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Introduction: Green Chemistry

The first principle of the Rio Declaration on Environment and Development states that *Human beings are at the centre of concerns for sustainable development—they are entitled to a healthy and productive life in harmony with nature*,[1] which highlighted the challenge to all of us to define the objectives of *sustainable development* and to provide scientific, technological, and social tools to achieve those objectives. We do not have to look too far back to see how a society could loose its sustainability—the rise and decline of Easter Island, discovered by Polynesians around 400 AD.[2] Its population reached a peak at perhaps more than 10,000, far exceeding the capabilities of the local ecosystem. The forests were cleared for agriculture and to move the giant stone monoliths, known as "Moai"s, from 1400 to 1600. Core sampling from the island has shown deforestation, soil depletion, and erosion resulting in overpopulation, food shortages, and ultimately the collapse of the society. Thus, the history of Easter Island shows that the sustainability of our civilization depends on whether we can supply the rapidly increasing population with enough energy, food, and chemicals simultaneously without compromising the long term health of our planet.

The most important goals of sustainable development are reducing the adverse consequences of the substances that we use and generate. Foremost among the fundamental changes this calls for is the shifting of the production of energy and carbon-based chemicals from fossil fuels to renewable resources. While it is difficult to predict the exact date of the depletion of fossil fuels, the transition to renewable materials should be accelerated because of the frequently and unexpectedly changing political/economical environments resulting in limited access and rising costs. But perhaps of equal significance is the need to deal with toxicities that are threatening the welfare of essentially all living things in real time. At the apex of these various predicaments sits the need of the chemical enterprise to adjust to the threats of anthropogenic chemicals that disrupt the chemical signals controlling cellular development, i.e., the so-called "endocrine disruptors".

The role of chemistry is essential in ensuring that our next generation of chemicals, materials, and energy is more sustainable than the current generation. Worldwide demand for environmentally friendly chemical processes and products requires the development of novel and cost-effective approaches to pollution prevention. One of the most attractive concepts in chemistry for sustainability is Green Chemistry, which is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and applications of chemical products.[3] Although some of the principles seem to be common sense, their combined use as a designer framework frequently requires the redesign of chemical products or processes. It should be noted that the rapid development of Green Chemistry is due to the recognition that environmentally friendly products and processes will be economical on a long term.

This thematic issue addresses many aspects of sustainable development, and the 21 articles demonstrate the complexity and the rapid progress of many areas of Green Chemistry in the last decade or so. It is important to note that the development of green products and processes requires that chemists and chemical engineers become molecular designers[4] and molecular engineers, respectively. They have to incorporate the properties of chemicals that are relevant to health and to the environment into the discovery and development processes. This approach is demonstrated by the papers on Green Chemistry Considerations in Entropic Control of Materials and Processes (by S. Trakhtenberg and J. C. Warner, University of Massachusetts at Lowell, USA), Design of Sustainable Chemical Products—The Example of Ionic Liquids (by J. Ranke, S. Stolte, R. Störmann, J. Arning, and B. Jastorff, University of Bremen, Germany), Designing Small Molecules for Biodegradability (by R. S. Boethling, E. Sommer, and D. DiFiore, U.S. Environmental Protection Agency, USA), Toward Greener Nanosynthesis (by J. A. Dahl, B. L. S. Maddux, and J. E. Hutchison, University of Oregon, USA), "Green" Atom Transfer Radical Polymerization: From Process Design to Preparation of Well-Defined Environmentally Friendly Polymeric Materials (by N. V. Tsarevsky and K. Matyjaszewski (Carnegie Mellon University, USA), Greener Approaches to Organic Synthesis Using Microreactor Technology (by B. P. Mason, K. E. Price, J. L. Steinbacher, A. R. Bogdan, and D. T. McQuade, Cornell University, USA), and Human Pharmaceuticals in the Aquatic Environment: A Challenge to Green Chemistry (by S. K. Khetan and T. J. Collins, Carnegie Mellon University, USA).

The challenges posed by the utilization of carbon dioxide as a renewable feedstock are discussed in two articles on the Transformation of Carbon Dioxide (by T. Sakakura, J.-C. Choi, and H. Yasuda, National Institute of Advanced Industrial Science and Technology, Japan) and Making Plastics from Carbon Dioxide: Salen Metal Complexes as Catalysts for the Production of Polycarbonates from Epoxides and CO_2 (by D. J. Darensbourg, Texas A&M University, USA). While economically attractive technologies for biomass conversion into chemicals are slow to emerge, the currently available scientific results and potential developments are summarized in the paper on Chemical Routes for the Transformation of Biomass into Chemicals (by A. Corma, S. Iborra, and A. Velty, Universidad Politécnica de Valencia, Spain).

One of the key areas of Green Chemistry is the elimination of solvents in chemical processes or the replacement of hazardous solvents with environmentally benign solvents. The development of solvent-free alternative processes is, of course, the best solution, and some of the key issues are addressed in the article on A Green Chemistry Approach to Asymmetric Catalysis: Solvent-Free and Highly Concentrated Reactions (by P. J. Walsh and H. Li, University of Pennsylvania, USA, and C. Anaya de Parrodi, Universidad de las Américas-Puebla, Mexico). However, if a solvent is crucial to a process, we should select from alternative solvents that will have no or limited impact on health and environment. The application of alternative solvents such as water, fluorous and ionic liquids, supercritical media, and their various combinations is rapidly increasing. While the application of water as solvent is demonstrated in the paper on Reactions of C−H Bonds in Water (by C. I. Herrerías, X. Yao, Z. Li, and C.-J. Li, McGill University, Canada), its natural fit to an energy efficient technology is shown in the article on Microwave-Assisted Synthesis in Water as Solvent (by D. Dallinger and C. O. Kappe, Karl-Franzens-University Graz, Austria). Ionic liquids have been on the forefront of the use of alternative and greener solvents in the chemical industry. The potential of ionic liquids in various areas of chemistry is discussed in several papers, including Lanthanides and Actinides in Ionic Liquids (by K. Binnemans, Katholieke Universiteit Leuven, Belgium), Catalysis in Ionic Liquids (by V. I. Pârvulescu, University of Bucharest, Romania, and C. Hardacre, Queen's University Belfast, Northern Ireland). The impacts of dissolved gases on the performance of solvents are addressed in the paper on Gas-Expanded Liquids (by P. G. Jessop, Queen's University, Canada, and B. Subramaniam, University of Kansas, USA). Finally, the use of greener solvents and chemicals is demonstrated by the article on Green Analytical Methodologies (by L. H. Keith, L. U. Gron, and J. L. Young, Environmental & Chemical Safety Educational Institute, USA).

Catalysis remains one of the most important fields of Green Chemistry by providing atom-economical, selective, and energy efficient solutions to many industrially important problems. The development of greener catalysts is discussed in the articles on Heterogeneous Gold-Based Catalysis for Green Chemistry: Low Temperature CO Oxidation and Propene Oxidation (by B. K. Min and C. M. Friend, Harvard University, USA), Photocatalysis for the Formation of the C−C Bond (by M. Fagnoni, D. Dondi, D. Ravelli, and A. Albini, The University of Pavia, Italy), Biocatalysis in Ionic Liquids (by F. van Rantwijk and R. A. Sheldon, Delft University of Technology, The Netherlands), and Biocatalysis in Supercritical Fluids, in Fluorous Solvents, and under Solvent-Free Conditions (by H. R. Hobbs and N. R. Thomas, The University of Nottingham, U.K.).

Finally, we hope that the excellent science presented in this, the second, green issue of *Chemical ReViews*[5] will inspire future research to generate scientific innovations needed to keep our planet green in a blue sky.

References

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(3) Anastas, P. T.; Warner, J. C. *Green Chemistry: Theory and Practice*; Oxford University Press: Oxford, 1998.
(4) Horváth, I. T. *Acc. Chem. Res.* **2002**, *35*, 685.
(5) Thematic Issue on Environmental Chemistry, *Chem. Re*V. **1995**, *95*, 1−257.

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