2011 World Materials Summit: Water Panel Report

The Challenge of Water

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Current State of the Technology

Processing of water has traditionally been divided into *water purification* and *water treatment*. Water purification refers to the technology used to purify source waters for food production, human-use, energy, and industry; while water treatment refers to the technology used to treat of waste streams from all-of-the-above. Many of the technologies used for purification and treatment are, understandably, closely related and can be approximately categorized into physical (coagulation, filtration, membrane separation, adsorption) chemical (chlorine-based disinfection, oxidation), and biological processes.

Current trends in water purification and waste-water treatment include increased use of membrane separations and increased use of advanced oxidation (ozone, peroxide) for disinfection and the destruction of low-level toxic contaminants.

Long Term Vision and Goals

Increase water supplies where and when they are needed through efficient purification of impaired water. Sources of water for human-use have been traditionally limited to relatively pristine, freshwater surface and ground water. Sources of water will be greatly expanded when we can cost-effectively purify seawater, brackish groundwater, and water contaminated by pathogens and hydrocarbons. Recycling of waste water will also play a critical role in increasing water supplies. In most parts of the world, all water, regardless of end-use, is distributed through the same system of pipes; and all waste streams are collected by a single system. Separating these systems will effectively increase water supplies.

Detect and selectively remove low-levels of toxic contaminants at low cost. Extremely dilute but highly-toxic inorganic and organic contaminants are a particularly challenging problem in water purification. New methods will enable the detection and destruction of such contaminants rapidly and at low-cost.

Disinfect without producing toxic by-products. Traditional methods of disinfection are based on homogeneous chemistry using chlorine-containing compounds. Chlorine disinfection has, however, an unintended consequence: generation of highly toxic compounds as a byproduct. A vision for the future is to replace chlorine-based disinfection with processes that effectively disinfect microbial and viral pathogens without generating toxicity.

Develop low-cost, robust systems with minimal energy and chemical inputs that can be deployed world-wide. All of the people of world require sources of clean water but many regions lack the infrastructure and access to capital needed to deploy and maintain the types of technology used in highly-industrialized societies. New approaches will improve the health and quality-of-life of billions of people that currently lack access to safe sources of water.

Materials Research Needs

Multi-functional materials . Significant reductions in cost and complexity can be achieved by developing materials with greater functionality. For example, membranes with the ability to self-clean or membranes that can both separate and disinfect could transform membrane processes. Materials that combine functions of concentration—e.g., selective adsorption or ion exchange—and catalytic destruction will enable more efficient decontamination. Heat-exchanger surfaces that are resistant to bio-fouling and scaling will increase the supply of high quality water by expanding the use of water contaminated by organics and minerals salts for cooling the condensers in electrical power generation.

Membranes. Membranes for seawater desalination are a relatively mature materials technology. Expanded use of membrane processes will face, however, a wider variability in the composition and quantities of water contaminants. We need to develop the science and engineering approaches that will enable the rapid development and deployment of new membranes that are optimized for specific applications at both large and small scales. Membrane processes that purify, treat, and recycle water at the scale of individual buildings will produce significant savings in water, energy-use, and safety. Interfacially polymerized polyamide (PA) is the work-horse material for reverse osmosis and nanofiltration but PA membranes are highly sensitive to oxidation by chlorine compounds used in disinfection, creating challenges for the control of biological fouling. The development of membrane materials or coatings that resist biofouling and scaling will greatly reduce maintenance, operating costs, and the discharge of chemicals to the environment. The separation of neutral small molecules, e.g., B- and As-containing species, by PA membranes is poor. Membranes that reject >99% of neutral small molecules may require the development of entirely new membrane chemistry and microstructures.

Detection and destruction of low-level toxic contaminants. Sensor materials and systems are needed that are sensitive, selective, and long-lived in natural water and in waste streams. Autonomous sensor and purification systems will enable rapid response without intervention by operators. Some sensing systems will require remote power by photovoltaics or thermoelectrics. Materials that enable continuous in-line operation and portability are needed. The efficiency of advanced oxidation by ozone and peroxide can be greatly enhanced by the development of high performance catalytic materials. Advanced photocatalytic materials may be able to combine the processes of the generation of oxidative species with the catalytic destruction of micro-pollutants.

Disinfection. Advances in materials are needed to improve the safety of water supplies, particularly in non-industrialized regions of the world. For example, materials are needed that enable sunlight-driven disinfection are sought. (An indirect approach might be illumination by high-efficiency UV LEDs that are powered by photovoltaics). Low pressure membranes need to be developed that can be easily cleaned and capable of removing viruses.

Molecular level understanding of membrane separations is currently lacking. For example, it is not currently possible to separately measure or predict the partition coefficient and mobility of a contaminant in the membrane; and there is no quantitative understanding of the connections between the molecular structure of the membrane and water permeability. The molecular-level physics and chemistry of oxidation and disinfection by photocatalysts are also poorly understood. These gaps in fundamental understanding impair our ability to design new materials for specific applications.

International Cooperation

As with energy, water is an international problem. World-wide energy use is growing; water use will grow too. Water, however, is almost unique among natural resources by its location at and crossing national boundaries. In fact, the flow of rivers dynamically moves this important resource from one country to another. As a consequence, water will increasingly become a cause of conflict between nations.

International cooperative research on materials for water purification and water treatment is very limited compared to the scope of the problem we face. We are aware of some current international collaboration that may serve as models for future expansion. Researchers in China have extensive interactions with Japan (JST and JSPS funding) and Korea on water treatment technologies; and with the EU on the basic science of pollution of surface waters. Saudi Arabia currently funds collaborative work with the US on desalination.

In the US, overall funding levels for research on materials for water are small and little additional funding is available for international cooperative research. US has much to gain from other countries who have invested heavily in water research and are facing severe problems sooner-rather-than-later. Some examples are China, Israel, Singapore, Saudi Arabia, Spain, and the Netherlands.

Industry has to be intimately involved in these research efforts because research universities alone cannot deploy materials on the scale needed in water purification and treatment. Waste water treatment in US and China totals 10^{11} m^3 per year. Cost is also an overriding issue.

Outreach

We need to raise public awareness of the value of water and the fact that clean sources of water need to be protected. Public understanding of the health and safety of water sources, and the risks associated with various water contaminants is limited. The message needs to get out that water recycling is a safe method of increasing water supplies and also has many benefit to the environment in reducing the use of energy and chemicals.