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## Target Areas for Nanotechnology Development for Water Treatment and Desalination

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It is of no surprise to many around the world that water is a priority research area: water is one of the most fundamental elements of our existence. We use water for drinking, cleaning, cooking, removing waste, recreation, manufacturing, cooling, and so on. These uses have criteria related to the quality for its intended purpose (e.g., drinking) and quality to minimize its harm to the environment when it is disposed after use. To meet these criteria, there is nearly always a treatment process that requires energy and chemicals. Our health and our environment are significant priorities. We have conflicting issues regarding energy usage and chemicals that lead to pollution and harmful by-products associated with their production, delivery, and disposal; hence, we need to minimize the usage of those resources while improving water quality and counter the risk of human illness or the damage to our ecosystems. This is therefore, the motivation for innovative technologies for water treatment: reduced energy and chemicals use. Of course this must be achieved at low cost.

## 1.1

### The Future of Water Treatment: Where Should We Target Our Efforts?

Many research endeavors ranging from fundamental to applied, typically address specific issues and aim to make improvements based on relative measures. For example, we can report improvements to new types of materials to remove microcystin, or we can, for the first time, apply a commercial ceramic membrane to filter an industrial waste. But what in common drives such efforts, and where is all this heading in terms of the greater needs of the society for low energy, safe, and reliable water?

Technologies that are used for water treatment include adsorption, coagulation, reaction, heating, and filtration. These have the effect of removing or deactivating/converting unwanted elements, such as salt, organics, odors, microbes, suspended solids, and toxins. The choice of technologies and the required removal varies considerably around the world, driven by specific quality needs or regulatory requirements. Water treatment systems must

- reliably provide water fit for its intended purpose (e.g., drinking water) and
- collect contaminated water (by humans and/or industry) and remove harmful components before its release to the environment or reuse.

The connection between these points (i.e., closing the loop) increases as technologies become more efficient, reliable, and available. Ideally, we might like to take any water source, regardless of its contamination, and convert it directly to drinking quality water. This is known as *direct potable reuse* and has many incentives for a future with sustainable water [1]. This pathway to adopting such treated wastewaters for applications that include human contact (irrigation, drinking, washing, etc.) will involve not only efficient technologies but also evidence of their reliability and is thus another measure from an innovative solution.

The argument for direct potable reuse is that it is far less energy and resource intensive than indirect potable reuse (i.e., holding the water in a large “diluting” body such as a reservoir before reusing). But under increasing economic, energy, and environmental pressures, we foresee that recent developments based on nanotechnology, which might take at least five years to come to market, are likely to become part of a future headed toward direct potable reuse systems. This might give some thought to how researchers might like to steer their work. For example, energy saving systems that produce high-quality water safely and reliably will be likely successes. The alternative to this is treating water that is “fit for purpose,” – it meets the minimum requirements for another purpose such as direct (nonpotable) reuse – for example, desalination of saline waste for reuse in an industrial boiler. Such opportunities require less public and government acceptance to engage (and are indeed already underway), but there must be a convenient user of this water to make fit-for-purpose treatment viable. So it appears that for technologies emerging in the next decade, we should aim to provide solutions that support the fit-for-purpose agenda, when the market for the water is known. Therefore, efforts that bring the costs and environmental impacts down to reliably deliver water for our direct consumption are most worthwhile.

In this book, we present nine chapters focused entirely on technology approaches to improve water quality. All of them essentially and ultimately aim to achieve fit-for-purpose, or even direct potable reuse, aligning with the future demands of the water industry. Specifically, the contributions have routes in nanotechnology respecting that the chemistry, materials, and thinking at this scale offers new opportunities for future water treatment. The technologies considered harness functions such as catalysis, sensing, diffusion, and adsorption.

## 1.2

### Practical Considerations for Nanotechnology Developers

Any new nanotechnology that demonstrates virtue for water treatment must undergo a rigorous process to validate its full commercial and environmental potential. We have listed the following considerations/questions that should be

determined/answered at the earliest phases of development to facilitate its success as a water treatment solution:

- Nanoparticles cannot reach people, animals, or the environment.
- No new hazardous by-products are inadvertently created.
- Unwanted materials and by-products (if created) are completely removed or mineralized.
- Is reaggregation of nanoparticles going to occur? Is this a problem?
- Is the process that must be installed to harness the nanotechnology simple? Can untrained people use it? Is it expensive?

On top of these specific considerations, the work must also consider the broader implications:

- Does the new treatment solve the problem or generate a new one?
- What is the fate of the contaminants – can we completely destroy them? Recover? Or maybe they are returned to the environment? What is the cost?

We propose that the aforementioned points be considered in any future research and in turn publications to be considered when weighing up if their nanotechnology is on the right path to becoming a practical water treatment process. As you will see in the following contributions from the authors' areas of expertise, there has been a focus on the new technologies in working toward real needs in the water industry.

### 1.3

#### The Water Treatment Market for New Nanotechnology

Clearly, with the recent scientific developments in the last decade in the field of nanotechnology, these aspire to commercial use. But how big is this market expected to be? A report published in early 2011 by BCC Research [2] looked at the current market status of nanotechnology applied to water treatment and forecasts its growth. In 2010, they estimated the market (in US dollars) for nanostructured products used in water treatment to be \$1.4 billion. By 2015, they expected this to grow to \$2.2 billion. Interestingly, this was mostly confined to established products including membrane technology, which is categorized as nanobased (reverse osmosis, nanofiltration, and ultrafiltration). Of the nine original contributions to this book, six are based on membrane technology, aligning with the significance of membranes picked up by the market report. For emerging nanomaterials such as nanofiber fillers, carbon nanotubes, and nanoparticles alone the market estimate was \$45 million in 2010, but is expected to grow rapidly to \$112 million by 2015.

We have pointed out that researchers should target their efforts at achieving potable water quality, or at best a significant and defined fit-for-purpose application. At the same time, this should be done with demonstrated opportunities for cost reduction, energy savings, and chemical reduction while no other consequences emerge as a result. With these taken into account, successful nanotechnologies are

expected by economists to experience growth in the sales in the next five years. Therefore, it seems safe to say that it is an exciting time for scientists and engineers to develop new technologies and theories as it is certain that the market will take them up in future. We are currently at the phase where science is demonstrating the concepts proposed, but there is still a lot of work ahead in terms of measuring the performance and economic potential in real application.

## 1.4

### Purpose of This Book

There are a multitude of agendas for improving desalination and water recycling deployment, for example, demand management, public perception, “simple” solutions, and of course new technologies. None of these will solve our water issues alone, but in this book, we focus on new technologies and thinking that have been borne out by exploring at the nanoscale, which has emerged only in the last decade from fundamental level research. The chapters presented in this book cover the major areas where nanotechnology has shown promise in addressing the issues in water treatment that are understood by industry.

In Table 1.1, we broadly divide water treatment into the three categories: pollutant removal, detection/monitoring, and desalination. Many water treatment efforts can be defined under these categories for relatively simple purposes as shown. Some of the chapters spread across these categories (e.g., desalination and pollutant removal). It is interesting to point out that despite these broad and highly differing purposes, the concepts behind the technology share a lot in common, such as catalysis, adsorption, materials engineering, colloidal chemistry, and molecular diffusion. These are well-known scientific pillars of nanotechnology. Therefore, the purpose of this book is not only to demonstrate working nanotechnological solutions for major water treatments but also to highlight the common sciences and achievements that bring about such solutions.

In the chapters, we show how nanotechnology leads us to develop new materials, improving existing technologies (e.g., membranes), and to enhance our understanding of complex processes (e.g., molecular simulations). Developing new materials from the bottom up offers new and exciting opportunities for efficiency improvements yet unseen by industry. Such materials are included in Chapters 2–4. Improving existing technologies is part of Chapters 5–9. For example, membrane technology has been successfully deployed at full scale for water filtration and desalination, but limitations are being realized through the ongoing issues related to fouling. Also, as current technologies such as membranes move into more challenging water treatment areas, these issues will become cost prohibitive. So the priority in research is to explore ways to enhance membrane life and performance by way of improved fouling tolerance and durability without compromising on the essential flux and selectivity features. We also broaden the thinking of nanotechnology beyond materials developing in Chapter 10, where nanodimension modeling gives fresh insight into molecular diffusion, interaction

**Table 1.1** The purposes of each water treatment category aligned to the chapters presented in this book and the nanotechnology concepts applied.

Category	Purpose	Chapters in this book	Nanotechnology concepts applied
Pollutant removal	Prevent micropollutants released to environment. Improve water quality for reuse.	Chapter 2 Chapter 4 Chapter 5 Chapter 8 Chapter 9 Chapter 10	Catalysis, adsorption, materials design, surface chemistry, colloidal chemistry, molecular diffusion, and molecular dynamics.
Detection/monitoring	Rapid and specific water quality monitoring. Improved performance of water treatment systems.	Chapter 3	Catalysis, adsorption, materials design, surface chemistry, colloidal chemistry, electromaterials, and optical physics.
Desalination	Access abundant ocean water resource. Improve water quality for reuse.	Chapter 5 Chapter 6 Chapter 7 Chapter 9 Chapter 10	Adsorption, materials design, surface chemistry, colloidal chemistry, electromaterials, molecular diffusion, and molecular dynamics.

chemistries, and fouling mechanisms. This not only contributes new science but also offers new approaches to manage plant operation to gain better performance of our current membrane technologies.

## 1.5

### Concluding Remarks

We have identified that fit-for-purpose, and ultimately direct potable reuse, should be on the minds of nanotechnology researchers when developing their technologies for likely uptake in no less than five years. The chapters in this book cover most of the global efforts underway to bring about these water treatment agendas. The authors of this book were identified when the book was conceived to provide expert contributions from their field, but we duly acknowledge that more nanotechnology research is being carried out beyond what has been published here particularly as the field is in a state of rapid growth with creative minds continually emerging with new ideas.

Finally, we would like to make a mention of the current state of the world in which this book was written, which has given priority to water treatment research. At the time of writing, the world was undergoing major economic issues, specifically the Global Financial Crisis. This had a direct consequence to funding research

that addresses our need for improving environmental and economic sustainability. Despite the uncertainty in global economies, climate change was recently accepted by politicians while society begins to witness never before weather activities such as severe and prolonged water scarcity and pollution. This is compounded by the rapid intensification of mining, resource extraction, and manufacturing that presents new water treatment challenges. So with the achievements in the fundamental science giving rise to nanotechnology in the last decade, now is an exciting time to drive emerging nanotechnology solutions to practically solve our most critical issues.

Whether you are an engineer or a scientist, a student, or working in industry or research, we hope this book serves your needs and gives you a comprehensive picture of the emerging nanotechnology and associated sciences now being applied to water treatment.

## References

1. Khan, S.J. (2011) The case for direct potable reuse in Australia. *Water – J. Aust. Water Assoc.*, **38** (4), 92–96.
2. BCC Research (2011) Nanotechnology in Water Treatment, BCC Research.