UN environment programme

GREEN AND SUSTAINABLE CHEMISTRY:
FRAMEWORK MANUAL

Executive Summary

Foreword

Resolution 4/8 on Sound Management of Chemicals and Waste, adopted by the United Nations Environment Assembly at its fourth session (UNEA-4) in 2019, welcomed the analysis of best practices in sustainable chemistry by the United Nations Environment Programme (UNEP) and recognized the value of developing a better understanding of sustainable chemistry opportunities globally. The resolution "requested the Executive Director, subject to the availability of resources and, where appropriate, in cooperation with the member organizations of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), to synthetize UNEP's analysis of best practices in sustainable chemistry into manuals on green and sustainable chemistry, in consultation with relevant stakeholders, by UNEA-5, and to continue the work on a holistic approach for the sound management of chemicals and waste in the long term, taking into account both the importance of the sound management of chemicals and the potential benefits of chemicals for sustainable development".

This Framework Manual introduces, in a structured way, various facets of green and sustainable chemistry, with the intention to foster general learning, reflection and scaling- up action based on a common global understanding of the concept. It features an organizing framework that unpacks various topics relevant in green and sustainable chemistry literature. Objectives and guiding considerations are offered to stimulate stakeholder action at various levels and in different settings. Ultimately, the Manual seeks to promote chemistry innovation that unveils the full potential of chemistry that is compatible with and supports the implementation of the 2030 Sustainable Development Agenda.

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1 Why do we need to scale up action on green and sustainable chemistry?

The Global Chemicals Outlook-II (GCO-II) recognizes that innovations in chemistry can work towards achieving the SDGs. The report also presents a number of trends that cause concern from a human health, environmental and sustainability perspective. The number of chemicals is ever increasing, and hazardous chemicals and other pollutants continue to be released and disposed of in large quantities, affecting individuals and communities worldwide. Synthetic chemicals are now ubiquitous in humans and the environment. Chemical pollution has become a major cause of human disease and premature death. The World Health Organization (WHO) estimated the burden of disease from selected chemicals at 1.6 million lives and 44.8 million disability-adjusted life years (DALYs) in 2016 (WHO 2018) which is likely to be an underestimate (UNEP 2019).

Many articles and products on the market contain hundreds of chemicals or chemical products which accumulate in significant amounts in material stocks, creating potential liabilities in the future. In addition, supply chains are becoming increasingly globalized, while the transfer of information about chemicals in production and products remains limited. These limitations create challenges for taking actions across the product life cycle, such as minimizing chemical releases during manufacturing, reducing consumer exposure and decreasing chemical emissions during recycling and final disposal.

GCO-II concludes that the global goal to minimize adverse impacts of chemicals and waste will not be achieved by 2020. More ambitious and urgent worldwide action by all stakeholders is required, and "Business as usual is not an option". Enhanced action needs to include immediate measures to minimize adverse impacts of existing chemicals, for example through bans and restrictions. Beyond these measures, the real opportunity in the 21st century resides in accelerating greener and more sustainable chemistry innovations. This can be achieved by scaling up innovation programmes, developing sustainable value chains that cover the entire lifecycle and commercializing chemicals and products that are sustainable.

2 How can green and sustainable chemistry contribute to sustainable development?

The momentum for green and sustainable chemistry is growing

The concepts of green and sustainable chemistry have gained significant attention around the world, given their potential to innovate and advance chemistry to help achieve the SDGs and their targets. While the concept of "green chemistry" was elaborated through the well-known 12 principles published in 1998 (Anastas and Warner 1998), "sustainable chemistry" has recently evolved as a closely related, yet more holistic concept (Blum *et al.* 2017; Kümmerer 2017). Furthermore, momentum is growing to stimulate a transformation in the chemical industry towards expanding the definition of performance to include sustainability considerations. Such a transformation will require going beyond traditional chemistry innovation approaches by integrating systems thinking and systems design ranging from the molecular level to positive impacts on the global scale (Zimmerman *et al.* 2020).

Opportunities for green and sustainable chemistry

Recent innovations in chemistry and advanced materials have created new opportunities throughout the value chain to advance sustainability. These include, for example: revolutionizing energy storage and battery development; creating sustainable building materials; improving the recyclability and biodegradability of a number of products; or turning carbon dioxide (CO_2) and wastes into chemical feedstocks and valuable products. Greener and more sustainable innovation at the interface of chemistry, biology and computer science is particularly promising (UNEP 2019).

The SDGs provide a powerful reference and pave the way for advancing the green and sustainable chemistry agenda. A large number of SDGs stand to benefit from the direct contributions of green and sustainable chemistry, including: zero hunger (SDG 2), good health and well-being (SDG 3), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), sustainable consumption and production (SDG 12), and climate action (SDG 13). By reducing and/or eliminating chemical hazards, associated health and environmental impacts and pollution, green and sustainable chemistry will also contribute to other SDGs, such as decent working conditions, and economic growth (SDG 8), innovation and infrastructure (SDG 9), life below water (SDG 14), and life on land (SDG 15).

The market potential for green and sustainable chemistry

Although differences exist in the characterization of green and sustainable chemistry, available - albeit limited - data suggests that supply and demand for greener and more sustainable chemistry products have significantly grown over the past years. The global green chemistry industry was reported to have a market value of more than US dollars 50 billion in 2015 (BCC Research 2016) and is projected to grow to US dollars 167 billion by 2027 (ReportLinker 2020). Asia and the Pacific, Western Europe and North America are the key market growth regions (Pike Research 2011).

Table 2.1: **Selected SDGs and targets relevant for green and sustainable chemistry** (UNEP 2019b, p. 644)

Sectors	SDG targets	Examples of opportunities for management and innovation
Agriculture and food	Target 2.4: sustainable food production	Scale up Integrated Pest Management (IPM) and agroecological approaches, including development and use of non-chemical alternatives and other beneficial agricultural practices
Health	Target 3.8: safe medicines and vaccines	Sound management of pharmaceuticals and disinfectants that contribute to antimicrobial resistance
Energy	Target 7.a: clean energy research and technologies	Improve technologies using resource-efficient, sustainable materials when decarbonizing the energy sector
Infrastructure	Target 9.1: sustainable infrastructures	Reduce raw material use and waste generation via advanced materials without creating future legacies
Industry	Target 9.2: sustainable industrialization	Ensure that chemical-intensive industries rely on best available techniques and best environmental practices
Housing	Target 11.1: safe housing	Reduce indoor air pollution through safer insulation and replace building materials of concern (e.g. asbestos)
Transport	Target 11.2: sustainable transport systems	Advance clean mobility, for example based on sustainable chemistry solutions for batteries
Tourism	Target 8.9: sustainable tourism	Adopt practices to reduce the chemical footprint of tourism services
Mining	Target 12.2: sustainable use of natural resources	While foremost ensuring sound management of mine tailings, tailings are reused and returned to the economy to the greatest possible extent possible
Labour	Target 8.8: safe working environments	Enhance risk assessment of chemicals of concern while promoting investment in green and sustainable chemistry to reduce hazardous occupational exposures
Education	Target 4.7: education for sustainable development	Mainstream green and sustainable chemistry into relevant curricula
Finance	Target 17.3: financial resources from multiple sources	Enhance use of green and sustainable chemistry metrics as criteria in investment

3 What can green and sustainable chemistry action achieve? Guiding considerations

A vision for green and sustainable chemistry

This Framework Manual fosters a vision of green and sustainable chemistry which emphasizes the potential of chemistry to become fully compatible with the 2030 Agenda for Sustainable Development. The vision covers both greener and more sustainable chemistry innovations, while also addressing toxic and persistent legacies associated with past chemistries. It can be achieved through new designs and innovations in chemistry that provide desirable functions and services of chemicals, materials, products, and production processes without causing harm to human health and the environment, while meeting broader development objectives.

Apart from the 12 Principles of Green Chemistry and the 12 Principles of Green Engineering, a reference framework that helps better understand what comprises "green and sustainable chemistry" does not exist. Nor does an agreed set of criteria exist to determine how "green" or "sustainable" a chemical or an industrial process is (UNEP 2019).

Objectives and guiding considerations

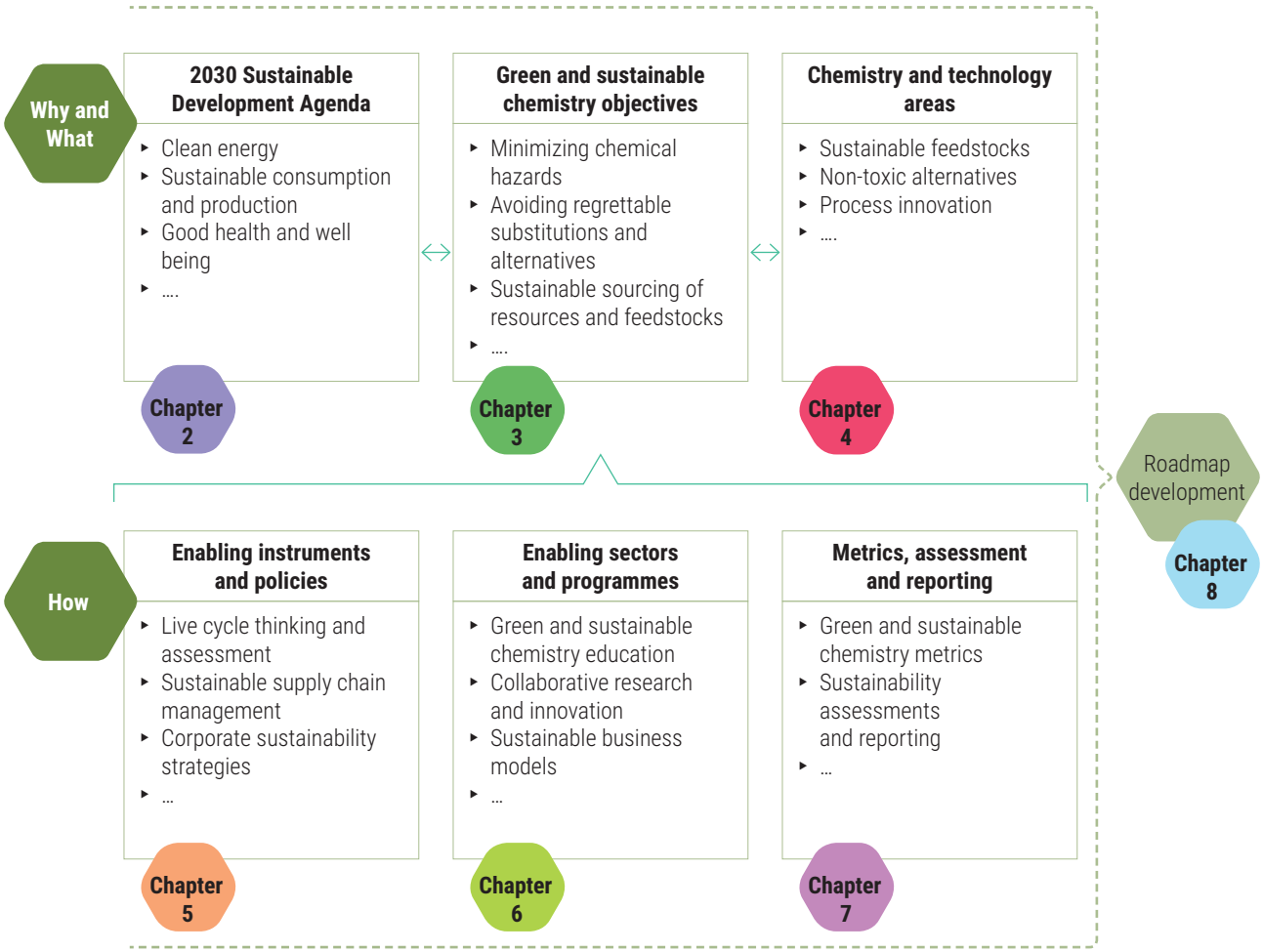
This Framework Manual presents 10 objectives and guiding considerations for what green and sustainable chemistry seeks to achieve. They range from molecular design based on green chemistry principles, to ensuring that chemistry innovations address societal needs. Recognizing that implementation of the 10 objectives and guiding considerations requires fundamental shifts in raising awareness, creating new knowledge, and innovation practices, the objectives encourage and seek to inspire actors to shift their chemistry innovations activities towards green and sustainable innovation.


Design of chemicals with minimized (or no) hazard properties for use in materials, products and production processes ("benign by design")
Minimizing chemical hazards
1
Avoiding regrettable substitutions and alternatives
2
Develop safe and sustainable alternatives for chemicals of concern through material and product innovations that do not create negative trade-offs
Use of sustainably sourced resources, materials and feedstocks without creating negative trade-offs
Sustainable sourcing of resources and feedstocks
3
Advancing sustainability of production processes
4
Use green and sustainable chemistry innovation to improve resource efficiency, pollution prevention, and waste minimization in industrial processes
Use green and sustainable chemistry innovation to create sustainable products and consumption with minimized (or no) chemical hazard potential
Advancing sustainability of products
5
Minimizing chemical releases and pollution
6
Reduce chemical releases throughout the life cycle of chemicals and products
Use of chemistry innovations to enable non-toxic circular material flows and sustainable supply and value chains throughout the life cycle
Enabling non-toxic circularity
7
Maximizing social benefits
8
Consider social factors, high standards of ethics, education and justice in chemistry innovation
Safeguard the health of workers, consumers and vulnerable groups in formal and informal sectors
Protecting workers, consumers and vulnerable populations
9
Developing solutions for sustainability challenges
10
Focus chemistry innovation to help address societal and sustainability challenges

4 How does the Framework Manual encourage action on green and sustainable chemistry?

The Framework Manual is structured alongside the elements of the conceptual framework "Advancing sustainability through green and sustainable chemistry" which was developed through a consultative process and is introduced below. Chapters 2, 3 and 4 address the question of: "Why" is green and sustainable chemistry needed and "What" does it aim to achieve, and in which specific innovation areas. Chapters 5, 6 and 7 focus on enabling tools and measures to advance green and sustainable chemistry (the "How"). These action-enabling elements range from promoting life cycle approaches to strengthening research and innovation policies and programmes. An important cross-cutting topic is the need to scale up awareness raising and education initiatives

Figure 4.1: **Advancing sustainability through green and sustainable chemistry**



at all levels that bring the green and sustainable chemistry to a range of potential actors through formal, non-formal and informal education.

Who are the stakeholders encouraged to use the Manual?

This Framework Manual targets a range of audiences and stakeholders concerned with the sound management of chemicals and waste. They include decision-makers and managers in:

- **Public authorities** responsible for regulating chemicals of concern and promoting innovation for safer chemistry.
- **Primary, secondary and tertiary education institutions** engaged in educating the next generation of scientists in the 21st Century.
- **Academic and research institutions** conducting basic and applied research in areas such as in chemistry, process engineering and product design.
- **Private sector** entities engaged in all stages of the value chain, from sourcing raw materials and feedstocks, to production, to recycling and disposal.
- **Consumers**, who can shape market demand towards safer and more sustainable products, with the choices they make.
- **Civil society organizations** involved in promoting sound management of chemicals and waste by public and private actors and consumers.
- **Labour organizations** seeking to protect workers from hazardous chemicals.
- **Citizens and the public at large** aspiring for more sustainable lifestyles and societies.

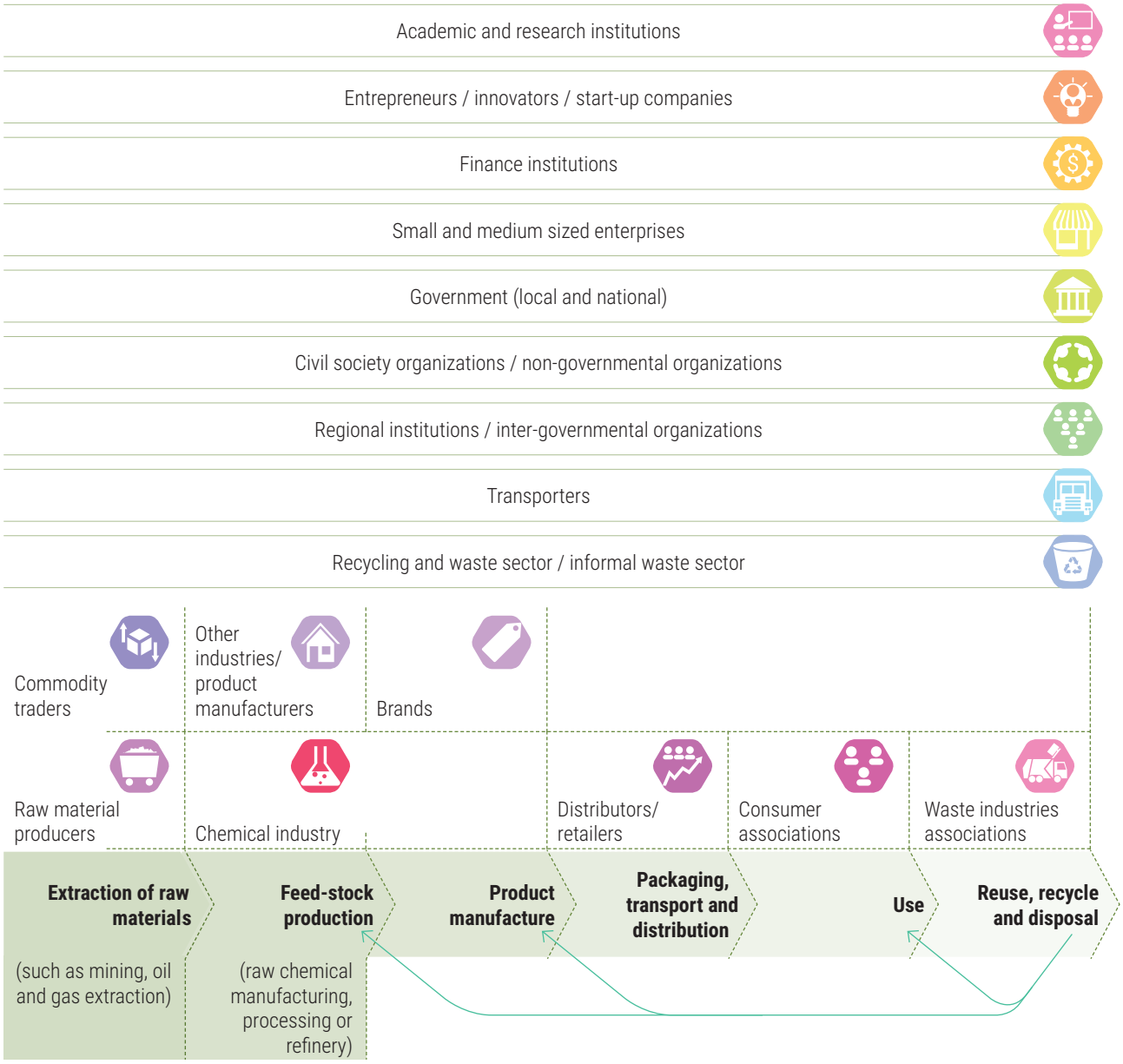
Figure 4.2 presents stakeholder and target audiences of green and sustainable chemistry in the value chain, building upon a similar mapping of the plastics value chain displayed in Ryberg, Laurent and Hauschild (2018).

Developing green and sustainable chemistry stakeholder road maps

The road map approach to support strategic planning and decision making has been used for many years and has proven to be a powerful instrument to drive innovation. In the chemical sector, roadmaps have been used to advance action to achieve the sound management of chemicals and waste. One example is the roadmap developed by chemical companies and industry association under the auspices of the World Business Council for Sustainable Development (WBCSD) exploring how the chemical sector can contribute to achieving various SDGs and targets (WBCSD 2018). Another example is the WHO Chemical Road Map, adopted in May 2017 by the World Health Assembly, identifying actions where the health sector has either a lead or important supporting role to play in advancing the sound management of chemicals and waste.

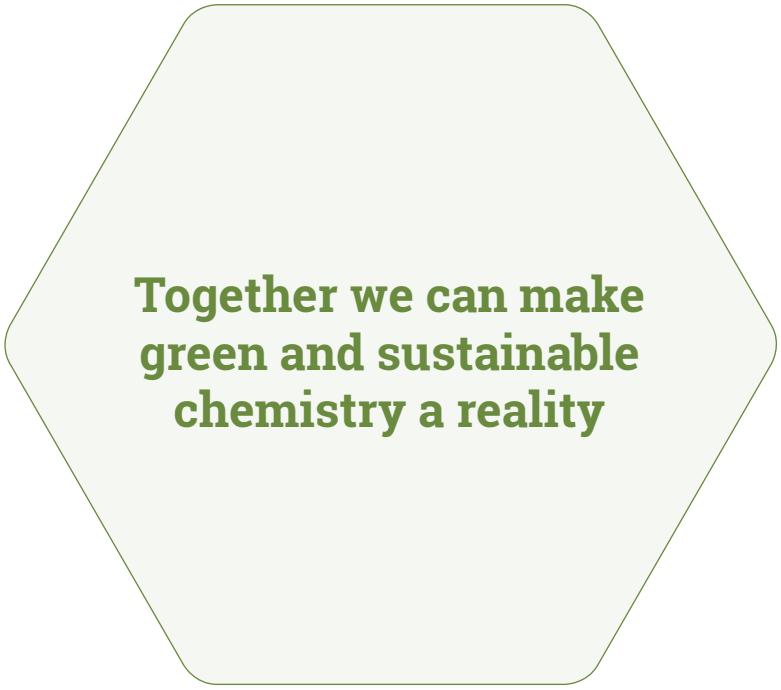
Consistent with the suggestion made by GCO-II, Green and Sustainable Chemistry Road Maps could be developed by diverse stakeholder groups, as important components of concerted national and global results-oriented action to achieve the sound management of chemicals and waste. These road maps could be developed at different levels and through different stakeholders, including individual governments (national, sub-national or local), chemicals and downstream sector companies, university and research institutes, and other concerned actors. They may also be developed around a singular issue like the case of the solvent management plans (SMP) formulated in the UNECE region. What they require is leadership within relevant organizations. Such leadership can come from the top through, for example, senior management, or from bottom-up, through interested and committed individuals.

Figure 4.2: Stakeholder and targets audiences of green and sustainable chemistry in the value chain
(Adapted from Ryberg, Laurent and Hauschild 2018, p.10)



The time is ripe for strategic action to advance green and sustainable chemistry

The trends and opportunities presented in the framework manual all point in one direction. Advancing green and sustainable chemistry offers many benefits, environmental, social and economic. However, leadership at all levels is still not sufficient and must improve in order to reap the full potential of green and sustainable chemistry. All actors and decision-makers, from public officials to company CEOs and heads of chemistry laboratories, are encouraged to consider the analysis and guidance provided in this framework manual and consider the initiation of a "Green and Sustainable Chemistry Road Map" within their organizations. UNEP encourages and welcomes the sharing of relevant initiatives to facilitate knowledge sharing across countries and stakeholders and to explore opportunities for capacity development. Beyond, at international and at national/regional levels, leading stakeholders such as governments, and regional/local authorities are encouraged to coordinate action and build with relevant stakeholders a coherent plan for action (or roadmap). Altogether, these efforts could enhance and scale-up concerted global action to advance green and sustainable chemistry, including in developing and transitioning countries.



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