

Chapter 8 – Green product design

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Recommendations

- RSC to promote the use of environmental life cycle analysis of products and systems in industry.
- Research councils and other bodies should fund programmes that aim to develop computer modelling software that predict efficacy and environmental performance of chemicals. Where such capability exists, technology transfer should be encouraged.
- Research councils to continue to support funding into green chemical technology and ensure that effective mechanisms for technology transfer to the chemical and water industry are established.
- RSC, through an expert working group on green product design, to advise research councils on how best to initiate funding programmes specific to green product design.
- RSC to form an expert working group on green product design, to advise on how to ensure sound and objective science is used in defining any legislation and regulations relating to the control of ingredients and formulation of consumer products.
- Government to consider policy that promotes products that are highly effective in their use and at end of life are reusable and/or recyclable or degrade quickly in the environment.

Introduction

Green product design is a broad concept that attempts to reduce the impact on the environment of a product from manufacture, use and disposal in a systematic and structured way.

Green chemistry, which can be seen as one element of green product design, involves pulling together tools, techniques and technologies that can help chemists and chemical engineers in research, development and production to develop greener products and processes, which may also have significant financial benefits. Green chemistry aims to improve the way that chemicals are designed, produced and used in chemical processes in order to reduce any impact on man and the environment. It is not just about industrial production. The principles involved apply equally to the use of chemicals in for example laboratories and education.

This chapter intends to give a brief introduction to green chemistry and green product design and to highlight a selected few case studies.

Green chemistry

The application of green chemistry has numerous potential benefits to sustainable water management. The 12 principles of green chemistry (below), developed by Anastas and Warner are the cornerstone of green chemistry¹.

- 1 **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
- 2 **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
- 3 **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
- 4 **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from

- agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
- 5 **Use catalysts, not stoichiometric reagents:** Minimise waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
 - 6 **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
 - 7 **Maximise atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
 - 8 **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
 - 9 **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
 - 10 **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
 - 11 **Analyse in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of by-products.
 - 12 **Minimise the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

The application of these principles to chemicals and chemical processes can have positive knock-on effects for sustainable water management. Principles 1 aims to

reduce waste, this means that ultimately less water treatment would be required at chemical and manufacturing sites and subsequently there will be less chemical burden for water treatment plants. Principle 9 aims to increase energy efficiency and this should result in a reduced requirement for steam and cooling water on site in addition to lower electricity demand.

Principle 8 states that safer solvents should be used. Water is used in the chemical industry as a solvent (to dissolve substances and to facilitate heat transfer), as a quench (to stop reactions), as a separating agent (to move chemicals to or from an organic phase), for cleaning equipment and for heating and cooling. Water used in these applications invariably becomes contaminated and needs to be treated whether on site or at treatment works and ideally processes should be designed to avoid wasteful steps. However, solvents are unavoidable in many reactions and water in the liquid, superheated or supercritical (a phase where it displays properties between liquid and vapour) state can be a highly effective solvent for a number of reaction types delivering high yields and little waste.

Green product design

Green product design extends the principles of green chemistry to the design and use of products and their ultimate disposal. This would include the design of highly functional products that are efficacious in their intended use, that possess little or no toxicity to human health and the environment and would biodegrade rapidly to innocuous degradation products that do not persist in the environment. This is also one of the key principles of the European Registration, Evaluation, Authorisation and Restriction of Chemical substances legislation (REACH) which seeks to minimise the impact of chemicals on humans and the environment along their whole life cycle.

Green product design is a different approach to that which is currently used. It requires that economic, social and environmental sustainability criteria are taken into

account when designing a product. This approach examines the product across the whole life cycle taking into account raw materials, synthesis, production, use and ultimate fate.

The structure and properties of chemicals are a critical factor in the environmental performance of products. Products are designed to fulfil a function, and it is important to remember that this is the major driving force for industrial research and development. Green product design is complementary to this because it is applied at the very start of the process, and seeks to produce products that are highly effective in addition to having minimal environmental impact. It is worth noting that minimal environmental impact does not necessarily mean readily biodegradable; it can also mean that the product is designed so that the chemicals are fully contained so that they never reach the environment, or that the product is designed to be reusable and/or recyclable.

Green product design of chemicals requires a complete understanding of relationship between structure and activity of chemicals (as discussed in chapter 5). Small changes in structure can have marked effects on properties such as biodegradability, environmental mobility and toxicity. Traditionally chemists have sought to apply knowledge of structure and activity towards maximising efficacy; this approach will need to be adapted to include criteria on environmental performance.

For example, tetrapropylene sulfonate (TPS), a surfactant used in detergents caused strong foaming in rivers and wastewater treatment works because it was poorly biodegradable because of its branched structure. This problem was overcome through the development of linear alkylbenzenesulfonates (LAS) which remain effective surfactants but degrade readily in the environment. However, this is not a true example of green product design as LASs have some performance issues and are also derived from non-renewable resources. A new class of surfactants, sugar fatty acid esters, has emerged on the market that are based on the reaction between a fatty acid (for example derived from vegetable oil) and a sugar (for example sucrose). These

surfactants are readily biodegradable and are based on renewable resources. Currently the market penetration of sugar fatty acid esters is relatively modest, due in part to the higher cost of these products.

Whilst initially adding extra criteria to a process, for example as drug discovery, might seem like an extra burden on industry, it can also be seen as an opportunity. The application of green product design will enable companies to meet and exceed environmental regulatory requirements. Green chemistry and life cycle assessment is designed to minimise waste, energy, water costs of products from cradle to grave; a process that applies the principles of green chemistry should in effect be the cheapest process. With a massively expanding worldwide market for environmental products and services (estimated to be worth over \$500 billion), green product design offers a significant commercial opportunity.

Chemists are now beginning to use structure activity relationships modelling software to predict both the activity and environmental behaviour of chemicals and to optimise performance on both these criteria (as discussed in chapter 5).

There are now examples of this approach being applied to emerging contaminants such as pharmaceuticals, although currently this is a far from common practice.

One example of this is the development of a range of cytostatic agents based on uracil². By replacing a hydrogen atom in uracil, a natural compound which is a constituent of DNA and RNA, with a fluorine atom (5-fluorouracil) alters its properties and it is a highly active anti-metabolite and therefore an active drug. However, carbon-fluorine bonds are notoriously strong and therefore 5-fluorouracil is not readily biodegradable. Work to improve the pharmaceutical properties involved moving the fluorine atom out of the uracil structure and into a sugar molecule attached to uracil. This resulted in a drug that had greater efficacy and also much improved

biodegradability. However, it is worth noting that in this case the driver was efficacy and not environmental performance.

In addition to designing products that have minimal environmental impacts at end of life it is also possible to design products with reduced impact on water either in terms of water volume use or potential impact on water minimise water use during their use phase.

Green product design in practice

The principles of green product design are being applied by many organisations both directly through the management of their own operations and indirectly through the design of the products and services they offer to consumers. Some examples from Unilever are used to illustrate what has already been achieved along with current activities.

The impact of our own manufacturing operations on water have been systematically minimised for many years by applying eco-efficiency principles. At an operational level, there are specific examples where manufacturing facilities have minimised or eliminated water impacts including a soap factory in India and an ice cream facility in Pakistan. Both facilities operate in water scarce regions and have implemented systems for on-site waste water treatment with water reused or sent for irrigation of surrounding agricultural areas with solids composted.

An example of the contribution of chemical sciences is the development of specialised surface coatings and finishes. These developments are important to improve the efficiency of production and cleaning operations in flexible manufacturing facilities making a range of products. The coatings will reduce the amount of product that sticks vessel walls and pipes resulting in less product loss and less wash water for cleaning.

The biggest contribution that green product design can offer to reduce total environmental impact however is through the products offered to consumers. A water-focussed life cycle assessment indicated that water use by consumers can often represent the single largest water impact. This is particularly true for laundry cleaning products. In India, for example, laundry water can be up to 25% of household water use – in many areas this water has to be collected from standpipes and carried to homes. An easy rinse laundry powder variant was developed that for a typical wash saved around 2 buckets of water. This presented a number of challenges for formulation chemists. In hand wash markets consumers like to see foam as a visible indicator of cleaning efficiency and from a technical perspective rinsing is important to ensure complete removal of soil from the clothes. Reformulation and modifying the active system gave the desired outcome and Surf Excel “Quick Wash” was successfully launched in 2 water-stressed states in India – Tamil Nadu and Andhra Pradesh. It is now available across the whole of India.

Another product successfully launch in India where the application of chemistry resulted in a water-related benefit to consumers is the Pureit water filter. The Pureit device is a stand-alone in-house water treatment system that produces water as safe as boiled water. The key contribution of chemical sciences was the development of a sustained chlorine dosing system that produces a consistent level of chlorine in a water reservoir sufficient to kill viruses and bacteria.

Whilst water as a sustainability theme has been a priority for a number of years we are continuing to find ways to better integrate water thinking into our product development and R&D activities. Environmental life cycle assessment approaches have been used for many years to understand and focus environmental impact reduction efforts. A new approach – Brand Imprinting – is helping to integrate social, economic and environmental considerations into brand development plans, pushing the boundaries of life cycle assessments.

The implications for an organisation where innovation is often brand-led is that this brand-led pull will increasingly focus on wider SEE perspectives and for many brands this will include impact on water.

¹ <http://www.epa.gov/greenchemistry/pubs/principles.html>

² Kümmerer, K, Green Chemistry, 9, (2007), 899-907