RSC | Advancing the Chemical Sciences

Environment, Health and Safety Committee Note on: Green Chemistry

'Green Chemistry' rather than being a new branch of chemistry is a philosophy that seeks to reduce the environmental impact of chemical processes and products. It can be considered as chemists aspiring to the principles of Sustainable Development (*Our Common Future*, 1987). This Note is designed to provide information and general guidance for members of the RSC, and to raise awareness of the principles and benefits of Green Chemistry. It is not intended to be a full or definitive guide and readers are urged to obtain more detailed information and/or expert advice if this is required.

The RSC recognises that there can be both real and perceived barriers to the greater adoption of green chemistry. However we believe that overall it should represent a major step change in the practice of chemistry. The practice of green chemistry is one of the most important ways in which chemistry and chemists can contribute to sustainable development.

WHAT IS GREEN CHEMISTRY?

Society has many concerns about 'chemicals' and their uses. For example safety issues such as fire and explosion, health effects such as carcinogenicity and endocrine disruption, and environmental impacts such as ozone depletion, climate change and impacts on ecosystems. The true extent of such risks is the subject of debate, and it can be argued that too little attention is given to the corresponding benefits that chemicals bring to society. Burgeoning pressure from consumers to address environmental concerns combined with increased focus on sustainable development have led to a sharp increase in the legislative monitoring of chemicals. One such piece of regulation, REACH (Registration, Evaluation and Authorisation of Chemicals) has been implemented by the European Union with the key central aim 'to protect human health and the environment from the risks arising from the use of chemicals.' Nonetheless society's growing concern for the environment and pressures for greater control of chemicals in the environment have now coalesced in the arena of 'Sustainable Development'. 'Green chemistry' is a major component in the way that chemistry as well as the chemical and related industries, have led and responded to sustainable development.

'Green chemistry' is essentially a philosophy rather than a new branch of chemistry. It requires that chemists examine products from a life cycle perspective and consider how green product design can be applied to minimise the environmental impacts of a product in its production (including raw materials), use, disposal and at end of life. It involves pulling together tools, techniques and technologies (the so called green chemistry toolkit) that can help chemists and chemical engineers in research, development and production to design and develop more eco-friendly and efficient products and processes, which may also have significant financial benefits. An objective is to imbed the green chemistry toolkit into the practice of all chemists. The principles involved apply equally to the use of chemicals in for example laboratories and education as well as in industry.

The term 'Green Chemistry' was first coined by the US Environmental Protection Agency. Their early definition of the subject is still widely quoted: *"'Green Chemistry' is the utilisation of a set of principles that reduces or eliminates the use or*

This Note was produced by a Working Party of the Environment, Health and Safety Committee [EHSC] of the Royal Society of Chemistry.

The Society is a registered Charity. Its Royal Charter obliges it to serve the public interest by acting in an independent advisory capacity. In order to meet this obligation the members of the EHSC are drawn from a wide range of backgrounds and serve on the committee as individual experts and not as representatives of their employer.

The EHSC welcomes comments on this Note. Please send them to the Committee Secretary:
Health, Safety and Environment Committee
Royal Society of Chemistry
Burlington House
Piccadilly
London
W1J 0BA

Tel: +44 (0) 207 440 3337
Fax: +44 (0) 207 437 8883
Email: ehsc@rsc.org

EHSC Notes are also available on the Society's web site at www.rsc.org

EHSC Notes are updated from time to time and details of the most up to date versions can be found on the Society's website www.rsc.org

Version 2: 04 December 2008

generation of hazardous substances in the design, manufacture and application of chemical products". However in practice 'Green Chemistry' is nowadays taken to cover a much broader range of issues than the definition suggests. As well as using and designing and producing 'better' chemicals with less waste, 'Green Chemistry' also involves reducing other associated environmental impacts, in particular reducing the amount of energy, non-renewables and other critical resources (e.g. water) used in chemical processes.

In practice 'Green Chemistry' embraces concepts such as:

- Atom efficiency (yield improvement) - designing processes to maximise the amount of raw material that is converted into the product
- Energy conservation – designing more energy efficient processes
- Waste minimisation including waste hierarchy - recognising that the best form of waste disposal is not to create waste in the first place
- Substitution - using safer, more environmentally benign raw materials and solvents or solvent free processes
- Replacing fossil fuel derived feedstocks and building blocks with those sourced from sustainable natural resources
- Improving the safety of chemical reactions and processes
- Designing chemical products with small environmental footprints including environmental compatibility at end-of-life

Reducing materials and energy use includes both raw materials and materials of construction. This clearly involves chemical engineering concepts such as process intensification. Waste is increasingly expensive to dispose of and is a major source of pollution arising from the chemical industry. Maximising atom efficiency is linked to waste reduction. This means designing chemical reactions so that as many atoms of starting material as possible end up in useful product. Although this seems common sense, sadly this approach is often not pursued. By improving resource efficiency 'Green Chemistry' should provide financial benefits from lower material usage, energy and capital expenditure costs in addition to the environmental benefits.

'Green Chemistry' also aims to reduce hazards and the risk to people as well as to the environment. This involves concepts such as inherently safe design of reactions and substitution of hazardous chemicals or those that pose a high risk. The RSC has produced a companion EHSC Note on 'Inherently Safer Chemical Processes'. The issue of substitution to reduce hazard and/or risk is a complicated one and an RSC Policy Statement on 'Risk-based Substitution in Chemical Processes', explores this issue in more detail.

It will be evident from the above that as with other sustainable development issues 'Green Chemistry' crosses traditional discipline boundaries. It involves 'joined up thinking' for example between chemistry, chemical engineering and other disciplines. If industry is to develop the cleaner processes and safer products now being demanded by the law and the public it will need to establish multi-disciplinary teams at the conceptual stage to pursue the 'Green Chemistry' approach.

In addition, in common with most sustainable development issues, 'Green Chemistry' often involves compromises and trade offs, for example reducing the energy used in a particular process might mean using slightly more toxic substances.

WHAT IS THE ROLE OF CHEMISTS IN 'GREEN CHEMISTRY'?

Chemists can use their knowledge of 'Green Chemistry' and its benefits to justify research into 'cleaner and greener' products and processes. In most cases it is readily demonstrable that a 'Green Chemistry' approach involving reduction of waste, materials and energy, will also lead to cost reductions and that this in turn will have a positive effect on profitability. In academia initiatives from national and trans-national (e.g. EU) funding agencies can encourage professionals to enter the area.

Although many of the technologies and tools required to make chemical manufacturing more sustainable are available, and indeed industry is already making significant progress, much more can be achieved. In order to move forward chemists need to understand, and overcome, the barriers, both real and perceived, that exist to innovation in this area. In some cases a culture change may be required before the potential financial benefits are fully appreciated. Professional chemists also have a major role in helping to encourage all interested parties, including industry, customers, pressure groups, governments, educationalists and researchers, to co-operate to ensure a cleaner and more sustainable future.

Barriers to introducing 'Green Chemistry' include:

- Absence of a 'level playing field', i.e. the lack of global harmonisation on regulation and environmental policy
- Rigid notification and authorisation processes which hinder new product and novel process development
- The frequent need for speed and certainty of outcome caused by short-term planning horizons
- Additional cost: although 'Green Chemistry' is often financially beneficial in the medium term, short term investment may be needed, e.g. to introduce a new technology or change a process route
- Unsophisticated accounting practices, which do not encompass total costs
- The difficulty of obtaining research and development funding
- Insufficient guidance on best practice for Green Chemistry
- The low profile of cleaner more sustainable chemistry in school and university teaching
- A lack of universally agreed metrics that allow chemicals and products to be assessed and compared across their life cycle
- A culture geared to looking at the product itself rather than the overall process and life cycle.

FUTURE PROGRESS

If chemists are to fully embrace all facets of sustainable chemical manufacturing a paradigm shift in the way chemistry and engineering are taught and practised is required. More attention needs to be given to the whole manufacturing process and life cycle of both products and waste. A companion EHSC Note on Life Cycle Assessment [LCA] explores some of these issues in more detail.

Chemists need to co-operate with other disciplines. In particular it is vital that chemists, biologists, biochemists and engineers work together to develop new sustainable processes. Only by combining the best ideas from all areas will the required technological leaps be made.

Concepts such as atom economy, energy efficient reactions, eco-friendly solvents, renewable feedstocks and benign-by-design, should be more prominent in basic chemistry education, and there should be less emphasis on the very narrow concept of immediate product yield.

READING LIST

http://www.dtsc.ca.gov/PollutionPrevention/GreenChemistryInitiative/upload/SAP_Report.pdf

RSC Green Chemistry Book Series, J H Clark and G Kraus,
http://www.rsc.org/shop/books/series/81.asp?seriesid=81

Green Chemistry: today (and tomorrow)
J H Clark, *Green Chemistry,* 2006, **8**, 17-21.

Our Common Future (1987), Oxford: Oxford University Press.

EHSC Note on Life Cycle Assessment (2005)
http://www.rsc.org/ScienceAndTechnology/Policy/EHSC/EHSCnotesonLifeCycleAssessment.asp

RSC Environment, Health and Safety Committee (EHSC) gratefully acknowledges the assistance and input of Professor James Clark in the revision of this Note.

This Note was prepared by a Working Party of the EHSC. The members of the Working Party were:
Dr I Wrightson [Chairman], S J Cooper, Dr M Crookes, Dr N King, Dr P Lewis, J Larner, Dr D H Lohmann, Dr C Maxwell, Mr D Perry, Mr D Sanderson and Dr S Lipworth [Secretary]

This Note is also available on the RSC website:http://www.rsc.org/