ADVANCING GREEN AND SUSTAINABLE CHEMISTRY INNOVATION IN THE BUILDINGS AND CONSTRUCTION SECTOR

Analysis and workshop outcome report

Contents

Acknowledgement:

The development of this report was led by Bioregional, in collaboration with the UNEP Chemicals and Health Branch and The Global Alliance for Buildings and Construction (GlobalABC) secretariat, and with support from the Life Cycle Initiative. The report is an output of the UNEP led expert workshop on Green and Sustainable Chemistry in the Buildings and Construction sector, which was held on 20 January 2023 in Paris, France. The workshop was held in the context of UNEP's work to develop Manuals on green and sustainable chemistry innovation, as requested by Member States at the Fourth Session of the United Nations Environment Assembly in 2019. Funding for the workshop, and additional activities to advance green and sustainable chemistry innovation in the buildings and construction sector, is generously provided by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

A. Introduction, methodology and scope

Introduction

There is strong concern about the global effects of chemicals on human health and the environment. UNEP's Global Chemicals Outlook II (GCO-II) found that hazardous chemicals and other pollutants continue to be released in large quantities and that the goal to "minimize adverse impacts of chemicals and waste by 2020" has not been achieved. With the global chemical market projected to double between 2017 and 2030, "business as usual" approaches are not an option. Whilst it is difficult to measure the effect in terms of environmental damage and health, the cost of inaction is estimated to be as high as 10% of global GDP[1]. However, estimates of the effect of action from chemical legislation passed to date are valued at least in "the high tens of billions" of US dollars per year[1].

The buildings and construction sector is a major downstream user of chemicals, including as feedstocks for production, bulk and speciality chemical additives (e.g. flame retardants, concrete admixtures), and building chemical products such as sealants and adhesives. Driven by urbanization, the sector is rapidly growing with the global market for construction chemicals expected to reach over 50 billion USD by the end of 2024[1]. While rapid growth in chemical-intensive industry sectors, such as buildings and construction, will create risks, new opportunities will also arise to advance sustainable consumption and production and product innovation.

With the world's building space expected to double before 2050, an in-depth transformation of the sector is critical to achieve the Sustainable Development Goals and the Paris Agreement. Additionally, the sector is central to the economy and societal prosperity. It is responsible for more than 200 million jobs globally and it accounts for 11-13% of global GDP[2]. It is important to consider the impact of the sector on health if these global challenges are to be overcome. In certain regions, people spend around 90% of their time indoors – the way in which homes are built and used is therefore essential for wellbeing.

This Document provides an overview of the buildings and construction value chain, and of the related chemical value chain. A section on "key stakeholders" elaborates on the roles of actors along the buildings and construction sector towards advancing green and sustainable chemistry. It concludes with a description of UNEP's 10 Green and Sustainable Chemistry Objectives and Guiding Considerations, and their application to the buildings and construction sector.

Background and Methodology

This document captures and summarises outputs of the **discussions, presentations and group breakout sessions at the expert workshop held by UNEP on Green and Sustainable Chemistry and Buildings and Construction on 20 January 2023, in Paris, France.** It aims to identify overarching themes, priority areas of focus, and key stakeholders' activities to advance the integration of green and sustainable chemistry into the buildings and construction sector.

The workshop was held in the context of UNEP's work to develop Manuals on green and sustainable chemistry innovation. The workshop brought together experts in green and sustainable chemistry, and those working towards a more sustainable buildings and construction sector. Participants included stakeholders who supported the development of UNEP's Manuals on Green and Sustainable Chemistry, and GlobalABC member representatives with expertise on building materials. Experts at the workshop had the opportunity to discuss

[1] Global Chemicals Outlook II. United Nations Environment Programme, 2019. Available from https://www.unep.org/resources/report/global-chemicals-outlook-ii-legacies-innovative-solutions
[2] The construction sector can pave the way for a green economic recovery. UNFCCC. Available from https://climatechampions.unfccc.int/the-construction-sector-can-pave-the-way-for-a-green-economic-recovery/

and exchange on the potential of chemical innovations to support a more sustainable buildings and construction value chain, as well as strategies and recommendations to reach that potential.

The workshop agenda included:

- An overview of the materials challenge in the buildings and construction sector
- Background on the UNEP Manuals produced on green and sustainable chemistry
- An initial introduction to the draft background document
- A report on the outputs from the IOMC workshop on chemical intensive economic sectors and value chains under the new "beyond 2020" framework on chemicals and waste
- Illustrative examples of green and sustainable chemistry action to contribute to a more sustainable buildings and construction sector, presented by participants.

Breakout sessions conducted in the workshop captured participants' experiences, explored key themes and enabled discussion on how green and sustainable chemistry activities could address impacts of the sector. A first set of breakouts explored actions related to chemical-intensive building products; the climate impacts of the buildings and construction value chain, resource use and biodiversity considerations. The second breakouts aimed to identify potential actions in the context of policy interventions, enhanced market dynamics, and communication and capacity building.

A draft of this document was circulated to participants prior to the workshop. Key insights and outcomes received from discussions, as well as written inputs contributed to the finalization of the document.

Scope

The scope of the buildings and construction sector addressed by this background document is taken to include:

- Domestic, commercial and public buildings – The materials and products used within these and the relevant processes with chemical impacts (manufacture, material installation, end-of-life treatment)
- Certain appliances – ventilation, lighting, cooling
- Built environment– e.g. concrete, asphalt, metal and wood coatings

B. Main facts and figures about the Building and Construction Sector and its relevance to chemicals

The Buildings and Construction Sector is seeing a rapid pace of expansion, particularly in emerging economies, resulting in increasing environmental impacts.

- Between 2018 and 2050, the share of the global population living in urban areas will increase from 55% to 68%, adding 2.5 billion to the world's urban population[3].
- The buildings and construction sector is estimated to grow by 3.5% annually, and already accounts for 37% of the world's energy- and process-related carbon emissions and over 34% of global energy demand.
- Building materials' embodied carbon impact accounts for around 9% of global carbon emissions.
- In fast-growing developing economies, building materials' associated GHG emissions are expected to double by 2060.
- Approximately 100 billion tonnes of waste globally are caused by construction, renovation and demolition activity, with about 35% of this waste being sent to landfills[4].

The Buildings and Construction sector is a major end market for chemicals.

[3] United Nations (2018) World Urbanization Prospects: The 2018 Revision.

[4] 2022 Global Status Report for Buildings and Construction. UNEP/GlobalABC. Available from https://globalabc.org/our-work/tracking-progress-global-status-report

- At USD 695 billion, the buildings and construction sector has the highest end market chemical revenue according to the Global Chemicals Outlook II, ahead of electronics, household, and agriculture[1].
- The market size for chemicals associated with building materials was estimated to grow by 6.2% annually between 2018 and 2023[5].
- Key chemicals used in the buildings and construction sector include bulk petrochemicals, industrial gases and speciality construction chemicals (e.g. concrete admixtures, protective coatings, asphalt modifiers, adhesives and sealants).
- The buildings and construction sector has the dominant market share for petrochemicals[6].
- End-use of petrochemicals in plastics by the buildings and construction sector is significant. Around 21% of the 47 million tonnes of plastic used in Europe are by construction[7]. A transition away from fossil-based feedstock is essential, and globally only around 10% of plastics are recycled[8].
- The global market for speciality construction chemicals is expected to grow by 9% per year to more than USD 50 billion by the end of 2024.
- Several chemicals of concern are used in the buildings and construction sector resulting in exposure and risks along the value chain (see next section for details).

Potential benefits of Green and Sustainable Chemistry innovation in the buildings and construction sector

- Green and sustainable chemistry, with consideration of UNEP's 10 Objectives and Guiding Considerations, can be applied to the buildings and construction sector to **address negative impacts on human health and the environment**, **and other key global sustainability challenges**. Safer design of chemicals and their manufacturing processes, alongside better chemical management, data provision and education of workers and end users can reduce the amount of chemicals entering ecosystems and their impacts on health.
- **Decarbonisation of buildings** can be accelerated by effective use of green and sustainable chemistry. For example, through speeding up market development of biobased construction materials to reduce dependence on fossil-based ones, and advancing the use of CO_2 as a feedstock or resource.
- **Circularity and resource efficiency** can be improved through chemistry innovation that avoids contaminating material flows, enables extended and multiple material life cycles, or increases the use of post-consumer feedstocks to manufacture building materials.

Achieving 'sustainable buildings' globally therefore requires a focus on chemicals throughout the lifecycle of materials and products used in buildings and construction, through a holistic approach that also seeks to address carbon emissions and resource efficiency alongside chemical safety aspects. Impactful actions will aim to reduce the chemical impacts of existing buildings, in retrofit works, deconstruction, as well as in new construction, and in the design of new building materials.

Key functions, applications and hazards of chemicals in building products

Chemicals used in the construction sector serve various functions, often related to resisting the typical conditions buildings may be exposed to (weather, moisture, microbial growth, fire), as well as improving durability and material properties (flexibility, setting times), and providing decorative functions. Some existing design of chemicals for these applications has resulted in high persistence. In some cases, chemicals that provide the desired function effectively are later found to be highly toxic.

[5] Mordor Intelligence, 2018. https://www.mordorintelligence.com/industry-reports/construction-chemicals-market
[6] Petrochemicals Market - Transparency Market Research
[7] Plastics Europe, 2018 Report
[8] International Energy Agency, https://www.iea.org/reports/chemicals

Chemical/Group	Application	Hazards[9]
Some Flame retardants	Plastic roofing materials, wood boards, expanded polystyrene panels, glue, sealants	Neurotoxicity, potential endocrine disruptor, liver impairments, and indication of immune modulating effects. Bioaccumulation and persistence in the environment.
Certain Phthalates	Plasticiser in PVC flooring and wall coverings, adhesives, sealants and varnishes	Toxicity for reproduction and potential for endocrine disruption
Certain solvents, formaldehyde and other VOCs	Paints, varnishes, adhesives, engineered wood products	Carcinogenic and reprotoxic effects, neurotoxic effects
PFAS	Wood boards, paint, damp proofing, insulation	Indications of liver effects, developmental effects, potential for endocrine modulating effects, and indication for effects on the immune system. Bioaccumulation and high persistence in the environment.
Heavy metals	Stabilisers, pigments, anti-corrosion agents	Human health concerns related to carcinogenicity, mutagenicity, toxicity to reproduction and other systemic toxicity effects
Asbestos	Insulation spray coating and boards, cement profiled sheets, bitumen products, flooring	Concerns for human health related to asbestosis, mesothelioma and lung cancer
Certain nonylphenol and octylphenol ethoxylates	Paints, varnishes, adhesives, sealants, putties	Concerns for the environment due to potential for endocrine disruption

Table 1 - Chemicals of concern in Building Products: illustration of applications and potential hazards

Innovation for chemical-intensive product categories

Depending on their use, different building materials inherently have different profiles in terms of their chemical composition, and potential for release. Some are relatively inert when installed (e.g. concrete and ceramic tile), but have higher risks of harm in production and at the end of life. Other materials have a much more chemical-intensive formulation resulting in risks at multiple life cycle stages of the material and the building they are installed in. Three examples are described below.

[9] Adapted from Chemicals of Concern in the Building and Construction Sector, UNEP

- **Carpet** is a globally used material that may contain as many as 44 hazardous substances[10]. Examples of hazardous substances in carpets include stain repellents, antimicrobial preservatives, flame retardants, as well as heavy metals. Acute and chronic hazards exist throughout the life cycle during production, use, and at end-of-life. Furthermore, the presence of hazardous chemicals in carpets, and other chemical intensive building materials, reduces the potential for material recovery and recycling.
- **Paints** have a high chemical intensity, and as a result, varied potential hazards. Chemicals such as alkylphenol ethoxylates and PFAS providing anti-microbial and binding functions, have associated hazards as detailed in Table 1. While **there is no known level of lead exposure that is considered safe for adults or children,** only 43% of countries have adopted lead paint laws[11]. Additional impacts come from microplastic release (paints are estimated to be the largest source of microplastic leakage at 1.9 Mt/year)[12], and the embodied carbon burden of fossil-based feedstock consumed by the sector.
- **Treated lumber products** are a similarly chemical intensive product that share some of the chemical concerns of paints. Chemicals used provide various waterproofing and pesticidal functions. Concerns have been raised on the effects of preservative compounds such as pentachlorophenol[13] and chromated copper arsenate (CCA) [14], which are phased out or restricted in some regions, but not all.

Using green and sustainable chemistry to address the impacts of building materials with high chemical intensity requires a full life cycle approach. Rather than only considering an approach of chemical-to-chemical substitution, a full **life cycle approach** helps to identify and address the greatest impacts and ensure a truly sustainable building and construction material is chosen. This full life cycle approach would consider the different trade-offs at the levels of chemicals, materials and the buildings, while minimising adverse effects to human health and the environment.

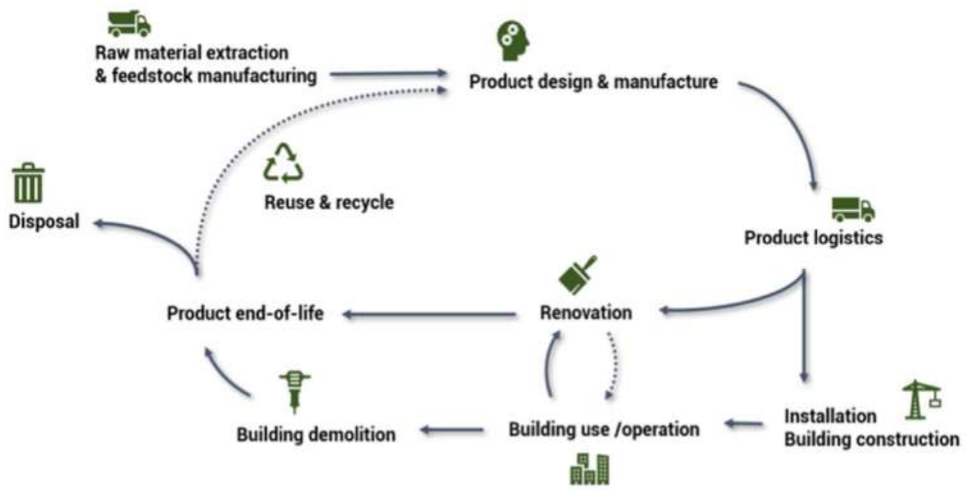

Figure 1: Life cycle of a building product from the UNEP report Chemicals of Concern in the Building and Construction Sector

For example, chemical use that increases lifetime and durability of a building material can address resource use and subsequent chemical production hotspots, which may provide an overall greater sustainability benefit than using a less chemically intensive formulation that results in a shorter material lifetime. However, decreasing the toxicity of building products is still critical, given that the intended application and performance can still be provided. Considering the application and location in which the material is used is also essential when making

[10] Healthy Building Network (2017) Eliminating Toxics in Carpet: Lessons for the Future of Recycling.
[11] 2021 Update on the Global Status of Legal Limits on Lead in Paint
[12] Plastic Paints the Environment, EA, 2021
[13] Decision Guidance Documents. Pentachlorophenol and its salts and esters. United Nations Environment Programme, Food and Agriculture Organisation of the United Nations. Available from http://www.pic.int/Portals/5/DGDs/DGD_Pentachlorophenol_EN.pdf
[14] Chromated copper arsenate timber: A review of products, leachate studies and recycling. Mohajerani, Vajna and Ellcock, 2018. Available from https://www.sciencedirect.com/science/article/abs/pii/S0959652618301306?via%3Dihub

decisions on chemical use in building products. For example, the need to use preservative chemicals within wood may depend strongly on whether the product is installed in a wet or dry environment.

Further guidance on applying green and sustainable chemistry within the buildings and construction sector, through UNEP's Objectives, is provided later in this document.

C. The building and construction value chain, and the chemicals value chains.

A visualization of how the buildings and construction value chain, and the chemical value chain interact is displayed in Figure 2. Opportunities for the uptake of green and sustainable chemistry innovations and action exist at various points and interfaces of the two value chains, as well as at certain decision-making stages of the project inception, contracting, procurement and management phases of building projects. Whilst some collaboration at the interfaces of the two value chains has been reported – for example, the Global GreenChem and Innovation and Network Program seeks to connect practitioners of green chemistry with the engineering sector - there is potential for much more, both for deploying technical solutions, as well as designing policy instruments.

The pace at which the two value chains operate is also a key consideration for seeking greater alignment. The construction and civil engineering sectors often work at a fast pace to deliver projects and reduce cost, leaving limited time to amend design specifications or consider alternative materials. By contrast, the chemicals industry operates in a more regulated environment with a potentially slower pace of R&D and product validation, due to the need to ensure chemical hazards are mitigated and performance is effective. As a result, there may be barriers to trialling and using more innovative and chemically-safer materials, if the availability of these materials is not aligned with key stages of a construction project

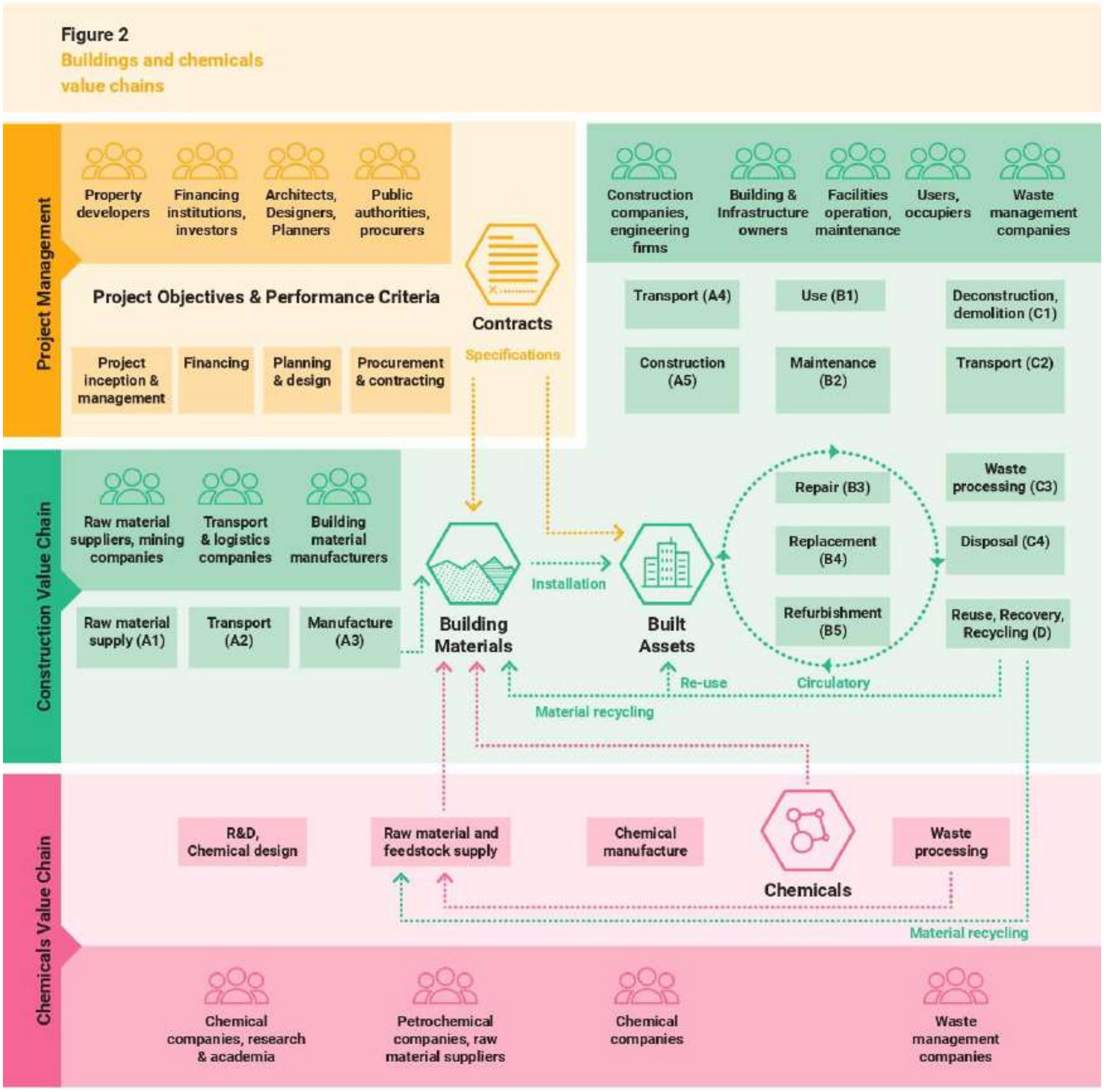

Figure 2 - The buildings and construction value chain and the chemicals value chain. Whilst it is acknowledged that a range of chemicals are widely used during the life cycle of buildings, this figure focuses on the use of chemicals in building materials specifically

D. Key stakeholders to enable the development and implementation of green and sustainable chemistry innovations for the buildings and construction sector

Various stakeholders (figure 2), as profiled in UNEP's Green and Sustainable Chemistry Framework Manual (See page 5-7, Figure 3.2 on page 30) and in UNEP's Practical Guidance for Strategic Action to Advance Green and Sustainable Chemistry, have the opportunity to initiate, demonstrate and scale up green and sustainable chemistry innovation for application in the buildings and construction sector. Actions and considerations for these stakeholders to address chemical impacts are outlined below. Actions considered to be of higher priority, from the outputs of the workshop, are explored in the 'key recommendations' section.

Impactful actions which improve sustainability performance in the built environment will often include contributions from a range of stakeholders. However, **the level of collaboration across the buildings and construction and chemicals value chains was considered by workshop participants to be insufficient.**

The chemical industry is a primary stakeholder with various opportunities:

- Developing chemicals, solvents and manufacturing processes that align with UNEP's Objectives for use in the design and production of building products. This may involve, at an early stage, further interaction between chemists and toxicologists.
- Setting business strategies to phase out high-impact chemicals and processes. For example, Lanxess and Ecolab have made a recent commitment to not develop or market any new products that contain substances of very high concern (SVHC)[15]. Attempting to stay ahead of legislation may also enable a first mover advantage.
- R&D activities which integrate green and sustainable chemistry objectives either in-house or in collaboration with the research and academia community. Assessing the return on investment of such activities can help sell the value of increased R&D internally.

Building material manufacturers can influence change through better procurement and sourcing, as well as through effective collaboration with chemical companies, guided by green and sustainable chemistry objectives.

- Green and/or sustainable procurement policies can include healthier and lower-impact chemical ingredients and materials in their specifications to suppliers. This can be supported by effective chemical inventory and substitution processes, using lists of regulated chemicals (such as the Cradle to Cradle Red List, or the California Prop 65 list), screening tools (such as GreenScreen - both free and paid-for services are available) and substitute and alternative assessment tools (e.g. ChemSec Marketplace, SciveraLENS).
- Embed UNEP's Green and Sustainable Chemistry Objectives and Guiding Considerations into innovation programs for process and product design. Resulting innovations could further the use of sustainable bio-based feedstocks, or enable recovery and re-use of building materials, reducing the need for virgin material extraction. Products that incorporate recycled materials can also reduce this burden, although risks related to contamination of recycled feedstock must be taken into account.

Raw material suppliers and mining companies can incorporate green and sustainable chemistry into their operations:

- Material extraction can have significant environmental, health and social impacts. Improved management, control and formulation of bio- and acid-leaching agents and other chemicals in extraction processes are important to reduce chemical impacts at this stage of the value chain.

[15] A substance of very high concern (SVHC) is a chemical substance with hazardous properties as defined under the REACH system for controlling chemicals in the EU. SVHCs may be placed on one or both of the 'Candidate List' and 'Authorisation List'. If a substance is added to REACH authorization list, it cannot be placed on the EU market or used after a given date, unless an authorization is granted for their specific use, or exempted.

Architects, designers, planners and engineers can play a key role in advancing green and sustainable chemistry objectives, through material specifications, as well as building design aspects.

- Specifying building design for dismantling, and enabling material reuse and chemical recycling can contribute to more sustainable feedstock sourcing and circular product design.
- Specifying products made through green and sustainable chemistry processes. This may include core materials such as wallboard, flooring and insulation, as well as products such as formaldehyde-free adhesives. Architects can also educate and raise awareness, as seen through the work of the Healthy Materials Lab.

Construction companies (builders, contractors) can influence the extent to which a building project deploys green and sustainable chemistry solutions. This may depend on the nature of the contract, for example, design-build, lump-sum and incentive-based contracts have varying potential to deploy best practice solutions. Contract types vary in the degree to which cost is a driver, and in their potential to deviate from the initial design specification.

- Firms can develop in-house knowledge of how to use greener building materials, which may require upskilling. For example, Rome Plastering Services developed their skills in using Breathaplasta, a chemically safer and healthier alternative to standard gypsum board.
- Contractors can develop and share accessible databases of preferred and 'red listed' materials with subcontractors who may be required to source them.

Property developers (real estate companies) can set procurement criteria that specifies green and sustainable chemistry aspects of building materials, which may be part of achieving a building ratings score. Additionally, if they are responsible for maintenance or retrofit, they are in a key position to address impacts of toxic legacy materials, and specify more sustainable solutions.

Financing institutions can incentivise best practice by setting criteria for funding, e.g. green mortgage financing aligned with green building rating schemes. To increase market scale for new innovative products, interventions could include bulk purchasing programmes or awards programmes and competitions.

- Green financial instruments can integrate UNEP's Objectives into the criteria of the instrument to fund the development of chemistry innovations that result in more sustainable building materials. BASF's green bond program gave investors the chance to invest in solutions that support a stable economy, including innovations for more sustainable building materials.

Public authorities, at the local, regional and national level can accelerate green and sustainable chemistry strategies for the building and construction sector through policymaking, helping to drive demand for chemically safer and more circular materials through incentives, procurement criteria and regulation.

- Setting green public procurement criteria on chemicals in building materials for procurers, and requiring evidence for compliance. The city of Tshwane in South Africa committed to apply national standards on sustainability for all new and refurbished municipal buildings and adopted a local bylaw to supplement the standards with requirements on waste management of building materials. The Tshwane city headquarters was built according to the city's sustainable public procurement guidelines and uses paint, adhesives, sealants and carpets with low or no VOCs. The European Commission's report on green public procurement for office building construction includes criteria which could drive demand for green and sustainable chemistry building products.
- Legislating for emissions limits from products, and required circularity processes on construction sites.
- Legislating for more stringent penalties for greenwashing or opaque sustainability claims (e.g., regarding a chemical substitution that does not reduce environmental or health impact).
- Developing policies and incentives to stimulate market demand, phase out harmful substances, encourage recycling and deconstruction, or drive innovation to specifically advance green and sustainable chemistry innovation for the buildings and construction sector. Examples seen include the California Carpet Stewardship Program, or various bills passed in the USA to prohibit use of toxic flame

retardants, including California's amendment to its building code that will allow the use of flame retardant-free foam building insulation in certain applications.

- Developing **roadmaps** and **longer-term policies** in relation to increasing affordability of green and sustainable chemistry solutions within building materials. This can help to outline clear policies for the market and promote transparent dialogue with industry. Appropriate phase-out plans may be included in these processes.

NGOs and civil society organisations can support the market for products incorporating green and sustainable chemistry:

- Championing best practices, providing practical advice, raising awareness of chemical hazards, and pushing the policy agenda. E.g., the work done by CHEM Trust on awareness raising of endocrine disrupting chemicals.
- Facilitating partnerships between the private and public sector and the research community to drive forward more sustainable solutions.
- Enabling market supporting solutions – for example in improving data provision. Civil society organisations may contribute to development of assessment tools, material passports and product information standards, e.g. the voluntary disclosure programme Global Minimum Transparency Standard.

The **research & academia** community, and **innovation hubs** providing funding, are a vital stakeholder, facilitator and collaborator in furthering green and sustainable chemistry technologies, data and methodologies on chemical use and exposure, and knowledge on product life cycles. Expert university centres such as Yale, York, and Technical University of Denmark (DTU) are accelerating solutions in this area. Interventions may include:

- Developing and validating new green and sustainable chemistry innovations. These can later be scaled up with the support of industry and funders.
- Universities can develop and disseminate tools to better understand the impacts of building materials, and to support the selection of alternatives. DTU hosts the global scientific consensus model USEtox to assess chemicals in building materials with a full life cycle perspective.
- Universities can lead trainings on green and sustainable chemistry. Building designers and architects are a key target group for the University of Washington's Green Chemistry and Chemical Stewardship Certificate Program , a course to give graduates tools to design safer chemicals and industrial processes.
- Training a new generation of chemists to apply green and sustainable chemistry as professionals is a key function of universities globally. In Nigeria, First Technical University and Bingham University have both signed Beyond Benign's Green Chemistry Commitment and now include green and sustainable chemistry concepts in independent courses, research and seminars.
- Universities can educate non-chemistry students (architecture, business, finance) on green and sustainable chemistry innovation, and its potential within the buildings and construction sector. In a green chemistry course at the University of Oregon (USA), business and architecture students took on the challenge of removing PVC from different product groups.

Certification and approval bodies and test houses can provide assurance to increase consumer confidence and market demand for products using green and sustainable chemistry, as well as potentially increased investment. The private sector has a responsibility to help fund the operation of testing facilities.

- Bringing innovative products to market requires significant time, and testing of the product. Testing and approvals processes may require new or updated standards and test methods. In Kenya, it is reported that the national Bureau of Standards uses ASTM and European Standards Specification to monitor the quality of gypsum products, among concerns that imported synthetic gypsum products may contain toxic substances.
- The Mahindra-TERI Centre of Excellence for Sustainable Habitat, a lab for material developers to conduct testing helps overcome the lack of data for innovative sustainable building materials. By promoting and data sharing, the lab helps to upscale the use of innovative materials, and reports on

these innovations through open public platforms to enable informed decision making by built environment professionals and citizens.

- Setting recommendations on maximum acceptable concentrations of chemicals of concern in building products can result in greater data transparency and drive the application of green and sustainable chemistry innovations to meet these limits. For example, the Cradle to Cradle products innovation institute sets limits through its Restricted Substances list, which is referenced by its Material Health Certificate Standard.

Professional associations, including **professional technical bodies and trade associations** with a remit covering both chemicals and construction (such as The Construction Alliance of South Africa, Plastics Europe, or the European Federation for Construction Chemicals) have a strong opportunity advance green and sustainable chemistry innovation along the buildings and construction value chain.

- Initiatives to support further development of green and sustainable chemistry may involve aligning whole industries such as plastics and smelting through minimum standards and championing best practices. These types of organisations may also provide funding and awards programmes for green and sustainable chemistry innovation.
- Smaller professional associations focused on one activity or product, such as The Clay Brick Association of Southern Africa, can facilitate collaboration for targeted development and application of green and sustainable chemistry innovations.

Labour organisations are key to establishing standards for work safety in relation to chemicals, enabling collective action, and advocating for improved policies that consider green and sustainable chemistry principles. In some regions with limited national institutional capacity, international bodies may provide support to advance these actions. The ILO's Framework for Action on Chemical Safety at Work recommends the implementation of labour standards for chemicals in sectors, including construction.

Waste management companies are key to driving greater circularity in the building and construction value chain, through conducting deconstruction and linking to companies who can facilitate end-of-life green and sustainable chemistry solutions. Companies involved in collecting and processing construction plastics play an important role in avoiding chemical releases from these products at end of life.

- Public-private partnerships can work to advance green and sustainable chemistry innovation through waste management. In Chile, a partnership between governments and a group of signatory companies to the clean production agreement, worked to create a company (REGEMAC) to monitor and manage construction waste[16]. REGEMAC collaborates with Chilean universities to develop innovative building products based on collected end-of-life material.
- Perks Deconstruction in the USA has championed deconstruction ahead of demolition, reducing chemical emissions from demolition and the need for new chemical production, as well as generating secondary market revenue from materials.

Users and occupiers of buildings can bring attention to the potential positive impacts on human health from the use of building materials enabled by green and sustainable chemistry innovation, and use their position to demand improved, chemically safer products from the market. Consumers or end-users are central to data transparency, and their demands to know the impacts and hazards of building materials can drive data sharing up the entire value chain. Under the Proposition 65 law in California (USA), landlords are required to notify tenants of the potential presence of certain chemicals in housing construction materials.

[16] Colorado, Muñoz, Monteiro. *Circular Economy of Construction and Demolition Waste: A Case Study of Colombia. https://doi.org/10.3390/su14127225*

E. UNEP Work on Green and Sustainable Chemistry

UNEA Resolution 4/8 on the sound management of chemicals and waste, adopted in 2019, highlights the importance of “minimizing and preventing, when feasible, the use of hazardous substances in material cycles” and “recognizes the value of developing a better understanding of sustainable chemistry opportunities”. The Resolution further requested UNEP to prepare Green and Sustainable Chemistry Manuals. Developed in consultation with experts from industry, academia, government, international organizations and NGOs, the UNEP Green and Sustainable Chemistry: Framework Manual provides a high-level overview of various scientific, technical and policy aspects of green and sustainable chemistry.

The Manual aims to **foster a vision that covers both green and sustainable chemistry innovations, while also addressing toxic and persistent legacies associated with past chemistries in order to minimize adverse impacts across the entire life cycle of chemicals and products**. Resolution 5/7, adopted in 2022, further emphasizes the cross-cutting relevance of sound management of chemicals to many of the goals and targets of the 2030 Agenda for Sustainable Development, and encourages the use of the Framework Manual.

UNEP’s Green and Sustainable Chemistry: Framework Manual, recognizes the potential of green and sustainable chemistry innovation to drive sustainability in key sectors, including buildings and construction. **“Chemistry innovation”, in this context, includes innovation in chemistry (i.e. new molecules/ chemical compounds), innovations in chemical engineering sciences (i.e. chemical processes and sustainable production), as well as in related areas (e.g. product development**). This background document builds upon the Framework Manual with key actions, strategies and examples to guide stakeholders towards enabling and applying green and sustainable chemistry within the buildings and construction sector.

At the heart of The Framework Manual are Ten Objectives and Guiding Considerations for Green and Sustainable Chemistry (UNEP’s Objectives). UNEP’s Objectives highlight the outcomes that green and sustainable chemistry seeks to achieve and may be used by stakeholders to guide innovation and chemical management actions. Ultimately UNEP’s Objectives seek to unveil the full potential of chemistry such that it supports, and is compatible with, the 2030 Sustainable Development Agenda.

The 10 objectives are shown below in Figure 3.

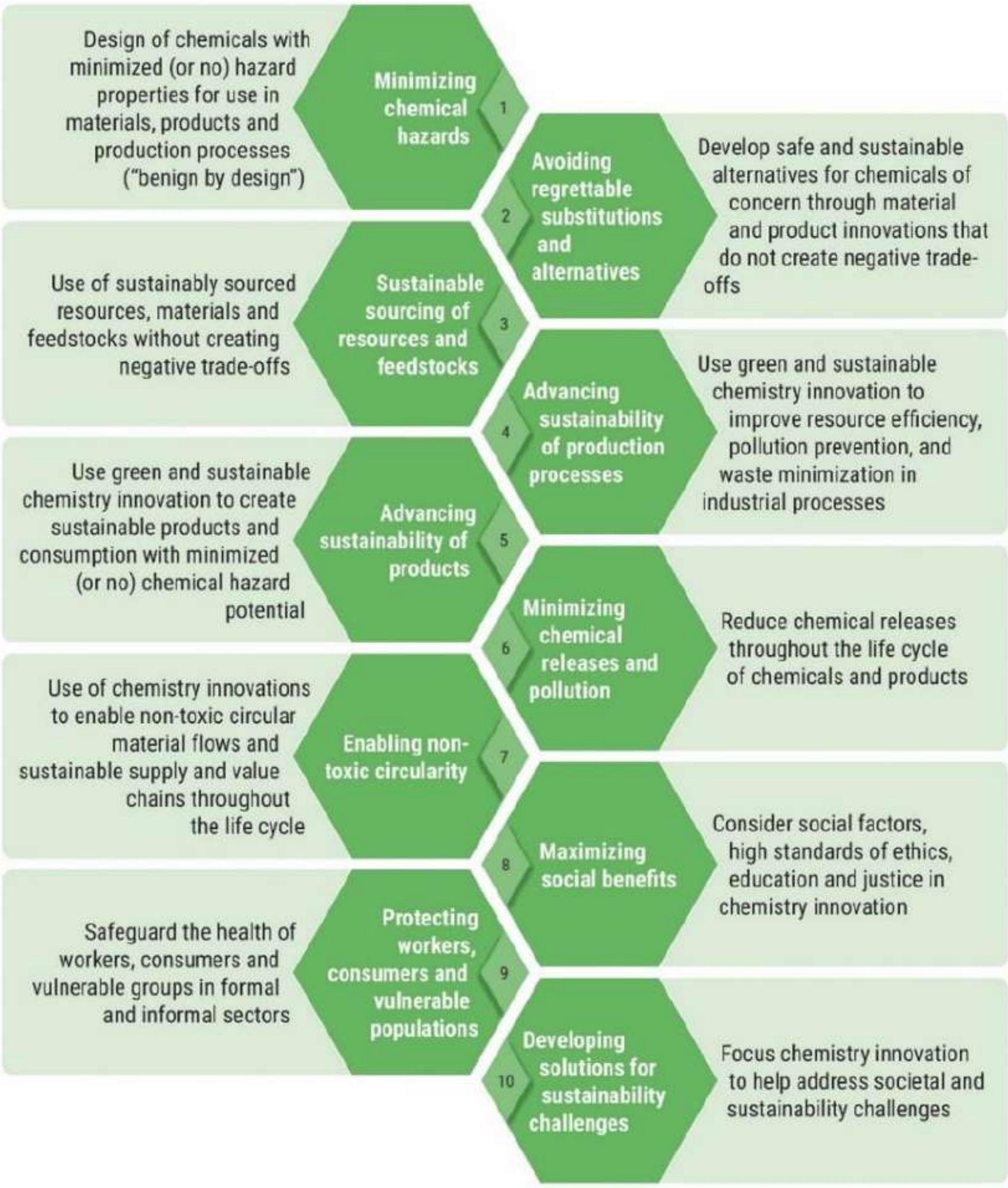

Figure 3 - UNEP's 10 Objectives for Green and Sustainable Chemistry

F. UNEP's Green and Sustainable Chemistry Objectives within the context of the buildings and construction sector.

This section provides further information on UNEP's Objectives in the context of the buildings and construction sector. For a complete description of each objective, please refer to the [Green and Sustainable Chemistry Framework Manual,]() chapter 3.

To maximise impact, and avoid burden-shifting, it is crucial that actions and innovations which aim to advance the green and sustainable chemistry solutions consider all the Objectives. As a result, the implementation and development of green and sustainable chemistry solutions, as well as the actions which seek to enable them, involve a range of stakeholders, working across multiple objectives.

UNEP's Objectives are explored further in Annex 1, with illustrations of actions relevant to the buildings and construction value chain. These include additional examples of green and sustainable chemistry innovations and enabling actions which seek to advance multiple Objectives.

Objective 1. Minimizing chemical hazards

This Objective is mainly concerned with improved design of chemicals and molecules for use in the building and construction sector. These "benign-by-design" molecules can provide functionalities to building materials with minimized hazard properties for the environment, occupants and workers. Alongside reduced toxicity, chemical design for Objective 1 aims to reduce persistence, enable degradability into non-hazardous components, and consider how chemicals pass through environmental media and are absorbed by humans and wildlife.

A key consideration under this objective is that the body of scientific knowledge around some chemicals and chemical families is still not complete. Designing new chemical solutions – particularly for the buildings and construction sector where a product or material may have a long service life – requires a precautionary approach to avoid the lock-in of future problematic chemical formulations.

Biomimicry is a useful approach to develop nature-inspired molecules which provide key functionalities to building products. Researchers at Columbia Forest Products used the blue mussel's ability to adhere to a range of difficult surfaces as a blueprint during the development of PureBond®, a high-performance wood adhesive. PureBond® uses modified soy proteins that mimic the properties of marine adhesive proteins used by the mussels to stick to irregular surfaces underwater. Incorporating the innovative benign-by-design molecule results in an alternative to typical fossil-based wood adhesive resins that contain formaldehyde, avoiding the associated health impacts for workers and consumers.

Objective 2. Avoiding regrettable substitutions and alternatives

Chemical substitutions or alternative materials can in some cases result in a building material or product with similar or worse hazard properties. In other cases, substitution may create negative trade-offs at other life cycle stages, or the effects of the substitutes or alternatives are not known.

This objective is relevant for building material and product designers, and chemists feeding into the sector. The benchmark is to design and introduce substitutes and alternatives that do not cause negative impacts or shift the burden to other sustainable development objectives such as climate change or biodiversity.

In the building and construction sector, this typically means the design of chemicals that perform certain key functions (e.g. preservatives, repellents, flame retardants, waterproofing) and are safer with reduced impact over their life cycle. The design of alternative materials may also take a non-chemical approach to performing a function (e.g., building materials that are naturally flame retardant can remove the need for chemical flame retardants).

Fully achieving the objective is enabled through the engagement of multidisciplinary teams, involving building material manufacturers, regulators and health and safety experts. Assessing and selecting chemicals by family (e.g. PFAS as a chemical family), rather than individual substances is recommended (as per the Green Science Policy Institute's Six Classes approach) as regulation is typically not able to keep pace with new substance development. It is estimated that the number of chemicals in global commerce is between 25,000 and 140,000[17].

[17] https://icca-chem.org/news/how-do-we-calculate-the-number-of-chemicals-in-use-around-the-globe/

Poor practice in substitution can lead to greenwashing – companies may eliminate a substance and make a "free-from" claim, but this is misleading if substitute chemicals or alternative materials are no safer, or have unknown effects. Transparency is reduced if a known hazardous chemical is substituted by a similar one that is not regulated or declared. Eco-labelling and standards can help to advance Objective 2.

A paper from Maertens et al[18] identified some common regrettable substitutions, including chemicals used in building materials. Substitution of Bisphenol A with Bisphenol S for use as a plasticiser is one common case mentioned in the paper, which does not address the concerns as an endocrine disruptor associated with the original chemical. Additionally, methylene chloride, which has been used as a solvent carrier in adhesives and a paint stripper, has been associated with carcinogenicity – substitutes such as 1-bromopropane in adhesives have also been linked to concerns of carcinogenicity and neurotoxicity and is considered regrettable by the authors' literature review. However, several examples of safer substitute chemicals for methylene chloride have been seen; the US Environmental Protection Agency identified several options for a Public Workshop on Use of Methylene Chloride in Furniture Refinishing; the ChemSec marketplace has identified several Evaluated Alternatives, such as Ecoatex.

Objective 3. Sustainable sourcing of resources and feedstocks

In the building and construction sector, this Objective is addressed by green and sustainable chemistry innovations towards increased use of lower-impact, renewable and recycled resources and feedstocks. This can reduce dependency on virgin materials.

This may include increased use of sustainably sourced bio-based input materials[19] (which may be seen in plastics and paint resins). When using post-consumer feedstocks, measures should be taken to avoid re-introducing hazardous chemicals back into the value chain (E.g. tyre waste has been trialled to produce silica aerogel composites for use in insulation, but it is essential that this does not cause chemical hazards in the new product). Robust testing of feedstocks for incentive and certification programs can help advance this Objective, without compromising health or sustainability.

Strategies and business models that use of CO_2 as a feedstock are also relevant under this objective and have great potential in the buildings and construction sector. For example, use of captured CO_2 has been demonstrated as an input material to initiate carbonate formation, which can be used in construction as cement or plasterboard.

Development of a Uponor's PEX Pipe Blue has a reduced carbon footprint of up to 90% compared to conventional fossil-based PEX piping, as a result of using post-consumer materials and carbon dioxide as a feedstock. The pipe makes use of Borealis' Bornewables feedstock, which is derived from waste from pulp production or residues from food processing oils, avoiding competition with food production.

Objective 4. Advancing sustainability of production processes

Innovations are needed from chemists, chemical and industrial engineers, and waste managers to improve resource efficiency, safety, and reduce pollution and waste in industrial processes for building materials.

[18] Avoiding Regrettable Substitutions: Green Toxicology for Sustainable Chemistry. Maertens et al, 2021. Available from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9432817/

[19] Bio-based materials must come from sustainable and traceable sources for this type of material to provide benefit and mitigate resource depletion, biodiversity impacts, land-use conflicts and other sustainability and social hotspots. Various global recommendations have been made for sustainable sourcing for bio-based products. In the EU, this requires verification under the renewable energy directive.

Longer term strategic thinking may be necessary when investing in R&D and equipment for process innovations, but cost savings may be achieved from safer processes and reduced regulatory burdens, which can speed up the return on investment.

PVC manufacture and chrome plating are common examples of high-risk processes for workers, while innovations in concrete production can have a significant impact on GHG emissions. Residues from the use of hazardous substances in production processes can result in exposure risks later in the value chain. For example, paint and spray foam insulation carry toxic exposure risks for installers.

Improved synthetic routes and catalysis, using lower operating temperatures and pressure, and use of more sustainable solvents are ways to advance sustainability of production processes. The Toxic Use Reduction Institute (USA) partners with industry to reduce hazardous chemical use in production. They worked with the SME Riverdale Mills to implement a process innovation which reduced the use of hydrochloric acid, and ammonium hydroxide during the manufacturing of wire mesh, a key product for the built environment.

Objective 5. Advancing sustainability of products

Green and sustainable chemistry approaches can advance the sustainability of finished building products and materials. Innovations can address multiple aspects of the product such as durability, energy- and material-efficiency and circularity, alongside ensuring products are non-toxic and safe.

Approaches here may employ alternative technologies and materials to advance the sustainability of the product types, but there is also a need for solutions that improve existing, conventional products and materials that will remain in use and on markets for the foreseeable future.

One approach to advancing this objective is through fundamental changes in the material used. For example, wood fibre insulation avoids some key negative impacts on human health and the environment from plastic-based insulation. Lime plaster is more naturally flame retardant than gypsum board removing the need for added flame retardant chemicals. Wilron, an adhesive manufacturing SME in Malaysia, re-designed its product portfolio from VOC- to water-based, resulting in access to new markets and healthier working conditions.

Market transformation towards more sustainable products can be supported through interventions and incentives from government to result in widespread economic and social benefits. Voluntary standards, use of green building rating schemes and innovative business models may be helpful approaches to advancing Objective 5. For example, specification of chemically safer adhesives in buildings ratings schemes have driven demand for low-VOC products. Solenis' Soyad Adhesive Systems have become highly active in this market, enabling a market leading position globally among alternative adhesives.

Objective 6. Minimizing chemical releases and pollution

Objective 6 guides the development of innovations with minimal chemical releases along the nexus value chains for both the building and construction and chemicals value chains. Innovations implemented at one stage of the value chain could minimize chemical releases at an earlier or later stage. For example, designing out a chemical of concern could eliminate releases during production, and at end-of-life.

Examples include reaction design that reduces polluting waste, designing out substances that may leach out of products in use, and recovery and recycling techniques that can reduce releases to the environment. For example, promoting the use of PFAS-free adhesives during construction, which do not compromise other relevant Objectives, eliminates problematic releases later in the value chain.

Beyond improvements from industry, advancements in chemical data management are central to this objective, for example through promoting material passports. Key data is often missing in the value chain for both chemicals and building and construction which prevents action on Objective 6. A proactive, rather than reactive approach that enables downstream companies to improve the gathering of chemical data is recommended.

Objective 7. Enabling nontoxic circularity

The presence of chemicals in building materials is often a major barrier to circularity. Green and sustainable chemistry innovations should seek to increase non-toxic material flows, extend life cycles and contribute to more sustainable supply chains. Re-use of existing materials and designing to avoid future waste generation are vital to achieve global resource efficiency objectives and, but attention to chemical content (chemistry for safe reuse) is critical. The use of construction waste, with special consideration to avoid the re-introduction of hazardous chemicals into the value chain, can also advance Objective 7.

Innovations for Objective 7 can be deployed alongside improved deconstruction and segregation techniques, and data solutions (the voluntary disclosure programme Global Minimum Transparency Standard, can improve transparency across complex global supply chains). High throughput chemical screenings of building materials, as in this study by *Huang et al* can help to identify products that impede circularity.

Composite materials are considered a major opportunity for improved circularity and application of green and sustainable chemistry, although the quality and safety of feedstock material is critical. Policies which make building materials that advance circularity more cost competitive can help to advance Objective 7.

Objective 8. Maximizing social benefits

Green and sustainable chemistry innovations that advance Objective 8 for the building and construction sector are fully compatible with broader social sustainability objectives, including, but not limited to ethics, education, and socio-economic justice. They may include, but are not limited to, innovations in building materials that enable healthier affordable or social housing.

Innovation and enabling actions can ensure social and economic benefits are fairly distributed. Potential impacts on important local industries and economies are also important to consider.

The PA Hemp Home, an initiative to use safer materials in accessible housing, used HempLime, a plant and mineral based material, that is naturally flame retardant and anti-microbial, eliminating the need for added toxic chemicals.

A paper from Asveld provides examples of how green and sustainable chemistry innovations could fail to deliver social benefits (e.g. if costs and benefits from biofuels are not fairly shared, or smaller suppliers are put at an economic disadvantage) and suggests how the original 12 principles of green chemistry could be expanded to include social considerations.

Objective 9: Protecting workers, consumers and vulnerable populations

Risks to construction workers, informal workers, vulnerable building occupants and fenceline communities are found along the buildings and construction value chain. Green and sustainable chemistry innovations which apply Objective 9 can result in safer worker conditions and healthier living environments for at-risk communities and people.

Safer techniques and routes for production of certain building materials and components, for example by avoiding the use of Cr(VI) in plating, can help protect workers in these hazardous sectors. The NGO Toxic Free Future worked with retailers to protect consumers by phasing out products that contained hazardous chemicals.

Chemical impacts from factory production of building materials, which may often be found in lower-income neighbourhoods may impact the health of local communities, and may also disproportionately affect other vulnerable groups, such as pregnant women or disabled people.

In some countries, where mandatory legislation is not yet in place (for example on lead in paints or asbestos), the general public may also be at a greater risk from detrimental chemical effects of exposure in the occupancy and end-of-life phases of buildings and materials.

Objective 10. Developing solutions for sustainability challenges

Beyond mitigating the more direct impacts of chemicals on human health and the environment, green and sustainable chemistry innovations in the buildings and construction sector can address key sustainability challenges such as climate change, material efficiency and biodiversity.

Interdisciplinary collaboration between chemists, toxicologists, marine scientists, carbon accounting experts, regional planners, and those in the social sciences is key to designing green and sustainable chemistry solutions that advance this Objective. The final Objective underlines the potential of green and sustainable chemistry innovation to advance the 2030 sustainable development agenda.

The buildings and construction sector has to date focused mainly on carbon reduction as a sustainability strategy, with a focus on this aspect in reporting frameworks. It is important that the sector also has sufficient knowledge on chemical impacts and solutions to address these issues more holistically, and that metrics, reporting frameworks, policies and incentives are geared to drive improvement across each of climate change, biodiversity and pollution, addressing the triple planetary crisis.

Green and sustainable chemistry innovations which advance the use of aerogels as superior insulation materials (see Thermulon as an example) could avoid the use of hazardous flame retardants, while also addressing the climate impact and material footprint of buildings. Green and sustainable chemistry innovations, such as new refrigerant gases, can also enable low emission, efficient building cooling systems. These are examples of how ambitious chemistry innovations can go beyond hazard reduction to cut across key sustainability challenges.

G. Key Recommendations to Advance UNEP's Objectives within the Buildings and Construction Sector.

The expert workshop resulted in several recommendations to guide and enable impactful actions which advance UNEP's Objectives within the buildings and construction sector. These recommendations are presented below to guide further action and discussion among stakeholders in the nexus buildings and construction and chemical value chain. As emphasized by workshop participants, it is critical to adapt these recommendations such that they consider local needs and conditions.

Identify priority chemicals and building materials to be targeted by green and sustainable chemistry innovation.

Resources are available to help identify key chemicals in building products and materials that may result in negative impacts on human health and the environment. The UNEP report Chemicals of Concern in the Building and Construction Sector and the GCO-II are good starting points for determining these chemicals and materials.

Identification of priority areas to deploy green and sustainable chemistry innovations can result in 'quick-wins' for certain regions. Lessons-learned from other regions which have successfully leveraged green and sustainable chemistry innovations may help to determine these priority areas. A set of questions to guide stakeholders in the identification of products, materials, processes and chemicals in the buildings and construction sector for which green and sustainable chemistry is needed and relevant may be a helpful approach.

Further study of the benefits and potential of eliminating certain chemicals can support prioritization. For example, policy analysis of potential phase-outs combined with market assessments of alternatives can help to convince stakeholders to act. in Indonesia a net benefit of USD 37.9 billion is estimated from enacting a lead paint law; in Malawi, LEEP's cost-effectiveness analysis of the benefits of interventions on lead paint estimate a net benefit of $14 per year of healthy life and $180 million saved in lost earnings.

Workshop participants suggested various priority building products and materials whose impact could be mitigated with green and sustainable chemistry innovation. A non-exhaustive list is provided below.

- **Paints and coatings** – solvent based products are typically chemically-intensive. In some regions, lead and other heavy metals remain a problem in paints. This product group has great potential for reducing toxicity, given that the market for safer paints is mature in many regions. This report by OECD examines the commercial availability and current uses of PFAS and non-PFAS alternatives in coatings and paints.
- **Treated timber** – a chemically intensive product with human health and environmental risks (for example from, chromated copper arsenate (CCA) wood coatings) which is still available in some countries. Timber is considered a key material in terms of addressing climate impacts, but the chemical hotspots of its treatment process are also a key consideration.
- **Adhesives and binders** – these are widely used products in construction, with the market size increasing. Technology and formulations are varied in the market, including some higher toxicity products, but improvements have also been seen in safer chemistry (such as further uptake of water-based and soy-based products). Well-designed adhesives and binders also have the potential to enable improved circularity by supporting further deconstruction.
- **Bio-based materials**, including green and sustainable chemistry solutions to provide biomimicry applications, have been identified as a key area for decarbonising and improving circularity of buildings[20].
- **Concrete**, due to the sheer volume in use globally and its significant contribution to global carbon emissions could benefit from green and sustainable chemistry solutions such as in admixtures, providing benefits such as increased setting times, durability and reducing the amount needed. A fairly large number of 'green' concretes are now available, with some incorporating recycled materials (fly ash, plastics, etc) – however it is necessary to ensure that these substances are not creating unintended consequences.

[20] Biomaterials Supporting the Transition to a Circular Built Environment in the Global South – Yale CEA, UNEP

- **Plastics –** use of plastics in the built environment can have benefits where the material has a long lifetime and durability, however in practice, issues are often seen from release of chemical additives, microplastics, contamination of recycled feedstock, and fossil fuel consumption. However, solutions that can use plastic waste as an input material can be an effective use of green chemistry, as is the development of bio-based feedstock for plastic.
- **Glass** is a widely used construction material and feedback from the workshop suggests there are some opportunities to address direct CO_2 release from the use of sodium carbonate in glass, as well as increasing the recycled content (around 70% is currently achievable). The glass market appears to have fewer, larger producers and as a result the uptake of green and sustainable chemistry solutions may be more centralised for this sector.

Projects addressing some of the above materials include:

- A study on development of a sustainable polymer and paint/wood coating system, able to be produced from bio-based ingredients using benign synthetic routes[21]
- A study on debondable adhesives and their use in recycling[22]
- Research areas explored by Yale CEA on bio-based materials.
- CO_2 pre-treatment and use of industry wastes to improve CO_2 sinking by aerated concrete[23]
- ISC3's workstream on plastics in construction develops region-specific solutions based on climate, available raw materials and other local conditions.
- The OECD publication on A Chemicals Perspective on Designing with Sustainable Plastics provides an integrated approach to sustainable plastic selection from a chemicals perspective, and identifies a set of generalisable sustainable design goals, life cycle considerations and trade-offs. This general guidance is complemented by two case studies on insulation and flooring

Identify and customize policy interventions and market instruments to drive the integration of green and sustainable chemistry innovations into the buildings and construction sector.

Building on the actions identified for 'public authorities' in the 'key stakeholders' section, the workshop outlined mechanisms by which policymakers can accelerate favourable market dynamics for green and sustainable chemistry solutions. Policy instruments which are tailored to local needs and characteristics will result in improved impact. Section 5.2 (Page 56) of the Framework Manual describes some of these policy instruments.

- **Public procurement.** This instrument can be effective when providing clear definitions and processes, and chemical considerations can be further integrated by key government stakeholders, supported by financing institutions, and regulating authorities.
- **Building codes.** These are most effective when processes included in codes are clearly defined, and quality impact evaluation is done. Chemical aspects should be holistically integrated with climate and energy specifications. Codes that incentivise exemplar performance alongside minimum standards (e.g. through ratings schemes or labels) can enable greater ambition.
- **Market pull factors.** These stimulate market demand by seeking to reward materials. They can be linked to financial incentives, labelling schemes that champion best practice (e.g. in EPDs or HPDs) or prizes.
- **Market push factors.** Implementing mandatory regulation related to chemicals, which has already been seen in many pieces of legislation that seek to phase out a harmful chemical, alongside effective market surveillance. This can be supported by other mandatory requirements, e.g. to provide safety data sheets, where this is not yet in place. Other more practical 'push' mechanisms can drive innovation, for example in Switzerland, where reducing the space for landfill has driven higher recycling rates.
- **Financing.** Incentive-based schemes could be applied to drive the development of green and sustainable chemistry innovations in the sector. This could result in to improved products and practices (e.g. more deconstruction), or to encourage service-based business models related to green and

[21] A sustainable polymer and coating system based on renewable raw materials, Hermens et al
[22] Debondable adhesives and their use in recycling, Mulcahy et al.
[23] CO_2 Pretreatment to Aerated Concrete with High-Volume Industry Wastes Enables a Sustainable Precast Concrete Industry, Yan et al.

sustainable chemistry (e.g. chemical leasing). Building finance frameworks can include chemical specific considerations, such as is outlined in the UNEPFI report on green mortgage development in Sri Lanka.

Take action to improve the transparency, traceability, generation and sharing of data across the chemicals and buildings and construction value chains.

Improved provision and flow of data on chemicals is central to enabling impactful green and sustainable chemistry innovation. Increased access to data that spans the entire building life cycle is needed on chemical aspects alongside carbon, circularity and raw-material sourcing. Government led centralized data sharing networks such as the Materials Genome Initiative (USA), could be entry points for generating and sharing chemical data for building materials. In China, 18 universities contribute to generation and sharing of data for the centralized Materials Scientific Data Sharing Network with construction materials included as a key material data category.

The issue of low data accessibility and supplier transparency in the chemicals value chain is well known and remains a challenge in the buildings and construction sector. One key data gap emphasized by stakeholders is that which concerns the fate of building products at the end-of-life stage such as recycling and chemical releases during incineration.

Development of standardised product information formats, which may be associated with material passports, could improve data flow and accessibility. Material passports have been a useful tool for over 20 years, and systems to deploy these are continuing to develop, but without any mandatory requirement currently. Whilst proprietary information on innovations and chemical formulations may require some protection in the market, as a general principle, the Dubai Declaration 2006 states that information on chemicals that pose a risk to human health and the environment should be provided. Legislation may be headed in this direction – e.g. the upcoming EU Sustainable Products Initiative is expected to place an emphasis on full transparency of chemical data. Data sharing solutions that protect trade secrets, such as encrypted databases, chemical content ranges and strengthened intellectual property protection, could respond to hesitations from suppliers.

Lessons can be learnt from initiatives such as the EU's mandatory EPREL database for reporting information on energy efficiency data for products. The Global Minimum Transparency Standard is an active project in this area, providing a tool for chemical disclosure, with equal access for all global stakeholders, both within and outside the value chain.

Support could be provided to companies that are front runners in data solutions which enable green and sustainable chemistry solutions – e.g. GreenSoft Technology Inc. provides a platform for Full Material Declaration (FMD) to validate compliance. Data solutions could come from select leading companies, or from industry collaboration. Financial support and policy incentives may be needed to bring data solutions to market at an appropriate timescale.

Developing a culture in the sector around transparency can complement better data provision. This may involve trade associations bringing product sectors together, as well as finding mechanisms where increased disclosure practices are incentivized. Stakeholders have pointed to the potential of front-runner companies to "break the dam" on data sharing.

New business models and collaborative approaches can accelerate the development of green and sustainable chemistry innovations for the buildings and construction sector.

Improved market conditions are needed to accelerate innovations. Alongside policy support, interventions are likely needed at multiple points in the value chain and from a range of stakeholders. Increased industry collaboration may speed up development and scaling of new technologies (such as improved synthetic routes, innovative materials and industrial processes). Section 6.3 (page 69) of the Framework Manual outlines how stakeholders can contribute to collaborative efforts to develop green and sustainable chemistry innovation.

Financing organisations are key to improving affordability of new innovations and scaling markets. Further inclusion of chemicals aspects in building ratings schemes (LEED, BREEAM, CASBEE, EDGE), which have already been a strong driver of decarbonising buildings, could improve public procurement and accelerate market transformation, as well as green mortgage products that specify green and sustainable chemistry materials. This could be extended to other product certifications, EPDs and HPDs, and methodologies for mass balance credit and life cycle analysis to increase recognition and funding eligibility for green and sustainable chemistry innovations.

Patents could also be leveraged as an instrument to incentive solutions– this could be in the form of a longer protection period, or appropriate compensation for technologies with a business case for wider rollout.

Consider the full building life cycle through a systems-thinking lens when developing and implementing green and sustainable chemistry solutions.

Green and sustainable chemistry innovations will provide maximum benefits to stakeholders when considering not just the product life cycle, but the entire building life cycle, which is often at least 50 years. This may include multiple retrofit cycles. Companies who originally manufactured and installed products may not even exist at the end of this period.

To integrate the entire building life cycle, solutions will require effective collaboration between the numerous actors spanning the value chain, and further regulation (e.g. on requiring extended producer responsibilities or data provision) may be needed to ensure a level playing field in the market. Further use of life cycle assessment is recommended to ensure that the point where chemical hotspots of building materials are encountered is correctly identified as part of the building life cycle.

Beyond the building level, actions and interventions that employ systems-thinking make a greater impact towards advancing UNEP's Objectives. Solutions that integrate systems-thinking will contribute to improvements at the bigger picture level of urban planning, building codes, land use policy, and biodiversity and climate adaptation strategies, as well as considering economic factors for a region or industry. This requires interaction between actors working on technological solutions (who may sit in either the chemicals or building materials value chain) with public authorities.

Develop and integrate assessment methodologies and indicators to measure impact and uptake of green and sustainable chemistry innovation in the buildings and construction sector.

A clear set of assessment methodologies are needed to measure the effect of green and sustainable chemistry solutions and enable impactful, targeted actions. Consistency and harmonisation of methodologies is needed to ensure a level playing field for industry, alongside development of indicators, with sufficient clarity to enable effective and engaging communication on the impact of solutions.

Further integration of green and sustainable chemistry indicators in existing green building ratings schemes was raised by workshop participants as an effective strategy that would enable a more holistic approach, whilst also addressing embodied carbon and resource efficiency. Efforts to further the use and accessibility of LCA to support green and sustainable chemistry solutions, with more attention paid to the relevant indicators in LCA (e.g. human toxicity, acidification) was suggested by workshop participants as well. Chapter 7 of the Framework Manual describes metrics and reporting frameworks that can be used to measure the impact of green and sustainable chemistry innovation.

Mainstream product stewardship solutions

Further enabling of product stewardship and take-back by manufacturers can provide benefits by closing material loops, improving tracking and management of chemicals in products, and supporting implementation of material data solutions. Actions in this area have already been seen in the form of extended producer responsibility, take-back schemes and product-as-a-service models. These approaches can also improve learnings about the properties of products and contained chemicals in situ, as taken-back products can be analysed at the end of life, giving a better understanding of their life cycle to determine potential green and sustainable chemistry solutions to be implemented.

The RessProKa project trialled a product-as-a-service business model for interior walls and flooring. Under this project, manufacturers assumed ownership over the full product life cycle and are responsible for return, remanufacture or recycling after use, instead of the conventional "build, sell, forget" process. Interface, a carpet company in the United States, offers take-back programs for certain carpet products to be recycled or repurposed.

Scale-up capacity building, collaboration and education to advance green and sustainable chemistry innovation in the buildings and construction sector

The level of interaction between the chemical industry and buildings and construction sectors was considered to be low by workshop attendees. It is important to identify the stakeholders with the most potential to advance green and sustainable chemistry innovation in the value chain, and assess where knowledge is missing amongst these key groups. Civil engineers and builders, architects and procurers can have great influence on the use of chemically safer building materials and products.

- Capacity building can increase partnerships to **support and communicate innovation**, as is seen through the work of the Mahindra-TERI Centre of Excellence for Sustainable Habitat in India.
- Other initiatives include the GreenChem Innovation and Network Program which **brings together stakeholders** across the chemical and engineering value chains to accelerate innovation and tackle existing problems at scale.
- ISC3's workstream on Sustainable Building and Living with a Focus on Plastics provides on the **ground training and support** to development of building codes, as seen through the work done with the Kenyan National Construction Agency.
- Other capacity building activities can increase the **use of tools** enabling chemical safety assessments. For example, use of the USEtox model has enabled assessment of the toxicity risk in a specific use case, and has been used to support the paint industry in Sri Lanka in moving towards low-VOC paints.
- **Eco-labelling schemes** are another instrument for communicating best practice in chemical use and innovation. There is scope to expand some schemes to further include chemicals, but it is imperative that schemes are rigorous and trusted. Eco-labels that are familiar to consumers can be extended to include building products to increase the awareness of the end-user.
- **Voluntary standards and labels** can be valuable drivers of improvement and useful communication tools if sufficiently robust and ambitious. However, in some cases, mandatory standards are a more effective instrument to transform markets and phase out chemicals of concern. Schemes should address impacts over the full life cycle of building products and materials – including assessment of production processes as well as the finished product, chemical safety of ingredients, intermediates and monomers as well as final polymers; and consideration of circularity potential.

Capacity building and educational interventions are particularly important in regions with greater vulnerability to chemical impacts, such as those with reduced infrastructure for medical treatment, and institutional capacity for legislation and education initiatives on chemicals of concern.

Consider the impact of green and sustainable chemistry actions on biodiversity, alongside human and environmental health, carbon and circularity.

Factors related to biodiversity are important to consider when deploying green and sustainable chemistry solutions for the buildings and construction sector. For example, timber and other bio-based materials are expected to be key technologies in the shift away from non-renewable materials, but impact on biodiversity of increased uptake of new materials, or increasing demand for existing ones, must be carefully monitored.

Further data and assessment of the impacts of chemicals, materials and construction life cycle processes (e.g. material extraction and demolition have a range of chemical impacts from leaching in mining, or use of chemicals in building demolition) on biodiversity – both existing and new – may be needed to ensure their use does not have unintended consequences.

Again, a systems thinking approach in which green and sustainable chemistry solutions considers the geography where they are deployed in and its specific biodiversity (e.g. around land-use strategies, urban agriculture and forestry) is key. There may also be an issue with a lack of responsibility for impacts on biodiversity, as this is often difficult to quantify and attribute – the roles of material extractors and building developers and owners in mitigating chemical risks and compensating for impacts may need to be further defined.

Annex 1 – Illustrative examples of products and practices using UNEP 10's Objectives and Guiding Considerations of Green and Sustainable Chemistry

For illustrative purposes, examples of products and other solutions in the buildings and construction sector that advance the Objectives – in some cases multiple Objectives – are provided. The examples are presented using the structure of the Framework Manual, describing "what" the innovation achieves and "how" it was enabled. Reviewing all of the Objectives during the development of innovation can ensure a proposed solution does not result in unintended negative impacts or trade-offs. Effects over the full building and product/material life cycle is key to ensuring that the innovations do not negatively impact any Objectives.

Soybean-based adhesives

<table>
<tr><td colspan="2">Example</td><td>PureBond – no-added formaldehyde, soybean-based adhesive used in wood board</td></tr>
<tr><td colspan="2">Description – "the what"</td><td>Soy-based adhesives are a proven and scalable adhesive solution to conventional urea-formaldehyde (UF) based adhesives.

The innovation was initially developed by Oregon State University scientist Dr. Kaichang Li, who researched how mussels hold on to ocean rocks tightly, essentially using an underwater 'glue'. This application of biomimicry led to further knowledge of the mussel amino acid 3,4-dihydroxyphenylalanine (DOPA) – Dr. Li's work identified that soybean protein is an abundant resource that can be modified to provide similar performance to marine adhesive proteins.</td></tr>
<tr><td colspan="2">Route to market – "the how"</td><td>Collaboration with Columbia Forest Products and Hercules Inc. enabled funding for R&D efforts to bring the PureBond adhesive to market.

Market demand for wood board adhesives that meet formaldehyde limits is increasing. Purebond panels achieve LEED credits by meeting emissions classifications within the California Air Resources Board (CARB) standard.</td></tr>
<tr><th colspan="3">Applying UNEP's 10 objectives and guiding considerations for green and sustainable chemistry</th></tr>
<tr><th colspan="2">Objective</th><th>Results of applying the Objective</th></tr>
<tr><td>1</td><td>Minimizing chemical hazards</td><td>Providing an alternative to urea-formaldehyde based adhesives, the product avoids a range of chemical hazards that may be encountered at the production, installation and in-use phase. Formaldehyde is classified as a known human carcinogen by the National Toxicology Program and according to the U.S. Environmental Protection Agency (EPA), the compound also causes respiratory problems and eye, nose and throat irritation.</td></tr>
<tr><td>2</td><td>Avoiding regrettable substitutions and alternatives</td><td>No-added formaldehyde (NAF) soy-based binders avoid the use of methylene diisocyanate (MDI) resins, a regrettable substitution for UF resins</td></tr>
<tr><td>3</td><td>Sustainable sourcing of resources and feedstocks</td><td>Soy meal-based protein is an abundant resource, with a low amount used for human food consumption, and avoids the use of fossil-fuel based feedstocks used in UF resins.</td></tr>
<tr><td>5</td><td>Advancing sustainability of products</td><td>Demonstration of this safer and more sustainable adhesive technology has begun to drive a shift in the adhesives market. Demand is growing for bio-based adhesives that help wood board manufacturers comply with formaldehyde regulations, and the technology is seeing industry acceptance due to its performance. Other companies such as Solenis have reported that over 150 million hardwood plywood panels have now been produced globally with their Soyad adhesive product.</td></tr>
<tr><td>6</td><td>Minimize chemical release and pollution</td><td>The adhesive formulation results in vastly reduced releases of airbourne chemicals, and meets the most stringent standards on formaldehyde emissions.</td></tr>
</table>

7	Enabling non-toxic circularity and minimizing waste	Soybean-based adhesives are readily biodegradable, avoiding environmental pollution at end-of-life, and increasing recyclability of building materials.
8	Maximizing social benefits	As a cost-competitive alternative to UF-based adhesives, the product application in buildings for a wider range of incomes, delivering social benefits.
9	Protecting workers, consumers and vulnerable populations	The chemically safer formula of the adhesive removes formaldehyde-related health hazards for both workers and building occupants.
10	Developing solutions for sustainability challenges	The adhesive technology addresses a range of sustainability challenges beyond only providing a chemically safer formulation. Use enables a greater amount of wood construction, increasing uptake of a renewable material. Dependency on fossil-fuel based feedstock is reduced, as well as the carbon footprint of the product.

Biobased paint resins

Example		Decovery – bio-based paint resins
Description – "the what"		Decovery have developed innovative synthetic routes for a portfolio of paint resins based on biobased materials, with up to 52% plant content reported for some products. One such synthetic route, based on use of the itaconic acid monomer, both reduces the carbon footprint of the paint, and from the different functionality provided by use of this innovative, versatile input material provides improved chemical resistance compared with conventional, fossil-based paints.
Route to market – "the how"		Covestro have launched an exterior coating containing a Decovery bio-based resin. At present, bio-based coatings only account for a small share of the market – in 2019 this was estimated at 5% by sales value. However, the market is projected to expand – SNS Insider reported that the bio-based coatings market had a value of 11.51bn USD in 2022, and is anticipated to reach 24.15bn USD by 2030. Legislation is seen as a future driver of growth for this market, according to some industry experts, with increased consumer demand expected in some markets, in particular the European market.
Applying UNEP's 10 objectives and guiding considerations for green and sustainable chemistry		
Objective		**Results of applying the Objective**
1	Minimizing chemical hazards	The formulation of the itaconic acid-based paint eliminates the need for alkylphenol ethoxylates, biocides and tin compounds in the paint, associated with various human health hazards. Resins can be produced from bio-waste, as well as some virgin plant-based feedstock.
3	Sustainable sourcing of resources and feedstocks	Biobased monomers from abundant sources reduce dependency on fossil-based feedstocks
6	Minimize chemical release and pollution	The product demonstrates similar performance to conventional paints in relation to hardness, film stress and paint scrubbing – thus reducing releases to the environment.
9	Protecting workers, consumers and vulnerable populations	Avoided use of alkylphenol ethoxylates protects painters and building occupants from the endocrine-disrupting effects of this chemical group.
10	Developing solutions for sustainability challenges	Whilst the market for bio-based paints has not yet reached maturity, early movers are crucial to transforming the market away from conventional paints. Bio-based paints have the potential to reduce the industry's carbon footprint and improve resource efficiency, where different functionality can be provided by novel molecules, there may be further opportunities to reduce the use of hazardous substances in conventional, fossil-based paints.

Fibrewood insulation in Finland

Example		Wood-based insulation products that avoid use of halogenated flame retardants and reduce use of fossil-based insulation products
Description – "the what"		Fiberwood, a start-up wood-based insulation company, makes use of byproducts of the wood industry. Their products have both a reduced carbon footprint in production and act to capture carbon, use a non-toxic flame retardant, and as a biodegradable material, address the hotspot of disposal of plastic materials.
Route to market – "the how"		Seed funding has been raised with Metsä Group's innovation company Metsä Spring contributing, as well as Stephen Industries and Business Finland. The funds will enable Fibrewood to develop its pilot plant and progress it towards large-scale production, with products expected to be on the market for small scale pilot projects in 2024. Product certifications and testing are needed and reported as ongoing.
Applying UNEP's 10 objectives and guiding considerations for green and sustainable chemistry		
Objective		**Results of applying the Objective**
1	Minimizing chemical hazards	Hazards from fossil-based adhesives (such as those containing formaldehyde) and halogenated flame retardants (linked to neurotoxicity, endocrine disruption and environmental persistence) are avoided in the product.
3	Sustainable sourcing of resources and feedstocks	The product utilises side streams of the mechanical wood industry alongside wood pulp, a renewable material.
5	Advancing sustainability of products	The main insulation materials on the market are currently mineral wool and plastic-based insulation (EPS/XPS/PUR). However, wood-based insulation provides a credible alternative with similar thermal properties to plastic insulation, and greater breathability than mineral wool.
6	Minimize chemical release and pollution	Pollution associated with plastic insulation materials at end of life is avoided.
7	Enabling non-toxic circularity and minimizing waste	The product is fully recyclable and reduces waste from the mechanical wood industry, which are not always effectively repurposed.
10	Developing solutions for sustainability challenges	Use of this material addresses a range of sustainability challenges alongside avoided use of toxic adhesives, halogenated flame retardants and plastic – addressing building energy-efficiency challenges and increased resource efficiency.

Development of halogen-free flame retardants

Example		Development of 'green' flame retardants at Åbo Akademi University
Description – "the what"		Various developments have been seen in solutions to move away from halogenated flame retardants in both plastic insulation and wood products. Sulfenamides, based on sulphur and nitrogen bond inhibit the chemical processes that maintain the burning process. This novel substance family is being trialled by various organisations - Åbo Akademi University have carried out research in the performance of the product in polystyrene; the Finnish company Kiilto report around 20 customer projects to test sulfenamides, and envision their potential use in plastic insulation, paint, and wood based materials.
Route to market – "the how"		The technology is not yet at market - Kiilto reported that commercialisation is inhibited by high initial costs, and substance registration under REACH costs up to several thousand Euros, with different polymer variations each requiring their own registration. It is envisaged by Kiilto that large customers and orders are required to make new formulations cost effective.
Applying UNEP's 10 objectives and guiding considerations for green and sustainable chemistry		
Objective		**Results of applying the Objective**
1	Minimizing chemical hazards	Novel molecule design enables an alternative to halogenated flame retardants, both new and legacy compounds such as HBCD, which are associated with neurotoxicity issues, and are a potential endocrine disruptor.

2	Avoiding regrettable substitutions and alternatives	Use of a different chemical family avoids issues with potentially regrettable substitutions of common halogenated flame retardants by chemicals that may have similar properties and hazards, but may not be restricted by regulation.
6	Minimize chemical release and pollution	Providing an alternative to halogenated flame retardants mitigates risks to the environment from their high persistence.
7	Enabling non-toxic circularity and minimizing waste	Presence of halogenated flame retardants in polystyrene insulation has been identified as a barrier to recovery and recycling of the material, or may cause contamination in recycled materials.
8	Protecting workers, consumers and vulnerable populations	Chemically safer flame retardants remove some of the risks of halogenated compounds that may affect vulnerable populations – links have been made to health issues for pregnant women and the unborn child. Halogenated flame retardants are still found in lower-income countries in consumer products, recycled plastic and waste, included imported waste.

Annex 2 – Summary of the call for inputs

Examples were presented at the workshop of initiatives that further UNEP's Objectives, and contribute to increased use of green and sustainable chemistry approaches by a range of stakeholders.

***The summaries have been prepared by the submitters themselves and UNEP does not confirm or deny any of the claims made in the written summaries ***

Kerstin von Borries, Technical University of Denmark – Applying USEtox in the building industry for minimizing and substituting chemical impacts over entire building product life cycles

- Presented the global scientific consensus model USEtox. Its models have been applied to 10,000 chemicals in 500 products. The application context is broad and supports screening the environmental performance of chemicals in building materials along their entire life cycle, combining supply chain impacts with building use and disposal impacts. Its use can help prioritize phase-out of chemicals in the building and construction sector, and identifying viable alternatives to chemicals of concern.
- USEtox can be used for building products and materials in a use context (e.g. through the building material interface, an example was provided of formaldehyde in wood flooring)- it provides data on the potential exposure of a user (far-field environment, near-field environment, human compartments), direct human points of entry, transfer to environment, relative measurement of risks, type of risk.
- The environment that the user (e.g. operatives or occupants) is exposed to is modelled. For example this may take into account a room, and consider the ventilation. The tool can reveal trade-offs when trying to balance sustainability goals – e.g. when installing insulation improved energy efficiency may be achieved, but indoor air quality may not be improved.
- Chemicals and building products are assigned characterization factors for human toxicity and freshwater ecotoxicity to establish a toxicity profile.
- The USEtox paint interface was used in Sri Lanka with companies in the paints sector to identify risks and opportunities for improvement in paint formulations.

Jens Krol, ISC3 - Sustainable Plastics Workstream

- Introduced ISC3's workstream on Sustainable Building and Living with a Focus on Plastics, including capacity building activities. Currently around 20% of building materials are made from plastics, and plastic waste as an input material has great potential to contribute to more sustainable building. However, its widespread use must be implemented carefully to avoid the introduction of hazardous chemical additives into building materials.
- The workstream promotes solutions including support to the informal sector, further life cycle analysis in the design and planning phase of building, increased deconstruction ahead of demolition, reducing the amount of hazardous additives used in building plastics and using materials made from residual biomass or secondary raw materials. The final report can be found here.

- A training course was produced based on the report, in Kenya in collaboration with the National Construction Agency, as part of work in Kenya to develop building codes.
- E-learning modules have been developed on GIZ's Atingi platform, and further content could be developed in the future. The ISC3 is interested in ideas for possible applications of the e-learning materials and collaboration with organizations.

Rana Veer Pratap Singh, TERI - Mahindra-TERI Centre of Excellence for Sustainable Habitat

- Presented on the Mahindra-TERI Centre of Excellence for Sustainable Habitat, a lab for material developers to support material testing and overcome the lack of data for innovative sustainable building materials, energy and water use (e.g. one project looked at the use of nano materials to improve the heat conductivity of water for space heating).
- The lab helps to upscale the use of innovative materials, and uses toolkits on open public platforms to enable informed decision making for built environment professionals and private citizens.

UNIDO and Ukraine National Centre for Resource Efficient and Cleaner Production – GreenChem Innovation and Network Program

- Presented on the GreenChem capacity building and innovation programme, active globally and nationally in Indonesia, Jordan, Peru, Serbia, Uganda and Ukraine, which aims to accelerate the green chemistry agenda.
- Scaling innovative business models is one focus, with one model trialled where companies lease building materials.

Henning Friege - Sustainable chemistry in the building sector – important links to resource management

- Highlighted the vast amount of materials used in buildings and the urgent need for more recycling
- Hazardous substances in construction materials carry risks for occupational and public health
- As use phases can be extremely long (30 to >100 years) there is a loss of important information and the risk assessments of materials can change during this time
- Practices that are proposed include:
    - Promoting dismantling ahead of demolitions
    - Avoiding hazardous compounds as far as possible in the first place
    - Continuous, dynamic documentation to provide an inventory of materials used
    - Further guidance on occupational health risks
- 10 key 'R' strategies are identified to encourage these practices, instead of business as usual:
    - R0 Refuse
    - R1 Rethink
    - R2 Reduce
    - R3 Reuse
    - R4 Repair
    - R5 Refurbish
    - R6 Remanufacture
    - R7 Repurpose
    - R8 Recycle
    - R9 Recovery
- Examples of projects seen addressing these strategies:
    - **Sustainable Waste management (Deutsche Bundesstiftung Umwelt)** – R8, R3. Deconstruction of buildings; Optimisation of the value chain for recycling – removal of legal obstacles and enforcement problems for the use of recycled materials in construction. Instead of linear, downcycling approaches
    - RePOST (Under ReziProk funding) – R7, R8. Separation of aerated concrete from construction waste for recycling and repurposing processes, instead of demolition without recovery.

- RessProKa (ReziProk) – R1, R3, R6, R8. Product as a service business model for construction products (e.g. interior walls, flooring). Under this project, manufacturers assume product responsibility over the full building product life cycle and are responsible for return, remanufacturer or recycling after use, instead of conventional “build, sell, forget” process.
- The above projects contribute to better documentation and building information management (BIM), risk prevention and using less material and reducing waste. These further Objectives 8 (Maximizing social benefits), 1 (Minimizing chemical hazards), 7 (Enabling non-toxic circularity), 2 (Sustainable sourcing of resources and feedstocks).

Additional examples of the application of green and sustainable chemistry innovations in the buildings and the construction sector, or actions which enabled application were collected via a call for input to participants before the workshop. They are presented below as they were submitted by stakeholders.

Project TyCCAO

Project TyCCAO is a collaborative initiative between various Senegalese and French government agencies and professional organizations to scale-up the use of products made from the invasive Typha reed. A key pillar of the project is the development of local and biosourced construction materials which incorporate Typha. The material may be better suited to the hot Senegalese climate. Workshop participants emphasized that the environment where the building material will be used should be considered when applying green and sustainable chemistry principles to develop new building materials.

The TyCCAO program will mobilize a number of French, Senegalese and Mauritanian institutions such as Universities, polytechnics of research centers, architects, training centers, and design offices. Local organizations were targeted for involvement.

Africa-Europe Bioclimactic Collaboration 21 (ABC21) Project

The ABC21 project is a collaborative project between stakeholders in Africa and Europe to develop and scale-up bioclimatic solutions for buildings in warm climates. Policymakers, educators, public sector authorities, development agencies and financing institutions are working together to advance the project.

The project has generated knowledge which could drive demand for green and sustainable chemistry building products, such as this report on indicators to assess indoor environmental quality. Case studies from the project, such as this residential project in Morocco, showcase how green and sustainable chemistry materials can enable low impact building design for hot climates.

Collaborative Aggregates LLC

Collaborative Aggregate is a company based in green and sustainable chemistry innovation to improve the sustainability of asphalt pavement. This technology uses biomaterials to enable the use of up to 100% recycled asphalt and aggregate while at the same time reducing the energy inputs during the pavement process.

Beyond Benign's Green Chemistry Commitment

The Green Chemistry Commitment is a voluntary program where University Chemistry and Materials Science undergraduate and graduate programs sign a commitment to work to evolving their curriculum to include the principles of green and sustainable chemistry. By so doing, they join a community of peers to share best practices. Students at institutions which sign the commitment may be better prepared to apply green and sustainable chemistry innovations as professionals along the nexus chemical and building and construction value chain.

Formaldehyde and Isocyanate Free Engineered wood composites

Formaldehyde and isocyanates are toxic materials widely used in the wood construction industry. A technology has been invented that performs as well as these materials at similar costs, based on green chemistry and does not use toxic ingredients.

BG Bau hazardous substances information system for construction purposes.

The BG BAU hazardous substance information system (GISBAU) offers comprehensive information on hazardous substances in construction, renovation and cleaning as well as operating instructions in accordance with §14 of the Hazardous Substances Ordinance.

The GSK Carbon Neutral Laboratories for Sustainable Chemistry at the University of Nottingham: A Community Scale Experiment with Global Impact

This example showcases best practice applied to designing and building a research laboratory for sustainable chemistry research. This building implements product innovation and raises awareness of sustainable chemistry innovations along the buildings and construction value chain.

Together with partners spanning industry and UK research councils the University of Nottingham has developed a unique shared vision to establish The GSK Carbon Neutral Laboratories for Sustainable Chemistry (CNL) which is unique in the World. Designed to ensure minimal environmental impact, incorporating the latest developments in sustainable construction, this iconic facility will have a zero impact in terms of embedded and operational carbon over the 25-year projected lifetime of the building.

In terms of architectural and infrastructural-based environmental certification the CNL recently achieved both BREEAM Outstanding and LEED Platinum status.

As the first 'carbon neutral' building of its type in the world, the CNL addresses this challenge head on. In the context of this building, 'carbon neutral' means that the entire carbon footprint of the building - from the materials used in construction (embedded) and the energy consumed during occupation, to eventual demolition and restoration of the site - will make no overall contribution to global greenhouse gas emissions.

Construction was led by principal contractors Morgan Sindall in partnership with architects Fairhurst Design Group (Manchester). At the heart of the project was an advanced team of design engineers and consultants.

In terms of traditional construction materials (i.e. concrete and steel), these are almost exclusively limited to the fabrication of the foundations and the ground floor slab, upon which the superstructure sits. The foundation piles are composed of approximately 3,200 tonnes of stone, , of which nearly 2,500 tonnes are recycled. The foundations are capped with a concrete floor slab (2,200 tonnes) which has a high degree of fly-ash substituted to reduce the carbon tariff of more traditional Portland cement-based material. The fly-ash used was a waste material recovered from Radcliffe on Soar power station which is located just 9 miles from the University.

Above the ground, the CNL is fabricated almost entirely from engineered timber (approx. 1,400 tonnes) and other renewables based materials. The structural frame is Glulam, with all other structural elements in cross laminated timber (CLT). The timber (Spruce - Picea alba) was sustainably forested and milled in the Bavarian forests before being shipped by barge to the UK to ensure that environmental impacts of transportation from the saw-mills to the construction site were minimized.

Externally, the CNL is finished with hard-wood timber cladding and colourways of terracotta tiling. To fully achieve the energy and carbon efficient targets of this project, the construction team investigated potential energy saving in earlier phases of material processing and led to the development of more appropriate materials or products. An excellent example being the external terracotta cladding (NBK.de). This material is naturally sourced clay, but the traditional production process requires two sequential high temperature firings, consolidation to a single firing rendered this product acceptable within our parameters, the performance of the finished product was not compromised.

Operationally, the CNL is built around a unique, energy efficient ventilation system that responds to the demands of scientists and indeed the environment around it. When laboratories are not in use, the system becomes ‘dormant’, using the minimum amount of energy to maintain safe ventilation; as the laboratory spaces become occupied and work begins, it ‘wakes up’ and starts to consume energy. All building power is generated, on-site using photovoltaics and via a sustainable biomass CHP.

Academic research on using CO_2 as a raw material: CO_2 used in the treatment of contaminated soil and waste to produce building aggregates.

There are different ways to mineralise CO_2 gas emitted from industrial processes. Manufactured carbonate-based products can, for example, substitute or augment 'traditional' construction materials or be used as fillers in plastic or paper. In respect of the products for use in the built environment, the mineralisation process (which mimics natural weathering) permanently sequestrates CO_2. There is potential to mineralise 32 gigatons of CO_2 in construction products according to the literature.

To achieve an early 'win' with wider benefits, the University of Greenwich team developed and commercialised a carbonation step for industrial process residues in 2012 delivering a manufactured carbonated aggregate. The mineralised CO_2 binds waste particles together in a monolithic product. In doing so, the risks associated with the waste are mitigated, the waste is given value and is diverted from landfill, and this protects virgin resources. Manufactured carbonated aggregates meet 'End of Waste' and BS EN standards. Currently, approximately 0.5 Mt/yr. of lightweight carbonated aggregates are manufactured under license in the UK. More recently, a mobile carbonation plant has been developed to combine solid and gaseous CO_2 waste at the site of an industrial process, with the first plant now successfully commissioned and operating for VICAT in France.

The know-how generated is being used by the Greenwich team in association with its spin-off company Carbon8 to develop new low-carbon construction products/products from diverse waste streams and proprietary materials. The challenges to wider take-up of this technology include:

- The conservative nature of the construction industry
- Lack of consistent policy on carbon capture and utilization.
- Inability to attract carbon 'credits'
- Prescriptive national/international materials standards
- Regulation on use of waste that differs between territories.
- Differences in interpretation and application of 'End of Waste'
- Public and industry perception of 'risk'

Academic Research on the use of industrial by-products (PFA and GGBS) in concrete

Portland cement underpins modern life like no other material, with over 4 billion tonnes being produced each year. However, this results in production of 6-8% of global CO_2 emissions. The cement industry is acutely aware of its need to reduce emissions and is now looking at how to achieve this. One common approach is the use of supplementary cementitious materials (SCMs) to produce composite cements. These have traditionally been industrial by-products, such as fly ash from coal-fired power stations (PFA) or ground granulated blast furnace slag (GGBS) from iron production. But, as we move to a greener economy, decarbonising energy and recycling more iron, supplies of traditional SCMs are dwindling. Thus, there is increasing interest in ensuring that existing SCMs are used as effectively as possible, and that alternative SCMs are developed.

Prof Black's research examines the durability of composite cements ensuring that they are used appropriately. His works show that SCMs can reduce carbon footprints while ensuring long-term concrete performance. More recently, he has been involved in examining the development of ternary limestone-slag cements, which offer the same performance as composite cements, but replacing some of the cement and the slag with limestone. This reduces carbon footprints while not placing strain on SCM reserves. In a similar fashion, his current research is looking to develop low-carbon cements from natural UK clay reserves, turning what are often excavation spoils into low-carbon cements**.**

A practical guide to assist waste managers in identifying wood waste that contains Substances of Concern (SOC)

Anthesis (consultants) recently completed research for the UK government on the needs of waste managers as users of further information on the chemical composition of waste. One of the questions posed in the research was 'how do we make the data practically useful'?

The Waste Wood Assessment Guidance produced by the UK Wood Recycling Association (WRA) was highlighted by Anthesis as a good example of where industry can come together to develop a sector wide position on the treatment decisions for waste that may contain substances of concern (SOCs), and although further work is being undertaken to simplify the information for on-site use, it offers a useful model for how complex chemical information can be collected, interpreted, and applied to specific product groups in the sector. Indeed, market pressure has begun to drive the application of the guidance in practice with some demolition contractors reporting in the research interviews that they are beginning to find it more difficult to send wood for recycling if it has not been tested and hence demonstrated to be non-hazardous. This is likely to incentivise greater use of the existing classification guidance and greater testing by industry to ensure that only those items that are hazardous are treated as such.

This intervention by the WRA will contribute to the development of a clean circular economy for wood.

Standardized digital content declarations for construction products

SundaHus works to provide structured material information management within the construction industry. Through detailed content declarations, construction products can be screened and checked to comply with the needs for their intended use now. But even more importantly, it is the foundation for Objective 7, enabling non-toxic circularity in the future when knowledge about the substances that make up the product might have developed further. Making this information digital in a standardized format is enabling much more efficient processing and evaluation of the information both now and in the future.