2021).

Industrial associations are seen as an important enabler for the transition to climate neutrality that may lead the companies in the transformation. As most of the companies are very small, the employer or industry organisation should support them with examples and offer them opportunities. Against this, in several countries, industrial associations have developed roadmaps for the chemical industry to become climate or carbon neutral. While the French organisation presented a preliminary roadmap for the decarbonisation of the chemical sector by 2030, the Finnish roadmap refers to carbon neutrality by 2045 and the German one to GHG neutrality until 2050. All roadmaps compare different quantitative scenarios examining different solutions and measures and their impact on GHG emissions.

[21] For example, the Italian trade unions Filctem Cgil, Femca Cisl, Uiltec Uil, signed an agreement with oil company ENI, see: http://www.industriall-union.org/sites/default/files/uploads/documents/2021/ITALY/ENI/eni_industrial_relations_protocol_2020_insieme_en.pdf

[22] See for example IG Metall and Bosch, https://www.igmetall.de/service/publikationen-und-studien/metallzeitung/metallzeitung-ausgabe-dezember/innovativer-tarifvertrag-fuer-innovative-geschaeftsideen


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The French roadmap does not define the scope of emissions included in their calculations. The German and Finnish roadmaps calculate direct emissions (scope 1), indirect emissions from the purchase of electricity and heat from external source as well as additional upstream and downstream emissions (scope 3) resulting from different scenarios. Finnish and German experts determine GHG emissions for one scenario where framework condition remain largely the same as today ("BAU" and "reference pathway" respectively), one intermediate scenario ("fast development" and "technology pathway") and one extreme scenario reaching full climate neutrality ("carbon neutral chemistry" and "GHG neutrality 2050 pathway"). The French roadmap distinguishes between the implementation of mature technological solutions such as enhancing energy efficiency and change of heat source and less mature solution such as use of hydrogen, CCS and electrification. For the latter, the effects of minimum, medium and maximum use or application (for example 20%, 33% and 40% of decarbonised hydrogen used in 2030) are determined. Furthermore, the Finnish publication also calculates the effect that chemical products have on the reduction of GHG emissions in other sectors ("carbon handprint").

Table 5: Roadmaps published by chemical industry associations in Finland, Germany and France

| | Roadmap to reach carbon neutral chemistry in Finland 2045 | Roadmap Chemistry 2050 - On the way to a greenhouse gas-neutral chemical industry in Germany | Roadmap for the decarbonisation of the Chemicals sector by 2030 |
|---|---|---|---|
| Initiated by | Chemical Industry Federation of Finland (Kemianteollisuus ry) | German chemical industry association (Verband der Chemischen Industrie-VCI) | „Chemicals and Materials" strategic committee[23] |
| Scope of GHG emissions considered | Scope 1-3+ "handprint" | Scope 1-3 | No definition |
| Scenarios | • Business as usual (BAU)<br>• Fast development<br>• Carbon neutral chemistry | • Reference pathway<br>• Technology pathway<br>• GHG neutrality 2050 pathway | Mature solutions<br>Less mature solutions<br>• Minimum<br>• Medium<br>• Maximum |
| Methodology | Quantitative calculations of GHG emissions, power use, investments, feedstock | Quantitative calculations of GHG emissions, power use, investments, feedstock | Quantitative calculations of GHG emissions reduction potential |
| Technologies/ solutions examined | Power-to-Chemicals<br>Energy efficiency<br>Electrification and power-to-heat<br>Raw material changes<br>CCS/CCU<br>Process development<br>Synthetic biology<br>Digitalisation | Chlor-Alkali-Electrolysis<br>Production of hydrogen<br>Ammonia synthesis<br>Methanol synthesis<br>Production of olefins and aromatics | Mature:<br>• Energy efficiency<br>• Decarbonated heat source<br>• Reduction of $N_2O$ emissions<br>• Reduction of HFC emissions<br>Less mature:<br>• Hydrogen<br>• CCS<br>• Electrification |

Source: Pöyry 2020, DECHEMA/FutureCamp 2019, Conseil national de l'industrie 2021

[23] The committee brings together the federations of the Chemicals (France Chimie, FEBEA, FIPEC and FNCG), Plastics and Composites (Polyvia), Paper and Cardboard (COPACEL) and Rubber (SNCP) industries representatives of the CFDT and CFE-CGC and the signatory Ministries (Economy, Ecological Transition and Labour)

In addition to the roadmap, the Chemical Industry Federation of Finland, together with Accenture, the Finnish Innovation Fund SITRA and Business Finland, a Finnish public actor that provides innovation financing and internationalization services, and promotes tourism and investment in Finland, has developed a "Circular economy playbook for chemical companies" in order to provide them with a good understanding of the importance of the chemical industry in accelerating the broader transition to a sustainable and circular economy across industries. Companies using the playbook shall be able to identify the competitive advantage that sustainable and circular business models can create for them through operations optimization, accelerated growth and enablement of downstream circularity, their key capabilities they need to develop to succeed in circularity and the potential barriers and ways to mitigate them (Kemianteollisuus et al. 2020). Future skills needs were addressed by the Dutch chemical industry association VNCI that coordinated a Human capital agenda for a better coordination of education and necessary qualification on the labour market (labour market monitoring, talent programs, broad networks). In a memorandum for the regional, federal and European elections 2019, essencia, the Belgian sectoral federation of the chemical industry and life sciences highlighted the importance of strengthening education and training (essencia 2019).

## Joint projects and initiatives

Joint projects and initiatives of the Social Partners are still rare. While in some countries, involvement is still limited to mutual invitations to summits on the topic of climate neutrality, in others exchange between Social Partners as well as with the government is further developed. For example, the German Social Partners are in close contact on the topic of climate neutrality and a good dialogue relationship has been established. They have launched several initiatives: the future forum for a sustainable plastics industry initiated by IG BCE (trade union) and GKV (employers' association) in 2011 for exchange and communication towards public and politics (GKV 2011), the Chemie³ sustainability initiative founded by VCI, IGBCE and BAVC developing sustainability guidelines for the chemical industry in Germany, a stakeholder dialogue involving IGBCE initiated by VCI (Dialog Basis/VCI 2019), the Social Partner Workshop for Innovation and Sustainability So.WIN (Chemie3 n.d.), a qualification offensive for the chemical industry, which the chemical industry's Social Partners agreed on as part of the 2019 collective bargaining agreement comprising a qualification advisory service launched by BAVC, IG BCE and the German Federal Employment Agency, a "Future skills report" and an analysis tool that can be used to better map the skills available in the company (BAVC 2020), a joint strategy on a hydrogen economy published by IGBCE and VCI (IGBCE/VCI 2020) as well as joint recommendations for action for the chemical and pharmaceutical industry drawn up by the German Federal Ministry of Economics resulting from an intensive dialog with BAVC, IG BCE and VCI (VCI/BAVC/IGBCE/BMWi 2021)).

### Responsible Care - implemented and monitored by Social Partners in Finland

Central themes of the Responsible Care programme include sustainable use of natural resources, sustainability and safety of production and products, well-being of the work community and open interaction and co-operation. In Finland, 98 companies have committed to the programme, representing some 80 % of all production in the chemical industry and some 60 % of its employees. The Chemical Industry Federation of Finland coordinates the implementation of the programme in Finland. Members participating in the monitoring and development of the programme include The Industrial Union, Trade Union Pro and the Federation of Professional and Managerial Staff (YTN) (Kemianteollissuus n.d.).

As part of the responsible care project within the project "Climate neutral chemistry", the association has been working with member companies since 2018. Two major goals are set: to reduce the footprint of operations and provide solutions to society to reduce their emissions to increase the carbon handprint. In the last two years, preparatory work has been carried out, creating technology roadmaps, playbooks, figuring out what strategic capabilities are needed and what are the framework conditions. Trade unions have been involved right from the start of the process.



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A closer cooperation among Social Partners and an enhanced dialogue between trade unions and employers' associations could increase the success and visibility of their activities.

### Feasibility and impact study of the European Green Deal and of industry decarbonisation on the chemical sector of the Czech Republic with focus on employment

In 2020, a study commissioned by the Czech social partners in the chemical industry SCHP ČR and the trade union ECHO was published, describing a wide range of issues related to meeting the objectives of the European Green Deal and the green transition of the economy. It analyses the impact of the Green Deal on employment and the planned sources of funding for measures to minimize this negative impact, including spending on wages and investments related to the creation of alternative jobs.

In the Czech Republic, industry is a significant part of the economy and accounts for a large share of employment. Therefore, the transition is more threatening than in countries where the share of industry in employment is lower. Economic actors will have to deal with significant negative cost pressure and declining demand. An approximation of the impact of the European Green Deal on the labour market in the chemical industry in the Czech Republic is carried out on the basis of models predicting the development of employment in three different scenarios between 2020 and 2030, showing that without an adequate response from the Czech Republic or the EU, jobs in the chemical industry will disappear.

A survey conducted in August 2020 among 30 members of the Association of the Chemical Industry of the Czech Republic found that about 89% of respondents perceive the European Green Deal as a threat, about 2/3 of companies plan to freeze their current headcount out of prudence regardless of economic developments and slightly more than half of companies expect that they will not have enough funds for wages and investment in human capital (CETA 2020).

## European/transnational level

At the transnational level, 13 trade unions from Denmark, Finland, Germany, Iceland, Norway, and Sweden represented by the Council of Nordic Trade Unions (NFS), the Friedrich-Ebert-Stiftung (FES), and the German Trade Union Confederation (DGB) have recently carried out a project entitled "The Road Towards a Carbon-Free Society. A Nordic-German Trade Union Cooperation on Just Transition". Based on six country reports analysing national climate policies and the respective national instruments, as well as economic and social consequences, a synthesis report gives political recommendations at national and European level to support the transition towards a carbon free society in a just and sustainable way highlighting the importance of education, training and better work environment, social protection and collaboration (FES 2021).

Furthermore, a joint trade union project funded by the European Social Fund has started in 2021 named "Werknemers als hefboom voor een circulaire economie" (Employees as leverage for a circular economy) initiated by Flemish trade unions cooperating with trade unions across Europe to gather concrete examples and guidelines for supporting the transition in terms of training, sector consultation, studies, mobilizing communication and events.

While there are also some European approaches involving for example the European Tyre and Rubber Manufactures' Association, finding a common approach at the European level still is difficult due to national differences regarding framework conditions and support but also with view to energy mixes and importance of the sector.

## Forward-looking skills for the rubber and tyre industry via a Pact for Skills

In October 2020, the European Tyre and Rubber Manufactures' Association proposes, in cooperation with the DRIVES (Development and Research on Innovative Vocational Educational Skills project funded by the Erasmus+ Sector Skills Alliances Programme, 2018-2021) and Alliance for Batteries Technology, Training and Skills (ALBATTS) partners, a strategy for the implementation of the European Commission Pact for Skills, for the Automotive ecosystem.

The aim is to put in place an up-/re-skilling framework which maximises industry competitiveness, job retention and new job opportunities –paving the way to a skills partnership for the whole automotive ecosystem. The initiative is supported by industry, educational and training institutions as well as the Social Partners Ceemet and industriAll Europe (ETRMA; 2020a; DRIVE, 2020).

## Cefic - Developing climate neutrality scenarios

At the end of 2019, cefic started to establish a scenario modelling tool for climate neutrality 2050 of the chemical industry. It adopts a cradle-to-gate approach producing four illustrative scenarios comprising electrification, circularity, biomass, and CCS. Technologies are considered in relation to their contribution to climate neutrality as well as their technological readiness and grouped in four categories: alternative processes enabling the use of low-carbon energy (such as electric crackers playing a central role in the production of basic chemicals and require a significant amount of energy to break down hydrocarbons into olefins and aromatics or ammonia from green hydrogen produced by electrolysis using electricity from renewable sources), low carbon heat and steam supply for example through electric or hydrogen boilers, alternative processes enabling the circular use of carbon (plastic waste pyrolysis or gasification, CO2 as feedstock, etc.) and carbon capture, transport and storage.

# 6. Conclusion and outlook

This report summarises the literature review and interviews carried out during the project highlighting framework conditions and corporate practices on the way to climate neutrality as well as fields of action to ensure a successful transition and the role of Social Partners. Information from chapters 1, 2 and 3 will be presented during the first Workshop in January 2022 that will explore the way the industrial transformation could go at company level, different technological possibilities, and the different abilities of companies to implement them and to adapt to change. Information from chapter 4 will be presented at the second Workshop as a basis for discussion of fields of action to ensure a successful transition for companies and workers and identification of the most pressing topics for Social Partners. Chapter 5 includes information on Social Partner initiatives at different levels that will be useful for the third Workshop that will be dedicated to the joint development of tools and recommendations on how social partners could tackle these topics. A final report combining information from this report and workshop results will be published in 2023.


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# 7. Interview partners

Representatives from the following organisations and companies have been interviewed for this report: 3F (Denmark), ACV-CSC (Belgium), BASF Personal Care and Nutrition GmbH (Germany), BASF SE (Germany), BAVC (Germany), BÜFA GmbH & Co. KG (Germany), Cefic (Europe), Covestro Deutschland AG (Germany), Evonik Industries AG (Germany), France Chimie (France), IGBCE (Germany), Kemianteollisuus ry (Finland), Reset Vlandeeren (Belgium), SIMA (Portugal), Stiftung Arbeit und Umwelt der IGBCE (Germany), Trade Union Pro (Finland), Unite the Union (UK), VCI (Germany), Worlée-Chemie GmbH (Germany).

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# Annex I: Examples

## Companies exploring new raw materials

**Use of sustainable raw material and recyclates at HEXPOL TPE GmbH**

By using sustainable raw materials and recyclates, HEXPOL TPE GmbH achieves an improved $CO_2$ balance, can contribute to an improved ecological balance and promotes the reuse of plastic waste (circular economy). In particular, the Dryflex Green series of TPE compounds based on renewable raw materials contributes to an improved carbon footprint. The plants needed to produce the bio-based plastic can also be grown on soils that are not suitable for growing plants for food. In this way, they do not displace food crops, improve biodiversity and comply with ethical soil management.

**Siemens and Evonik: production of specialty chemicals using $CO_2$ and renewable energy**

The project named Rheticus was launched in January 2018. "The first phase, Rheticus I, focussed on developing a technically-feasible basis for artificial photosynthesis using a bioreactor and electrolysers. In artificial photosynthesis chemical and biological steps are combined allowing energy to be used to produce chemicals from $CO_2$ and water. In Rheticus II, they combine previously separated plants in a test facility that will use $CO_2$ and renewable energy to produce specialty chemicals. The facility is located at Evonik's site in Marl, Germany."

**Carbon4PUR**

Answering to the SPIRE-08-2017 "Carbon dioxide utilisation to produce added value chemicals" call for action launched in 2015 as part of the Horizon 2020 programme, the Carbon4PUR research and innovation project will develop and demonstrate a novel process based on direct chemical steel mill gas mixture conversion, avoiding expensive physical separation, thus substantially reducing the carbon footprint and contributing to high monetary savings. The consortium and the development are organised along the full value chain starting with the provision and conditioning of industrial emissions from a steel to a chemical company fully in line with the concept of industrial symbiosis.

**Carbon2Chem**

The aim of the "Carbon2Chem" project is to obtain valuable basic materials for the chemical industry from metallurgical gas by adding green hydrogen in catalytic processes. The project is funded by the German Federal Ministry of Education and Research with 60 million Euros over four years and involves 17 partners from industry including ThyssenKrupp and Covestro, the Max Planck Society, the Fraunhofer Society and universities. The aim is to use 20 million metric tons of metallurgical gas - about one third of the total annual volume. This would avoid ten percent of the annual $CO_2$ emissions of all industry and manufacturing in Germany. In five to seven years, Carbon2Chem will be ready for large-scale use.

**Renewable Carbon Initiative (RCI): an initiative of eleven leading companies from six countries**

The companies participating in the initiative launched in September 2020 are Beiersdorf (Germany), Cosun Beet Company (The Netherlands), Covestro (Germany), Henkel (Germany), LanzaTech (USA), Lenzing (Austria), Neste (Finland), SHV Energy (The Netherlands), Stahl (The Netherlands), Unilever (UK) and UPM (Finland). The initiative strives to create cross-industry platforms that will demonstrate feasibility of renewable carbon in tangible activities. One main target will be to advocate for legislation, taxation and regulation changes to give renewable carbon a level commercial playing field. In addition, raising awareness and understanding of renewable carbon level is to be achieved.

**Covestro: polyether carbonate polyols and thermoplastic polyurethane based on $CO_2$ technology**
Covestro is developing and marketing new polyether carbonate polyols produced with the aid of $CO_2$ under the name cardyon™. With Desmopan® 37385A, the company now offers the first representative of a new series of thermoplastic polyurethanes (TPU) containing polyether carbonate polyols based on CO2 technology. Compared to conventional TPU materials, the new TPU products leave a smaller carbon footprint and help to close the carbon cycle.

**Cooperation of global energy company Iberdrola and the largest fertilizer producer in Spain Fertiberia**
In summer 2020, Iberdrola and Fertiberia announced plans to start producing green ammonia for emission-free fertilizers. The companies have signed an agreement, which will trigger an investment of 150 million Euros, to construct the largest plant in Puertollano by 2021 to produce green hydrogen for industrial use in Europe. Iberdrola will construct a photovoltaic plant (100 MW), a battery installation and a system for producing green $H_2$ by electrolysis from 100 % renewable sources. The green hydrogen will be used at the Fertiberia fertilizer plant in Puertollano, making it the first European company in its sector to develop large-scale expertise in the generation of green ammonia. The initiative will generate up to 700 jobs and avoid emissions of 39,000 $tCO_2$/year.

**Bio-based alternatives to PET bottles: from plant bottle to paper bottle**
The consumer goods industry has also been looking for bio-based alternatives to PET bottles in the last few years. In 2009 for example, the Coca-Cola Plant BottleTM packaging was introduced. It is partly (up to 30%) made from bio-based sources and, according to the company, the bottles are fully recyclable. Almost 10 years later, Coca-Cola has opened this technology to competitors. Recently, paper bottle projects entered the scene. In 2020, PepsiCo joined the Pulpex consortium (with Diageo and Unilever) to create and scale the world's first recyclable paper bottle. Further paper bottle projects are Paboco® and YXY® by Avantium.

Sources: Avantium, Brown 2020, Coca-Cola, Iberdrola, 2020, Jasi 2019, nova-Institut GmbH n.d., Paboco, PepsiCo, Pulpex Consortium, Renewable Hydrogen Coalition 2020, RUB 2016, TPE-Forum 2021, wdk 2019b, https://www.carbon4pur.eu/about/the-project

## Companies exploring alternative energy sources

**Global EnerTec combines waste disposal and decentralised power supply**
Since 2016, high-quality raw materials are obtained from waste rubber using thermo-catalytic degassing technology. The process temperature is around 550 degrees Celsius. Due to various catalysts added depending on the material mix, no pollutants are produced in the process. Oil and gas are also purified in the plant and converted into electricity and heat in a combined heat and power plant(CHP). With 500 kg of scrap tyre granulate per hour, 14 MWh of electricity may be produced in 24 hours.

**Bayer Finland reducing its carbon footprint**
At the beginning of 2020, Bayer switched to completely renewable energy at its Turku production plant, which significantly reduces $CO_2$ emissions. Bayer Finland requires a certificate of origin from all its energy suppliers, which confirms that electricity and heat have been produced completely renewable and without nuclear power. The steam from the Turku production plant is produced at Turku Energia's wood chip power plant built in Bayer's industrial area. Thermal energy is purchased as renewable from Turku Energia. As part of its carbon neutrality goal, Bayer Finland is launching a carbon footprint compensation program compensating for the company's remaining carbon footprint.


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**Worlée-Chemie GmbH using waste heat**

For 10 years, Worlée-Chemie GmbH has been obtaining part of its primary energy requirements from a biogas plant. While the electricity is fed into the grid, Worlée uses the waste heat from the CHP units to heat the thermal oil circuit. The waste heat has a temperature of around 400 degrees Celsius, while thermal oil is heated to 300 degrees Celsius. In this way, less natural gas is burned.

**Evonik investing in hydrogen**

Evonik is investing in replacing coal-fired power plants at the Marl Chemical Park with combined-cycle gas turbines (CCGT). These are designed in a way that hydrogen can also be used in the future if sufficient green hydrogen is available. In Lingen, Evonik has launched the GetH2 project together with RWE, BP and two grid operators. A natural gas pipeline operated by Evonik no longer in use is being used to transport hydrogen via the Marl Chemical Park. In addition to this North-South connection, there will also be an East-West connection from a wind farm in Rotterdam. The project partners want to show that it is also possible to build a hydrogen economy using existing pipelines.

**Kemira: Elasticity of demand helps reduce emissions**

Kemira's industrial chemicals production facilities require a lot of electricity, especially to produce sodium chlorate. Kemira is involved in demand elasticity, where production plants temporarily reduce their electricity consumption when electricity consumption is high in relation to its supply. This happens, for example, during severe frosts. Thanks to the elasticity of demand, electricity consumption peaks level off, which reduces the need to use backup power plants. This in turn reduces emissions, as reserve power is often generated by fossil fuels.

Sources: ADK 2018, Remes n.d., Interviews

## Companies exploring recycling methods

**Waste-to-chemicals project in Rotterdam**

The Waste2Chemicals initiative is a consortium of 8 international companies, including Enerkem, Air Liquide, Nouryon, and Shell which intend to begin a joint production of bio-based methanol and ethanol from municipal waste. The technology is compatible with existing waste infrastructure and is intended to enable wastes that cannot be mechanically recycled to be converted into fuels and high-quality chemicals via synthesis gas.

**Recycling of elastomers that are difficult to dispose of at BASF Polyurethanes**

BASF Polyurethanes GmbH develops, produces and distributes polyurethane precursors with a market-oriented focus with over 1,700 employees at the Lemförde site. In-house recycling is a high priority at BASF Polyurethanes, but some melts from the start-up process of synthesis plants to thermoplastic polyurethane can no longer be processed. Even incinerating the waste proves to be extremely difficult. In a joint cooperation with the company PKF (Pletz Kunststoffe in Form) from Ruschberg, a process was developed to shred this waste, which is unsuitable even for incineration, to separate it from other foreign materials and then to produce cable bridges from it by injection moulding.

**Carbios – „Enzymes powering the circular economy"**

The French start-up Carbios has designed and developed an innovative enzymatic recycling process. It uses an enzyme to depolymerise PET. The resulting monomers then are purified and re-polymerised. According to the company, the process allows the production of 100% recycled and 100% recyclable PET products without losses of quality. In 2021, the innovation is at pilot stage. The operational start-up is planned in the company's demonstration plant in autumn 2021. To industrialise their innovation, Carbios has joined with both academic and well-known industrial partners (L'Oréal, PepsiCo, Nestlé Waters, Suntory Beverage & Food Europe). Furthermore, they collaborate with Novozymes (enzyme production) and Technip Energies (engineering in the areas of energy, chemistry, and bio-sourced industries).

**Fraunhofer Institute - the CreaSolv® Process**

According to the Fraunhofer Institute, this solvent-based recycling process technology allows an efficient separation of plastic composites and contaminated post-consumer waste. Contaminants, additives, or odorous substances are removed during the process and the target polymer is recovered from the solvent by precipitation. The product (plastic recyclate) is said to be of high quality. Therefore, the process allows the closed-loop recycling of contaminated plastic waste and complex mixtures of plastics like laminated materials, or waste electronic and electrical equipment. For specific results, the CreaSolv® process is combined with mechanical, chemical, and thermal processes.

Sources: Carbios 2021, Enerkem 2019, Fraunhofer IVV n.d., wdk, 2019b European Circular Economy Stakeholder Platform



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# Annex II: Sub-sector specific technological developments

## Chemical industry

### Main products of the chemical industry and their relevance for GHG emissions

The chemical industry is composed of several sub-sectors that are not always clearly defined and delimited against each other[24]. Cefic distinguishes base chemicals, specialty chemicals and consumer chemicals. Basechemicals include organic chemicals such as ethylene, propylene or butadiene and inorganic chemicals such as ammonium, sulphuric acid, or chlorine and represented about 59% of total EU27 chemical sales in 2019 while specialty chemicals comprise auxiliaries for industries, paint and inks, crop protection and dyes and pigments accounting for 26 %. Consumer chemicals are sold to end customers, such as soaps and detergents, perfumes and cosmetics. They represented 14.9% of total EU27 chemical sales in 2019 (Cefic 2019a). Manufacturing of base (or commodity) chemicals is situated at the beginning of the chemical value chain. They are the starting materials for the synthesis of all other chemical products and are consequently expected to remain an important part of the mixtures of chemicals that may be produced in 2050. Their production is also responsible for two thirds to 75 per cent of the $CO_2$ emissions of the chemical industry (DECHEMA/ FutureCamp 2019). In manufacturing of commodity chemicals, GHG emissions mainly result from combustion of fuels for heat and pressure generation and production of hydrogen gas as feedstock in synthesis processes (Schiffer et al. 2017).

### Most important promising technologies related to decarbonisation in the chemical industry

Energy efficiency enhancements will play a more important role in the specialty than in the base chemical industry, but potentials will decrease until 2050 for both (DECHEMA/FutureCamp 2019). Electrification of processes has the potential to reduce GHG emissions in the commodity and specialty chemical industry (VoltaChem 2016). While the transformation process towards greenhouse gas neutrality requires efforts by the entire base and specialty chemical industry (DECHEMA/FutureCamp, 2019), the most important GHG emissions reductions can be made in base chemical production (see for example BASF 2021a). Due to their importance for $CO_2$ emissions, being the largest base chemicals in terms of volume and starting materials for the synthesis of all other chemical products, chlorine, ammonia, methanol, olefins and aromatics are most discussed in literature and interviews (see for example McKinsey 2018, DECHEMA/ FutureCamp 2019, ICCA/IEA/ Dechema 2013, Cefic/Ecofys 2013, Material Economics 2019, Chan et al. 2019 and Fleiter et al. 2019, CE Delft 2018, DECHEMA 2017).

Applying currently available Best-practice technologies (BPTs) could already lead to important energy saving and emissions reduction in catalytic processes in ammonia, methanol, olefins and BTX production. To further reduce emissions, technologies such as sustainable biomass feedstocks and hydrogen from renewable energy sources will have to be further developed (ICCA/IEA/Dechema 2013). The following pathways to decarbonisation of base chemicals production are discussed regarding chlor-alkali electrolysis, ammonia, methanol, olefins and aromatics production:

- #### Chlor-alkali electrolysis

Chlorine-alkali electrolysis is the most electricity-intensive process in the chemical industry. The most used process is membrane technology accounting for 83.3% of the installed capacity in Europe in 2019 (EuroChlor 2020). A further development of the membrane process using an oxygen-depolarised cathode (ODC) reduces the electrical power consumption considerably, but in return no longer produces hydrogen.

24 VCI, for example, includes pharmaceutical products in the definition of specialty chemicals.

The use of ODC technology will, given the existing energy mix, lead to considerable reductions in GHG emissions (Voß 2013a). Chlor-alkali electrolysis is a mature technology with $CO_2$ emissions arising due to the electricity required in its production. It is assumed that no new, disruptive technologies will displace the already existing electrochemical processes. Incremental improvements in process efficiency will continue, however their effect is relatively modest compared to the effect from the decarbonisation of the electricity system (DECHEMA/FutureCamp 2019).

## • Hydrogen production

For decarbonizing manufacturing of the base chemicals mentioned below, avoiding energetic and material $CO_2$ emissions in hydrogen production is essential. The most widely pursued approach to produce "green hydrogen" is the electrolytic splitting of water into hydrogen and oxygen. An alternative is polymer electrolyte membrane electrolysis, where the energy consumption and especially the costs are still higher than those of alkaline electrolysis. Also, in the case of high-temperature electrolysis the electricity demand can be significantly reduced. However, this technology has only been used in a few pilot plants so far. Methane pyrolysis, the thermal non-catalytic splitting of methane into hydrogen and carbon at high temperatures, represents another possibility for the provision of "green" hydrogen. The energy requirement of hydrogen production via methane pyrolysis is significantly lower than that of water electrolysis, however technical readiness is only expected from 2040 on. Methane pyrolysis is currently being pursued in research and pilot projects, among others by BASF, Linde and ThyssenKrupp. Other processes for the provision of "green" hydrogen include the gasification of biomass and organic secondary raw materials such as plastics, as well as solar thermal processes (DECHEMA/FutureCamp 2019).

## • Ammonia synthesis

Ammonia is mainly produced via steam methane reforming of natural gas combined with Haber-Bosch synthesis. Alternative, low-emission processes are based on the supply of hydrogen via water electrolysis and methane pyrolysis. Production costs are still significantly higher than for a conventional plant due to the high demand for natural gas in relation to the hydrogen produced for the process. Cost parity is therefore not likely to be achieved until 2050 (DECHEMA/FutureCamp 2019). Furthermore, several new methods such as biological nitrogen fixation using bacteria, electrochemical production of ammonia directly from nitrogen and water and chemical looping processes involving chemical or electrochemical reactions producing ammonia as a by-product (The Royal Society 2020) exist. Using renewable energy and feedstock is estimated by researchers to be a good solution in the short term as they can be combined with the existing Haber-Bosch process making it easier for companies to implement. Still, in the long run, alternatives to this process must be further developed (c&en 2019). As a large part of ammonia is combined with $CO_2$ and used in urea-based fertilizers, it will also l be important to find solutions for decarbonisation either by using other fertilizers, the use of $CO_2$ directly captured from the air (DAC) combined with zero-carbon ammonia or use of biogas as the input to a SMR process, then capturing $CO_2$ to be used in the production of urea-based fertilizers (Energy Transitions Commission 2018).

## • Methanol production

In Europe, methanol is produced almost exclusively from natural gas. Recent applications such as Methanol-to-Olefins (MtO) for plastics will further promote growth leading to significant upscaling challenges. Renewable methanol can be derived from biomass or synthesized from green hydrogen and $CO_2$ ("green e-methanol") leading to an important need for green hydrogen and electrolyser capacity, biomass such as forestry and agricultural waste and by-products, biogas from landfill, sewage, municipal solid waste (MSW) and black liquor from the pulp and paper industry and sustainable $CO_2$ for example from DAC as feedstock. CCU is an option but is only seen as a transition solution. Production technologies are already fully commercial, however at higher cost compared to fossil fuel-based alternatives (IRENA 2021). Due to the relatively high biomass requirements, methanol production from biomass is not very resource efficient (DECHEMA/FutureCamp 2019). There are several plants for bio-methanol and e-methanol production already in place in Europe. For example, established in 2011, a plant of Carbon Recycling International (CRI) in Iceland produces e-methanol from geothermal $CO_2$ and $H_2$ from water electrolysis. Several consortia in Belgium, the Netherlands, Germany and Denmark use the same feedstock.


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Furthermore, bio-methanol plants are operational in Sweden (Södra using extraction from pulping process), Germany (BASF using natural gas/biomethane) and the Netherlands (OCI/BioMCN using natural gas/biomethane) (IRENA 2021).

- **Production of olefins and aromatics**

To produce olefins and aromatics, in the cracking process, the hydrocarbon chains of the feedstock, usually naphtha, are thermally cracked with the help of steam. Methane, hydrogen and heavy oil are produced as by-products and have so far been burnt to cover the energy requirements of the process resulting in $CO_2$ -emissions. By heating the process with electricity, these emissions are avoided, and the by-products can be used in other processes. The electrically heated cracker is currently in the development stage. The technology will be ready for use in the next 10-15 years, however, cost parity compared to conventional crackers will not be reached soon. In addition to electrical heating, feedstock for obtaining naphtha may be changed from crude oil to biomass from sustainable resources. Alternative routes to olefins and aromatics can in principle also be established via methanol building on the low-emission methanol processes described above requiring extensive additional production capacities for renewable methanol (DECHEMA/FutureCamp 2019). Nevertheless, steam cracking of hydrocarbons is and will continue to be the main industrial process to produce light olefins in the coming decades (Amghizar et al. 2020).

# Pharmaceutical industry

## Main products of the pharmaceutical industry and their relevance for GHG emissions

The pharmaceutical industry researches, develops, produces and sells medicine and medical devices. That includes prescription drugs that need the intervention of a doctor, self-administered products on prescription, self-administered drugs and products sold “over the counter”, which means in general stores, and all sorts of tools and devices surrounding medical acts and interventions. The clients of the pharmaceutical industry are therefore: hospitals, medical professions, stores, drugstores, and individuals. The industry is structured by major transnational companies (“Big Pharma”) covering nearly all therapeutical areas and market segments; and a growing number of small companies specialized either on a few products and molecules (R&D start-ups), on generic medicines, or on a part of the processes, namely the production (manufacturers). The industry can be divided following several factors:

- The type of products, either on prescription or OTC (over the counter)
- The therapeutical areas (oncology, diabetes, respiratory diseases, etc.)
- The model of companies (big integrated ones, small manufacturers, specialized start-ups)

It is difficult to access a global carbon footprint of the pharmaceutical industry. It is partly caused by the uneven classification of the industry into sectorial unions and/or employers regroupments. In several countries, the pharmaceutical industry is considered as part of the chemical sector, in some others, it is a separated sector. Moreover, several major actors of the pharmaceutical industry are part of wider world leading chemical companies (Bayer, Roche) and some of the industry’s plants across Europe are part of the major chemical factories of the continent.

A first attempt to establish the carbon footprint of the industry has found that the emission’s intensity in 2015 was 48.55 Mt-$CO_2$e per million of dollars, that is 55% higher than the automotive industry, and leads to an estimate of 52 MMt-$C0_2$e for the sector. The big pharma actors were engaged in reduction trajectories of their emissions from 2012 to 2015. The study points to a major variability between the major actors, that can partly be explained by the product mix of their portfolio (Belkhir & Elmeligi, 2019).

The growing importance of the ecological issue and the implementation of regulations and laws have raised the awareness on this topic and some companies have calculated their carbon footprint. A good example is the global analysis provided by GSK. GSK, a major manufacturer of inhalers to trat respiratory diseases, has an estimated 15.9 Mt-$CO_2$e per year. 7.2 Mt (45%) comes from the purchased goods and services; 1.3 (8%) come from their own operations, mainly energy consumption; 6% come from their logistics; 40% come from the patient use of products, mostly the inhalers (GSK carbon footprint, 2020).

Sanofi, in comparison, as identified that 54% of their carbon footprint come from their purchased goods and services, 10% from capital goods, whereas direct emissions (scope 1 & 2) account for 13% of the global emissions (Sanofi carbon footprint, 2020). Even if various initiatives have been taken to lower their impact, transportation of raw materials (coming from east Asia) and products all across the world and travel from employees, including the salesforce, remain secondary in the carbon footprint of the global industry.

The main providers of GHG emissions for the industry are:

- Sourcing of raw materials from the chemical industry and energy to support the production processes
- The implementation of the chemical or biological processes to generate the medicine, especially the manufacturing of API (Active Pharmaceutical Ingredient)
- The use of devices by individuals or medical professions, especially inhalers used to fight several respiratory diseases

The importance of that last item on the carbon footprint of GSK indicates that the carbon footprint of the industry is highly dependent on the therapeutic areas and ways of inoculation of the medicines. Therefore, the carbon impact of the companies and the answers will vary depending on the strategic choices made by each company.

## Most important promising technologies related to decarbonisation in the pharmaceutical industry

There are four major points on which the pharmaceutical industry can work to lower its carbon footprint: Energy saving, especially related to heating and cooling, a reflexion on the production processes to diminish the number of actions involved, a change in the sourcing of materials used in manufacturing as well as issues regarding product design.

### • Energy savings, heating and cooling

The initiatives mentioned by the major actors of the industry in their environmental actions reports (or equivalent) are mainly initiatives to address the energy savings and heat/cold production issues (EFPIA 2020). For example:

- A Combined Heat Power unit in a UCB site in Belgium improving the efficiency and replacing natural gas with biomethane progressively
- More efficient heat pumps on AZ sites in Sweden
- Solar panels on plants' roofs by Pfizer
- A better leak control in the chillers and coolers and a change of refrigerant solution in Sanofi's French sites

All those initiatives show that the technologies are mature enough to be implemented at a global scale, to reduce and optimise the carbon footprint of the manufacturing plants. The last point has been identified as a priority by several actors of the industry. Moreover, several actors of the industry have integrated an internal carbon price, to value the carbon impact of their projects in their investment decisions (Johnson & Johnson; Novartis, 2020).

### • Reducing the actions involved in production processes

A study of the manufacturing process of pharmaceutical tablets in 2018 showed that modifications aiming to eco-efficiency can lead to a reduction of 73.2% of the GHG emissions per tablet and induced a lot of other major gains (Hindiyeh and al. 2018). The tableting process is the manufacturing process by which a powder is compressed to form a tablet, which is one of the common forms of medicine in the industry. The powder includes the API (Active Pharmaceutical Ingredient) and various excipients. Several types of processes can be used to produce the tablet, the most efficient one being the direct compression. Nonetheless, those processes generate GHG emissions.

The article studies a manufacturing plant in Jordan. The manufacturing process has been changed to reduce the number of steps and use different ones, without modifying neither the machines nor the competences needed to operate them. The change of process led to massive reductions in the use of time and energy, and therefore, in GHG emissions.


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The same product has been reached with a new process mobilizing 71% less time and 73.2% less energy, and therefore GHG emissions. That study paves the way for a process-efficiency reshaping, leading to more resource efficiency. Nonetheless, the reduction of GHG depends on the energy sourcing of the manufacturing plant.

With a similar perspective, another article in 2019 demonstrates that the number of steps in manufacturing similar medicine will determine the carbon footprint of said product. The study looked at 20 different anaesthetic APIs and showed a 1 to 273 (!) difference between the different products. It also concludes to a corelation between the number of synthesis steps in the manufacturing and the carbon footprint. The study focused on 20 products on a cradle to gate analysis and concluded that the more synthesis operations, the bigger the GHG emissions. Moreover, the majority of GHG emissions of the less ecological products was due to direct venting of waste gas post-use (Parvatker and al. 2019).

That leads to two conclusions:

- the industry needs to simplify its manufacturing processes to lower its carbon footprint
- the product design and user recommendations are critical to reduce the global GHG impact of the industry.

Another study on anaesthetics in the UK showed that manufacturing processes and utilization guidelines could have a significant impact on the GHG emissions, especially by using vapour capture technology (VCT) to reuse the gas previously lost. The various combinations tested lead to a 1-50 difference (Hu and al., 2021).

## • Product design and recycling

The use and end-of -life stages contribute to 90% of the carbon footprint of the HFA (hydrofluoroalkane) inhalers[25] used to treat asthma. Dry-powder inhalers have a 10 times smaller carbon footprint than HFA ones. HFA have replaced CFC as propellants in the metered-dose-inhalers (most commonly the Ventolin) due to the concerns regarding the impact of CFC on the ozone layer. Nonetheless, the main one, HFA-134a has a considerable global warming potential, 1300 times higher than that of $CO_2$. The study concludes that reducing the amount of propellant in MDIs by 67% reduces the GWP by the same percentage and switching from HFA 134a to HFA 152a would reduce it by 93%. Moreover, the recycling of partially used MDIs can lead to a recuperation of up to 20% of the HFA contained in them. Nonetheless, dry powder inhalers still have a lower carbon footprint, 380 time lower than the basic HFA 134a MDI option (Jeswani and Azapagic 2020). The GWP of the HFA inhalers across the world is the equivalent of the GHG emissions of 5.5 million diesel cars. The increase of atmospheric pollution will lead to the development of respiratory diseases and the use of such products. Therefore, that issue is a major one in order to tackle the industry's GWP. As pointed out in the EFPIA White Paper, Chiesi is already implementing the HFA change in its inhalers.

Several key dynamics of the industry can be used to improve the efforts to reduce the pharmaceutical industry's GWP:

- The industry faces a new cycle of R&D, including new cross-therapeutic area projects and the development of genomic medicine on the one hand and big data on the other hand. In this context, innovative devices and manufacturing processes can be implemented, including the concerns raised earlier
- Following social concerns and issues, the industry is leading towards the development of biological molecules instead of chemical ones. The biological products represent 29% of the global pharmaceutical market in 2019 and will grow to reach 35% in 2026. They already account for half the R&D projects in the industry. A case study on the production of 7-ACA (a core chemical structure for the synthesis of several antibiotics) has shown that the biocatalytic route was greener than the chemical synthesis one, which uses 60% more energy, 16% more mass, and emits twice the amount of GHG. Therefore, the growing importance of biological processes instead of chemical synthesis ones will lead to a more eco-efficient industry (Henderson et al. 2008).

[25] The metered dose inhaler (MDI) was developed in the 1950's. The propellant used in MDIs used to contain CFCs (Chlorofluorocarbons). The propellant in most of the MDIs now is an HFA (hydrofluoroalkane) propellant.

# Plastics industry

## The European plastics industry and its relevance for GHG emissions

The European plastics industry consists of plastics manufacturers, plastics processors, plastics machinery manufacturers and plastics recyclers. According to Plastics Europe, it employs over 1.5 million people in more than 55,000 companies (mostly SMEs) along the entire value chain. More than 90% of the sector's employees and companies can be assigned to the plastic converters. For decades, the plastics industry has been growing dynamically. In 2019, it created a turnover of over 350 bn Euros (Plastics Europe 2020a).[26] While plastics production in the EU has been stable in recent years, the EU's market share is decreasing. It is expected that in the short to medium-term, market demand and production will further increase in - and shift to - emerging economies, the USA, and the gulf region.

Plastics cover a wide range of synthetic or semi-synthetic materials based on polymers which are mostly fossil-based (crude oil or natural gas) and just to a very small extent based on alternative feedstock (e.g., renewable or recycled). Therefore, the industry is largely dependent on raw material prices and availability and its products are literally built out of carbon. Plastics have become key materials in various sectors. By end-use markets, demand for plastics in Europe is highest in packaging (39.4%), followed by building and construction (20.4%), automotive (9.6%), electrical and electronic (6.2%), household, leisure, and sports (4.1%), agriculture (3.4%), and others (16.7%). Lately, for example, the disruptions in the automotive industry have affected the plastics industry with a sharp decline in demand.

While innovative plastic materials can contribute to the economical use of energy and resources, as well as reduced emissions in other industries, large quantities of greenhouse gases are emitted at each stage of the plastic lifecycle. It is estimated that around 61% of $CO_2$ emissions relate to production, 30% to the processing industry and 9% to waste disposal (Stiftung Arbeit und Umwelt der IG BCE 2021, BUND 2019). It is estimated that the global GHG emissions from plastics would reach 15% of the global carbon budget by 2050 if plastics production continued to grow like in the past four decades and not considering any mitigation strategies (Zheng, J., Suh, S. 2019). Furthermore, the growing amount of plastic waste and related global problems like marine litter or microplastics in the environment add to a negative image of the industry in society and to both public and political concern.

Compared to other materials, reuse and recycling rates of plastics still are low. In 2018, out of 29.1 million tons of European plastic post-consumer waste, 42.6% ended up in energy recovery (incineration), 32.5% in recycling and 24.9% in landfill. While compared to 2006, recycling has doubled (+100%), energy recovery has increased significantly (+77%) and the amount of waste going to landfill has been reduced (-44%), there is still room for improvement. There are multiple reasons for low recycling rates: many of them are cost- and technology-related. However, the expansion of plastics recycling could offer new and profitable business opportunities to European companies (Cp. McKinsey 2018b).

## Most important promising technologies related to decarbonisation in the plastics industry

Since end-of-life emissions will probably become by far the dominant source of emissions, it will be increasingly important to reduce them. System changes in four key areas are required: feedstock (from fossil feedstock to end-of-life plastics and biomass feedstock), production (from unabated steam cracking and polymerisation to new, clean production processes), use (from single-use to materials-efficient and circular use), and end-of-life (from incineration and limited mechanical recycling to materials recirculation) (Material Economics 2019).

[26] Sources for figures in this chapter unless indicated otherwise: Plastics Europe: Plastics – the Facts 2020 (Plastics Europe 2020a). Figures for Europe relate to EU-28, Norway, and Switzerland.



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- ## Prerequisites for a circular plastics economy: product/eco design and waste management

A circular economy approach has been identified as (one) key to the decarbonisation of the industry. This means that ideally all plastics should be kept in the economy (at their highest value) and out of the environment. Two fundamental elements in this circle are the product design on the one hand and waste management on the other hand. "Sustainability-by-design" for example can be achieved by integrating safety, circularity, and functionality within innovative technologies at the material or article level of plastics (Suschem 2020). To extend the lifecycle of plastics, products must be designed in a way that makes them more suitable for recycling (physical, chemical, or biological), reuse, or repair, moving away from single use. For producing companies, adapting to new designs also has a great potential to cut the Extended Producer Responsibility costs (Plastics Recyclers Europe 2021b). In terms of waste management, improved waste collection systems and advanced (highly automated) waste sorting technologies (identification, separation) as well as the related infrastructure will be essential to increase the recycling of plastics.

- ## Recycling process technologies

Innovative plastic recycling process technologies, involving either physical or chemical processes or both, could act as a "gamechanger" on the way to a carbon neutral plastics industry if they succeeded in increasing the recycling rates of plastics. According to Plastics Recyclers Europe, plastics recycling can save up to 80% of $CO_2$ emissions (Plastics Recyclers Europe 2021a). Up to now, mechanical recycling is the most popular recycling method in Europe. Mechanical recycling is defined as the "processing of plastics waste into secondary raw material or products without significantly changing the chemical structure of the material" (ISO 2008). The mechanical recycling process (also classifying as "material recycling") is a well-established process for thermoplastic materials such as PET bottles. Solvent-based processes[27] (dissolution) represent another type of physical recycling technologies. Still, there are several limits to mechanical recycling technologies. One key challenge is the quality of output (recyclates / secondary plastics) that largely depends on the quality of input. "Downcycling" to lower-value plastics is a well-known problem. In the years to come, mechanical recycling must therefore be optimised and expanded. This includes further development of waste (pre) treatment technologies reducing the contamination of input streams.

In May 2021, PlasticsEurope announced an increase in planned chemical recycling investment by European plastics manufacturers: from 2.6 billion Euros in 2025 to 7.2 billion Euros in 2030 (PlasticsEurope 2021). Chemical recycling technologies, as a complement to mechanical recycling, could have the potential to facilitate the recycling of plastic waste that is currently (almost) not recyclable using mechanical recycling technologies (e.g., contaminated, mixed polymer and composite plastics as well as thermosets) and thereby closing the carbon cycle. They can either separate different types of plastics and/or plastics from other materials as well as removing impurities and hazardous substances from the material cycle. Plastic polymers are broken down into monomers or chemical building blocks that can then be fed into another chemical process to make new products. Chemical recycling technologies are often also referred to as feedstock recycling or feedstock recirculation. One main opportunity of chemical recycling is that the "output material" can be processed and used again and again without any downgrading (KIDV 2018). Thus, it is also suitable for food-grade applications for example. On the downside, chemical recycling requires new infrastructure, secure feedstock supply, integration with other chemical processes, and substantial energy inputs (Material Economics 2019). To make the recycling economically feasible, chemically recycled feedstock is very likely blended with other raw materials in the chemical manufacturing complex which poses problems in terms of traceability (Ellen MacArthur Foundation 2019). At present, solvolysis[28], pyrolysis, gasification and depolymerisation processes are the four most frequently mentioned chemical recycling technologies. A wide range of processes fall under these collective terms.

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[27] Solvent Recycling Systems uses a state-of-the-art distillation process with automated monitoring to reclaim solvents that have become contaminated in cleaning operations. The recyclers heat a spent solvent to its boiling point in a tank, causing the solvent to vaporize and separate from its contaminants.

[28] Solvolysis isa chemical reaction in which the solvent, such as water or alcohol, is one of the reagents and is present in great excess of that required for the reaction. The solvents act as or produce electron-rich atoms or groups of atoms (nucleophiles) that displace an atom or group in the substrate molecule.

They are at different maturity levels, largely focused on the pilot scale, and it might take another ten to twenty years (depending on the respective technology) until they are ready for the market at large scale (Stiftung Arbeit und Umwelt der IG BCE 2021).[29]

- ### Alternative feedstocks and innovative materials

One step towards the decarbonisation of the plastics industry could be the increased use of bioplastics. According to European Bioplastics (2018), there are at least three categories of bioplastics that must be differentiated: either biobased (regrowing), biodegradable, or both. Biobased plastics are not necessarily biodegradable whereas petroleum-based plastics can be biodegradable. Biobased plastics are (partly) derived from renewable resources (e.g., agricultural or forest feedstock such as sugarcane, corn, or cellulose). Several biomass feedstocks can be processed into bioethanol, bio-methanol, biogas, or bio-naphtha, which can then be used to produce conventional plastics. Among the established processes are anaerobic digestion or gasification processes that use methanol as a new platform chemical which then can be turned to olefins (methanol-to-olefins). Both processes require large amounts of electricity and biomass. Therefore, there are opportunities for more innovative resource-efficient routes in this field (Material Economics 2019). Today, biobased plastics represent only up to 1% of EU annual plastic consumption, but their market share is growing (European Commission 2018a).

When bioplastics reach their "end-of-life", new challenges arise. Biobased plastics such as polylactic acid (PLA) or polyhydroxyalkanoate (PHA) for example are biodegradable but separate recycling processes and streams still must be established and certain volumes must be achieved for economic viability. If not, these materials can contaminate the existing conventional recycling streams and degrade the quality of recycled plastics. On the industrial (and political) side, adequate waste collection and treatment / composting infrastructure are needed.

# Rubber industry

## Main products of rubber industry and their relevance for GHG emissions

In 2018, there were about 7,000 companies active in manufacturing of rubber goods in the European Union with a turnover of 80 billion Euros and 355,000 persons employed. One fifth of the companies produced rubber tyres and tubes or retreaded and rebuilt rubber tyres creating more than half of the turnover with about one third of the employees (Eurostat, 2021a).[30] Most of the companies in the sector are SMEs (about 98%) including many micro enterprises with less than ten employees (ETRMA 2019b). Manufacturing of other rubber goods comprises products of natural or synthetic rubber such as rubber plates, tubes, pipes, hygienic articles, rubber thread or yarn, rubber rings or balloons and many more (Eurostat, 2008). Among the top 10 general rubber goods producing companies in 2017 there have been two German companies (Continental Ag and Freudenberg Group) as well as the French Hutchinson SA and the Swedish company Trelleborg. As to tyre production, Michelin (France), Continental (Germany) and Pirelli (Italy) were listed in the top 10 in 2018 (ETRMA 2019a). The most important market for general rubber goods is the transport sector including automotive, rail, ships, aviation and aerospace accounting for 63% of sales (ETRMA 2019b).

[29] Another promising technology is plastic pyrolysis, the thermochemical decomposition of a material at high temperatures in an oxygen-free atmosphere (with or without the presence of a catalyst). Depolymerisation is a method, involving solvents and heat, where polymer chains are broken down into shorter chains and monomers which then can be polymerised again. Gasification processes can, under high temperatures, turn plastics into syngas which can be used as a building block for new polymers. Costs of gasification are influenced by the costs of oxygen and hydrogen needed for the gasification into syngas and the subsequent reaction to produce methanol. It is important to note that waste-to-energy (energy recovery) processes including plastics-to-fuel processes (e.g., pyrolysis) are not classified as recycling in Europe and that they are not part of a circular economy.
[30] NACE C22.1 (Manufacture of rubber products), 22.11 (Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres) and 22.19 (Manufacture of other rubber products), data on company number has to be used with caution as definitions differ.


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$CO_2$ emissions per tonne of tyres produced have decreased by up to 20% between 2005 and 2019 (ETRMA, 2020c). Typically, 80% of the whole-life $CO_2$ emissions of a car tyre arise from its use. Production of raw materials and energy account for 10%, end of life processing for 5% while tire manufacturing can only be held responsible for 3%. The remaining 2% of $CO_2$ emissions are created by transport. Accordingly, research and innovation activities are largely focused on the reduction of rolling resistance to reduce fuel consumption and hence emissions in operation (BTMA, n.d.).[31]

## Most important promising technologies related to decarbonisation in the rubber industry

To reduce GHG emissions in the rubber industry, circular economy and recycling, the choice of raw materials and energy use are the most important starting points.

### • Circular economy and recycling

In accordance with the slogan "Reduce, reuse, recycle", a long-standing design-for-reuse strategy has been implemented by the tyre industry with retreaded tyres recovering material and extending the lifetime of tyre using tyre casings several times (ETRMA, 2020b). The tyre industry also has been pioneering the circular economy for decades with End-of-Life Tyre management companies exploring areas for recycled tyres. In energy or thermal recycling, the used tyres replace primary energy sources, i.e. fossil fuels. Due to their high calorific value (high energy yield with low material input), scrap tyres are in demand as a fuel in waste treatment plants or in cement production. Scrap tyres are used as a secondary raw material, for example as vibration dampers in construction or in running tracks, stable mats, fall protection flooring, moulded articles or artificial turf pitches. In addition, recovery of raw materials through pyrolysis decomposing old tyres into carbon black, oils, gas and steel (see for example Trelleborg, 2021) or devulcanization (see for example Versalis, 2019 or Wintersteller et al. 2020) also contribute to the circular economy.

### • Alternative and renewable raw materials

Natural rubber as a renewable raw material has a considerable potential for both climate neutrality and sustainable development (Gitz et al. 2020). However, the potential contribution of rubber to climate change mitigation is generally negative when rubber replaces primary or secondary forests, but positive when planted on very degraded land. When planted in monoculture, it is harmful to biodiversity, but swidden agriculture and mosaic landscapes may have more positive effects (CGIAR, 2019). Natural rubber is already used extensively in various products. To widen applications, specialty NRs (epoxidized natural rubber and deproteinized natural rubber) have been developed as alternative material from more sustainable resources with properties comparable to the synthetic counterparts (Rubaizah, 2021). Natural rubber also will play an important role in plastics substitution and the circular bioeconomy. Substitution needs will create a new demand (Martius, 2021). Apart from Hevea rubber tree, guayule and Russian dandelion are considered as alternatives for polyisoprene production that, however, have not yet evolved as commercially viable alternatives (IRSG, 2020e). Also, when it comes to synthetic rubber, green biodegradable rubbers are under development (Mondragon, 2017). For example, US researchers have developed a process to extract butadiene, from which rubber and plastic are made, from trees and grasses. Using a new catalyst developed in the lab consisting of phosphorus, silica and zeolite, butadiene from biomass sugar in a three-step process can be produced (Pressetext, 2017). Also in 2017, Versalis (Eni) and Genomatica, have announced that they have successfully advanced to pilot-scale production of bio-butadiene (bio-BDE) from fully renewable feedstock (bioplastics Magazine, 2017). Furthermore, with peptizers and processing promoters for elastomer compounds made from the fruit of the oil palm, $CO_2$ emissions may be significantly reduced for example in tyre production (Lanxess, 2020). Finally, $CO_2$ together with maleic anhydride can be used as a feedstock in elastomers (Meys et al. 2019).

[31] A study at Nokian tyres even concludes that 87 % of the GHG emissions were formed during the use of the tyres and that the manufacturing of the tyres comprised only a small amount of the total GHG emissions (2.1 %), see Kokko, 2016, for further information see also: Piotrowska et al., 2019.

- ## Energy sources and efficiency in the production process

In addition to decarbonisation options substituting natural gas by using biomass boilers, electric boilers, hybrid boilers or hydrogen boilers (Abdallas Chikri et al. 2019) or using photovoltaic systems for electricity supply and waste heat from a power plant to vulcanize[32] the tyres (Fricke, 2020), rubber chemicals may support the energy reduction in rubber processing through vulcanising agents and accelerators helping achieve vulcanisation in a more efficient way at lower temperatures thus saving energy (ERCA, 2019).

[32] Vulcanization is a chemical process that converts natural rubber and other polydiene elastomers into cross-linked polymers. The most common vulcanization agent is sulfur. It forms bridges between individual polymer molecules when heated with rubber.



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