NANOTECHNOLOGY

A Revolution in Manufacturing

(Revised: June 2006)

When the White House introduced the National Nanotechnology Initiative (NNI) in 2000, they said:

These developments are likely to change the way almost everything -- from vaccines to computers to automobile tires to objects not yet imagined -- is designed and made.[1]

If you have actively been trying to keep up with the latest scientific trends, then you have most likely read about nanotechnology. The hype level surrounding it is large and growing. But, then again, the promise is nothing less than a revolution that will affect us all.

We have heard people discuss nanotechnology as though it is a product – something one can build a company around and invest in. Actually, nanotechnology has a quite different meaning. The NNI defines nanotechnology as follows:

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications.[2]

Manufacturing methods that utilize nanotechnology are in use today in making tennis balls, clothes, electronics, medicine and a myriad of other things. In fact, at this writing, we know of over 1,000 companies that claim to be working in nanotechnology in at least 11 vastly different industrial sectors.

This paper will attempt to describe nanotechnology, discuss its impact in investment today and the possibilities it portends.

Some Basics About Nanotechnology

The best way to think about nanotechnology (as it relates to business) is probably as a method of manufacturing things at the molecular level.

In possibly the best video explanation of nanotechnology we have every seen, Ralph Merkle[3] (who was a Nanotechnology Theorist at Zyvex Corporation and is now a professor at Georgia Tech College of Computing) described it in a very effective way. Borrowing from his explanation (with some small variance):

- A meter is a little over a yard in length. It's a familiar measure; we all know about how long a meter is.
- A thousand times smaller than a meter is a millimeter. We all know how small a millimeter is. We can see it on our rulers. It's small, but it's visible.

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[1] *National Nanotechnology Initiative Leading to the Next Industrial Revolution,* White House press release, January 21, 2000.
[2] National Nanotechnology Initiative website: http://www.nano.gov/html/facts/whatIsNano.html
[3] Ralph Merkle, *The Incredible Shrinking Science*, TechTV, 2002

- A thousand times smaller than a millimeter, is a micrometer (or, micron). And this is very, very small. We can barely see a micron under the most powerful optical microscopes. A human hair is about 100 microns thick.
- And a thousand times smaller than a micron, is a nanometer. We're talking about the size level of atoms and molecules. Things so small you need very special (and very expensive) equipment to see.

It is at the nanometer size level that researchers are working, which is where the term "nanotechnology" comes from. The overall idea is to manipulate molecules to build useful things. That is, we want to combine molecules in such a way as to make products.

1 METER (39.37 INCHES)	**1 METER (39.37 INCHES)**
0.1 METER = 1 DECIMETER	**10 DECIMETERS = 1 METER**
0.01 METER = 1 CENTIMETER	**100 CENTIMETERS = 1 METER**
0.001 METER = 1 MILLIMETER	**1000 MILLIMETERS = 1 METER**
0.000001 METER = 1 MICRON	**1,000,000 MICRONS = 1 METER**
0.000000001 METER = 1 NANOMETER	**1,000,000,000 NANOMETERS = 1 METER**

Nanotechnology, then, refers to "the ability to work at the molecular level, atom to atom, to create large structures with fundamentally new molecular organization".[4]

The results are products with molecular precision, high efficiencies and few, if any, defects. And they may even be less expensive.

Why Nanotechnology?

If you start at the molecular level, you have *precision* at the molecular level, and therefore, better quality and repeatability than could otherwise be possible. Again, citing Merkle, products made using these methods would be "lighter, stronger, smarter, cheaper, cleaner and more precise".[5]

And this is not just a pipe dream. There are a number of companies that are already using refinements made at the nanometer size level to improve their products. General Motors is using lighter, stronger materials based on nanoparticles in some of their vehicles (as one researcher said, "if you have weight savings, you have fuel savings").[6] Wilson is producing premium tennis balls with nanometer-thick rubber interior coatings and Burlington uses nanocoatings to provide protective layers in its coats.[7] And there are many, many other examples.

The Next Industrial Revolution

There are a lot of numbers being thrown around about the size of the "nanotechnology market". It's been reported that, in 2005, $32 billion in nano-enabled products were sold worldwide.[8]

Dr. M.C. Roco, a Senior Advisor for Nanotechnology with the National Science Foundation, put the projected world market of products with nanotech components at $1 trillion by 2015, representing

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[4] National Nanotechnology Initiative, June 2002
[5] Ralph Merkle, *It's A Small, Small, Small, Small World*, Technology Review, Feb/Mar 1997
[6] Ellen Fussell, *Tiny Science Thinks Big, InTech*, June 1, 2004
[7] Eric Roston, *Very Small Business*, *Time*, September 15, 2002
[8] *Nanotechnology in $32 Billion Worth of Products; Global Funding for Nanotech R&D reaches $9.6 Billion*, Lux Research Press Release, dated May 8, 2006

an increase of 2 million new jobs.[9] More recently, Lux Research projected a $2.6 trillion market for nanotechnology-enabled product by 2014.[10]

At the October 2005 Foresight Conference in San Francisco, the keynote speaker was Carl F. Kohrt, CEO of Batelle. He broke down the $1 trillion figure like this (in the billions of dollars):[11]

Electronics	**$300**
Materials	**$340**
Pharmaceutical	**$180**
Chemical Manufacturing	**$100**
Aerospace	**$70**
Tools	**$20**
Improved Health Care	**$30**
Sustainability	**$45**

These kinds of forecasts portend a new industrial revolution – a change so vast that it will profoundly affect each and every one of us.

A key indicator in all this excitement can be found by analyzing the activity of the US patent office. The have been so many patents issued that relate to nanotechnology that the US patent office recently created a new class (Class 977 Digest 1) with over 250 new subclasses to address just nanotech-related disclosures. Although we have no definite number, we can estimate (based on conflicting numbers from others) that there are probably somewhere between 2,500 and 4,000 issued US patents that directly relate to nanotechnology, with something close to 3,000 or 4,000 new applications being received annually (another related indicator was seen at a recent nanotechnology conference; a presenter pointed to the sponsor list and noted there were 6 companies, 4 research institutions and *8 law firms*).

Certainly within the next 10 years, we could see nanotechnology in drug delivery, energy storage, displays and environmental cleanup. In the decades following, we should see it in quantum computers, molecular manufacturing and fuel cells.

We're talking about a major change, hopefully for the better, in people's everyday lives.

What's the Latest on Nanotechnology?

As of June 2006, we counted 1,068 companies in the database of *Nano Investor News* that claim to be working in a field related in some way to nanotechnology (including some that are working in "small" technology).[12]

In June 2006, the National Center for Manufacturing Sciences published a report (funded by the National Science Foundation) titled "2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry". In it, 18% of the nearly 600 respondents said they were already

[9] M.C. Roco, *National Nanotechnology Initiative Overview*, ASME Workshop Presentation, September 22, 2004
[10] Charles Pillar, *Science's Tiny Big Unknown*, Los Angeles Times, June 1, 2006
[11] Carl F. Kohrt, *Achieving the Nanotech Vision: Multiple Horizons for Beneficial Applications*, 13th Foresight Conference on Advanced Nanotechnology, October 24, 2005
[12] www.nanoinvestornews.com

marketing nanotechnology products and an additional 64% said they would be doing so within the next 5 years.[13]

In addition, Lux Research indicated that there are 1,500 companies that have "announced intentions to pursue nanotechnology strategies".[14] Almost all major universities have nanotechnology centers (including MIT, Caltech, Stanford, Yale, UCLA, and dozens [maybe hundreds] of others[15]) and governments are pumping billions of dollars into nanotechnology research. In fact, the money spent on nanotechnology makes it the largest scientific initiative since the Apollo mission.[16]

The following table indicates the reported amount of money spent on nanotechnology-related research and development since 1997. However, it should be kept in mind that these numbers could be a little deceptive. The definition of "nanotechnology" varies from country to country, so what one part of the world considers nano may not fit another's definition. In addition, there are some variables as to what constitutes government investment as opposed to contracts, etc.

Government spending on nanotechnology (in millions of dollars)[17]

	1997	1998	1999	2000	2001	2002	2003	2004	2005
United States	$116	$140	$165	$270	$422	$604	$790	$1,593	$1,700
Western Europe	$126	$140	$165	$200	$270	$400	$650	$970	$1,100
Japan	$120	$113	N/A	$245	$465	$650	$800	$1,000	$1,700
Other Countries	$70	N/A	N/A	$110	$380	$500	$810	$996	$100

Companies are also spending a huge amount of cash in nanotechnology research, totaling $3.8 billion in 2004.[18] In 2002, *Nano Investor News* reported that their database had identified 490 companies involved in nanotechnology. As we stated earlier, that same website reports 1,068 companies today. There are certainly many more.

We are sure that the majority of these are good companies that are striving to bring better, less expensive products to the marketplace.

But, there needs to be some caution in all this growth. Whenever there is a "hot" area for investors and business, there seems to be a lot of hype. During the "dot com" era, the markets were flooded with companies built on hype and little more. With no real business basis, many (if not, most) of the "dot com" companies eventually failed.

There could be some "cashing in" on the term "nano". Apparently, many companies that claim to be working in "nano" do not actually qualify as true nanotechnology companies. In a 2002 Forbes article, Josh Wolfe (a co-founder and managing partner of Lux Capital, as well as the author of the

[13] *2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry*, National Center for Manufacturing Studies, Ann Arbor, MI, June 2006
[14] *Spending on Nanotechnology to Top $8.6 Billion in 2004*, Lux Research press release, dated August 17, 2004
[15] A list of research institutions can be found at the website www.nanoinvestornews.com
[16] *Nanotechnology Patents and Challenges*, Patent Café Magazine, May 18, 2004
[17] Sources include: The US National Nanotechnology Initiative (which accounts for most of the government spending in nanotech by the US); NanoInvestorNews; *Nanotechnology: Where Does the US Stand?* Matthew M. Nordan, testimony before the Research Subcommittee of the House Committee on Science, June 29, 2005.
[18] *Nanotechnology: Where Does the US Stand?* Matthew M. Nordan, testimony before the Research Subcommittee of the House Committee on Science, June 29, 2005

Nanotech Report – a monthly publication from Forbes) portrayed many companies as “nano pretenders”. While discussing some of the shortcomings of apparent “major” nano players, Mr. Wolfe described others as "hype". He wrote of the desire of companies in the past to use "tech" and "dot-com" in their names to get attention from Wall Street; today, the word is "nano".[19]

What’s next?

For nanotechnology to become truly widespread, there are a number of difficulties that must be overcome. The NCMS report referred to earlier surveyed small and large American nanotechnology companies and found that the largest barriers to full acceptance and use of nanotechnology in the U.S. today include high costs, regulatory concerns and intellectual property matters (there were other barriers listed as well, but these seem to us to be the more valid issues.[20] The processes need to become standardized and united with other manufacturing techniques.

In summary . . .

Think about how different things are today, in 2006, compared with 1906. Some of the things we have today that were not available then include:

- Plastics
- Birth control pills
- The integrated circuit
- Penicillin
- The personal computer
- Commercial air travel
- Radio
- Television

. . . and countless other innovations.

With nanotechnology, the differences between today and 100 years from now will be even more astounding.

The 2000 press release issued by the White House when they announced the National Nanotechnology Initiative also read, in part:

Nanotechnology is the new frontier, and its potential impact is compelling.[21]

We couldn’t agree more.

[19] Josh Wolfe, *Beware of Nano Pretenders*, Forbes, August 1, 2002
[20] *2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry*, National Center for Manufacturing Studies, Ann Arbor, MI, June 2006
[21] *National Nanotechnology Initiative Leading to the Next Industrial Revolution*, White House press release, January 21, 2000.