Sustainable Water

The role of the chemical sciences

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Key chemical science challenges

- **Predict** the effect of climate change on global, national and regional water availability and quality, so as to inform adaptation and infrastructure planning.

- **Develop** portable technologies for analysing and treating contaminated groundwater that are effective and appropriate for use by local populations.

- **Create**, demonstrate, and deploy sensor networks that provide accurate real time measurements of the status of European water quality, so as to inform strategies for improving water quality across Europe.

- **Understand** and accurately predict the environmental fate of man-made chemicals, particularly emerging contaminants and their metabolites.

- **Design** chemicals and products that are highly effective in their use, and at end of life, are reusable and/or recyclable or degrade quickly in the environment.

- **Develop** advanced water treatment technologies that are highly effective and that significantly reduce energy demand.

- **Widen** the adoption of the principles of green chemistry, and apply the principles of integrated pollution prevention and control, to chemical manufacture, with the aim of reducing waste, energy use, and water use.

- **Agree** standard goals (recommendations) for the use of different water qualities in households, agriculture, industry and leisure.

Foreword

Water is an essential sustaining constituent for all life. It permeates throughout all our lives and is deeply embedded in our cultural backgrounds. The basic human needs of a secure food supply and freedom from disease depend on it. Access to safe drinking water and sanitation varies dramatically with geography and many regions already face huge shortages. One of the world's greatest challenges is to address the issue of how we manage more sustainably our water resources.

The chemical and molecular sciences can help to provide solutions in terms of how we look after the hydrological cycle. Some key questions need to be answered and chemical and molecular scientists can help to solve these issues. How will climate change induced perturbations in global precipitation affect global water availability and quality? What technological developments are required to achieve accurate real-time monitoring of water quality across a whole country/continent? What is the behaviour of emerging contaminants in the environment and how can we apply this knowledge to green product design? What developments are in the pipeline to increase the efficiency of water treatment?

By looking at key issues such as sustainable water, EuCheMS can effectively help bring scientists together to share knowledge and to help address important challenges that will affect society over the next few years.

Professor Giovanni Natile
President, EuCheMS

Introduction

Providing sufficient quantities of water at an appropriate standard to satisfy domestic, industrial, agricultural, and environmental needs is a global challenge. To do this in a sustainable way in the face of massive population growth, climate change and man-made pollution, is one of the greatest challenges of the 21st century. This report, intended for policy makers, highlights the vital role that the chemical sciences will play globally in sustainable water management.

Sustainable water management means doing better than we have in the past and doing more with less. Sustainable water management requires a complete understanding of the hydrological cycle, including the inputs and outputs of the system, and using this information to develop better technologies and practice to manage the water resource. In particular, scientists have an important role in understanding and predicting the impact of climate change, which will inform decision makers about water supply and flood defence infrastructure for the future.

The chemical sciences are critical in the treatment of water in both making it potable and also in removing contaminants from wastewater and industrial waste streams to protect receiving water bodies, often used as raw water for water supply. With adequate support the chemical sciences will aid the development of advanced treatment technologies such as membrane, ultraviolet, specific adsorption and advanced oxidation processes. For example, it has been suggested that future developments could include smart pipes for water and wastewater distribution that monitor and treat water *in situ*. Additionally, the chemical sciences are important in the development of treatment technologies and standards for rainwater use and for subpotable and potable reuse of domestic wastewater. Water transport and treatment is energy intensive and it is anticipated that globall energy requirements will increase as nations are forced to exploit water resources of poorer quality.

Human activity has resulted in the emergence of chemical contaminants in the environment, typically mobilised by water. Further research is required to understand the fate and environmental risk of emerging contaminants including pharmaceuticals, industrial chemicals, personal care products and nanoparticles. With support, the chemical sciences will develop advanced monitoring technology, such as advanced sensors, to provide real-time information wirelessly on water quality and contaminants. The ultimate goal for the chemical sciences is to develop products that are designed not only to be highly effective in their use but to degrade to harmless products on reaching the environment.

Integrated Water Resource Management

The ideal scenario

This scenario aims to illustrate ways in which integrated water resource management could be implemented if the entire system could be redesigned from first principles. It is obvious that in many countries such a redesign is impossible; however, a number of the principles outlined here are relevant to all situations. It is important to strive towards an ideal scenario so that progress can be made en route.

Water resource

Water use is minimised. Water resources are used sustainably, balancing reasonable human needs with environmental needs, maintaining natural hydrological flow regimes and natural geomorphological forms.

Due to improvements in climate change models, the effect of climate change on precipitation and consequently flooding, drought, and water availability, can be more accurately predicted both nationally and globally. As a result, an integrated approach is established that maximises water capture, minimises flood risk, and minimises the agricultural and health impacts of drought.

Water demand

Domestic

Sufficient treated water is delivered to houses and industry to meet potable water demand. Other domestic, industrial and agricultural needs are met through non-potable water that is treated to an appropriate legal standard. Rainwater and grey water are harvested, treated (to satisfy legal and appropriate standards) and used in all buildings for appropriate purposes. Decentralised and centralised water reuse systems offer chances for water saving in densely populated areas. Smart meters monitor and inform households on their water and energy usage and customers are rewarded for reduced usage.

Workable codes for sustainable housing are adopted that ensures new houses are water efficient. Additionally, the existing housing stock is progressively retrofitted to high water efficiency standards. Household products and appliances, such as washing machines and detergents are designed to work effectively with minimal water and energy demands, and produce waste streams that require minimal treatment and are recycled as grey water. There is effective collaboration between water companies, users, appliance manufacturers and chemical companies.

Agriculture

Rainwater is harvested and improved agricultural practice, such as zero tilling, is employed to maximise rainwater use and minimise soil erosion. Grey water that meets appropriate standards is used for irrigation where possible. Water efficient irrigation systems and practices are routinely employed that minimise water use and ensure water demand is met sustainably. Agrochemicals (fertilisers, herbicides and pesticides) are designed and employed to maximise efficacy, minimise crop treatments and degrade quickly in the environment. Agrochemical inputs are minimised by the application of integrated pest management strategies. Livestock management systems are in place to keep animal wastes from water.

Industry

A continuous external supply of water for internal use is regarded as a privilege and not a right. Industry minimises water use and maximises water and heat recycling saving both energy and water bills. State of the art systems are routinely used that are highly efficient, safe and low maintenance. The principles of waste minimisation, established in the 1990's are taken seriously. The industry offers good chances for a zero emission system, where all wastes are reused or destroyed on-site.

Chemical industry

The chemical industry routinely applies the principles of green chemistry, minimising water uses resources, energy, risk and cost. Chemicals are designed to be highly effective and at end of life to be reusable and/or recyclable or to degrade quickly in the environment.

Where appropriate, water is advantageously used as an effective solvent in either the liquid, superhot or supercritical phase to facilitate efficient chemical transformations or processes.

Water treatment

Potable water treatment

A minimal amount of water is treated to a potable standard using state of the art high throughput technologies, greatly reducing energy and chemical inputs compared to the current situation. Routine technologies include efficient membranes, adsorptive, catalytic and, photochemical processes.
The distribution network will have a significantly smaller capacity than is currently the case, and move towards being leak free.

Wastewater treatment

Sewage production is minimised through waste minimisation practices and greater water reuse and recycling. Smart sewer pipes are used that monitor and treat sewage in situ from source to the treatment plant negating the need for energy intensive treatment at sewage treatment works. Sewage treatment works treat wastewater to an appropriate standard utilising advanced anaerobic and oxidation processes that minimise chemical and energy inputs. Methane from anaerobic processes is captured and converted to energy in efficient processes providing energy and heat for the treatment processes. Energy and chemical demand at wastewater treatment works is further reduced due to minimal contaminants in sewage streams because chemical inputs to the environment are designed to degrade.

Industrial waste streams

Industrial waste streams are treated on site and valuable chemicals and materials are recycled. In the chemical industry, the routine practice of green chemistry maximises yield and minimises product and co-product formation minimising treatment requirements.

Water monitoring

Water is monitored at all stages via an extended network of wireless sensors that provide continuous real-time information on the chemical and biological status of the water, and feeds back into mechanisms for process control. Problems of water quality are recognised early and can be dealt with appropriately; additionally the polluter can be identified through the application of environmental forensics and can be brought to justice. Advances in analytical chemistry, miniaturisation and wireless technology mean that emerging contaminants are detected and identified early. Monitoring in agriculture and industry leads to optimisation of processes which results in energy and cost savings, reduced wastage and environmental burden.

Green product design

Accurate predictive models of environmental fate and health implications of chemicals are applied in chemical design so that effective but environmentally compatible chemicals and products are produced.

Summary of chemical science priorities

Underpinning chemistry	Applications
Materials chemistry	• Breakthrough in membrane technology for microfiltration, nanofiltration, ultrafiltration and reverse osmosis to significantly reduce costs and improve process efficiency for the removal of particulates, precipitates and micro-organisms. • Improved coagulants that deliver effective performance but produce minimal solid residues. • Advanced adsorbents are developed to remove emerging contaminants from wastewater treatment works. • Development of materials and manufacture of remote wireless water sensors capable of operating for at least one year without maintenance. • Development of smart pipes that allow monitoring of potable water and wastewater in situ. • Development of self healing pipes that reduce water leakage. • Technology transfer of bactericidal coatings from domestic and industrial applications to water applications, such as pipes. • Novel anti-corrosion coatings and chemicals for the minimisation of corrosion in pipe-work and deposition of solids from process water in industrial processes.
Catalysis	• Advanced oxidation processes including photocatalysis are developed to remove emerging contaminants from wastewater treatment works.
Green chemical technology	• Application of principles of green chemistry reduces water usage and wastewater from chemical industry processes. • Products are designed to minimise water and energy use during their production and use. • Products are designed to be efficacious in their intended use and to degrade quickly to benign products in the environment.
Chemistry biology interface	• Advanced anaerobic processes are developed that reduce the cost and increase the efficiency of wastewater treatment. • Chemists and biologists collaborate to develop sensitive and robust remote biological sensors to detect both chemical and biological species.
Photochemistry	• Improved quantum and energy efficiency of ultraviolet treatment for both the destruction of organic species and the disinfection of water. • Development of ultraviolet processes to treat potable water in distribution pipes and sewers.
Industrial chemistry	• Industry to implement fully the principles of waste minimisation. • Aqueous waste streams are treated on site and products are recycled, minimising the chemical burden in water.

Underpinning chemistry	Applications
Modelling	• Improved understanding of global, national and regional effects of climate change upon precipitation, with particular emphasis on modelling drought and flooding. • Development of models to predict the effect of climate change on groundwater resources. • Improved understanding of how floods activate and redistribute contaminants around the landscape. • Models that predict the environmental fate of chemical contaminants are developed. • Models that predict the impact of mixtures of chemicals in low concentrations on environmental and human health, if possible, are developed.
Environmental chemistry	• The environmental fate of emerging contaminants, particularly pharmaceuticals, new industrial chemicals and nanoparticles, is understood and risk analysis is carried out.
Physical organic chemistry	• A detailed understanding of the rate and mechanism of degradation of environmental contaminants and the formation of intermediate metabolites is developed.
Toxicology	• Toxicology of environmental contaminants and their transformation products is understood.
Analytical chemistry	• Portable field-testing kits for heavy metals and organic pollutants are developed that are quick, accurate, cheap and reliable. • Appropriate standards are developed that allow greater grey water and rainwater use as well as subpotable and potable wastewater reclamation. • Calibration data is available for passive samplers that allow them to be demonstrated alongside current monitoring networks. • Sensor validation strategies are developed for new sensors including passive and remote wireless sensors. • Quality control procedures are developed for sensors, onsite-monitors and passive sampling. • Improved active/passive sampling techniques leading to better sensors. • Develop guidance on analytical quality control for the water sector covering the developments in sampling, sensors and analysis. • Bioanalytical test systems and sensors are developed for integrated bioeffect monitoring (e. g. eutrophication, specific toxicities).

About EuCheMS

The European Association for Chemical and Molecular Sciences (EuCheMS) is a non-profit-making organisation. Its object is to promote co-operation in Europe between non-profit-making scientific and technical societies in the field of chemistry and molecular sciences. EuCheMS provides a powerful single voice for chemists and the chemical sciences in Europe through its activities and development of policy. The organisation can draw upon significant resources, having 50 member societies which in total represent some 150,000 individual chemists in academia, industry and government in over 35 countries across Europe.

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