The role of chemistry in inventing a sustainable future

Stephen A. Matlin, Goverdhan Mehta, Henning Hopf and Alain Krief

The Sustainable Development Goals adopted at a UN summit in September 2015 address many of the great challenges that our planet faces this century. Chemistry can make pivotal contributions to help realize these ambitious goals, but first it must undergo major changes in its priorities, approaches and practices.

One of the most important and remarkable events in the 70-year history of the United Nations (UN) occurred on 25 September 2015, when the 193 member states — more than 150 represented at the head-of-government level — agreed on a collective global mission to transform the planet to achieve a sustainable future[1]. This mission is spelled out in 17 Sustainable Development Goals (SDGs) with a target date of 2030 (Box 1); progress towards them will be measured against 169 specific indicators[2]. These SDGs represent a profound shift in the world's approach to development over the past 15 years. Whereas the Millennium Development Goals agreed by governments at the UN in 2000 focused on specific problems of the world's poor and shaped the development aid policies of the richest countries[3], the new SDGs embrace a global vision of development for all, based on the core principle of sustainability and with responsibility shared by all countries. It is clear, however, that the SDGs will not be achieved without a massive effort: estimates[4] suggest that implementation of the goals, which was discussed in the three-day UN summit following their adoption, will cost US$5–7 trillion (approximately 7–9% of global GDP) every year until 2030.

Chemistry's role in the SDGs

The chemical sciences provide understanding of the physical and chemical properties of atoms and molecules and practical methods for creating new molecular structures with useful applications. Chemistry is a 'platform' or 'central' science, underpinning fundamental aspects of a range of established and emerging sciences including biochemistry, nanoscience, molecular and synthetic biology, physics and soft condensed-matter physics; as well as many major practical advances seen in such fields as agriculture, biotechnology, energy, ecology, the environment, genetics, information technology, materials and medicine; and the dramatic rises in overall human wealth and well-being during the past two centuries[5].

The UN's adoption of the SDGs has profound consequences for the world of chemistry and related molecular sciences. The chemical sciences can — and must — play a key role in developing the processes, products and monitoring mechanisms that the SDGs envisage. These emerging approaches must involve innovation that is frugal[6], disruptive[7] and widely applicable as well as sustainable. But to do so, all domains of chemistry — academia, industry, funding agencies, the professional bodies and associations at national and international levels — need to become involved and adopt the SDGs as a central concern and as a driving force for reform.

At the outset, it is vital that chemistry acknowledges that it has played a dual role in the unfolding picture of global development. On the positive side, the knowledge and products contributed by chemistry — providing sources of energy; a host of materials including polymers, plastics, semiconductors and solid-state display devices; agents for crop protection and plant growth; pharmaceuticals and much else — have been a major factor in the advances in human wealth, health and well-being over the past two centuries[8] and justify chemistry's claim[9] to be the 'quality-of-life' science *par excellence*. It promises to go on being the source of innovative new products and processes, including smart

Box 1 | Sustainable Development Goals.

1. End poverty in all its forms everywhere.
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
3. Ensure healthy lives and promote well-being for all at all ages.
4. Ensure inclusive and quality education for all and promote lifelong learning.
5. Achieve gender equality and empower all women and girls.
6. Ensure access to water and sanitation for all.
7. Ensure access to affordable, reliable, sustainable and modern energy for all.
8. Promote inclusive and sustainable economic growth, employment and decent work for all.
9. Build resilient infrastructure, promote sustainable industrialization and foster innovation.
10. Reduce inequality within and among countries.
11. Make cities inclusive, safe, resilient and sustainable.
12. Ensure sustainable consumption and production patterns.
13. Take urgent action to combat climate change and its impacts.
14. Conserve and sustainably use the oceans, seas and marine resources.
15. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.
16. Promote just, peaceful and inclusive societies.
17. Revitalize the global partnership for sustainable development.

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materials for better lifestyles, catalytic processes for light harvesting towards hydrogen production and carbon dioxide fixation, new vaccines and drugs for currently incurable diseases, 'nanobots' for drug delivery and sensors for disease diagnosis, to name but a few.

On the other hand, chemistry must also accept responsibility as one of the sources of many of the processes and products that have inadvertently contributed to a range of emerging global problems. The extent to which the activities of human beings are having a major effect on the physical characteristics of the planet is reflected in the adoption of the term 'Anthropocene Age' to describe the current period[10]. Changes to Earth's environment — air, land and sea — occasioned by human activity have accelerated in the past 200 years resulting in global warming, damage to the protective ozone layer and depletion of natural resources. Increasing energy consumption, industrial activity, population growth and urbanization add pressure to the planetary system and it is clear that major changes are now needed if multiple crises (relating to food, water, climate and energy) are to be avoided and humanity is to move to a path of sustainability.

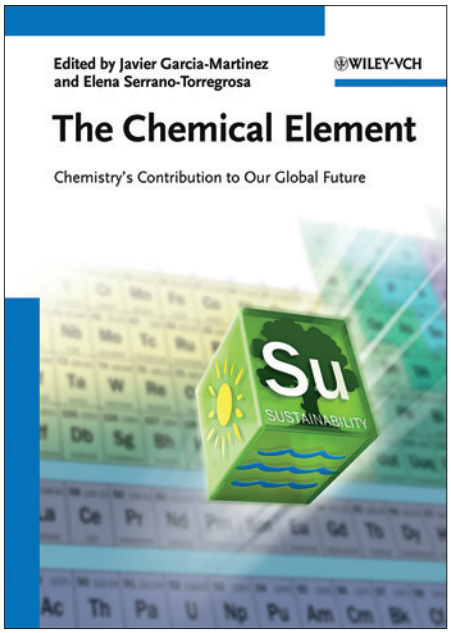
Ethical concerns should be incorporated in every endeavour related to the chemical sciences.

Chemistry must now engage vigorously as one of the key forces that can identify and implement solutions to avert or mitigate potential crises and provide sustainable processes and products for the future. As the basis of a wide range of technologies — in combination with its time-tested and well-established capacities for innovation — chemistry can help to meet all of the SDGs to varying degrees. In particular, the chemical sciences are central to (i) the development of clean and sustainable forms of energy, for example, through efficient capture of solar energy, clean fuel cells and carbon capture, storage and reuse; (ii) the application of green chemistry principles and processes to manufacturing and for materials substitution; (iii) ensuring the efficient and affordable recycling of resources in short supply including 'endangered elements'[11] and natural products; and (iv) developing new analytical techniques needed for more effective monitoring of the environment. Chemistry is also a key resource for addressing risk in an evidence-based and rational manner which acknowledges that no human activity can be entirely risk-free but that acceptable levels can be identified by risk assessment, management and mitigation. Thus, the SDGs provide an unrivalled opportunity for chemistry to embrace grand challenges and to make a positive contribution to the worldwide effort towards sustainability.

How chemistry must change

Sadly, there is little evidence of awareness of the SDGs, and their central importance, among the majority of practicing chemists or their professional bodies. How many people in the world of chemistry are even aware of the SDGs and of the multiple crises that they aim to address? Chemists too often busy themselves with compartmentalized, short-term problems and research interests and fail to see the bigger picture. As a group of chemists in the International Organization for Chemical Sciences in Development (IOCD) with a deep concern for the future of both the planet and the chemical sciences, we issue a call to all our colleagues to adopt the SDGs — just as their governments have done — and use this platform to reposition chemistry in a broader context and to ensure that chemistry plays its role as the central sustainability science[12,13]. The representation of a fictional new element 'Su' on the cover of a book marking the 2011 International Year of Chemistry (pictured) captured the essence of this ambition[14].

To achieve chemistry's potential, there cannot be business as usual. Education in chemistry at all levels needs reforms that will place its past achievements and current capacities in the context of the wider picture of global development. Such a change will not only motivate those who study chemistry in order to practice it, but also help to develop better chemistry literacy among the population as a whole. This increased level of understanding will lead to a greater awareness of chemistry's potential role in finding solutions to the challenges that lie ahead, rather than only being seen as a source of problems. Importantly, many of the contributions that chemistry can make towards the SDGs require working in close concert with other disciplines to identify solutions that are practical, affordable and sustainable. Chemistry should not be taught or practiced without an in-built consideration of these wider relationships — that is, education and practice in chemistry must be re-oriented so that it inculcates skills in inter-disciplinary and trans-disciplinary approaches informed by systems thinking and by concerns



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for the principles of sustainability and responsibility. The chemical industry should not fear sustainable chemistry as a new cost but rather see it as a new opportunity — for example, a 2011 report[15] estimated that green chemicals will save industry US$65.5 billion by 2020.

Chemistry is conducted in the real world and its practice impacts on many interconnected systems. For example, the waste generated by chemical reactions (whether from small-scale laboratory or large-scale manufacturing processes) needs to be safely and sustainably managed; the raw materials used must be sourced efficiently, cleanly, safely and sustainably; the products of manufacture which find household, industrial and agricultural uses must be tested for their biological and environmental safety and disposed of or recycled sustainably. Moreover, the human system is also part of the picture at every stage: chemistry events don't just happen — they are the result of decisions taken by people, related to diverse human drivers including curiosity and aspirations for success, wealth or power. The chemistry system therefore interlinks with a host of other overlapping systems including the biosphere, the environment, human and animal health, economics, politics and ethics.

An emphasis on ethical concerns should be incorporated in every endeavour related to the chemical sciences. The calls for industry to wholeheartedly embrace ethical rules and practices and engage in responsible chemicals management and responsible innovation[16] and the current efforts of the Organization for Prevention of Chemical Warfare (OPCW) to develop

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a 'Hippocratic Oath' for chemists[17,18] signal moves in the right direction — but they need to be adopted and actively driven forward by the major chemistry bodies and rigorously pursued.

Conclusions

Chemistry can re-imagine itself as a champion and driver of sustainable development, transforming its image from often being seen as the source of environmental pollution and degradation to being recognized as the core sustainability science — a key driver of practical, sustainable and ethical solutions to many of the world's greatest challenges in the twenty-first century.

To do so, it will need to undergo radical reforms that amount to a redesign of the field — encompassing chemistry's image, approaches and practices — that will affect education, research and its funding patterns, and engagement with other disciplines, industry and society. We believe that these changes are desirable because the world needs chemistry's best endeavours to avert or mitigate the many global crises that are currently unfolding. We also believe that the proposed changes will reinvigorate the entire field of chemistry and transform its appeal as an ethical science worthy of investment and esteem by society. ❐

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