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水污染解决途径：从源头上削减化学品输入

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化学品 (包括药物及个人护理品) 的大量使用造成的水体污染已成为全球广泛关注的水质安全问题[1]。尽管这类污染物在水中的浓度不高，但其健康风险却不容低估，特别是多种化学品共存时，其导致的复合污染效已引起高度关注[2]。传统的污水处理和饮用水处理工艺对种类繁多的化学品并不能实现有效去除[3]，如何解决水中的化学品污染这一环境问题，成为环境科学与工程领域的一大挑战。2018 年，德国吕纳堡大学的 K. KÜMMERER 和美国辛辛那提大学的 D. D. DIONYSIOU 教授等提出了从源头削减化学品输入的水污染解决途径[4]，其主要观点发表在著名学术期刊《Science》上。

该文指出，鉴于当前污水和饮用水处理技术对水中化学品的去除普遍存在局限性，人们应该将更多的关注转移到化学品污染的源头预防上。只有采取了足够的源头污染削减措施，后续水的处理过程才更有针对性，才能更有效地实现水质控制目标。对于如何削减源头化学品输入，文章提出了如下几个方面的具体措施和建议。

对于来自工业废水中的化学品污染，可以采取的削减措施有：在生产过程中尽量减少各种化学品的使用；使用可生物降解的化学品替代不可生物降解的化学品；把具有不同成分的过程用水相互分隔开来；生产过程的辅助化学品实现完全闭环，做到重复利用 (零排放)。实践已经证明，在半导体和纺织等工业行业，通过分离、结晶、纯化等技术手段实现污染零排放是可行的。对于市政污水来说，实现源头分离和重复利用较为困难，但在生活日常用品 (如洗涤用品和化妆品) 中尽量使用可生物降解的成分，并尽可能减少化学品种类和用量是可行的。绿色与可持续化学方面的研究成果也为削减水体化学品的输入提供了一些解决方案。

从化学品的设计开始就充分考虑其环境友好性，并对其进行全生命周期评价也是解决水体污染问题的一个重要措施。通过对产品设计和组成成分的改进，可以实现其在工程过程或自然过程中被彻底分解和矿化。

除了上述措施，还应该超越对化学品功能和应用的单一认识，深入了解原材料和产品在局部、区域、国家乃至全球层面的变化和流动动态，不断提高对产品设计目标和功能的全方位认

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识，从而找到减少化学品种类、降低化学品复杂性的可行途径。

从政策和制度层面，政府应该大力提倡源头控制，激励企业创新，生产环境友好的化学品，鼓励消费者使用低毒和易降解的化学品。对于企业排污收费要综合考虑各项指标，不仅包括化学需氧量、氮、磷等传统指标，也应对持久性有机化合物、重金属等污染物设定限值，增加非绿色产品的生产成本。

文章最后强调，既然人们对化学品危害性的认识和相应限值的建立总是落后于新化学品的增加速度，那么，采取化学品污染的预防性措施、从源头降低其输入应是必然的选择。

我国目前的水污染形势依然严峻，水体污染控制与治理急需新的思路和战略规划，该文提出的观点值得业界思考和关注。

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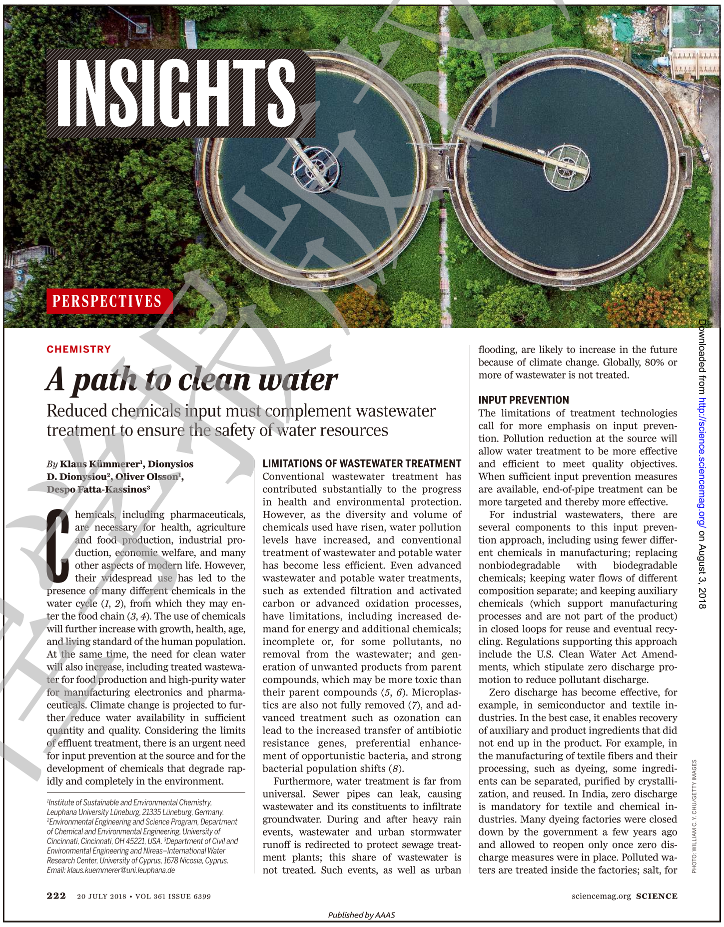

INSIGHTS

PERSPECTIVES

CHEMISTRY

A path to clean water

Reduced chemicals input must complement wastewater treatment to ensure the safety of water resources

By **Klaus Kümmerer[1], Dionysios D. Dionysiou[2], Oliver Olsson[1], Despo Fatta-Kassinos[3]**

Chemicals, including pharmaceuticals, are necessary for health, agriculture and food production, industrial production, economic welfare, and many other aspects of modern life. However, their widespread use has led to the presence of many different chemicals in the water cycle (*1*, *2*), from which they may enter the food chain (*3*, *4*). The use of chemicals will further increase with growth, health, age, and living standard of the human population. At the same time, the need for clean water will also increase, including treated wastewater for food production and high-purity water for manufacturing electronics and pharmaceuticals. Climate change is projected to further reduce water availability in sufficient quantity and quality. Considering the limits of effluent treatment, there is an urgent need for input prevention at the source and for the development of chemicals that degrade rapidly and completely in the environment.

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LIMITATIONS OF WASTEWATER TREATMENT

Conventional wastewater treatment has contributed substantially to the progress in health and environmental protection. However, as the diversity and volume of chemicals used have risen, water pollution levels have increased, and conventional treatment of wastewater and potable water has become less efficient. Even advanced wastewater and potable water treatments, such as extended filtration and activated carbon or advanced oxidation processes, have limitations, including increased demand for energy and additional chemicals; incomplete or, for some pollutants, no removal from the wastewater; and generation of unwanted products from parent compounds, which may be more toxic than their parent compounds (*5*, *6*). Microplastics are also not fully removed (*7*), and advanced treatment such as ozonation can lead to the increased transfer of antibiotic resistance genes, preferential enhancement of opportunistic bacteria, and strong bacterial population shifts (*8*).

Furthermore, water treatment is far from universal. Sewer pipes can leak, causing wastewater and its constituents to infiltrate groundwater. During and after heavy rain events, wastewater and urban stormwater runoff is redirected to protect sewage treatment plants; this share of wastewater is not treated. Such events, as well as urban flooding, are likely to increase in the future because of climate change. Globally, 80% or more of wastewater is not treated.

INPUT PREVENTION

The limitations of treatment technologies call for more emphasis on input prevention. Pollution reduction at the source will allow water treatment to be more effective and efficient to meet quality objectives. When sufficient input prevention measures are available, end-of-pipe treatment can be more targeted and thereby more effective.

For industrial wastewaters, there are several components to this input prevention approach, including using fewer different chemicals in manufacturing; replacing nonbiodegradable with biodegradable chemicals; keeping water flows of different composition separate; and keeping auxiliary chemicals (which support manufacturing processes and are not part of the product) in closed loops for reuse and eventual recycling. Regulations supporting this approach include the U.S. Clean Water Act Amendments, which stipulate zero discharge promotion to reduce pollutant discharge.

Zero discharge has become effective, for example, in semiconductor and textile industries. In the best case, it enables recovery of auxiliary and product ingredients that did not end up in the product. For example, in the manufacturing of textile fibers and their processing, such as dyeing, some ingredients can be separated, purified by crystallization, and reused. In India, zero discharge is mandatory for textile and chemical industries. Many dyeing factories were closed down by the government a few years ago and allowed to reopen only once zero discharge measures were in place. Polluted waters are treated inside the factories; salt, for

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