Science and Technology

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built using the microfabrication and micromachining processes that have made microelectronic fabrication one of the largest industries in the world economy. As researchers delve further into this field and as micromachining and similar techniques grow ever more routine, the costs of MEMs will be driven lower and applications in industry, medicine, and transportation may be widespread.

MOLECULAR MANUFACTURING—Molecular nanotechnology, unlike micromachining, starts at the bottom and works up, building materials and structures one atom at a time. This process has been described in the literature since 1986 and could eventually be used to build both nanoscale and macroscale structures. It is already made possible on a primitive level by the advent of scanning tunneling microscopes, which allow atoms to be picked up and positioned at will, subject to the laws of chemistry. To achieve economically viable nanoscale assembly, namely, the aggregation of large numbers of atoms in a finite time, a system of molecular "assemblers" has been proposed. "Assemblers" are self-replicating molecules capable of reproducing themselves in large numbers and then gathering and positioning other atoms and molecules in desired constructions. By analogy to biology, these electromechanical devices would use only those atoms needed, building up to the desired product. In such processes, industrial waste would be minimized, recycling of materials would be almost total, energy would be used most efficiently, and a vast number of new products and capabilities would be made possible.

Research in mechanical engineering, molecular biology, chemistry, and physics is leading to advances in this interdisciplinary field. With a realizable system of practical molecular manufacturing, the very definitions of design, manufacturing, and factories would be profoundly affected. Miniaturization Technologies, a recent study published by the Congressional Office of Technology Assessment, estimated that the first versions of the molecular “assemblers” may be realized in 5 to 10 years.

Manufacturing Design Technologies—in addition to the processes and equipment needed to produce complex products, a wide range of technologies is also needed to prepare for manufacturing. For example, both the product and the manufacturing process must be designed prior to production. This can involve a number of tools and techniques, such as computer-aided design and process modeling and simulation. It includes the design of production facilities, equipment, and tooling and may even require the planning and design for an entire manufacturing enterprise. Integrated development of enterprise design