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Accelerating the industrial transition with safe-and-sustainable-by-design (SSbD)

Lya G. Soeteman-Hernández, *[a] Joel A. Tickner,[b] Ann Dierckx,[c] Klaus Kümmerer,[de] Christina Apel[d] and Emma Strömberg[f]

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Safe-and-sustainable-by-design (SSbD) is a pre-market approach that integrates innovation with safety and sustainability along the entire life cycle. It aims to (i) steer the innovation process towards a sustainable industrial transition; (ii) minimise the production and use of substances of concern and phase them out in material and product flows; and to (iii) minimise the impact on health, climate and the environment during sourcing, production, use and end-of-life of chemicals, materials and products. The aim of this perspective is to share reflections on how an SSbD approach can accelerate the industrial transition towards safer and more sustainable chemicals, materials, processes, and products, and circular value chains. To achieve the speed, efficacy and efficiency needed to support this urgently required transition, an efficient science–policy–industry interface is imperative. It is essential that the safety and sustainability knowledge generated in research supports policy and, more importantly, is taken up by industry. Bridges are needed between research, policy, investment, and industry through closer collaboration. But there is also a need for internal collaboration within companies along the life cycle of products. This means a stronger alignment between research and development (R&D), sustainability, design, business, and production departments. To bridge these different silos, a community and platform is needed as a multi-sectoral "one-stop-shop" to bring the field of innovation closer to the fields of safety and sustainability (environmental, social, economic). Policy needs to set goals, related criteria and methodologies, and incentives; academia and research need to support the development of knowledge, data, and tools needed and provide critical interdisciplinary education; and industry has to make its information on chemical impacts and choices transparent and institutionalise it in a systematic and thoughtful way.

Sustainability spotlight

To operate within the planetary boundaries and ensure human well-being, innovations need to be safe-and-sustainable-by-design (SSbD) from the very beginning of the development of (new) chemicals, materials, processes, and products. For this, an efficient science–policy–industry interface is necessary to link the field of innovation directly to the fields of safety and sustainability (environmental, social, economic). SSbD can contribute to the Sustainable Development Goals (SDGs) with expected positive impacts on *e.g.* 'good health and wellbeing' (SDG3), 'water quality' (SDG6), 'decent work and economic growth' (SDG8), 'responsible consumption and production' (SDG12), 'climate action' (SDG13), 'life below water' (SDG14), and 'life on land' (SDG15). Furthermore, this perspective also contributes to 'quality education' (SDG4), 'industry, innovation and infrastructure' (SDG9), and 'partnership for the goals' (SDG17).

Introduction

Safe-and-Sustainable-by-Design (SSbD) is a voluntary innovation approach to guide the development of new chemicals and materials, processes, and products.[1] This approach aims to steer the innovations towards a sustainable industrial transition. A key objective of SSbD is to minimise the production and use of substances of concern and to phase them out in material and product flows by developing SSbD alternatives, in line with, and beyond existing and upcoming regulatory and market obligations. Another ambition is to reduce the volumes of chemicals and materials and to ultimately minimise the impact on health,

[a]*National Institute for Public Health and the Environment (RIVM), Center for Safety of Substances and Products, Bilthoven, The Netherlands. E-mail: lya.hernandez@rivm.nl*
[b]*Sustainable Chemistry Catalyst, University of Massachusetts Lowell, Lowell, MA, 01854, USA*
[c]*essenscia, Belgian Federation of the Chemical Industry and Life Sciences Sector, Brussels, Belgium*
[d]*Leuphana University of Lüneburg, Institute of Sustainable Chemistry, Lüneburg, Germany*
[e]*International Sustainable Chemistry Collaborative Center ISC3, Bonn, Germany*
[f]*IVL Swedish Environmental Research Institute, Stockholm, Sweden*

climate and the environment during sourcing, production, use and end-of-life of chemicals, materials, and products.[2–4] SSbD is not a new approach, but has its roots in decades of effort around cleaner production, green chemistry,[5] sustainable chemistry,[6,7] and benign by design.[8–12] What makes it pertinent today is the increased urgency and its incorporation as a key approach in the European Chemicals Strategy for Sustainability.[13]

Humanity is operating outside six of the nine planetary boundaries[14] highlighting the need for a system change in innovation to meet the United Nation's (UN) Sustainable Development Goals (SDGs).[15] The size of the global chemical industry is projected to quadruple between 2020 and 2060,[16] while consumption and production are rapidly increasing in emerging economies. Global sustainability is progressively more challenging with the increased complexity in global supply chains and the trade of chemicals and products. Hazardous chemicals and other pollutants (for instance plastic or electronic waste) threaten human health and ecosystems.[17] Given the urgency to transition towards a safer and more sustainable way of innovating, preventive concepts like SSbD can accelerate this transition. Now is the right timing to bring this concept to practice to have a profound industrial impact. From a policy perspective, at least in Europe, the European Commission has developed a framework[2] along with a recommendation[3] and a methodological guidance[4] to support SSbD implementation. Industry, all value chain actors – particularly chemical manufacturers but also some downstream users – and industry associations are engaged in the process, too. For instance, the European Chemical Industry Council (Cefic) has published several reports,[18–20] including a guidance to unleash the transformative power of innovation,[20] to support the development of a practical SSbD approach. From a policy perspective, the OECD has published several reports on the Safe(r) and Sustainable Innovation Approach (SSIA), which combines SSbD with Regulatory Preparedness.[21] From a science perspective, there is an increasing number of publications on SSbD methodology,[22–24] tools,[25,26] and case studies.[27,28] Given the importance of these stakeholder groups in accelerating the industrial transition, an efficient science–policy–industry interface is a necessity. This will address the urgency of making SSbD implementable and applicable, not just for industry giants but also for small and medium-sized enterprises (SMEs).

The goal of this perspective is to share reflections on how an SSbD approach can accelerate the industrial transition towards safer and more sustainable chemicals, materials, processes, and products, and circular value chains. The ideas for this perspective were formed during a webinar organised by the EU-funded project IRISS† about trends and possibilities with SSbD (28th of May 2024). During the webinar, examples from the industry were highlighted and the IRISS SSbD community‡ – a permanent network bringing together all stakeholders working on or interested in SSbD – was launched.

† IRISS is the international ecosystem for accelerating the transition to Safe-and-Sustainable-by-Design materials, products and processes; https://iriss-ssbd.eu/iriss.

‡ The IRISS SSbD Community; https://iriss-ssbd.eu/iriss/become-a-member.

Strengthening science–policy–industry interface

Science

Research. From a research perspective, a common understanding of how to apply SSbD in practice is needed. Stakeholder consultations showed that it is vital that SSbD is pragmatic, flexible and applicable to a wide range of applications and users early in the innovation process.[29] SSbD is an opportunity to leverage the state-of-the-art toxicological approaches, including new approach methodologies, early in the design process.[30–35] For early sustainability assessment, further development is needed on ex-ante and prospective life cycle assessment (pLCA). Furthermore, tools and methods are needed to easily and consistently evaluate all important safety and sustainability dimensions within the innovation process and in an implementable way along the whole value chain. At this point, there is inconsistency in how companies across sectors evaluate various sustainability attributes beyond safety.[36] Data management needs to be at the core of safety and sustainability assessment with findable, accessible, interoperable, and reusable (FAIR) data. Five areas have been identified to be highly dependent on implementation of the FAIR principles: (i) digitalisation to leverage innovation towards a green transition; (ii) improving existing data sources and their interoperability; (iii) navigating SSbD with data from new scientific developments; (iv) transparency and trust through automated assessment of data quality and uncertainty; and (v) "seamless" integration of SSbD tools.[37]

Skills, competencies and education. Interdisciplinary SSbD education and training are key elements to support the implementation of SSbD across sectors, now and in the future. Training and up-skilling opportunities for professionals (for key stakeholders in industry, regulators, decision-makers in policy, and other stakeholders along the life cycle) and the integration of SSbD into university curricula will equip the current and next generations with the required multi-disciplinary skillset. Shorter education offerings such as bootcamps§ or Summer Schools¶ can complement this. At the university level, SSbD integration into the curriculum should not be limited to just natural sciences and engineering disciplines. It is equally important to educate university students in health and social sciences and business management, as they may be in future leadership positions in industry and influence company culture, business model, and company operations, or in leadership roles in governments and regulatory authorities. Organisations such as Beyond Benign‖ and the International

§ The European Commission has organised two SSbD bootcamps in 2023 and 2024; https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/chemicals-and-advanced-materials/safe-and-sustainable-design_en.

¶ The Leuphana University of Lüneburg, Germany, organised an Summer School on Sustainable Chemistry and SSbD in 2024; https://www.leuphana.de/en/institutes/insc/summer-school-sustainable-chemistry/summer-school-2024.html.

‖ https://www.beyondbenign.org/.

Sustainable Chemistry Collaborative Centre** are working at the forefront of curriculum and skills to prepare the next generation chemistry and engineering workforce to lead SSbD implementation. In addition, societal education and tools (creating consumer demand for SSbD products) should not be neglected to support informed consumer choices.

Workforce training. Up-skilling the current workforce is a necessity in order to address the multiple pressures of research & development (R&D). In addition to high demand on cost-effective performance, R&D scientists and technicians increasingly need to consider safety and sustainability elements. This also applies to business leaders who are often focused primarily on cost and revenue generation over sustainability. Soft skills are also needed to co-create pragmatic solutions and innovations that support safer and more sustainable options. SSbD up-skilling should be further tailored to specific industries and value chains to accommodate their respective safety and sustainability needs.

Policy

A solid international risk management framework. The UN Global Framework on Chemicals (GFC) for a Planet Free of Harm from Chemicals and Waste[38] promotes initiatives to enhance the sound management of chemicals and waste. The GFC is a multi-stakeholder and multisectoral framework involving all relevant sectors, including environment, health, agriculture, and labour, and stakeholders across the life cycle of chemicals at the local, national, regional, and global levels, as well as consideration of environmental and social aspects that are critical to the sound management of chemicals and waste. SSbD should be embedded in this GFC in order to support the right balance between carrots (incentives, soft regulation) and sticks (regulations). This would accelerate the industrial transition towards chemicals, materials, processes, and products that are safe and sustainable by design and ultimately transform policy, education, and the marketplace.[39]

Carrots – incentives. For SSbD to be implemented in practice, there is a need for policy incentives. Given the nature of SSbD as a voluntary approach, without incentives there will be little drive for companies to change their corporate strategies and to invest in embedding SSbD in R&D. Supportive policies such as those created under the US Inflation Reduction and recognition programs such as the US EPA's Safer Choice[40] can both stimulate supply and demand for SSbD (particularly when coupled with regulation and procurement). Safer Choice is a Pollution Prevention program that helps consumers, businesses, and purchasers to find products that perform and contain ingredients that are safer for human health and the environment. It includes practices that reduce, eliminate, or prevent pollution at its source, such as using safer ingredients in products. Market creating policies, such as the US Creating Helpful Incentives to Produce Semiconductors (CHIPS)[41] Act can drive competitiveness and new markets when simultaneously linked to sustainability and SSbD, given the impact of many chemistries utilized in semi-conductor production in driving circularity. Integrating SSbD to reporting requirements, such as those under the Corporate Sustainability Reporting Directive (CSRD) in Europe can provide an additional incentive for implementation. Other incentives could be fast-track or accelerated approval or permitting procedures for demonstrating SSbD solutions. Transparency of criteria and assessments, along with third-party review, can increase trust in SSbD innovations, ensure incentives are offered to the best SSbD solutions, and avoid "greenwashing".

Financial support from investors is also needed to complement public sector funding and policy incentives.

Finally, support for SMEs in implementing SSbD, for example through government-supported initiatives (CHIPS Act, SPINE†† network), is a critical policy need given the limited resources in many companies.

Industry

In order to meet policy, investor and market ambitions, companies across sectors increasingly need to integrate safety and sustainability in their corporate strategy and core organisational values. This can help to create a corporate structure that supports champions in firms that will drive SSbD. Importantly, SSbD can play a role in addressing multiple sustainability goals, given most products and processes rely on chemistry. This cultural change within industry will allow for innovating the R&D process and production. A corporate risk and sustainability governance process is needed with allocation of resources to facilitate the internal organisation of companies to implement SSbD (for instance bring together R&D with ESG/finance, sustainability and regulatory affairs). The combination of a multi-disciplinary R&D ecosystem can help to future-proof companies and support the 'fail early, fail cheap' way of working. To support SSbD implementation, companies can also innovate their business models, including "service" models needing no or less chemical products. Recently, a conceptual framework was developed embedding SSbD into sustainable business model innovation and new product development; and in the training for innovation managers *via* the integration of SSbD in the innovation management professional designation.[42] SSbD closely aligns with new business approaches around sustainable competitiveness, which involves conditions where businesses thrive, the health and environment are protected, sustainability goals are met, and everyone has an equal chance at success.[20,43]

The practical application of SSbD in the business innovation process and across the value chain and life cycle of a product can be improved and accelerated through: (i) better communication and collaboration internally and externally (for example by asking the right safety and sustainability questions);[43–47] (ii) sharing best practices; and (iii) having clear & flexible criteria and tools to avoid paralysis by analysis. Here, initiatives such as the EU Digital Product Passport can support in the traceability along the value chain.[48] SSbD products are likely to have additional (initial) costs in terms of time and money due to the required SSbD assessments and (potential) changes needed in R&D, production processes,

** https://www.isc3.org/.

†† SSbD International Policy Network (SPINE).

reformulation, *etc.*[49] In addition, changes along the entire value chain are required and collaboration and coordination is needed between suppliers, formulators, manufacturers, and retailers to find compromises that will result in benefits for all.

Beyond resources, industry needs support in applying the SSbD framework in practice in the form of harmonized criteria, guidance, and tools. Currently there are two guidance reports: one from the European Commission[4] and one from Industry.[20] The recent guidance on SSbD from industry,[20] pays extra attention to product–application combinations, regional and sectoral differences, and transparently identifying and addressing trade-offs along the value chain and lifecycle. For additional practical support, an SSbD toolbox‡‡ is under development in the PARC project§§ and can be broadly applied by industry (SMEs and large companies alike).

Conclusions

SSbD has great potential to be a catalyst for the industrial transition to safer, more sustainable and circular chemicals, materials, processes, and products. In order to achieve the speed, efficacy, and efficiency needed to support this transition; an efficient science–policy–industry interface is imperative. It is essential that the safety and sustainability knowledge generated in research supports policy and, more importantly, has industrial uptake and use. Bridges are needed between research, policy, investment, and industry through closer collaboration. Collaboration is also needed within the companies and between companies along the product life cycle. This means a stronger internal corporate alignment between R&D, sustainability and business teams on design and production of chemicals, materials, processes, and products. External stakeholder alignment is also needed with authorities, customers, users, recyclers and other end of life sectors such as the water sector.

To bridge the different silos, it is necessary to build a multisectoral community of practice and a platform as a "one-stop-shop" to bring the field of innovation closer to the fields of safety and sustainability (environmental, social, economic). This is the aim of the recently launched IRISS SSbD Community¶¶. Policy needs to set criteria and provide support, goals, and incentives; researchers methodology to support the development of knowledge, data, and tools needed; industry the practical knowhow and collaboration to drive SSbD innovations in the marketplace. There is a need for transparency in criteria, assessment, and data including FAIR data and information, to drive and implement SSbD in a trusted, systematic and thoughtful way.

Data availability

No primary research results, software or code have been included and no new data were generated or analysed as part of this perspective.

‡‡ SSbD Toolbox; **https://parc-ssbd.eu**.

§§ Partnership for the Assessment of Risks from Chemicals (PARC); **https://www.eu-parc.eu/**.

¶¶ Join the IRISS SSbD Community; **https://iriss-ssbd.eu/iriss/become-a-member**.

Author contributions

Conceptualisation – Lya G. Soeteman-Hernández, Emma Strömberg writing – original draft – Lya G. Soeteman-Hernández, Joel Tickner, Ann Dierckx, Christina Apel writing – review & editing – Lya G. Soeteman-Hernández, Joel Tickner, Ann Dierckx, Christina Apel, Klaus Kümmerer, Emma Strömberg funding acquisition – Lya G. Soeteman-Hernández, Klaus Kümmerer, Emma Strömberg.

Conflicts of interest

There are no conflicts to declare.

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