Definition and Criteria for Sustainable Chemistry
Created by the Expert Committee on Sustainable Chemistry (ECOSChem)
December 2022

Sustainable chemistry is the development and application of chemicals, chemical processes, and products that benefit current and future generations without harmful impacts to humans or ecosystems.

INTRODUCTION AND CONTEXT SETTING

Background

The practice and application of chemistry – particularly over the past 100 years – has resulted in novel discoveries and innovative processes, materials, and products that have significantly contributed to economic development, public health, and improved quality of life. The vast majority of the chemistries and chemical processes used today were developed for their functionality, innovative properties, performance, and cost. However, potential health and safety impacts to workers, communities, and ecosystems were generally not considered during their development. As a result, while providing important benefits, the ways in which many chemicals have been, and currently are, designed, extracted, developed, manufactured, transported, used, recycled, and disposed of have caused, and continue to cause, significant damage to humans, ecosystems, and the climate.

Many of these impacts have been known for decades or even centuries. Well-known chemicals management disasters[1] have contaminated drinking water, air, soil, and marine environments and have contributed to disease and death in humans as well as adverse impacts to flora and fauna. Additionally, toxic chemicals in everyday consumer products present health risks to humans and ecosystems during product manufacturing, use, and disposal. For example, per- and polyfluoroalkyl substances (PFAS), used for many water and oil resistance applications, are detected globally in the environment and in human bodies and are associated with thyroid disease, cancer, and other health impacts[2]. Chemicals management has improved in recent decades, yet many fundamental health, safety and sustainability issues related to chemicals have not been solved. Chemical exposures disproportionately harm people of color and indigenous, immigrant, frontline, low-income, and communities and societies undergoing industrialization, as well as other marginalized groups. Exposures are also exacerbated through climate change related events (i.e., sea level rise, increased hurricane frequencies, etc.) and illegal activities (i.e., waste dumping, the production and use of banned pesticides, etc.) that most often occur near or adjacent to these same communities and societies. These myriad chemical exposures, in addition to other environmental exposures and social and environmental disparities, contribute to cumulative impacts[3] that must be addressed. In short, the current practice and application of chemistry – from education, to investment, to manufacturing, and policy – must be transformed to ensure that current and future generations – indeed, all of the Earth's inhabitants – can thrive.

The Need for Sustainable Chemistry

As we are rapidly approaching "planetary boundaries"[4] for chemical pollution, we are seeing irreversible damage to many of Earth's ecosystems and the species they support. Sustainable chemistry represents a vision for chemistry that is aligned with sustainability frameworks addressing pressing global challenges, such as the UN Sustainable Development Goals. In contrast to the current state of affairs, sustainable chemistry is a systems-based approach to the practice of chemistry that recognizes that humans are part of their environment along with non-living resources and other living organisms.

Sustainable chemistry is not a new concept, but rather, is rooted in and expands on more than four decades of research in environmental and green chemistry. Sustainable chemistry builds on green chemistry principles[5] and concepts to guide the design and development of molecules that are safe and more sustainable. Sustainable chemistry encompasses questions related to the sources of chemical building blocks, the application of chemistry in complex global commerce, and the implications for chemical products at their end-of-life. Further, it considers the development of new chemicals, materials, processes, or products in terms of the function[6] they provide. This includes the consideration of whether that function is even necessary in an application, and if so, whether that function can be fulfilled in a safe way or eliminated by process or product design changes. Some chemical products, such as pesticides, pharmaceuticals, and antimicrobials, among others, include chemicals with functions designed to be toxic, but that may be deemed "essential"[7]. By design, there may not be a way for these products to meet this definition of sustainable chemistry; however, for these products and sectors, the criteria outlined below provide guideposts for design that minimize potential impacts.

Developing A Definition and Criteria for Sustainable Chemistry

Many organizations have worked to define and describe sustainable chemistry or have developed principles for safety and sustainability for chemistry applications, including environmental justice principles centered around chemicals management[8]. Through research, analysis, and extensive discourse, the Expert Committee on Sustainable Chemistry (ECOSChem) – representing a broad set of constituencies – has built upon these foundations with an aim to develop a clear and actionable definition and set of criteria that may be adopted and adapted to different constituencies and decision contexts, including in policy, education, corporate, and investment decision making. It is also intended to guide chemical, material, process, and product design and implementation in different settings.

The definition and criteria outline both a desired end state and a path for what sustainable chemical products should aim to achieve and against which to measure progress, recognizing that few, if any, chemistries or chemical products today will meet the definition and criteria. Hence, a set of indicators for each criterion that can measure continuous improvement will be needed, considering the large scale at which chemical industries, and the downstream sectors that depend upon them, operate. The definition and criteria for sustainable chemistry will also need more contextualization by sector and type of chemistry practiced, and more specificity in terms of the metrics and timelines by which progress will be measured, to truly make these elements actionable. We recognize that there are often significant uncertainties in our understanding of chemical exposures and impacts – though these should not be a reason to postpone action. As such, we need to use the best available information, as well as continuously improve our understanding of how chemicals, materials, products, and processes impact complex human and natural systems, to effectively understand potential impacts and eliminate them through design.

Looking Forward

Significant increases in research funding for alternative chemical feedstocks, chemical and process design, renewable energy production, and innovative business models will be required[9] to achieve this definition and criteria. It will also require social sciences research to understand sustainable growth of overall production and consumption patterns, given a growing global population. Strong transparency and engagement with and protections for workers, communities, consumers, and the environment, will also be necessary to ensure that cumulative impacts and potential trade-offs are identified and minimized. Sustainable chemistry will also require rebuilding trust in science, industry, and government institutions, particularly with communities that have historically been disproportionately impacted.

Ultimately, achieving sustainable chemistry is a journey of continuous improvement that starts with a bold vision for the future of chemistry and global chemical systems, acknowledges and addresses past harms, and provides beneficial products and services for humanity with as few negative human and environmental impacts as possible. A complex network of actors, including governments, industries across sectors and the value chain, investors, academics across disciplines, educators, civil society, and the public all play different, yet critical, roles in supporting and implementing sustainable chemistry. This will require communication, cooperation, and transparency of decisions.

[1]These include the near extinction of predatory birds due to DDT exposure, the gas leak at Union Carbide in Bhopal, India that killed thousands of people and injured many more, hazardous waste dumping at Love Canal in New York that contaminated drinking water and caused birth defects, cancer, and other adverse health impacts, and the depletion of the ozone layer by chlorofluorocarbons (CFCs), resulting in a global rise in skin cancers and other diseases.

[2]Pelch et al. “PFAS health effects database: Protocol for a systematic evidence map”, *Environ Int*. 2019;130:104851. doi: 10.1016/j.envint.2019.05.045.

[3]United States Environmental Protection Agency, Office of Research and Development. Cumulative impacts: Recommendations for ORD research. External review draft, January 2022. https://www.epa.gov/system/files/documents/2022-01/ord-cumulative-impacts-white-paper_externalreviewdraft-_508-tagged_0.pdf.

[4]Persson et al. “Outside the Safe Operating Space of the Planetary Boundary for Novel Entities”, *Environ Sci Technol*. 2022;56(3):1510-1521. doi: 10.1021/acs.est.1c04158.

[5]Anastas and Warner “Green Chemistry” 1998. Oxford University Press, ISBN: 9780198506980.

[6]Tickner et al. “Advancing Safer Alternatives Through Functional Substitution”, Environ. Sci. Technol. 2015;49(2): 742–749. doi: 10.1021/es503328m.

[7]Cousins et al. “Finding essentiality feasible: common questions and misinterpretations concerning the “essential-use” concept”. *Environ Sci Processes Impacts*. 2021;23, 1079-1087.

[8]Louisville Charter for Safer Chemicals. The Environmental Justice Health Alliance (EJHA) for Chemical Policy Reform. https://ej4all.org/about/louisville-charter.

[9]National Academies of Sciences, Engineering, and Medicine. Call for Community Input: Enhancing the U.S. Chemical Economy through Investments in Fundamental Research in the Chemical Sciences. https://www.nationalacademies.org/our-work/enhancing-the-us-chemical-economy-through-investments-in-fundamental-research-in-the-chemical-sciences.

DEFINITION

Sustainable chemistry is the development and application of chemicals, chemical processes, and products that benefit current and future generations without harmful impacts to humans or ecosystems.

CRITERIA

To meet the spirit of this definition, sustainable chemistry should achieve the following criteria. For each criterion, sector- and chemistry-specific metrics and timeframes will need to be developed in order for these criteria to be actionable.

EQUITY AND JUSTICE

A sustainable chemical, material, process, product, or service[a] will…

- Be designed or implemented with the authentic engagement of potentially impacted communities to help avoid negative social impacts[b].
- Be designed or implemented in a way that does no harm and, when feasible, prioritizes sustainable chemistry innovations on the remediation of harms to communities and societies[c] that have been disproportionately impacted at any stage of the lifecycle of the chemical process or product lifecycle.
- Protect workers, marginalized groups (e.g., indigenous, immigrant, frontline, and low-income communities, and communities of color), and vulnerable groups (e.g., children, those who are pregnant, and the elderly).
- Be designed or implemented in a way that does not create new problems or shift harms across the value chain[d] or to other communities, societies, countries, or generations.
- Be designed or implemented in a way that supports local economies and ensures product access and affordability for marginalized groups.

[a]A chemical service "involve(s) a strategic, long-term relationship in which a customer contracts with a service provider to supply and manage the customer's chemicals and related services." Chemical Strategies Partnership, http://www.chemicalstrategies.org/implement.php.
[b]Social impacts may include, but are not limited to, chemical-related illness and stress to workers, communities, and societies, impacts from the process or product on cultural resources, and impacts on livelihoods of communities and societies, including access to jobs, natural resources, property values, and other human needs.
[c]Historically disproportionately impacted communities and societies may be located where chemicals, materials, and products are extracted, produced, transported, sold, used/consumed, and/or disposed of.
[d]The value chain describes the full range of activities that firms and workers do to bring a product from its conception to its end use and beyond. This includes activities such as design, production, marketing, distribution, and support to the final consumer.

TRANSPARENCY

A sustainable chemical, material, process, product, or service will…

- Have had its health, safety, and environmental data[e] disclosed in an accessible[f] format to individuals, workers, communities, policy makers, and the public.
- Include scientifically defensible verification for sustainability, health, safety, and other claims. The sources for verification should be openly accessible.

- As much as possible, include a chain of custody so that chemicals and materials used in the product and process are traceable throughout their lifecycle.

[e]These data include information on chemical ingredients, resource and energy use, emissions, and other sector-specific information.
[f]Accessibility refers to materials that are free of charge and easy to understand by those that speak different languages, are accessing materials in non-digital formats, or have other differing abilities (e.g., are hard of hearing, seeing, etc.).

HEALTH AND SAFETY IMPACTS

A sustainable chemical, material, process, product, or service will…

- Be without hazards[g], including hazardous components, emissions, and toxic byproducts and breakdown products, to people and ecosystems across its existence[h].
- Not result in releases, including releases of byproducts or breakdown products, that persist or bioaccumulate.

[g]Hazards can include toxicological, physical, and other types of hazards. Eliminating hazards is the operational trajectory of sustainable chemistry while risk reduction is a short-term and incomplete strategy. A product or process that achieves only risk reduction cannot be considered sustainable.
[h]Existence refers to both product and process lifecycles. The product lifecycle includes design, extraction, production, transportation, use/re-use, recycling, and end-of-life. The process lifecycle includes design, initial research and development, testing, piloting, scale-up, implementation, functional lifetime, and decommissioning/scale-down.

CLIMATE AND ECOSYSTEM IMPACTS

A sustainable chemical, material, process, product, or service will…

- Utilize renewable, non-toxic chemical building blocks[i].
- Be without negative impacts on climate and biodiversity, including impacts on habitat and resource degradation.
- Be without harmful releases to air, water, and land across its lifecycle, including for transportation and distribution.
- Minimize energy use and greenhouse gas emissions across its lifecycle, including for transportation and distribution.

[i]Chemical building blocks refer to molecular units or compounds that can be used as ingredients to synthesize more complex chemical materials or products.

CIRCULARITY[j]

A sustainable chemical, material, process, product, or service will…

- Be designed to have a lifetime appropriate to its use and enable safe reuse and non-toxic recycling[k].
- Prioritize resource and energy efficiency, conservation, and reclamation, reduced consumption of finite resources, and waste prevention, minimization, and elimination[l].

[j]A circular economy is a “model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended.” The European Parliament.
[k]Recycling can include mechanical and chemical recycling. Chemical recycling and other emerging technologies for recycling and recovery should be closely evaluated for their hazards to avoid shifting negative impacts.
[l]Waste minimization and elimination should be practiced across the supply chain, including for extraction, development, production, use, reuse, and disposal.

APPENDIX A

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APPENDIX B

Background and Origins of this Project

Project rationale: Sustainable chemistry has been broadly defined to date, including its connection to other fields, such as green chemistry. With its incorporation into the European Chemicals Strategy for Sustainability (the concept of Safe and Sustainable by Design) and the US Sustainable Chemistry R&D Act, as well as increasing demands for sustainable chemistry from investors and the marketplace, there is a pressing need to develop a clear and concise definition and actionable criteria. This project's efforts aim to develop a definition and criteria such that it could be adopted by a different business, investor, educational, and government audiences (in particular, the White House Office of Science and Technology Policy which is tasked with creating a definition and criteria).

Project progress to date: The 20-person Expert Committee on Sustainable Chemistry (ECOSChem) was formed in Spring 2022 and includes representatives from industry, academia, governmental and non-governmental organizations. The charge of ECOSChem was to establish an ambitious, actionable definition and criteria for sustainable chemistry that can enable effective government policy, inform business and investor decision making, enhance chemistry education, and spur the adoption across all supply chains of chemicals that are safer and more sustainable. ECOSChem deliberations were informed by key government and non-governmental efforts on the topic to date. Over the course of the project, five large group meetings and several smaller subcommittee meetings, along with online discussions shaped a draft definition and criteria that can catalyze future progress and actions.

Project support: The ECOSChem process was facilitated and supported by Beyond Benign, a nonprofit focused on K-12 and university green chemistry and sustainability education and the Sustainable Chemistry Catalyst of the Lowell Center for Sustainable Production (LCSP) at the University of Massachusetts Lowell, a research and engagement center focused on accelerating the transition to safer, more sustainable chemicals and products. The initiative was funded by the New York Community Trust and other philanthropic funders.

External engagement: Beyond Benign and the Lowell Center for Sustainable Production hosted two external engagement meetings on November 1st and 3rd, 2022. At these meetings, the Project Team introduced the project and the draft definition and criteria and then participants moved into sector breakout groups for discussions facilitated by the Project Team, with the support of ECOSChem members. Organizations were also to send feedback over email or through an online submission portal. In addition, ECOSChem members conducted discussion sessions within their own networks. *Note: the preamble was not shared or discussed at these meetings.*