# Harnessing Materials for Energy

"Energy can be neither created nor destroyed," say our science books, "but can only be transformed from one form to another." Humankind and nature have been engaged with this transformation since life began on this planet. Nature does this with plants absorbing sunlight, an infinitely large energy resource, and producing oxygen and energy in useable forms—not very efficiently, but extensively. Humans are engaged in a similar task of transforming energy into forms they want from the sources that contain it and using this energy for their needs. With time, we have learned to produce and use energy more efficiently and economically from a variety of resources: coal, hydropower, oil, natural gas, nuclear, and so on. The energy contents of these resources vary, but the new ones are richer. Along with this search for new resources, humans have also learned to be more efficient in tapping them. Compare, for example, the animal-dung-fueled cooking stove with an efficiency of a few measly percent with a modern gas-fueled stove. An efficient fuel and better design enabled by excellent materials made this difference.

For wider distribution and ease in usage, energy is now transported over long distances through electricity grids or gas pipelines from central locations. In many societies, individual needs are supplied through these centralized systems. Yet we are getting increasingly accustomed to using energy not just for basic needs of life but for enriching it. The world's primary energy consumption increased to 14 terawatt-years per year, almost 50 times the pre-industrial level of about 0.3 terawatt-years per year. The world population grew about five times in the same period.

Every source of energy is like a tributary flowing into a river of energy where all resources combine. Like rivers that enrich agricultural lands, energy streams—wherever they have flowed—have also created regions of human development and economic prosperity. Like the geography atlas, the energy atlas of the world is also uneven. There are regions of deprivation and of unmet needs. There are also countries that are racing to produce more and more energy. The statistics are compelling: Sub-Saharan Africa consumes one-tenth of the energy that North America enjoys. China, in 2006 alone, built more electric power plants than the total installed capacity of Great Britain. Even among developed countries, there are unfulfilled needs for more energy.

With all countries clamoring for more energy, are there dangers of energy tributaries running dry? Some analysts suggest that oil wells might be depleted within 70–80 years. Natural gas might run out a little later. The present reserves of uranium might be adequate for only 80–90 years. Yet the fears of energy running out might be based on the present economic models. If higher costs are acceptable, oil could be extracted from oil sands, and lean uranium ores could be mined to recover the metal. There are also no imminent dangers of running out of coal, which remains a vital workhorse for energy generation. Moreover, one hour of solar radiation has energy equivalent to the world's annual primary energy consumption.

If we analyze the energy challenges of today, running out of resources does not emerge as the major worry. Yet there is another worry, greenhouse gas emissions, that is becoming more insidious and urgent. Energy production from fossil fuels results in $CO_2$ emissions. Coal expels the most, almost 1 kg for every kilowatt-hour of power produced. The current greenhouse gas concentration in the atmosphere is about 430 parts per million (ppm), up from 280 ppm in the pre-industrial years. If the present trend continues unchecked, the concentration could well cross 800 ppm by the end of the century. $CO_2$ is a long-lived greenhouse gas, difficult to capture and mitigate. The recent report of the Intergovernmental Panel on Climate Change (IPCC) has concluded that most of the observed increase in globally averaged temperature since the mid-20th century is very likely (the emphasis is by the IPCC) due to the observed increase in greenhouse gas concentrations. If nothing is done to mitigate the $CO_2$ problem, the consequences could turn out to be catastrophic for human life and well-being. It is paradoxical that the people living in the developing countries, who consume far less energy and emit less $CO_2$ than the developed countries, will experience the more serious effects. Although one might argue at length about the nature and extent of environmental damage, it is also important for the scientific community to develop various options to contain $CO_2$ pollution.

Are there ways to control the greenhouse gas emissions without harming the environment? What are the energy technologies that emit no or minimal $CO_2$? Are there technologies and policies that help to minimize energy demand and consumption? These questions along with a few corollaries shape the theme for discussions on energy.

Many new energy-saving technologies are now emerging. Light-emitting diodes that can replace incandescent bulbs, electric cars and hybrids that substitute for petrol engines, and high-voltage direct-current transmission of electric power instead of alternating-current transmission are some of the energy-saving options. There are also concerns about the availability of more efficient energy storage systems. Storage is going to become increasingly important because some of the renewable resources generate power only intermittently.

We began this discussion by citing a list of energy-providing materials and their limitations. The criteria for their choice have been based on their availability, accessibility, and affordability. To this list, we must now add three other imperatives: The sources must be sustainable, they should emit a minimum of $CO_2$, and they should not pose dangers to global security. The "no $CO_2$" resources have to be made efficient, economical, and available. There will be new materials and newer technologies, but these might not come quickly. After all, it took more than a century for electricity to become pervasive, and old materials and technologies will continue to serve until the new ones stabilize.

This special volume of *MRS Bulletin* on energy is the first of its kind in which the magazine addresses a major societal issue. This issue has contributions from energy experts from many countries and reflects not only the growing global concerns on energy but also the opportunities that materials researchers can tackle. Some of the new materials are already available, and many are or will be under development. Nuclear fusion might still be many decades away, but already, there are experiments with new materials to make fusion safe and viable. Hydrogen, as is often said, is not a fuel, but as a carrier of energy, perhaps it would make a difference when combined with fuel cells. Solar cells might turn out to be relevant in forms that we can now only imagine and work toward.

In a recent article in the *New York Review of Books*, physicist Freeman Dyson extolled biotechnologies that might in the future provide plants with solar photovoltaic "black" leaves that absorb every wavelength of light and are more efficient in transforming sunlight than natural leaves. We hesitate to go that far, but we do believe that materials research has the potential to provide some happy surprises in addressing what is now turning out to be the most critical problem for our society. Hence, this volume.

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