Definition: This extended definition focuses on "molecular manufacturing," the term that the author prefers to "nanotechnology."

Introduction: This document begins by discussing the current confusion about the meaning of the term. Following that is a formal sentence definition. The formal sentence spills over into the following sentence. The introduction ends with an overview of what the rest of this extended definition will cover.

EXTENDED DEFINITION

Molecular Manufacturing

Since nanotechnology has seized popular imagination, it has been used loosely to refer to research where dimensions, quantities, and locations are around 1,000 nanometers. However, the "nanotechnology" that leaders like K. Eric Drexler, Ralph C. Merkle, and others are talking about refers to a process in which essentially every atom can be put in the right place at manufacturing costs not greatly exceeding those of the required raw materials and energy. This makes possible the manufacture of almost anything for which we can provide detailed atomic specifications. Because their concept of nanotechnology refers to manufacturing atom by atom and molecule by molecule, leading nanoscientists sometimes prefer the term "molecular manufacturing." The following further explores this new technology and its applications [5].

Comparison: To establish the definition of molecular manufacturing more firmly, this next section contrasts molecular manufacturing to current manufacturing.

Manufacturing Technologies: Current and Future

Merkle uses LEGOs to explain the basics of molecular manufacturing. Common forms of manufacturing such as casting, grinding, and milling manipulate atoms in what he calls "great thundering statistical herds." In current manufacturing methods, we can "push the LEGO blocks into great heaps and pile them up," but we cannot fit them together the way we want at the molecular level [5]. If we had a manufacturing process that gave us that level of control, we could rearrange the atoms in a chunk of coal to make a diamond or the atoms in ordinary sand to make a computer or the atoms in dirt and water to make potatoes. This is what Merkle and others call "molecular manufacturing."

Classification: This extended definition uses classification to discuss essential types of molecular-manufacturing devices. Remember that in extended definition, you must select from the other kinds of writing discussed in Part 1 of this book.

An example illustrating this contrast is lithography, the essential manufacturing process used to build computer chips. Continued improvements in lithography have enabled us to work with dimensions less than one micron. But despite the improvements in computer hardware capability that submicron lithography has made possible, this manufacturing method will probably reach its fundamental limits in the first two decades of the 21st century. Merkle and others believe that nanotechnology will provide a "post-lithographic" manufacturing process. It will enable us to build inexpensive computer systems with "mole quantities of logic elements that are molecular in both size and precision" [5].

Molecular Manufacturing: Essential Components

Merkle identifies two concepts essential to molecular manufacturing: positional assembly and self-replication.

Headings: Because this is a relatively short document, it does not use first-level headings (unless you consider the title a first-level heading). In fact, you can imagine this entire document as a background section in a longer report on molecular manufacturing. In any case, a heading like "Molecular Manufacturing: Essential Components" is a second-level heading, as defined in Chapter 7. Headings like "Positional assembly" are third-level headings.

Positional assembly. To get "the right molecular parts in the right places," some form of positional assembly is required. This implies robotic devices that are molecular both in their size and precision. The idea of such devices, as strange as it may seem, is not new. Richard Feynman, considered one of the founding theorists of nanotechnology, introduced this idea in "There's Plenty of Room at the Bottom," his famous 1959 presentation to the American Physical Society: "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom" [2]. According to Drexler, "Just as today's engineers build machinery as complex as player pianos and robot arms from ordinary motors, bearings, and moving parts, so tomorrow's biochemists will be able to use protein molecules as motors, bearings, and moving parts to build robot arms which will themselves be able to handle individual molecules" [1].

Direct quotations: This document uses more direct quotations than other documents in this book. Notice, however, that the quotations are always attributed to a source—you know who made the quoted statement. Notice, as well, that in every case the direct quotation has something individualistic about it. For example, the phrase "respectable speck" deserves quotation marks, but a "small dot" would not.

Self-replication. For objects to be manufactured inexpensively and efficiently, self-replicating components are also needed. This idea was originally put forth by John von Neumann in the 1940s. Such a device would make copies of itself and manufacture the desired objects [5]. In *Engines of Creation,* Drexler foresees replicators whose components will include molecular "tape" to supply instructions, a reader to translate those instructions into arm motions; and several assembler arms to hold and move workpieces. Drexler calculates that such a replicator will add up to one billion atoms or so and, working at one million atoms per second, will copy itself in one thousand seconds (about fifteen minutes). Working singly, a replicator would need a century to stack up enough copies to make a "respectable speck." But with replicators making copies of themselves, the process would produce a ton of copies in less than a day [1].

Molecular Manufacturing: Applications

When they discuss applications of molecular manufacturing, nanotechnologists such as Ralph C. Merkle, K. Eric Drexler, and Richard Smalley become downright visionary. Self-assembling consumer goods; computers billions of times faster; extraordinary inventions (impossible today); safe and affordable space travel; a virtual end to illness, aging, and death; no more pollution and automatic cleanup of already existing pollution; molecular food synthesis and thus the end of famine and starvation; access to a superior education for every child on Earth; reintroduction of many extinct plants and animals; terraforming on Earth and in the Solar System—these are the things they foresee [7].

Borrowed information: This definition uses the number system to identify the sources of information that were used. Remember that it does not matter whether the borrowed information is directly quoted, paraphrased, or summarized. It's still borrowed and needs "citations" to indicate the source. This document uses bracketed numbers to indicate the source.

Medicine. One of the most far-reaching applications is medical research. To treat disease, current medical technology uses techniques involving drugs, radiation, and surgery. These techniques are generally slow, tedious, and sometimes dangerous. Nanotechnological agents (often called "nanites") could perform the tasks of drugs, radiation, and surgery far better. Instead of relying on open heart surgery to remove a blockage in an artery, nanites could be inhaled and find their way through the body to the specified artery and pick apart the blockage without causing any harm. Some nanotechnologists believe that "nanomedicine" will enable people to live for indefinite amounts of time [4]. According to one nanomedicine researcher, Richard Freitas, nanomedicine, which he defines as "the ability to direct events in a controlled fashion at the cellular level," will be "the key that will unlock the indefinite extension of human health and the expansion of human abilities" [3].

Applications and effects: As an additional way of exploring the meaning of nanotechnology, this definition discusses applications and their effect on society. Thus short definitions, comparison and contrast, as well as cause and effect have all been used to extend this definition.

Space exploration. Another area that will benefit from this new concept is space exploration and aerospace technology. Nanosystems could be used to manufacture the materials, fuel, and hardware needed in spacecraft. These materials would cost virtually nothing because nanites will be able to rearrange the molecules of any common substance into those of another. And these same processes can be used on other planets using common materials found there to create oxygen, food, and other substances needed to sustain human life. And if nanomedicine enables people to live practically forever, we'll need to settle other planets to keep from overpopulating Earth.

Computer industry. An area where nanotechnology may make its first practical impact is the computer industry. Nanosystems may enable the manufacture of computer chips with a cost of less than a dollar per pound, with operating frequencies of tens of gigahertz or more, with a size of roughly 10 nanometers per device, and with extraordinarily low energy requirements (or as Drexler puts it, "roughly the energy of a single air molecule bouncing around at room temperature") [6].

Conclusion: When?

When asked how soon these scientific miracles may happen, nanotechnologists are the first to say that they just do not know. However, *Wired* magazine in 1995 assembled some of the top minds in nanotechnology and asked them to estimate when certain critical events in the advance of nanotechnology might occur. Their predictions for when we might see the first molecular assembler (a device for position assembly discussed previously) ranged from 2000 to 2025; for a nanocomputer, 2010-2100; for cell repair, 2018-2050; for a commercial product, 2000-2015; for laws regulating nanotechnology, 1998-2036 [6].

Information sources: Occurring here at the end is the list of information sources used to write this document. The style used here is the number system. Notice that the items are alphabetized and numbered. Notice, as well, that quotation marks are used around article titles, while italics are used for book titles (even though they appear on the Web). And finally, these entries include both the publication date and the date the writer of this extended definition accessed them.

Information Sources

1. Drexler, K. Eric. *Engines of Creation: The Coming Era of Nanotechnology* 1 April 1997. **www.foresight.org/EOC.** Accessed 2000, February 28.
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3. Freitas, Robert A. "Nanomedicine." 28 January 2000. **www.foresight.org/Nanomedicine.** Accessed 2000 February 28.
4. Hunter, Richard. "Nanotechnology and its Applications." No date. **www.personal.psu.edu/dept/scifi/science/articles/nano.html.** Accessed February 28, 2000.

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