Nanotechnology Sector Report

Technology Roadmap Project

Prepared by:

NANOTECHNOLOGY

Introduction

Nanotechnology is predicted to become the basis for remarkably powerful and inexpensive computers, fundamentally new medical technologies that could save millions of lives, sensors important in military application as well as environmental protection, and new zero-pollution manufacturing methods that could create greater material abundance for all [1]. According to key policy makers, the development of nanotechnology as the latest mega trend in science and engineering will bring a wave of radical innovation and perhaps, because of its potentially broad impact, spark a new industrial revolution [2].

Nanotechnology is defined here as the control of materials and devices at a molecular and atomic scale or a series of disciplines that works at the atomic and molecular level to create many types of structures or devices with improved molecular organization. Basically however, there are two domains of interest, the top down approach meaning refinement of practices and techniques to the point that they operate at the nano level or the bottom up approach that focuses on building materials atom by atom.

Nanotechnology is unique because of the large government investment in its development worldwide. Further it has potential importance for greatly enhancing existing products as well as enabling significant future opportunities. Its potential reach of number of industries impacted may be even greater than biotechnology. This report is divided into five main sections. In the first section we identify the main segments and sub sectors that nanotechnology companies fall under. The next section describes the market size and growth over time, while the third section looks at the technological trends in the nanotechnology industry. The final two sessions describe the economic impacts of nanotechnology and a summary of our findings thus far, respectively.

1. Segments and sub sectors

The main segments and sub sectors associated with the nanotechnology industry are as follows:

- **Tools and Devices:** Instrumentation (AFM), ISAM, Molecular Switches, Nanodevices and systems,
- **Materials:** Nanotubes, Fullerenes, Powders, Ceramics, chemical manufacturing which includes thin film coatings, nanocomposites, etc.
- **Nanobio:** Drug Delivery, Diagnostics, molecular biology, Bionanodevices and systems etc.
- **Others (**includes, Modeling & software**):** Simulation (Nano Cad), Virtual Reality (CAVE), etc.

[1] Roco MC, Williams RS, Alivisatos P (eds). *Nanotechnology Research Directions – Vision for Nanotechnology in the Next Decade.* ITRI, WTEC, p. 221, 1999.

[2] Siegel RW, Hu E, Roco MC (eds). *Nanostructure Science and Technology – R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices.* Dordrecht (The Netherlands): Kluwer; p. 335. 1999.

We identified over 800 companies worldwide that are in some way involved with nanotechnology. It must be noted that there is no SIC or NAICS code for the Nanotechnology Industry. The percentages of the main industry segments that the US companies fall under, based on their NAICS classification, shows that the industry with the maximum percentage of nanotechnology companies is the electronics /electrical /semiconductor manufacturing industry(Table 1).

Table 1: Percent US Private and Public Companies based on NAICS Codes (and SIC codes)

SIC codes	*Includes NAICS codes*	*Industry Classification*	*No. Private*	*No. Public*
	21	**Mining**		1
2812, 2833, 2841, 3272, 3499, 3264, 2821	32518, 32541,32561,327999, 332117, 335991, 325)	**Chemical Manufacturing**	8	5
3586,	331, 333, 3364, 325211, 333913)	**Other Manufacturing**	6	5
3671, 3559, 3287, 3674, 3679, 3842, 3825, 3826, 3829, 3625	3344, 33411, 333295, 333314, 334413, 334419, 334510, 334515, 334516, 334519, 335314	**Electronics/Electrical/Semiconductor Manufacturing**	11	15
2833, 2835, 2836,	325411, 325413,325414,339131	**Biological and Chemical Manufacturing**	4	4
5085, 5169	425, 423840, 423690, 424690	**Wholesale**	5	3
2741, 7372, 4813	511120, 511210, 517	**Information**	3	1
for lawyers and legal services- 8111, 8712	54	**Professional, Scientific and Technical Services**	5	4
6712/6719	55	**Management of Companies and Enterprises**	1	
8299	61	**Educational Services**	1	
around 8699 but nothing direct	81	**Other Services**	2	
9511	92	**Public Administration**		1

2. Nanotechnology Markets

2.1 Market growth and size

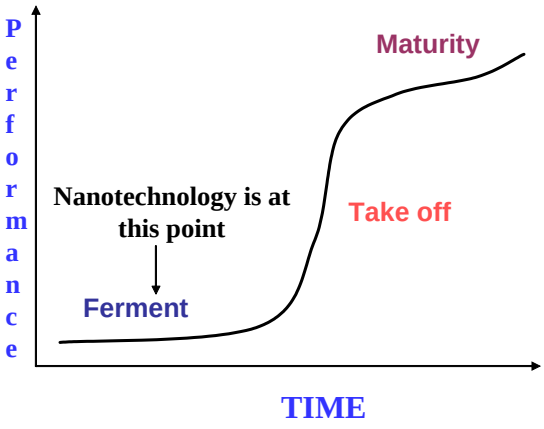
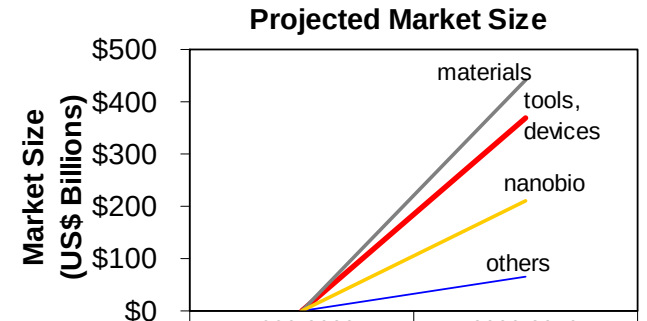


Figure 1: A clear point in the industrial life cycle of nanotechnology development



	1990-2000	2000-2010
Tool and devices	$0	$370
Others	$0	$65
Materials	$0.13	$440
Nanobio	$0	$210

Figure 2: Market size vs. Time for all Nanotechnology Products

As previously mentioned, there is wide agreement on the fact that there are large discrepancies in market forecasts for nanotechnology and that it is at an early stage of development (figure 1). The "nanotechnology market" as a unified market was defined by the National Science Foundation in its "Societal Implications of Nanoscience and Nanotechnology" report from March 2001, with the much publicized estimate of $1 trillion by 2015. Many organizations such as Evolution Capital, In Realis, National Science Foundation (NSF), Nano Business Alliance (NBA), CMP-Cientifica and SRI have since attempted to estimate the nanotech market; nonetheless the truth about these forecasts is that they are based on "anyone's guess" on how much impact nanotech will have and when [3]. That said, estimates for the different segments from the most conservative to the most optimistic range (in US $ billions) as follows: Materials- $400-$440; Tools and devices- $340-$360; Nanobio- $170-$210; and others ranging between $65-$90. Our estimates for the key nano sub sectors identified (figure 2) are based on the most predominantly accepted numbers. (NSF, In Realis, NBA). Based on these estimates, among the three levels (Ferment, Take off, Maturity) in the industry life cycle we can place the nanotech development to be at the fermenting level at present (figure 1), where the industry is really up for grabs, people aren't sure how to price their products, or even sure if this is an exclusive industry by itself. The market growth for all the nanotech products is estimated to be 44% over the next 12-15 years (figure 2). Present day products that are already on the shelves in the market include stain repellent and wrinkle-resistant threads, high-performance ski wax, deep penetrating skin care, OLED digital camera, high-performing sunglasses, nanotech-socks, and high-tech tennis rackets and balls.

Important technological discoveries and inventions form a basis of projected growth of the markets in each of the sub sectors of nanotechnology and confirm that the main sub sectors associated with nanotechnology and nanoscience are primarily chemical and semiconductor manufacturing. The next important milestone would be breakthroughs in the field of global-scale nano-manufacturing.

2.2 Technology trends – prospects and uncertainties

A recent paper [4] using nanotechnology terms adopted in previous NSF database searches identified 89,153 patents in the USPTO database issued over the period 1976-2002. Nanoscale science and engineering related patents were dominated by the industries of electronics and chemical/ catalysis/ pharmaceuticals. Significant growth of patenting activity was also observed in chemical/ catalysis/ pharmaceuticals industry since 1997. Chemistry, molecular biology and microbiology were revealed to be the technology fields with the most influential patents—those patents, which had been cited frequently by subsequent patents. Semiconductor device manufacturing, process chemistry, molecular biology and microbiology and organic compound part of the class 532-570 series were revealed to be the technology fields that had been building on the most recent cutting-edge technology development.

However, looking at the market impact of nanotechnology products (Figures 3, 4a, 4b) we observe that the market is accepting of the products and even ready, but a focused effort is integral to the actual development of the products.

[3] Glapa, Steven "A critical investor's guide to nanotechnology, February 2002.

[4] Huang, Zan, et al., Longitudinal patent analysis for nanoscale science and engineering: country, institution and technology field, *Journal of Nanoparticle Research*, Kluwer Acad. Publ., Vol. 5, Issue 3-4, 2003.

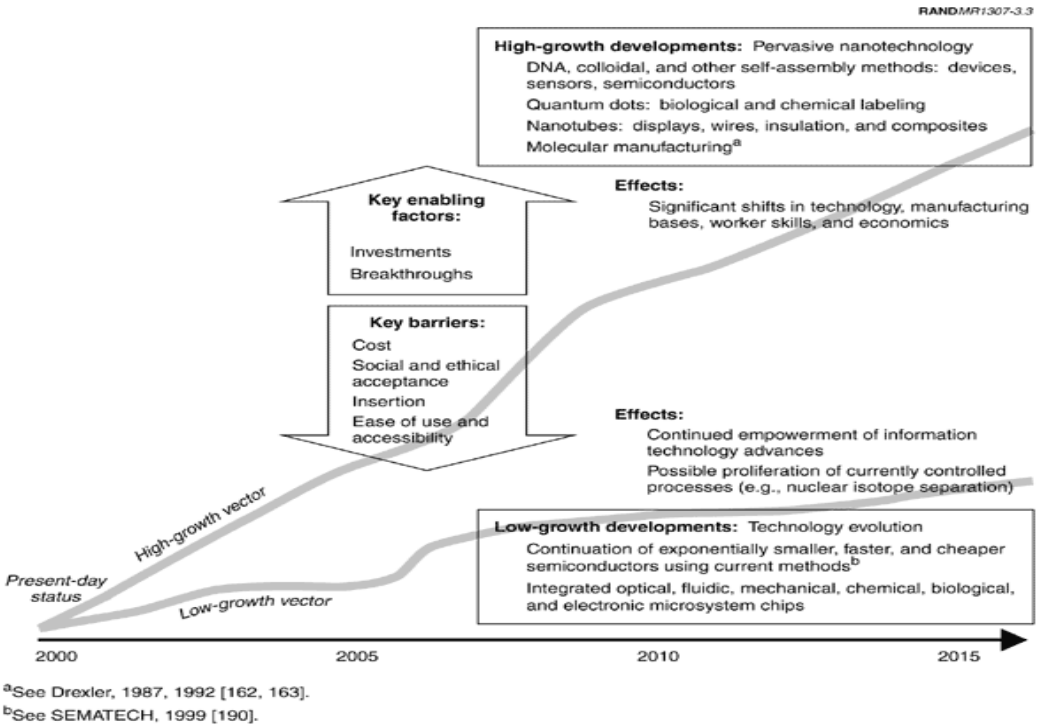


Figure 3: Range of Possible Future Developments of Nanotechnology

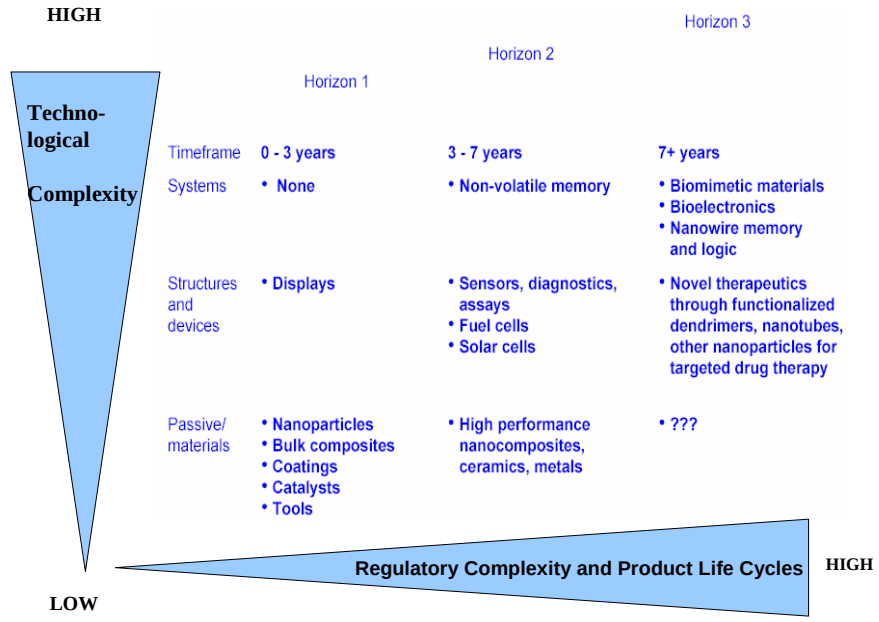


Figure 4a: Market Impact of Nanotechnology (Atom works, 2003[5])

[5] Sean Murdock (2002), A disruptive technology with the potential to create new winners and redefine industry boundaries, AtomWorks-presentation about nanotechnology business roadmap for the industry.

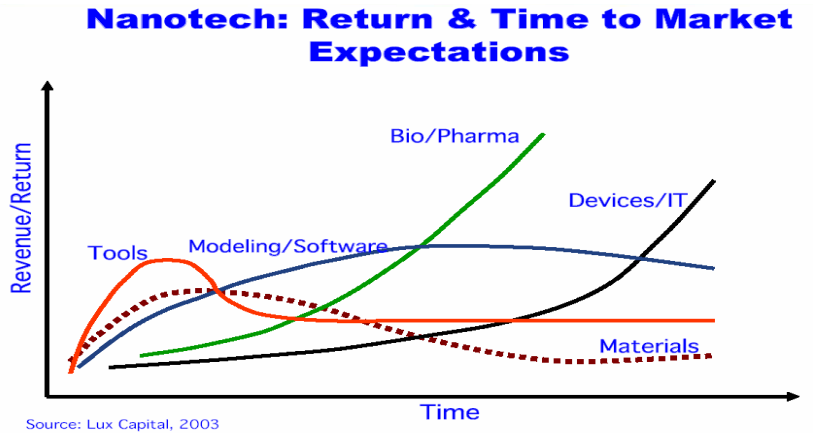


Figure 4b: Market Acceptance for each sub sector (Lux Capital, 2003[6])

3. Value chain:

As mentioned earlier there are large discrepancies over the definition of nanotechnology and subsequently its markets, whether it is nano-sized particles or any product influenced by nanotechnology and based on this definition we see below (figure 5) the value chain of the nanotechnology industry.

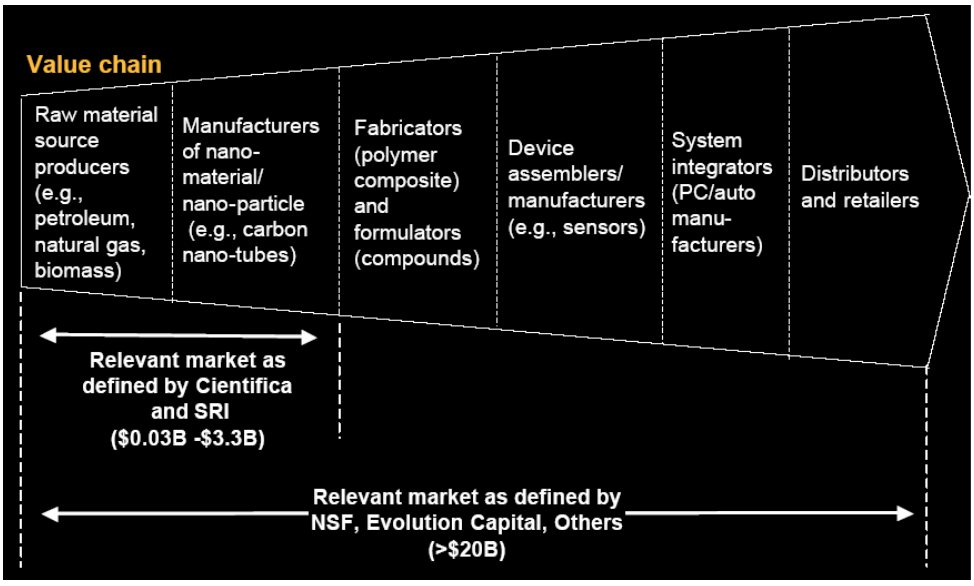


Figure 5: Based on the nanotech market definition effect on market forecasting[7]

[6] *The Nanotech Report*, Lux Capital 2003.
[7] Sanghvi, Sunil, "Nanotech: Positioning today for long term value creation", Chicago: Nanocommerce 2003.

4. Economic Impact

Global, broad investment in all sectors associated with nanoscience or nanotechnology research is increasing. US government funding has increased six-fold from 1997 to more than $774 million in 2003. Japan invested approximately $810 million in 2003 bringing the total world investment in nanotechnology R&D to US $2.9 billion.

Our database shows that over thirty five countries have initiated national initiatives in nanotechnology and as previously mentioned that there are over 800 companies currently active in some aspect of nanotechnology. Among the 800 companies there are 67 public companies and 223 private companies in countries other than the US. There are 91 US–based public companies and 317 US–based private companies. There have been approximately 352 new US–based startups since 1989. Two of these start-ups can be found in the Capital Region of NY (table 2). The overall growth rate, however, of the total number of startups doing bottom up research is the greatest for Germany, while the growth rate for the total number of startups doing top-down research is greatest for Taiwan.

Table 2: Number of Nanotech public and private companies in the World, USA and specifically in the Albany-Troy-Schenectady Area

Country/State/City	*No. of Public Companies*	*No. of Private Companies*
World	**67**	**223**
USA	**91**	**317**
New York	**5**	**21**
Tricity Area		
Latham	**1**	
Troy		**2**

With these estimates of investments from the government and the increasing number of private and public nanotech companies, some of the potential economic impacts are highlighted below (table 3).

Table 3: Economic and technological impacts of the nanotechnology sector

Direct Impact	Indirect Impact	Induced Impact
Application of nanotechnology, as an enabling technology is anticipated to create over one million jobs and contribute billions of dollars to the US economy over the next decade and over 2 million nanoworkers in 15 years		Industrial and post-industrial supply chains will be changed. Example, the demise of silicon is expected in 15 years time.
Real cost reductions for essential goods and services	If infrastructure and country is prepared one can expect robust gross national product, high productivity, global trade, leadership, sustainable economic growth, global patent leadership, superior industrial competitiveness, integrated education and training resources, strong investment climate, plentiful capital liquidity, high investment on R&D, low unemployment, high government and industry collaboration.	Institutions of learning, financial services and certainly manufacturing will be reshaped.
US$1 Trillion market for nanoproducts (NSF) by 2015; 2000 startups expected worldwide in 2004		If infrastructure and country is ill-prepared then a lot of nations will be playing catch up. Ill-prepared resources include: lack of skilled talent, poor education and training, growing but still low investment in R&D, fragmented industry support, poor investment climate, insufficient liquidity, fragmented government and industry collaboration.

5. Summary

The breadth of the industries that will be affected by nanotechnology is very large and it is expected that some platform technologies will serve more industries in improved manufacturing and product performance enhancement than others. The problem that this complexity imposes for market forecasters is multifold. Market forecast focused on a certain industry will not reveal the entire demand picture for a product. It seems that it would be appropriate to integrate cross-industry factors in order to find the aggregate demand for the different nanotechnology markets by building value chain verticals in each market. The difficulty, however, is that products in certain markets have different values associated with nanotechnology, and different industries are expected to have different values for the same technology. Despite this caveat our analyses lead us to summarize the sub sectors and their rank as follows (Table 4).

Hence, finding the right growth rate is not trivial, since the numbers vary widely from more optimistic growth rates of 100% in the chemical manufacturing industry to the more pessimistic growth rates of 20% to 30% in other industries. It is a lot easier to forecast anything that is evolutionary, as the evolutionary nanotechnology is much closer to commercialization. The only barriers to adoption are materials performance, scalability and price. However as seen earlier (section 2.2), important breakthroughs in molecular/ nano manufacturing are imperative in order to bring about any form of significant revolutionary changes in the industry.

Table 4: Summary of findings

Sub Sectors	*Rank Market Size*	*Market Size*	*Rank Growth*	*Growth (%)*
Materials	**1**	**440**	**2**	**23.8**
Tools &Devices	**2**	**370**	**1**	**47**
Nanobio	**3**	**210**	**3**	**20**
Others	**4**	**65**	**n/a**	**n/a**

6. Conclusion

While nanotech on the one hand is a very new area, claims have been made that it has already impacted markets (e.g. products like stain repellents and high tech tennis rackets) and even that it has been around for thirty or more years (e.g. the first molecular electronic device was invented 30 years ago). More importantly, new discoveries such as carbon nanotubes and quantum dots are fuelling excitement about future nanotech markets. A review of the growth of patents, company activities, and interviews with company representatives and discussions with nanotechnology scientists and engineers confirm that this excitement is grounded in reality. The reviews and discussions further suggest that nanotech's first impact will be in the areas of coatings, films, and sensors and thus rightfully ranking (table 4) the materials sub sector as having the largest market followed by the devices and then the nanobio sectors. Most agree that the impact will be significant and could be revolutionizing.