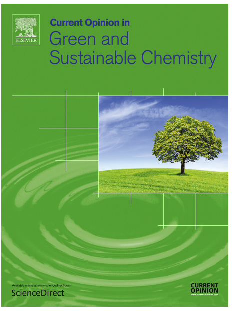

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The United Nations Sustainability Goals:
How Can Sustainable Chemistry Contribute?

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The United Nations' Sustainable Development Goals (SDG's)[1] have exceptional value in identifying key areas of challenge that need urgent improvement if we are to move away from the unsustainable trajectory that we are on. The place that is a major shortcoming of these goals is that they take a highly integrated and inextricably linked system, and express them as individual areas such as food, water, poverty, materials, empowerment, etc. In the absence of systems thinking, there is an excellent chance of noble intentions bringing about unintended and perhaps counter-productive consequences [2]. As we employ sustainable chemistry and the tools of its scientific basis, green chemistry, to address so many of these challenges, it is important to integrate these tools not as isolated individual principles or methods, but rather as an integrated interconnected system as well.

The pursuit of a sustainable society and civilization is the challenge that has been recognized by our generation and will definitionally need to be met by all generations into the future [3]. These challenges are at the centerpiece of the UN Sustainable Development Goals. It is difficult, if not impossible, to imagine a scenario where the goal of sustainability can be attained unless the fundamental chemistry that comprises the material and energy basis of our society and economy is transformed to be healthful rather than toxic, renewable rather than depleting, and restoring rather than degrading [4].

While there have been isolated examples of making individual chemical products or types of synthetic methods more environmentally benign over the course of the past century [5,6], a systematic approach to the design of chemistry aligned with sustainability was introduced in 1991, defined as "the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances" and codified by a set of principles in 1998 [7]. This approach known as green chemistry has been practiced in academia and industry throughout the world and has created a body of knowledge that is an important scientific foundation for the changes that need to take place in the move toward sustainability.

The term 'sustainable chemistry' has been introduced more recently and possesses numerous definitions [8,9,10,11,12] that have propagated by individuals, researchers, companies, trade associations, not-for-profit organizations, and governmental entities. One of the world's largest retailers, Walmart, even uses the definition of green chemistry as its definition of sustainable chemistry [13]. While there are groups and individuals that are happy to say that green chemistry and sustainable chemistry are the same thing, there are others that propose substantively different definitions for sustainable chemistry from that of green chemistry [14].

Why are definitions important?

What is being proposed in all of these discussions and debates is a conceptual construct that can act as a framework for change from the status quo of traditional chemistry over the past two centuries. One essential element in the introduction of any new definition, especially of a concept, is clarity. Vague, nebulous, and plentiful definitions of a single concept are antithetical to bringing about the kind of alignment and focus that the new concept is trying to drive. In other words, if people are confused about what sustainable chemistry even is, it is difficult to imagine that from that confusion will arise a clear path on how to attain it.

Green Chemistry has, from the outset, been known as “the chemistry of sustainability” [15]. Key to this is moniker is the obvious fact that **green chemistry is chemistry.** There are few people that would argue that a sustainable world can be achieved in the absence of green chemistry. However, it is equally true that green chemistry alone, no matter how fundamental, broad in reach and impact, is not going to be sufficient for achieving a sustainable civilization.

Sustainable chemistry - genuine sustainable chemistry that is not merely a marketing phrase - cannot be conducted in the absence of green chemistry. If, as some have suggested, sustainable chemistry is merely using chemistry to address sustainability problems such as those addressed in the SDG’s climate change, energy generation, water purification, food production, or the manufacture of medicines, regardless of adhering to the Principles of Green Chemistry, this would allow for the high potential of tragic unintended consequences. These are sometimes referred to as “doing the right things wrong” [16]. Purifying water to achieve disinfection may be doing the right thing. But if you achieve it with acutely lethal substances such as chlorine that creates persistent and toxic disinfection by-products – you’d addressed a sustainability challenge in an unsustainable way.

Just as you cannot bake a delicious cake with rotten eggs and spoiled milk, you cannot achieve sustainable chemistry or a sustainable world if the material basis is toxic and depleting. Therefore, any construct of genuine sustainable chemistry would need to recognize that Green Chemistry needs to be its centerpiece, heart and soul, central and essential element.

However, as we recognize that there is more to a sustainable world than just chemistry, we need to recognize that there are and should be many more aspects to sustainable chemistry. These aspects should enable and empower the conduct and impact of the chemistry of sustainability. This requires an ecosystem of economics, policy, interdisciplinary engagement, equity, education, regulation, metrics, and awareness.

THE CHALLENGES OF SUSTAINABLE CHEMISTRY RELEVANT TO SDGs

It would be easy and simplistic to create a listing of the technological overlaps between the UN SDGs and green-sustainable chemistry. Because chemistry is at the molecular level it necessarily is relevant to the wide range of topics including health, means of production, well-being and health, clean water, food production, ecosystem health, etc [17]. The less obvious wicked problem is the non-technical aspects of sustainability. If sustainable chemistry is striving to be a central driver in achieving the power and potential of using chemistry for achieving sustainable development goals, then there are a number of challenges that it needs to address across all aspects of the chemical enterprise and all elements of society that this enterprise impacts.

Economics

Transforming our traditional chemical enterprise into one aligned with a sustainable trajectory requires significant change. Currently, there is a very high investment in status-quo infrastructure that generally represents, at best, the design thinking and awareness of ecological and societal consequence of many decades ago. If the mining methods, manufacturing methods, distribution methods, and use profiles were developed before there was an awareness of sustainability consequences, there is no reason to believe that they were optimized, or even adequate for today’s circumstances. Einstein is often quoted as saying “Problems cannot be solved at the same level of awareness that created them.” With our current level of awareness of what is acceptable for an enterprise to maintain its license to operate, comes a need for a new level of investment.

The great challenge for the investment community is that the life-cycle for chemical products are extremely capital intensive – especially when compared to other low capital investments that financiers have as alternatives such as software applications. The idea that the highest and best use for a capital investment is to displace existing “pipe-in-the-ground” and transform it into a stranded asset is extremely difficult. These suboptimal and unsustainable assets are still producing profits and from an investment point of view, are not always the most unappealing.

What economic incentives need to be put in place to mobilize capital such that the return on investment (ROI) profile is acceptable and attractive for investors? Some potential shifts include making the wasteful and toxic infrastructure less acceptable from either a legal or consumer perspective. Most of the legal requirements placed on a chemical product in the market, if they exist, are focused on the final molecule. There is little focus on the life-cycle of the product and the origins of its feedstocks nor the way it is transformed [18]. If the ability of a product to be legally sold were tied to whether it was sustainably produced, this has the potential to shift the investment profile for some of the largest chemical manufacturing processes.

It is a commonly accepted generalization that consumers are not aware of how their chemical products are made [19]. Much like legal perspectives, consumer perspectives are focused on the final product if at all and almost not at all on the products life-cycle. If consumers and even large retailers became aware of the processes by which these products were made, there would likely be a shift of some magnitude toward those that were less wasteful, depleting, and polluting [20]. With this shift, there would be a concombinent shift of appeal to financial investors since, once again, embedded flawed infrastructure, would be less useful.

Critical capital investment is also often stymied by the categories or investment "buckets" that often dictate consideration of various types of investment. For example, an investor may define areas of technology investments around water technologies, waste technologies, food technologies or energy technologies. One of the most exciting things that is coming out of the sustainable technology world is the discovery, development, and demonstration of so-called nexus technologies [21].

Nexus technologies are often defined as being able to accomplish several goals simultaneously, by design. For our purposes, this would be applied to sustainability goals. For example, a water splitting technology that enables renewable energy sources like solar or wind, allows for energy storage, and produces purified water [22]. Another technology may deal with waste sewage while producing energy or power [23]. A desalination plant may both purify water and capture unutilized energy sources [24]. Judging an investment on any of these nexus technologies requires looking at them as a whole system with multiple value streams, but yet too often these technologies are viewed in terms of a single investment bucket, energy-only, water-only, etc.

Systems thinking is not only necessary in our design of our chemical technologies, it's also essential in terms of our investment strategies if we are going to move to a world of sustainable products, processes, and systems.

Equity

The chemistry of sustainability cannot simply be the chemistry of the wealthy and powerful few. Any vision of sustainable chemistry needs to be inextricably linked to equity. The chemical enterprise, while bringing about life-saving medicines, increased food production, and eradication of many pests, has also played a role, both directly and indirectly, in environmental injustice and health/welfare disparities [25]. Acute tragedies from living in close proximity to chemical manufacturing, transport, and disposal are well documented internationally [26,27] as are the statistical chronic health consequences of "fenceline" communities [26]. The products most likely to contain some of the most questionable chemicals of concern are also those that are the lowest price and most likely to be purchased by those in the lowest socio-economic stratum.

Economic drivers may require that the new performance and innovations that many green chemistry technologies are demonstrating a priced at a premium to justify the research, development, and risk taken to develop new products. However, achieving products that perform their current functional performance but have been rid of the toxicity or other hazards must not come at an economic penalty to the most economically vulnerable. To do so, would relegate freedom from poisoning as something that can only be purchased by the economically privileged.

In addition, many of the chemical technologies being developed are most immediately applicable in the industrialized world. These technologies often fit within established supply chains and manufacturing schemes. However, in the developing world and emerging economies, there are often different circumstances related to the availability of reliable power, the extent of export/import infrastructure, the relationship between labor and mechanized productivity, etc. For these reasons, simply putting green chemistry technology designed for industrialized systems, would be either ineffective or counter-productive. Design of "appropriate technologies" means understanding the context and circumstances of where and how the new technology will be implemented [28]. Being able to productively utilize new chemistries that respect the cultural, societal, ecological, and ethnic sensitivities is as critical to the ultimate positive impact of a new product or process as the underlying science and engineering.

Regulatory Framework

As long as change in our current products processes, and systems is necessary to move toward sustainability, innovation will need to be encouraged and the status quo will need to be discouraged. A regulatory floor that disallows practices that diminish the health of people, prosperity, and the planet must exist and be a certainty. Historical frameworks that provide lenient treatment of existing unsustainable chemistry must be dismantled and replaced by regulatory incentives to drive innovation within the sustainable chemistry context [29].

One pathway to driving this innovation is through a recognition that no one ever bought a chemical. The bought the function provided by the chemical. They bought service the chemical provided. They bought the performance of the chemical. In the same way, the societal goal to advance sustainability is not to regulate a chemical, it is to address the unintended consequences of the chemical. Therefore, rather than simply identify a list of individual chemicals, it will be most important to identify those attributes that bring about the unintended consequences in the first place [30]. This approach has the benefits of being more effective and cross-cutting while preserving the ability of chemical designers to innovate and get maximum value for the efforts [31].

Empowerment - Who Does the Work?

It may be true that "Who does the research often decides what research gets done." What that often means is that if the population of researchers and those engaged in all aspects sustainable chemistry is not demographically diverse, then neither will be the perspectives that inform questions the key questions that frame the efforts. It is likely not a reasonable conclusion to believe that people of different backgrounds, genders, perspectives, life experiences, economic circumstances, ethnic heritages, national identities, are not all going to answer these questions in the same way; questions such as:

- How do you measure value? Of a product? Of an ecosystem? Of a life?
- How do you define performance? Narrowly around a specific function or broadly around all of the consequences of a product life-cycle?
- What risk is acceptable? To a worker? Consumer? The planet? Future generations?
- What are acceptable levels of return on investment? Private investment? Societal investment?

Sustainable chemistry needs to explicitly increase the diversity of those involved in the chemical enterprise because diversity begets resilience and homogeneity begets vulnerability. At a minimum, some unquantifiable part of the dilemma of traditional chemistry has come from the reinforcing echo brought about by the same voices representing a narrow slice of world of talent and wisdom that needs to be part of the solution.

Conclusion

The SDG's and sustainability writ large can only be genuinely advanced by chemistry designed to be sustainable such as that outlined and practiced through green chemistry. Sustainable chemistry promotes, advances, enables, and empowers the implementation of the chemistry of sustainability. Hmmm, sounds like a definition.

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