Transition to Tomorrow:
Social Institutions at the Threshold of Nanotechnology's Molecular Epoch

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Abstract

Nanotechnology heralds the potential for fundamentally new capabilities for humankind. With the promise of this technology comes the concomitant possibilities of either wondrous prosperity and freedom or a wretched, hard-scrabble existence under cruel oppression. Whichever the case, it up to us to choose which path we will travel. The time to consider these issues and their tradeoffs is now, before things change. This essay raises various topics with the purpose of provoking the debate and discussion amongst all those who are interested in the promises and pitfalls that such a radically new technology may make manifest.

Onset Of The Molecular Epoch

Thanks to the emergence of nanotechnology[1], we stand at the threshold of a new epoch in human affairs, moving through a societal transition from today's accelerating technology to a tomorrow of dramatic human consequences. From the industrial age, through the information age, and into the molecular age, the near-time, anticipated capabilities of nanotechnology will yield a potential for good and evil beyond anything ever experienced or hardly ever imagined.

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[1] Nanotechnology means technology at the nanometer scale, that is, measured in billionths of a meter, the size of atoms. Molecular nanotechnology refers to the anticipated ability to position individual atoms according to exact specification. It is on the near horizon of science and engineering today, and part of everyday activities in labs like those at HP and IBM, and myriad small companies and universities. Nanotechnology is fundamentally interdisciplinary, bringing together physics, chemistry, biochemistry, materials science, mechanical engineering, and the computational sciences. For purposes of this discussion, the "strong form" of nanotechnology is considered (that of molecular construction) and an admittedly optimistic approach if brought forth. Nevertheless, it is recognized that the implications and fears of nanotechnology do not need to be substantiated by scientific fact: simple misperceptions and misunderstandings are sufficient to spook people around the world.

This transition heralds a promise of cornucopia or cataclysm, perhaps both, because nanotechnology leads to the capability to create materials and fabricate objects piece by piece from their basic, constituent elements, with properties and capabilities heretofore hardly imaginable. The very basis of our culture, our society and our human institutions may soon be wholly transformed, possibly causing fundamental changes in our communities and our relations with each other. The time to address such issues is now, before things change. Otherwise, the technology itself, or the climate that surrounds it, may severely retard societal evolution, constrained by our own disregard or lack of forethought, or driven by the specter of fanatics and despots.

People, places and things are all made from arrangements of their elements, their atoms, so the ability to exactly position elements yields an opportunity to make nearly anything desired to exacting precision. Moreover, because nanotechnology has the capacity to affect all things, it will affect all other technologies as well, making it the cardinal "meta" technology. This technological advance has implications as profound as our human precursors first learning to make tools, the harnessing of fire, making metal from ore, or humanity inventing how to count. Nanotechnology delivers a fresh, essential challenge to how we think, how we work, how we see our future and how we are to plan for it. And the time to plan is now because the entire fabric of our society[2], our economy, our institutions and our daily lives may be altered in dramatic and traumatic ways only dimly evident from the perspective of today.

Total (or near total) control over the structure of matter will intrinsically revolutionize our lives. No aspect of our daily living—let alone other technologies—will remain untouched. Entirely new devices and products, including advanced pharmaceuticals and medical devices, super strong and ultra light materials for houses, cars, furniture, highways, bones, teeth, and clothes will emerge. This could mean better computers and networks, bigger databases and faster decision-support, better medicine and healthier foods, better cars and aircraft, as well as better light bulbs and household appliances. When we consider how each of these familiar devices has revolutionized our lifestyles, we can see that technology forms the social environment within which we live. What would your life be like today without the light bulb, the phone, the car, the computer and the Internet? Or worse yet: a world without vaccinations, antibiotics, eyeglasses, and dental fillings.

Technological change and social change are intricately interwoven. Paradigm-shifting change, such as that anticipated with nanotechnology, can be expected to render a nearly unfathomable transition on our social institutions. And, because most of the paradigms[3] of our everyday lives derive from our daily interactions within the institutions where we learn and work, play and pray, explore and reflect,

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[2] In this essay, "society" is often mentioned in the singular as a journalistic device. Today's world is an amalgam of many societies which can be distinguished along various dimensions of contrast. In the general case, the nature of the oncoming society is not known, and likely unknowable, until it has emerged and future generations look back on it. Nevertheless, in many cases the singular form will be used, unless context calls forth otherwise.

[3] Paradigm in this sense follows that of Thomas Kuhn in his seminal work *The Structure of Scientific Revolutions.*

we can expect dramatic public and private uncertainty to unfold. Things will change. Basic chemistry teaches us that whenever we modify structure, we break bonds, and this typically generates heat. We may have very entropic days ahead.

Standards We Live By

Innovation[4] has the capacity to alter our daily lives—antibiotics, fabrics, phones, cars, TV, computers, lights, cameras—all stand to be improved by nanotechnology. It has the potential to yield a truly non-polluting manufacturing industry, incredible advances in medicine and health, stunning evolution in computer technology, and, in effect, nearly an end to scarcity of food, knowledge, and other critical things. What is currently precious and rare may well become commonplace. And it will give us low-cost access to low earth orbit by serendipity, to start an adventure of tapping limitless energy just a few hundred miles above us, and an unlimited mother lode of metal and ore just a bit further away. However, scarcity often derives from political, not technical, limitations and times of transition are times when political forces face their greatest threat, and as would be expected, respond with their greatest retort.

The essential factors as we move through this transition will not necessarily be the technical opportunities and constraints, but the actions of the structural elements of society: human organizations and institutions, leaders and demagogues, the innocents and the oppressors, as these new capabilities unfold and shock present-day dominant power bases. What is so new about nanotechnology is that on a societal scale, and in the timeframe of our social institutions, this change is occurring very rapidly. Also, especially thanks to the Internet, we are truly becoming a global community, not just from our industrial actions of aircraft or pollution, weapons or disease epidemics, but also from the standpoint of information, awareness, and communication. These, in turn, primarily impact our human interactions and expectations.

Often, technological change has moved at a rate where societal evolution could keep pace, or at least catch up during the times between the great shifts. This may no longer be the case where we have technology advancing at breakneck speed, and transmitted around the globe – through many differing societies, each with unique, characteristic sensibilities – at the speed of light in today's interconnected world.

This may dwarf the entire history of technical evolution in a single transition, as we enter an era where most materials, objects and devices could be made to a pristine quality with an efficiency hardly imaginable today, and made inexpensively and in abundance. Nanotechnology holds the potential to provide entirely new tools for humanity. Our understanding of our environment, our commerce and even the nature of technology itself could go through an abrupt change.

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[4] Innovation as used herein reflects the notions of Professor Everett Rogers and his books on *Diffusion of Innovations* and Clayton Christensen's notions expressed in *The Innovator's Dilemma*.

The Internet alone through the World Wide Web has already changed the nature of both scientific research and scientific communication. The essence of knowledge generation is accelerating. Today, scientists can find information faster, more easily, and from all parts of the world. Similarly, it's often the case that papers are posted to websites or circulated by email leading to a more rapid spread of fresh findings or scientific or technological news. With this acceleration comes a change in the speed of which the practice of science, engineering, and technology has progressed for hundreds of years. Now, findings released during the afternoon in Europe are known in the USA by the time people come into work in the morning of that same day. As the world becomes more interconnected, so does the practice of the technical disciplines. Together, these coalesce to lead to a speed up of the world to which society must react as well.

Already, the World Wide Web is ushering in an age of interactive world libraries, interlinked via speedy computer networks, available from a home, car or office, and with ever increasing mobility – wherever a person may roam. Every day sees better and more intelligent software to simplify exploring, learning and creating knowledge. This level of symbolic processing, integrated across the planet and with communication satellites and perhaps eventually to libraries in orbit reachable from a rooftop dish, with accelerate the potential for human intellectual progress by factors not measurable by today's standards of comparison. In turn, this may well create a transition to a knowledge age, making use of the tools and information gained from the molecular age.

Knowledge generation will be both an enabler and a consequence of the advance toward nanotechnology. While on the path, such things as advancements in the understanding of molecular processes and chemistry, inventions in design and visualization software, and cross-cultural collaboration are among the many areas where intellectual progress will make great strides. Today's expanding computer capabilities are already enabling speech and pattern recognition leading to a future were people can converse with computers on certain topics, query vast storehouses of information and databases, and get timely responses, thereby getting a more complete picture, spotting gaps, or identifying areas where new thinking is necessary. In essence, the speed of invention and the spreading awareness of new things and ideas is accelerating. But these advances are trivial compared with the communication and computing capabilities that nanotechnology will make possible.

Nanotechnology will yield ultra-small, ultra-fast computers. This will deliver computing power unfathomable by today's standards. With nanofabrication, petabyte computer memories and storage will be cheap, plentiful, and of course, microscopic in size, allowing for huge databases available on tiny chips. This invites exceptionally large and complex computer programs (or ecologies of agents, scripts, plug-ins, embedded code, helpers, etc.) to run on wallet-sized machines – or perhaps as fashionable, wearable accessories such as simple jewelry like a ring or earring, yet containing vast amounts of information available at an instant.

Impact on Social Institutions. Technologies typically have dramatic and unanticipated impact on societies, their social institutions, and humanity as a whole. Whether the innovation is the airplane or the printing press, the rocket or the telephone, antibiotics or the computer, new devices—especially the information machines -- along with new processes and new ways of working, have all disrupted the pattern, pacing and content of human relations with our families, colleagues and companions.

Ultimately, these have changed the nature of the "self" in the ever-recurring, more modern, day-to-day world in which we now sojourn.

One thing is clear should the promise of molecular nanotechnology become manifest: Society will be swept into a transition from a time of scarce resources to a time of potential material abundance. As all things change around us, so will the way we act with each other. And we will shift from the industrial era where people fitfully seek jobs and endure suffering employment, through an uncertain global economy of idle factories, useless institutions and many irrelevant human skills, into a world that by today's standards is one of economic chaos – a world that may only value human uniqueness, creative spark, useful knowledge, and worthwhile relationships. And where will this leave our institutions? They embody the means and expectations of working and living with each other – especially given certain institutions that are interwoven through the fabric of our lives – the government, banking, schools, churches – as well as the economic aspects we take for granted – the nature of the "firm" or "agency" where we work, and what we do will all change.

While such technical advances can be foreseen with exact precision, the impact on our institutions and humanity cannot be foreseen to an exact engineering specification. The complexities of people's expectations, their perceptions, intentions, and desires will emerge as a critical factor influencing the social and political environment within which nanotechnology development is conceived by people and constrained by institutions. The concept of an "institution" can mean many things to many people, but from the perspective of societal change, institutions have a general meaning of the embodiment of a significant practice, procedure, or collective behavior on the part of people. Thus, when society changes, institutions often change. Moreover, when institutions change, it also indicates that society, and the roles and activities of people, are changing as well. The impact on the human factors -- our personal, social and economic relationships—will become even greater challenges than the technical facets that can be designed, computed, and predicted.

The path to the Molecular Epoch could be filled with pitfalls of a dangerous conceit that all technological advance will be beneficial and work out for the better. Nanotechnology is raising this issue today by modifying our basic assumptions and choices about how we live life. The oncoming Molecular Epoch of human affairs brings to us the capability to solve our most pernicious social problems—poverty, hunger, public health—and our human nature is soon to be tested for its worth as future solutions come available and we decide what to do with them as individuals and groups, and whenever institutions weigh the changes and options from their own perspectives. Time will tell what will be revealed as our human nature in this transition from today to tomorrow.

These changes portend a cardinal tearing of our social fabric—one that may wrench our personal relations with ourselves and our families, with our neighbors and coworkers, especially considering that "work" as we know it in the industrial era may well become obsolete in the way "work" is practiced today. With increasing globalization the nature of interdependency, as well as its combinatorial risks, continues to pervade everyday life of individuals and institutions. Whether it is banking or pollution, military intervention or charity, fashion or scholarship, it is now a global community that is both participant and recipient of overt actions and their unintended consequences. In short, promise and problems are no longer localized but have global context.

Yet, these could be times of wondrous opportunity for the human spirit. All we must do is to choose. That is, choose good goals, adhere to responsible values, and develop cooperative methods of working together. Hopefully, we will speak with humility, act wisely with forethought, and welcome responsible oversight. This is a promise of a potential for a new human ecology, driven by fundamental advances in science, engineering and technology, likely arriving at the doorsteps of our homes, offices, factories, schools, and places of worship and reflection, in only a few years. Nanotechnology may abruptly change not only our standards of living, but more importantly, the standards we live by.

The Relentless Path to Nanotechnology

What is it about nanotechnology that so differently calls forth such optimism and concern? Let's take a moment and revisit the underpinnings of technology and society, in a very simplified view, and why nanotechnology is essentially a fundamentally technical and social force being unleashed all around us, and why this is so important now.

Historical Framework

Lucretius is generally credited with conceiving of atoms as fundamental units, or elements. Nobel laureate Richard Feynman can be thought of as the progenitor of nanotechnology, although he is not known to have specifically used the term. Feynman explicitly recognized atoms as objects that could be manipulated. In his 1959 address to the American Physical Society (published in '60) titled "There's Plenty of Room At the Bottom" (http://www.zyvex.com/nanotech/feynman.html), Feynman foresaw small machines that would make smaller machines which, in turn, would make even smaller machines. In this talk he stated that ". . . as far as we can see, the laws of physics do not prohibit manipulating things at the atomic level."

Feynman's insight, followed to the limiting case, sees atoms being placed, one by one, in precisely defined positions stipulated by careful engineering design. At present, two camps rally around contrasting paths to nanotechnology – the "top-down" approach that envisions every smaller devices, taking MEMS[5] and moving beyond down to the molecular scale, and the "bottom-up" approach that anticipates the efforts of physics to specifically manipulate atoms one-by-one to construct building blocks that could then be assembled into ever increasing sized devices[6]. (Depending on your point of view, chemistry and biology could fit into either camp.) Irrespective of whether a "top down" or "bottom up" approach eventually leads to nanotechnology within ten or one hundred years, Feynman's

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[5] MEMS, or micro electro mechanical systems, is the archetype of the "top down" path to ultra miniaturization, leading to nanotechnology. This approach focuses on continually making smaller and smaller objects with mechanical purposes. See the web links at the end of the essay for more information.

[6] This "bottom up" approach is presented most vividly by K. Eric Drexler in his seminal work *Engines of Creation.*

general idea of manipulating atoms one by one is a confluence of science and engineering that both surrounds us today and has continual economic pressure to become more refined tomorrow.

Scientific American, as quoted on the jacket of *Engines of Creation*, says "nanotechnology has a curious ring of inevitability," recognizing that a variety of pathways lead toward total molecular control, making it more question of "when" instead than "if." This process toward precise control at a smaller and smaller size is on the technology path of electronics, biotechnology, materials science and laboratory instrumentation (e.g., atomic force microscopes)[7]. To a large extent, nanotechnology is an extension of basic chemistry; it is the "new" chemistry of the new millennium.

Fortune Magazine in 1988 recognized that nanotechnology is one area where huge future fortunes are to be made. The British newsmagazine *The Economist* in 1992 pointed to molecular manufacturing as an emergent technology that would fundamentally alter the economic relationships among people and nations. *Time* magazine, in a special 1992 issue written in anticipation of the year 2000, accepted nanotechnology as a basic part of daily living in the years beyond 2000.

In the two early defining books of nanotechnology -- *Engines of Creation* and *Nanosystems* -- K. Eric Drexler explored using elements and molecules as fundamental engineering building blocks, and the manufacturing and fabrication implications of applying this capability to placing atoms according to explicit design. In the forward to *Engines*, Professor Marvin Minsky of MIT credits Drexler with recognizing that "what we do depends on what we can build," and, given the potential of atom stacking mechanisms, asking the key question: "What can we build with atom stacking mechanisms?" This has been leading to an intellectual fruition of Feynman's notions and to the anticipation of the field Drexler is considered to have termed "nanotechnology."

Shortly after the publication of *Engines of Creation*, some critics suggested that the notions of nanotechnology were interesting, but too fanciful because it just wasn't feasible to move atoms around one by one. Nevertheless, the progress of science and technology moved on. Soon thereafter, in 1988, IBM scientists moved 35 individual Xenon atoms on a nickel substrate to spell out the letters "IBM," the world's smallest word[8]. It's propitious to note that the first public demonstration of nanotechnology was a word, a fundamental and intrinsically human invention, foretelling of the immense impact of these advances on humanity: "In the beginning was the Word . . . ." is a theme that resonates with many around the world, albeit in a much less irreverent context.

Technology Enables Modern Life

Technology refers to the totality of the means employed to provide objects for human sustenance and comfort. Nanotechnology, as a means of fabricating objects, fits into this definition, but invites a

[7] Various instruments are at the leading edge of atomic manipulation. See, for example, http://www.molec.com/, http://micro.magnet.fsu.edu/primer/digitalimaging/, http://www.beckman.uiuc.edu/research/menhome.html.

[8] See, for example, http://www.almaden.ibm.com:80/vis/stm/atomo.html

totally new set of ideas because the ability to precisely manipulate elements and molecules is a set of anticipated capabilities that will come to underlie all other material technologies and provide capabilities to revolutionize the non-material ones. As a means to provide new objects, and by extension new products and services, we can expect novel materials and capabilities, leading to novel living patterns, new ways of socializing, and yielding fresh approaches to cooperation and competition.

Technology is intrinsically interwoven into our daily lives. We have become accustomed to continual improvements in our standard of living, brought about by astounding inventions, better medical care, and countless time-saving conveniences. Without as much as an afterthought, we pick up a phone, clean our eyeglasses, fill up the car, go to a movie, stop for a snack, listen to a jazz band, figure the tip on a calculator, lurch through traffic lights on the way home, and then, before bedtime, browse the web from our wireless laptop and book a flight for the holidays, while we earn more extra miles by charging it to an airline credit card. This scenario, or parts of it, are not uncommon experiences for many people. Each aspect of the scenario is the result of technology which is focused through institutions, and now defines the nature of daily life.

The modern world, especially the United States, Europe and Japan, hosts developed societies with a relentless press for improved technology. Many factors coalescence into this pressure including constant consumer demand for new and better products, huge defense establishments that want the latest technological advances for surveillance, subterfuge or weaponry, and medical research that seeks better procedures, prostheses and medicines to avert and relieve human suffering. Of special note are the computer electronics industry which continually drives for miniaturization, and the biotechnology industry which relentlessly strives for increased molecular control. Each contributes regular steps of technological refinement, improvement and advance. This process is the backbone of the "military-industrial-academic-complex" as well as research universities, consumer product development and the commercial competition of the interlinked and interactive global economy.

Having been socialized by slogans promising "better living through chemistry," or "progress is our most important product," or "it's a man-made world," the concepts of "technology" and "modern" have become synonymous in the American (and frequently European and Japanese) public's mind. There's no reason to expect this relentless progress to slow. It's more likely that it will accelerate to the point where humanity will be seriously challenged to keep pace. Nanotechnology will put this rate of change into overdrive, perhaps beyond the safe operating speed of the modern, post-industrial world. What lies ahead requires focused attention and careful forethought, because the industrial forces now driving us toward nanotechnology are not soon to stop; in fact, they probably make it inevitable. The forces driving the emergence of nanotechnology are diverse and relentless, and these will be pivotal in shaping the human and social consequences of this next, great step in technology.

Technological advance is limited only by human imagination, physical law, the progressive accumulation of knowledge, and the capability of tools that can be built. The social context we presently live within — the worldwide economy and electronic global village — are relentlessly driving to nanotechnology, i.e., total control over the structure of matter, and subsequently, manufactured objects. Nanotechnology, in one sense, is a horizon regarding the types of physical tools and products that humanity will be able to build because basic elements — atoms — are used as building blocks. These in turn make molecules, which then make larger and larger items until large, macro-scale objects of everyday living are fabricated. The materials, tools and objects that will be built, and the capabilities they portend, are cleverly imaginative. And the changes initiated by such advances will impact every aspect of living. The impact on the way we live our lives, our jobs and social context will be profound.

Although some technological advances may seem more apparent than real, especially the cosmetic and marketing nature of many consumer products, many advances do make positive contributions to the overall quality of life. At the heart of these advances, however, are research, development and innovation. And as aspects of commerce, government and education, they have become institutionalized. Taken together, they drive the relentless advance toward increased control at a smaller and smaller level, and leading in the not to distant future to control at the molecular level.

Continual Refinement of Miniaturization

Materials are the root of technological civilization. The world has marked its ages by the materials it has used and the products it made: the stone age and the bronze age led to the industrial age and the information age. The machine age is passing and the molecular age is emerging. Starting from the stone age, human effort has resulted in increasingly refined control over things at an ever smaller scale. Early on, this was making tools, chipping away at stones and reducing them to smaller objects, fashioned by design and manipulated by human hands. Later, machines were invented. From space craft to computers, medical instruments to telephones, power plants to batteries, materials technology and ever increasing capacity for humans to exert control at every smaller scale. These have generated the wonders and marvels of yesterday that have become indispensable to our lives today. This increased level of control over material objects has been the hallmark of technological advance.

The essential notion of industrialization is manufacturing. Industrialization drives continual refinements in instruments, tools, assembly, and logistics. The relentless economic and commercial press for "new and improved," coupled with an accelerating advance in electronics and biotechnology, combine together to yield increasingly fine control over the assembled structure of matter. In modern times, the economic and performance pressures in the electronics industry have exerted relentless design and manufacturing pressure to craft smaller and smaller components that will run faster, be more energy efficient, handle more complex operations, can be made in increasingly bulk volume, and become significantly cheaper with volume.

With biotechnology, drug designers detail specific molecular structures and work to identify particular binding sites for activation or inhibition, then they enlist tiny molecular machines (i.e., bacteria) as factories to mass-produce pharmaceuticals. The world has even seen pictures of a mouse with a human ear –cloned from grafted genes – growing out of its back on the evening network news in the USA.

The confluence of electronics and biotechnology, and their continual drive to control smaller and smaller details, leads to using the smallest realistically available components of matter as building blocks. With continual, concomitant refinements with computational methods, capabilities, visualization the ability to conceive – and then construct – nano-scale devices is on the near horizon.

Whether the most effective approach comes to be from the "bottom up" or from the "top down[9]," it appears that each brings forth a relentless march towards nanotechnology. In the limiting case, this means using elemental atoms themselves as Lego Blocks or Tinkertoys, to construct materials and objects with specific properties, restricted only by the laws of chemistry and physics or the blinders of parochial vision. This is the essential scientific idea of molecular nanotechnology.

Nanotechnology

Over the past several years, nanotechnology has become a popular word used to describe nearly any research or process at the nanometer scale. Molecular nanotechnology will use atoms and molecules as its essential raw materials. For present purposes, nanotechnology refers to the precise positioning of atoms and molecules in accord with explicit engineering design, thus yielding the "thorough control" mentioned earlier. Coupled with ingenuity and tools, this inexorably leads to straight-forward applications: improved instruments and tools, stunningly new materials, stupendous advances in information processing and computing; fabulously enhanced health; and a profusion of marvelous benefits.

Up close, a debate rages regarding whether the "top-down" or the "bottoms-up" approach to nanotechnology will be most propitious. The "top-down" approach, centered with MEMS, sees ever increasing miniaturization whereas the "bottom-up" approach foresees atoms being used as elemental building blocks to build specific devices on an atom by atom basis, which in turn are assembled together to make yet larger constructions. The essence of this "religious" debate is irrelevant to the topic at hand because by whichever path molecular mechanical control comes forth will challenge us all with the same types of social questions regarding the human condition and our horizons. The focus here is on the social relations of people, our institutions, and the future that awaits us.

The "Top Down" Approach of Micro-Electronic Machine Systems. Particularly in the area of electronic chip manufacturing, practitioners are continually seeking to create smaller and smaller feature sizes on microprocessors and memory chips. Similarly, the MEMS approach is driven to craft mechanical devices at ever smaller confirmations. One rough, approximate way to think about this is that one begins with a large chunk of atoms or molecules and then "whittles away" what isn't needed. Also, the process of material deposition on chip wafers are done from the bottom up, but without concern to explicit atomic layout aside from using masks or lithographic means of creating bulk features on the wafers. These general ideas are termed by some as 'top down" because they don't reflect the precise positioning on an atom by atom or molecule by molecule according to an explicit point by point design.

The "Bottom Up" Approach of Molecular Construction. Nanotechnology is a straight-forward expectation of today's continual press toward miniaturization, leading to the total control over the structure of matter at the molecular level. Nanofabrication refers to manufacturing and fabrication processes at the nanometer scale. This process will create building blocks with heretofore unheard of precision by constructing molecules that are then assembled together into larger components, which are in turn assembled into yet larger units until macroscopic products are created. Nanofabrication will combine nanotechnology capabilities along with engineering design and the entrepreneurial spirit to establish new methods for manufacturing, new ideas for business, and will use the basic driver of our economic system – business —to eventually supplant our current economic system as nanofabrication becomes the dominant method for producing goods in the developed world. Wildfire diffusion will spread these capabilities globally.

Nanotechnology is the limiting case of material control because with the capability to precisely position selected atoms according to explicit engineering design, it becomes practical to fabricate materials and objects in flawless accord with specification. As nanotechnology and nanofab devices are developed and become commonplace, they too, in turn, will replace older less effective materials and less efficient fabrication methods.

Soon, the progress in the molecular sciences will lead us into the molecular age when new, advanced, strong but inexpensive materials are the norm, not a rarity. Just a cursory glimpse at several contemporary industries shows the significant changes poised to sweep our economy. With these advances will come an inevitable impact on our civilization as well. Whether the capabilities of molecular construction and control are achieved from the "top-down" approach of making increasing more precise and smaller molecules, or from the "bottom-up" approach assembling molecules atom-by-atom is irrelevant because each leads to the general control of the structure of materials as an eventual end result at some point of convergence of their intellectual efforts. In other words, irrespective of the path taken to nanotechnology, the general capability to manipulate atoms and molecules individually, and with exacting precision, is the emergent nature of nanotechnology. Here, atoms are basic building blocks. What can be built by them is as unbounded as human imagination, constrained only by basic laws of science.

New materials directly imply wholly new devices that can be made from them. Their diversity will only be limited by human creativity, the progress of knowledge, the laws of science, and the social constraints on production and distribution. Already, foresighted individuals have visualized nanoscopic submarines to go into the body and repair cells or halt aging. At the other end of the scale, is a vision of seeing huge solar sails only a few molecules thick, efficiently transporting objects around solar space up above our Earth's gravity, creating an interplanetary ferry of ore, metal, or other materials from the Moon, Mars, or asteroid belt. Others anticipate general products—like toasters, TVs and bicycles—are expected to be easily made by nanofabrication techniques; products in which every single atom can be recycled whenever a more advanced model is desired and design is available. The sources and dissipation of the energies involved will be a question of discussion for some time coming.

The Concept of the Molecular Assembler. The essential power of nanotechnology, from the "bottom up" point of view, rests in the idea of the "assembler" described so well in Drexler's *Engines of*

Creation. In basic terms, the molecular assembler is a device, as tiny as a complex molecule, that is best thought of as an ultra-tiny robot. Combined with creative design tools, advanced computational and visualization systems, these nanoscopic machines are the hands by which the future will be built. These are the engines of that will create the Molecular Epoch. With the ability to precisely position elemental atoms according to exact, engineering design specifications, comes the new materials, improved instruments, radical advances in health care and stupendous opportunities for new devices: cars, bicycles, toilets, faucets, lamps and spacecraft are just a few.

With nanotechnology (at least in the "bottom up" form), an assembler will be able to assemble a copy of itself, then it and each replicate make more, and the whole bunch grows in number exponentially. This means that countless hoards of devices can be fabricated, then assemble themselves together as needed. This yields a new era where the main method of fabrication will be molecular manufacturing. This is the essential capability that will cause nanotechnology to be such a potent force of social change. The core economic aspect of the assemblers is that they will be very, very cheap to replicate. This means low-cost manufacturing, and from that, low-cost goods. This is the heart of the transition of the society of today to the hopeful plentitude of the Molecular Epoch.

The assembler is the device that will change forever the world we know. Why? Because an assembler will have the ability to fabricate another— making it a "replicator" of itself. Each of them will then replicate themselves again, then again. Then all of them will make yet and more. Quickly—very, very, quickly—teeming hoards of tiny assemblers will be working together, with exacting precision to make more assemblers. When there's enough of these for the task at hand, the assemblers will be redirected to move on to the next step, which might be to fabricate special materials, new diagnostic instruments or whatever else is needed at the moment, and do this from inexpensive and plentiful raw material feedstock.

Replicators are the devices that Drexler tagged "engines of creation." He foresees replicators leading to a general household appliance, about the size of a microwave oven, that can make many diverse products according to programmed instructions. Such a device would then allow the homeowner to make a new toaster, lamp, eyeglasses or new shoes at the press of a button. It's important to note that this means that most manufacturing may become local, but what will be transferred from one distant place to another will be the designs for making things. In other words, no longer will products be moved long distances, just the information to make them. Instead of transporting atoms, we'll be jiggling bits. The emergent questions regarding the evolution of intellectual property in terms of design and fabrication methods are, and will be, mind-boggling.

More to the point, however, a homeowner could make another replicator. The economic, social and spiritual consequences of such a device are awesome and staggering. In itself, such a device renders obsolete nearly all of the basic underlying assumptions of our economic and social institutions, the usages of currency, the nature of employment, and how we structure our daily activities. Only with forethought will we survive this transition.

Nanotechnology: Enabling a New Civilization

Nanotechnology leads to a wholly-new refinement in the ability to fabricate objects, beginning with special instruments and materials, and leading eventually to nanoscopic devices with revolutionary powers to heal or spy, assemble or disassemble. This implies entirely new and revolutionary manufacturing capabilities, ones that will make higher-quality and lighter-weight products to the most exacting specifications possible, at low cost, and in relative abundance. Moreover, these fabrication methods may consume less energy and will be able to eventually extract a basic feedstock directly from the air by removing an atmospheric pollutant (e.g., carbon dioxide). That is, manufacturing at the molecularly precise scale could take today's waste and pollution and use it to fabricate products of heretofore unheard of quality, strength and durability, and do this at minuscule costs, for example, by fabricating a diamond-like substance termed "diamondoid" directly from carbon.

Nanotechnology leads to a new way of thinking about the world around us. With control over matter at the molecular level comes the capacity to improve all manufactured and fabricated objects. Four areas are particularly interesting in terms of their impact on the human community: materials, instrumentation, symbolic processing and energy.

The anticipated impact of nanotechnology has an immense scope. The range of potential effects can only be captured by broad strokes and innovative thinking across all human institutions and organizations, and their influence on means of production and distribution, and impact on the quality of human life throughout the world. It is necessary to identify next steps, discuss alternative pathways, explore promising avenues, identify stakeholders who are to be helped or hindered, decide, plan and seek funding sources—the military, academia, or venture— and then, having decided, act with dispatch. The Molecular Epoch will create in its wake a new civilization. Below are several fundamental changes in living and lifestyle heralded by the relentless emergence nanotechnology.

Economic Complexities

Nanofabrication will provide new methods, materials and processes for manufacturing. On one hand, the path to molecular control will be forged by immense human intellectual effort: designs, experiments, software, law, policy, etc. But, at the same time, it could render obsolete nearly all of the "factory" or "assembly line" jobs used by the industrial revolution. The nature of work and pay will change in a time of material abundance. Knowledge work, already the key ingredient in the global economy, will become the *sine quo non* of the upcoming age.

Those without appropriate education and training, workers and their families, will suffer in both physical and psychological manners. Many of today's organizations that mete out scarce materials and processes, and thereby provide millions of jobs, could no longer serve productive economic purpose. People who drop out of school will be dropping out of life for all intents and purposes. In the next generation, productive human work will require education, training and mental discipline. This raises an open question as to whether an education system, optimized for the rote lessons of the industrial age, and bent on removing the creative and individual spark of students can survive the transition and actually enable a learned workforce for the future. Perhaps the current educational system in itself will be the key roadblock and institution that inhibits our development or attempts to prohibit broad discourse on the topics at hand.

This is perhaps one of the most basic challenges yet to confront humanity. Which tools will be needed? How might they best be used? This leads to a primal question related to such social change: What are the unique and sustainable contributions brought forth by the humans and their organizations? Who will be served? Who will be trusted?

Institutional Redefinitions

Organizations are where most people spend much of their time. Most contemporary organizational structures are inventions of the industrial revolution. The corporation, the modern educational system, factories, labor unions, office parks, representative government and social clubs for leisure time are a few examples. This creates patterns of affiliation among people: friendships, collegial networks, coworkers, and club members. More importantly, this leads to common points of view, patterns of behavior, and expectations about other people's actions and conversations. In short, our patterns of affiliation and our patterns of conversation and communication are tightly interwoven. Moreover, they exist in a set of molds formed in the industrial revolution.

As organizations restructure or disappear, people's patterns of affiliation will likewise alter, leading to new patterns of affiliation and conversation. The primary groups and organizations of peoples identity, will also change, yielding new ideas, new ways of thinking, and new ways of living. History has shown that wars have been fought over less. The time to question the roles and likely futures of our social institutions is now, irrespective of the fact that we are so totally mired in the industrial and information ages. The way today we manage health and aging, education and apprenticeship, military strength and diplomatic offerings all show evidence that they are for a world of another day that is falling all around us. When the fundamentals of daily living change, all things change.

A Dangled Promise

These are real and imminent developments taking shape today in the world, and the laboratories, the classrooms, and the Internet sites, all around us that may yield entirely new opportunities. But human problems require human solutions. Technology in itself does not solve problems; it simply offers new solutions we can consider. Moreover, nanotechnology, as it weaves it way through our understanding and economic fabric, portends yet new, emergent problems, perhaps cataclysmic ones by calling forth the shadow of economic chaos, political turmoil and military terror, to say nothing of the capacity of these anticipated changes to utterly ravage social relations and the social context and succor provided by institutions, some of which have survived for over a thousand years, although many of which are a consequence of the industrial revolution.

It is a very human thing to do, to take skeptical measure of the promises being foretold by molecular nanotechnology. These ideas at first seem larger than life, of mythical proportions, the stuff of which dreams (or nightmares) are made. Yet, these are not dreams but clear visions of sane minds and sound science, not at all far-out fiction. Nanotechnology derives from real things starting with basic elements like carbon, nitrogen, oxygen and hydrogen as building blocks. The chemistry and physics do not require a willing suspension of disbelief or vivid imagination. Chemistry makes the stuff of our world, and we are all part of it, Thanks to plentiful elements, chemistry and computers, new tools and human ingenuity, nanotechnology is continually becoming an integral part of our world, too.

Nanotechnology seeks to create molecular materials by human intention. Nature does this already, as the coded DNA in your body proves by having made your teeth, bones, and sense of smell. The tree outside your window is a marvel of molecular engineering. But now under the human hand, and the motivations that may color and characterize human intention, the outcomes can lead our thoughts and actions to worlds of bounty or alarm.

Impact On Institutions. Social change may be gradual or radical. With the onset of the Molecular Epoch, driven by an accelerating technology yielding control over the structure of matter — radical change is a plausible scenario. We may see a time when our basic social institutions, and the functions they have served, are buffeted by incomprehensible situations. Family, work, economics, politics, religion, education, leisure, relationships, and nearly every aspect of how human beings come together and do things will be altered. Some institutions, like governments and organized religion, have for centuries (if not millennia) provided structure and focus for human action and enterprise. These institutions themselves may no longer fill their basic functions as people are swept into the Molecular Epoch. For so long, our institutions have been the glue that has held our societies together. What will happen as this glue loses its holding power or suddenly gives way?

Our transition to tomorrow may be fraught with challenges to established institutions focused on spending every effort to enforce their status quo. They will be faced by a bewildering complexity of change. The question will arise whether these institutions and organizations are protecting their own existence in a comfortable (and profitable) form, or are protecting the interests of their constituents or members. Whichever the case, the more established the institution, the stronger will be its power, and exercise thereof, to protect itself. And from this, the greater will be the consequences on people affected by its struggle, realignment or its collapse. We do recall the "crime" of Galileo from simply pointing his telescope at Jupiter and communicating about its moons. We do recall the Inquisition.

Power Of Scarcity. The history of our human community, to a large extent, is the chronicle of a continual battle: one vying to control limited physical and intellectual resources in a world besieged by oppressive scarcity. Since our industrial dawn, politics has served to maintain the interests of stakeholders whose fortunes derived from this scarcity and their control over these limited resources. In most of today's societies, the things we do to make a living—and the people we work with—largely determine how we see ourselves and others. And these are lessons learned in institutions and organizations that emerged to confront scarcity of physical resources, human ingenuity and productive enterprise. These lessons have been enforced on us for eons. And now, things are again ready for a major change.

In every society, there are those who benefit from scarcity – perhaps scarcity of materials, but at times scarcity of opinions or countervailing voices. A time of abundance, even if it is not broad spectrum or widespread, has the capacity to undermine those whose power and authority, wealth or position, is a consequence of that scarcity and their role as a gatekeeper or controller over the distribution of goods or ideas. When things change, their world will change too, and likely from their perspective, not for the better. History is replete with those who expend every effort to maintain their position and power by coercion or by drumming up intolerance, and there's no reason to expect the oncoming social change to suddenly lead to a different outcome. It's not expected that sudden technical advance will yield human enlightenment by itself. This may be much longer in coming.

If we expect that nanotechnology could yield, as measured against today's global standard of living, a culture of relative material abundance, then the potential for dramatic social change is extreme. The nature of wealth will change, the nature of work will change, and in a world where ultra-tiny machines may yield material goods beyond even the dreams of Croesus, wisdom and creativity may well become the only crucial human "value-added" when nanotechnology and nanofabrication methods simply replace much human labor both on the factory floor and behind the office desk. This just isn't the onset of robots in the workplace, as the industrial age is witnessing, but an influx of nanotechnology's ultra-tiny machines to make or fix all sorts of things, from diamonds to viruses, or assemble themselves together to form cars or computers. This heralds the beginning of what Crandall has called the "culture of abundance."

Yet weapons of alarming and undreamed fright, economic and cultural displacements that could dwarf those of the industrial revolution, and may put forth a serious challenge to the value of humanity as an economic or social force. A plethora of alarming or wondrous scenarios could just as readily emerge, with a vast array of potential outcomes. The issues we address today will influence the balance of the outcomes that come to be realized around us.

Healthful Longevity and Social Institutions. Nanotechnology's anticipated impact on health will change civilization in the most literal way by altering forever the current and eons-old presumption of generational cycles. In broad strokes, the Molecular Epoch could foster a time when disease can be eliminated, aging can be inhibited or reversed, and the entire human body could be incredibly enhanced by means of technology: unbreakable bones, eagle-eye vision, a bloodhound's acuity of smell, or—in other terms—be able to design a person's body type, physique or other features as desired. Nurture will surpass nature, and design will overtake destiny.

Nanotechnology could lead to medical diagnostics able to identify biological processes and agents with molecular precision. Therapeutics and transgenics will likely emerge quickly to treat any disease, correct congenital defects and obviate genetic disorders. As a result, people will live a very long time. Precise molecular control yields the fountain of youth. People's friends and family will also live a very long time, as will rivals, antagonists and enemies. Future generations will not be the only ones to inherit pollution, deficits and foolish policies: those who cause such things will also be around to endure the consequences of their actions, perhaps leading to a much better developed sense of consequence to the world's peoples. Humanity will hopefully learn to keep its nest clean.

The social impact of healthful longevity is central to understanding the forces to be unleashed in the Molecular Epoch. Extensive, healthful longevity may well rearrange the day-to-day priorities of people because for those who live many, perhaps hundreds, of years, the consequences of their decisions and behavior will last as long. And fresh opportunities for new professions, lifestyles, and pursuits emerge.

On the dark side, these capabilities could forge pernicious, highly specific genetic weapons. With the recent advances in mapping the human genome, the speculative mind can easily envision custom tailored weapons that could eradicate a bloodline – those of a family with particular genetic markers. Or target all those with a specific marker sequence for a disease and bring it into a state ravaging the body. As the lessons of World War II so ghastly illuminated, there are those who will stop at nothing in their attempt to rid the earth of those who displease them. Never Forget.

Many aspects of our social and economic structure are to be affected by this dramatic change, including family, wealth, education, career planning and waste disposal. Many, many of our current environmental problems result from inefficient manufacturing and an underdeveloped sense of consequence. Our fundamental notions of family and parents, children and relatives will see a metamorphosis due to healthful life extension, especially when a child may be born and, many years later, goes to their great-great-great-grandparent's second doctoral graduation. In today's terms, we already see increasing life spans in the more developed nations. We may see lifespan extension of much greater magnitude, yield our current thinking of "generations" as simply anachronistic.

Conquering disease and repairing aging cells are straightforward expectations of molecular nanotechnology. This capacity in and of itself raises fundamental ethical questions regarding what humanity does with precise, molecular control over DNA: Animals by design? Humans to spec? (A notion brought all to real by the movie *GATTACA* or Huxley's classic *Brave New World.*) Let someone else choose to turn your brown eyes blue? The eugenics atrocity of WWII was hopefully a unique occurrence never to be repeated. Or, perhaps it was child's play considering what could happen. The path to the fountain of youth is emerging before us. And, given the general, anticipated capability of nanotechnology, the central issues become ones of what will be done, who will decide, and what process will empower them to have such command over choice. These powers will soon be at hand. The clock is ticking.

Historical Vigilance

History cautions us that the social consequences of technology are often profound, frequently unanticipated, and usually dramatic. Already, today, we can see that nanotechnology will impact our basic human institutions to an essential degree, especially those that arose during the industrial revolution. As Alvin Toffee illustrated in *Future Shock,* the future always arrives too fast and in the wrong order. Moreover, in *The Third Wave* he recognized that in every country, in every society on the planet, are some people just waiting for an opportunity to make George Orwell's nightmare a reality.

We are soon to see that power relations among people will come to depend upon the skills of tomorrow, not the wealth of today, or parent's estates of yesterday. When today's artifacts of wealth, such as diamonds, may be made from dirt or ashes as an impromptu task with an appliance, when today's economic skills are rendered irrelevant, and when today's political structures are required to find their own value in terms of tangible benefit to those served, we will be careening along a terminal road into a molecular society whose form and function are driven by nanotechnology and whose human relations are shaped by forces yet unknown.

A transition of this magnitude will alter the very nature of the manifestations of fame and fortune, of pride and avarice, of charity and philanthropy, of joy and sorrow, of reverence and reflection. Human nature may manifest itself in significantly different forms—ones hardly imaginable today. Having technology that improves our health will not necessarily yield a happier life; technology that promises to make people smart does not mean they will be good. The basic forces of human nature, of good and evil, of motivation and sloth, of fact and opinion, of agreement and argument, of dominance and submission, of individual rights and systematic oppression, of generosity and greed, will remain. How these will take shape can not be decreed, but by considering these issues today some foresight can be offered for tomorrow.

Societal evolution teaches there is no turning back from these inevitable changes. The times ahead hold promise of bounty and abundance for everyone, not just today's stakeholders of wealth and power. Those with today's greatest fortunes and power will not necessarily be individuals of consequence or even recognition in the anticipated molecular society. Today's institutions of states and churches, of education and occupations, of governments and corporations, and other inventions of the industrial revolution may soon begin to expire during the current century. The basic ideas of family and community, of relationship and belonging, of contribution and purpose, may become unrecognizable by today's standards and expectations. Business itself may completely transform, into what we don't yet know. Institutions yet unheard of will emerge. Personal reasons for existence will be anybody's guess.

These are among the issues clamoring for attention as the Molecular Epoch emerges. We stand today at the threshold of a new epoch of humanity with societal evolution at the cusp of nanotechnology as we transition from today to tomorrow. We are about to embark on an remarkable journey. It heralds the next, great step of our human spirit.

Emergent Questions

Our qualities and our character will be revealed in our relations with each other. Human factors such as status, aspiration and attainment, social dominance, authoritarianism, greed and advantages derived from scarcity are the conservative forces of the status quo will become manifest in forms not yet known. What will those in positions of power, particularly those in institutions who thrive based on today's scarcity, do to each other and to people at large when scarcity may no longer be the basic operative of social or political power? Will this become a halcyon time of mentors or an eon of masters? Every era of social change has witnessed the rise of demagogues whose only expertise seems to be their capacity to frighten people and at time move them into mass social action against the inevitable forces of change. Irrespective of how inevitable the forces of change are, history is replete with the rise of those who have sent millions to their untimely and horrific deaths in the quest of a vision of a new world order or the likes of the Luddites organizing against forces of advances of technology all around them.

While the technical challenges of nanotechnology are significant and daunting of their own accord, the complications of human interaction may be more profound. Considering how often human emotions—many of them not so noble—are often aroused from the mere discussion of technologies, as witnessed in discourse regarding contraception to biotech, evolution to biology, space development to environmental sustainability, TV viewing to computing, security to freedom, it's clear that all societal evolution comes at a precious price.

The nanotechnology revolution and emergence of the Molecular Epoch promises a world of material abundance where the economics and politics of scarcity may vanish, but through this process an even deeper scarcity in the quality of the human spirit may be revealed. This leads to key questions. We begin by asking:

- Does humanity know how to behave with abundant opportunity, when most physical needs can be met? How can we learn to act in a manner to bring forth the bounty of abundance?
- Which forms will our institutions and social relations take?
- What will be the purpose of our emergent institutions?
- How will our current institutions adapt or react?
- What will optimum survival look like?
- What could the unbounded human spirit achieve in a world free of political and economic oppression?
- What defenses can be brought forth to inhibit the rise of demagogues and instead let freedom ring?
- What will be the nature of manufacturing, and manufacturing enterprises? What will be the impact on today's notion of having a "place of work" where people go to spend their days and, around the activities of economic production, form many social relations?
- And, most importantly, what will the nature of human and social relations be like through this transition?

These are initial questions, which are expected to be refined and expanded as the debate moves forward.

As a society we buy knowledge and progress by the premises we accept, and the assumptions we live by, conscious or otherwise. Nanotechnology may well create a society where our present-day assumptions of daily living and our institutions are rendered inoperative, simply irrelevant, or wholly counterproductive. It is doubtful that our transition is going to be much more enlightened than any of those in the past, especially as institutional purposes are buffeted by reality and found to be inadequate.

Closing

Civilization is the total sum of the social heritage, expectations and aspirations inherited by one generation from its predecessor. Language, mores, knowledge and artifacts form a continuity that provides the thread that weaves together people into the human community over time. Today's progress toward increasing miniaturization and the coalescing focus of chemistry, biology, electronics and software development on molecular control is yielding nanotechnology, which leads to total control over the molecular structure of matter, within the laws of science and constraints of human ingenuity. What will come in the wake of nanotechnology, however, is the potential for a fundamental dislocation of our entire civilization when molecular tools, fabrication and devices become available and could yield a time of material abundance or utter terror. The challenge before humanity is to anticipate these developments and exercise foresight regarding possible and likely consequences.

This is our test.

Author's Note

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Suggested Reading

Burnham, John C., *How Superstition Won and Science Lost: Popularizing Science and Health in the United States.* Rutgers University Press, 1987.

Denning, Peter (ed.), *The Invisible Future: The Seamless Integration Of Technology Into Everyday Life.* McGraw-Hill, 2001.

Drexler, K. Eric, *Engines of Creation*, Anchor, 1987.

---- *Nanosystems: Molecular Machinery, Manufacturing, and Computation.* John Wiley & Sons, 1992.

Lewis, James and Crandall, B.C. (eds.), *Nanotechnology Research and Perspectives,* MIT Press, 1992.

Regis, Ed, *Nano: The Emerging Science of Nanotechnology: Remaking the World-Molecule by Molecule,* Little Brown & Company, 1995.

Rogers, Everett, *Diffusion of Innovations,* Free Press, 4th edition, 1995.

Toffler, Alvin *Future Shock.* Random House, 1970.

---- *The Third Wave.* Bantam, 1981.

Some Suggested Nano Links (As of August 2002)

- National Nanotechnology Initiative: http://www.nano.gov/
- NanoJournal: http://www.nano-tek.org/main.html
- Nanotech Planet: http://www.nanotechplanet.com
- The Foresight Institute: http://www.foresight.org/
- NanoDot: http://www.nanodot.org
- Zyvex's nano plethora: http://www.zyvex.com/nano/
- Rensselaer Polytechnic Institute Nanotechnology Center: http://www.rpi.edu/dept/research/centers/nanotech.html
- Cornell Nanofabrication Facility http://www.cnf.cornell.edu/CNF/Affiliates/AffiliateInvitation.html
- Center for Nanoscale Science and Technology at Rice U.: http://cnst.rice.edu/cnst.html
- The Institute of Nanotechnology (UK): http://www.nano.org.uk/
- NASA—Nano Team Page: http://www.nas.nasa.gov/Groups/SciTech/nano/index.html
- NanoWorld! http://www.uq.edu.au/nanoworld/
- IBM's "atomo" site: http://www.almaden.ibm.com:80/vis/stm/atomo.html
- Nanotechnology On The WWW http://www.lucifer.com/~sean/Nano.html
- National Nanofabrication Users Network: http://www.nnun.org/
- Feynman Prize in Nanotechnology: http://www.zyvex.com/nanotech/feynmanPrize.html
- Microworlds - Exploring the Structure of Materials: http://www.lbl.gov:80/MicroWorlds/
- Periodic Table of the Elements: http://www.cs.ubc.ca/elements/periodic-table
- Quantum Science Research at Hewlett Packard Laboratories: http://www.hpl.hp.com/research/qsr/
- MEMS at Sandia National Labs: http://mems.sandia.gov/scripts/index.asp
- MEMS & DARPA (US Military): http://www.darpa.mil/MTO/MEMS/
- The MEMS Exchange: http://www.mems-exchange.org/
- MEMS industry group: http://www.memsindustrygroup.org/

Nanotechnology is the engineering method in which fully functioning devices are manufactured at the molecular scale. Through this method, the devices that are manufactured will be having higher performance than the conventional ones. The items will be constructed from the bottom up with the help of high performance techniques and tools. Undoubtedly, nanotechnology is going to be the future, as studies are going on in diversifying the technology from materials with dimensions in nano scale to materials in dimensions of atomic scale. Some new methods like molecular self-assembly have been develo Nanotechnologyâ€™s rapid development worldwide is a testimony to the transformative power of identifying a concept or trend and laying out a vision at the synergistic conuence of diverse scientic research areas. This chapter provides a brief perspective on the develop-ment of the NNI since 2000 in the international context, the main outcomes of the R&D programs after 10 years, the governance aspects specic to this emerging eld, lessons learned, and most impor-tantly, how the nanotechnology community should prepare for the future.Â 1999), which was adopted in 2000 as an ofcial document by National Science and Technology Council (NSTC). These were the signicant steps toward establishing nanotechnology as a dening technology of the 21st century. The denition of Nanotechnology is a common word these days, but many of us donâ€™t realize the amazing impact it has on our daily lives. According to the United States National Nanotechnology Initiative, nanotechnology is â€œscience, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers.â€ One nanometer is a billionth of a meter, or 10-9 of a meter. For comparison, a sheet of newspaper is about 100,000 nanometers thick. Molecular Epoch ! involves major social changes founded on â€œtotal (or near total) control over the structure of matterâ€, â€œnovel materials and capabilities, leading to novel living patterns, new ways of socializing, and yielding fresh approach to cooperation and competition â€¦. stunningly new materials, â€¦ fabulously enhanced health, and a profusion of marvelous benefitsâ€. 3.Â nanotechnology is nothing but an umbrella, comprising three elements: science, engineering and technology at the nanometer scale. whatâ€™s created may be called: nanoartefact, the key to its production is systems integration, materials science and engineering, mesoscopic physics, full quantum physics, chemistry, biology, â€¦, new forms of mechanical engineering

Molecular nanotechnology. Quite the same Wikipedia. Just better.Â Molecular manufacturing is a potential future subfield of nanotechnology that would make it possible to build complex structures at atomic precision.[19] Molecular manufacturing requires significant advances in nanotechnology, but once achieved could produce highly advanced products at low costs and in large quantities in nanofactories weighing a kilogram or more.[19][20] When nanofactories gain the ability to produce other. nanofactories production may only be limited by relatively abundant factors such as input materials, energy and software.[20].Â This could help coordinate efforts for arms control.[27] International institutions dedicated specifically to Now the scientists are pushing for the new epoch to be officially recognised. "We don't know what is going to happen in the Anthropocene," says geographer Professor Erle Ellis of the University of Maryland. "But we need to think differently and globally, to take ownership of the planet." Anthropocene, a term conceived in 2002 by Nobel laureate Paul Crutzen, means "the Age of Man", recognising our species' ascent to a geophysical force on a par with Earth-shattering asteroids and planet-cloaking volcanoes.Â Putting humans at the centre of our planet's activity represents a paradigm shift in the way geologists usually think of our species â€“ as a mere blip on the long timescale of Earth. There have been seven epochs since the dinosaurs died out around 65m years ago. Machine-phase nanotechnology - A molecular nanotechnology pioneer predicts that the tiniest robots will revolutionize manufacturing and transform society. September 2001. Scientific American 285(3):74-75.Â lecular manufacturing technology, it. helps to look at the macroscale machine. systems used now in industry. Picture a.