The role of technology in achieving water security

Ian Thompson

Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK

The development of technologies for the provision of clean and plentiful supplies of freshwater has been a central feature of successful civilizations. In advanced economies, we have grown to assume that the tap at home will always provide as much as we want of clean drinking water. Rapid economic development and population growth globally, in particular in cities, are hugely expanding expectations for modern water services. Ageing assets and a changing climate mean that even mature economies with a huge stock of water infrastructure face substantial challenges. These challenges can only be met by a change in behaviour, better infrastructure, improving efficiency of current technologies and the development of completely new technologies. For instance, the established use of drinking water to flush toilets, water gardens and wash cars is not a sensible use of vital resources, including energy. The future will require technological innovation, improved thinking about the exploitation of water supplies and better incorporation of new technologies into current and future infrastructure.

We are fortunate in the UK and most of the developed world in being secure in the knowledge that our domestic water supplies are safe to use and consume. Effective regulation and established technologies ensure that instances of microbial pathogens and chemical contaminants entering our water supplies are rare. In this regard, we still owe an enormous debt of gratitude to the civil engineers, most notably Joseph Bazalgette, who in the 1860s designed and constructed the water treatment system, which is still the blueprint for many parts of the world. It is this infrastructure that the Victorians put in place that we still largely rely on to ensure that wastewater is effectively treated and recycled. Indeed, the technology has changed little since those pioneering days.

However, the rapidly expanding global population and its tendency to concentrate in mega-cities are putting untold pressure on sewage processing and all aspects of current water treatment systems, which after all...
were designed for the needs of the past centuries. Some of the most pressing demands in terms of modern requirements include the need to:

- reduce the energy/carbon footprint of established water treatment methods or replace them with more efficient alternatives;
- treat high-concentration and toxic industrial effluents, which until recent legislation were disposed to landfill;
- treat low-concentration/trace high-impact contaminants, such as hormones derived from excreted contraceptive hormones and other endocrine disruptors;
- recover high-value resources, such as precious metals (e.g. platinum) derived from street wash-off originating from catalytic converters of vehicles;
- transform the high-organic-component wastewaters to renewable energy in the form of microbial methane generation or bioplastics; and
- reduce current dependence on centralized national water supply grids and introduce the ability for more localized self-sufficiency.

A few striking facts highlight some of these challenges and the urgent need for new technologies to maintain water quality in the face of modern-day needs. Perhaps the most alarming are plummeting sperm counts, which some research suggests have halved in the past 50 years. This is attributed, in part at least, to the ineffectiveness of current sewage treatment processes to remove the remnants of contraceptive pills excreted in urine [1,2]. The same hormone contaminants have been attributed to the increased cases of prostate cancer [3,4]. Similarly, increasing incidence of Parkinson’s disease has recently been attributed to the occurrence of industrial solvents in aquifers providing potable water [5,6].

Added to the concerns of unintentional contamination is the increasing realization that the national water supply grid is dependent upon a relatively few strategically vital pumping stations, which play a critical role in distributing essential supplies. Targeted debilitation of these stations would disrupt supplies to the millions currently entirely dependent on the national grid supply system. Thus, there is drive from Government to develop an infrastructure and accompanying new technologies that will enable more self-sufficiency, decentralization and the ability to isolate contaminated sources. However, one of the most significant needs in terms of societal security is the urgent requirement for technologies that reduce the high energy/carbon footprint associated with current water purification and distribution systems [7–9].

In recent years, there have been significant advances in several technological fields that will inevitably impact positively in terms of making current water delivery systems much more secure and energy efficient. For instance, with the introduction of molecular biology, which came with the resolution of the DNA structure, it is now possible to obtain unique insights into the microbial processes that are central to the water cleaning systems we are so reliant upon [10]. These provide comprehensive assessments of the key functional communities of microorganisms that transform potential toxic sewage and other wastewater effluent into clean potable water and renewable energy in the form of methane generation. With such information, it is possible to assess the potential efficiency of the treatment system, optimize performance, identify key pinch-points, and importantly predict potential failures. A particularly exciting development is the advent of ‘bacterial biosensors’, which are the modern-day equivalent of the miners’ canary [11,12]. With this technology, bacteria emit light that can be easily detected when conditions are good. However, as with the canary response, as conditions deteriorate, for example, the introduction of a very toxic chemical, light emission decreases in proportion to the degree of toxicity. The potential of this immediate and highly sensitive feedback mechanism holds enormous promise for improving performance and control, and pre-empting system failure. A very recent spin-off of molecular biology is that of synthetic biology, the design and construction of new biological functions and systems not found in nature, whose potential for deployment in the water industry is currently being investigated [13].
Another comparatively recent development and significant step-change technology is the introduction of nanotechnology, particularly in the form of nanomaterials. As the name suggests, these materials are manufactured to nanoscale, which significantly alters their physical properties via quantum mechanics, resulting in dramatic alterations and even the introduction of completely new material properties. A striking instance of such property change is gold, which is typically inert, but at nanoscale becomes highly reactive and an effective catalyst. The enormous excitement and potential that this new technology holds is reflected in the recent award of the Nobel Prize to two UK scientists for ‘graphene’, a monolayer building block of graphite [14]. The potential of this nanomaterial and the whole field of nanotechnology in terms of advancing water technology are genuinely very exciting and await exploration. However, work has already started in a range of applications, including:

— the application of nanoscale iron to treat recalcitrant and toxic industrial solvents in groundwater [15];
— nanoscale sensors for real-time in situ detection of chemical contaminants (organic and metal) and microbial pathogens [16, 17];
— nanofilters to remove potentially toxic pesticides/hormones from potable water [18, 19];
— nanobiocides that specifically target and kill off water-borne pathogens [20];
— magnetic particles for attachment and manipulation of cells, including those with useful traits;
— targeted removal of pathogens [21]; and
— self-sterilizing containers for on-site generation of potable water.

Microbes have always played a central role in the maintenance of a healthy environment, and, with growing emphasis on low-energy and sustainable systems, their use is likely to grow and impact even more on the water industry. Fortunately, microorganisms have exceptional properties, which, for instance, enable them to treat toxic wastes as nutritional opportunities, so that a disposal problem is transformed to a clean renewable energy opportunity. However, if left to their own devices, they can wreak havoc, and in some cases this can lead to large-scale death and famine. Manipulation via nanomaterials as indicated in the points above is one approach of several whereby cross-disciplinary skills and tools from the physical and chemical sciences can be exploited to optimize biological performance.

With effective guidance and more engineered control, microbes will continue to detoxify water, treat our waste and work harmoniously with new technologies as they come on board. The key challenge for water technologists today and in the future is to exploit this biological potential even more effectively and scale up their processes so that they can service the increasing needs of rapidly growing populations. Inevitably, this will require the skills of engineers, a discipline trained in methodical thinking, which will be applied to vital issues of biological process control and scale-up. However, the application of the disciplined thinking and mindsets of engineers to biological systems, which are so notoriously unpredictable and stochastic, will require effective multi-disciplinary training and a new breed of engineers.

References