POSTERMINARIES

Bottleneck Science

If you read this column regularly, you may soon notice a theme to this year's offerings. I am taking a look at different ways that materials science can be described. I am still in search of a short, universally understandable description for use on airplanes, at cocktail parties, and (in this postmodern age) in chat rooms. And you can tell that I am not really a chat room person. Given all the possibilities, who would shroud their webby anonymity in the guise of a middle-aged, white male materials scientist? Still, once it is out there, you always have to explain it—the materials science bit, I mean; the rest is usually understood.

When I was an undergraduate student, one rather jaded instructor suggested that materials science has always been, and will always be, the great technological bottleneck. His position was that most if not all technological concepts are prevented from instant realization by the lack of the necessary materials, so the development of new materials is the rate-limiting step in technological advancement. Intoxicated by his own sudden insight, and probably enjoying the pleasure of a captive audience, he went so far as to suggest that the "messy and inefficient" age of steam-powered rail transport, however revered and romanticized, was purely a product of the lack of sufficient copper to make electric trains. Well, that does not quite check out.

The world's first commercial steam passenger train service was established between Liverpool and Manchester, England, in 1831. George Stephenson powered his famous "Rocket" locomotive using an engine design adapted from the static steam engines that had been in commercial use since the 1690s, the first use of those steam engines having been to pump water out of mines to increase the production of copper. At the time of Stephenson's Rocket, electric motors were not even a bench-top curiosity, and are generally believed to have been invented in about 1832, by Michael Faraday. Just too late to save us from the awful age of steam locomotion! The limiting step was not the production of copper wire, but the inspiration of genius. (Incidentally, Faraday made his living as a metallurgist, in between making all of his stunning electrical discoveries. From this perspective, you can make a case that materials science enabled all of electrical engineering.) But do not believe everything those college instructors tell you—and always remember that they just do not reckon on you actually checking the facts.

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Necessity is still the mother of invention, though, and there are many materials that have been invented in response to a particular need. A barrier to the improvement of small clocks and watches in the 1840s was the inconsistent quality of the steel used for the balance spring, which has the same function in a small timepiece that a pendulum has in a larger mechanical clock. Sheffield clockmaker Benjamin Huntsman secretly set about making more consistent steel for this application and invented the crucible steel process, which produced the highest-quality steel for most all applications for the better part of a century thereafter. Time marches on (in ever more precisely measured increments), and today we rely largely on quartz crystals in the role for which crucible steel was originally developed.

There are many other examples of performance enhancements coming out of new materials development, but I can find relatively few cases of completely new inventions having to wait for the right material to be developed. Hydrogen fuel cells are arguably still awaiting the invention of the right solid-electrolyte material. We might also consider some of the fantasies of Galileo Galilei, many of which are yet unrealized. Generally speaking, the thinking of modern inventors seems to be constrained within a box made of the available materials of the day, and "out-of-the-box" thinkers like Galileo, who are willing to speculate about what might be done if only we had the right stuff, only seem to show up once or twice in each millennium. Nevertheless, each incrementally new generation of aircraft, and of their engines, seems to rely upon new, stronger, lighter, or higher-temperature materials. Likewise, recent generations of integrated circuits have benefited from copper interconnects replacing aluminum, and the next generations still await improved low-κ and high-κ dielectrics, so there are always demands for the materials scientist to pursue.

The development of appropriate materials is almost always the narrowest bottleneck in the flow of technological progress—at least, it is when the economy is in good enough shape to provide the necessary demand. Does this make us feel bad? Is materials science the bad actor in the quest for technological advancement? Well, take comfort from the manufacturing viewpoint that says, "Time spent on anything other than the narrowest bottleneck in the production process is time wasted." According to this view, none of the readers of this column is guilty of wasting time—except perhaps the time taken to read this page.

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