Dialogue Paper
2021 01 13

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Key Characteristics of Sustainable Chemistry

Towards a Common Understanding of Sustainable Chemistry[1]

Dialogue Paper by the International Sustainable Chemistry Collaborative Centre (ISC_3), Bonn, Germany[**]

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Preamble

In 2015 the United Nations (UN) set out 17 Sustainable Development Goals (SDGs) to ensure a sustainable future of our planet. They address a plethora of impending, inter-connected, global megatrends such as population growth, industrialization and urbanization, food security, healthcare, water and sanitation, climate change, etc. to ensure a sustainable future development. Chemistry is both, a non-normative science and a normative economical sector. As such both are indispensable for achieving the targets set within the 17 UN SDGs. Many products of chemical and allied industries contribute to high living standards and increasing life expectancy. However, the ever-increasing extraction of resources, waste and environmental pollution generated by their extraction, by synthesis, manufacturing, and other processes, by the use of products and at the end of their life are in strong contrast to sustainability. Impacts on humans and the living environment have been accompanying negative trade-offs until today.

Products of chemical and allied industries are used because they offer a certain service or function. Considering firstly non-chemical alternatives and alternative business models, including stimulation of non-chemical sustainable innovations and products as well as alternative sustainable business models is of utmost importance for the chemical sector of the future. Such business models have to stop purely focussing on economic goals. In order to sustain any innovation or alternative product offerings, the inclusion of social and societal improvements is inevitable. Innovations need to be developed on all levels which are responsible, trustworthy, transparent and traceable. They have to

[1] The "Key Characteristics" of Sustainable Chemistry are used to describe the domain of Sustainable Chemistry. A definition is neither possible nor desirable because of its manifold facets, complexity, and openness to proper innovation needed.

** First presented at the ISC_3 stakeholder forum in November 2020. The authors are grateful for insightful comments from the members of the scientific board of ISC3 and many stakeholders in the field of green chemistry and sustainable chemistry.

be monitored continuously. Thereby chemistry both as a scientific discipline and sector can be held in high regard for their sustainability-directed activities, services and products.

Current and future practice of chemical and allied industries have to be aligned with general sustainability principles such as sufficiency, consistency, efficiency, resilience. This together with respecting the planetary boundaries as well as precaution as core principles will create new economic opportunities that simultaneously will go beyond purely economic-driven decisions. They will generally lead to benefits for the planet as a whole and all societies all over the world[2]. This has to be applied to all of chemistry including the chemical sector[3], from resources to manufacturing, to application and end-of-life of products and service by all stakeholders including the transformation of current education models, re- and up-skilling workforce.

Sustainable chemistry is a framework giving guidance on how chemistry as a scientific and economic asset spanning multiple supply chains and consequently the whole life cycle can comply with the principles of sustainability for the betterment of our planet. The key-characteristics as outlined below are constitutive for Sustainable Chemistry.

Key characteristics of Sustainable Chemistry[a]

1. HOLISTIC: Guiding the chemical science and the chemical sector towards contributing to Sustainability in agreement with sustainability principles and general understanding and appreciating potential interdependencies including long-distance interactions and temporal gaps between the chemical and other sectors.

2. PRECAUTIONARY: Avoiding transfer of problems and costs into other domains, spheres and regions at the outset[b], preventing future legacies and taking care of the legacies of the past including linked responsibilities.

3. SYSTEMS THINKING: Securing its interdisciplinary, multidisciplinary and transdisciplinary character including a strong disciplinary basis but taking into account other fields to meet Sustainability to its full extent. Application as for industrial practice including strategic and business planning, education, risk assessment and others including the social and economical spheres by all stakeholders.

[2] These are principles of general sustainability. The Sustainable Development Goals of the United Nations are embedded in these. Albeit most often the SDGs are currently the first framework addressed by SC it must not ignore the important framework of sustainability in general.

[3] The chemical sector is composed of the chemical industry as well as allied industries such as pharmaceutical, home and personal care, construction, mobility, energy, electronics and IT, etc.

4. ETHICAL AND SOCIAL RESPONSIBILITY: Adhering to value to all inhabitants of plant earth, the human rights, and welfare of all live, justice, the interest of vulnerable groups and promoting fair, inclusive, critical, and emancipatory approaches in all its fields including education, science, and technology.

5. COLLABORATION AND TRANSPARENCY: Fostering exchange, collaboration, and right to know of all stakeholders for improving the sustainability of business models, services, processes and products[c] and linked decisions including ecological, social, and economic development on all levels. Avoiding all "green washing" and "sustainability washing" by full transparency in all scientific and business activities towards all stakeholders, and civil society.

6. SUSTAINABLE AND RESPONSIBLE INNOVATION: Transforming fully the chemical and allied industries from the molecular to the macroscopic levels of products, processes, functions and services in a proactive perspective towards sustainability[d] including continuous trustworthy, transparent and traceable monitoring.

7. SOUND CHEMICALS MANAGEMENT: Supporting the sound management of chemicals and waste throughout their whole life cycle avoiding toxicity, persistency and bio-accumulation and other harm of chemical substances, materials, processes, products and services to humans and the environment.

8. CIRCULARITY: Accounting for the opportunities and limitations of a circular economy including reducing total substance flows, material flows, product flows, and connected energy flows at all spatial and temporal scales and dimensions[e] especially with respect to volume and complexity.

9. GREEN CHEMISTRY: Meeting under sustainable chemistry application as many as possible of the 12 principles of green chemistry[f] with hazard reduction at its core when chemicals are needed to deliver a service or function whenever and wherever this complies with sustainability.

10. LIFE CYCLE: Application of the above-mentioned key characteristics for the whole lifecycle of products, processes, functions and services on all levels, e.g. from molecular to the macroscopic levels and all sectors in a pro-active perspective towards sustainability.

Additional text as background information

a. Because of the many facets of chemistry, chemical products and their application, a definition of sustainable chemistry is neither desirable nor feasible. Some key characteristics that characterize the concept of sustainable chemistry are given here to better understand SC itself and its aims and scope, and to foster its sound application. A brief description could be "Sustainable chemistry is achieved, if chemistry contributes in a sustainable manner to sustainability". In other words, the principles of sustainability are applied to and implemented into the chemical sector (chemical industries and downstream users of their products). In this understanding sustainable chemistry is a guiding principle to align the practice of chemistry with sustainability principles.
   This is very general and demonstrates that each case has to be regarded separately in detail to decide if and how far it contributes to a more sustainable solution. In contrast to green chemistry, sustainable chemistry is not primarily focused on chemical products themselves but includes service-based business or even non-chemical alternatives for a certain function.
   As a guiding principle it starts by asking about a required service or function and whether there is a non-chemical more sustainable alternative available before asking firstly which already existing or new chemical product could be used to deliver the service or function. In other words, according to SC a specific function does not necessarily have to be met by using a chemical product but could be delivered by a service or a new design or as a combination of both which would result in strengthening the application of alternative business models relying on (specific) knowledge over tonnage for return of investment.

b. E.g., a composite lightweight material may be used in a car to save fuel. However, such a material may anyway need much energy to be manufactured albeit meeting green chemistry principles and may be of high complexity. Recycling of such materials needs also much energy and is not completely feasible. Waste and other residues are resulting, however at another place and/or time in the future because of the long lifetime of a car. Recycling facilities may not be available or recycling of such a tailored plastic material may economically not be viable. A transfer of problems (avoiding CO_2 emissions) from one system (the car/mobility sector) to another, i.e. the recycling sector will result from it and arise in the future only.
   It needs action already at the stage of development and prior to marketing, of chemicals, chemical products, technologies and services; reduction of damage/"repair"/remediation costs and the associated economic risks for enterprises and public bodies)

c. A broad understanding of the term “products” is used here as many primary products of chemical industries are used and incorporated by downstream users into their products. Therefore, products are individual chemicals, physical or chemical mixtures of them on various levels (e.g. atomic for alloys or electrical appliances, or constituents e.g., additives in plastics, disinfectants) or both of them, e.g. flame retardants or dyes in a computer or in textiles or as constituents of different building blocks.

d. SC includes economic innovation and competitiveness in the long term including all external costs (see b). Products and production methods produce confidence in industrial users, private consumers and customers from the public sector and thus result in competitive advantages. Competitiveness of the chemical industries has to be maintained and improved via SC.

e. If an innovation rate is too high or product lifetime too short it may create problems in the future. E.g. if the rate of the introduction of new cell phones, notebooks or pads is higher than the ones possible for the recyclers to adapt their technologies, many products (e-waste) will not be recycled. In that sense new and better materials and products could be less sustainable than their previous generation.

f. If a function or service requires the use of a chemical product this product should be designed, synthesized and manufactured in agreement with the 12 principles of green chemistry, i.e. aiming at meeting as many principles on the highest possible level and not just one. Green chemistry is focused on synthesis of chemical products (often understood as organic molecules) and processes to synthesize them with less waste and less energy and less hazard. The application of its principles does not automatically result in more sustainable molecules, let alone complex products and materials per se as it addresses the production of chemicals and pharmaceuticals only. For example, how many of the twelve principles must be met to call a product green or at least greener? Only one or need it be all 12? If not all twelve - which ones? Green chemistry recommends using renewable resources. However, these also need resources to be grown or extracted and refined. Green chemistry does not address total substances, materials and product flows, neither on local nor on regional or global level. Furthermore, efficiency in synthesis for a product does not stand for an improved overall resource efficiency or reduced substance and materials flows as there can be rebound effects: using only low concentrations of a precious metal e.g. for an electronic component makes recollection, recovery and recycling technically more challenging and economically less favourable and therefore leads to material dissipation. Furthermore, resource efficient production may lead to decreased pricing, higher product demand and ultimately increased manufacturing. This could in total result in an increased use of resources instead of less. An increase of efficacy most often requires increasing purity or concentration needing more separation steps. Sometimes it could therefore be preferable to go for lower efficacy and efficiency. In other words, striving for optimum efficiency and efficacy is the target instead maximising them. Catalysis is recommended for good reasons, but metals are not renewable. Catalysts may safe energy within the synthesis; however, they also need resources etc. to be manufactured. Furthermore, catalysts can only change the speed of a chemical reaction but not the energy needed to synthesize a chemical of higher energy content than the starting material, e.g. synthesis of methane from carbon dioxide will always need additional energy, more than will be regained by incinerating methane. These examples demonstrate, that a broader, more holistic and systems-thinking oriented framework is needed. Such a framework or guiding principle starts from the service or function needed, asks first whether there is a service-based approach to deliver this function and only if the answer is no a chemical one is applied, in the best case based on a service-based business model that needs less chemicals than a purely chemical one.