# A peek at the year 2050

*A majority of minority and women hires. Globalization's culture shock. More part-time, freetime, flextime. Miniaturization and microfabrication. Automation. Playing with atoms. And virtual everything.*

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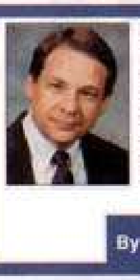

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Perhaps the best way to consider the future of manufacturing is to examine broad industry trends. Among the themes likely to dominate manufacturing through the first decade of the 21st century are a continued emphasis on quality, concurrent approaches to everything (especially design, processing, and distribution), and globalization (especially marketing, distribution, and customer support).

A pervasive focus on quality has been the hallmark of our industry through the 1980s and 1990s, and it will continue to be a major driver. Elements like statistical process control (SPC), quality function deployment (QFD), design of experiments (DoE), "re-engineering" of operating processes, and other quality improvement efforts will continue to become less faddish, and more a part of standard manufacturing processes.

Concurrent product design and manufacturing process development will grow and become the standard for generating new products and processes. New products will be configured in a manner that is most "producible" based on existing or planned manufacturing processes. This represents a real improvement over today's typical approach, which involves designing the product and worrying later about how to build it. It will, however, require design engineers to move out of their current comfort zones of "techno-speak," and learn to effectively receive and translate enduser (customer) needs into critical product characteristics. On the technology front, design engineers, manufacturing (process) engineers, and tool designers will all be looking at 3D solid models of the products as they are constructed, and continuously contributing to their development. Those changes will require the application of powerful, "intelligent" configuration management software. Iterative design evolution will also incorporate the real-time input of key characteristics and associated measurement data from quality engineers, so that resulting designs are complete with inspection and statistical process control (SPC) criteria. Managing all of this will require some expertise in all of these areas, and more importantly, strong interdisciplinary team management skills.

Globalization will be a major change agent over the next two decades. Led by globalization in markets and distribution activity, mainstream manufacturers from all major industrialized countries will find themselves drawn into multinational operations. This will dramatically affect management training and skills requirements, as well as the cultural make-up of multinational manufacturing work forces, particularly in management and technical areas. Cultural diversity training will be required, enabling managers to be more effective in surmounting the barriers that commonly arise with differences in language, cultural norms, and "virtual" work relationships. Both technical translation issues (ranging from English vs metric data to machine control language translators) and workplace issues (flextime and remote workers vs the need for real-time communications for collaborative problem solving) will have to be resolved. We can already see the first significant developments in this area with the advent of information systems that support "Supply Chain Management" (SCM). SCM is a term recently coined to describe our extension of visibility and strong communication ties into both upstream suppliers and downstream customer operations. Beyond Electronic Data Interchange (EDI), supply chain management involves sharing visibility of schedules, cost information, delivery information, design data,

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and inventory availability in real time throughout the extended enterprise known as the supply chain.

Today, sites for production operations are most often selected based on such criteria as the availability of skilled labor, access to distribution channels, tax breaks, and other political-economic incentives. Over the next decade domestic production facilities will shift from the Midwest to the Sun Belt states and especially to second-tier cities and large-city suburbs. Examples include Tucson, AZ, Albuquerque, NM, and Austin, TX. Internationally, fabrication (particularly low-tech fabrication operations–metalbending, sewing, etc) will cascade from industrialized countries to less-developed industrializing countries such as this will allow companies to take advantage of lower labor rates, looser environmental regulations, and trade offsets. Mainland China and many of the Pacific Rim countries will absorb this work.

Actual factory size will begin to diminish as equipment becomes more compact, materials become more adaptable to enduse shapes, and efficiency improves, and also as large manufacturers move away from vertical integration. This represents opportunities for growth in companies that do castings and forgings, ceramic production, and work in fiberglass, graphite composites, and other manufactured polymers. Factories in the year 2010 will employ half the number of a decade earlier. Automation of repetitive and hazardous tasks, along with the outsourcing of relatively low-value-added fabrication operations, will result in the near-elimination of direct labor and related support for those areas.

More than 80% of all new hires over the next decade will be women and ethnic minorities. This will pose challenges for all employers, manufacturing companies among them. Language barriers will be problematic, as increasingly technical work procedures and product specifications must be effectively communicated throughout the increasing diverse work force. In addition, more dual-income homes will translate into pressure on employers to provide

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broader and more flexible benefits, such as on-site day care. Human Resources, a critical aspect of any company's operations, will face new challenges as a result of two primary factors. First, the work force will not have all the education, skills, and training required to operate the increasingly complex manufacturing and information processing equipment. Educational levels, both in the US and in most other industrialized nations, are woefully inadequate and will not improve quickly enough to keep pace with future workplace demands. These shortages will be most debilitating in engineering, product and process research, and computer sciences.

Secondly, the values of tomorrow's workers will be quite different. People entering the manufacturing work force are less eager for overtime pay and for job stability at any cost. They are more likely to be interested in free time and personal fulfillment. As a result, the most talented people will be far less responsive to the bureaucracy and regimens imposed regularly by many of today's monolithic manufacturing companies. This will manifest itself in the rapid growth of temporary workers contracted for specific assignments, freelance management specialists and technical people, and telecommuting from distant locations in job categories not requiring face-to-face dealings. Flextime and job sharing will certainly become a matter of course.

Dramatic growth in automation levels will continue through 2010. Rather than our earlier vision of an army of humanoid robots moving up and down aisles and assembling manufactured goods in the place of people, the robotics applications in factories will build on initial successes in redundant operations, hazardous processes (such as welding and spray painting), and move into areas requiring precision and high levels of accurate repeatability (such as data entry and mixing of chemical compounds) as well as areas where human strength is inadequate (such as the continuous lifting of heavy loads.) Applications of automation will follow a deployment pattern that differs somewhat by industry.

Aerospace companies will use robots for assembly assignment, hole drilling, and fastener installation. Combinations of machine vision and photonics will also enable automation of operations currently requiring separate coordinate measuring machines (CMMs) and similar devices.

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## 2010-2030

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Information Systems that incorporate the knowledge gained from the experience of recognized human "experts" as resource data bases and decision-support tools are known as "knowledge-based systems." Knowledge-based systems will be used in virtually every major business process of manufacturing companies. They will determine optimum product configurations and availability, enable supply chain management professionals to calculate optimum inventory investment levels and procurement timing, enable finance departments to take maximum advantage of lending rates, tax laws, and other financial opportunities, assist transportation/distribution professionals in identifying the lowest-fare carriers and shortest-time distribution channels, and allow production departments to schedule optimum production flow rates so as to maximize direct labor efficiency. These systems will emerge from the burgeoning technologies of expert systems, natural language processors, telecommunications, and computers. Most of the physical computer and system infrastructure hardware exists today to produce them, and software tools are very close. The missing element here is primarily focus on the part of commercial system developers.

Technology integration will be a critically differentiating characteristic as lines blur between materials sciences and manufacturing engineering, between sales and distribution, and between design and production. Cross-training will enhance the breadth of individual expertise levels. Single workstations operated by one or two individuals may be able to take the "design" process from concept through (simulated) testing, (simulated) marketing, production process development and scheduling, packaging development, and distribution channel selection. These new integrated technologies will significantly reduce risks and costs associated with new product development and launch.

Automation will continue to grow as a percentage of the value-adding component of manufacturing. Interchangeable "plug-and-play" process component equipment should become available in this period for most standard manufacturing processes, assuming that we have dealt with interface communications standards and protocol issues. Examples include:

Net-shape fabrication centers that take raw aluminum and part design data as inputs and yield completed component parts as output; and, subassembly centers that configure assembly tooling continuously and perform the assembly itself, based on assembly instructions, virtual part placement simulation that avoids interferences, and assure minimal deviation in every critical interface. Linking these components through a master process management system, the factory will become a set of "virtually" managed physical processes linked in a network spanning each element from design through delivery.

The period from 2030 through the 2050s in manufacturing will be typified by the developments of microfabrication, virtual marketing and testing, and biocomputing.

Microfabrication will be the most sweeping transformation for manufacturing since the advent of the computer. It will allow the fabrication of materials and parts at the molecular level, building them with the features we desire (strength, weight, flexibility, and so forth) at incredible levels of material efficiency. Left behind will be the era of excavating ore from the ground, refining it, and beating it into the forms we want. Common materials such as sand (silica) will require minor modification to configure them into extremely property-rich manufacturing materials. In nature, raw materials such as iron ore and silicon are produced in their relatively corrupt forms when two or more reactive chemicals bump into one another, rearranging to form new elements. But with the advent of nanotechnology, microscopic assemblers will grasp reactive molecules and combine them only in preplanned and controlled ways. Through these controlled and repetitive combinations, complex structures may be built up a few atoms at a time. Molecular engineering will become similar to working with Tinkertoys. Molecular assemblers will add carbon fibers to objects a few at a time, building up a piece of diamond-fiber composite. The resulting material, and therefore the structure produced, will be many times stronger and lighter than traditional ones. Indeed, they will be stronger and lighter than anything we can build today.

Virtual marketing will move to the forefront of marketing, sales, and distribution activity. Based on enormous volumes of information available through accessible on-line services and databases, "virtual" markets may be accurately evaluated without major cost.

The rapidly-spreading use of biocomputers promises to deliver staggering computational power and memory capabilities in this time frame. Combined with nanotechnology, prodigious information processing "horsepower" will easily support the now-unwieldy needs of effective "virtual marketing." Some fairly detailed studies indicate that microassemblers could ultimately construct the processing equivalent of today's computers in about [illegible] of the volume of a typical human cell.

Location will begin to wane in importance as microfabrication becomes possible, and the capability to do "portable manufacturing" emerges. Since face-to-face labor requirements will be virtually eliminated, and "pollution" or other environmental side effects can be effectively abolished, there should be very little restriction as to appropriateness of such "factory" sites. Automation will be at the heart of most microfabrication operations, since handling molecules and monitoring molecular construction are not activities for which humans are well suited. The use of nanotechnology for production of parts that are near or complete "net shape" means that no offal will exist to be disposed of, since parts are constructed a few molecules at a time. With no waste of this type to be disposed of, and with the vastly "cleaner" nature of these operations in terms of both physical material (solvents, lubricants, etc), and noise levels, manufacturing will be a completely different world from the one we know today. As a result, living next door to a "factory" won't pose the kinds of problems it does today. Indeed, aside from the traffic pattern and docks for raw material delivery and product shipping, it will differ little from any other structure in a commercial neighborhood. Factory size will become a function of manufacturing equipment size, which should continually become smaller just as computers did.

Trends that are likely to continue to be prevalent after 2050 include the advent and deployment of other nanotechnology operations (namely microassembly, disassembly, replication, and altered replication), and the return to space exploration. Nanotechnology will eventually supplant traditional manufacturing processes, replacing not only fabrication but assembly processes as well. Disassemblers may be constructed that allow virtually any substance to be broken down into its molecular components. We should be able to disassemble just about anything, and reconstruct it molecule-by-molecule, replicating it over and over again, even with alterations. Manufacturing will most closely resemble today's pharmaceutical industry, with vats and pipes and mixing slurries of chemicals. The traditional material removal-based fabrication methods employed in most American manufacturing sites will migrate to less-developed nations, then disappear entirely, going the way of blacksmithing and glassblowing.

As nanotechnology opens new vistas of economy and power for manufacturing, the lure of space exploration will likely become irresistible again. New industries supporting space exploration will spring up to expand earth's domain without ruining our existing habitat. This should enable us to manufacture substances in space that can only be readily generated in gravity-free environments. Initial forays will be in industries like pharmaceuticals and high-tech electronics. Subsequent work will include exotic alloys and ceramic/glass materials. These processes will yield the critical, low-volume/high-cost materials required for some future manufacturing operations.