Federal Ministry
Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

Definition of Green Chemistry

Position paper of the Austrian Platform of Green Chemistry (PGC)

Legal notice

Media owner, publisher, editor:
Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology, Radetzkystraße 2, 1030 Vienna, Austria
Photo credits: Cover: stock.adobe.com – ipopba
Vienna, 2022

Introduction

The Austrian Platform Green Chemistry (PGC) understands “green chemistry” to mean a holistic approach by which the concept of sustainability will be integrated into the fundamentals of chemistry and established as a core standard among all chemical industry actors. Here, the entire process from the design and engineering of a new substance to its production, processing, use, reuse, and disposal should be evaluated. In line with the objectives of the European Union’s Green Deal and the European Chemicals Strategy for Sustainability – resource preservation, safety, and sustainability – green chemistry shall contribute materially to

- continuously reducing the hazard potential of chemicals for humans and the environment over the entire life cycle,
- ensuring that the processes for the production of chemicals – from raw material sourcing to the marketing of substances and mixtures – are safe and environmentally friendly while minimising greenhouse gas emissions and resource consumption,[1]
- ensuring that the use of chemicals in consumer goods production is based on the principles of safety and sustainability, and
- ensuring that the waste materials and residues that are generated over the entire life cycle of a chemical are returned to the material cycle, unless they can be avoided.

The PGC does not view green chemistry as a new discipline in chemicals science, but as a societal commitment to producing chemicals energy- and resource-efficient and using them in a circular manner to the greatest extent possible based on the principles of protecting human health and the environment. This comprises all aspects from the values imparted to children and their education to research, economy, and industrial practice. The PGC views the 12 principles of green chemistry drafted by John Warner and Paul Anastas as a very useful, concrete, and ambitious roadmap for achieving this future state.

---

[1] In accordance with the 2030 Raw Materials Master Plan and the Circular Economy Strategy, a central goal is to replace primary raw materials with secondary materials, and to replace fossil raw materials with biogenic raw materials

Background paper on the development of the definition of the term "green chemistry" used by the Austrian Platform Green Chemistry

In 2020, the Platform Green Chemistry was created at the initiative of the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Environment Agency Austria (UBA) as a nexus of collaboration among experts from science, education, public administration, the chemical industry, and stakeholder representatives for developing and promoting green chemistry in Austria. Together, they are elaborating a national program of measures for green chemistry and are providing recommendations to the climate protection minister in this matter.

This document presents the definition of "green chemistry" as it is understood by the PGC and examines it in more detail in the context of chemicals policy.

Introductory remarks

With the release of its communication on the Green Deal[2], the European Commission under the Presidency of Ursula von der Leyen provided crucial impetus for the environmental policy of the European Union for the coming decades. Despite the high level of energy efficiency that it has already achieved, the chemical sector has the third-highest energy consumption of any industry in Europe and the most intensive use of raw and input materials. Because of this, it is being confronted with particularly challenging tasks in relation to the explicit goal of ensuring sustainable and climate-neutral production in Europe by 2050.

Shortly thereafter, the European Commission laid down concrete goals relating to the Green Deal for the manufacture and use of chemicals in the new Chemicals Strategy for Sustainability[3] (CSS), thus creating a very ambitious groundwork for the redefinition of the European chemical policy instruments to put the sustainability approach of the Green Deal into action in the chemical industry.

In a workshop held by the European Commission (Directorate-General for Research and Development, DG RTD) on the topic of "Safe and Sustainable by Design" for the entire

---

[2] European Commission: The European Green Deal, COM (2019) 640 final

[3] European Commission: Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment, COM (2020) 667 final

manufacturing sector, Director[4] Kestutis Sadauskas, a founding member of the CSS, noted that the chemicals strategy has three major goals: creating a non-toxic environment, realising a circular materials economy, and climate neutrality[5]. When climate neutrality is viewed as an objective of a resource-sparing and efficient economy as was already anchored in the Rio Declaration of 1992, this gives rise to the three general goals for chemicals policy:

- safe chemicals
- resource and energy efficiency
- circularity

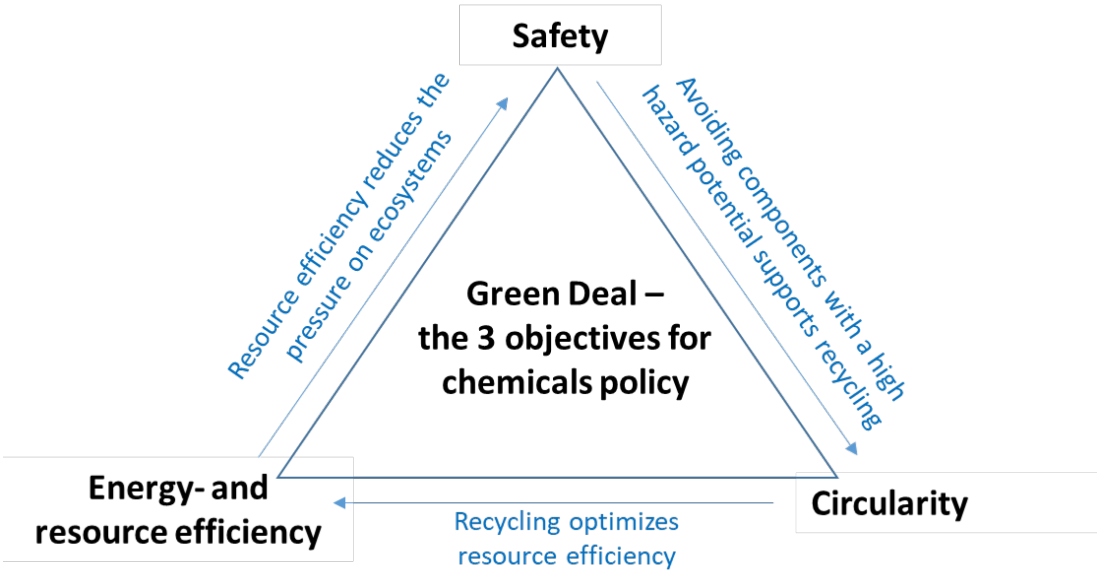
These goals form the basis for a comprehensive definition of green chemistry for the Austrian PGC.

[4] EU Commission, DG ENV, Director of Circular Economy and Green Growth (ENV.B)
[5] https://euagenda.eu/videos/54370

Operational goals of Green Chemistry

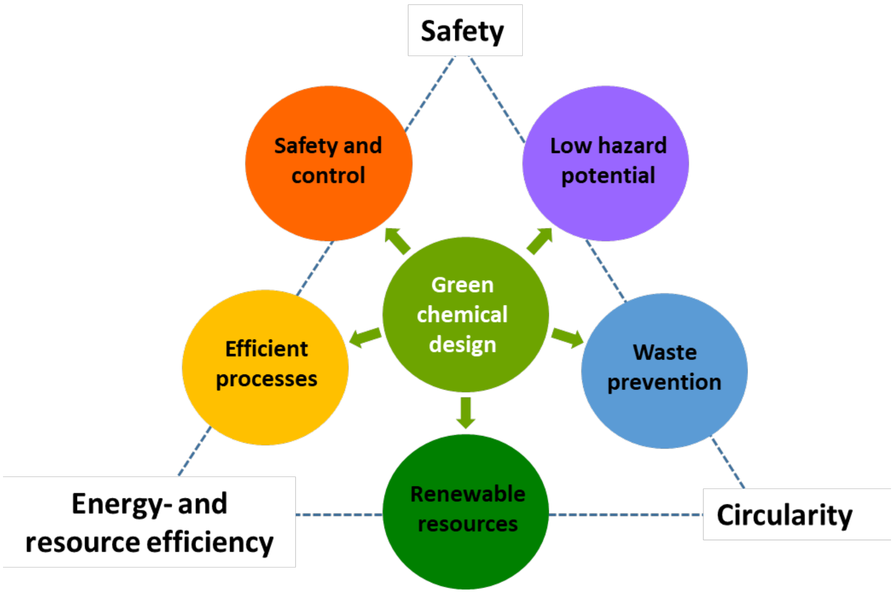
As shown in the following figure, the general goals named above support one another:

Figure 1 The three principal goals of the Green Deal for chemicals policy



These three very general goals must be elaborated and operationalised so that they can be applied in practice. In the view of the PGC, five fundamental criteria towards which green chemical production must be oriented can be derived from the three goals. These criteria must be taken into account in the development and synthesis planning of a new chemical in line with the core principle of "safe and sustainable by design" that is already anchored in the CSS. The following figure illustrates the central role that these five criteria play as the foundation of the innovation process for new substances.

Figure 2 Five Criteria of green chemical design based on the 12 principles of green chemistry



All aspects that are relevant for the substitution of a problematic substance with a better alternative must be taken into account in the design phase. For example, if irreconcilable conflicts arise between the desired functionality and an associated adverse characteristic in terms of one of the three above goals, other – possibly non-chemical – alternatives must be considered.

When applying these five criteria, it is important to stress that these must not be applied selectively, but cumulatively, in other words in their entirety. This must especially be taken into account in the development of quantitative metrics for the evaluation of these criteria.

Discussion of the individual criteria and their relevance of green chemistry

1. Low hazard potential of all involved substances

This goal applies to synthesis products and, taking particular account of protecting employees and the environment, to the raw materials, solvents, auxiliaries, intermediates, catalysts, and the like used in the synthesis process. In the CSS, this goal is manifested in the vision of a “non-toxic environment” and a “zero-pollution strategy”. As far as materials and compounds that will be brought onto the market are concerned, this goal is especially operationalised through the two framework regulations REACH and CLP, though the CSS is proposing numerous expansions and improvements that are currently part of a broad discussion on the revision of these two instruments. However, the raw materials, solvents, auxiliaries, catalysts, and the like that are used in the synthesis process do not currently play a central role in the risk assessment of the synthesis product, and are thus not always addressed sufficiently in the chemical safety reports in particular.

Low hazard potential is also an essential prerequisite for making waste materials chemically recyclable. The presence of so-called legacy substances, i.e. chemical constituents that are currently restricted but that are contained in older products that were brought onto the market before the enactment of a restriction (such as plasticisers in plastics), can prevent the recycling of the waste materials or at least make it more difficult if these substances have high hazard potential. Circularity-based chemical manufacture must thus also seek to only employ substances with minimal hazard potential for this reason as well.

2. Waste prevention

In the waste policy hierarchy, prevention is the top priority and must therefore also play a major role in chemicals policy. The proper disposal of waste requires complex waste management systems and is causing chemical manufacturers to avoid waste to the greatest degree possible in the interests of economic efficiency. Nevertheless, the work of British chemist Roger Sheldon has shown[6] that the quantities and hazard potential of the waste generated in the processes are still considerable. A mass of generated waste per tonne of

[6] For example Roger A. Sheldon: The E factor 25 years on: the rise of green chemistry and sustainability, Green Chem., 2017,19, 18–43; DOI: https://doi.org/10.1039/C6GC02157C

produced product (E factor) of 10-100 is typical for fine chemicals and pharmaceuticals. Thus, the goal of avoiding waste should be made a foundational principle in the design phase for a chemical. The company should not follow this principle solely for economic reasons (avoiding disposal costs), but also for reasons of precautionary environmental and health protection and maximum resource efficiency, in conformity with the concept of circular economy.

3. Use of renewable raw materials

In a high-technology society, renewable raw materials are both biogenic materials and secondary raw materials that contain valuable chemical components[7]. With the Bioeconomy Strategy[8] and Circular Economy Strategy[9], the European Commission has assigned high importance to the above-mentioned renewable sources for the provision of raw materials. Now, these goals must be formulated and implemented in concrete projects under the framework of chemicals policy in particular. As discussed above, the use of larger quantities of secondary raw materials will only be possible when the additives in the chemical materials have as low a hazard potential as possible and do not impair recyclability. This will ensure that the secondary raw material is of sufficient quality. In this context, it is important to note that there are currently no uniform quantitative benchmarks at the EU level for assessing the fulfilment of the green principles. There are numerous assessment approaches that were developed for very specific product categories, but no recognised harmonised green metrics. This is necessary in general for the manufacture of green chemicals, but also in particular for chemical production from secondary raw materials and biogenic resources.

4. Efficient production

When considering the history of the chemical industry, it is astounding to see how long inefficient processes can remain in use. In the early phases of the industrial revolution, mountains of waste and unused by-products grew in and around the centres of the chemical industry, representing not only a serious health and environmental risk, but also an egre-

---

[7] This particularly includes carbon dioxide. The employment of CO_2 as a chemical raw material while using renewable energy is thus an important field of green chemistry (“CO_2 chemistry”).

[8] https://ec.europa.eu/info/research-and-innovation/research-area/environment/bioeconomy/bioeconomy-strategy_de

[9] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_de

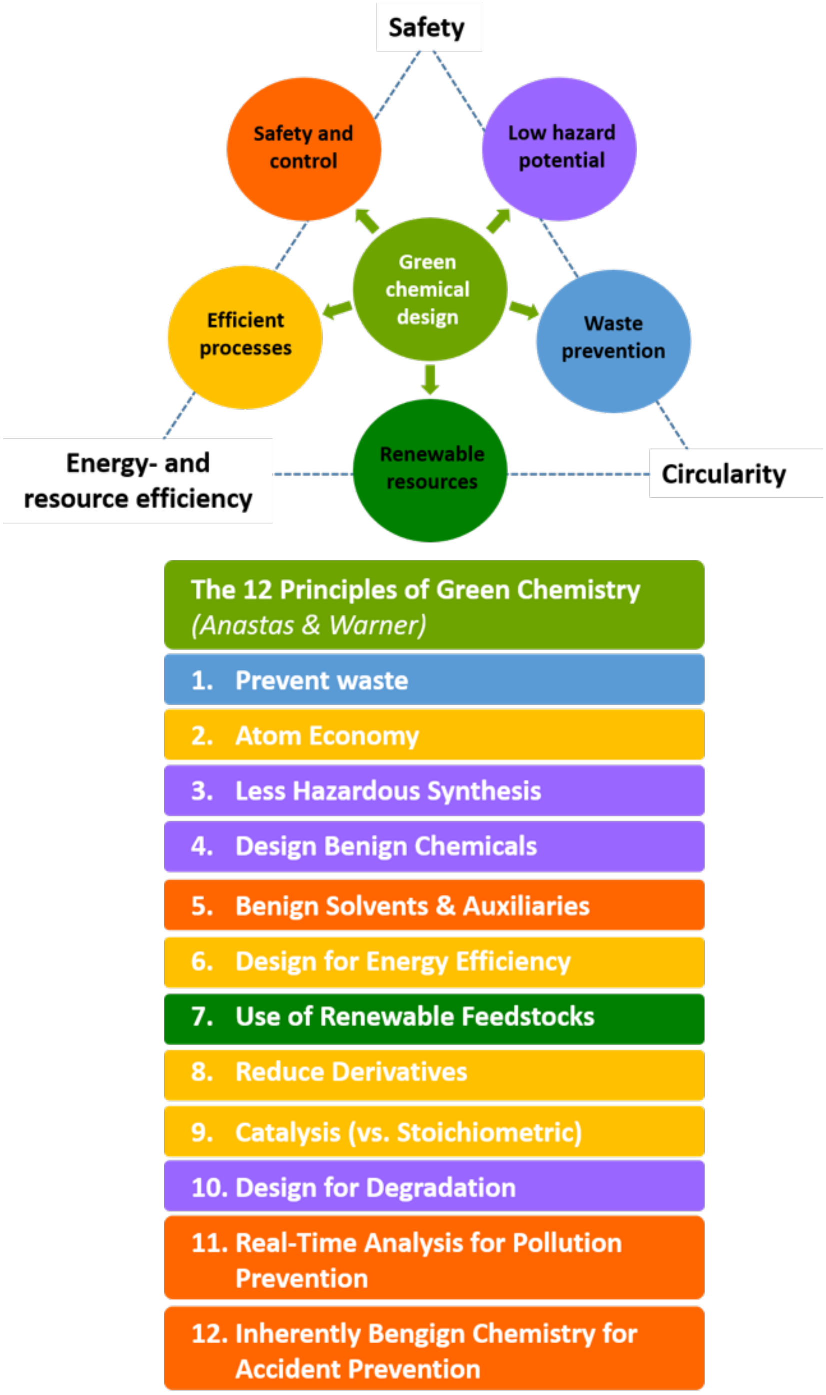
gious sign of the extremely inefficient use of material resources. Process innovations usually resulted in the reduction of this inefficiency, but were often only implemented when they brought economic advantages. Land use, water and air pollution, and waste of resources were often accepted as unfortunate but unavoidable consequences of industrial progress. This was also true for the consumption of energy sources, especially wood and coal in the early industrial period. Even though enormous progress has been made in process efficiency in the meantime, it is astounding that material and energy efficiency is still assigned relatively little importance in chemistry education even today. The concept of resource efficiency (in terms of energy and material) should thus assume a central role in the chemical industry, from training to technical process implementation.

5. Safety and control in processes

Tremendous progress has also been made in process safety since the catastrophic accidents in Seveso, Minamata, and Bhopal, especially in the western industrialised countries. Nevertheless, very dangerous substances are still created in chemical production, above all as intermediate products that represent a particular risk to employees. The relocation of production sites to countries with lower wage levels and often lower safety standards is still a threatening scenario for the industrialised countries. Reindustrialisation as is being called for today in the context of reducing global dependency will only be accepted in our society if the vision of the largely pollutant-free manufacture of substances with as low a hazard potential as possible becomes a reality. The vision of a safe and continuously monitored process is especially important for the creation of safe workplaces where chemicals are handled.

These 5 criteria can be broken down further in the field of synthetic chemistry. In the 1990s, US chemists John Warner and Paul Anastas drafted the 12 principles of green chemistry, which have since become a non-codified but widely accepted standard in the relevant chemical literature when the goal is to make processes and methods more sustainable and environmentally friendly. The following figure shows how these 12 principles can be assigned to the five previously discussed fundamental criteria. They thus represent a further key operational elaboration of the specified goals.

Figure 3 The five criteria for green chemical design and the 12 principles of green chemistry



What is Green Chemistry?

Against this background, the PGC understands the term "green chemistry" to mean a holistic approach by which the concept of sustainability will be integrated into the fundamentals of chemistry and established as a core standard among all actors in the chemical sector. Here, the entire process from the design and manufacturing of a new substance to its production, processing, use, reuse, and disposal is being evaluated. In line with the objectives of the European Union's Green Deal and the European Chemicals Strategy for Sustainability – resource preservation, safety, and sustainability – green chemistry shall contribute materially to

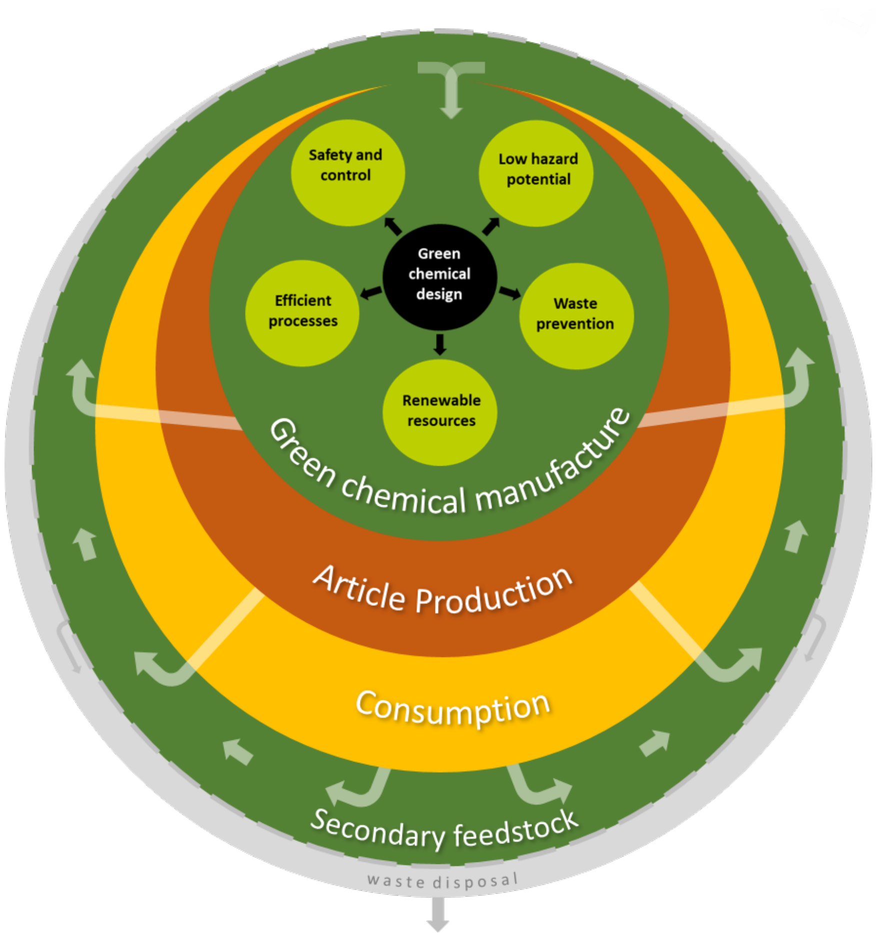
- continuously reducing the hazard potential of chemicals for humans and the environment over the entire life cycle,
- ensuring that the processes for the production of chemicals – from raw material sourcing10 to the marketing of substances and mixtures – are safe and environmentally friendly while minimising greenhouse gas emissions and resource consumption,
- ensuring that the use of chemicals in consumer goods production is based on the principles of safety and sustainability, and
- ensuring that the waste materials and residues that are generated over the entire life cycle of a chemical are returned to the material cycle, unless they can be avoided.

The PGC does not view green chemistry as a new discipline in chemicals science, but as a societal commitment to producing chemicals energy- and resource-efficient and using them in a circular manner to the greatest extent possible based on the principles of protecting human health and the environment. This comprises all aspects from the values imparted to children and their education to research, economy, and industrial practice. The PGC views the 12 principles of green chemistry as a fundamental, concrete, and ambitious roadmap for achieving this future state.

[10] In accordance with the 2030 Raw Materials Master Plan and the Circular Economy Strategy, a central goal is to replace primary raw materials with secondary materials, and to replace fossil raw materials with biogenic materials

They should therefore serve as the cornerstones of chemicals policy under the Green Deal, concentrated into the five foundation criteria proposed above, as shown in the following figure.

Figure 4 Green Chemistry in manufacturing and consumers goods



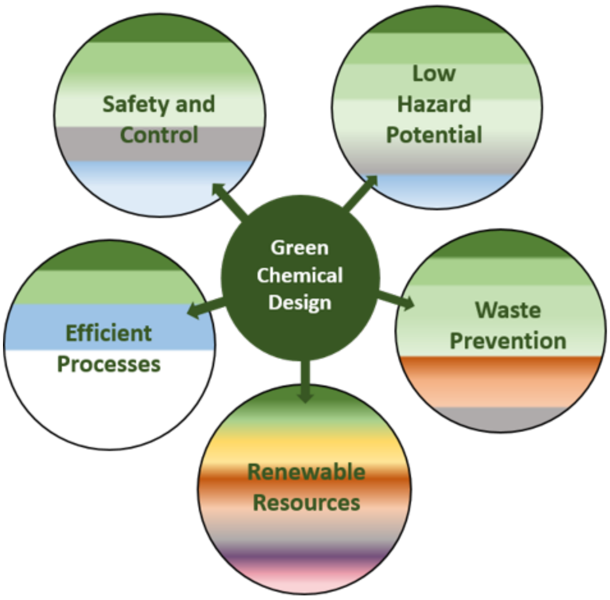
The desired function in a sustainable society is at the start of a technical development. When it becomes apparent that a new process or substance is the best option for a product, the development should take place as indicated in Figure 4. The principal characteristics of the substance must first be determined and its structural details developed. This is followed by extensive laboratory tests, and even in these early phases, it is decisive to carefully assess the principles of green chemistry and to look at this stage for alternatives for chemicals that do not satisfy these principles. This can only be completed in a plausible and efficient manner when there are uniform standards for green chemistry[11]. Once this part of the design phase is completed, it is followed by technical process implementation in which not only thermodynamic and kinetic issues but of course, also the principles of green chemistry must be taken into account. This is particularly relevant for, respectively, employee protection, process safety, optimal energy management, availability and environmental assessment of the required raw materials, minimisation of environmental effects, and the maximum re-use or recyclability of waste materials. The design phase is completed following the successful operation of a scaled pilot facility and the work can then begin on the actual production process. All problems that arise in this and subsequent phases relating to health, environmental, ecological, or resource-use issues generally require considerably more involved measures, up to and including the substitution of the unsuitable substance. Substitution policy, for example under REACH, still takes effect only in this or even later technical development phases. The Green Deal is seeking to learn from these mistakes and has made the principle of "safe and sustainable by design" a core aspect of European chemicals strategy. The PGC supports this innovation and advocates for making the principles of green chemistry an integral and foundational element of the design of new substances and processes as shown in the figure above.

Green Chemistry in a European context

The current European discussion is highly focused on the question of which instruments are most suitable for implementing a "safe and sustainable by design" strategy (SSbD) in the European manufacturing industry, and which qualitative and quantitative criteria are appropriate for harmonising the SSBD. This discussion is relevant for chemicals and mixtures, which form the backbone of the entire manufacturing sector. Without addressing the diverse questions that arise in this context in detail, the following figure is intended to demonstrate the complexity of this undertaking for the production of chemicals. The figure uses colour codes to assign the fundamental criteria for the green design of a chemical as presented by the PGC in this paper to the individual European regulations, initiatives, and strategies that are currently relevant for these criteria.

[11] This also often involves the concept of green metrics.

Figure 5 Currently discussed initiatives on EU chemicals policy as of autumn 2021 and their relevance to the criteria for the design of a chemical



Potentially relevant Policy Fields
Chemicals Strategy for Sustainability (CSS)
Horizon Strategic Plan 2021-2024
7th + 8th Environment Action Plan (EAP)
Zero Pollution Action Plan
Bioeconomy Strategy
Biodiversity Strategy for 2030
Circular Economy Action Plan
Waste and Recycling Framework Directive
Circular Plastics Alliance
Ecodesign for Sustainable Products Regulation
Industrial Emission Directive (IED)
Water Framework Directive
Strategic Framework on Health and Safety at Work
Renewable Energy Directive (RED – II)
Future Common Agriculture Policy (CAP)
Farm to fork Strategy

Annex

Potentially relevant policy fields:

Chemical Strategy for Sustainability (CSS)
Horizon Strategic Plan 2021-2024
7th Environment Action Plan (EAP)
8th Environment Action Plan (EAP)
Zero Pollution Action Plan
Bioeconomy Strategy
Biodiversity Strategy for 2030
Circular Economy Action Plan
Waste Framework Directive
Circular Plastics Alliance
Ecodesign Directive
Industrial Emissions Directive (IED)
Water Framework Directive
Strategic Framework on Health and Safety at Work
Renewable Energy Directive (RED – II)
Future Common Agriculture Policy (CAP)
Farm to fork Strategy

Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology
Radetzkystraße 2, 1030 Vienna, Austria
+43 (0) 800 21 53 59
servicebuero@bmk.gv.at
bmk.gv.at