Accelerating action

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Implementation Programme 2

"Industry Engagement and Action along Value Chains"

Workstream on Green and Sustainable Chemistry Innovation

Global Roadmap for advancing Green and Sustainable Chemistry

From shared principles to sector-wide action

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About this document:

The draft Global Roadmap for Advancing Green and Sustainable Chemistry proposes priority actions to accelerate the transition towards safer and more sustainable chemistry across sectors and value chains. It covers four themes: innovation from laboratory to industrial application; strategies in value chains and sectors; knowledge, evidence and education; and financing. It addresses barriers to developing, adopting and scaling solutions, identifying actions and relevant stakeholders while building on existing initiatives and networks. Designed as a voluntary, action-oriented guide, it supports implementation adapted to different national circumstances and capacities. The draft remains a work in progress and will be refined through stakeholder consultation.

Global Roadmap for advancing Green and Sustainable Chemistry

From shared principles to sector-wide action

Disclaimer

This document is a first draft, developed by members of the "Green and Sustainable Chemistry" thematic work stream of the GFC, and consulted with other thematic work streams under the GFC, as well as IOMC-participating organisations. Insights are intended to be presented at GFC IC1, and input received at IC1 as well as through additional subsequent consultations will inform the next draft of the Roadmap. As such, the current draft is to be considered a work-in-progress.

1. Introduction and context

"Business as usual is not an option!" This recognition is one of the most important conclusions and calls for action of the Global Chemicals Outlook II (GCO-II). The United Nations Environment Assembly translated this into a clear mandate for green and sustainable chemistry: T hrough Resolution 4/8 (2019) it welcomed the analysis of best practices in sustainable chemistry and requested UNEP to develop manuals on green and sustainable chemistry, which led to the Green and Sustainable Chemistry Framework Manual and its ten objectives and guiding considerations, and through Resolution 5/7 (2022) it welcomed that Manual and encouraged its use. As a milestone for changing track and moving towards a pollution-free future, the global community then adopted the Global Framework on Chemicals (GFC) in 2023. The GFC itself, through its Strategic Objective D, recognises the prominent role of green and sustainable chemistry for achieving the goals and the ambition of the Framework.

Green and sustainable chemistry is a critical enabler of competitiveness, value, and sustainability across industry sectors and value chains. It paves the way to a safer, circular economy and contributes to the sustainable development goals by minimising negative impact and maximising positive benefit. In order to implement green and sustainable chemistry, it is important to identify approaches, pathways, methods and solutions which promote safer and more sustainable chemicals and uses along the life cycle.

Accelerating action on green, safe and sustainable chemistry is one of the main themes of the first International Conference (16-20 November 2026 in Geneva/Switzerland).

1.1 Introduction to green and sustainable chemistry

Green and sustainable chemistry seeks to create value and retain the societal benefits of chemistry while preventing or substantially reducing its adverse effects (Global Chemicals Outlook II). Green chemistry, set out in Paul Anastas and John Warner's twelve principles (1998), is preventive at its core: R ather than controlling emissions or treating waste after the fact, it designs out hazards, waste and inefficiency at source. Sustainable chemistry takes a wider systems view, extending this preventive design across the full life cycle of chemicals, materials and products and weighing resource and energy use, circularity, climate and biodiversity, economic viability, and the protection of workers and communities. The two

approaches have converged into a single framework (Zuin Zeidler, 2023[1]), expressed for the purposes of this Roadmap by UNEP's ten objectives and guiding considerations for green and sustainable chemistry.

This Roadmap builds directly on that work. UNEP's Green and Sustainable Chemistry Framework Manual synthesised best practices into the ten objectives that provide the common reference used throughout this document. Over recent decades, and initially in industrialised economies, risk management for chemicals evolved from end-of-pipe pollution control towards prevention, cleaner production and inherent safety, and more recently towards life-cycle and circular-economy thinking that ties chemistry to climate, resource use and the Sustainable Development Goals. This progress remains uneven across regions, and making the benefits of green and sustainable chemistry accessible to all is a central aim of this Roadmap.

Green and sustainable chemistry is a direction for research, investment and governance towards chemical processes, products, and functions that are safe, low-carbon, resource-efficient and compatible with circular material flows. This depends on having clear criteria so that finance, procurement and policy can be steered towards real solutions and away from possible regrettable substitutions. It has the potential to reduce risks to human health and the environment while strengthening the competitiveness of the businesses and economies that lead the transition. The challenge is implementation: ensuring that the continued innovation in chemistry delivers essential societal benefits without transferring unacceptable costs to people, ecosystems or future generations.

1.2 The case for action and the substitution gap

The production and use of chemicals continue to grow rapidly, with the volume and diversity of chemicals of concern entering products, value chains and the environment, faster than current systems can assess or manage them. Managing these risks downstream remains necessary, but it is insufficient to protect health and environment. The task is to go beyond chemicals management and actively drive the design, adoption and scaling of safer and more sustainable solutions. Developing safer and more sustainable alternatives is only the first part of the challenge: innovation alone, without tackling the barriers to adoption across value chains, markets and finance, will not close the gap. This Roadmap addresses both the generation of safer solutions and the conditions needed for their adoption at scale.

The need for action is well documented. UNEP's 2019 Global Chemicals Outlook II (GCO-II) reported that the chemicals sector exceeded US$5 trillion in 2017 and was projected to double by 2030, and it attributed some 1.6 million deaths in 2016 to selected chemical exposures. The World Health Organization subsequently estimated that the limited set of chemicals for which robust global data exist caused around 2 million deaths and 53 million disability-adjusted life years in 2019. Because only a small subset of exposures has been quantified, these figures are a lower bound. They omit many chronic effects, chemical mixtures, cumulative and occupational exposures, ecosystem damage and exposures in countries with limited monitoring, while incomplete information on substances in products further obscures the true scale.

Some hazards persist despite established alternatives, while others are only now coming into focus. Per- and polyfluoroalkyl substances (PFAS) illustrate the newer challenge: a class of thousands of highly persistent and toxic substances used across textiles, electronics, food packaging, cosmetics and firefighting foams, where safer functional alternatives are still needed in many cases and where regulators are moving forward, as with the proposed universal restriction under the EU's REACH Regulation and state policies in the US. At the same time, long-known and avoidable hazards remain widespread. UNEP places the global

[1] www.science.org/doi/10.1126/science.adk7430

cost of lead exposure in 2019 at around US$6 trillion, yet as of 2023 fewer than half of all countries had legally binding controls on lead paint, and UNEP's 2023 Chemicals in Plastics report associated more than 13,000 substances with plastics, over 3,200 of them with hazardous properties of concern.

The major assessments do not simply call for better downstream control; they call for upstream prevention, safer design and substitution. GCO-II concluded that business as usual was not an option; UNEP's Assessment Report on Issues of Concern examined nineteen chemical and waste issues in 2020 and, in a 2024 follow-up, found many still unresolved. The GFC turned this direction into time-bound expectations, including prioritising safer alternatives in research and innovation by 2030 (Target D4), identifying and reducing priority chemicals of concern in major sectors by 2030 (Target D6), and phasing out highly hazardous pesticides by 2035 where risks are unmanaged and safer, affordable alternatives exist (Target A7).

Despite this repeated and increasingly specific direction, delivery has been slow and uneven. The principal global 2020 goal was missed, production and value chains have expanded faster than regulatory, monitoring research & development (R&D) waste-management capacity, and substitution has tended to be reactive and substance-by-substance rather than systematic, class-based and function-oriented. The result is a substitution gap: T he distance between the well-documented need to replace chemicals of concern and the rate at which safer, more sustainable alternatives are designed, assessed, adopted and scaled. This gap is sustained by barriers that can be addressed, namely missing hazard and use data, confidential supply chains, slow regulation, economic lock-in, weak demand signals, limited scale-up finance and the risk of regrettable substitution. These barriers are what this Roadmap sets out to tackle across its themes, from strengthening data and evidence to building innovation and safe-by-design capacity, aligning policy and market demand, and mobilising finance for implementation. For the same reason, the Roadmap emphasises tracking progress through outcomes, such as exposures reduced or hazardous substances eliminated, rather than through activities alone.

1.3 The global governance landscape

A global focus on substitution of chemicals of concern with safer alternatives, dates back to the Montreal Protocol of 1987, which called for the phase out of chlorofluorocarbons, with mechanisms to ensure that substitutes were safer. In 2008, the Intergovernmental Forum on Chemical Safety passed a resolution calling on nations and companies to institute programs to substitute chemicals of concern with safer alternatives. The Stockholm Convention on Persistent Organic Pollutant's listing process is tied to an analysis of alternatives to provide information to inform potential solutions. The Strategic Approach to International Chemicals Management (SAICM) was adopted in Dubai in 2006, building on the previous Intergovernmental Forum on Chemical Safety. It was a voluntary, multisectoral and multi-stakeholder policy framework rather than a treaty. Its importance lay in bringing governments, intergovernmental organizations, industry, labour, civil society and academia together around the goal of sound chemicals management. It promoted national capacity, information exchange, risk reduction, governance and work on emerging policy issues that were not always adequately covered by existing conventions. The ambitious SAICM goal of achieving sound management of chemicals and waste was not achieved by 2020, underscoring persistent gaps in capacity, financing, information, regulation and implementation, but SAICM helped in moving international discussion beyond controlling a limited list of pollutants toward managing chemicals throughout their life cycles.

The adoption of Green and Sustainable Chemistry into the GFC was the result of a parallel policy and knowledge-building process that developed during the transition from SAICM to the post-2020 framework. Three considerations drove this development.

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Managing existing risks was not enough

Traditional chemicals management often begins after a hazardous chemical has been developed and placed on the market. Authorities then assess its hazards and risks, establish exposure limits, regulate particular uses, control emissions and waste, or restrict / prohibit the substance. These measures remain essential, but experience shows that this predominantly downstream approach could not keep pace with the number and volume of chemicals entering global markets. It could also encourage regrettable substitution, in which one hazardous chemical is replaced by a structurally or functionally similar hazardous substance.

Green and Sustainable Chemistry adds an upstream question: can chemicals, materials and processes be designed from the outset to provide their intended functions with less hazard, lower resource consumption and fewer life-cycle impacts? This way of thinking shifts attention from only managing harmful chemicals toward preventing harm through design and innovation.

Chemicals policy became connected to the SDGs

The adoption of the 2030 Agenda and Sustainable Development Goals broadened the context of the post-2020 negotiations. Chemicals and waste were no longer treated only as environmental-control issues. They were increasingly linked to:

- health and occupational safety;
- sustainable production and consumption;
- climate change and decarbonization;
- biodiversity;
- food and agriculture;
- resource efficiency and circularity;
- human rights and environmental justice; and
- sustainable industrial development.

UNEP's preparatory work for the post-2020 process explicitly examined connections between chemicals and waste and seven broader areas: health, biodiversity, work, climate, agriculture and food, human rights, and sustainable consumption and production.

Green and Sustainable Chemistry supplied a conceptual bridge between conventional chemical safety and these broader sustainability objectives.

International mandates strengthened the basis for green and sustainable chemistry

Several resolutions of the United Nations Environment Assembly (UNEA) progressively strengthened the international basis for sustainable chemistry:

- UNEA resolution 2/7 (2016) invited governments, organizations and other stakeholders to submit information on sustainable chemistry practices and approaches; UNEP subsequently analysed these submissions and related scientific and policy literature.
- UNEA resolution 4/8 (2019) asked UNEP to synthesize best practices into manuals on green and sustainable chemistry and to continue developing a holistic, long-term approach to chemicals and waste; in response, UNEP developed the Green and Sustainable Chemistry: Framework Manual, including ten objectives and guiding considerations. Its purpose was to create a common international understanding and connect chemical innovation to the SDGs.
- UNEA resolution 5/7 (2022) welcomed the Framework Manual, emphasized environmentally sound innovation and encouraged stakeholders to use it; the manual therefore gave negotiators and stakeholders a recognized vocabulary for discussing

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Green and Sustainable Chemistry. It framed GSC not as a replacement for chemical safety regulation, but as a complementary approach involving hazard reduction, sustainable feedstocks, climate considerations, resource efficiency, circularity, safe products and production, and wider social and economic considerations.

Green and sustainable chemistry was included as an integral element and concept in the GFC. It is principally embedded in Strategic Objective D, which concerns safer alternatives and innovative and sustainable solutions in product value chains.

Two targets are especially important:

- Target D1: By 2030, companies should consistently invest in and achieve innovations that advance sustainable chemistry and resource efficiency throughout the life cycle of chemicals.
- Target D2: By 2035, governments should implement policies encouraging production based on safer alternatives and sustainable approaches throughout the life cycle, including best available techniques, green procurement and circular-economy approaches

These targets distribute responsibility between companies, which are expected to invest and innovate, investors and governments, which are expected to create enabling policy and market conditions.

Green and sustainable chemistry is also supported indirectly by GFC targets concerning access to information on chemicals in materials and products, research and data generation, education and professional training, safer alternatives and substitution, sectoral and value-chain initiatives, sustainable procurement, corporate reporting and due diligence, prevention of pollution and waste, financing and capacity-building and engagement of economic sectors beyond environment ministries.

The GFC therefore treats green and sustainable chemistry as a cross-cutting implementation approach, not simply as a laboratory research topic. The GFC states that, while chemicals-management capacities must be strengthened, the framework is also intended to catalyse a transformational shift towards green and sustainable chemistry in the chemical industry and downstream sectors. It uses a life-cycle approach covering chemical design, production, use, products and waste. The framework seeks to influence technological development, investment, procurement and business practices. Nevertheless, green and sustainable chemistry does not replace sound chemicals and waste management. Regulation, classification and labelling, monitoring, enforcement, exposure control, remediation and waste management remain indispensable. Nor does describing a chemical as “green,” bio-based or recyclable automatically make it sustainable. At a minimum, a sustainable chemical needs to be safer. So hazard, exposure, resource use, climate effects, social impacts and end-of-life outcomes still have to be assessed together.

2. About this roadmap

Strategic Objective D of the GFC stipulates that “Safer alternatives and innovative and sustainable solutions in product value chains are in place so that benefits to human health and the environment are maximized and risks are prevented or, where prevention is not feasible, minimized.” Together with its Targets D1-D7, Strategic Objective D sets out a range of systemic changes that specified stakeholders need to complete by 2030 or 2035, respectively. To pave the way to their implementation, the systemic changes need to be broken down into

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individual themes, action areas and ultimate actions that stakeholders in countries, value chains and economic sectors should embark on by priority.

The full set of actions supporting the implementation of Strategic Objective D can best be presented as a roadmap, the Roadmap for green, safe and sustainable chemistry ("GSC Roadmap"). Its development and the consultation process involving many stakeholders are set out below.

2.1 How the roadmap is developed

The GSC Roadmap development follows from a corresponding mandate from GFC stakeholders; it has been compiled under the "GSC workstream" under GFC Implementation Programme 2.

The elaboration of themes, action areas and actions started with contributions of a core drafting group within the GSC workstream. The resulting draft of the roadmap will be consulted with the other experts of the GSC workstream at first, and then with other thematic work-streams that have been set up under the GFC Implementation Programmes. Finally, further input and validation by stakeholders will be sought at the first International Conference (IC1) in November 2026, while finalisation and publication of the GSC Roadmap is envisaged for end 2026.

2.2 Purpose and scope

The GSC Roadmap compiles action areas and priority actions under four themes:

- Theme 1: GSC innovation from laboratory to industrial application
- Theme 2: GSC strategies in value chains and sectors
- Theme 3: Knowledge, evidence and education
- Theme 4: Financing green and sustainable chemistry

Under each theme, relevant action areas are identified. For each action area, several actions are set out and implementing stakeholders specified.

The GSC Roadmap should build on, connect and strengthen existing international, regional and national initiatives rather than suggesting new implementation structures.

2.3 Audience and how to use this roadmap

The GSC Roadmap is a voluntary and action-oriented guide rather than a binding instrument. It should be considered as a living document that will continue to evolve through ongoing engagement and implementation.

The target audience of the GSC Roadmap are governments, industry and value chains of all sectors, research and technology organisations, academia, intergovernmental organisations, and finance actors. While it reflects a global, multi-sectoral and multi-stakeholder ambition, any developed actions should be adapted to regional priorities and national circumstances, to levels of industrial development and to available resources. Implementation in low and medium income countries will look very different than in more developed ones. Overall, its successful implementation will depend on leadership, policy coherence, financing, partnerships, capacity building, knowledge sharing and monitoring.

Different countries, companies, sectors and other stakeholders will be in different places in their progress towards implementing the Roadmap, given policy, technology, and financial infrastructure and expertise. As such, the roadmap is underscored by a three tier maturity

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model of: Initiating; progressing; leading to distinguish the types of activities that would be expected at different phases of each action item.

Theme chapters

3. Theme 1. GSC innovation: from laboratory to industrial application

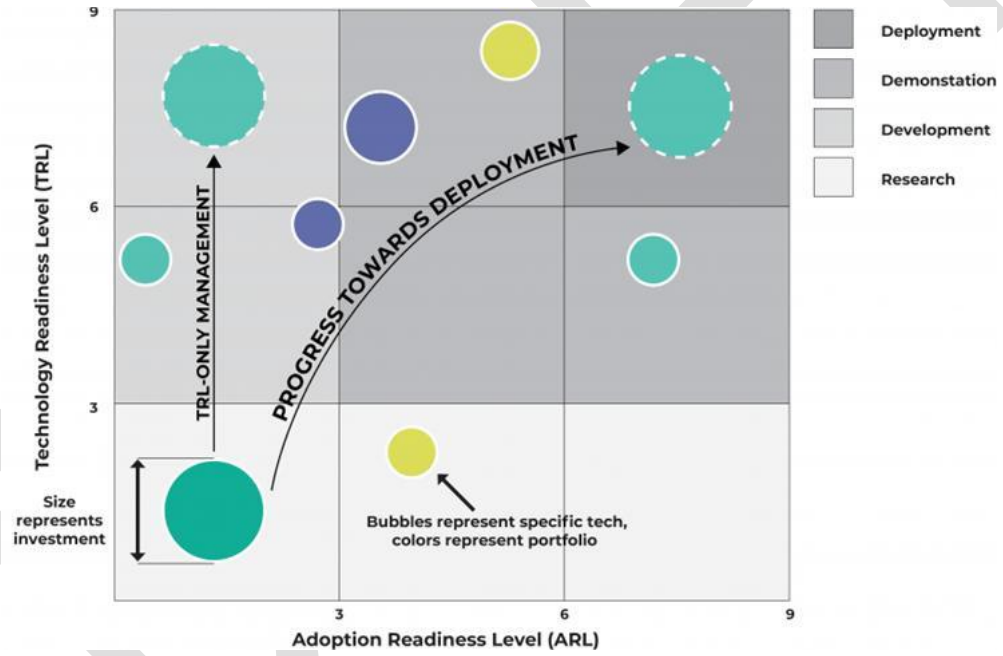
As noted previously, there are many barriers to green and sustainable chemistry that global action can help resolve. A fundamental challenge is moving innovations from laboratory to application and scale. Creating a green and sustainable chemistry innovation in a research lab is only the starting line of the process. That innovation must be evaluated for safety and sustainability, developed, piloted, validated, demonstrated in an industrial process, and ultimately scaled. In this respect, lessons learnt from industry frontrunners suggest that SMEs should not try to copy the "GSC machinery" of large corporations, but start small, focussing on product change, avoiding costly dead ends.
Each step of this innovation process requires funding and support. Innovation theory discusses multiple valleys of death where strong innovations do not succeed frequently due to lack of sufficient finance or capital to build manufacturing capacity. However, industrial application poses another set of challenges. Many – particularly novel - innovations may not easily fit into existing manufacturing assets or they may work differently requiring new capacity. This question of feasibility – where a green and sustainable chemistry solution may have good performance – but is not currently feasible given manufacturing or supply chain structure is often missed in innovation discussions. Overall, this suggests to consider trade-offs not only to relate to other sustainability parameters, but to any trade-offs that need to be managed in the practical realities of companies.

This theme addresses the supply side of the challenge: generating safer and more sustainable solutions and maturing them from the laboratory to industrial readiness. The barriers to adopting those solutions once they exist, across value chains, sectors and markets, are the focus of Theme 2, and the two are interdependent, since an innovation that is never adopted delivers no benefit. Some actions therefore span both themes, particularly those concerned with adoption. Finance, addressed in Theme 4, is a critical element of moving innovations from bench to scale and is touched on here where it is closely tied to the innovation pathway.

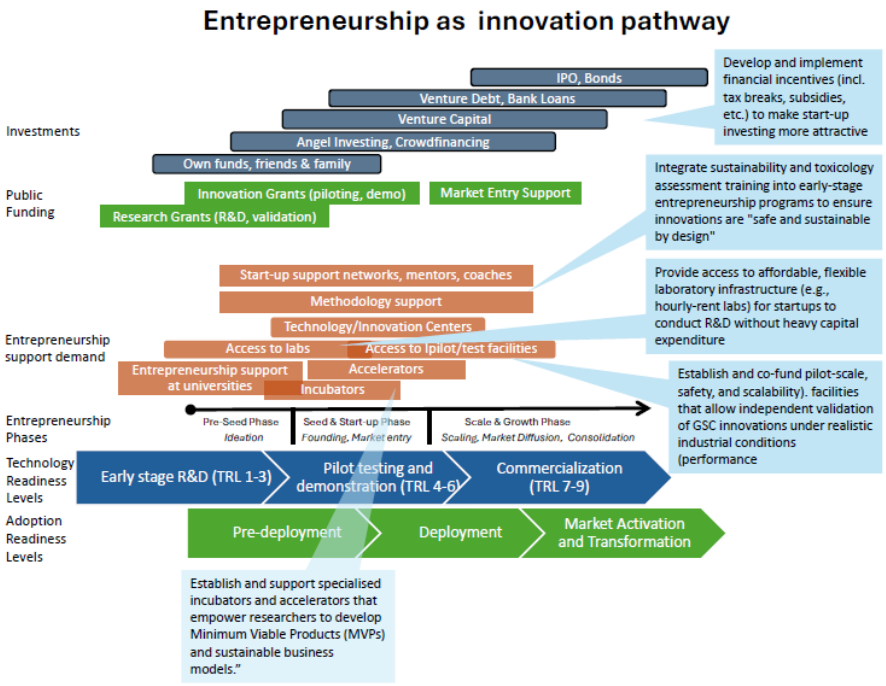
As a starting point, it is important to consider the innovation pathway and the sets of needs – incentives, finance, support – from early stage to adoption phases. Innovation policy often refers primarily to „technology readiness levels" (TRLs) which indicate where a technology is on its pathway from idea to demonstration to scalable technology. But equally important is ""adoption readiness"[2], which refers to barriers to deployment including capacity to scale (manufacturing, training, etc.), willingness in the market to pay, available finance and other factors which are critical to scaling a technology. Finally, „substitution readiness" is a more recent term which refers to barriers to substitution including availability of manufacturing assets, equipment to use an innovation, reformulation requirements in the value chain, regulatory hurdles, etc.

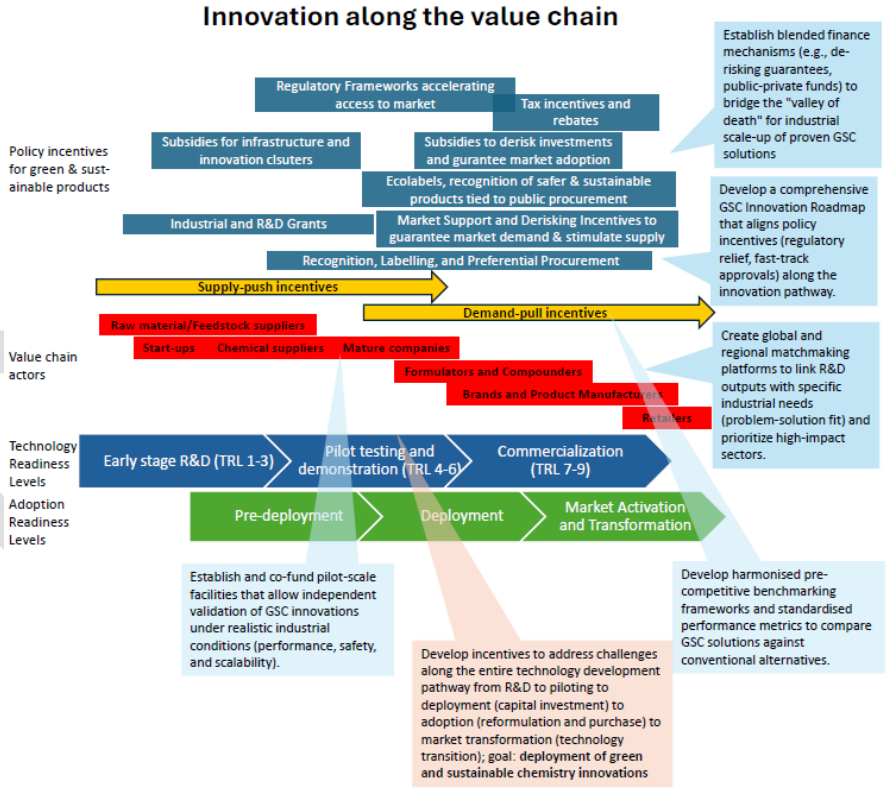
[2] The term „adoption readiness" is used by the US Department of Energy.





The actions outlined below are summarized in the following two figures - the first of which outlines the early innovation/entrepreneurship pathway and the second the innovation to adoption pathway.



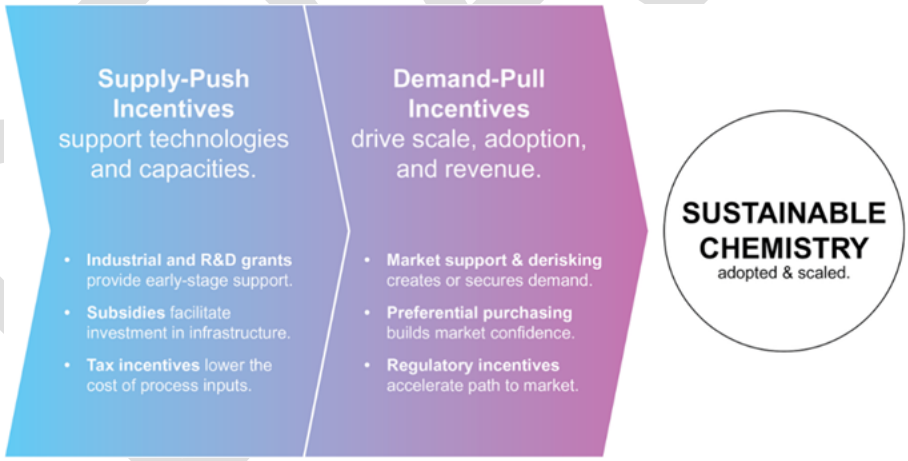


3.1 Incentives along the entire technology development and adoption process

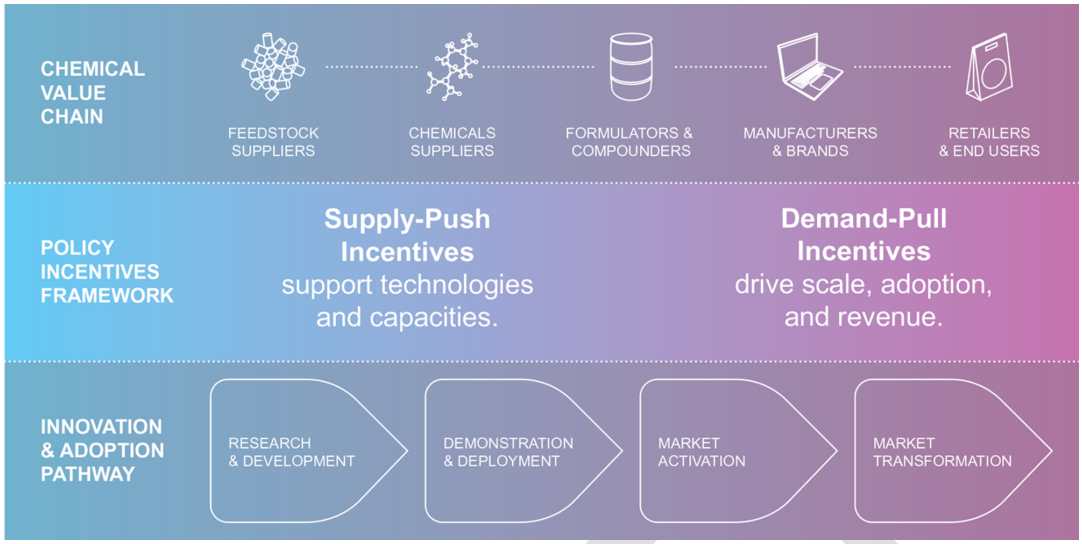
Action: Governments should establish incentives to address GSC barriers along the entire technology development pathway from R&D to piloting to deployment (capital investment) to adoption (reformulation and purchase) to market transformation (technology transition).
Rationale: Sustainable chemistry investments often face significant barriers for durable and predictable support that derisks private investment and collaboration along the value chain to support adoption.
Key Actors: IGOs, governments

While early-stage funding for R&D and initial prototyping is often available to entrepreneurs, funding and other incentives for piloting, demonstration and deployment and ultimately market adoption for green and sustainable chemistry lag. These are the most expensive parts of the R&D and deployment process and ones where it is difficult to obtain finance, particularly for novel innovations without proven markets. Government incentives – including off-take agreements, purchase price guarantees, and other incentives can help derisk private investment including joint ventures and other collaborations to scale a technology. Overall, the thoughtful and reinforcing interplay between government policies, incentives and finance play a critical role in moving GSC innovations from lab to market to scale.

Government incentives can both create demand and push supply of green and sustainable chemistry solutions where they consist of adaptable combinations of incentives along the innovation and adoption pathway applied to different actors in the value chain. It can make sense to co-develop such a policy incentives framework with companies and other actors. A successfully co-created framework was developed by the University of Massachusetts Lowell and Change Chemistry in collaboration with more than 50 companies and other actors, see the figure below:



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The framework consists of sets of incentives - and examples of their application - that could be applied along the technology innovation and adoption pathway and the whole value chain and could support innovation, commercialization, adoption, and market transformation, while derisking private investment and finance. It can flexibly be adapted to the unique economic and industrial circumstances of countries.

Next steps: UNEP with OECD and input from countries should create a "GSC incentives framework", i.e. a framework of incentives needs across the R&D, piloting, development, deployment and adoption pathway to support sustainable chemistry with the goal of deployment of green and sustainable chemistry innovations. The framework should be adaptable to different regions.

3.2 Shared infrastructure to support GSC innovation and entrepreneurship

Action: Governments, with support from the private sector, should establish shared infrastructure to support early stage R&D, piloting and business development
Rationale: Entrepreneurs and early stage companies often lack sufficient resources to perform required lab research and design or pilot test innovations. Shared infrastructure – from labs to pilot facilities to business support can eliminate a large barrier to support and create ecosystems of innovators. These resources could be co-funded by governments and the private sector and supported by academia and research institutes through in-kind support.
Key Actors: IGOs, Governments, IGOs, universities and research organisations, investors, industry, academia

A key challenge for early stage and even more mature companies in the chemistry sector without available capital is access to infrastructure to research, pilot, demonstrate, and initiate market development for GSC solutions. The current generation of chemistries benefitted from sustained government infrastructure support including pipelines, transportation routes, access to government laboratory space and technical support. Governments can help create networks of infrastructure and support for companies[3]. In many countries universities provide technology-transfer support including lab spaces for spin-outs at early stage for research and development of so-called „minimal viable products". In the global south availability of

[3] The US National Laboratories provide a model of such infrastructure support.

infrastructure is often more restricted and access for early stage companies is even more difficult.
Generally, funding of lab space, equipment and pilot facilities for individual start-ups and small companies would be extremely capital-intensive, hence sharing and renting models are the preferred and more meaningful alternative. Needs include:

- Access to affordable, flexible laboratory infrastructure for startups to conduct R&D without heavy capital expenditure;
- Pilot-scale facilities that allow independent validation of GSC innovations under realistic industrial condition;
- Shared production infrastructure, including bioreactors that reduce capital expenditures;
- Sustainability assessment resources to evaluate innovations and minimize regrettable substitutions;
- Access to support by specialised incubators and accelerators that empower researchers to develop minimum viable products (MVPs) and business models for GSC innovations.

Next steps: Governments should develop an inventory of: Infrastructure needs of both early stage and more mature companies in developing and adopting sustainable chemistry; available government, academic, and private sector resources that can be leveraged and connected to support GSC innovations, including gaps that could be filled through new infrastructure developments or international collaborations.

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3.3 Capacity building for entrepreneurs in GSC

Action: Academic and research institutions should integrate sustainability and safety assessment training into technology and entrepreneurship programs to ensure innovations are developed that are both "safe and sustainable by design". Furthermore capacity building is needed around business, regulatory and market relevant topics, which are key to successful entrepreneurship.
Rationale: Early stage companies, frequently spin outs from academic institutions, often lack business, market, regulatory and legal knowledge. In addition, knowledge on the health, safety and sustainability aspects of innovations is widely lacking or at least exceeds the expertise in small founding teams of start-ups.
Key Actors: IGOs, academia, industry

This action links with the Actions in Section 5 regarding education. While changing, considerations of toxicity and sustainability are not generally part of the core curriculum of chemistry, engineering, or even business programs. As such, innovations are often created with little consideration of their health, safety, or sustainability implications. While well intentioned, such innovations can result in unintended impacts. Sometimes, innovations designed to solve one sustainability challenge - such as energy conservation or renewable energy technology, can create new toxicity hazards. As such, training and education at both the undergraduate and graduate levels as well as for entrepreneurs can ensure that new innovations are designed with a broad set of sustainability attributes in mind but also that entrepreneurs understand potential hazards and trade-offs as they design new solutions and understand resources and tools available to assess them.

Equally important, start-ups in the field of green and sustainable chemistry need an integrated support ecosystem. Financing must be combined with market validation, regulation, technology transfer, IP protection and long-term support. Founding teams with primary focus on the scientific-technological side need support in business planning and development. Only in this way can technologically promising approaches be transformed into viable business models and scalable solutions. Beyond general start-up consulting, young companies need expertise specific to the chemical industry. This includes, in particular aspects such as chemical regulations and approvals, safety and permitting issues, certification and quality assurance, business model development, sales and market development, scaling and internationalization, and access to industry partners and supply chains.

Resources to support early stage companies -identified in Action 3.2 - could come from governments (eg, as part of specialized incubators), academic institutions, sectoral organizations and larger strategics with sustainability assessment resources. Start-up support networks and organisations such as ISC3 can also play an enabling role.

Next steps: In conjunction with the activities envisioned in Sections 3.2 and 5.X (education) outline training and support needs for both university students and professionals in early stage and more mature companies to enhance business and market related knowledge as well as sustainability and safety assessment capacities for both chemical and material design as well as in alternatives assessment

3.4 Global platforms to link green and sustainable chemistry solutions providers to those trying to solve GSC challenges

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Action: Governments, IGOs, and industry should create global and regional matchmaking platforms to link R&D outputs with specific industrial needs (problem-solution fit) and prioritize high-impact sectors
Rationale: There is often a mismatch between industry needs along value chains and the innovations that can solve them. Having specific and hands-on ability to connect seekers and solvers around specific challenges can accelerate innovations to market.
Key Actors: IGOs, governments, industry

There is often a disconnect between the technology needs and problems to be solved in industry and academic or early-stage R&D. Research funding for academics is often focused on basic research and distant from the needs industry. Start-ups often focus attention on an interesting idea, but have little connection to the needs and challenges of adopting a specific technology in manufacturing supply chains. While tools, such as PitchBook, exist to identify start ups globally, more "hands-on" tools and networks could more effectively connect seekers and solvers, such as . regular start up events focused on specific sectors and technologies[4]. A useful tool is also a technology needs list developed by stakeholders in areas where they would like to see innovation[5]. These technology needs can then serve as the basis of global collaborative innovation challenges or other awards. A global – with regional hubs – network of innovators in GSC can help industry identify potential academic and early stage company partners to address GSC challenges in sectors leveraging matchmaking platforms that link research and development to high-impact industrial needs.

Next steps: UNEP/UNIDO should create a list of GSC innovation needs for priority GFC sectors that UNEP and other IGOs can distribute to individual countries and business associations. UNEP/UNIDO should develop a model technology needs hub that could serve as a basis for innovators to respond to industry needs.

3.5 Criteria and performance metrics for green and sustainable chemistry solutions

Action: Develop harmonised and standardised performance metrics to compare GSC solutions against conventional alternatives.
Rationale: Having clear criteria for GSC innovations addresses a key barrier, supports investment certainty, guides innovation, and avoids greenwashing and regrettable tradeoffs
Key Actors: IGOs; governments

Linked to Action 4.1 in this roadmap, to support incentives, investment, and clarity in value chains, there is a critical need for clear criteria for measuring GSC innovations to understand improvements and trade-offs versus incumbents. Such criteria are important for avoiding greenwashing, ensuring investment stability, and ultimately avoiding regrettable substitutions. The GFC finance group has outlined a clear rationale for consistent criteria and certifications for defining a safer chemical. While the OECD and others have developed criteria for defining a safer chemical, simple sustainability criteria (intrinsic to the molecule or process) have been more difficult to achieve.[6] Harmonized tools and criteria that are comprehensive but usable across countries and regions for evaluating chemical design and

[4] See the website of ISC3
[5] See the website of Change Chemistry
[6] The European Safe and Sustainable by Design Framework provides guidance; however, its complexity means that its utility for most early stage companies and LIMCs is limited currently.

alternatives could both address a key barrier to GSC (lack of consistent criteria) while guiding innovation, incentives, and investments.

Next steps: UNEP/UNIDO/OECD should, in conjunction with the GFC Finance Workgroup and Chemical Footprint Workgroup, develop a set of harmonised criteria for defining and evaluating GSC innovations and safer alternatives against incumbents that can be adopted by different types of firms and globally.

4. Theme 2. GSC strategies in value chains and sectors

Chemicals are used across every industrial sector in complex global value chains that comprise innovators, chemical suppliers, distributors, compounders and formulators, product manufacturers, retailers and users. The different parts of the value chain often span countries and regions. The GFC Targets D1-D6 prioritise policies, investments, and market actions that both identify and reduce priority chemicals of concern with priority given to sustainable solutions and safer alternatives. The GFC further highlights a number of chemical intensive priority sectors for action, including: agriculture, textiles, electronics, construction, and healthcare. Each has unique challenges, needs, and opportunities to advance green and sustainable chemistry.

This theme addresses the demand side: pulling safer and more sustainable solutions through value chains and sectors into widespread use. It complements Theme 1, which focuses on generating and maturing those solutions; here the emphasis is on the market, policy and value-chain conditions that determine whether proven alternatives are actually adopted.

Defining value chains

Value chains can be defined in multiple ways – from gate to gate, from cradle to gate, from cradle to grave. Depending on how they are defined the value chain can include: Product designers/chemists – academia and research institutes; raw material/Feedstock manufacturers; different tiers of chemical manufacturers; compounders, converters, formulators, and processors; product manufacturers and brands; retailers, purchasers, and end users; collectors and recyclers and reprocessors (for circular products). Additional participants in the value chain include governments, workers, investors, certification bodies and NGOs.

The following two graphics – taken from earlier UNEP work on green and sustainable chemistry in the construction and textile sectors – demonstrate the range of potential actors in supply chains that could be engaged in substituting a chemical of priority concern or adopting a green and sustainable chemistry solution. To define a value chain such that it will be useful for advancing green and sustainable chemistry, it is critical that relevant stakeholders from the chemical industry and the sector of interest are involved. Figure X is a value chain that resulted from consultation with stakeholders along the buildings and construction and chemical value chains. This ensured buy-in from the necessary people, and provided a foundation for continued action towards the implementation of green and sustainable chemistry innovation in the buildings and construction sector.

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Figure 1. Linear representation of activities along the textile value chain (UNEP 2020), aligning with value chain tiers

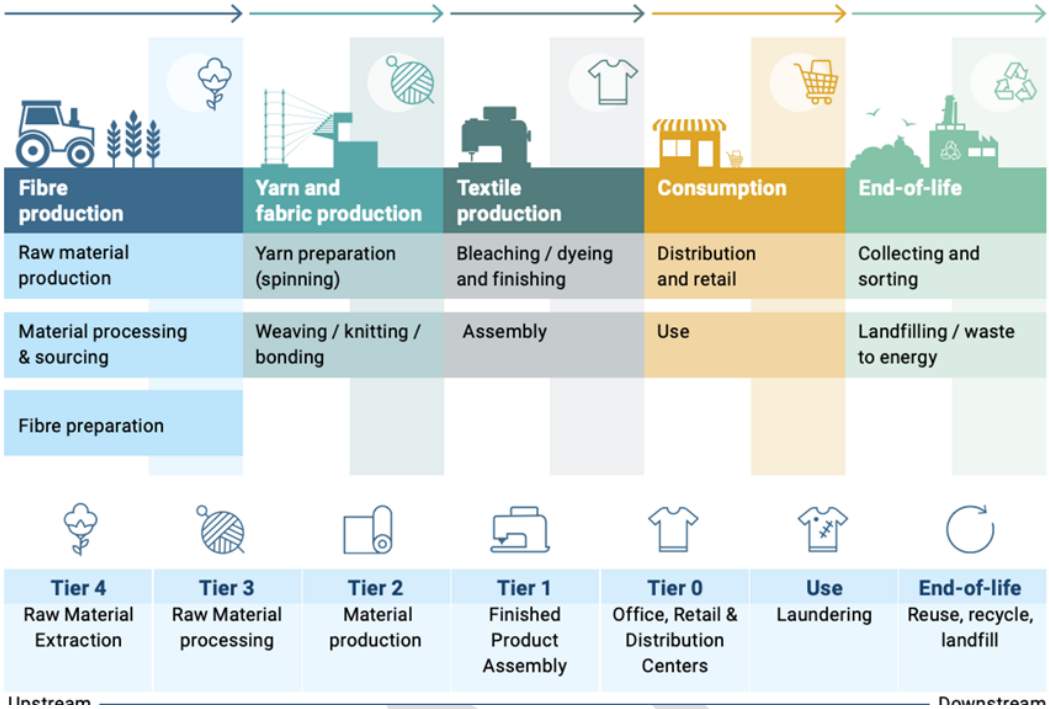
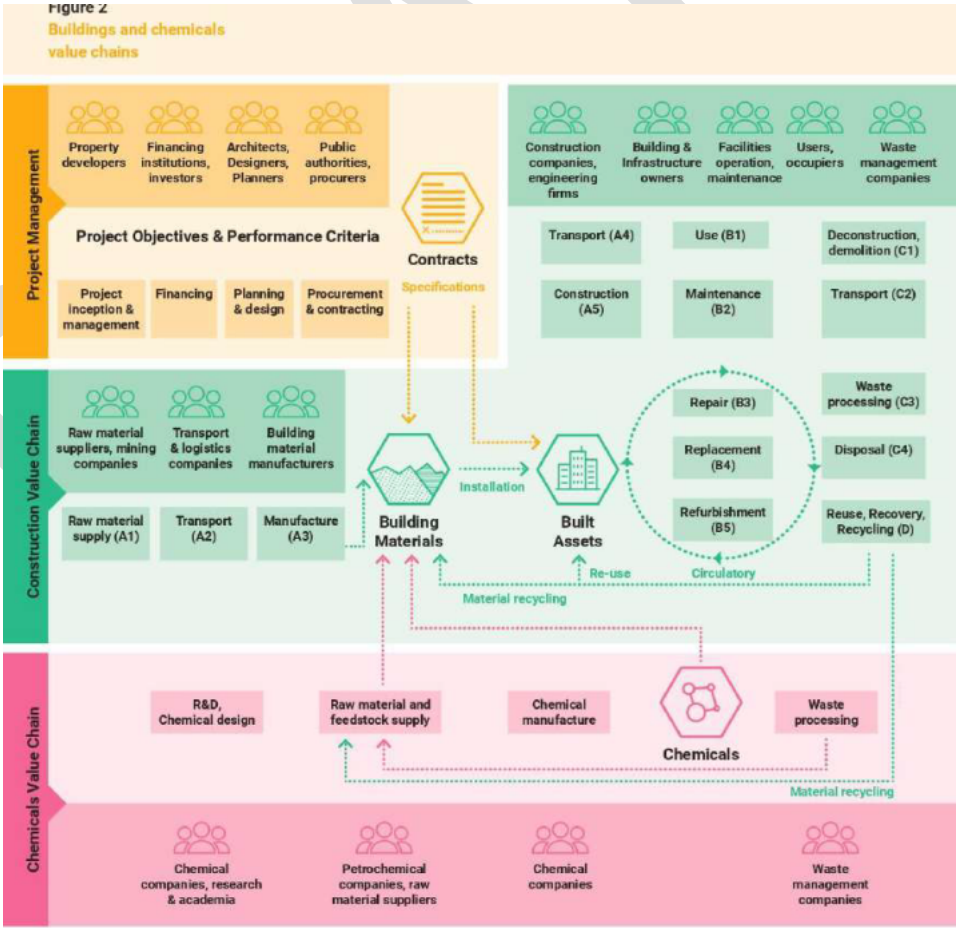


Figure 2
Buildings and chemicals value chains



Growing green and sustainable chemistry takes the whole value chain: policy, market action, education and investment all need to reflect this. Innovators and chemical suppliers regularly create safer and more sustainable alternatives, but these struggle to reach the market. To date, green and sustainable chemistry has taken root mainly in small, niche product categories with higher margins, while decisions across value chains still tend to favour the price and performance of incumbent chemistries.

The main obstacle is incumbency. Established, low-cost chemistries dominate global supply chains, backed by decades of optimised production, infrastructure, capital investment and supportive policy. Developing alternatives demands substantial R&D, reformulation, recertification and regulatory approval, often over 3 to 15 years, and the alternatives may perform differently, lack scale or require new suppliers, creating high switching costs and risks. Short-term return-on-investment expectations sit uneasily with the long timelines and patient capital that green and sustainable chemistry needs, and shifting regulatory and market priorities add further uncertainty.

Barriers to alternatives development vary across the value chain[7]: Early-stage companies struggle to secure sustained investment through the "valley of death" and to win market commitments; chemical suppliers face inconsistent demand and unclear signals, including what counts as "green and sustainable"; brands and formulators must manage supply disruptions and the burden of reformulation and testing; and retailers face limited resources to identify safer products and low consumer willingness to pay a premium.

Barriers and needs vary considerably across sectors as do supply chains; however, a set of core questions can help guide sectoral alignment on priorities and interventions to address barriers. These include:

- What are the priority chemicals of concern for the sector and most important uses and applications in need of substitution and/or green and sustainable chemistry innovations?
- What are the unique challenges of the sector in substitution of priority chemicals of concern or adoption of green and sustainable chemistry innovations?
    - Are there specific parts of the value chain for this sector that pose specific challenges for innovation and adoption?
    - Are there important requirements (performance or regulatory, etc) that impact the sector?
- What are the priority interventions the sector could implement to address barriers and challenges?
    - What are key accelerators and enablers in the sector that could be leveraged to accelerate innovation and substitution?
    - What are the opportunities for pre-competitive sectoral and/or value chain collaboration to implement interventions aimed at addressing barriers?

The Green and Sustainable Chemistry Core Drafting Group identified the following actions designed to advance green and sustainable chemistry across the value chain.

4.1 Enabling policy frameworks

Action: Develop new or adapt existing policies that create common criteria and standards for chemicals of priority concern and safer and sustainable alternatives and that drive innovation, substitution, and adoption of GSC alternatives, including functional substitutes and alternative business models.

[7] See e.g. the analysis performed by Green Chemistry Council (now Change Chemistry) in 2015.

Rationale: This action is intended to integrate green and sustainable chemistry into sectoral policies, regulatory frameworks, standards, and industrial strategies, creating enabling conditions for the adoption of GSC across value chains. This includes incentives for safer and more sustainable products, the management and substitution of chemicals of concern, regulatory coherence, and regional harmonization of standards and approaches. Clear and consistent government policy creates predictability, drives innovation, and supports adoption.
Key Actor: Governments

Policy is a critical driver for green and sustainable chemistry. Even if an alternative saves money over time, compared to an incumbent, the upfront costs of R&D, manufacturing capacity, retrofitting of production equipment, reformulation, recertification, and inertia needed to change long standing value chains may be too much of a barrier. The barriers are even greater when there are no specific policy or market pressures on incumbent chemistries. Policies – such as restrictions, disclosure requirements, and other regulatory requirements can drive change – so called "sticks". However, innovation literature indicates that equally important are policy incentives that overcome support innovation and adoption – pull or "carrot" policies.

Policies should incentivize not only chemical substitution but "functional" substitution where an alternative process, product, or service model replaces the function of the chemical of concern. For example, replacement of copper or tributyltin in anti-fouling for recreational boats could include other safer biocides, alternative coatings, or boat washing.

Important to the effectiveness of policy to drive green and sustainable chemistry to both spur investment and market action, and avoid greenwash and regrettable substitutions are clear and consistent, yet flexible, criteria for both safer and sustainable chemicals. Similarly, globally consistent criteria for defining priority chemicals of concern is equally important to guide policy, see i.a. the criteria developed by OECD, the European Commission or US EPA [8].

Next steps:
● Inventorize key barriers to green and sustainable chemistry innovation and adoption in priority sectors and across regions and business types to develop a more nuanced and global policy framework.
● Collect examples of key policy models globally that have or could most effectively drive or drive substitution of problematic chemicals innovation and adoption of sustainable chemistry.
● Develop harmonized global criteria for green and sustainable chemistry building from existing criteria established by OECD, private sector organizations and others, including the inverse of criteria for priority chemicals of concern that would be considered inconsistent with green and sustainable chemistry.

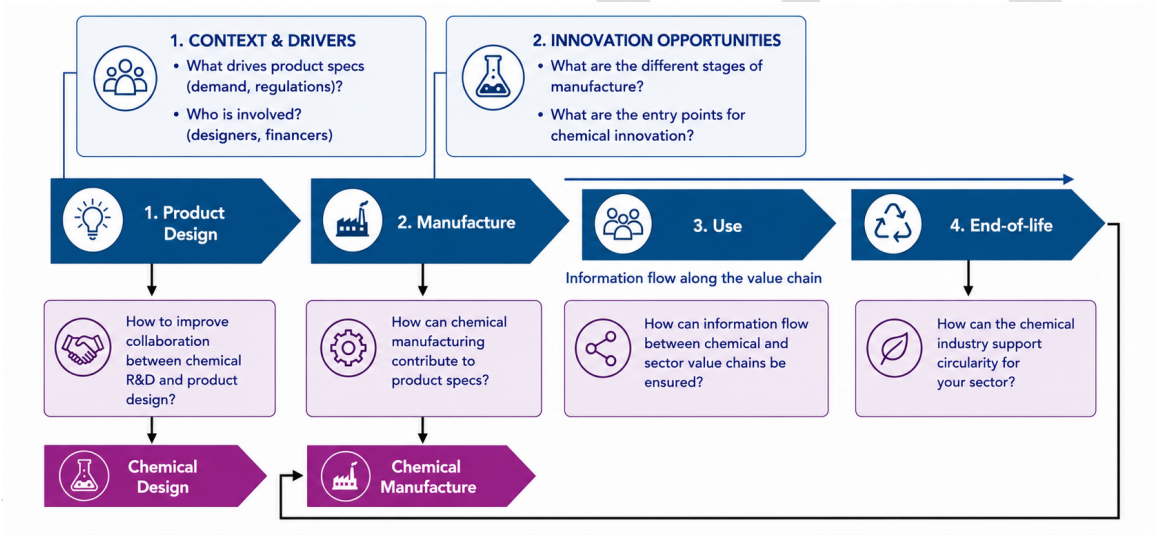
4.2 Sectoral Roadmaps

Action: Establish roundtables for key industrial sectors consisting of stakeholders representing the chemical and sectoral value chains to co-develop voluntary roadmaps that identify opportunities for green and sustainable chemistry innovation and build value chain approaches towards implementation.

[8] The Organization for Economic Cooperation and Development (OECD) has established a set of criteria for defining a safer chemical, the European Commission has criteria for Substances of Very High Concern, and the US Environmental Protection Agency through its Safer Choice Program has established criteria for safer alternatives in particular chemical functional categories.

Rationale: This action is designed to align sectors and product value chains on substitution and innovation needs and priorities, reducing hazards through, for example, multi-stakeholder sector commitments that identify priority substances for substitution and set shared phase-out timelines. Supporting clear and aligned signals to the innovation community and drive market activation for green and sustainable chemistry, sectors and product value chains will require consistent processes and approaches to identify and prioritize chemicals of concern and specific applications or uses for substitution, product design and reformulation, and risk management actions while identifying key barriers and needs for substitution that can be translated to the policy makers, innovators, and investors.
Key Actors: Industry; RTOs; IGOs; governments

While policy provides an important driver for green and sustainable chemistry, sectoral and value chain action can expedite innovation and adoption by providing clear and consistent signals to the value chain on chemicals to avoid and innovation priorities. Sectoral roadmaps would prioritize hazardous chemicals for substitution, set shared timelines for use reductions and safer alternatives while addressing key innovations and adoption needs through value chain dialogues. The figure below is a skeleton value chain to be used as a starting point for discussions among these sectoral roundtables.



Building on Previous Work

A number of sectors including textiles and electronics have established sector-wide restricted substances lists or manufacturing restricted substances lists. Many companies establish their own lists. While most of these lists are based on either government restrictions or government lists of priority substances of concern, some add in additional chemicals or materials subject to scientific or NGO concerns or are likely to be regulated. However, these lists are most often not used to then prioritize the most relevant uses or applications of those chemicals for substitution. This is important when a chemical is broadly used in a sector or value chain to identify and refine those that are priorities for action.

Sectoral roadmaps and initiatives may benefit from commonly agreed criteria to guide the development of safe and effective alternatives. . [9]Engagement of a number of both front runner brands and more traditional ones in the process will strengthen the criteria.

An example of such engagement at UN level was the UNEP Green and Sustainable Chemistry project, assembling an expert group consisting of stakeholders in the construction sector, and those involved with green and sustainable chemistry innovation. A workshop identified priority chemicals of concern, and discussed how far along safer alternatives were towards market adoption. Actions were then identified to move those alternatives closer to market adoption, with each action listing key stakeholders to be involved.

Overall, consistent frameworks for both identifying priority chemicals of concern and safer alternatives as well as consistent prioritization approaches could help align actions across sectors where a chemical may be broadly used. The NGO ChemForward has developed a hazard assessment framework for sectors to align on chemicals of concern, fill data gaps, and measure progress in substituting priority chemicals of concern.

Next steps:
- Create sectoral working groups with stakeholders along the value chains of both the sector (electronics, agriculture, textiles) and the chemical industry
- Develop guidance on best practices for establishing sectoral or category product-level prioritization and commitment processes
- Create inventory of sectoral and company prioritization and action processes.

4.3 Green and Sustainable Chemistry Innovation and Substitution Clusters

Action: Establish sector roundtables and facilitate collaboration with value-chain partners to co-develop and evaluate safer and more sustainable solutions for priority chemicals of concern and applications
Rationale: This action follows the previous action and focuses on collaboration within sectors and along value chains to accelerate innovation and adoption of green and sustainable chemistry innovations for priority chemicals and applications of concern. Collaborative innovation across sectors and along value chains can accelerate green and sustainable chemistry innovation and adoption by more effectively addressing technology and performance needs, sufficient market availability, and cost. It allows for shared cost and learning.
Key Actors: Industry; start-ups, RTOs, academia, investors, governments

To address key barriers to innovation and adoption of green and sustainable chemistry solutions, lower costs, and accelerate innovation and adoption processes, sectors or product value chains – supported by governments and others – can establish pre-competitive collaborative innovation clusters. There are many examples of such innovation clusters – ranging from government- and industry-funded industry/academic/research institute collaborations, to sectoral organization initiatives, to government funded research and innovation centers.
Examples of pre-competitive collaborative innovation clusters include:

[9] Example: The Green Chemistry & Commerce Council developed a set of criteria to guide development of safe and effective preservatives that has been used throughout value chains to prioritize innovation in safer preservatives and substitution of those that do not meet the criteria.

- Efforts among ZHDC partners to evaluate alternative solvents and durable water repellents used in the textile sector;
- The EU's recently established „Substitution and Innovation Hubs", to support sectors and supply chains in collaborative substitution processes;
- The „whole-of-supply-chain" approach as applied by the Toxics Use Reduction Institute in Massachusetts (USA). The approach is to advance safer substitutes for specific applications, e.g. hexavalent chromium conversion coating alternatives in the aerospace sector, lead-free soldering for electronics and safer adhesives for construction;
- Efforts in the European metal plating sector to evaluate alternatives to hexavalent chromium.

Importantly, case examples and best practices for collaborative supply chain innovation and substitution efforts should be established, addressing key concerns around confidential business information and anti-competitiveness. Similarly, governments and investors need to create enabling conditions for companies and other actors in value chains to collaborate to solve innovation and substitution challenges. Such collaborations should move beyond chemical-for-chemical substitutions and consider innovations that decouple economic value from chemical volume, including service-based and chemical-leasing models that optimize resource use and reduce waste.

Next steps:
● Develop guidance on best practices for establishing sectoral or value chain substitution and green and sustainable chemistry collaborative innovation initiatives, including how these could be applied in LIMCs and with SMEs.
● Create inventory of sectoral value chain collaborative substitution and green sustainable chemistry projects, including those supported by governments as well as other organizations.

4.4 Infrastructure to support SMEs and LIMCs in substituting chemicals of concern

Action: Leverage existing resources, like UNEP/UNIDO Cleaner Production Centres and existing substitution and pollution prevention centers to create globally-networked resources to assist particularly SMEs and LMICs in substituting chemicals of concern with safer and more sustainable alternatives
Rationale: This includes actions to make production safer and more resource-efficient, such as drawing on cleaner production networks to help small- and medium-sized enterprises reduce implement pollution prevention reduction measures and support safer alternatives. Substitution is difficult, particularly for SMEs and in LIMCs where information, knowledge, and technical and operational resources may not be readily available.
Key Actors: Governments; IGOs

SMEs, particularly in Low and Middle Income Countries (LMIC), often lack technical expertise and resources to identify, evaluate, and adopt toxic reduction and resource efficiency measures. SMEs do not have expertise in health and safety, process design or have access to critical resources.

Experience from the Massachusetts Toxics Use Reduction Institute (TURI) and other pollution prevention centers globally shows that technical and information support, training, convening, and piloting and demonstration projects can accelerate adoption of safer alternatives, toxics, reduction and improved chemicals management. The results of such support can be

impressive, and 50% reduction in the use of priority chemicals of concern and 70% reduction in hazardous waste are possible[10], alongside increased competitiveness and cost savings among companies. Research institutes could support academic-industry research and community engagement (for example firefighters) in toxics reduction and substitution efforts[11].

As to substitution centers, a distributed „hub-and-spokes model" (a system design where multiple outlying nodes (spokes) connect to a single central node (the hub)) could provide an effective mechanism for connecting expertise in specific chemicals, product categories, sectors, or supply chains. Global coordination – through UNEP or UNIDO – could help create global networks of expertise and collaboration on substitution with regional support mechanisms.

Next steps:
● Develop guidance on best practices in research and technical assistance centers/networks to support informed substitution and green and sustainable chemistry particularly for SMEs and in LIMCs.
● Inventory existing efforts to build substitution and green and sustainable chemistry innovation support.
● Establish a global working group on substitution and green and sustainable chemistry technical support to industry to identify funding mechanisms, build collaborative/connected networks of expertise and discuss needs/barriers.

4.5 Consistent and transparent data to evaluate GSC solutions along value chains

Action: Develop consistent, transparent, and actionable approaches to assess safety and sustainability aspects of green and sustainable chemistry innovations to evaluate different alternatives, ensuring data accessibility and availability throughout value chains and to different stakeholders
Rationale: This action helps ensure sufficient data on chemical hazards, toxicity and sustainability impacts is available to support innovation green and sustainable chemistry and avoid regrettable substitutions. Transparent and available data (including consistent definitions and criteria for safer and sustainable) can support investment, enable trust and accountability.
Key Actors: IGOs, governments

The substitution literature abounds with cases of regrettable substitution, where one hazardous chemical is substituted with one of equal or different toxicological concerns. Consistent, good quality, and transparency data on toxicity and other sustainability attributes is a persistent challenge to green and sustainable chemistry innovation and adoption. Having such data can reduce regrettable substitution, support value chain action, and enable investment. The increasing availability of tools and databases – including chemistry, AI, and NAMs and hazard assessment tools – is enhancing the ability of innovators and companies to more comprehensively evaluate alternatives and new innovations. However, these tools have not always been transferred or translated to the needs of LIMCs and SMEs. For example, implementation of the European Commission guidance on Safe and Sustainable By Design would require technical resources beyond the reach of most companies.

[10] Reference pending.
[11] Such support was provided by TURI.

Relatively simple tools to collect and compare information on chemical hazards and other sustainability attributes could provide useful information to companies along value chains in identifying priority chemicals of concern and evaluating safer alternatives. Turned into computations models, these same tools can help designers identify potential red flags at the design stage. The ultimate goal is translatable information o support innovators and value chains in designing and evaluating alternatives, avoiding regrettable substitutions.

Next steps:
● Inventory existing tools and databases for their applicability to decision-making in design and chemical selection in SMEs and LIMCs
● Establish a working group to determine hazard and other sustainability attribute needs across the value chain, company size, and region to improve upon or develop new tools to support action on priority chemicals of concern and safer alternatives.

4.6 Processes to collect information on chemical use across global value chains

Action: Develop and collect data on chemical use along value chains to enable prioritization, identification of green and sustainable chemistry and pollution prevention opportunities, and measure progress towards reduction in chemicals of concern and growth of alternatives.
Rationale: Better data on chemical use in sectors and along value chains enables prioritization and evaluation of actions to reduce chemicals of concern and grow GSC solutions
Key Actors: Governments; IGOs

A well-recognized and historical critical barrier to both understanding priority chemicals of concern and their uses across sectors and value chains globally is the lack of consistent and transparent data on chemical use. The lack of such data not only creates risks, as the case of hundreds of unexpected uses of PFAS has identified, it also inhibits the ability for companies, workers, and communities to both implement risk management measures or take action on priority chemicals of concern, such as substitution. Knowing what chemicals are used in what products is a core principle of product stewardship – you can't manage what you can't measure. Such data are also critical to investors understanding chemical risk in supply chains.

The lack of information on chemical use in manufacturing and supply chains creates a further barrier to prioritization, as it is then not possible to determine which uses are most important to substitute given use or exposure. Nor is it possible to identify innovation needs and focus on substitution actions with the greatest benefits[12].

In addition to identifying priorities and interventions, data on chemical use is critical to measuring progress towards substitution and pollution prevention, evaluating the efficacy of interventions, and tracking the growth of green and sustainable chemistry solutions.
Given advances in digitization, tracking chemical use in manufacturing processes and products should not be an impossible task. Many product sectors – particularly formulated products and autos, sometimes also the building materials sector – already collect detailed chemical ingredient data.

[12]The Massachusetts Toxics Use Reduction Program provides a comprehensive picture of the value of use data in identifying priority chemicals, uses, and sectors and evaluating progress, see TURI resources here.

Public and private sector models for disclosing information on chemical use are emerging, from the Digital Product Passport in Europe, to ChemForward's "donuts", to the Massachusetts Toxics Use Reduction Program data reports. Key to such efforts is consistency and transparency in what data are collected and in what format, allowing interoperability. Ensuring data and data collection systems are available throughout global supply chains and for LIMCs and SMEs should be a priority.

Next steps:

- Establish a working group on establishing global chemical use information in manufacturing and through value chains to explore options for improved chemicals use data collection and identify best practices that can serve as foundations for individual companies to develop collection systems.

5. Theme 3. Knowledge, evidence and education

Strengthens the evidence base for GSC and builds the skills and awareness needed across education levels and professional practice.

5.1 Evidence base and advocacy

Action: Generate, synthesize and make accessible, data and case studies, in collaboration with academia and diverse knowledge- and stakeholders, to strengthen the economic and health case for GSC innovation, including the risks of inaction.
Key Actors: NGOs, IGOs, Academia, Industry

Action: Develop evidence-based communication campaigns and public awareness programmes that translate technical data into accessible information for broad audiences and into actionable messaging for policymakers and investors to support the uptake of GSC solutions.
Key Actors: NGOs (science communication), IGOs, Academia

5.2 Formal education

Action: Update national curricula and strategies to integrate GSC principles, life cycle thinking and related competencies across all levels of education, especially in chemistry, engineering and life sciences disciplines.
Key Actors: Governments (education ministries), Academia

Action: Develop open-access educational resource repositories, guidance and train-the-trainer programmes to support educators with adaptable approaches to integrate GSC concepts into curricula and learning outcomes.
Key Actors: Academia, IGOs, NGOs, Youth Groups

The Master's Program in "Sustainability Sciences: Resources, Materials and Chemistry" launched in 2025 at Leuphana University of Lüneburg, Germany, focuses on bridging the gap between GSC - which is usually more confined to the laboratory scale - and practical implementation on a large scale across various sectors. Unlike traditional chemistry

programs, this new course is rooted in systems thinking, case studies and global supply chains, with the aim of reshaping the traditional industrial structure.

5.3 Professional application and lifelong learning

Action: Facilitate global and regional communities of practice and learning platforms that enable peer-to-peer and cross-sectoral exchange of practical implementation experiences and best practices across industry, academia and diverse knowledge-holders.
Key Actors: NGOs, IGOs, Industry, Academia

Action: Establish certified professional training programmes and vocational courses on GSC tailored for workers and management in high-impact sectors, including early career professionals transitioning out of formal education, to build the skills and competencies needed to advance GSC transformation within these sectors.
Key Actors: Industry Associations, Unions, Academia, IGOs

Action: Empower youth leadership and agency in advancing GSC transformation, including strengthening the role of youth- and student-led networks in evidence generation, knowledge translation, and advocacy, and supporting capacity-building and skills development.
Key Actors: Youth Groups

6. Theme 4. Financing green and sustainable chemistry

Public and private finance along the TRL and deployment pathways are critical to scaling sustainable chemistry. The GFC Finance Working Group has focused its attention both on minimizing the reputational, litigation, and regulatory risks associated with chemicals of concern but also how to leverage and align finance to drive GSC solutions from laboratory to scale. Work in climate finance provides a model that can be applied to GSC in the future, where government funding and incentives help derisk private sector investment. "Patient money" has been identified as a key barrier to GSC at scale, given the long innovation cycles and high capital costs in chemicals manufacturing. Understanding financial needs along the development and adoption pathway and the types of finance mechanisms required at each is an important first step. Existing understanding is outlined in Figure X [ABOVE]. An integrated approach to linking public, private, and blended sources of finance to support directed toward GSC will be critical for global growth.

6.1 Public finance and incentives

Action: Governments should establish dedicated public finance and incentives for green and sustainable chemistry along the innovation and adoption pathway, tied to clear GSC criteria.
Rationale: Governments play a critical role in derisking innovation and adoption of GSC solutions, sending clear market signals of priorities and directions through incentives and funding
Key Actors: IGOs, governments

Action 3.1 notes the needs for incentives to drive innovation, piloting, and deployment of GSC solutions. These are often challenged by the incumbency of existing technologies and a lack

of willingness to pay a green premium along value chains. Renewable energy technologies have scaled in part due to sustained, durable government incentives and funding. Finance and incentives needs differ depending on the stage of development of the technology and value chain position as demonstrated in the following graphic. Government incentives and finance play an important role in derisking private investment. Further, government incentives and finance should be tied to clear criteria and review processes for safety, sustainability and innovation, of sufficient duration to enable innovation and market adoption to occur and encourage sustained private finance and be phased out once they have achieved their goal.

Table 13. Relevance of Incentive Types to Innovation Stage, Adoption Stage, and Value Chain Position

	Innovation Stage					Adoption Stage				Value Chain Position				
	Early-Stage R&D	Pilot Testing	Prototype Development	Demonstration	Commercialization	Pre-Deployment	Deployment	Market Activation	Market Transformation	Feedstock Suppliers	Chemical Suppliers	Formulators / Compounders	Brands / Manufacturers	Retailers / End Users
Supply-Push Policy Incentives														
Industrial and Academic R&D Grants														
Foundational knowledge	●	○	○	○	○	●	○	○	○	●	●	○	○	○
Innovation to application	●	●	●	●	○	●	●	○	○	●	●	●	○	○
Piloting, demonstration & early deployment	○	●	●	○	○	●	●	○	○	●	●	●	●	○
Subsidies														
Financial	○	○	○	○	●	○	●	○	○	●	●	○	○	●
Market-based	○	○	○	○	●	○	○	●	○	●	●	○	○	●
Infrastructure/ecosystem	●	●	●	●	●	●	●	○	○	●	○	●	○	○
Policy	○	○	○	○	●	○	●	●	○	●	●	○	●	○
Tax Incentives														
Production tax credits	○	○	○	○	●	○	●	●	●	●	●	○	○	○
R&D tax credits	●	●	●	○	○	●	○	○	○	●	●	○	○	○
Investment tax credits	○	○	○	●	●	○	●	○	○	●	●	○	○	○
Demand-Pull Policy Incentives														
Market Support & Derisking														
Content requirements	○	○	○	○	●	○	○	●	●	●	●	○	○	○
Market assurances	○	○	○	○	●	○	●	●	●	●	●	○	○	○
Cost supports	○	○	○	○	●	○	●	○	○	○	○	○	●	●
Labeling, Recognition & Purchasing														
Labeling/Recognition	○	○	○	○	●	○	○	●	●	○	●	○	●	●
Preferred purchasing	○	○	○	○	●	○	○	●	●	○	●	○	●	●
Regulatory														
Taxes/Fees	○	○	○	○	●	○	○	●	●	○	●	○	●	●
Disclosure requirements	○	○	○	○	●	○	○	●	●	○	○	○	●	●
Regulatory process	○	○	○	○	●	○	○	●	○	○	●	○	●	○

Next steps: Leveraging the Change Chemistry Sustainable Chemistry Incentives Framework and other analyses, UNEP should develop a recommended public incentives and finance framework for GSC tailored to the level of development or adoption of the technology and maturity and position of the company in the value chain.

6.2 Private and blended capital

Action: UNEP Finance should convene private and public funding agencies to develop a finance infrastructure for GSC that could serve as a hub for identifying and discussing investment needs, addressing challenges, creating innovation and funding prizes, combining resources, and ways to more effectively align finance towards verified GSC solutions.
Rationale: More effective linking of finance from angel and venture to private equity, bonds and debt equity can help create a more coherent and connected ecosystem of funding and finance for GSC. Such an infrastructure can bring in more funding, address barriers, and link funding streams.

Sustainable chemistry finance - from angel and venture to private equity and other finance for sustainable chemistry are dispersed and unconnected. More coherent and coordinated public-private finance could help overcome the various valleys of death in sustainable chemistry bench to deployment. This includes finance for LIMCs which could include other mechanisms like multi-lateral banks and the GFC and GEF funds.

6.3 Investment signals, metrics and disclosure

Action: UNEP/UNIDO and OECD should develop clear investor-facing criteria and metrics for sustainable chemistry so that innovations are aligned with sustainable finance.

7. Cross-cutting enablers. Leadership, communication and coordination

7.1 Leadership and governance

Action: Governments and relevant intergovernmental organisations should establish clear leadership and governance arrangements for green and sustainable chemistry at national, regional and global levels.
Rationale: GSC cuts across multiple policy areas, institutions and levels of governance. Clear leadership and governance are needed to provide strategic direction, clarify responsibilities and ensure coherent implementation of the actions across this Roadmap.
Key Actors: Governments; IGOs; regional organisations

At the national level, governments should identify clear institutional responsibility for GSC and ensure that relevant ministries and agencies are connected. Depending on national circumstances, this could build on existing chemicals and waste, sustainability or other relevant governance mechanisms.

At the regional level, existing cooperation mechanisms can support exchange between countries, facilitate peer learning and, where appropriate, greater alignment of approaches. At the global level, existing GFC and other relevant mechanisms should provide strategic coordination across the thematic areas of this Roadmap and help identify common implementation gaps and priorities.

Governance arrangements should connect the actions under the individual themes without duplicating the sectoral, technical and stakeholder coordination mechanisms established within them.

Next steps:
● Governments should identify existing institutional responsibilities for GSC and clarify national leadership where needed.
● Regional actors should identify opportunities to strengthen exchange and alignment through existing mechanisms.
● GFC stakeholders should clarify how existing global mechanisms can support strategic coordination across the Roadmap.

7.2 Multi-level coordination and partnerships

Action: Governments, IGOs and other stakeholders should strengthen multi-stakeholder coordination and partnerships to support implementation of GSC across the thematic areas of this Roadmap.
Rationale: GSC implementation depends on decisions and actions by governments, industry, research and academia, finance actors and civil society. No single actor can address the policy, innovation, knowledge, financing and market barriers to GSC alone. Coordination and partnerships can help align priorities, combine complementary expertise and resources, and address implementation gaps.
Key Actors: Governments; IGOs; industry; research and academia; finance actors; civil society

Multi-stakeholder coordination should connect actors across the different areas of GSC implementation and facilitate collaboration where challenges require joint action. This may include linking policy makers with innovators and industry, connecting finance actors with emerging GSC solutions, or bringing scientific and technical expertise into implementation processes.

Such coordination should complement, rather than duplicate, the more specific partnerships and collaborative mechanisms established under the individual themes, including sectoral and value-chain collaboration.

Next steps:
● Identify priority implementation challenges that require coordination across stakeholder groups or thematic areas.
● Identify existing partnership and coordination mechanisms that can address these challenges and strengthen connections between them where needed.

7.3 Building on existing structures and networks

Action: Governments, IGOs and other stakeholders should leverage and connect existing initiatives, platforms and networks to support GSC implementation rather than creating parallel structures.
Rationale: A wide range of international, regional, national and sectoral initiatives already address elements relevant to GSC. Better connecting and using these structures can accelerate implementation, make use of existing expertise and resources, and reduce duplication.

Key Actors: Governments; IGOs; industry; research and academia; relevant networks and initiatives

Existing structures can provide implementation channels for actions across the Roadmap, including innovation, value-chain action, knowledge and education, and finance. Where gaps remain, existing initiatives should first be assessed for their potential to expand their scope or connect with other mechanisms before new structures are established.

This approach can also support the exchange and replication of effective practices across countries, regions and sectors while allowing implementation to be adapted to different contexts.

Next steps:
● Map relevant existing initiatives, platforms and networks at international, regional and national levels and identify their potential contribution to GSC implementation.
● Identify gaps, overlaps and opportunities to strengthen connections between existing mechanisms across the Roadmap's thematic areas.

7.4 Inclusive and context-responsive implementation

Action: Governments, IGOs and other stakeholders should ensure that GSC implementation is inclusive, accessible and responsive to different regional and national contexts, capacities and stakeholder needs.
Rationale: Countries, companies and other stakeholders differ significantly in their technical and institutional capacities, access to finance and technology, and ability to implement GSC actions. Implementation approaches therefore need to reflect different circumstances while ensuring meaningful participation and access to opportunities and resources.
Key Actors: Governments; IGOs; industry; research and academia; civil society

Implementation across the Roadmap should take into account the particular needs and capacities of LMICs and SMEs and support their participation in the transition towards GSC. Technology transfer and capacity development can help address implementation gaps and should be integrated into relevant actions across thematic areas rather than treated as stand-alone activities.

Inclusive implementation should also ensure meaningful participation of groups whose perspectives and knowledge may otherwise be underrepresented, including women and youth, and appropriately recognise indigenous and local knowledge. This can strengthen the relevance and effectiveness of GSC actions and help ensure that implementation responds to different social, economic and regional circumstances.

Next steps:
● Review actions across the Roadmap to identify barriers to participation and implementation for different regions and stakeholder groups, particularly LMICs and SMEs.
● Identify where capacity development, technology transfer and more inclusive participation need to be strengthened within the thematic actions.

7.5 Communication and advocacy

Action: Governments, IGOs and other stakeholders should use coordinated and targeted communication and advocacy to build a shared understanding of GSC and mobilise stakeholders to implement the actions of this Roadmap.
Rationale: GSC is relevant to a wide range of stakeholders with different priorities, incentives and levels of awareness. Strategic communication can help translate GSC into messages relevant to different audiences, build support for implementation and encourage uptake across sectors and regions.
Key Actors: Governments; IGOs; industry; research and academia; civil society

Communication should be tailored to different audiences and demonstrate how GSC contributes to relevant environmental, health, economic and industrial objectives. Evidence, case studies and narratives developed under Theme 3 can provide the basis for this communication and should be translated into accessible formats for policymakers, industry, investors and other stakeholders.

Communication efforts should be coordinated across existing initiatives and channels to reinforce common messages, increase visibility and support engagement with the actions identified throughout the Roadmap.

Next steps:
- Identify priority audiences and communication needs for GSC implementation.
- Develop shared core messages and audience-specific communication approaches, building on the evidence and case studies developed under Theme 3.
- Use existing communication channels and networks to disseminate messages and support uptake of Roadmap actions.

8. Conclusion and next steps

To be elaborated

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