THE LARGE PROBLEM OF WATER SHORTAGES

If you are looking for a project or a career path in materials research, there are promising areas that could have a huge potential impact in the area of sustainability of environmental resources. Let's take a look at the sustainability of earth's freshwater resources, and how it is being affected by materials research.

Most of us think that water for drinking and bathing is abundant, but that is not really true.[1] Most of the water is in our oceans. Only 3% of earth's water is fresh water, and only a small fraction of that is accessible. Add to that factors associated with worldwide population growth, as well as increasing reliance of agriculture and other industries on significant volumes of fresh water, and there are real problems ahead in terms of the availability of water. Several countries do not have enough groundwater to sustain their current populations.[1]

There are vast inequities in the availability of fresh water from country to country and from location to location within countries because of geographic disparities in rainfall and availability of groundwater. The Atacama Desert in Chile, which has been extremely dry for 3 million years, receives (on average) 15 mm of rain per year.[2] Some locations in the Atacama receive only 1–3 mm of rain per year. Contrast this with some cities in the northeastern state of Meghalaya in India that receive an average of almost 12 m of rain per year.[3] The city of Cherrapunji in this region was recorded to have received 9.3 m of rain in July 1861, and 26.461 m of rain from August 1860 through July 1861.[3]

In southwestern parts of the United States, the vagaries of weather patterns have led to severe water shortages that are already affecting the availability of drinking water and water for agriculture, industries, and household use. California is currently in a multi-year drought. Reservoirs in California and other southwestern states in the United States have lost a significant amount of water. Some are too dry to supply water. The water level in Lake Mead, Nev., is 120 feet below the level measured in 2000.[4] The snow pack in the Sierra Madres, the source of water for many California cities, has been significantly below normal for several years in a row. News sources are reporting that the snow pack is at 83% of its level for the same time last year, which was also a below-average year for snow. I have jokingly told many of my friends that, if this keeps up, water will become so expensive that it will be cheaper to buy new clothes than to wash those I have. Maybe this is not really a joke. Or maybe we'll take advantage of California's temperate climate, and California will become a clothing optional society. If so, I need someone to recommend a really good diet!

Most of us who live in highly industrialized societies think of the availability of clean fresh water as abundant. The US government has attempted to ensure an abundance of clean water through regulatory provisions, including those in the Federal Water Pollution Control Act (passed in 1948), the Clean Water Act (passed in 1972), and the Water Quality Act (passed in 1987).[5] With the passage of these and other laws, residents in the United States are blessed with an abundance of water resources, and have become accustomed to an abundance of clean water. It is shocking to us then, when we hear of the problems in locales such as Flint, Mich., where poor decisions made by those entrusted with water quality have resulted in lead from lead pipes leaching into the water system and exposing thousands of adults and children to lead poisoning.[6] It is even more shocking when we hear that there may be millions of miles of old lead pipes transporting potable water in the United States that could suffer from the same problems.[7]

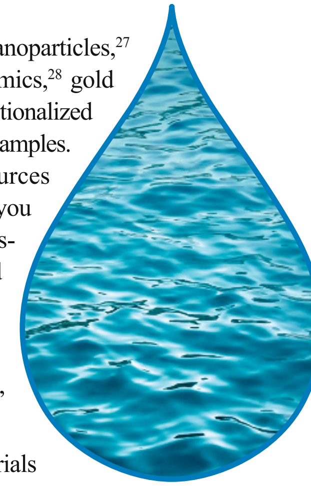
In many other places around the world, the water is so polluted that drinking it or bathing in it is a threat to human health and life. Human waste, sometimes with little to no treatment, is routinely returned to groundwater, streams, rivers, and then to estuaries. The Ganges River in India is severely polluted[8] as are other rivers in Africa, Asia, Australia, Europe, and South America. Around the world, agricultural runoff with residues of fertilizers, pesticides, and animal waste is allowed to return to groundwater and to flow into streams, rivers, and estuaries. Some areas near the mouths of large rivers flowing into an ocean or sea have become dead zones that support no marine life. The outflow of the Mississippi River has produced a growing dead zone in the Gulf of Mexico.[9]

It is relatively well known that it is not safe to eat fish from some waters because they contain high concentrations of mercury that can cause health problems in humans. What is not so well known is that mist from those same waters contains compounds of mercury that can be transported to local beaches. In some beach areas (e.g., Los Angeles), as much as 50% or more of the annual moisture comes from fog or mist that rolls in from the ocean. Recent studies by researchers have shown how compounds of mercury can be transported by the mist.[10] The mercury concentrations are not enough to pose an immediate threat to human health, but mercury is showing up in spiders and insects, which are eaten by birds, lizards, rodents, and their predators. The concentrations of mercury in these environments can become large enough to be a threat to our ecosystems.

Materials researchers are making headway toward mitigating or solving many of these problems. Research is ongoing into developing better materials for water pipes and mains, for solar water disinfection and purification, and for environmentally friendly methods of fertilization and pest control. Materials researchers are also already contributing to efforts to ensure the sustainability of our fresh-water resources through desalinization and purification of water, as well as treatment of polluted groundwater, streams, rivers, and estuaries.

Filters for desalinization must efficiently remove salts from water without being damaged at high pressures or by exposure to chlorine and other substances in the water; they must also be resistant to biofouling.[11] Modern desalinization plants based on reverse osmosis use polymeric filters. Recent research on advanced technologies for filters for desalinization have focused on filter membranes that can be nanostructured, including microporous silica,[12] graphene oxide sheets with nanopores,[13] thin sheets of MoS_2 with nanopores,[14] hollow-core fibers made of sulfonated-imidazole polymer,[15] zeolites,[16,17] carbon nanotube membranes,[18,19] and mixed-matrix membranes,[20] which may involve zeolite nanoparticles or carbon nanotubes in polymeric membranes. Significant investment in research into desalinization is being made in Israel[21] and Saudi Arabia,[22] among others.

Materials research into purification of water has embraced new technologies such as carbon nanotubes,[23] graphene,[24] graphene oxide,[25] graphyne,[26] copper nanoparticles,[27] macroporous honeycomb alumina ceramics,[28] gold nanoparticles,[29] CuO nanorods,[30] and functionalized magnetic nanoparticles,[31] to name a few examples.



Sustainability of our natural resources is critical to the future of humanity. If you are interested in further reading on sustainability, I encourage you to read the *MRS Bulletin* issue on "Materials for Sustainable Development" (April 2012).[32] I also suggest the special section on "Rethinking the Global Supply Chain" (*Science* **344**, 1100 [2014]).

If you are looking at a career in materials research, I encourage you to consider materials research in areas of resource sustainability, such as water sustainability, and the many peripheral materials topics that are associated with water desalination, purification, and conservation. Those of you looking for other ways to contribute could look for charitable organizations associated with providing water to people. One of my favorites is Hope Springs Water,[33] a nonprofit organization whose mission statement is to "provide safe water, sanitation, and public health education in developing countries."

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REFERENCES

1. https://www.wilsoncenter.org/sites/default/files/popwawa2.pdf.
2. https://en.wikipedia.org/wiki/Atacama_Desert.
3. https://en.wikipedia.org/wiki/Cherrapunji.
4. http://www.livescience.com/51916-lake-mead-drought-photo.html.
5. https://en.wikipedia.org/wiki/Clean_Water_Act.
6. M. Torrice, *Chem. Eng. News* **15**, 26 (2016).
7. http://www.huffingtonpost.com/entry/lead-pipes-everywhere_us_56a8e916e4b0f71799288f54.
8. http://www.newsweek.com/2015/10/02/ganges-river-dying-under-weight-modern-india-375347.html.
9. http://www.noaanews.noaa.gov/stories2015/080415-gulf-of-mexico-dead-zone-above-average.html.
10. J. Kemsley, *Chem. Eng. News* **25**, 32 (2016).
11. A. Rodríguez-Calvo, G.A. Silva-Castro, F. Osorio, J. González-López, C. Calvo, *Hydrol. Curr. Res.* **5**, 167 (2014).
12. M. Elma, C. Yacou, D.K. Wang, S. Smart, J.C. Diniz da Costa, *Water* **4**, 629 (2012).
13. http://phys.org/news/2015-11-materials-desalination-cheaper-efficient.html.
14. http://www.labnews.co.uk/news/new-material-water-desalination-02-12-2015.
15. https://www.sri.com/work/projects/advanced-hollow-fiber-membrane-water-purification.
16. N. Liu, L. Li, B. McPherson, R. Lee, *J. Membr. Sci.* **325**, 357 (2008).
17. J. Lu, N. Liu, L. Li, R. Lee, *Sep. Purif. Technol.* **72**, 203 (2010).
18. C.H. Ahn, Y. Baek, C. Lee, S.O. Kim, S. Kim, *J. Ind. Eng. Chem.* **18**, 1551 (2012).
19. M. Majumder, P.M. Ajayan, in *Comprehensive Membrane Science and Engineering*, E. Drioli, L. Giorno, Eds. (Elsevier, 2010), p. 291.
20. D. Li, H. Wang, *J. Mater. Chem.* **20**, 4551 (2010).
21. http://www.ide-tech.com/blog/publication/bankrolling-10-breakthrough-technologies-megascale-desalination.
22. http://www.wdrc.kaust.edu.sa.
23. Y. Baek, C. Kim, D.K. Seo, T. Kim, J.S. Lee, Y.H. Kim, K.H. Ahn, *J. Membr. Sci.* **460**, 171 (2014).
24. Y. Liu, J.H.D. Lee, Q. Xia, Y. Ma, Y. Yu, L.Y.L. Yung, J. Xie, C.N. Ong, C.D. Vecitis, Z. Zhou, *J. Mater. Chem. A* **2** (39), 16554 (2014).
25. B. Mi, *Science* **343** (6172), 740 (2014).
26. K. Jianlong, X. Zhou, H. Lu, F. Wu, J. Fan, *Nanoscale* **6** (3), 1865 (2014).
27. T.A. Dankovich, J.A. Smith, *Water Res.* **63**, 245 (2014).
28. L. Du, W. Liu, S. Hu, Y. Wang, J. Yang, *J. Eur. Ceram. Soc.* **34** (3), 731 (2014).
29. M.R. Bindhu, M. Umadevi, *Mater. Lett.* **120**, 122 (2014).
30. P.K. Raul, S. Senapati, A.K. Sahoo, I.M. Umlong, R.R. Devi, A.J. Thakur, V. Veer, *RSC Adv.* **4** (76), 40580 (2014).
31. A.S. Helal, P. Decorse, C. Perruchot, S. Novak, C. Lion, S. Ammar, J.-M. El Hage Chahine, M. Hémadi, *AIP Adv.* **6** (5), 056601 (2016).
32. A.Y. Ku, A.P. Shapiro, *MRS Bull.* **37**, 439 (2012).
33. http://hopespringswater.org.