Beyond 2020: Green chemistry and sustainable chemistry

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Introduction

The Strategic Approach to International Chemicals Management (SAICM) addresses significant health and environmental harms caused by chemical exposure and makes a global political commitment to reform how chemicals are produced and used in order to minimize those harms. Heads of State at the 2002 World Summit on Sustainable Development in Johannesburg called for the development of SAICM. While the agreement is not legally binding, its basic texts represent a consensus of Environment Ministers, Health Ministers and other delegates from more than one hundred governments who attended the first International Conference on Chemicals Management (ICCM1), held in Dubai, February 2006.

Green chemistry has been an important element of sound chemicals management since the first years of SAICM. In the SAICM agreement, the expectation set for green chemistry is that it should improve standards of living and lead to greater protection of health and the environment. [1] In 2014, the United Nations Environment Assembly, recognized a new term, "sustainable chemistry," noting that the private sector should apply sustainable chemistry because, *"Industry has a special responsibility, as designer, producer and use of chemicals and products…"*[2] Green chemistry is well defined and has a history of more than 20 years as a formal sub-discipline of chemistry. Sustainable chemistry also has important historical endorsement. Both concepts are useful in the Beyond 2020 process.

A discussion of green chemistry and sustainable chemistry must also recognize that neither concept replaces the need for sound chemicals management and dealing with legacy issues. Currently, industrial production and use of chemicals is shifting to developing and transition countries.[3] This shift is accompanied by continued or increased use of pesticides and increasing use of products containing hazardous chemicals.[4] UNEP's Global Chemicals Outlook notes that one-third of all chemical consumption may be in developing countries by 2020 and that, *"the prospect for widespread and multifaceted exposures of communities and the environment to chemicals of high and unknown concern also increases."*[5]

As delegates plan for the future of cooperation on chemical safety, defining and supporting a new paradigm of non-toxic chemical design and use could provide an important contribution to a sustainable

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[1] UNEP (2006) Strategic Approach to International Chemicals Management: SAICM texts and resolutions of the International Conference on Chemicals Management, "We are determined to realize the benefits of chemistry, including green chemistry, for improved standards of living, public health and protection of the environment." http://www.saicm.org/images/saicm_documents/saicm%20texts/SAICM_publication_ENG.pdf

[2] UNEP (2014) Strengthening the sound management of chemicals and wastes in the long term, Proceedings of the United Nations Environment Assembly of the United Nations Environment Programmed at its first session, UNEP/EA.1/10

[3] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[4] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[5] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

economy. The goal is that countries not only manage dangerous chemicals better by applying stricter legislation and its enforcement, but that industry designs safer, non-toxic chemistries from the start. This has important links to occupational health and safety, pollution prevention, and sustainable development patterns, and provides a clear, proactive role for the private sector to reduce and eliminate the use or generation of hazardous substances in the design, manufacture and application of chemical products.

The high costs of hazardous chemicals

Hazardous chemicals and wastes, *"are a public health issue of global concern."*[6] Today, children are born *"pre-polluted,"*[7] with representative studies measuring at least dozens, if not hundreds, of toxic and otherwise hazardous chemicals in children before birth through their mother's exposure. Pediatricians note a *"silent pandemic"* of disease and disability associated with exposure to toxics and pollution during childhood, many of which do not manifest themselves for years or decades.[8] Health effects associated with chemical exposure include damage to body organs, cancer, asthma, diabetes, and birth defects, among others.[9]

UNEP's Global Chemicals Outlook notes that hazardous chemicals also have damaging environmental effects. For example, the effects of hazardous chemicals on aquatic organisms include, *"cancers, disrupted reproduction, immune dysfunction, damage to cellular structures and DNA, and gross deformities."*[10] Harms in predator species include, *"thinning of eggshells, disruption of parental behavior, reproductive disorders, and cancers, among other effects."*[11]

Unfortunately, the harms associated with hazardous chemicals represent costs that are externalized by the industry onto the public and the environment. As noted by UNEP, *"The vast majority of human health costs linked to chemicals production, consumption and disposal are not borne by chemicals producers, or shared down the value-chain. Uncompensated harms to human health and the environment are market failures that need correction."*[12]

The magnitude of the costs externalized by the chemical industry is enormous. Conservative estimates of some of these externalized costs include:

- US$90 billion for health-related pesticide costs in Sub-Saharan Africa from 2005 – 2020. As a means of comparison, the entire 2009 Overseas Development Assistance to the health sector in Africa was US$4.8 billion – a fraction of the health-related costs due to pesticides alone.[13]

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[6] UN Human Rights Council (2015) Report of the Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes, Başkut Tuncak, A/HRC/30/40

[7] National Cancer Institute (United States), "Reducing environmental cancer risk" (2010).

[8] Grandjean P, Landrigan PJ (2014) Neurobehavioural effects of developmental toxicity, Lancet Neurology 13:330-338

[9] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[10] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[11] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[12] UNEP (2012) *Global Chemicals Outlook: Towards the sound management of chemicals*, p 118, ISBN 978-92-807-3320-4

[13] UNEP (2012) *Global Chemicals Outlook: Towards the sound management of chemicals*, p 99, ISBN 978-92-807-3320-4

- €157 billion as a median annual health cost for diseases associated with endocrine disrupting chemicals in the European Union. The diseases include IQ loss and associated intellectual disability, autism, attention-deficit hyperactivity disorder, childhood obesity, adult obesity, adult diabetes, cryptorchidism, male infertility, and mortality associated with reduced testosterone. The authors noted that this estimate was conservative, as it represented only those EDCs with the highest probability of causation and a broader analysis would have produced greater estimates of burden of disease and accompanying costs.[14]

- US$236 billion annual costs for pollution associated with the production and use of volatile organic compounds. This is an underestimate, as it excludes damage to most natural resources as well as water pollution and land use change and waste in non-OECD countries.[15]

- US$977 billion annual costs related to childhood lead exposure in low- and middle-income countries. This figure represents 1.20% of global GDP in 2011. The authors note that the largest burden of lead exposure is now borne by low- and middle-income countries.[16]

None of these figures reflect the full magnitude of human suffering or damage to ecosystems. Chemistries that reduce hazard have a key role to play in helping to internalize the costs of chemical production, use, and disposal.

Green chemistry and hazard reduction

Green chemistry has been recognized as a scientific approach within chemistry for two decades. It is a broad concept but is most frequently associated with efforts at hazard reduction. The widely accepted definition of green chemistry as proposed by the founders of the field is, *"the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products."*[17] US EPA notes that green chemistry, *"applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal."*[18] The Green Chemistry and Commerce Council describes the important role of product developers, manufacturers, brands, and retailers in implementing green chemistry, noting that they can do this by, *"changing design specifications, sourcing materials and products that incorporate green chemistry practices, changing manufacturing practices to substitute or reduce the use of hazardous chemicals, and developing and implementing policies that restrict chemicals of concern in the products they source, make, and/or sell."*[19]

Less hazard is key to green chemistry. US EPA describes less hazardous chemicals as substances that are less toxic to organisms, less damaging to ecosystems, not persistent or bioaccumulative in organisms or the environment, and inherently safer to handle and use because they are not flammable or explosive.[20] In its guidance on alternatives, the Stockholm Convention POPs Review Committee notes that safer

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[14] Trasande L, Zoeller RT, Hass U, Kortenkamp A, Grandjean P, Myers JP, DiGangi J, Bellanger M, Hauser R, Legler J, Skakkebaek NE, Heindel JJ (2015) *Estimating Burden and Disease Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union*, J ClinEndocrinolMetab 100: 1245 – 1255 doi: 10.1210/jc.2014-4324
[15] UNEP (2013) Costs of inaction on the sound management of chemicals; p 11, Job numbe DTI/1551/G
[16] Attina TM, Trasande L (2013) *Economic costs of childhood lead exposure in low- and middle-income countries*, Environ Health Perspect 121: 1097-1102 doi: 10.1289/ehp.1206424
[17] Anastas PT, Warner, JC (1998) Green Chemistry: Theory and Practice, Oxford University Press: New York
[18] https://www.epa.gov/greenchemistry/basics-green-chemistry#definition
[19] Green Chemistry and Commerce Council (2015) An agenda to mainstream green chemistry http://www.greenchemistryandcommerce.org/documents/An_Agenda_to_Mainstream_Green_Chemistry.pdf
[20] https://www.epa.gov/greenchemistry/basics-green-chemistry#twelve

alternatives should not have hazardous properties, *"such as mutagenicity, carcinogenicity or adverse effects on the reproductive, developmental, endocrine, immune or nervous systems."*[21]

The principles of green chemistry

In the 1990s, Anastas and Warner developed 12 principles of green chemistry to guide implementation (please see the green chemistry principles in Annex 1). A key concept in the green chemistry principles is to create designs that minimize and eliminate toxicity while maintaining function. This implies that green chemists must also utilize knowledge of toxicology and environmental health. As Anastas has noted, designing according to green chemistry principles requires, *"innovative approaches to chemical characterization that state that hazard is a design flaw and must be addressed at the genesis of molecular design."*[22] US EPA has further outlined how green chemistry can positively impact the pollution prevention hierarchy, particularly through source reduction and prevention of chemical hazards. This includes the following elements:[23]

- Designing chemical products to be less hazardous to human health and the environment
- Making chemical products from feedstocks, reagents, and solvents that are less hazardous to human health and the environment
- Designing syntheses and other processes with reduced or even no chemical waste
- Designing syntheses and other processes that use less energy or less water
- Using feedstocks derived from annually renewable resources or from abundant waste
- Designing chemical products for reuse or recycling
- Reusing or recycling chemicals

The principles of green chemistry address key issues in the design and manufacturing of chemicals and a few examples are described below.

Persistence is one of the key negative characteristics of persistent organic pollutants – and green chemistry principles call for design and use of chemicals that fulfill their function, then break down into innocuous degradation products. This principle requires designing features that permit biodegradation, hydrolysis, and/or photolysis into the chemical itself. While challenging, the principle was implemented for surfactants used in US wastewater treatment plants in the 1960s. Eliminating persistence is also consistent with obligations detailed in Article 3 of the Stockholm Convention, which requires Parties with regulatory schemes to prevent production and use of chemicals that have the characteristics of persistent organic pollutants, including persistence.[24]

Fossil fuels are intimately linked to producing carbon-based chemicals – but oil, coal, and natural gas are not renewable. Green chemistry principles call for use of renewable feedstocks and in practice this points to use of biomass as a source of carbon. In 2002, the US Department of Energy predicted that by 2030 a bioenergy and bio-based products industry would be well established. [25] The current use of plant oils to make biodiesel and lignin and plant oils to make plastics indicates that this green chemistry principle can

[21] UNEP (2009) General guidance on considerations related to alternatives and substitutes for listed persistent organic pollutants and candidate chemicals, Report of the Persistent Organic Pollutants Review Committee on the work of its fifth meeting, UNEP/POPS/POPRC.5/10/Add.1

[22] https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/gc-principle-of-the-month-4.html#articleContent_headingtext_2

[23] https://www.epa.gov/greenchemistry/basics-green-chemistry#twelve

[24] UNEP (2004) Article 3: Measures to reduce or eliminate releases from intentional production and use, Article 3.3 and 3.4, The Stockholm Convention on Persistent Organic Pollutants

[25] https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/green-chemistry-principle--7.html

be implemented. A key issue will be implementing it without competing for food sources. Like the design aspects of green chemistry, this principle also extends chemistry into other disciplines such as agronomy, toxicology, engineering and others.

The green chemistry principles are also relevant to chemical manufacturing. Solvents play a key role in chemical reactions and represent 50% - 80% of the mass in a standard batch synthesis. Solvents are also relevant to toxicity. One estimate indicates that, *"solvents account for about 75% of the cumulative lifecycle environmental impacts of a standard batch chemical operation…and drive most of the energy consumption in a process."*[26] The green chemistry principles for safer solvents provide a key link to cleaner production.

The green chemistry principle of "Real-time analysis for Pollution Prevention" is another connection to manufacturing and an objective of the SAICM Overarching Policy Strategy.[27] The use of real-time analysis prevents pollution by providing essential feedback to ensure processes are working properly and detect problems before major emissions or accidents occur. Real-time analysis also reveals the true nature of an operation without biases inherent in selecting certain time periods.
Finally, green chemistry principles call for inherently safer chemistry to prevent accidents. In 2012, in the US alone, there were an estimated 27,500 toxic chemical spills associated with 1000 deaths. [28] UNEP's Global Chemicals Outlook notes that petrochemical accidents in China in 2006 caused losses of approximately USD$11billion – not including injuries, loss or damage to human life, or environmental damage. [29] An explosion at a single plant in France in 2001 caused 30 deaths, 10,000 injuries, and caused damage costs of approximately USD$1.8 billion. [30] Clearly, the green chemistry principle of inherently safer chemistry has an important role to play in accident prevention.

Inherently safer chemistry is also highly applicable to preventing work-associated illnesses. Green chemistry occupies the top position in the hierarchy of safety controls because, *"the most effective means of increasing safety is eliminating the hazard component."*[31] Less effective steps include the use of engineering controls and administrative and work practice controls that require certain actions from the employer or worker. The least effective safety control is the use of personal protective equipment. Even in a country with established infrastructure for chemicals regulation such as the US, the government estimates that, *"workers suffer more than 190,000 illnesses and 50,000 deaths annually related to chemical exposures."*[32] The US Occupational Safety and Health Administration notes that these diseases include cancers and diseases of the lung, kidneys, skin, heart, stomach, brain and nerves.[33] The Global Chemicals Outlook notes that the costs associated with occupational injury and illness in the chemical

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[26] https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/green-chemistry-principle--5.html
[27] UNEP (2006) Strategic Approach to International Chemicals Management: SAICM texts and resolutions of the International Conference on Chemicals Management http://www.saicm.org/images/saicm_documents/saicm%20texts/SAICM_publication_ENG.pdf
[28] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf
[29] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE
[30] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE
[31] https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/green-chemistry-principle--12.html
[32] https://www.osha.gov/dsg/safer_chemicals/index.html
[33] https://www.osha.gov/dsg/safer_chemicals/index.html

industry can be significant. In 2004, preventable diseases caused by chemical exposures cost California insurers and workers USD$1.4 billion.[34]

SAICM objectives reflect green chemistry principles

Key SAICM objectives and parts of its Global Plan reflect many of the principles of green chemistry. The green chemistry principle of prevention is reflected in the SAICM Overarching Policy Strategy as an objective to, *"reduce the generation of hazardous waste, both in quantity and toxicity"*[35] The green chemistry principle of designing safer chemicals is reflected in the SAICM Dubai Declaration, which notes the need to develop, *"safer alternative products and processes, including non-chemical alternatives."*[36] SAICM's Overarching Policy Strategy includes the need to promote *"cleaner production, informed substitution of chemicals of concern and non-chemical alternatives"* and undertake research to develop, *"safer chemicals and cleaner technologies and non-chemical alternatives and technologies."*[37] SAICM also commits to ensure that research and development is performed in relation to, *"development of safer chemicals and cleaner technologies and non-chemical alternatives and technologies."*[38] The green chemistry principle of pollution prevention is strongly supported by the SAICM Overarching Policy Strategy objective to, *"give priority consideration to application of preventive measures such as pollution prevention."*[39]

The benefits of green chemistry

Application of green chemistry principles leads to clear benefits for human health, environment, and the economy. Some descriptions from the US EPA about these benefits include the ones below.[40] Added notes describe relevant SDGs.

Human health

- Cleaner air: Less release of hazardous chemicals to air leading to less damage to lungs (Relevant to SDGs 3, 7, 11)
- Cleaner water: less release of hazardous chemical wastes to water leading to cleaner drinking and recreational water (Relevant to SDGs 3, 6, 11, 14)
- Increased safety for workers in the chemical industry; less use of toxic materials; less personal protective equipment required; less potential for accidents (e.g., fires or explosions) (Relevant to SDGs 3, 8, 12)
- Safer consumer products of all types: new, safer products will become available for purchase; some products (e.g., drugs) will be made with less waste; some products (i.e., pesticides, cleaning products) will be replacements for less safe products (Relevant to SDGs 3, 12)

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[34] UNEP (2013) Global Chemicals Outlook – Towards sound management of chemicals, ISBN: 978-92-807-3320-4, Job Number DTI/1639/GE

[35] UNEP (2006) Strategic Approach to International Chemicals Management: SAICM texts and resolutions of the International Conference on Chemicals Management http://www.saicm.org/images/saicm_documents/saicm%20texts/SAICM_publication_ENG.pdf

[36] UNEP - WHO (2006) Strategic Approach to International Chemicals Management http://www.saicm.org/index.php?option=com_content&view=article&id=73&Itemid=475

[37] UNEP - WHO (2006) Overarching policy strategy, para 14, 15 Strategic Approach to International Chemicals Management http://www.saicm.org/index.php?option=com_content&view=article&id=73&Itemid=475

[38] UNEP (2006) Strategic Approach to International Chemicals Management: SAICM texts and resolutions of the International Conference on Chemicals Management http://www.saicm.org/images/saicm_documents/saicm%20texts/SAICM_publication_ENG.pdf

[39] UNEP (2006) Strategic Approach to International Chemicals Management: SAICM texts and resolutions of the International Conference on Chemicals Management http://www.saicm.org/images/saicm_documents/saicm%20texts/SAICM_publication_ENG.pdf

[40] https://www.epa.gov/greenchemistry/benefits-green-chemistry

- Safer food: elimination of persistent toxic chemicals that can enter the food chain; safer pesticides that are toxic only to specific pests and degrade rapidly after use (Note this should also include non-chemical methods and agroecology techniques; Relevant to SDG2)
- Less exposure to such toxic chemicals as endocrine disruptors (Relevant to SDGs 3, 6, 12, 14)

Environment

- Many chemicals end up in the environment by intentional release during use (e.g., pesticides), by unintended releases (including emissions during manufacturing), or by disposal. Green chemicals either degrade to innocuous products or are recovered for further use (Relevant to SDGs 2, 6, 9, 12, 14)
- Plants and animals suffer less harm from toxic chemicals in the environment (Relevant to SDGs 12, 15)
- Lower potential for global warming, ozone depletion, and smog formation (Relevant to SDGs 11, 13, 14)
- Less chemical disruption of ecosystems (Relevant to SDGs 12, 14, 15)
- Less use of landfills, especially hazardous waste landfills (Relevant to SDGs 11, 12)

Economy and business

- Higher yields for chemical reactions, consuming smaller amounts of feedstock to obtain the same amount of product (Relevant to SDGs 9, 12)
- Fewer synthetic steps, often allowing faster manufacturing of products, increasing plant capacity, and saving energy and water (Relevant to SDGs 9, 12)
- Reduced waste, eliminating costly remediation, hazardous waste disposal, and end-of-the-pipe treatments (Relevant to SDGs 9, 11, 12)
- Allow replacement of a purchased feedstock by a waste product (Relevant to SDGs 9, 12)
- Better performance so that less product is needed to achieve the same function (Relevant to SDGs 9, 12)
- Reduced use of petroleum products, slowing their depletion and avoiding their hazards and price fluctuations (Relevant to SDGs 9, 12, 13)
- Reduced manufacturing plant size or footprint through increased throughput (Relevant to SDGs 9, 12)
- Increased consumer sales by earning and displaying a safer-product label (e.g., Safer Choice labeling[41]) (Relevant to SDGs 9, 12)
- Improved competitiveness of chemical manufacturers and their customers (Relevant to SDG 9)

In 2015, the American Sustainable Business Council (representing 250,000 US businesses) and the Green Chemistry & Commerce Council (a business to business forum) released a report outlining the potential economic value of safer chemistry. The two business groups define safer chemistry as practices that include, *"reducing the use and generation of hazardous substances, reducing the human health and environmental impacts of processes and products, and creating safer products."*[42]

To illustrate this, the Councils note that Kaiser Permanente, a large US health care provider, requires medical product vendors providing USD$1 billion worth of products annually to disclose product

[41] https://www.epa.gov/saferchoice/learn-about-safer-choice-label

[42] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf

ingredients.[43] Kaiser Permanente *"considers that it has the right to know"* and uses the information to phase out chemicals of concern such as carcinogens, mutagens, reproductive toxicants, and persistent bioaccumulative toxins.[44] In 2014, the company spent its USD$30 million furniture budget on products that did not contain toxic flame retardants.[45]

The American Sustainable Business Council and Green Chemistry & Commerce Council report notes that safer chemistry's potential is not fully realized and makes several recommendations, including: encouraging businesses to evaluate their individual business case for safer chemistry; tracking safer chemistry metrics; quantifying societal benefits of safer chemistry; leveraging capital flows toward safer chemistry; and quantifying potential job growth and revenue opportunities.[46]

Sustainable chemistry

Sustainable chemistry attempts to expand conventional chemistry to include environmental, social, and economic aspects. The social aspects should include decent, safe working conditions and respect for human rights and labor rights, including the ILO Core Labour Standards.[47] [48]

To date, sustainable chemistry has only been vaguely defined, leaving the term open to any number of interpretations, including chemistries that do nothing to reduce harm. Leaving the term "sustainable chemistry" without a clear definition invites labeling all kinds of current chemistries as sustainable chemistry, watering down the term to render it nearly useless and leaving opportunities to "greenwash" chemistries with a term that suggests social or environmental benefits that do not exist. Some may even want to completely replace green chemistry, which is well-defined, with a more ambiguous concept of sustainable chemistry as a way to shift the focus away from hazard reduction. A more precise definition of sustainable chemistry is needed to clarify the relationship between hazard reduction and other desirable social or environmental outcomes. Green chemistry should be an obligatory part of sustainable chemistry so that hazard reduction is fully incorporated into the sustainable chemistry concept.

Currently, sustainable chemistry is a broad concept but is most frequently associated with efforts to achieve resource efficiency. For example, OECD has defined sustainable chemistry as follows:

"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

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[43] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf

[44] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf

[45] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf

[46] American Sustainable Business Council, Green Chemistry & Commerce Council (2015) Making the business and economic case for safer chemistry http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf

[47] Workers and Trade Unions Major Group (2010) Discussion papers submitted by Major Groups, Commission on Sustainable Development, E/CN.18/2010/11/Add.6 http://www.un.org/esa/dsd/resources/res_pdfs/csd-18/e_cn18_2010_11_add6.pdf

[48] http://www.ilo.org/global/standards/lang--en/index.htm

stewardship practices that will provide increased performance and increased value while meeting the goals of protecting and enhancing human health and the environment."[49]

Principles of sustainable chemistry

The German Federal Environmental Agency (UBA)[50] has prepared a document outlining the agency's positions on the principles of sustainable chemistry and criteria that should be applied to the concept.[51] While UBA does not provide a concise definition, the general principles of sustainable chemistry are outlined as:

- *Qualitative development: Use of harmless substances, or where this is impossible, substances involving a low risk for humans and the environment, and manufacturing of long-life products in a resource-saving manner;*
- *Quantitative development: Reduction of the consumption of natural resources, which should be renewable wherever possible, avoidance or minimization of emission or introduction of chemicals or pollutants into the environment. Such measures will help to save costs;*
- *Comprehensive life cycle assessment: Analysis of raw material production, manufacture, processing, use and disposal of chemicals and discarded products in order to reduce the consumption of resources and energy and to avoid the use of dangerous substances;*
- *Action instead of reaction: Avoidance, already at the stage of development and prior to marketing, of chemicals that endanger the environment and human health during their life cycle and make excessive use of the environment as a source or sink; reduction of damage costs and the associated economic risks for enterprises and remediation costs to be covered by the state;*
- *Economic innovation: Sustainable chemicals, products and production methods produce confidence in industrial users, private consumers and customers from the public sector and thus, result in competitive advantages.*

Sustainable chemistry and hazard reduction

Fully defined, sustainable chemistry could address resource efficiency, social and economic effects and hazard reduction. The connection between sustainable chemistry and hazard reduction has been addressed in a recent US proposal. US Senator Chris Coons proposed a *"Sustainable Chemistry Research and Development Act"*[52] in the US Congress that updates the definition of Sustainable Chemistry to contain both goals of resource efficiency and efforts to reduce and eliminate hazards:

The term 'sustainable chemistry'' means the design, development, demonstration, and commercialization of high quality chemicals and materials, chemical processes and products, and manufacturing processes that eliminate or reduce chemical risks to benefit human health and the environment across the chemical lifecycle, to the highest extent practicable, through—
(A) increasing the use of more sustainable, renewable, or recycled substances and materials;
(B) increasing the use of substitutes for rare substances;
(C) promoting safe and more efficient manufacturing;
(D) minimizing lifecycle impacts, including environmental and health impacts;
(E) optimizing product design and encouraging the reduction of waste and the reuse or recycling of chemicals and materials to account for the end of life or the final disposition of the product; or

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[49] http://www.oecd.org/chemicalsafety/risk-management/sustainablechemistry.htm
[50] https://www.umweltbundesamt.de/en/topics/chemicals/chemicals-management/sustainable-chemistry
[51] German Federal Environment Agency (2009) Sustainable Chemistry: Positions and criteria of the Federal Environment Agency
https://www.umweltbundesamt.de/en/publikationen/sustainable-chemistry
[52] https://www.congress.gov/bill/113th-congress/senate-bill/2879/text

(F) increasing the design and use of safe molecules, chemicals, materials, chemistries, and chemical processes.

At its best, sustainable chemistry could shift the entire industry to safer production and improve environmental protection, consumer safety and occupational health and safety by eliminating hazards. The goal should be that countries not only manage dangerous chemicals better, but that industries design safer, non-toxic chemistries from the start. Green chemistry and sustainable chemistry are both critical to this goal—both concepts could offer valuable guidance to the overarching goals of SAICM. However, this will only happen if sustainable chemistry is clearly defined in a way that includes reducing the hazards of chemicals over their lifecycle as a priority.

Because of major barriers to entry on the market for safer chemicals, including externalized costs, limited access to information and economies of scale for existing chemicals, it is unlikely that a transformation of the chemicals sector will happen on a voluntary basis, only inspired by sustainable chemistry. Strict regulation is necessary to support this shift. On the policy level, sustainable chemistry focused on hazard reduction could create a level playing field for business worldwide and create support for frontrunners. This will require government support and actions to develop regulations and enforce them.[53] As UNEP and SustainLabour note, *"The political will to invest in innovation and research, to adopt regulatory frameworks that prioritize clean production and green chemistry incentives, and to promote capacity development for appropriate action are some of the doors that need to be unlocked."*[54]

> Outcomes for green chemistry and sustainable chemistry

1. UN Environment produces a report by 2022 focused on practical steps for hazard reduction in chemical design and use[55] with a special emphasis on developing and transition countries.
2. ILO conducts capacity-building workshops at SAICM regional meetings on how hazard reduction with inherently safer chemistry can reduce chemical accidents and insure worker health and safety.
3. UN Environment and the SAICM Secretariat conduct capacity-building workshops in SAICM regional meetings on how legal frameworks can facilitate hazard reduction in chemicals design and production.
4. The private sector implements benchmarking tools to assure hazard reduction and avoidance in the design of new chemicals and assessment of current products, and reports on progress at each ICCM.

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[53] Tuncak, B (2013) Driving innovation. How stronger laws help bring safer chemicals to the market, Center for International Environmental Law http://www.ciel.org/Publications/Innovation_Chemical_Feb2013.pdf

[54] SustainLabour, UNEP (2015) Sound and Sustainable Management of Chemicals, A training manual for workers and trade unions, ISBN : 978-92-807-2961-0, UNEP Job Number : DR https://www.sustainlabour.org/documentos/EN159-2008.pdf

[55] This should include an account of particularly hazardous chemicals that should be phased out as soon as possible, including from products.

Annex 1: The principles of green chemistry

The 12 principles[56] of Green Chemistry are:

1. Prevention: It is better to prevent waste than to treat or clean up waste after it has been created.

2. Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. Less Hazardous Chemical Syntheses: Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. Designing Safer Chemicals: Chemical products should be designed to effect their desired function while minimizing their toxicity.

5. Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. Design for Energy Efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Design for Degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. Real-time analysis for Pollution Prevention: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Inherently Safer Chemistry for Accident Prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

[56] Anastas PT, Warner, JC (1998) Green Chemistry: Theory and Practice, Oxford University Press: New York