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A Farewell to Harms: The Audacity to Design Safer Products

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TOO MANY CHEMICALS

The unprecedented explosion of the manufacture and adoption of synthetic chemicals into commerce after World War II introduced a panoply of products and materials that improved the standard of living for many people and spawned a multitrillion dollar chemical industry. From plastics to pharmaceuticals, building materials to electronics and glues, many of these innovative products have made life easier to afford and enjoy. Computers are accessible to the general public, clothing options are mind-boggling, and our access to consumer goods produced from petroleum-based chemicals is essentially unlimited. But we need to stop and ask ourselves: Are there too many chemicals?

Firmly acknowledging the societal benefits resulting from advancements made by the chemical enterprise, we must also observe, with the same unbiased eye, that the consequences of unintended hazard tethered to the process of chemical production and utilization have resulted in lamentable environmental degradation and adverse impacts on human health. These environmental side effects have most often manifested because of a lack of systems thinking in the life-course of chemical manufacturing and distribution. As a modern society, we have done a poor job determining the fate and effects of compounds before they reach the market. Even though we have extensive testing programs, too many adverse effects are discovered after products and chemicals are distributed throughout our environment. To start, we should determine the “molecular itinerary” of a compound, knowing or predicting the where, when, why, who, and when of a molecule’s odyssey. This is analogous to a travel agent providing a detailed itinerary for a long, multicity trip. If both are done correctly, everyone is happy, healthy, and returns home safely with adverse events avoided or minimized.

COMFORTABLY NUMB

Society has come to accept the practice of incorporating chemicals into consumer products without questioning the potential harm that these molecules could have on their health, the
The health of their children, or to the Earth. We should spur the notion of “acceptable” risk in our products and materials. Hazard must be considered a design flaw and minimized or eliminated as part of any endeavor to create new products, treat drinking water, or develop the ubiquitous handheld electronic device. Although many products undergo extensive testing, the general public falsely assumes that industry and regulatory entities are able to assure safety of all chemicals before their introduction into commerce. If we are unable to evaluate the potential consequences of human exposure, then we must again ask, are there too many chemicals?

**DESIGNING SAFER CHEMICALS**

Is there a way to design safer materials and products or reduce the number of chemicals we use?

The short and encouraging answer is yes, but the task is not trivial. People generally purchase a function, not a chemical. For example, a person chooses a color for a new couch, not a pigment. It would be preferable that the color red could be achieved without using a potentially hazardous dye pigment. Scientists have successfully mimicked the tiny structures used to make multicolored butterfly wings so beautiful, suggesting that our ability to design colors has evolved to a point where we can utilize materials with a much better safety profile.

Ideally, each chemical would have a complete and comprehensive profile available for all to see; however, that is presently not the case. Most of the 80,000 or so chemicals in the marketplace are toxicologically stealth, thrust upon the marketplace devoid of background checks. We can and must remedy this unsustainable situation. Enterprising chemists, with the input of toxicologists, environmental, and other allied scientists, have the potential to rehabilitate delinquent molecules by adding, subtracting, or otherwise altering molecular features, to reduce hazard. This rehabilitation results in new molecules, each of which must endure independent scrutiny to characterize hazard (preferably *a priori*).

**TWENTY-FIRST CENTURY TOXICOLOGY**

The adage “what doesn’t kill you makes you stronger” is not applicable to chemical exposures. As a society, we continue to design molecules and products and materials in the absence of adequate toxicology information at our own peril. Although many industries invest considerable effort into designing safer products, there are still numerous sector and companies that do not prioritize safety. Premature production and commercialization of inadequately characterized products subjects us to unknown risks of illness, premature death, and possible loss of environmental resources. Walking quickly, eyes straight and cocksure, toward the edge of a cliff with an uncharted end is not a sound strategy for wellbeing at the individual or societal level. We can and must do better. We can reimagine the chemical enterprise.

Intelligent researchers, armed with modern science, powerful computers, and support from renewed societal interest in embracing a more sustainable lifestyle, gave birth to a new way of evaluating hazards, particularly harmful chemicals. Toxicology in the 21st Century, or
Tox21, is the child of this renaissance in toxicology that endeavors to understand the how and why something causes cancer, or brain damage, or birth defects, not merely that it does. Moreover, efforts like Tox21 attempt to greatly increase the number of compounds for which we have toxicity data. This type of information, understanding the mechanisms of toxicity, is a sea change in both understanding the toxicity of existing chemicals and providing molecular designers with critical guidelines to design safer chemicals and products. Imagine the satisfaction and peace of mind that comes from knowing the chemical you are putting on the market has undergone rigorous safety testing. This puts the horse before the cart, where it belongs.

IN OVER OUR HEADS?

Green Chemistry and Toxicology represent a modern Thermopylae. The Spartans’ plan at this infamous battle was brilliantly conceived and courageously executed. Against all odds and severely outnumbered, they devised a bold, innovative plan, fought valiantly, and nearly defeated an enemy with far superior numbers. Although ultimately defeated, the Spartans made a statement to take a heroic stand, refusing to yield. This act can provide inspiration to modern day scientists to act with mirrored conviction to dramatically reduce the toxicological burden from our places of business, homes, and environment. Exposures to complex environmental mixtures, such as air pollution (Cohen et al., 2017), have killed many more than died at Thermopylae, making this analogy more apropos than one may want to admit. The enemy at our gate numbers over 80,000—the estimate of synthetic chemicals in usage today. Although many among those may be friend and not foe, without more than a minimal understanding of their toxicity it is impossible to tell the difference.

Are there too many chemicals? As toxicologists, it is reasonable to state that here are too many chemicals for which we have inadequate toxicity data. However, over the next century we will need even more chemicals to address pressing societal, industrial, and medical needs. The diversity of chemical space provides a wealth of new molecules with ever more unique functions. We do not want to stifle innovation. Innovation and technology requires the development of new precursors and components that allow us to have more effective medication, more powerful gadgets, and more efficient transportation. However, the challenge is that as we design and produce new chemicals we must do so with an aggressive effort to minimize harm to human health and to our environment. Toxicology would benefit from a shift from reactionary science to one of preemptive science. However, this is not something the field of toxicology alone can accomplish; it will require engagement with those involved in the design and manufacturing processes. This is where the partnership with Green Chemistry enters. Green Chemistry embraces preemptive science and is in need of toxicological expertise. The fields of Toxicology and Green Chemistry have complementary goals and need to develop more extensive collaborations.

Four years ago Toxicological Sciences published an editorial encouraging this type of collaboration between the fields of Green Chemistry and Toxicology (Zimmerman et al., 2014). This issue provides a series of articles that represent a next step in this collaboration and explore the future of green chemistry and how toxicologists can participate in the improved design of chemicals (Albert et al., 2018; Coish et al., 2018; DeVito, 2018; Hartung
and Maertens, 2018; Kokel and Török, 2018; Ostadjoo et al., 2018; Rusyn and Greene, 2018). We hope that this series of articles will draw attention to the need for the fields of Green Chemistry and Toxicology to work together to help address the current and emerging challenge we face from our chemical world.

References


Figure 1.
The greening of chemistry. Approaches that lead to the development of chemicals and products that minimize impact on our environment can help transition us from the Industrial Age to the Green Age. Toxicologists and chemists have important roles to play in this transition.