Viva La Revolution!

JOHN H. GIBBONS

Predictive Paper

Centuries ago, Sir F. Bacon declared that "dreams and predictions ought to serve but for winter talk by the fireside." Yet the lure of postulating on the possibilities and responsibilities of science and technology as we enter the next millennium inevitably overwhelms caution. Perhaps this is true because the pace of science and technology's advance in the past 100 years has been so remarkable. My parents, born at the turn of the century, witnessed many amazing changes: the arrival of the automobile and airplane, the spread of radio and television, the eradication in this country of smallpox and polio. Their grandchildren—my adult children—have seen X-rays supplanted by magnetic resonance imaging (MRI), the fax give way to the Internet, and the discovery of DNA evolve at a blistering pace toward an understanding of the human genome that promises the alleviation of many more diseases. Yet even with these fantastic developments, I am still impressed with the observation of L. Thomas, who found that the greatest discovery of the twentieth century was the discovery of the extent of human ignorance.

What my grandchildren will witness in the twenty-first century remains a matter of considerable speculation. As N. Bohr admonished, "It is risky to make a prediction, especially if it's about the future." Some keen observers contend that five key technologies, currently in various stages of penetrating the marketplace, are all the ingredients needed to produce a global economic transformation on a scale never experienced before. They are computing, telecommunications, biotechnology, nanotechnology, and alternative energy.

The steady adoption of personal computers (Fig. 1) by businesses, governments, and individuals is already transforming the ways we learn, interact, and produce goods and services. The result of improved process controls has been much improved energy and resource efficiency as well as less pollution and higher quality of products and services. The convergence of computing technology with telecommunications technology promises further advances.

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Fig. 1. Computers have become an integral part of every aspect of human endeavor. Here, students in a library view applications of their choice, accessed from a central data base. (Courtesy of IBM Corp.)

Telecommunications is creating a networked world where personal communication, entertainment, education, and commerce will increasingly take place by means of a pervasive digital medium. With continuing advances, physical distances will become less and less important, and "distance learning" and "virtual firms" will become the rule rather than the exception.

Biotechnology and work on human and plant genomes are on the verge of creating entirely different approaches to agriculture and to medicine that will complement more traditional means of improving food supplies and preventing and treating disease. The highly fruitful partnership among medicine, science, and engineering that has produced breakthroughs such as MRI also holds vast potential for future improvements in the quality of disease prevention, diagnosis, and treatment.

Early in the twenty-first century, nanotechnology will become a reality, allowing scientists and engineers to construct objects one atom at a time. Research is currently under way with a single molecular amplifier (Fig. 2), but this concept will have applications across many fields

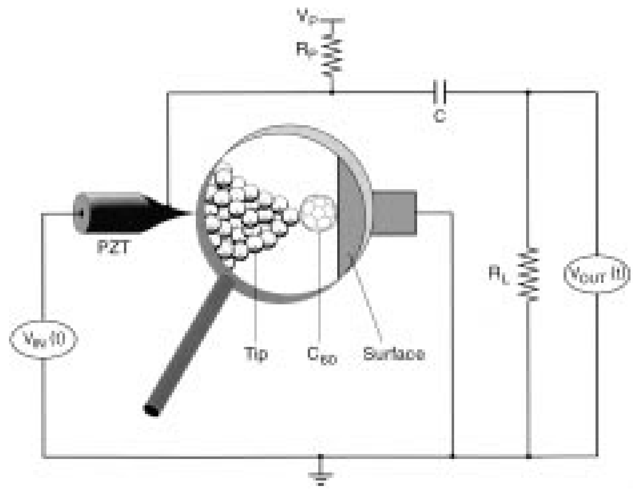

Fig. 2. Our ability to manipulate atoms and molecules on an individual basis has opened up a new experimental frontier that makes feasible the quest for single molecular-scale devices as successors to the transistor. Shown is the schematic electric circuit diagram of an electromechanical single molecule amplifier. (C. Joachim and J. K. Gimzewski, "A Nanoscale Single-Molecule Amplifier," *Proc. IEEE,* vol. 86, p. 187, Jan. 1998.)

of science and technology. It will be a ubiquitous tool for research and possible applications (e.g., in advanced information systems, robots, and sensors as well as in medicine). Such small-scale technology will revolutionize the exploration of outer and inner space, enabling, for example, more advanced medical diagnostics and treatments.

And throughout the next 50 years, new forms of energy supply and utilization technologies will allow economic growth to continue with vastly less impact on the environment. It is likely that these new technologies will provide critically needed relief to rapidly rising CO_2 levels in the atmosphere. Successful deployment would provide the basis for global economic progress unconstrained by energy shortages.

My attempt at prophecy may be no more than what G. Elliott referred to as "the most gratuitous form of error." Clearly, though, if history is any judge, science and technology will continue to have tremendous impacts on our economic well being and our quality of life. Advances in science continually enrich our lives, not only by enabling new ways to satisfy our physical wants but also by feeding our unquenchable urge to explore and understand. Technology invention, the partner of science, also transforms our lives and expectations. Yet these forces can have adverse impacts as well. There is no more compelling evidence of this truth than the case of climate change from our vast additions of greenhouse gases to the atmosphere. Climate change and other stresses, such as pollution and loss of biodiversity, are man-made problems requiring man-made solutions. Maintaining economic progress, stabilizing human population growth, and fulfilling our obligations to our children and the planet they will inhabit will likely be the greatest challenge of the twenty-first century (if we are wise and fortunate enough to avoid deadly conflict). Like it or not, we have come into a time when human activities are overwhelming other "natural" forces, and we are transforming the global environment.

The needs of the economy, looming problems of pollution and climate change, and threats to national security should instill a new sense of urgency in the search for new forms of energy supply and utilization technologies. Research on efficiency of energy conversion and use deserves higher priority, and low-carbon fossil fuels, nuclear power, and renewable resources merit renewed attention. If we succeed in developing and deploying these technologies, there will be many benefits:

- lower monetary costs of supplying energy and the cost of energy services;
- increased productivity of U.S. manufacturing;
- increased U.S. exports of high-technology energy-supply and energy-end-use products and know-how;
- reduced dependence on oil imports here and in other countries;
- diversification of the domestic fuel- and electricity-supply portfolios to build resilience against the shocks and surprises that an uncertain future will likely deliver;
- reduced emissions of hazardous air pollutants, slowed build-up of heat-trapping gases in the atmosphere, and enhanced prospects for environmentally sustainable and politically stabilizing economic development in many of the world's potential trouble spots.

The United States is ideally positioned to lead a global effort to use science and technology to fulfill the challenge of supplying goods and services at minimal total cost, including to the environment. We are technically sophisticated; we are open and innovative; and we are presently the major users of the world's resources. Scientists and engineers from all walks of life have a role to play in this effort. Trends toward public-private partnerships, in research and development as well as in regulatory spheres, will likely intensify in coming years. Government-industry-university cooperation, rather than coercion, is the key to hastening progress toward our domestic goals.

International cooperation will also come increasingly to the forefront of scientific endeavor. Already, we are dependent on global collaboration for advances in physical and life sciences; witness the Large Hadron Collider, nuclear fusion research, global environment studies, and ongoing plant and human genome projects. The stability provided to our bilateral and multilateral relationships with other countries by solid science and technology cooperation may also be our surest route to sustained, peaceful coexistence. With our help, all the inhabitants of this planet can use the tools provided by science and technology to satisfy our curiosities, provide for our wants, and exercise our stewardship responsibilities.

J. Weisner—my dear friend, mentor, and "companion" in this paper—wrote of technology as a substitute for evolution. I agree that we have exploited scientific knowledge for adaptive purposes that accrued to our advantage.

Thirty years later, I would also turn that knowledge to revolutionary purposes, in the Jeffersonian sense. Jefferson defined a revolution as the extraordinary event necessary to enable all ordinary events to continue. If we use them wisely, elegantly, science and technology can enable a future in which the things we hold dear can continue indefinitely.

John H. Gibbons was born in Harrisonburg, VA, in 1929. He received the bachelor's degree in mathematics and chemistry from Randolph-Macon College, Ashland, VA, in 1949 and the doctorate degree in physics from Duke University, Durham, NC, in 1954.

Following his formal training in physics, he spent 15 years with Oak Ridge National Laboratory, where he studied the structure of atomic nuclei, with emphasis on the role of neutron capture in the nucleosynthesis of heavy elements in stars. Beginning in 1970, he pioneered studies on how to use technology to conserve energy and minimize the environmental impacts of energy production and consumption. In 1973, at the start of the nation's first major energy crisis, he was appointed the first Director of the Federal Office of Energy Conservation. Two years later, he became Director of the University of Tennessee Energy, Environment and Resources Center. In 1979, he became Director of the Congressional Office of Technology Assessment, which provides Congress with nonpartisan, comprehensive analyses on a broad spectrum of issues involving technology and public policy. His tenure there lasted until his presidential appointment on February 2, 1993. He currently is Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy, Washington, DC. He is Cochair of the President's Committee of Advisers on Science and Technology and is a Member of the Domestic Policy Council, the National Economic Council, the National Security Council, and the National Science and Technology Council, which coordinates science and technology policy and budgets across federal government. As the highest ranking science and technology official in the administration, he also represents the U.S. government in major multilateral and bilateral international forums. He is the author of numerous publications in the areas of energy and environmental policy, energy supply and demand, conservation, technology and policy, resource management and environmental problems, nuclear physics, and origins of solar system elements. His most recent book is *This Gifted Age: Science and Technology at the Millennium* (New York: Springer-Verlag, 1997).