The importance of sustainability ethics, toxicity and ecotoxicity in chemical education and research

Terry Collins,† Associate Editor for the Americas of *Green Chemistry*, strongly emphasises the important role of green chemistry in ensuring our sustainable future

Our modern high-technology civilization is not sustainable. This statement, since the publication of the Brundtland Report, has come to encompass two ideas presented here from the negative perspective. Firstly, many essential activities that, individually and collectively, are carried out each day to make our civilization work cannot be carried on into the indefinite future in anything approximating their current form. Secondly, we are operating our civilization in such a way that significant substance underpins the judgment that the welfare of future generations will not be comparably advantageous to our own. These ideas, now broadly accepted in a growing consensus, imply that someone is responsible for fixing things. If unsustainable technologies are part of the problem, the technical leadership has clear responsibility, and chemists are important members of that technical leadership. We must first ask, for each chemical problem identified, whether solutions are conceivable. If the answer is yes, our responsibility translates into a duty to engage fervently in finding solutions. If the answer is no, our responsibility translates into a duty to alert civilization to move away from the dependence that is undermining it.

Many technologies are part of our sustainability dilemma because their operation is incompatible with the long-term wellbeing of living things. Most of the known offenders are fundamentally chemical in nature and have developed since the First World War. We have been experiencing their benefits and discovering their damage for only a brief moment in human history and so it is not surprising that their novel sustainability challenges are difficult for us to deal with. The twentieth century growth in new technologies brought a dramatic increase in the quantity and complexity of the matter that flows daily from the ecosphere into the economy as its nourishment and, after the economic value has been extracted, back to the ecosphere from the economy as its waste. Some of the waste is toxic or ecotoxic, a portion of this exceptionally so, almost invariably in ways that were not perceived when the source technologies were developed. And undoubtedly, we will find other grim downsides of anthropogenic environmental pollutants to add to endocrine disruption, cancer causation, and stratospheric ozone depletion. Chemists are the master manipulators of matter and therefore, in principle, have the ability to design against toxicity and ecotoxicity.

†Lord Professor of Chemistry and Director of the Institute for Green Oxidation Chemistry, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA.

During the twentieth century, chemists essentially mastered synthetic chemistry. Of course, there is much more to learn but our synthetic organic colleagues can now make virtually any organic chemical found in nature. This is a dazzling historical accomplishment for human beings from a starting point in a little over a century ago. But also during the twentieth century and on rare occasions much earlier, we realised that certain chemicals exhibit potent toxicity and ecotoxicity. How is it that we chemists have become incredibly powerful at making molecules and materials while hardly informing our students of anything in the subject areas of toxicity and ecotoxicity? Is this not a major breakdown in common sense? Does this not leave our students incompetent to practice chemistry while simultaneously ensuring that known harmful consequences are avoided for themselves, other people and the environment? These errors of the twentieth century, still rampant in the United States but being set right in a growing number of universities elsewhere, cannot be allowed to persist into the twenty-first century. The case for action is strengthened as the sustainability dilemma dawns on us all, bringing into focus the until-now obscure subject of sustainability ethics, which must be taught as an integral component of chemical education. The most important book in the field was written by Hans Jonas—'The Imperative of Responsibility: Finding an Ethics for the Technological Age'.

How should education change to better promote a sustainable future? In most universities the requirements of understanding for new chemists in the fundamentals of sustainability ethics, toxicity and ecotoxicity asymptotically approach zero. When, where, and how will this knowledge that is pivotal for producing chemists who can competently advance towards a sustainable future through their work be introduced into the curriculum? Those portions of endocrine disruption, cancer causation and ozone depletion that result from human activity arise because of the chemical properties of the economy–ecosphere matter flows. Toxicity and ecotoxicity arise because certain chemicals, having functional groups or regions that are, for example, electrophilic, nucleophilic or lipophilic, interact through these philicities with biochemicals or environmental chemicals to produce reactions that negatively impact the natural order. The philicities are unifying concepts of chemical reactivity. It would not be a huge departure from the current mechanistically oriented pedagogical approach to integrate reactions that have toxic and ecotoxic consequences as illustrations of the reactivity concepts. Bernd Jastorff, Reinhold Störmann and Uwe Wölcke from the University of Bremen do precisely this in their highly creative German textbook entitled, 'Struktur-Wirkungs-Denken in der

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Chemie—eine Chance für mehr Nachhaltigkeit'. Hopefully, this landmark work will soon be translated into many other languages. Chemists must quickly gain knowledge of toxicity and ecotoxicity to allow the design ethos of green chemistry to work properly.

The challenge is not simply one of educating future chemists, but also one of informing existing faculty of the ability they have to contribute to sustainability through green chemistry research. The incentives for academic faculty to embrace sustainability research early in the history of green chemistry are considerable. Just as sustainability presents us with the most troubling and complex technical challenges we face, it also highlights the most important technological opportunities crying out to be cracked by today's chemists. Finding the solutions will result in major economic progress. The new green processes can benefit the inventors and their universities if the intellectual property is properly protected. While green chemistry funding in the United States is currently inadequate, as Joan Brennecke and Mary Kirchhoff pointed out in a recent editorial (*Green.Chem*, 2003, **5**(2), 614), the arguments for expanded support are overwhelmingly strong and eventually will prevail. It is the saving grace of human beings that young people are idealistic. Through sustainability-related research, young chemists can advance the human journey in an entirely positive manner. Therefore, senior chemists who embrace sustainability problems will have access to the rapidly growing number of first class graduate students who wish to pursue a career in green chemistry.

How will green chemists and others interested in the educational change brave the veto from those academic and industrial colleagues who reject the call for change? We must find ways because so much is at stake. Achieving a sustainable civilization is foremost among our goals, but treasured possessions are also on the block. For example, currently there is widespread debate and concern in the chemical community about the low quality of our public reputation with particular concern that this might be driving brilliant young people away from chemistry. Correcting the above educational deficiencies is a required foundation of any honest attempt to improve our image. The public relations efforts, which have become so popular within certain sectors of industry and which so often amount to little more than stabs at hoodwinking the public into believing that black is white, will likely drag us all deeper into the deceiver's quagmire. The fact that any particular sector of the chemical industry has done and may still be doing much good for humanity does not provide it with an adequate defense for wilfully distorting or suppressing information concerning the dangers of any of its processes or products. Yet this shallow defense, coupled with a commandeering of credit for outstanding contributions from other sectors, is too often the chosen camouflage when the deceit becomes public. This behaviour, wherever it arises, will continue to hurt the chemistry community as a whole.

There is no defense whatsoever for the chemistry community not to move on and address the educational and research challenges of sustainability. Those who worry that scientific depth may be at stake simply do not know enough about what is going on right now in the infant field of green chemistry. We would all do well to let go of our anxieties over imagined consequences for our academic and industrial systems and open our minds to green chemistry's boundless potential to advance the human condition. The chemical enterprise as a whole will get stronger, not weaker, in the exercise. Only by becoming competent at designing chemical reactions and processes that are consistent with a sustainable future can chemistry achieve the honorable state in the public arena that we all desire for it. Couple such a state with a reasonably staged movement away from existing polluting products and processes and the general public will begin to picture chemistry accurately as a vital, exciting, and noble life-promoting profession.

How should research change to better promote a sustainable future? There are two limits for strategic planning linked by a continuum. At one limit, we could simply wait and do little that is ambitious or remarkable, abiding by the conviction that the best approach for enabling the required genius and breakthroughs to manifest themselves will be to operate the current panoply of research support programs along traditional lines. However, we must succeed in moving expeditiously toward a sustainable future. It is completely unacceptable that the over-consumption of nonrenewable natural resources and toxicity and ecotoxicity should lead to the gradual or precipitous collapse of our civilization while we all stand by and watch. So if we choose to collectively function at or near this strategic boundary, then we must ensure that brilliant young scientists will find their own ways to launch sustainability-oriented research careers. If nothing more happens than the committed continue to talk, write, and otherwise promote chemical sustainability problems—that is all that will happen.

At the second extreme, we could establish significant funding programs in green chemistry and other areas of sustainability-related education and research. If we choose to collectively function at or near this strategic boundary, then we owe it to society to have confidence among ourselves that the resources will lead to genuine sustainability-promoting research. The chemical community will be well equipped to serve the public in this mode when it has developed generally-held convictions of what important green chemistry is and, equally important, of what it is not. This will require expanded debate and consensus within the community and this journal, *Green Chemistry*, can help by providing an appropriate forum.

In my opinion, it will be obvious when chemists have fulfilled their singular historic obligation to promote sustainability through education and research. Every newly graduated chemist will have a thorough understanding of the fundamentals of sustainability ethics, toxicity and ecotoxicity and will know how to avoid pollution when designing chemicals and chemical processes. Chemists will have developed nonpolluting affordable technologies suitable for mass distribution that can convert solar to electrical and chemical energy with high efficiency. Through the properly informed design of chemicals and chemical processes, an economically vibrant, safe technology base will have been invented that is attractive to industry while being neither toxic nor ecotoxic. Scientists will have expanded the use of renewable organic materials, obtained from recently dead as opposed to fossilized organic matter, and will have optimized their balance in the global composition of chemical feedstocks—green chemists are already major participants in this important work.

Green chemistry has the potential to provide modern man with his most potent technical rudder for changing the quantity and constitution of the ecosphere–economy–ecosphere matter flows to steer our civilization toward a sustainable course. Therefore, the development of this journal by the Royal Society of Chemistry represents a timely positive tug at the helm, as it will do much to propel green chemistry forward.