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Unleashing the power of materials science for a sustainable future

Bruno Ehrler[1,*]

A key factor in accelerated climate change has been our consumption- and materials-based societal needs, with little historical regard to our finite natural resources and harmful by-products of industrialization and manufacturing. At the same time, materials science may provide a key to preventing climate catastrophe. Here, Bruno Ehrler discusses how materials scientists can do more for a sustainable planet.

The climate crisis is a slowly unfolding disaster that will dominate the lives of the next generation. The consequences for daily life in all climate scenarios are dramatic, ranging from more severe heat, cold, flood, and drought events to biodiversity loss, devastation of food supplies, uninhabitable places leading to mass migration, and more.[1] Yet, the range of possibilities and threats depends heavily on the decisions we are making today.

Developing new solar cells, batteries, recycling technology, and many other sustainable technologies requires materials-based solutions. Materials scientists are thus a key to preventing the climate catastrophe. Yet, there is a large gap between this heroic, gigantic task and the reality of lab work and perceived importance of materials science. There is also a gap between the importance of the challenge, affecting large parts of modern life, and the public attention and funding directed toward materials science that works on sustainable solutions. The pressing questions are thus: are we as materials scientists doing enough, and are we doing the right things to play our part in preventing the climate catastrophe?

Many materials scientists have entered the discipline because they wanted to help end the destruction that humanity is causing with the use of fossil fuels and other finite resources. The reality of a PhD student, however, consists of tedious lab work, in which improvements to knowledge and technology appear far removed from the application, progress is incremental, the sense of teamwork is often absent, and feedback is mostly negative (see Figure 1). While this environment is a breeding ground for frustration and imposter syndrome and a real test of stamina, it rarely appears as an environment of inspirational change of human activity on a global scale. Yet paradoxically, it is the best way we know to develop the technology to fight the upcoming climate catastrophe.

Materials scientists develop sustainable technology

These technical solutions are desperately needed. Burning fossil fuels is the largest contributor to greenhouse gas (GHG) emissions. Currently, 72% of all GHG emissions are caused by fossil fuels.[2] In addition, our fossil-fuel addiction often helps oppressive and aggressive regimes to power. The dependency on those regimes prevents decisive action in case of violation of international law and human rights. To stop burning fossil fuels, we need to develop better solar cells, batteries, heating and cooling solutions, carbon capture technologies, sustainable solutions for heavy industries like concrete and steel, and synthetic fuels for aviation and shipping. The recent surge in new materials like perovskite-based semiconductors or solid-state electrolytes will accelerate the introduction of new materials-based innovations.

Many of these new sustainable technologies are growing exponentially[3] and will hopefully continue to do so for decades to come. We will fabricate enormous amounts of these products: dozens of solar panels every second, wind parks on the kilometer scale, gigawatt hours of battery storage in every country, and billions of heat pumps.[4] These numbers make it abundantly clear that the technology needs to be designed for recycling (circular design) right from the start, thus now, to prevent drowning in waste.[5] Currently, most of our materials are "single-use," thrown away after the product is at its end of life. The result is an increasing scarcity of materials, which, much like the fossil-fuel dependency, makes countries that are rich in these materials disproportionally powerful. Thus, we need to stop both the burning of fossil resources and the single use of our finite materials supply.

Three ways materials scientists can be more effective in fighting climate change

Technology developed by materials scientists will help in the mission to stop unsustainable materials use. However, to have real impact in reducing emissions and materials use, materials scientists need to do more than develop technology.

[1]AMOLF, Science Park 104, Amsterdam XG 1098, the Netherlands

*Correspondence: b.ehrler@amolf.nl

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Figure 1. Saving the world can be tedious
From SMBC Comics.

Influence political forces

So far, one of the most effective tools in fighting climate change is top-down policy, often motivated by bottom-up protests and demand. A few decades ago, the most likely projections of climate change were extinction-level amounts of global warming, with temperature rises predicted as high as 3°C–6°C by 2100.[6] However, recent changes in policy, such as the introduction of a price for carbon within the European Union,[7] have turned the trend, and global emissions have been stable for almost a decade. Stabilizing emissions can only be the start; we need to reduce emissions to zero for a stable climate, but the emission stabilization is progress that had been unthinkable a few decades ago. While the promise of the Paris agreement to limit warming "well below 2°C" will most likely not be kept, a recent study shows that staying "just below 2°C" is in fact likely if the pledges of all countries, the so-called nationally determined contributions, are implemented fully and on time (see Figure 2).[8]

2°C of warming leads to very significant change of our environment but prevents an extinction-level catastrophe. Yet, the pledges still need to be implemented into national law, and then into action, fully and on time. Even better, more stringent pledges or implementing the pledges earlier would limit the warming further, reducing the economic and humanitarian impact. As materials scientists, we have powerful voices to drive this political change. We can write to our local representatives, give public lectures, write popular articles, encourage journalists to write about sustainable materials solutions, participate in science events, join political organizations (political parties, Scientists for Future, etc.), or even become active politicians. Constant and increasing pressure on politics from well-informed voices will be a valuable and sometimes even welcome contribution to the public debate.

Excite a new generation for materials science

While particle physics, space exploration, quantum physics, and life sciences have managed to spark the public imagination, materials science is "the most useful thing you have never heard of."[9] We need a new generation of young materials scientists that are excited by the thought of grain boundaries, stress-strain tensors, and understanding degradation mechanisms. To do that, we need to improve communication. Space travel did not excite generations by talking about fuel injection and cosmic radiation damage, but by talking about the vastness of space and the opportunities and unknowns that lie far outside of human reach.

Materials science can learn from these examples. Let us share the vision of a clean, prosperous world, where materials are beautiful, useful enablers of human endeavors. Let us talk about the grand unknowns in our field, reaching from understanding the interaction of atomic particles to the impact on a global scale. And let us take communication as seriously as other disciplines, producing shiny documentaries, printed material, and a constant media presence. This seriousness about communication includes a need to pour funding into professional communication. Such re-direction of funding efforts should be governed by the national funding agencies, and the role of materials scientists is to encourage their agencies to do so. Also, we need to join forces between

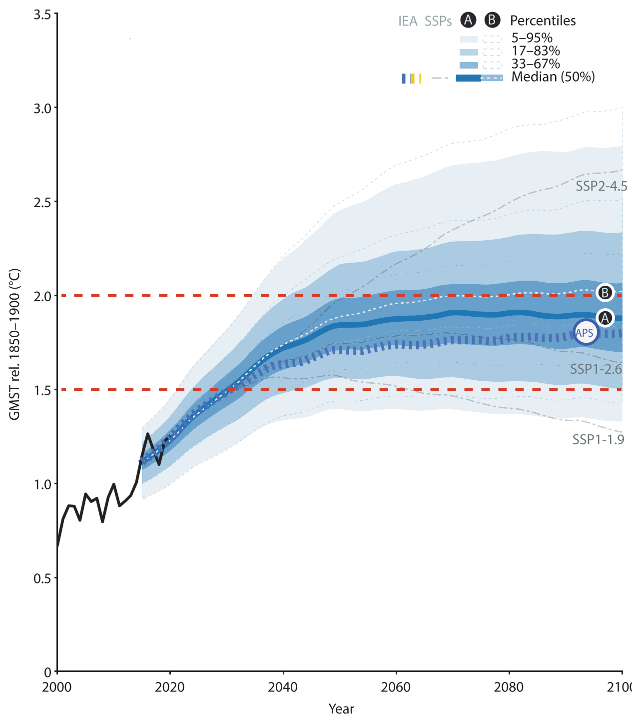

Figure 2. Simulations of the global temperature until 2100 assuming all current pledges for climate policies are implemented fully and on time

Figure adapted with permission from Meinshausen et al.[8]

related sub-disciplines to tell larger, more connected stories. Again, learning from other disciplines, the various sub-disciplines of quantum computation have managed to tell a relatively consistent and grand story, which has made it all the way into popular culture. Overall, to be more successful in implementing sustainable materials, the public will need to be taken along on the journey of the material transition, because this transition will lead to large societal changes in how we use energy and products. Materials science is in everyone's hand—it also needs to be in everyone's head.

Form large organizations around the common aim

We need to be more organized to solve the large-scale problems we are facing. Materials science needs to become big science. We can, once again, learn from fields like particle physics, life science, and space exploration. Here, a common goal leads to consortia of several hundred scientists making organized and large-scale discoveries. While material challenges often appear isolated and comparatively small-scale, this appearance changes with the advent of the need for sustainable materials transition. Designing circular and sustainable solutions for power generation, heavy industry, transport, and consumption needs to involve all stakeholders, from the fundamental science to the applied science, the industry, the end users, and the waste treatment and materials recovery. Only large consortia can organize these efforts. Forming these consortia, however, needs new thinking from funding agencies and scientists alike. Funding agencies need to move to more programmatic and long-term funding of sustainable materials science. Materials scientists need to change the way interactions and collaborations work. Research groups need to orient their research along a common roadmap rather than along the PI's personal interest. Choices need to be made in the research focus on that roadmap, and the roadmap needs to be followed consistently when applying to funding calls. Organized well, such large-scale scientific projects can lead to a more inclusive, fairer, more powerful, more visible, publicly valuable,[10] and better funded field.[11] Turning attention away from individual "star scientists" and toward "team science" would be a welcome side effect of creating a more sustainable materials world. At the same time, these large consortia for developing the existing materials solutions need to be accompanied by smaller research groups, similar to the current field, to ensure the invention of innovative, disruptive technologies.[12]

The 21st century stands in the light of the first true global challenge humanity is facing. Our current lifestyle is changing the air every human breathes, and continuing this lifestyle will have devastating consequences. Materials science has the tools and the responsibility to help solve this challenge. But materials science needs to grow with the challenge. We as materials scientists need to have a louder voice in politics, we need to excite a new generation of young explorers, and we must organize ourselves better. Then, and only then, will we be truly unleashing the power of materials science.

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DECLARATION OF INTERESTS

The author declares no competing interests.

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