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Perspective

Time to Break the "Lock-In" Impediments to Chemicals Management

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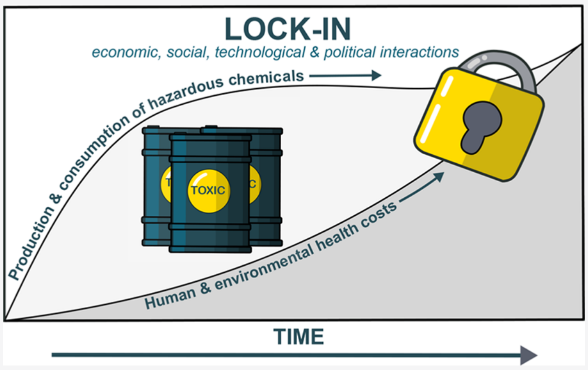
ABSTRACT: Despite enormous national, regional, and global efforts on chemical management, the widespread use of hazardous chemicals continues in many parts of the world even after decades of there being well-known risks to public and/or ecosystem health. This continued supply and use, despite strong evidence of negative impacts, is not unique to chemicals management. In the field of climate change, the concept of "lock-in" has been used to explain the complex interactions among economic, social, technological, and political dynamics that reinforce global reliance on the extraction and use of fossil fuels. Learning from carbon "lock-in" phenomena, this Perspective explores the challenges of chemicals management from the perspective of lock-in through three case studies: paraquat, perfluorooctanesulfonic acid (PFOS), and asbestos. These case studies illustrate that most current chemicals management frameworks fail to address the concerns arising from this complex interplay by not involving all relevant stakeholder groups that are part of lock-in, from producers to consumers. This results in a relatively narrow consideration (e.g., only demand but not supply) of the effectiveness and consequences of regulations. We submit that to break lock-in and address the global threat of chemical pollution, current approaches to managing hazardous chemicals should be broadened to take a comprehensive approach to understanding and managing factors contributing to lock-in, notably both supply and demand on national and international scales.



KEYWORDS: *hazardous chemicals, "lock-in" analysis, chemicals management, science−policy, paraquat, PFOS, asbestos*

INTRODUCTION

Chemical pollution is a significant and growing threat to humanity and the global environment.[1−3] While national, regional, and global efforts have been made over the past decades to establish regulatory and policy frameworks to address chemical pollution,[4] widespread use of hazardous chemicals continues in many parts of the world, even after they are found to be of public health or environmental concern.[5] For example, although knowledge of lead and its health risks dates back to ancient Egypt,[6] and an international convention on white lead in paint was established in 1921, lead exposure is still a major cause of premature deaths worldwide.[7] Unfortunately, lead is far from an isolated case—global chemicals management has been ineffective time and again. While the path to regulation of each chemical (effective or not) has unique characteristics, the general approach to date has been narrow, often focused on addressing only the demand or supply of the chemical, and in isolation from other considerations.

Current ineffective management is generally not due to a lack of knowledge of hazards or uncertainty surrounding effects (which is most often blamed for lack of progress) but rather that once chemicals and the technical, industrial, and governance systems that deliver them are in place, interrelated economic, social, technological, and political dynamics emerge that reinforce and maintain their use. This is akin to carbon lock-in dynamics identified in the climate change literature.[8−10] We contend that similar dynamics make chemicals management difficult even in the face of clear information about hazards and risks and that adopting a lock-in perspective may be useful both for grasping the challenges and barriers to managing hazardous chemicals and for identifying ways to overcome them.

In relation to climate change, lock-in refers to the economic, social, technological, and political dynamics and interactions that reinforce the status quo—the global reliance on the extraction and use of fossil fuels.[8−10] Economically, lock-in

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results from various investments—such as infrastructure, corporate organization, and education—that account for specific modes of production and consumption and the economies that build around them.[8] Socially, lock-in is reflected in behaviors and attitudes, such as how fossil-fuel-based modes of transportation are considered natural, or the way cities are designed for transportation by cars.[11] Technologically, lock-in can be reflected by some major car manufacturers' focus on incremental improvement of combustion engines that rely on fossil fuels and reluctance to transition to alternative electric vehicles. Politically, lock-in can be found in the coalitions and distribution of power among actors in society that favor the continued dominance of fossil fuels.[12]

These dynamics present major impediments for transitioning to a low-carbon world, as they require fundamentally changing existing infrastructure and processes. Such changes often incur new expenses, are time-consuming, and can be politically and socially challenging, since not all stakeholders may immediately benefit from the changes. Thus, even in the face of growing urgency around climate change and clear evidence of its harm, it appears more feasible and practical in the short term to double down on the existing model of fossil fuel production and use, although it is widely acknowledged that doing so is catastrophic in the long term.[13]

Efforts to regulate carbon that do not take lock-in into account often fail against the locked-in system's inertia.[10] As just one example, the Paris Accord focuses primarily on demand-side measures to reduce fossil fuel consumption but does not plan for significant supply-side measures. In response to the decreased demand for fossil fuels as energy sources, uptake in new markets or applications, like plastics, is sought by the fossil fuel industry as ways to maintain and grow the overall demand.[14] Thus, some have argued that only by controlling both the supply and demand of fossil fuels can agreements successfully overcome carbon lock-in.[14] Similar dynamics are evident with the social and political aspects of disrupting carbon lock-in.[8]

A lock-in perspective may provide important insights for managing hazardous chemicals. An aspect of this, as described by incumbency, has been discussed with respect to hazardous chemicals.[15] Lock-in can lead us to look for confounding factors that inhibit the effective management of hazardous chemicals in light of economic, social, technological, and political dynamics. We consider this conjecture through three case studies that begin to explore the challenge of chemicals management from a lock-in perspective. This is not a full analysis of lock-in but rather a demonstration of the concept—how a broader lock-in perspective can provide a new approach to chemicals management. Specifically, we explore how imbalanced response measures that privilege one side of the supply−demand relationship are unlikely to be effective because of lock-in dynamics. Our case studies examine examples where barriers to effective regulations have been high: paraquat, perfluorooctanesulfonic acid (PFOS), and asbestos. This analysis generates lessons learned for overcoming lock-in and suggestions for pursuing global sound management of chemicals.

■ PARAQUAT

Paraquat dichloride is a broad-spectrum herbicide used in more than 100 countries[16] due to its low price and high efficacy in a variety of settings.[17−19] Paraquat is also highly toxic to humans and has no available antidote.[17,19−21] Acute paraquat poisoning results in multisystem organ failure, with an estimated 70% case fatality rate, while chronic exposure has been linked to Parkinson's disease, depression, and chronic respiratory issues.[18,19,22]

The same factors that make paraquat an effective herbicide—its potency, availability, and price—have also contributed to paraquat becoming a means of suicide in many countries.[23] For example, paraquat resulted in 56% of pesticide poisonings in England and Wales between 1945 and 1989,[24] 35.5% of pesticide-related deaths in the Republic of Korea between 1996 and 2005,[25] and 63% of all suicides in Trinidad and Tobago between 1986 and 1990.[26] A long history of accidental fatalities from paraquat poisoning has also been documented, including death caused by accidental ingestion of residual amounts in a container[19,20] and by dermal exposure in occupational settings.[19,27]

Concerns over the risks posed by paraquat stretch back to the 1960s. Yet, lock-in has hampered attempts to reduce those risks, both through the costs of moving away from the existing industrial infrastructure for its production (supply) and the business model supporting its continued use (demand).[17,20] In the 1980s, the British-based producer of paraquat, Imperial Chemical Industries (ICI), faced particular regulatory pressure in Japan due to a string of murders and the more than 1000 suicides committed annually with paraquat in the country.[28−31] In the same period, ICI also sold a solid formulation of paraquat in the UK that was significantly safer. Compared to the liquid formulation, solid paraquat was diluted 10-fold and significantly harder to swallow in the quantities needed to kill an adult. This formulation would have satisfied the Japanese government's demands for increased safety—in fact, the government's registration committee had even asked ICI in 1976 whether it would be possible to sell the solid formulation in Japan.[30] However, ICI chose not to do so, as the new formulation would entail additional shipping and production costs, as well as significant investments into new production facilities.[17,20,28] Although this new formulation would be safer, and would allow ICI to continue sales of its product, the upfront costs incentivized ICI to keep its existing production model and therefore hindered efforts to control paraquat.

Producer interests in the status quo contributed to lock-in through the economic costs of change, but they have also been translated into political pressure. In addition to fending off Japanese regulations, paraquat producers also successfully influenced policy in Europe to maintain the (inadequate) regulatory status quo.[29] In 1986, the European Parliament drafted a "Resolution on Agriculture and the Environment."[29] According to internal ICI meeting notes from January 1986, the paraquat producers' lobby succeeded in removing explicit references to paraquat from the resolution.[29]

Decades later, policymakers were finally successful in passing legislation restricting the use of paraquat in many jurisdictions, including in the Republic of Korea, Sri Lanka, Switzerland, the United Kingdom (UK), and the European Union (EU). However, legislation in the UK has focused on banning domestic use while leaving exports intact. Consequently, Syngenta (ICI's successor) exported thousands of tonnes of paraquat from the UK in 2019.[32] Paraquat continues to be profitable for the company, with sales estimated at US $640 million in 2011.[33]

In contrast to the countries (mostly high-income) who have phased out paraquat use through demand-side regulations, other countries (mostly low-income) have seen continued growth in demand.[19] For example, paraquat has consistently been among the top-imported herbicides in Central American countries such as Guatemala, El Salvador, and Honduras, where it is used for a wide variety of crops.[19,34] Given the importance of agriculture to these countries' economies, the low price of paraquat relative to other herbicides, and the direct economic benefits of its use (increased yield and reduced labor demands), the cost of transitioning to a less toxic alternative might be simply too expensive and difficult to coordinate.[19]

Lock-in to paraquat consumption in low-income countries goes beyond economics, extending to the information available on alternatives. In 1983, ICI claimed "there is a use for paraquat 'on every hectare of agricultural land in the world.'"[19] Decades of such promotion lead to popular beliefs that there are no alternatives—and for some, this is true, as they have never received training on the use of alternatives.[19,35] In other words, in addition to increasing the costs of transition, producer interests and the dominance of certain chemicals influence the embedded practices and knowledge that go along with use of the chemical.

Low-income countries with strong demand for paraquat have opposed global restrictions, further illustrating the feedback effects of lock-in that integrate economic, social, and political channels; reinforce the status quo; and resist change. For example, countries like Guatemala and Indonesia, both of whom import paraquat, are among the most vocal opponents to listing paraquat under the Rotterdam Convention, a measure that does not ban chemicals but rather promotes informed trade. For these countries, the cost of finding and transitioning to an alternative to paraquat likely seems prohibitive, although these calculations (almost) always externalize the health costs of paraquat and therefore underestimate the economic and public health benefits of alternatives.

Lock-in results from the complex interplay of economic interests (on both the supply and demand sides), social embedding, and political behavior. The producers of paraquat, ICI and Syngenta, resisted improving the safety of their product and worked to continue its production and export because of the significant investments needed to shift away from established, highly profitable paraquat production processes to new alternative business areas. Infrastructure in low-income countries, including the training of farmers to use and depend on paraquat and the establishment of local businesses profiting from paraquat sales, has reinforced continuing use in these countries. Producers and consumers also came together to thwart effective global regulation, even in the face of clear evidence of harm.

■ PFOS

PFOS and its precursors were among the organofluorine compounds the American company 3M produced, starting in the 1950s.[36,37] PFOS and its precursors were widely used in many consumer and commercial applications, including in firefighting foams and as a mist suppressant in the production of chromium steel plating.[37−41]

In this latter case, it was anticipated that PFOS would benefit workers by reducing their exposure to hazardous hexavalent chromium (Cr(VI)), but unfortunately PFOS itself is highly toxic to humans and wildlife, while its stability allows it to persist and accumulate in the environment.[36−39,42,43] Sixty years after its first use, PFOS is now globally distributed and is widely found in the blood of humans, birds, and other wildlife, where it has been linked to various negative health outcomes.[36−38,41−44]

Starting in 1977, internal investigations started at 3M that would find evidence of PFOS's toxicity and bioaccumulative potential.[45−47] These concerns were not relayed to the public, and 3M only halted production of PFOS and its precursors in 2002 following a voluntary agreement made with the United States (US) Environmental Protection Agency in 1999.[37,38,41,44]

Despite 3M's domination of PFOS production (78% of the global supply in the year 2000), the company's phase-out did not stop the use of PFOS and its precursors.[37,43] Over the five decades in which they were used, PFOS and its precursors became an integral part of various supply chains and production methods, including in the production of chromium steel plating, resulting in dependence by these industries.[39−41,43] Finding an alternative that could substitute effectively for PFOS and its precursors, while remaining affordable, was difficult in many cases and impossible in others, particularly in the short timespan between 1999 and 2002.

Continuing demand ultimately interfered with efforts toward the global phase-out of PFOS. In 2009, when PFOS was to be listed under the Stockholm Convention on Persistent Organic Pollutants, several countries stepped forward to request exemptions. For example, Japan claimed that PFOS was present in 70% of video endoscopes used around the world and that a phase-out would have a "huge cost" and a "social impact."[48] Brazil, the main consumer of the PFOS precursor-based pesticide Sulfluramid, claimed that its ban would result in the loss of up to 14.5% of trees in the country with a cost of US $6.7 billion a year.[48] In response to these concerns, the Conference of the Parties agreed on exemptions under the Convention for many uses of PFOS and its precursors.[36,41,43] Similarly, the US, which is not a party to the Convention, has numerous exemptions in its regulations on PFOS, including for major uses such as chromium plating.[40,41,49]

While global demand was maintained, supply was almost completely eliminated following 3M's exit (small-scale production continued in Europe and Japan), leaving a large, unfulfilled demand for PFOS and its precursors.[36,37,43] In China, small-scale production of PFOS and its precursors had existed for several decades, largely to satisfy domestic demand.[39,43] In 2002, when 3M ceased all production, only 30 tonnes were produced in the country annually.[38,39] By 2006, production of PFOS and its precursors in China had grown significantly to nearly 250 tonnes and leveled out at around 100 tonnes per year by 2008, mainly to fill demand in Europe and elsewhere.[36,38,39] It was not until 2009 that PFOS was added to the Stockholm Convention, which then initiated regulations of PFOS production and use on a global scale. China, as a Party to the Stockholm Convention, issued a ban on its production, import, and use in 2011, except for the exemptions allowed under the Convention.[50]

However, by 2011, the shifts in production to China had also created a new issue of lock-in for that country, wherein significant investments were made in facilities and companies dedicated to producing the compounds. To capture these expenses would require years of continued production of PFOS and its precursors.

The costs of overcoming this more recent lock-in are substantial. The World Bank, through funding from the Global Environment Facility Trust Fund, has pledged hundreds of millions of US dollars toward transitioning China away from production of PFOS and its precursors.[51] This includes US \$113.2 million to reduce current usage of the compounds, US \$6.3 million to support regulations, and US \$44.7 million to assist producers in developing, registering, and switching to alternatives.[51]

Much of these costs and the long delay in global phase-out of PFOS could have been avoided had countries and producers initially instituted comprehensive measures on both the supply and demand of PFOS and its precursors. Had the rationale for 3M's voluntary phase-out been clearly communicated between governments and across sectors, and had PFOS entered into global chemicals management discussions, then the establishment of a new supply chain in China or elsewhere might have been avoided. This would have required a more comprehensive analysis of existing PFOS uses and early involvement of downstream users to develop feasible safer alternatives and a clear timetable for transition.

■ ASBESTOS

Asbestos has been used since the 19th century, with production skyrocketing during the 20th century due to demand for construction, fireproofing, and insulation.[52] Exposure to asbestos has well-known, well-demonstrated, and long-standing links to adverse health effects, most notably mesothelioma.[53−61] Despite this, in 2020, global production, primarily in China, Russia, and Kazakhstan, stood at 1.2 million tonnes, with most demand in China and India.[53,59,60,62]

For much of the 20th century, though, it was Canada that led global asbestos production, accounting for more than half of all asbestos mined in those 100 years.[57,63,64] The vast majority (95%) of asbestos was mined in the province of Quebec, with operations centered around the towns of Asbestos and Thetford Mines.[52,63] Production peaked in 1973 at 1.7 million tonnes per year, declining steadily in the years afterward.[64−73] By 2006, production was at 186,000 tonnes per year.[63]

Even as domestic demand declined amidst health concerns, the economic, social, and political importance of the Quebec asbestos industry ensured that all levels of government continued to support the industry, even when that meant countering the government's own scientific advice.[52,74,75] Because regions like Asbestos, Quebec had developed with the asbestos industry, restricting supply through regulations would need to be counterbalanced by significant financial supports for affected workers—otherwise, governments risked angering important constituencies in an important electoral battleground.[52,61,64,74] The political complexities of regulating the asbestos industry were further complicated by a cultural association between the asbestos miners union and the Quebec sovereignty movement at an already sensitive time.[52,61,74]

Rather than risk political repercussions by regulating supply, Canada sought to maintain foreign demand for its asbestos by lobbying low-income countries to continue accepting Canadian exports. In 1984, the Canadian government collaborated with industry groups to found the Chrysotile Institute.[53,61,75] Over the next few decades, the Chrysotile Institute received more than CA \$20 million from the Canadian government[76] with the strategy of building demand outside of Canada.[64−73] For example, the Chrysotile Institute lobbied governments in Asia, South America, and Africa to continue accepting Canadian asbestos exports and to prevent passage of new regulations on asbestos, as shown in increasing exports to these regions following 1984.[52,61,64−73]

To promote international demand, the Chrysotile Institute spread "false science" disputing claims that exposure to asbestos was the cause of mesothelioma and other lung diseases, even as Health Canada claimed the opposite and while Canada tightened its regulations on domestic use.[61,74,75] In another attempt to maintain its export markets, the Canadian delegation to the Rotterdam Convention opposed the listing of asbestos under the Convention from 2003 up until the Quebec asbestos industry shut down in 2012.

By 2012, attempts to generate new markets for asbestos had been insufficient to compensate for the loss of the American and European markets that followed discovery of asbestos' health impacts.[61,74] Increased competition for production from Russia, Brazil, and other countries with weaker environmental regulations also threatened the ability of the industry to make a profit.[61,64,74] Only two mines remained in operation in Quebec, and deposits were close to exhaustion.[61,74] To remain in business, the Jeffrey mine in Asbestos needed a CA \$58 million loan, which the Quebec government agreed to guarantee.[52,61,74] Once completed, the mine would be able to export 225,000 tonnes of asbestos a year to countries in Asia.[61,74] However, intense media scrutiny of the loan guarantee prompted a newly elected Quebec government to cancel the deal in September 2012.[61,74] Both Quebec mines closed down completely shortly thereafter.[61,74]

These events illustrate a relatively rapid surmounting of lock-in to asbestos. Days after the new Quebec government essentially shut down the industry by canceling the loan guarantee, the Canadian government announced that it would no longer oppose the listing of asbestos under the Rotterdam Convention as a "logical consequence"[77] of recent events, not because of the hazards of asbestos, but because asbestos was no longer domestically important. A few months before, in March 2012, Canada ceased its funding for the Chrysotile Institute, which then closed.[61,74] The money intended for the loan guarantee was diverted to support the economic transition of affected workers and towns.[61,74] In 2018, a complete ban on asbestos use was implemented in Canada.[78] Canada's role in obstructing the listing of asbestos under the Rotterdam Convention has largely been taken up by other producers of asbestos, with the listing remaining undecided as of March 2022.[79]

During these years in which Canada supported its asbestos industry in spite of public health evidence and guidance, Canadian asbestos workers and their close contacts continued to be exposed to the mineral, the effects of which will continue for years to come. In 2011, 2331 cases of mesothelioma and lung cancer were attributed to asbestos exposure in Canada with an estimated burden of CA \$831 million in direct and indirect costs.[58] Projections estimate that the number of new cases of mesothelioma would peak in 2020 for men and in 2025 for women, with a total average of 315 cases per year between 2008 and 2032.[63] Further, most exposure to Canadian asbestos will occur in importing countries, which are mainly lower-income countries with more lax environmental and occupational regulations than Canada.[64] These countries will not have the same capacity that Canada has to deal with the health, societal, and economic burdens of asbestos-related diseases.

When the hazards of asbestos became known, Canada's lock-in to asbestos production ensured that the government continued to support the industry and even acted to increase demand for its supply in other countries. Canada did so while moving to limit the exposure of its own population to the mineral. Encouragingly, Canada did eventually overcome its lock-in to asbestos supply through a complex interplay between economic, social, and political considerations. The same loan previously intended for retaining the status quo was repurposed to support the transition of affected workers and towns, a path to breaking lock-in that can be considered elsewhere. Had investments such as those into the Chrysotile Institute been used instead for a transition out of asbestos, it may have been possible to break the lock-in earlier, thereby reducing health and societal costs.

■ PATH FORWARD

As these case studies show, lock-in occurs through a complex interplay on both sides of the supply−demand relationship. Occurring on different geographical scales, lock-in comes through and is the effect of the interactions between economic investment, social factors, politics, and technological constraints.

Yet, current measures to manage hazardous chemicals generally have narrow scopes, focusing primarily on either supply or demand without a global perspective of the supply−demand relationship. For example, European countries limited their own demand for paraquat while continuing to supply other countries. For PFOS and its precursors, the rapid phase-out of 3M's supply in the US, while global demand remained largely intact, practically invited the increase in production elsewhere. This brought challenges for China and other producers when global restrictions on demand were developed. Conversely, when demand for asbestos in high-income countries shrank amid health concerns, the viability of Canada's supply was threatened, causing Canada to create demand in new markets. This action by Canada has caused the exposure of populations in these markets to a well-demonstrated health hazard. Sadly, the low-income countries, whose populations are most vulnerable to the adverse effects of hazardous chemicals, are also the most vulnerable to locking into their production and/or demand, while bearing the attendant costs of harm. This is largely due to a lack of national capacity and regulatory frameworks for understanding the full scale of risks (including externalized long-term health and societal costs) and managing them, as well as a lack of technical and financial capacity to transition to safer alternatives.

These case studies further illustrate the limitations of current regulatory frameworks for hazardous chemicals in addressing the complex economic, social, technological, and political dynamics and their interactions: most current chemicals management frameworks fail to address the concerns of relevant stakeholder groups enmeshed in lock-in, from producers (e.g., the asbestos miners in Canada) to consumers (e.g., downstream industrial users of PFOS and its precursors; farmers in low-income countries that became dependent on paraquat over the decades).

To increase effectiveness by breaking lock-in, regulatory and policy frameworks need to adopt more holistic perspectives, including expanded consideration of both sides of the demand−supply relationship and externalities such as societal costs of public healthcare and cleanup.

For paraquat, breaking lock-in entails the costs for manufacturers of developing and industrializing alternative products and for establishing soft infrastructure in low-income countries to assist local industry and farmers in adopting alternatives. The continued use of PFOS and its precursors exemplifies the need to work with not just one manufacturer in one country (3M in the US) for an immediate phase-out of a chemical. Rather, work needs to commence early on at a global scale through, for example, multilateral environmental agreements such as the Stockholm Convention. This work would entail developing and implementing a comprehensive plan for phase-out and transition to safer alternatives in a reasonable time frame. Canada's experience with asbestos demonstrates that decades-long support of an industry, based on short-term direct economic and political benefits, can have significantly higher long-term health and societal costs. Instead of prolonged support for asbestos production and essentially supporting the growth of international demand, lock-in could have been broken earlier through support for transitioning affected mining communities.

These examples make the case for taking a more comprehensive approach to managing hazardous chemicals. Against the background of increasingly intensified global trade of resources, chemicals, and waste, it is time to strengthen global measures so that they can react rapidly to issues with emerging evidence of concern by addressing both the supply and demand of hazardous chemicals in a holistic manner. It is also time to embed long-term thinking and to consider all relevant actors and interactions on national to international scales, relevant to lock-in when designing and implementing measures. Substantial initial investments and sunk costs may be seen as impossible hurdles in the short term; however, addressing these early on has proven to be more cost-effective and efficient in the long term. While not elaborated on above, it is expected that the lock-in perspective can support the development and implementation of effective class-based measures to phase out hazardous chemicals. This support comes from considering lock-in, which can lead to regrettable substitution as existing infrastructure and know-how are seen as the most feasible and economically viable solutions for substitution in the short term. Breaking the lock-in would promote making new investments in technologies and infrastructure to implement long-term, safer, and more cost-effective alternatives.

Learning from this Perspective, future studies are warranted to perform more detailed lock-in analysis on the management of hazardous chemicals to provide additional insights on lessons learned and factors effective for breaking lock-in. At the same time, with the United Nations Environment Assembly that has taken place in 2022 and the successor of the Strategic Approach to International Chemicals Management to be decided in 2022−2023, we call on policymakers, joined by leaders in business and civil society, to build comprehensive and creative solutions that are mindful of lock-in, to solve the global environmental crisis of chemical pollution.

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Notes

The authors declare no competing financial interest.

Biography

Dr. Zhanyun Wang has recently joined the Technology & Society Laboratory at the Swiss Federal Laboratories for Materials Science and Technology (EMPA). As an environmental chemist by training, his research interests focus primarily on understanding the life cycles and risks of various anthropogenic chemicals in the technosphere and natural environment. He is also very interested in exploring novel and pragmatic approaches to advancing sound chemicals management, enabling a sustainable circular economy, and strengthening the science−policy interface on chemicals and waste.

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