Electronic Supplementary Material (ESI) for RSC Sustainability.

Comments on the Request for Information (RFI) from the public on Federal programs and activities in support of Sustainable Chemistry

To: White House Office of Science and Technology Policy (OSTP)
Attention: Melanie Buser

Respondent: Expert Committee on Sustainable Chemistry (ECOSChem)
Respondent Type: Multidisciplinary committee of members from academia, government, non-governmental organizations, and industry.

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The Expert Committee on Sustainable Chemistry (ECOSChem) was formed in 2022 with the charge of establishing an ambitious, actionable definition and criteria for Sustainable Chemistry that can enable effective government policy, business, and investor decisions, support chemistry education that accelerates innovation, and spur the adoption across all supply chains of chemicals that are safer and more sustainable. ECOSChem deliberations are informed by key government and non-governmental efforts on the topic to date. The primary outcome of this 20-member Committee will be a published statement (anticipated in early 2023) that outlines a vision of Sustainable Chemistry and sets forth a usable definition and associated criteria that can catalyze future progress and actions. This process is facilitated by Beyond Benign and the Lowell Center for Sustainable Production at the University of Massachusetts Lowell (Project Team).

The OSTP RFI requests voluntary responses to inform and guide policies and actions related to Sustainable Chemistry. ECOSChem wishes to respond to **Topic 1 of the RFI: Definition of Sustainable Chemistry**, which requests comments on what the definition should include as well as how the definition of Sustainable Chemistry relates to the common usage of "Green Chemistry" and whether these terms should be synonymous, exclusive, complementary, or if one should be incorporated into the other.

ECOSChem is currently evaluating global efforts to date in defining "Sustainable Chemistry". The Project Team conducted a literature review of existing definitions, including peer reviewed, and grey literature, in addition to interviews with key stakeholders. Because of their similarity, definitions for the terms "sustainable chemistry", "green and sustainable chemistry", "safe and sustainable by design (SSbD)", and "safe by design (SbD)" were included in the review. Forty-four journal articles, reports, and website documents were identified as being informative to the charge of ECOSChem given its focus on definitions, principles, or criteria related to the terms noted above. The Project Team identified 10 explicit definitions outlined by academic, governments, industry, and NGOs. This list should NOT be considered exhaustive but rather informative of the existing landscape of useful definitions.

ECOSChem members discussed these 10 definitions at its meeting on May 17, 2022, identifying elements that were particularly informative and noting whether there were missing definitions or concepts not captured by the Project Team. The meeting concluded with the ECOSChem members present finding that the 10 definitions adequately summarize the efforts to date and will refer to these going forward with the project. These 10 definitions are summarized in Table 1 of the attached appendix below, organized alphabetically and with links to the documents provided in the table.

APPENDIX A: Thematic Analysis of Definitions (and Related Terms) for Sustainable Chemistry

A thematic analysis of the definitions below was developed to support a critical assessment of domains within each definition and related word choices, with use frequencies of these themes depicted in Figure 1. In order of frequency, the dominant themes included: (A) Protecting human/environmental health; (B) chemicals, substances, materials, processes, products, services, and technologies; (C) lifecycle/circularity; (D) resource efficiencies/conservation; (E) innovation; (F) design, manufacturing, and production; (G) creates social and economic value; (H) sustainability/sustainable development; (I) climate change/neutrality; (J) creates shareholder/stakeholder value; (K) holistic/interdisciplinary approach; and (L) Function. While not included as a theme, 2 definitions (Dow 2015 and Kummerer and Clark 2016), distinguish between “green chemistry” and “sustainable chemistry”, which might be useful for consideration going forward.

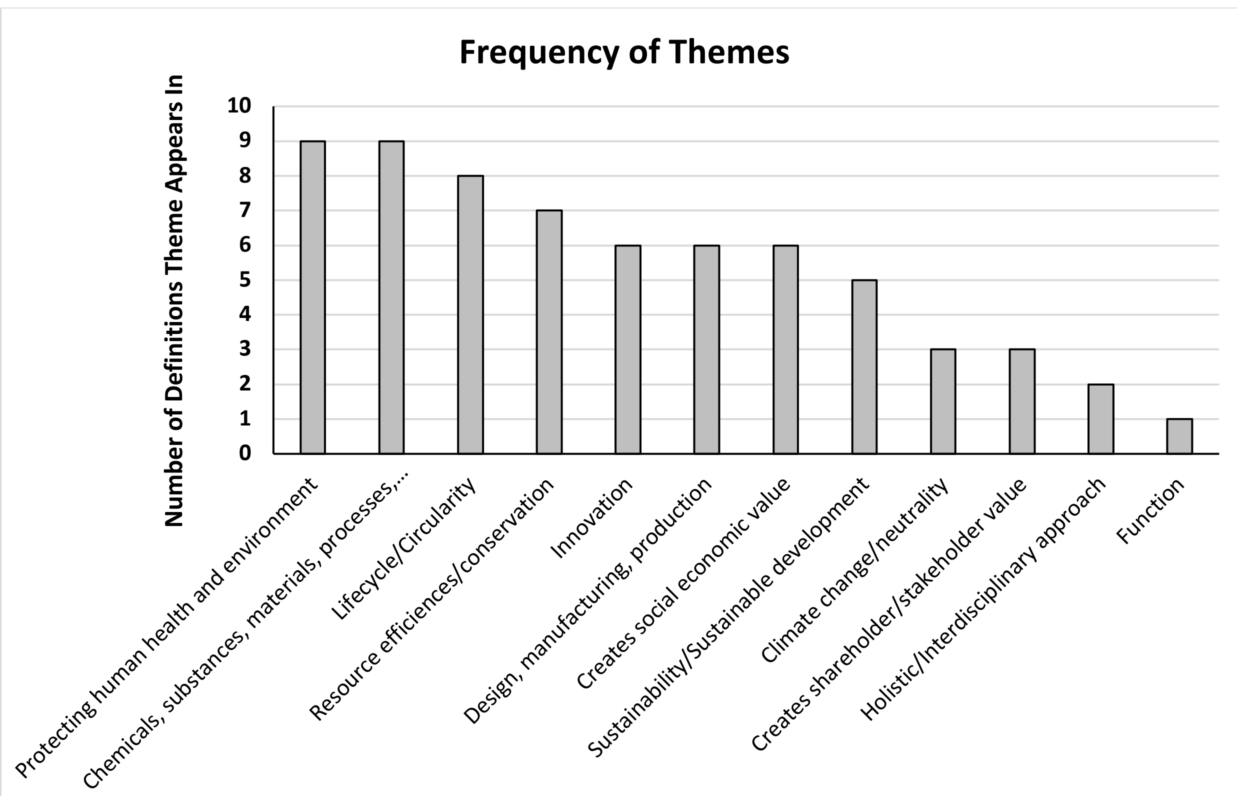

Figure 1. A frequency table of themes that appear in the 10 definitions analyzed.

A. Protecting Human/Environmental Health (includes terms related to enhancing quality of life, safe/safer, environmentally benign substitutes/alternatives, pollution prevention, least adverse effects, prevent/reduce harm/exposure, minimizes risk). All but one definition (9 of 10) included explicit language in the definition related to human health and the environment. The exception (Kummerer and Clark) subsumes the concepts within the use of the term "green synthesis" and addresses it within other sections of their paper, just not within an explicit definitional statement. The definitions vary regarding how environmental health is addressed. Some use more positive framing – "are safe and deliver environmental value"; "safe and more environmentally benign" – others use terms such as "less toxic" or "reducing harmful impacts to human health and the environment".

- Blum et al. 2017: "…with the **least adverse effects**"; "…**avoids rebound effects, damage and impairments to human beings, ecosystems and natural resources**."
- CEFIC 2021 [SSbD]: "…that are **safe and deliver environmental…value** through their applications."
- Dow 2015: "…enhance the **quality of life** of current and future generations."
- EU Commission 2021 [SSbD]: "…while **reducing harmful impacts to human health and the environment**"
- GC3 Sustainable Chemistry Alliance 2019: "…are **less toxic to human health and the environment**; have lower energy consumption and related emissions; have reduced natural resource impacts"
- Marion et al. 2017: "…the development of an even **safer and more environmentally-friendly** chemistry"
- OECD 2004: "…**safe and more environmentally benign**…"
- OECD website: "…while meeting the goals of **protecting and enhancing human health and the environment**."
- OECD 2020 [SbD]: "…identifying the **risks and uncertainties concerning humans and the environment**."

B. Chemicals, Substances, Materials, Processes, Products, Services, and Technologies. It's not just chemistry/chemicals that are addressed in several definitions, but how they are used in materials, processes, products, and technologies. All but one definition (9 of 10) referred to at least two of the terms in this theme, though there is no consistency as to which terms are used across definitions. Many however use chemicals and products.

- Blum et al. 2017: "…uses **approaches, substances, materials and processes**"
- CEFIC 2021 [SSbD]: "…put on the market **chemicals, materials, products and technologies**"
- Dow 2015: "…the design and development of chemical **products and processes**."
- EU Commission 2021 [SSbD]: "…use of **substances, materials and/or products**…"
- GC3 Sustainable Chemistry Alliance 2019: "…use of **chemicals and materials**…"
- Kummerer and Clark 2016: "…application of **chemicals and products**."
- OECD 2004: "…safe and more environmentally benign **chemical products and processes**."
- OECD website: "…safe and more environmentally benign **chemical products and processes**."
- OECD 2020 [SbD]: "…safety of the **material/product and associated processes**…"

C. Lifecycle/Circularity (includes terms related to reuse, recycling, and product stewardship). Conceptualizing chemistry across product lifecycles, including the concept of circularity, is an element common across 8 of 10 definitions. In these definitions, "across the lifecycle" relates to some desirable impact at every stage of a chemical product's development and/or existence, for example "safe and more environmentally benign products/processes" or "waste minimization." Terms such as "reuse" and/or "recycling" are used in some definitions to refer to specific aspects to improve circularity. One definition uses the term "lifecycle thinking" and another uses the term "product stewardship".

- Blum et al. 2017: "…sustainable chemistry applies substitutes, alternative processes and **recycling concept, supporting resource recovery** and efficiency."
- CEFIC 2021 [SSbD]: "…preventing harm to human health and the environment **throughout the life cycle**"
- Dow 2015: "…the **application of lifecycle thinking** to the products and solutions…"
- EU Commission 2021 [SSbD]: "…reducing harmful impacts to human health and the environment **along life cycle stages**."
- GC3 Sustainable Chemistry Alliance 2019: "…reduction of waste and the reuse or recycling of chemicals and materials **across the product lifecycle**."
- OECD 2004: "…minimisation of waste at **all stages of a product life-cycle**…"
- OECD website: "…Sustainable chemistry is also a process that stimulates…**product stewardship practices** that will provide increased performance and increased value…"
- OECD 2020 [SbD]: "…safety of the material/product and associated processes **through the whole life cycle,** from the Research and Development (R&D) phase to production, use, recycling and disposal."

D. Resource Efficiencies/Conservation. A focus on using resources efficiently is a focal point in 7 of the 10 definitions. Some definitions say this more explicitly such as Blum et al. and Dow, while others imply this or provide examples of resource efficiency, such as the GC3 Sustainable Chemistry Alliance. Marion et al. specifically points out the availability of resources, perhaps alluding to the ability to even access them for use in the future.

- Blum et al. 2017: "…supporting **resource recovery and efficiency**."
- Dow 2015: "…understand how to use **resources more efficiently**…"
- GC3 Sustainable Chemistry Alliance 2019: "…use of chemicals and materials that…**have lower energy consumption** and related emissions…"
- Kummerer and Clark 2016: "…related to the **use of resources**…"
- Marion et al. 2017: "…issues related to **accessing different resources**…"
- OECD 2004: "…should strive to **maximise resource efficiency**…."
- OECD website: "…seeks to improve the **efficiency with which natural resources are used**…"

E. Innovation (includes terms related to improvement, novelty, and discovery). The concept of innovation is used in 6 of 10 definitions. The majority of these are also newer definitions. For example, the OECD website refers to its 2004 definition, but then expands it to address the concept of innovation. The GC3 Sustainable Chemistry Alliance does not use the term "innovation" and instead addresses the innovation cycle through the phrase "design, development, demonstration and commercialization."

- Blum et al. 2017: "…stimulates social **innovations**" and develops value-creating products and services."
- CEFIC 2021 [SSbD]: "…to **innovate** and put on the market…"
- Dow 2015: "…applies Dow's technology and **innovation capabilities** to develop products and solutions…"
- GC3 Sustainable Chemistry Alliance 2019: "Products of sustainable chemistry demonstrate **improvements.**…"
- OECD website "…that **stimulates innovation** across all sectors to design and discover new chemicals, production processes, and product stewardship practices."
- OECD 2020 [SbD]: "…identifying the risks and uncertainties concerning humans and the environment **at an early phase of the innovation process** so as to minimize uncertainties, potential hazard(s) and/or exposure."

F. Design, Manufacturing, Production. Of the definitions, 6 of 10 refer specifically to the design, manufacturing, and/or production aspects that could be considered an important focus for sustainable chemistry.

- EU Commission 2021 [SSbD]: "…an approach to the **design**, development and use of substances, materials and/or products…"
- GC3 Sustainable Chemistry Alliance 2019: "The term "sustainable chemistry" includes the **design**, development, demonstration, commercialization and/or use of chemicals and materials…"
- Kummerer and Clark 2016: "…other aspects related to **manufacturing** and application of chemicals and products. It aims not only at **green synthesis or manufacturing** of chemical products…"
- OECD 2004: "Sustainable chemistry is the **design, manufacture** and use of …"
- OECD website: "Sustainable chemistry encompasses the **design, manufacture** and use of…"
- OECD 2020 [SbD]: "…from the Research and Development (R&D) phase to **production**, use, recycling and disposal."

G. Creates Social/Economic Value. The notion of chemistry that provides for economic and social value is found in about half of the definitions (6 of 10). One definition (Kummerer and Clark) does not use the term "value" but rather states that sustainable chemistry addresses economic and social aspects of how such chemistries are manufactured and used. Marion et al. use the term "addresses economic competitiveness and societal concerns" rather than "value".

- Blum et al. 2017: "…develops **value-creating** products and services."
- CEFIC 2021 [SSbD]: "…deliver environmental, **societal, and/or economical value** through their applications."
- Dow 2015: "…use resources more efficiently, minimize its footprin**t, provide value** to its shareholders and stakeholders…"
- Kummerer and Clark 2016: "…**economical, social and other aspects** related to manufacturing and application of chemicals and products."
- Marion et al. "…integrates the priorities of **economic competitiveness and societal concerns**"
- OECD website: "…will provide increased performance and **increased value**"

H. Sustainability/Sustainable Development (includes terms related to sustainability challenges and resource access problems). Use of the term sustainable development or aspects of term "sustainability" are featured in 6 of 10 definitions. Two definitions (Dow; Kummerer and Clark) include explanatory text that seek to differentiate green chemistry from sustainable chemistry; both elevate applying green chemistry principles/concepts but distinguish sustainable chemistry from green chemistry as it is applied to directly solve sustainability challenges.

- Blum et al. 2017: "…contributes to positive, long-term **sustainable development**"
- Dow 2015: "…to **address sustainability challenges** related to areas such as climate change, water scarcity, food provision and safety, and healthy societies"
- GC3 Sustainable Chemistry Alliance 2019: "…**have lower energy consumption and related emissions; have reduced natural resource impacts…"**
- Kummerer and Clark 2016: "…includes the contribution of such products to **sustainability itself**."
- Marion et al. 2017: "…must ensure the longevity of the human, animal, and vegetable species whilst taking into consideration issues related to accessing different resources (carbon, water, metals), problems of access to energy, global warming, the exponential increase in the human population."
- OECD 2004: "Within the broad framework of **sustainable development**, government, academia and industry should strive to maximise resource efficiency through activities such as energy and non-renewable resource conservation, risk minimisation, pollution prevention, minimisation of waste at all stages of a product life-cycle, and the development of products that are durable and can be reused and recycled."

I. Climate Change/Neutrality (includes terms related to global warming). Use of terms related to climate change appeared in 3 of 10 definitions.

- CEFIC 2021 [SSbD]: "Those chemicals, materials, products and technologies enable accelerating the transition towards a circular economy and **climate-neutral society**."
- Dow 2015: "The successful application of Sustainable Chemistry results in commercially viable products that help society to address sustainability challenges related to areas such as **climate change**…"
- Marion et al. 2017: "…problems of access to energy, **global warming**, the exponential increase in the human population, for which chemistry must allow a serene development…"

J. Creates Shareholder/Stakeholder Value (includes terms related to competitiveness). Use of terms related to creating shareholder or stakeholder value appeared in 3 of 10 definitions.

- Dow 2015: "…in order to understand how to use resources more efficiently, minimize its footprint, **provide value to its shareholders and stakeholders, deliver solutions to its customers**…"
- Kummerer and Clark 2016: "…includes all aspects of a product related to sustainability, e.g. social and economic aspects related to the use of resources, **the shareholders, the stakeholders and the consumers**."
- Marion et al. 2017: "…the social and environmental impact of the value chain, and the erosion of biodiversity, while of course **maintaining economic competitiveness to create profit and business**."

K. Holistic/Interdisciplinary Approach (includes terms suggesting partnership across all sectors). Use of terms related to fostering a holistic or interdisciplinary approach in the Sustainable Chemistry field appeared in 2 of 10 definitions.

> – Blum et al. 2017: "…Sustainable chemistry is based on a **holistic approach**, setting policies and measurable objectives for a continuous process of improvement…."
> – OECD website: "Sustainable chemistry is also a process that stimulates innovation **across all sectors** to design and discover new chemicals, production processes, and product stewardship practices…"

L. Function. Use of this term appeared in 1 of the 10 definitions.

> – EU Commission 2021 [SSbD]: "…use of substances, materials and/or products that focuses on **providing a function (or service)**…"

Additional Relevant Summary Documents That Provide Context:
Of the 44 documents reviewed, 2 were not included as main contributors towards a definition but are featured here as summaries of existing efforts and stakeholder analyses. These include:

<u>2018 Government Accountability Office (GAO) "Chemical Innovation: Technologies to Make Processes and Products More Sustainable"</u>
"Stakeholders do not agree on a single definition of sustainable chemistry, but there are some common understandings of what this term means. In total, we asked 71 representatives of stakeholder organizations how they or their organization define sustainable chemistry. The most common response we received, with 28 respondents agreeing, was that sustainable chemistry includes minimizing the use of non-renewable resources such as feedstocks. The second most common response (27) was that sustainable chemistry is similar, synonymous, or interchangeable with green chemistry. However, 17 stakeholders described sustainable chemistry as broader than green chemistry. Stakeholders mentioned various ways in which sustainable chemistry may go beyond green chemistry, for example by considering the entire life cycle of a process or product, or by incorporating economic considerations."

<u>2019 United Nations Environmental Program (UNEP) "Analysis of Stakeholder Submissions on Sustainable Chemistry Pursuant to UNEA Resolution 2/7"</u>
"The majority of respondents felt that an international definition of sustainable chemistry would be valuable…and suggested…a slightly higher preference for a detailed international definition compared to a simple one (72 % vs. 67 % agreement). In considering a simple definition, the large majority of participants (79% agreement) supported a suggested option to frame it along the Brundtland Commission's definition of sustainable development as follows: "Sustainable chemistry is the design, production, use, recycling and disposal of chemicals to support implementation of the 2030 Agenda for Sustainable Development and meeting the needs of the present, without compromising the ability of future generations to meet their own needs"".

"Stakeholders see sustainable chemistry as playing a key role in achieving the SDG Target 12.4 on the sound management of chemicals and wastes, including implementation of the Strategic Approach to International Chemicals Management and the chemicals and waste multilateral environmental agreements, and other related aspects of SDG 12 on sustainable consumption and production. The submitted cases address all stages of the life cycle, including chemical and non-chemical alternatives; efficient and safe use and reduction of emissions and exposure; and waste management, recycling and remediation of pollution, thus highlighting potential synergies between chemicals and waste and resource efficiency."

Table 1: Sustainable Chemistry/Safe and Sustainable by Design Definitions

Entity/Link	Year	Term	Definition
Blum et al.	2017	Sustainable Chemistry	Sustainable chemistry contributes to positive, long-term sustainable development. With new approaches, technologies and structures, sustainable chemistry stimulates social innovations and develops value-creating products and services. Sustainable chemistry uses approaches, substances, materials and processes with the least adverse effects. Therefore, sustainable chemistry applies substitutes, alternative processes and recycling concept, supporting resource recovery and efficiency. Thus sustainable chemistry avoids rebound effects, damage and impairments to human beings, ecosystems and natural resources. Sustainable chemistry is based on a holistic approach, setting policies and measurable objectives for a continuous process of improvement. Networking sustainable chemistry with interdisciplinary scientific research, education, consumer awareness, corporate social responsibility and sustainable entrepreneurship serves as important basis for sustainable development.
CEFIC	2021	Safe and Sustainable by Design	The chemical industry defines Safe and Sustainable-by-Design as a process to innovate and put on the market chemicals, materials, products and technologies that are safe and deliver environmental, societal, and/or economical value through their applications. Those chemicals, materials, products and technologies enable accelerating the transition towards a circular economy and climate-neutral society and preventing harm to human health and the environment throughout the life cycle.
Dow Chemical	2015	Sustainable Chemistry	"Sustainable chemistry involves the application of lifecycle thinking to the products and solutions Dow brings to society, in order to understand how to use resources more efficiently, minimize its footprint, provide value to its shareholders and stakeholders, deliver solutions to its customers, and enhance the quality of life of current and future generations. Sustainable Chemistry is a lens through which Dow examines its products, to better understand the role of those products in addressing sustainability challenges. It is a concept that identifies the existence of global sustainability challenges, applies Dow's technology and innovation capabilities to develop products and solutions that address these challenges, and recognizes that chemistry has an essential role to play in advancing sustainability for society. The successful application of Sustainable Chemistry results in commercially viable products that help society to address sustainability challenges related to areas such as climate change, water scarcity, food provision and safety, and healthy societies.

			Sustainable Chemistry differs from Green Chemistry in that Sustainable Chemistry is a general concept that seeks to understand and optimize the role of a chemical product in addressing sustainability challenges. Green Chemistry, on the other hand, seeks to apply a set of well-defined principles to the design and development of chemical products and processes. In this sense, Sustainable Chemistry can be advanced by applying the tools of Green Chemistry to develop new products and processes that help to solve sustainability challenges.
EU Commission	2021	Safe and Sustainable by Design	SSbD is defined as "an approach to the design, development and use of substances, materials and/or products that focuses on providing a function (or service), while reducing harmful impacts to human health and the environment along life cycle stages.
Green Chemistry & Commerce Council (GC3) Sustainable Chemistry Alliance	2019	Sustainable Chemistry	The term "sustainable chemistry" includes the design, development, demonstration, commercialization and/or use of chemicals and materials that: are less toxic to human health and the environment; have lower energy consumption and related emissions; have reduced natural resource impacts; include optimized product design that results in the reduction of waste and the reuse or recycling of chemicals and materials across the product lifecycle. Products of sustainable chemistry demonstrate improvements in at least one of these properties, without significant degradation in another property, in their production, use, and/or end of life as compared to chemicals and materials in similar use.
Kummerer and Clark	2016	Green and Sustainable Chemistry	Sustainable chemistry includes economical, social and other aspects related to manufacturing and application of chemicals and products. It aims not only at green synthesis or manufacturing of chemical products but also includes the contribution of such products to sustainability itself. In general, only rarely are aspects that go beyond the chemicals themselves and their technical issues addressed by green chemistry, whereas sustainable chemistry generally includes all aspects of a product related to sustainability, e.g. social and economic aspects related to the use of resources, the shareholders, the stakeholders and the consumers
Marion et al.	2017	Sustainable chemistry	Sustainable chemistry can be defined as the development of an even safer and more environmentally-friendly chemistry but one which also equally integrates the priorities of economic competitiveness and societal concerns. Sustainable chemistry is a complex equation which must ensure the longevity of the human, animal, and vegetable species whilst taking into consideration issues related to accessing different resources (carbon, water, metals), problems of access to energy, global warming, the exponential increase in the human population, for which chemistry must allow a serene development, the social and environmental impact of the value chain, and the erosion of biodiversity, while of course maintaining economic competitiveness to create profit and business.
OECD	2004	Sustainable Chemistry	Sustainable chemistry is the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. Within the broad framework of sustainable development, government, academia and industry should strive to maximise resource efficiency through activities such as energy and non-renewable resource conservation, risk minimisation, pollution prevention, minimisation of waste at all stages of a product life-cycle, and the

			development of products that are durable and can be reused and recycled.
OECD	Website	Sustainable Chemistry	Sustainable chemistry is a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes." Sustainable chemistry is also a process that stimulates innovation across all sectors to design and discover new chemicals, production processes, and product stewardship practices that will provide increased performance and increased value while meeting the goals of protecting and enhancing human health and the environment.
OECD	2020	Safe by Design	The SbD (Safe-by-Design, Safer-by-Design, or Safety-by-Design) concept refers to identifying the risks and uncertainties concerning humans and the environment at an early phase of the innovation process so as to minimize uncertainties, potential hazard(s) and/or exposure. The SbD approach addresses the safety of the material/product and associated processes through the whole life cycle: from the Research and Development (R&D) phase to production, use, recycling and disposal.

APPENDIX B: Expert Committee on Sustainable Chemistry (ECOSChem) Members*:

- Abigail Noble, California Department of Toxic Substances Control (DTSC)
- Alexandra Caterbow, HEJSupport
- Cecilia Wandiga, Centre for Science and Technology Innovations (CSTI)
- Christopher Blum, German Federal Environment Agency (UBA)
- David Constable, ACS Green Chemistry Institute
- Eeva Leinala, Organisation for Economic Cooperation and Development (OECD)
- Gabriela Kaczmarska, The LEGO Group
- Heather Buckley, University of Victoria
- Julie Gorte, Impax Asset Management
- Kathy Curtis, Moms for a Nontoxic New York
- Klaus Kummerer, Leuphana University Lüneburg
- Martin Wolf, Seventh Generation
- Maya Nye, Coming Clean
- Pam Spencer, The ANGUS Chemical Company
- Rory O'Neill, International Trade Union Confederation (ITUC)
- Ryan Bouldin, Bentley University
- Saskia van Bergen, Washington State Department of Ecology
- Shari Franjevic, Clean Production Action
- Tom Welton, Imperial College London
- Ylva Weissback, H&M Group

*Affiliations for purposes of identification only and does not represent organizational endorsement