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Editorial

Our Role in Solving Global Challenges: An Opinion

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Not a day goes by that I do not ask myself if I am making the best use of my expertise and time left on Earth. We each have the privilege of a turn at life and I believe in contributing positively as much as I can while I am here. This essay aims to suggest research areas to which chemists and others in related fields can contribute, to help preserve and sustain the world for future generations by addressing problems of global importance. But before I do so, I think it best to introduce myself to you, so you may read my suggestions with better understanding of what informs my point of view.

I suspect that many *JACS* readers became scientists because of enduring curiosity about the natural world, a love of mathematics, or both, as in my case. At some point, though, it was not enough for me to indulge in scientific research for its own sake. Instead, I felt—and feel—compelled to contribute my skills to help the planet and all its inhabitants not just to survive but thrive. That is the engineer in me—a physical scientist aiming to serve society. As you read this piece, please keep that context in mind.

I also write from the perspective of a multidisciplinarian, having spent the first half of my faculty career as a physical chemist and the last half as a mechanical/aerospace/chemical engineer/applied mathematician, training Ph.D. students and postdocs from a half-dozen different disciplines. My words thus may appeal beyond chemists to other scientists and engineers as well.

Finally, I also come with experience beyond faculty research/teaching/mentoring, having helped advance the tripartite mission of universities for nearly 15 years as an administrative leader: first as Princeton University's Founding Director of the Andlinger Center for Energy and Environment, later as its Dean of Engineering and Applied Science, then as UCLA's Executive Vice Chancellor and Provost, and now as Senior Strategic Advisor and Associate Laboratory Director for the Princeton Plasma Physics Laboratory, one of the U.S. Department of Energy's 17 National Laboratories. Those roles, along with other service activities, such as chairing the National Academies' congressionally mandated study on carbon utilization, inform the viewpoint I express below. I bother with this prelude so that you, the reader, can decide if anything I say below rings true for you. Onward!

The older one gets, the more one realizes that time is limited and precious. We each have limited time to make a difference in the world. And frankly, the world has limited time for us, for our species, if we don't do more to take care of it. What do I mean and how can each of you contribute?

Some of the intertwined challenges of this century that I believe all scientists and engineers can help solve include:

- Climate change, including mitigation, adaptation, and intervention
- Environmental degradation, including waste and recycling
- Energy transition, including efficient electricity generation, transmission, and storage, and carbon-neutral fuels
- Freshwater and food scarcity, including sustainable water production and agriculture
- Infectious disease and human health

It is obviously not a complete list. It is simply my view of some of the most serious current global threats that science and engineering can help address. (Many societal ills fall outside our purview.) An earlier version included the threats posed by unregulated artificial intelligence and dissemination of misinformation. I struck them as a category, despite their threats to the fate of human beings and the future of democracy. I did so because it is not entirely obvious how chemists can help with those challenges, much of which lies at the intersection of computer science, mathematics, sociology, and politics.

Although it is possible to contribute individually, many of these problems are so complex that we are most likely to make progress within teams of experts from different disciplines. I urge you to think about the problems most important to you, overlay those with your skill set, and start reading, quizzing experts, going to conferences and workshops, and visiting centers focused on those problems. Your first objective should be to understand the history of successes and failures that came before, as well as the state of the art. Then, after having humbly done your homework, bring your lens of expertise and experience to the problem, offering new ideas to investigate. By doing so, undoubtedly you will help advance these fields in the coming years. Note that you do not have to have the equivalent of my long resume to make substantial contributions. However, you must have deep knowledge of your chosen discipline, demonstrated adjacent relevant expertise, and an ability to be unremittingly self-reflective as to whether your skills and perspective indeed will bring something new to the field. Then, submit a preproposal to relevant (governmental or private) funding bodies with aligned interests to get started. This has been my approach over multiple decades.

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Let's dig into each of these challenges a bit more. Again, a caveat: this is my personal viewpoint. Others may add to my list or may disagree. They may even suggest that one of the problems is already solved (even asserting that they have solved it). Be skeptical of the latter, frequently self-serving, claims. Unless you see successful, widespread deployment of a solution, at the very least the problem is not fully solved and there is room for further research discovery. That said, the technology piece indeed *might be* solved and rather it is public acceptance that is lacking. The latter is critical for new technologies; it is a point that we scientists don't often think about. We must start to do so from now on. Because as we find technical solutions, early engagement of communities that could be affected by their deployment is critical. Technologies die not just because of the so-called "valley of death" but because of not engaging affected communities as partners early on in decision-making[1]—a caution to keep in mind. Moreover, such engagement cannot consist of scientists merely lecturing stakeholders about new technologies, assuming the latter's obvious benefits will be immediately understood and accepted. Rather, engagement must start with empathic listening to community concerns, scientifically valid or otherwise, and responding respectfully to work through those concerns. Let's use these opportunities to converse and to educate, with humility rather than arrogance. A final note of caution: sometimes solving one problem can introduce another. For example, electrification of nearly everything—suggested below—then challenges supply chains for critical elements, be it copper for expanded electricity grids to lithium, cobalt, nickel, and other metals for a multitude of sustainable energy technologies. If we harm the environment further through unsustainable mining practices to supply those elements, have we really helped the Earth as a whole? Such questions merely motivate more areas of research, e.g., into sustainable mining and recycling of critical elements, touched on further below.

Returning to the list of chemistry-relevant global challenges:

■ CLIMATE CHANGE MITIGATION, ADAPTATION, AND INTERVENTION

Imagine a world where we arrested climate change so that the Earth's warming trend was reversed and extreme weather, droughts, wildfires, floods, melting glaciers, and rising sea levels became rare or ceased completely.

How do we get there? *Mitigation* refers to defossilizing our civilization and, at a minimum, eliminating methane and carbon dioxide emissions. Chemists can contribute through research that aids building a circular carbon economy, using carbon wastes rather than extracted fossil carbon, to create chemicals and materials. Let's electrify every process possible, powered by clean electricity, to minimize emissions. Think about how to convert thermal fossil-fuel-driven processes of today to electrified chemical conversions of tomorrow. As this will take decades to deploy, in the meantime we must consider *adaptation*, i.e., the development of new means to live in a warming world. One example could be synthesizing inexpensive, adaptive building materials to keep us warm in the winter and cool in the summer. Another could be engineering drought-resistant crops and agricultural techniques that don't require freshwater. Beyond adaptation, active *intervention* refers to, e.g., carbon dioxide and methane removal from the atmosphere by efficient sorbents, catalytic conversion, and storage in durable solid products such as carbon fibers and carbonate aggregates. Such a strategy can contribute to the carbon economy while removing major sources of global warming. Intervention can also mean, more controversially, and in my opinion to be deployed only as a last resort, manipulation of the planet's ability to return radiation to space. This strategy might involve designing optimal aerosols to thin out cirrus clouds—a kind of cloud seeding—to allow our overheated planet to cool by enabling more heat to escape into space. Another tactic might be to inject optimal aerosols into the stratosphere to mimic the temporary cooling effect of volcanic eruptions that works by reflecting incoming sunlight. My own current work largely falls into this first global challenge category: (i) basic research into zero-to-negative-carbon-emission production of chemicals and materials; (ii) launching team science efforts in climate change mitigation and intervention; and (iii) advising government and other entities on climate and energy issues.

■ ENVIRONMENTAL DEGRADATION, WASTE, AND RECYCLING SOLUTIONS

Imagine a world where toxic waste no longer exists in our soil, water, and air.

Let's harness our expertise in chemistry, biochemistry, and geochemistry to bring new ideas and fresh efforts to clean up industrial (including chemical, fossil, mining, and nuclear) and agricultural wastes. *Imagine a world where plastic plumes in the ocean and municipal solid waste in landfills were put to some productive use in a circular economy other than burning, which just contributes to more carbon pollution.* Sustainable separation, conversion, and recycling processes need our skills, our innovative ideas. As mentioned earlier, if we can achieve sustainable recycling across these industries, we can limit extractive mining, with its history of environmental harm. That said, we must also develop sustainable mining and recycling to meet the ever-increasing demand for critical elements.

■ ENERGY TRANSITION, INCLUDING EFFICIENT ELECTRICITY GENERATION, TRANSMISSION, AND STORAGE; CARBON-NEUTRAL FUELS; AND EFFICIENT USE

Imagine a world where energy is not reliant on fossil carbon sources.

Chemists can contribute to clean electricity generation, transmission, and storage, largely through materials innovation; development of materials and processes for sustainable production of carbon-free fuels such as hydrogen or ammonia; synthesis of lightweight, strong, recyclable materials for fuel-efficient vehicles; and more. Along with generations of other researchers (not cited for brevity's sake), my research group and I spent many years contributing ideas[2] to zero-carbon-emission electricity generation (from solar-cell[3] to fuel-cell[4] to fusion-first-wall[5] materials) and studying properties of lightweight metals;[6] we continue our long-standing research into sustainable production of fuels and feedstocks (hydrogen, syngas, methanol, ammonia, etc.).[7] I cite my own work here as a convenience to the interested reader who thus may gain more insight into the perspective I bring to this essay.

■ FRESHWATER AND FOOD SCARCITY, INCLUDING SUSTAINABLE WATER PRODUCTION AND AGRICULTURE

Imagine a world where every human being (and animal) has access to abundant fresh water and food.

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Chemists can continue to innovate in developing sustainable methods and materials for harvesting and purifying freshwater and for growing robust food crops with less fertilizer and less water (or with brackish water), and in developing fertilizer alternatives that do not contribute to greenhouse gas emissions (as urea does upon decomposition) or runoff pollution that kills our natural ecosystems, and more.

■ INFECTIOUS DISEASES AND HUMAN HEALTH

Imagine a world where infections of all kinds could be prevented and where health preservation rather than illness mitigation was the order of the day.

The COVID-19 pandemic drove home just how vulnerable we are as a species. A concerted campaign is needed, to which chemists can contribute, to develop pan-(corona)virus vaccines that not only prevent severe illness, hospitalization, and death but prevent infection in the first place, independent of variant type. The same demand for diagnostics and remedies holds for all infectious diseases, as well as for so many other life-threatening conditions such as cancer and quality-of-life threats such as dementia. The complexity of the human body holds many opportunities for chemists to help improve human health. That said, akin to the essential community outreach regarding new technology deployment mentioned earlier, we must provide proactive communication by incontrovertible experts to combat misinformation regarding the effectiveness of medical advances. As we know, medical misinformation is an ongoing challenge that shows no signs of dissipating and will require constant, vigilant attention.

I hope the list above provides you with food for thought for which areas of research would bring even more meaning to your life, to contribute to repairing and improving our world. We only have one Earth. We all live here. I hope we can all find a way to coexist and preserve the planet and ourselves. We are all precious. I am trying to do my part, both in my research that for the past 17 years has been focused on sustainable energy and carbon mitigation[8−10] and in my leadership roles, including our recent launch of electromanufacturing and aerosol science for the climate initiatives at the Princeton Plasma Physics Laboratory and the Simons Foundation, and related advisory board service for the National Academies and beyond. I believe all of you readers have something to contribute, too. I look forward to seeing what our community brings forth, to heal our precious Earth and ourselves, in the decades ahead, not a moment too soon.

■ DISCLAIMER

These comments are mine alone as an individual and do not represent the views of any organization with which I am affiliated.

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Notes

Views expressed in this editorial are those of the author and not necessarily the views of the ACS.

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