The Royal Society of Chemistry (RSC) welcomes the opportunity to comment on the scoping of the Royal Commission on Environmental Pollution's (RCEP) study on the environmental effects of novel materials and applications.

The RSC is the largest organisation in Europe for advancing the chemical sciences. Supported by a network of 43,000 members worldwide and an internationally acclaimed publishing business, our activities span education and training, conferences and science policy, and the promotion of the chemical sciences to the public.

In scoping its study, the RSC recommends that the RCEP must first be clear as to what constitutes a novel material for the purposes of this study and therefore what breadth of substances will be covered. The term 'material' is used to describe a whole host of substances and the usage of the term varies amongst different scientific and lay communities. Consequently, the RSC recommends that the RCEP considers two methods of categorising novel materials. Firstly, novel materials should be categorised by their chemical and physical structure and properties as this may have some bearing on their environmental effect. Secondly, novel materials could be categorised properties and applications.

Chemical and physical structure of materials

Polymers and plastics - polymeric materials are made from repeating molecular chains, often of organic origin and consist mainly of light elements such as carbon and hydrogen. Non-organic elements are routinely added to plastics during manufacture to enhance or suppress specific properties. In the last decades, there has been a revolution in polymeric materials with the discovery of flexible electronically conducting polymers that can be made into thin-film-transistors, capacitors, resistors, and diodes.

Solid-state ceramics – Solid-state ceramics can broadly be defined as inorganic non-metallic or semi-conducting materials. Some ceramics, such as silica, have properties that make them useful for novel devices, such as magnetic, piezoelectric (generates an electric charge when mechanically deformed) or superconducting behaviour. Fibrous ceramics such as graphite and aluminium oxide have also been in important in the production of light and strong reinforced composite structural materials.

Glasses - A glass is a material that does not have a crystalline structure (such structures are known as amorphous). Glasses have found new application in high technology fields, particularly the semiconductor microelectronics industry and the fibre optic cable industry.

Metals and alloys – Metals and alloys, which are mixtures of metals, are highly conducting materials with high malleability and ductility. In recent years novel alloys have been developed with new properties such as shape-memory alloys that 'remember' their original shape after deformation, and can be returned to it by heating.

Nanoparticles, nanotubes and colloidal materials - Crystalline arrays of particles can be formed from colloids; system in which finely divided particles, which are approximately 10 to 1,000 angstroms (1 angstrom is 10^{-10} m or a ten billionth of a metre) in size, are dispersed within a continuous medium. These materials have many applications that will take advantage of their regular structures such as photonic materials, membranes, filters and templates for patterning other materials. Such materials can be made from inorganic or organic sources such as silica or polystyrene.

Particles with dimensions in the order of nanometres (I nm = 10^{-9} m) are known as nanoparticles. They can be made from almost any materials but may acquire properties that differ from their bulk due to the increased surface area exposed at the nanoscale that leads to increased reactivity. In the case of semiconductor materials, additional 'quantum' effects are seen and such nanoparticles are known as 'quantum dots'.

As well as particles, an increasing number of nanotubes are being discovered and utilised. Carbon nanotubes are already being used in composite materials and research is underway on their use in nano-electronics.

Liquid crystals - Substances that exhibit a phase of matter that has properties between those of a conventional liquid and solid are known as liquid crystals and represent a discrete, fourth state of matter. Liquid crystals are used extensively as display materials but are rapidly finding wider applications in other arenas, for example active optical and microwave control elements. Their applications often rely on the optical properties of liquid-crystalline molecules in the presence or absence of an applied electric field. Liquid crystals might be regarded as part of a wider class of molecular materials, another example of which might be optically non-linear materials.

Composite materials - Engineered materials consisting of more than one material type designed to display a combination of the best characteristics of each of the component materials. Fibreglass is a familiar example, in which glass fibres are embedded within a polymeric material diving it strength from the glass and flexibility from the polymer. Today novel nano-composite materials are being designed that combine one or more nanoparticle in a (usually) polymer matrix which posses even better barrier properties, or fire resistance or strength. This rapidly expanding field is generating many exciting new materials with novel properties. The inorganic components can be three-dimensional framework systems, such as zeolites; two-dimensional layered materials, such as clays and metal oxides, and even one-dimensional and zero-dimensional chains and clusters.

Properties and applications of novel materials

Structural materials: materials to carry a structural load such as concrete, metal alloys and fibreglass.

Packaging materials: material used to protect something, conventionally hydrocarbon plastics and polymers but more recently biodegradable packaging materials made from plant-based materials.

Electronic materials: materials used to produce electronic components such as semiconductor materials used in integrated circuits or dielectric materials used in capacitors. New novel conducting polymers are being developed for flexible and printable electronic circuits and components.

Electrolyte materials: conventionally electrolytes were liquids but recent fuel cells and batteries contain solid ceramic electrolytes or polymer electrolyte materials formed by dispersing a salt at the molecular level in a high molecular weight polymer such as poly(ethylene oxide).

Magnetic and Spintronic materials: some metals and ceramics display magnetic behaviour. Magnetic materials are used in motors and transformers, in computer memory and sensors.

Photonic/optoelectronic materials: these are materials that can control and manipulate light and are essentially optical semiconductors. Photonic materials technology is expected to increase efficiency of optical fibres and allow microscopic lasers to be built. It is also expected to be used in the construction of photonic circuits that can stand-alone or be integrated into semiconductor circuits.

Photovoltaic and photoactive materials: semiconductor device that converts the energy of sunlight into electric energy. These materials are crucial for photovoltaic cells to produce solar energy. They can contain ceramic or polymer materials. Photoactive materials such as titanium dioxide nano-films have been used to produce coatings that allow windows to be self-cleaning. Additionally photoactive nanoparticles are being used in sunscreen where they are designed to absorb ultra-violet light (thus stopping it reaching the skin).

Responsive or smart materials: these novel materials are able to respond to their environment and could have a large number of applications from food packaging able to sense the condition of the food, to materials able to selectively deliver drugs at a tumour site. These materials are often polymers.

Biomedical materials: this covers a wide range of materials types but involves their use in biological devises, implants or drug delivery systems. These materials often have highly engineered surfaces to improve biological compatibility. In recent years biodegradable polymer scaffolds have been developed for tissue engineering and recent advances in nanotechnology is allowing engineered materials to more effectively mimic biological tissues and thus improve their function. Polymers, glasses and ceramics are used as biomaterials.

These categorisations are not exhaustive but give some indication of how materials could be classified and how complex any classification would need to be.

Controlling the use of novel materials

In looking for groups of materials that may cause concern in terms of their environmental effect, it is crucial to consider the type of application they are to be used for and thus the level of exposure that could be expected. For example, many advanced novel electronic materials will be used in hermetically sealed devices and environmental exposure is likely to be very limited and only relevant when looking at life cycle and disposal issues.

The RSC has some concerns that hazard based approaches and the precautionary principle may be used for the regulatory control of novel materials and new applications of existing chemicals in situations where risk based approaches are more appropriate. The appeal of hazard based and the precautionary principle approaches is that they are easier to apply and administer, however such approaches may result in misdirection of effort to mitigate risk because they do not deal with the likelihood that particular hazards may be realised. Comparative risk assessment should aim to optimise the choice of options for a particular situation, taking into account potential risks to health, wildlife and the environment and the benefits to society as a whole.

The application of the ‘precautionary principle’ has to be proportional to the risks involved. By adopting a ‘gate keeping’ approach and a ‘hard’ precautionary approach there is a danger that innovation may be stifled through the disproportionately high barriers to introducing the new and probably less risky materials. Innovation is essential to achieving sustainable development, and chemistry can provide a range of 'solutions' to support sustainable development.

Therefore the RSC holds the view that it is vitally important that regulations, aimed at mitigating negative environmental and health impacts, be based on risk. Novel materials should generally not be subject to restriction on the basis of intrinsic hazard alone. Intrinsic hazard is not a good measure of the actual threat that a substance poses to humans or the environment. Risk is a better measure because it is based on the likelihood that an intrinsic hazard associated with a material will cause actual harm.

Nanomaterials

Advances in nanoparticulate materials have highlighted regulatory ambiguities in this area. It is clear that nanomaterials can possess different properties to the bulk materials from which they are derived. An example would be gold, which is inert in bulk, but nanoparticles of gold exhibit strong optical scattering and absorption at visible and near-IR wavelengths which have been used to photothermally destroy cancerous tumors in mice. At present regulatory and testing regimes do not take account of these differences explicitly. This area may need some consideration but any measure of environmental harm must again be risk based.

Life cycle assessment

Novel and advanced materials, especially those in the development phase, offer an opportunity to develop sustainable manufacturing processes and sustainable supply chains. New materials, in many cases, have potential environmental, economic and societal benefits over conventional materials. Examples include energy efficiency (e.g. low emissivity glass coatings), reduced fuel consumption (e.g. lighter materials of construction), improved communication (e.g. fibre optics), and reduced waste (e.g. biodegradable packaging). To fully understand the implications of the manufacture, use and end-of-life of novel and advanced materials the RSC recommends that life cycle assessment (LCA) is applied during their development and used to minimise environmental impacts and maximise economic and societal benefits.

Life-cycle assessment (LCA) methods can be used to assess materials and energy flows throughout the life cycle of a given product or process. LCA can be used to identify environmental impacts, inefficient processes, high-energy use (and therefore where it could be reduced) and exchanges of materials with the environment. LCA does not, however, give an indication about how best to act upon the observations. Theoretical LCA studies could be used to predict life cycle implications for novel and advanced materials and for comparing alternative processes and supply chains with respect to environmental impacts. There is still work required on developing internationally standardised and unbiased LCA methodology that can be used for comparative studies.

The information that LCA provides on materials flows could be used to indicate how, where and in what quantity novel and advanced materials or their by-products might be expected to end up in the environment.

Sustainable chemistry

Novel and advanced materials and processes required to manufacture them offer the opportunity to take full advantage of the tools and techniques that have been developed through green chemical technology (GCT); for example, environmentally low impact solvents, efficient catalysts and biocatalysts, renewable raw materials, process intensification, process optimisation software tools, separation technology and alternative energy sources such as microwave heating and sonication. The application of GCT has the potential to result in reduced costs, emissions, wastage of raw materials, energy consumption, risk and hazard, use of non-renewable resources and also result in faster manufacturing.

Novel and advanced materials also offer an exciting opportunity to apply the principles of green product design (GPD)[1] when considering material requirements. GPD provides the opportunity to think outside the box of conventional material properties and consider what properties and/or effects are actually desired and then design the material and process incorporating the principles of green chemistry[2] throughout the supply chain in order to minimise environmental impact whilst maximising economic benefit and regulatory compliance.

[1] http://www.crystalfaraday.org
[2] http://www.epa.gov/greenchemistry/principles.html

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