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Career Choice and the Chemical Industry

By Dr Anne Chapman

A *Scientists for Global Responsibility* Briefing

Summary

The chemical industry is one of the major employers in science and technology. On the one hand, its products have greatly expanded the range of materials available to society but, on the other, some of the synthetic chemicals it produces cause significant harm to human health and to the environment. This briefing discusses the main ethical issues related to this industrial sector, as well as new developments in regulation and technology, and assesses how these affect career choice. It points to areas which have potential to improve the environmental and health performance of the sector.

Introduction

The products of the chemical industry – synthetic chemicals – are used in a huge array of common products such as paints, plastics, medicines, pesticides, cosmetics, synthetic fabrics and cleaning products. In many respects modern life as we know it would be unthinkable without the chemical industry. In the UK, the industry employs 210,000 people nationwide, and accounts for 2% of Gross Domestic Product. It currently spends £3.8 billion a year on R&D [1]. It includes some very large corporations, such as ICI and Zeneca, but also a large number of small and medium-sized enterprises. Chemical companies may be involved in making bulk quantities of basic chemicals, or may specialise in the synthesis of small quantities of a very large number of compounds. Oil corporations, such as BP and Shell, are often also involved in the chemicals sector as crude oil is the feedstock for the production of most synthetic organic chemicals.

The other side of this picture is the damage to human health and the environment caused by synthetic chemicals. Most obvious, perhaps, has been pollution from chemical manufacturing processes. At the start of the industry, in the 1820s, the production of soda for the textile industry in North West England produced hydrogen chloride and a black ash that leached sulphide, causing devastation of the surrounding countryside. Complaints eventually led to the first UK pollution control legislation, the *Alkali etc. Works Act, 1863*. Now the chemical industry is highly regulated. Companies have to obtain an Integrated Pollution Prevention and Control permit to operate their plant. These specify the type of technology that can be used, wastes produced, allowed emissions to air and water, and provisions for site cleanup. In Britain they are issued and enforced by the Environment Agency (in England and Wales) or the Scottish Environmental Protection Agency.

About the author

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Ethical careers in science, design and technology

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While pollution from manufacturing has caused severe local damage, probably of greater general significance is the often unexpected effects of certain synthetic chemicals during and after their intended use. Some uses rely on known toxic effects of chemicals. In times of war this has included the use of chemicals as weapons. In peacetime, toxic chemicals have been used in the 'war' against other species that we regard as pests. However, time and again, the harmful effects of a chemical have been found not to be limited to toxic effects that we find useful. One reason why there have been so many surprises with synthetic chemicals is that novel chemicals have generally been assessed in terms of the hazards of older chemicals. Thus, in the 1930s, when they were first synthesized, chlorofluorocarbon (CFC) refrigerants were considered safer than previous refrigerants, because unlike the latter they are not toxic or flammable. Organo-chlorine pesticides, introduced in the 1940s did not have the acute toxicity of the previous arsenic-based compounds. It was only after these substances had been produced in enormous quantities and spread all around the globe that the destructive effects of CFCs on the stratospheric ozone layer and of organo-chlorine pesticides on bird populations were discovered.

The effects of many persistent chemicals are not limited to locations near their production and use. Such chemicals (referred to as persistent organic pollutants or POPs) are distributed over long distances through a process of 'global distillation'. At warmer latitudes they evaporate, to be taken by the prevailing winds to colder latitudes, where they condense and adhere to soils and vegetation, eventually accumulating in the food chain. The Arctic, being down-wind of most industrialised nations, is thus the sink for many industrial chemicals. The highest concentrations of polychlorinated biphenyls (PCBs) in human blood, for example, have been found in a population of Inuit living in the remote Canadian Arctic [2].

Rachel Carson's 1962 book, *Silent Spring* [3] drew attention to the devastating effects of agricultural pesticides on wildlife and raised concerns about the carcinogenicity of such chemicals. In 1996, another book, *Our Stolen Future* [4], highlighted the phenomenon of endocrine disruption: the fact that many synthetic chemicals can interfere in our hormone system by mimicking or blocking hormones. Hormones are chemical messengers produced by the body that control growth, development and the body's responses to all sorts of stimuli. Interfering with them can have a wide range of health effects. Most attention has focused on the huge number of chemicals that seem to mimic the female hormone oestrogen. Our exposure to oestrogenic chemicals could be involved in the observed recent increases in breast, testicular and prostate cancers, as well as declines in sperm counts.

It is now recognised that even at very low concentrations, synthetic chemicals may be having subtle but significant effects on our health and that of other organisms [5]. However, the low concentrations at which chemicals may be affecting our health, the shear number of chemicals to which we are exposed (our bodies now contain several hundred chemicals that did not exist 70 years ago), the uncertainties implicit in current testing methods, and the difficulty of establishing standardised testing regimes for effects such as endocrine disruption, all mean that it is very difficult to link particular health effects with particular chemicals. This is a problem because regulation is premised on being able to identify such causal links. Restrictions on the production and use of a synthetic chemical have to be justified by evidence that there is a risk that the chemical causes harm to human health and the environment, where risk is understood as the probability of the chemical causing a specified type of harm. If a chemical is novel and we know little about how it might interact in the biosphere, but cannot identify the harm it may cause, regulation generally does not consider there to be a risk. In debates about regulation, risk-based approaches are often opposed to precautionary approaches. Precaution puts more weight on avoiding possible harm, on placing restrictions on the production and use of chemicals where there are grounds for thinking that they *may* be harmful, even if clear evidence that they do cause harm is not available.

An often overlooked impact of the chemical industry and its products is that it has frequently displaced more natural materials or processes and the ways of life and ecosystems associated with them. In the nineteenth century the industrial synthesis of the natural dyes alizarin and indigo from constituents of coal tar led to the collapse of the French madder industry (the madder plant being the natural source of alizarin) and the Indian indigo industry [6]. The current move towards the use of plastic rather than cork stoppers for wine bottles threatens the destruction of the Cork Oak forests of Portugal, which currently provide a sustainable livelihood to local communities. As the market for cork is lost these forests are being felled to make way for other economic activities [7]. There are many other examples.

Developments in regulation

The regulation of chemicals in the European Union is currently going through a period of major change. The impetus for this has been the realisation by governments and regulators of how little we know about the long term effects of synthetic chemicals. This officially recognised 'knowledge gap' is not a matter of the inherent limitations of knowing about the more subtle effects of synthetic chemicals, or the problem that we encounter them in mixtures, but the simple fact that standard test data on long term toxicity is not available for most commercially produced chemicals. The lack of data was first brought to light by the US pressure group, the Environmental Defence Fund, in 1997 [8]. When the US Environmental Protection Agency did its own survey, they found that a complete package of basic information was available for only 7% of the 2,863 high production volume chemicals on the US market [9]. The situation in Europe is not substantially different [10].

To remedy this situation the European Union is bringing in a new regulation, REACH, published by the European Commission in October 2003 [11]. REACH stands for the Registration, Evaluation, Authorisation and restriction of Chemicals. REACH will require that all synthetic chemicals manufactured or imported in quantities above 1 tonne per annum per company be registered, with registration requiring the submission of a dossier containing specified information about the chemical, including test data. The number of substances that will require registration is estimated to be around 30,000. For higher volume substances a 'chemical safety assessment', assessing the risks associated with specified uses of the chemical will have to be prepared. Substances of 'very high concern' (those that are carcinogenic, mutagenic, toxic to the reproductive system, or that are persistent, bioaccumulative and toxic) are to be subject to authorisation. This involves reversing the normal burden of proof in chemicals regulation: those wishing to manufacture or use them will have to show that risks from the use are adequately controlled, or that the socio-economic benefits outweigh the risks, taking into account alternative substances or processes. The regulator does not have to show that risks from that use are unacceptable.

While there is little outright opposition to the goals of REACH within the European chemicals industry, there is concern about the bureaucracy it will involve and the costs of the tests needed to register a substance, costs that will have to be paid by the industry. Industry has lobbied hard to reduce the amount of testing they need to do, making it less likely that REACH will succeed in fulfilling its central aim of overcoming the 'knowledge gap' with respect to chemicals. One of the main issues is how to decide the priority for registration (as it will not be possible to register all the tens of thousands of chemicals at one time) and also the amount of data that must be included in the registration dossiers. The Commission proposed basing this purely on the amount of a substance manufactured or imported by each company, but this is seen by many as arbitrary and unrelated to the risks posed by the various chemicals. CEFIC, the European Chemical Industry Council, have proposed that prioritisation be risk-based. Substances of high concern should be registered first, and those registrations should be accompanied by more data on long term toxicity than required for lower priority substances. The UK Chemicals Industry Association takes a similar view, calling for REACH to be applied "pragmatically and proportionately… with realistic deadlines". Otherwise, it warns, the "adverse effect on international competitiveness will be excessive and unwarranted" [12]. Environmental groups are concerned that this approach will perpetuate the existing situation in which there is little data on many substances – and therefore no evidence of risk – and so more data does not have to be obtained. Because there is no evidence of risk, no restrictions are placed on the production and use of such substances which may well be hazardous.

Concern over the amount of testing of chemicals that REACH will require also comes from those opposed to the use of animals in these tests. A coalition of animal protection organisations has been campaigning for a completely non-animal test strategy. They claim that such a strategy, involving consideration of molecular structure, comparison with related compounds, tests on cell cultures, and on human volunteers (e.g. for skin irritancy of substances thought not to be irritants), would be scientifically more robust, as well as more humane, than existing animal tests [13].

Another area of contention is whether consumers should have the right to know what chemicals are in the products they buy. Currently, this information is generally not available, even to retailers, except for certain products. Environmental groups are campaigning for information on chemicals in products to be publicly available, perhaps on websites, if it not on the label. Industry is opposed to such provisions and cites the need for commercial confidentiality, though also argues that consumers will not know what to do with such information.

Ethical career paths in the chemicals sector

There are clearly big opportunities for graduates from a wide range of disciplines to work towards increasing our understanding of the effects of chemicals, improving their regulation, reducing our use of hazardous chemicals, and making their production less polluting and more sustainable. In this section, we outline many of these opportunities including some suggestions for possible employers. However, as the sector is very large with employment opportunities constantly changing, we suggest that after you have selected from below the areas you find especially appealing, you make use of more detailed data sources, such as 'Links for Chemists' [14], to help find the current courses and employers in those areas.

Improving understanding and regulation

Implementing REACH will obviously require people with relevant knowledge and skills in environmental chemistry, toxicology and related disciplines. Many will be employed by the chemical industry to compile registration dossiers, but the regulatory authorities will also have an increase in their workload and require suitably qualified people. A new European Chemicals Agency to oversee REACH and hold the registration data is being set up in Helsinki. Each Member State will have its own Competent Authority to manage the regulation nationally. At the time of writing, the detailed regulatory framework in the UK is still under development, so readers are recommended to look at government websites [15] for the latest information. This will indicate which employers are involved and how.

The introduction of REACH is also likely to highlight the need for increased understanding of the effects of synthetic chemicals, leading to more opportunities for research in this area. Areas for investigation could include: the monitoring of synthetic chemicals in consumer products, the indoor environment and in the human body; the behaviour and fate of chemicals in the environment; the relationship between exposure to synthetic chemicals and health effects such as allergies, infertility and cancer. A wide range of university departments and research institutions will be involved in this research.

Another possible career option is working for one of the environmental groups who campaign to strengthen the regulation of chemicals – for examples see [16]. However, there are a limited number of jobs available, so it often helps to gain experience within the organisation by working as a volunteer. They may also be a source of funding for research projects.

Scientists and engineers also have an important role to play in the implementation of the Chemical Weapons Convention that was adopted in 1992 banning production and stockpiling of chemical weapons. Work in this area is co-ordinated by the Organisation for the Prohibition of Chemical Weapons (OPCW), and tasks include developing safe and effective methods to destroy stockpiles of chemical weapons, and methods to verify that weapons have been destroyed and/or are not being produced [17].

Product and process design to eliminate hazardous chemicals

Many products and processes that currently use chemicals recognised to be hazardous can be redesigned to eliminate those chemicals. This may mean using alternative chemical products, or non-chemical methods. Paints, for example, can be reformulated so they are water-based, rather than organic-solvent based, so do not release volatile organic compounds when used. The production of semi-conductors frequently uses halogenated organic compounds and heavy metals such as lead, but it is possible to produce them without. For example, the electronics company Samsung has developed a 'green semiconductor' that contains no lead or halogenated compounds, and is also cheaper to produce and of superior quality [18]. The technique of life-cycle analysis, which compares the various impacts of products over their complete life-cycle (from extraction of raw materials to disposal) has been developed to help assess competing products and materials [19]. The Centre for Environmental Strategy at the University of Surrey is a leading research centre in this area [20].

Companies vary in their policies on the elimination of hazardous substances from their products. Campaigns by environmental groups have focused on asking companies to phase out the use of specific chemicals. Greenpeace, for example, has asked major manufacturers of electronics products to commit to phasing out 20 hazardous substances, including phthalates, alkylphenols, brominated flame retardants and PVC. They have ranked the various manufacturers [21], and this ranking could be an aid in choosing between prospective employers.

One important change which can potentially reduce a company's consumption of chemicals is for it to switch from buying chemical *products* to buying chemical management *services*. The supplier of such services has an interest in minimising the amount of chemical used and the expertise to achieve this. Case studies have shown that significant reductions in chemical use can be achieved [22].

Production of safer chemicals

Eliminating hazardous chemicals from products and processes will often require the commercial production of safer alternatives. One possibility is to return to some of the plant-based products that predominated before the large scale production of synthetic chemicals from petroleum [23]. This is already happening to some extent. One can buy soya-based printing inks and paints and a range of polymers can be produced from plant-derived materials to replace oil-based plastics [24].

In developing new chemical products it is important that the hazards of the previously used substances are not simply substituted by equally problematic, though different, hazards (for a discussion of substitution see [25]). In addition to the known harmful effects of a substance there are probably at least three aspects of a chemical which should be considered [26]. The first is the novelty of the substance: how different is it from naturally occurring chemicals, or from substances whose effects and interactions in the biosphere we understand well? A novel chemical is not necessarily hazardous, but our ignorance about it means that, for all we know, it may cause harm. The second is its persistence. If a non-persistent chemical turns out to be hazardous, after initially being thought to be safe, it will quickly be removed from the environment if its production is stopped. In contrast, persistent chemicals stay around, perhaps accumulating in some environments (while decreasing in others), so their effects are longer-lasting. The third is the degree to which a chemical will be dispersed in the environment, either because its use involves it being dispersed (e.g. pesticides), or because it has properties such as volatility or solubility that render it mobile and it is used in situations where it is not contained, or the containment fails.

Cleaner production

In the past, cleaner production and environmental management at chemical production facilities has primarily been a matter of minimising or treating emissions and wastes. It involved ensuring that valves, tanks and pipework do not leak; that emissions to air were rendered acceptable by removal of particulates, odours or acids; and that waste was treated and properly disposed of. More recently attention has been given to the actual chemistry of the production process, the possibilities of changing the synthesis pathways and reaction conditions, and the use of feedstock from renewable sources, so that production is more efficient with regard to energy and materials, and inherently safer. This approach has been termed 'Green Chemistry'. For more information, see the website of the Green Chemistry Network [27], a network set up by the Royal Society of Chemistry and based at the Department of Chemistry in the University of York.

One of the concepts used in Green Chemistry is that of 'atom economy'. Chemical synthesis almost always involves the production of a mixture of compounds. This is not a problem if there is sufficient demand for all the products, but often this is not the case. Some of the products are unwanted, and are therefore 'wastes'. Ideas of

efficiency which only take into account the yield of the desired product ignore the fact that there is a dis-benefit from producing the waste. There are often a number of possible reaction pathways by which a desired chemical can be synthesised. In these cases, proponents of Green Chemistry suggest that the pathway that should be chosen is the one that has the greatest 'atom economy'. This means that the mass of atoms in the desired product should be maximised relative to the total mass of atoms in the reaction (thus taking into account waste products as well as reactants).

Industrial synthesis of chemicals is often inherently dangerous and energy-consuming because it uses high temperatures and pressures to achieve the desired reactions. Any breach in the containment of reactants under pressure is likely to lead to them being dispersed – into the wider environment if secondary containment systems also fail. The solvents generally used to provide a medium for reactions also present problems. Organic solvents are volatile, so easily dispersed, and are often toxic. Meanwhile, concentrated acids are highly corrosive. Attempts to make reaction conditions inherently safer and less energy-consuming have focused on the use of novel catalysts, to enable reactions to take place at lower temperatures and pressures, and on alternative solvents. The latter include ionic liquids, which are essentially salts that have a large organic molecule as one of the ions. They are not volatile so they are less likely to be dispersed than organic solvents, and they can be recovered and reused after the reaction. Sometimes they may catalyse a reaction, as well as providing a medium for it. There are potentially billions of different ionic liquids so solvents can potentially be tailor made for the reaction.

Conclusions

The mass production of synthetic chemicals since the 1950s has brought great changes to the products that we use in our everyday life, and many think these changes have been overwhelmingly beneficial. Others though point to the effects synthetic chemicals have on our health and that of the planet, effects that are we are only now just beginning to be fully aware of. For them, our production and use of novel synthetic chemicals has been an arrogant experiment with life on this planet.

One thing is certain though: the chemical industry, in Europe at least, is about to experience a time of great change, brought in by the introduction of a new regulatory regime. This should bring many opportunities for scientists and engineers from various disciplines to help to make our production and use of chemicals safer and more sustainable. An ethical career will involve working in an organisation committed to achieving this and avoiding those employers that insist, as parts of the chemical industry have done in the past, on unobtainable proof that a chemical causes a particular type of harm before accepting any restrictions on its use.

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Ethical careers in science, design and technology

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This briefing is one in a series, produced as part of the *Ethical careers in science, design and technology* programme. The programme is intended to give information and advice to students and professionals in science, design and technology about the wider ethical dimensions of careers in these fields. Each briefing focuses on a field in which these professions can play a major role, either good or bad, and examines the social and environmental controversies in that area. It then gives guidance on how to make an informed, 'ethical' career choice. Other briefings in the series cover issues such as: climate change; cleaner technology; corporations; sustainable development; the military; and animal experiments. For more details – including a list of 'ethical employers' – see **www.sgr.org.uk/ethics.html** or contact us (details below). The series of briefings is edited by Dr Stuart Parkinson and Vanessa Spedding, Scientists for Global Responsibility (SGR).

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