Materials science in the Anthropocene: MRS gets serious about sustainable development

Martin L. Green

Civilization on our planet took a sharp turn about 250 years ago, at the beginning of the industrial revolution, and has accelerated on that highway ever since. Arguably, its impact on humankind is equivalent to that of the invention of fire. The enormous consequences of industrial activity, positive and negative, could not have been anticipated then, but the bottom line today is that per capita global consumption of energy (Figure 1a) is higher than ever, and demand for materials (relative to the year 1900), as measured by mine production data, has increased by factors of three to 6000, depending on the metal (Figure 1b). Total population (Figure 1c), as well as those segments of the population doing the consuming, is also increasing. Now we speak (informally, thus far) of the Anthropocene,[4] the first geological epoch in which human activity is deemed to have had an effect on the Earth's ecosystem. Questions arise: For how much longer can economic growth and demand for goods be sustained, and can the same human ingenuity that started the industrial revolution mitigate its effects?

So there's a mess, and it involves many materials-related issues–what better time for the Materials Research Society (MRS) to engage, in a big way? Recently, much effort has gone into introducing a new and rich research field, "materials for sustainable development," to MRS (see the sidebar). What is it all about?

- "Materials for sustainable development" lies at the intersection of materials science, engineering, and sustainability.
- It is characterized by:
  - □ enormous materials and energy scales (gigatons and terajoules),
  - □ complexity, requiring a system-wide approach involving the input of scientists, industrial ecologists, engineers, economists, sociologists, and public policy experts, and
  - □ the use of life-cycle assessment

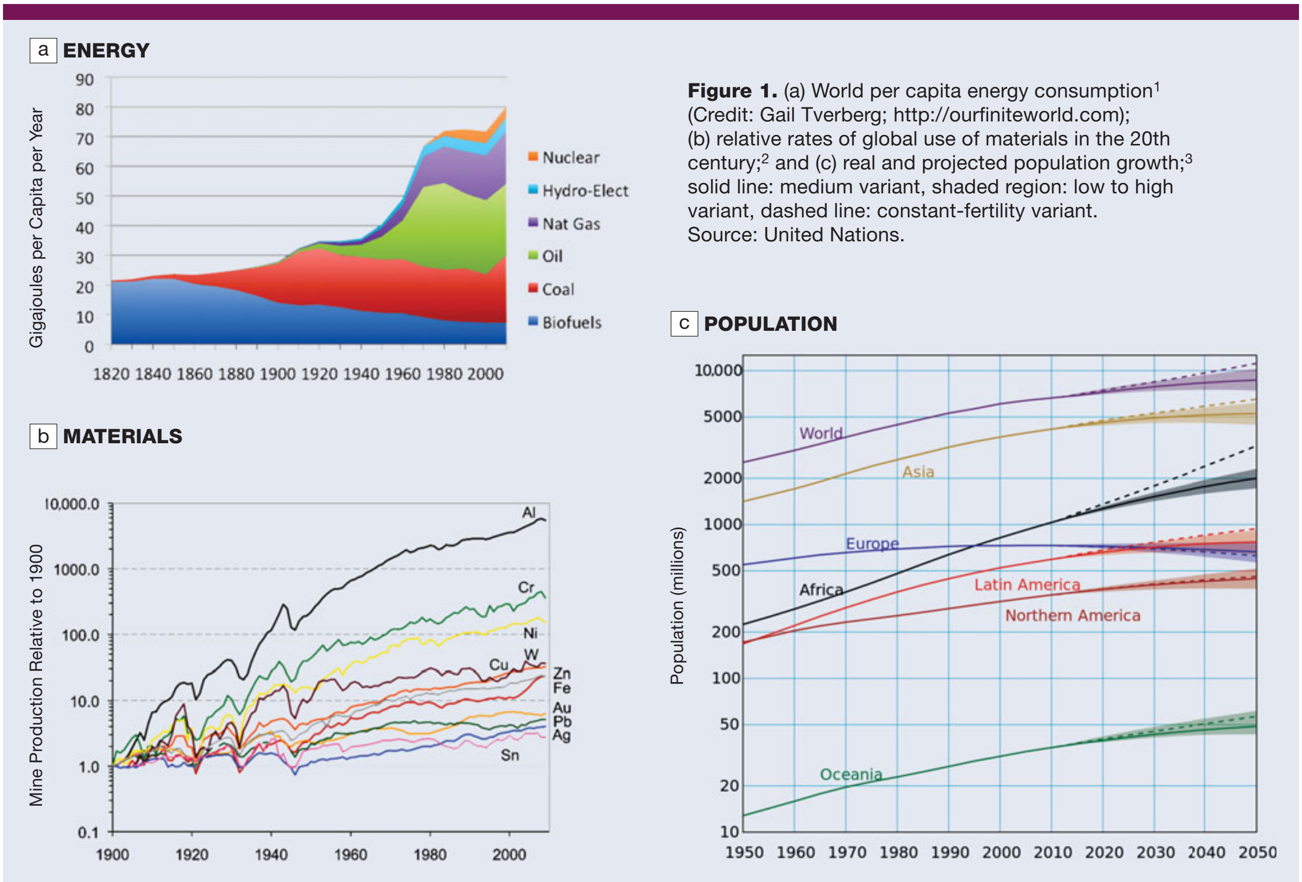

Figure 1. (a) World per capita energy consumption[1] (Credit: Gail Tverberg; http://ourfiniteworld.com); (b) relative rates of global use of materials in the 20th century;[2] and (c) real and projected population growth;[3] solid line: medium variant, shaded region: low to high variant, dashed line: constant-fertility variant. Source: United Nations.

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Materials Research Society addresses sustainable development www.mrs.org/sustainability

Publications

MRS Bulletin, "Materials for Sustainable Development," **37** (4), 2012
Free online

MRS/Cambridge University Press, *Fundamentals of Materials for Energy and Environmental Sustainability* (2012)

MRS Energy & Sustainability: A Review Journal
Soon to be launched

Symposia

2014 MRS Fall Meeting

- Sustainable Solar-Energy Conversion Using Earth-Abundant Materials
- Scientific Basis for Nuclear Waste Management
- Materials as Tools for Sustainability

2014 MRS Spring Meeting

- Earth-Abundant Inorganic Solar-Energy Conversion
- Materials for Carbon Capture

2013 MRS Fall Meeting

- Sustainable Solar-Energy Conversion Using Earth-Abundant Materials

2013 MRS Spring Meeting

- Materials for Sustainable Development
- Nanotechnology and Sustainability

2012 MRS Fall Meeting

- Materials as Tools for Sustainability
- Scientific Basis for Nuclear Waste Management

Panels

2012 MRS Spring Meeting

The Many Facets of Sustainable Development

2012 MRS Fall Meeting

Sustainability: Building Teams to Tackle Complex Problems

Funding for both panels was provided by the National Science Foundation.

Public Outreach

Strange Matter Green Earth

An international traveling materials science exhibition currently in development

(LCA), a core methodology for quantification of energy, materials, and water footprints.

Because materials are technology-enablers, sustainable development will not be possible without the involvement of the materials community. Therefore MRS should embrace it.

It would be appropriate for all human endeavors to be informed by the principles of sustainable development, since none of our planet's resources are infinite, and there are only a few sustainable sources of energy. However, materials researchers and engineers may be unattached to, or unaware of this nascent movement; perhaps they are weary of the overuse of the words (Figure 2). Due to the complexity of the issues involved, the scale, and the variety of contexts and meanings employed, sustainable development is not a simple matter to engage. Even experts in the field struggle with definitions.

The nexus between sustainable development and materials science is enormous, encompassing materials efficiency (conservation, substitution, reusing, repurposing, recycling, lightweighting), materials life-cycle assessment, critical materials, materials flow analysis, energy (materials that enable alternative energy technologies, that mitigate problems of fossil-fuel technologies, and that increase energy efficiency), and mitigation of undesirable impacts on environment and human health due to economic growth (corrosion, toxic wastes, and water and air pollution).

Of course, MRS has always been involved in materials for sustainable development—Symposium A (Photovoltaics) has been programmed annually since the 1970s. But for the most part, MRS has not been engaged in the system-wide thinking typical of sustainable development. "Materials for sustainable development" encompasses much more than materials science and engineering, as is illustrated in the example of Figure 3, the classic plot of photovoltaic solar-cell efficiency as a function of time. The remarkable progress shown in this graph represents decades of research and development by materials researchers and engineers, physicists, electrical and chemical engineers, and professionals in numerous other disciplines. They all shared the goal of harnessing a sustainable form of energy, and could be said to have been working in the field of sustainable development—but not really.

One truly working in sustainable development would ask these types of questions: If, for example, I want 50% of

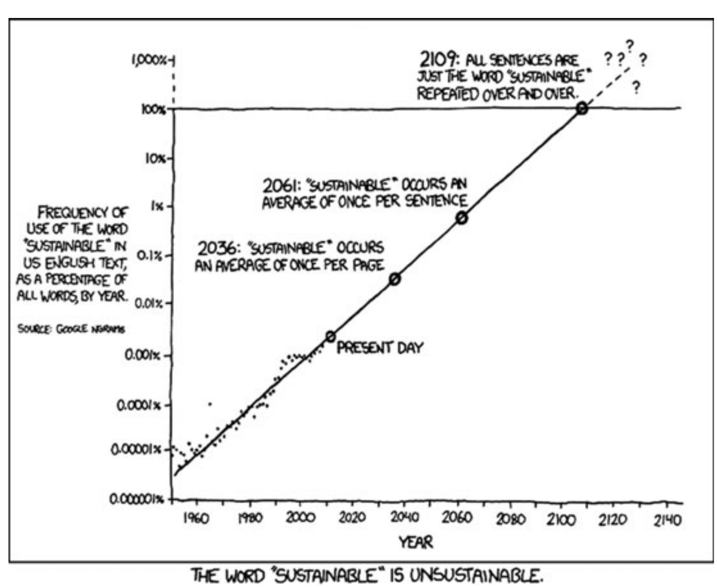

Figure 2. Perhaps "sustainable" is an overused word.[5] Source: http://xkcd.com.

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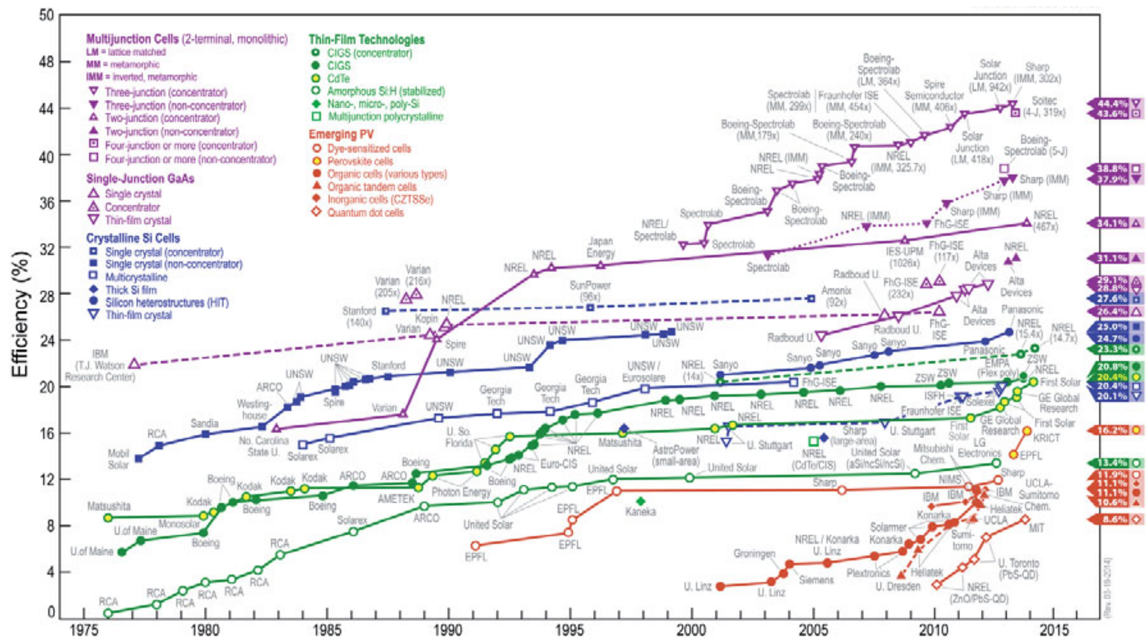

Figure 3. Progress in photovoltaic cell efficiency.[6] Source: NREL.

the world's power to be solar-generated in 2050, using high-efficiency cells containing tellurium, what are the implications for the availability of tellurium? Since tellurium is a "hitch-hiker" element, that is, it is a by-product of copper production, what does increased tellurium production mean for the copper industry and economy? What will I do with all that tellurium when the cells reach end-of-life—can we recycle tellurium? Very few of the people whose magnificent work is depicted in Figure 3 were trained to think that way.

Through professional societies like MRS, we have the platform to engage in conversations with colleagues in our field as well as other relevant disciplines that will enable us to confront the science and engineering of sustainable development. For example, at the 2012 MRS Spring Meeting, MRS held a forum that encouraged materials researchers to take such a holistic approach. The speakers and panelists included not only materials researchers, but also professionals and researchers with expertise in industrial ecology, water resources, social science, economics, and venture capital, enabling the materials community to obtain a more complete understanding of the diverse disciplines that play a role in solving complex sustainable development issues.

The forum held at the 2012 MRS Fall Meeting followed on from the Spring forum, addressing the practical challenges researchers face in building successful teams to tackle problems in sustainable development, bringing industry, government, academic, and international student perspectives to bear on the topic. Both forums can be accessed online—see the sidebar for details.

We learned from these forums that there is nothing that we do as humans to ensure our survival (food, water, materials, shelter, economy, health) that lies outside of its boundaries. So, in addition to being extremely important, the field of sustainable development is fascinating. Did you know that five materials (steel, cement, aluminum, plastic, and paper) account for more than 50% of all industrial CO_2 emissions? Did you know that less than 1% of many critical elements (e.g., rare earths) are currently being recycled? What about this: That the products of urban mines (e.g., chopped-up electronic waste) are richer in many expensive and critical elements than the mines from which they originally came? Or that it has been calculated that if the health-related costs of burning fossil fuel were properly accounted for, some forms of electric power production (e.g., solar, nuclear) would already be at grid parity?

The MRS membership is international and represents academia, government laboratories, and to a lesser extent, industry. It is likely that many of us have colleagues who are involved in some aspect of sustainable development. Let's reach out to these people with the goal of defining relevant sustainable development projects that broaden the research horizons of MRS members. Then, let's bring those colleagues into the MRS family. Together, we have a lot of work to do.

References

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